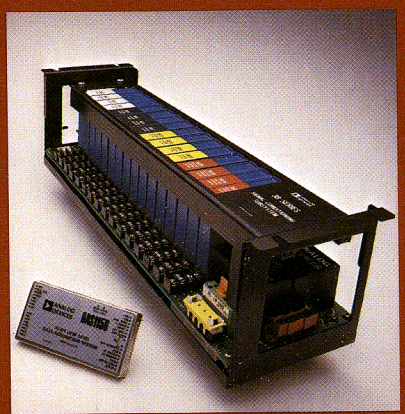


# Modules
# Subsystems

ANALOG DEVICES

# How to Find Product Data in This Databook

The Databook contains Data Sheets for all products recommended for new designs, lists of Available Products not databooked here (data sheets upon request), and a Substitution Guide for products no longer available, plus Selection Guides and a wealth of background information.

## THERE ARE TWO VOLUMES

*VOLUME I* contains technical data on our *integrated circuits and hybrids* for data acquisition.
*VOLUME II* has all data-acquisition products manufactured in the form of *modules, cards, instruments, discrete-assembly subsystems and systems.*

## DO YOU KNOW THE MODEL NUMBER?

*If you know the model number,* turn to the product index on page 1-18 (back of book) and look up the model number. You will find the Volume, Section, and Page location of data sheets bound into Volume I and Volume II.

If you're looking for a form-and-function-compatible version of an integrated circuit or hybrid product originally brought to market by some other manufacturer (second source), add our "AD" prefix (or "ADSP", for digital signal processing ICs) and look it up in the index.

## IF YOU DON'T KNOW THE MODEL NUMBER

There are two ways to find a device to perform your function:

1. **FIND YOUR FUNCTION IN THE LIST ON THE OPPOSITE PAGE OR ON PAGE 2–1**
   Turn directly to the appropriate Section (or Volume). You will find one or more functional Selection Guides at the beginning of the Section. The Selection Guides will help you find the products that are closest to satisfying your need, and their Volume-Section-Page locations. Use them to compare all products in the category by salient criteria, no matter which Volume their technical data resides in.

2. **IF THE FUNCTION IS NOT LISTED BY A NAME THAT YOU RECOGNIZE**
   Find it in the diagram (opposite page). It will help you find the Selection Guides for products in that functional category. Then use the Selection Guide(s) to find the Volume-Section-Page locations of products that will come closest to satisfying your need.

## A RELATED PRODUCT MAY BE WHAT YOU REALLY WANT

Text in each section often mentions related or complementary product categories having a greater or lesser degree of functional integration.

## IF YOU CAN'T FIND IT HERE . . . ASK!

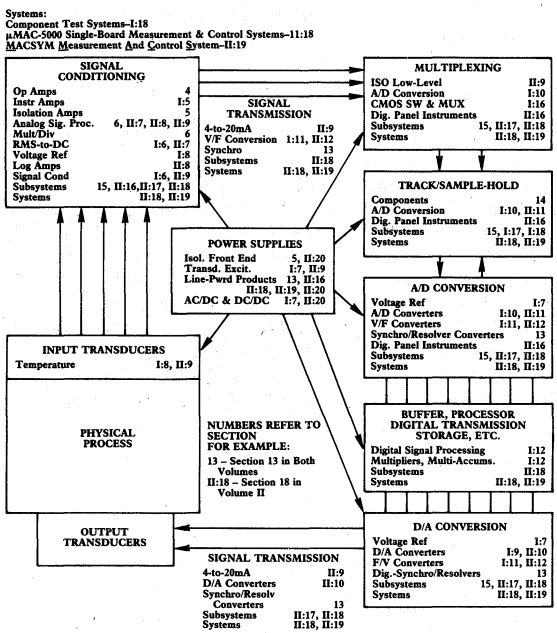
See Worldwide Service Directory, 1–16 and 1–17, at the back of this volume.

ANALOG DEVICES

# DATA-ACQUISITION DATABOOK 1984

## VOLUME II
## MODULES-SUBSYSTEMS

### PICTORIAL GUIDE TO PRODUCT CATEGORIES





General Information 1
Table of Contents 2
Ordering Guide 3
Operational Amplifiers 4
Isolation Amplifiers 5
Analog Multipliers/Dividers 6
RMS-to-DC Converters 7
Log-Antilog Amplifiers 8
Temperature Transducers & Signal Conditioners 9
Digital-to-Analog Converters 10
Analog-to-Digital Converters 11
Voltage-Frequency Converters 12
Synchro & Resolver Converters 13
Sample/Track-Hold Amplifiers 14
Data Acquisition Subsystems 15
Digital Panel Instruments 16
Microcomputer Analog I/O Subsystems 17
μMAC 18
Measurement-and-Control Subsystems 18
MACSYM 19
Measurement & Control Systems 19
Power Supplies 20

ANALOG DEVICES

# DATA-ACQUISITION DATABOOK 1984

## VOLUME II
## MODULES-SUBSYSTEMS

© Analog Devices, Inc., 1984
All Rights Reserved

Information furnished by Analog Devices is believed to be accurate and reliable. However, no responsibility is assumed by Analog Devices for its use; nor for any infringements of patents or other rights of third parties which may result from its use. No license is granted by implication or otherwise under any patent or patent rights of Analog Devices.

Specifications and prices shown in this Databook are subject to change without notice.

Products in this book may be covered by one or more of the following patents. Additional patents are pending. See individual data sheets for further information:

U.S.: 3,007,114, 3,278,736, 3,355,670, 3,441,913, 3,467,908, 3,500,218, 3,530,390, 3,533,002, 3,685,045, 3,729,660, 3,747,088, 3,793,563, 3,803,590, 3,842,412, 3,868,583, 3,872,466, 3,887,863, 3,890,611, 3,906,486, 3,909,908, 3,932,863, 3,940,760, 3,942,173, 3,946,324, 3,950,603, 3,961,326, 3,978,473, 3,979,688, 4,016,559, 4,020,486, 4,029,974, 4,034,366, 4,054,829, 4,092,698, 4,123,698, 4,136,349, 4,141,004, 4,213,806, 4,250,445, 4,270,118, 4,268,759, 4,286,225, 4,309,693, 4,313,083, 4,323,795, 4,338,591, 4,349,811, 4,363,024, 4,374,314, 4,383,222, 4,395,647, 4,399, 345, 4,400,689, 4,400,690, DES 233,909. U.K.: 964,513, 1,310,591, 1,310,592, 1,364,233, 1,470,673, 1,470,674, 1,537,542, 1,531,931, 1,571,869, 1,590,136, 1,590,137, 1,599,538, 2,008,876, 2,012,135, 2,032,659, 2,040,087, 2,050,740, 2,081,040. France: 70.10561, 71.28952, 74.25263, 75-27557, 76 01788, 76 08238, 77 20799, 79 24021, 80 00960, 111 833. West Germany: 20 14 034, 21 39 560, MR 9379. Italy: 933,798. Japan: 452,263, 1,092,928, 1,101,824, 1,180,463. Canada: 984,015, 1,006,236, 1,025,558, 1,035,464, 1,054,248, 1,141,034, 1,141,820, 1,143,306, 1,150,414, 1,153,607, 1,157,571. Sweden: 7603320-8.

# Contents


| | Page |
|---|---|
| Contents | 1-1 |
| General Introduction | 1-2 |
| Contents of Volume I | (back) 1-3 |
| Product Families Not Included in the Databook But Still Available | (back) 1-13 |
| Substitution Guide for Product Families No Longer Available | (back) 1-14 |
| Technical Publications | (back) 1-15 |
| Worldwide Service Directory | (back) 1-16 |
| Alpha-Numeric Product Index | (back) 1-18 |

# General Introduction

Analog Devices designs, manufactures, and sells worldwide sophisticated electronic components and subsystems for use in precision measurement and control. More than six hundred standard products are produced in manufacturing facilities located throughout the world. These facilities encompass all relevant technologies, including bipolar, $I^2L$, CMOS, and hybrid integrated circuits–and assembled products in the form of potted modules, printed-circuit boards, and instrument packages.

State-of-the-art technologies have been utilized (and, in many cases, invented) to provide timely, reliable, easy-to-use advanced designs at realistic prices. Nearly twenty years of successful applications experience and continuing vertical integration insure that these products are oriented to user needs. The continuing application of present state-of-the-art and the invention of future state-of-the-art processes strengthens the leadership position of Analog Devices in data-acquisition products.

**MAJOR PROGRESS**

Since the publication of our two-volume *1982 Databook* and its 1983 companion update volume, nearly 50 significant new products have been introduced. They are identified by bullets (•) in the index and in the table of contents for each section of this Databook. Examples of these new products include: The AD7226 Quad DAC – 4 bus-interfaced voltage-output 8-bit DACs on a single monolithic CMOS chip; the AD670 8-bit "ADCPORT," a complete ready-to-go monolithic μP-compatible 8-bit a/d converter with on-chip instrumentation amplifier; the AD667 complete 12-bit voltage-output D/A converter with 2μs voltage-settling time; the AD9700 monolithic DAC for raster displays; the ADSP-1110 single-port 16-bit multiplier/accumulator for digital signal-processing; and the complete, expandable, stand-alone μMAC-5000 single-board measurement-and-control system, programmable in powerful μMACBASIC.

**MODULES-SUBSYSTEMS**

The list of product-category "bleed tabs" opposite the "How to Find It" Guides on the inside front cover of this Volume is a functional summary of our modular and board-level component, subsystem, and instrument classes. The complete table of contents, starting on page 2-1, provides a detailed panorama of products and functions, irrespective of technology, appearing in both Volumes of this Databook.

**TECHNICAL SUPPORT**

Analog Devices offers extensive technical literature, which discusses the technology and applications of products for precision measurement and control. Besides comprehensive data sheets, of which there are many outstanding examples in this book, we offer Application Notes, Application Guides, Technical Handbooks (at reasonable prices), and several serial publications, including *Analog Dialogue*, our technical magazine, which provides in-depth discussions of new developments in analog and digital circuit technology as applied to data-acquisition and control, and MCDigest for users of subsystems and systems. We maintain a mailing list of engineers, scientists, and technicians with a serious interest in our products. In addition to data-book catalogs–such as this one–we also publish several short-form catalogs, on specific product families. You will find typical publications described on page 1-15 at the back of the book.

**SALES OFFICES**

Backing up our design and manufacturing capabilities and our extensive array of publications is a network of sales offices and representatives throughout the United States and most of the world. They are staffed by experienced sales and applications engineers, and many of them maintain a local stock of Analog Devices products. Our Worldwide Service Directory appears on pages 1-16 and 1-17 at the back of the book.

**PRODUCTS NOT CATALOGUED HERE**

For maximum usefulness to designers of new equipment, without unwieldy size, we have limited the contents of the Databook to products most likely to be used for the design of new circuits and systems. If the data sheet for a product you are interested in is not in either Volume turn to page 1-13, at the back of this book, where you will find a list of older products for which data sheets are available upon request. On page 1-14 you will find a guide to substitutions for products no longer available.

**PRICES**

At Analog Devices, we recognize that accurate, up-to-date prices of our products are an important consideration in making a choice among the many available product families. However, since prices are subject to change, current price lists and/or quotations are available upon request from our sales offices.

*(this section continues at the back of the book)*

# Table of Contents

2

## Section Contents – Volumes I and II


| | Volume–Section | |
|---|---|---|
| Amplifiers, Instrumentation | I – 5 | |
| Amplifiers, Isolation | I – 5, | II – 5 |
| Amplifiers, Log-Antilog | | II – 8 |
| Amplifiers, Operational | I – 4, | II – 4 |
| Amplifiers, Sample/Track-Hold | I – 14, | II – 14 |
| Converters, Analog-to-Digital | I – 10, | II – 11 |
| Converters, Digital-to-Analog | I – 9, | II – 10 |
| Converters, RMS-to-DC | I – 6, | II – 7 |
| Converters, Synchro & Resolver | I – 13, | II – 13 |
| Converters, Voltage-Frequency | I – 11, | II – 12 |
| Data Acquisition Subsystems | I – 15, | II – 15 |
| Digital Panel Instruments | | II – 16 |
| Digital Signal Processing Components | I – 12 | |
| MACSYM Measurement-and-Control Systems | | II – 19 |
| μComputer Analog I/O Subsystems | | II – 17 |
| μMAC Measurement-and-Control Subsystems | | II – 18 |
| Modulators/Demodulators | I – 6 | |
| Monolithic Chips | I – 17 | |
| Multipliers/Dividers | I – 6, | II – 6 |
| Power Supplies | | II – 20 |
| Signal Conditioners | I – 8, | II – 9 |
| Switches and Multiplexers | I – 16 | |
| Temperature Transducers | I – 8, | II – 9 |
| Test Systems, Component | I – 18 | |
| Voltage References | I – 7 | |

# Contents of Volume II


## Ordering Guide – Section 3 Page

## Operational Amplifiers – Section 4

Selection Guides
- General-Purpose Op Amps . . . . 4 – 2
- High-Accuracy Op Amps . . . . 4 – 3
- Fast/Wideband Op Amps . . . . 4 – 4

General Information . . . . 4 – 5
Selection Principles . . . . 4 – 5
Definitions of Specifications . . . . 4 – 12
Bibliography on Op Amps . . . . 4 – 16
50J/K Fast-Slewing and Settling Amplifiers . . . . 4 – 17
51A/B Fast Wide-Temperature-Range Amplifiers . . . . 4 – 17
52J/K High-Accuracy Low-Bias FET-Input Amplifiers . . . . 4 – 19
171J/K High-Output-Voltage Amplifiers . . . . 4 – 21
234J/K/L Low-Noise Chopper-Stablized Amplifiers . . . . 4 – 23
235J/K/L Inverting Economy Low-Noise Chopper-Stabilized Amplifiers . . . . 4 – 23

## Isolation Amplifiers – Section 5

Selection Guide . . . . 5 – 2
General Information . . . . 5 – 6
Definition of Specifications . . . . 5 – 8
277J/K/A Isolated Operational Amplifier . . . . 5 – 9
281 Synchronizable Drive-Oscillator for 286J and 292A . . . . 5 – 11
284J Stand-Alone Isolator . . . . 5 – 11
286J Driven Isolator for Multichannel Applications . . . . 5 – 11
289J/K/L High-Performance Synchronizable Self-Contained Isolation Amplifier . . . . 5 – 17
290A Lowest-Cost Stand-Alone Isolator . . . . 5 – 21
292A Lowest-Cost Driven Isolator for Multichannel Applications . . . . 5 – 21

## Analog Multipliers/Dividers – Section 6

Selection Guide . . . . 6 – 2
General Information . . . . 6 – 5
Definition of Specifications . . . . 6 – 7
429A/B Wideband 4-Quadrant Multiplier . . . . 6 – 9

## RMS-to-DC Converters – Section 7

Selection Guide . . . . 7 – 2
General Information . . . . 7 – 4
Performance Specifications . . . . 7 – 5
442J/K/L 8MHz-Bandwidth rms-to-dc Converters . . . . 7 – 7

## Log-Antilog Amplifiers – Section 8


Page

Selection Guide . . . . . 8 – 2
General Information . . . . . 8 – 3
Definitions of Specifications . . . . . 8 – 5
755N/P High dc Performance Log-Antilog Amplifier Module . . . . . 8 – 7
757N/P Log-Ratio Amplifier Module . . . . . 8 – 11
759N/P Low-Cost, Widest-Bandwidth Log-Antilog Amplifier Module . . . . . 8 – 7


## Temperature Transducers & Signal Conditioners – Section 9


Selection Guides
- Temperature Transducers . . . . . 9 – 2
- Signal Conditioners
  - Temperature Transducer Signal Conditioners . . . . . 9 – 3
  - Voltage-to-Current Converters . . . . . 9 – 4
  - Strain Gage/RTD Conditioners . . . . . 9 – 5
  - Isolated Transducer Signal Conditioners . . . . . 9 – 6
  - Two-Wire Transmitters . . . . . 9 – 7
  - 3B Series I/O Subsystems . . . . . 9 – 9
  - 4B Series Alarm Limit System . . . . . 9 – 10

General Information . . . . . 9 – 11
AC2626J/K/L Stainless-Steel Temperature Probe (AD590) . . . . . 9 – 13
2B20A/B Voltage (0 to +10V) to Current (4-to-20mA) Converter . . . . . 9 – 15
2B22J/K/L Isolated Voltage (0 to +1V to 0 to +10V) to Current (4-to-20mA) Converter . . . . . 9 – 19
2B23J/K Programmable Output Isolated Voltage-to-Current Converter . . . . . 9 – 23
2B24A/B Loop Powered Isolator . . . . . 9 – 27
2B30J/K/L Strain Gage/RTD Signal Conditioner . . . . . 9 – 29
2B31J/K/L Self-Powered Strain Gage/RTD Signal Conditioner . . . . . 9 – 29
2B34J Four-Channel RTD/Strain Gage Signal Conditioner . . . . . 9 – 35
2B35J/K Triple-Output Transducer/Conditioner Power Supply . . . . . 9 – 39
2B50A/B Isolated Thermocouple Signal Conditioner . . . . . 9 – 41
2B52A Isolated Thermocouple Temperature Transmitter . . . . . 9 – 45
2B53A Thermocouple Temperature Transmitter . . . . . 9 – 45
2B54A/B Four-Channel Isolated Low-Level Thermocouple/mV Conditioners/Multiplexers . . . . . 9 – 47
2B55A Four-Channel Isolated High- or Low-Level Signal Conditioner/Multiplexer . . . . . 9 – 47
2B56A Four-Function Thermocouple Cold-Junction Compensation . . . . . 9 – 53
2B57A 4-to-20mA Current Transmitter for AD590 Temperature Transducer . . . . . 9 – 57
2B58A Linearized RTD Temperature Transmitter . . . . . 9 – 61
2B59A Low-Cost RTD Temperature Transmitter . . . . . 9 – 63
3B Series Signal Conditioning I/O Subsystem . . . . . 9 – 65
•4B Series Alarm Limit Subsystem . . . . . 9 – 69


•New product since publication of *1982–1983 Databook Update*.

## Digital-to-Analog Converters – Section 10


Page

Selection Guides

General Purpose 8-Bit DACs . . . . . 10 – 3

General Purpose 10-Bit DACs . . . . . 10 – 4

General Purpose 12-Bit DACs . . . . . 10 – 5

High Resolution DACs . . . . . 10 – 6

CMOS Multiplying DACs . . . . . 10 – 8

LOGDACs . . . . . 10 – 11

8-Bit μP-Compatible DACs . . . . . 10 – 12

12-Bit μP-Compatible DACs . . . . . 10 – 14

Video Display DACs . . . . . 10 – 17

Video Speed Current Output DACs . . . . . 10 – 19

Video Speed Voltage Output DACs . . . . . 10 – 20

General Information . . . . . 10 – 21

Specifications and Terms . . . . . 10 – 22

DAC1136/DAC1138 High Resolution 16- and 18-Bit DAC Modules . . . . . 10 – 27

DAC1146 Low Cost High Accuracy 18-Bit DAC Module . . . . . 10 – 35

MDD Ultra-High-Speed Deglitched 8- and 10-Bit DAC Modules . . . . . 10 – 39

MDMS Ultra-High-Speed 8-, 10-, and 11-Bit Multiplying DACs . . . . . 10 – 43


## Analog-to-Digital Converters – Section 11


Selection Guides

8-Bit A/D Converters . . . . . 11 – 2

10-Bit A/D Converters . . . . . 11 – 5

12-Bit A/D Converters . . . . . 11 – 8

High Resolution A/D Converters . . . . . 11 – 12

Video A/D Converters . . . . . 11 – 15

General Information . . . . . 11 – 20

Specifications & Terms . . . . . 11 – 22

ADC1130/ADC1131 14-Bit High-Speed ADC Modules . . . . . 11 – 27

ADC1140 Low Cost 16-Bit Analog-to-Digital Converter . . . . . 11 – 31

•ADC1143 Low Power/High Performance 16-Bit ADC . . . . . 11 – 35

CAV-0920 9-Bit Video ADC . . . . . 11 – 39

•CAV-1040 10-Bit Video ADC . . . . . 11 – 43

CAV-1210 12-Bit Video ADC . . . . . 11 – 45

MAH Ultra-High-Speed 8- and 10-Bit ADC Modules . . . . . 11 – 49

MAS Ultra-High-Speed 8-, 10-, and 12-Bit ADC Modules . . . . . 11 – 53

MATV Video 8-Bit ADCs with Built-In Track-Hold . . . . . 11 – 57

MOD-1005 10-Bit 5MHz Video ADC with Built-In Track-Hold . . . . . 11 – 61

MOD-1020 10-Bit 20MHz Video ADC with Built-In Track-Hold . . . . . 11 – 65

MOD-1205 12-Bit 5MHz Video ADC with Built-In Track-Hold . . . . . 11 – 69


•New product since publication of *1982–1983 Databook Update.*

## Voltage-to-Frequency and Frequency-to-Voltage Converters – Section 12

Page

Selection Guides
Voltage-to-Frequency Converters . . . . . 12 – 2
Frequency-to-Voltage Converters . . . . . 12 – 4
General Information . . . . . 12 – 5
451 100kHz to 20kHz Adjustable Frequency-to-Voltage Converter . . . . . 12 – 7
453 1kHz to 200kHz Adjustable Frequency-to-Voltage Converter . . . . . 12 – 7
458 100kHz Voltage-to-Frequency Converter . . . . . 12 – 13
460 1MHz Voltage-to-Frequency Converter . . . . . 12 – 13

## Synchro & Resolver Converters – Section 13

Selection Guide . . . . . 13 – 2
General Information . . . . . 13 – 4
API1620/1718 Synchro/Resolver Angle Position Indicators and Digital Converter . . . . . 13 – 5
DSC1705/1706 Digital-to-Synchro Converters (14/12 Bits) . . . . . 13 – 9
DTM1716/1717 Digital Vector Generators . . . . . 13 – 13
•IPA1751, OSC1754 Inductosyn™ Preamp and Power Oscillator . . . . . 13 – 17
IRDC1730/1733 12-Bit, Tracking Inductosyn™/Resolver-to-Digital Converter . . . . . 13 – 21
IRDC1731 4000 Count, Tracking Inductosyn™/Resolver-to-Digital Converter . . . . . 13 – 27
•MCI1794 MULTIBUS™ Compatible Multi-Channel Interface . . . . . 13 – 31
RTM/STM1686/1696/1736/1697/1737 5VA Output Transformers . . . . . 13 – 33
SAC1763 Synchro/Resolver-to-Linear dc Converter . . . . . 13 – 37
SBCD1752/1753/1756/1757 BCD Output Synchro-to-Digital Converters
(Low Profile, 12/10/14 Bits) . . . . . 13 – 41
SCDX/RCDX1623 Solid State Control Differential Transmitter . . . . . 13 – 45
SDC1700/1702/1704 Synchro-to-Digital Converters (Low Profile, 12/10/14 Bits) . . . . . 13 – 49
SDC/RDC1721 16-Bit, High Accuracy, Three-State Latched Output S/D Converter . . . . . 13 – 55
SDC1725/1726 Synchro-to-Digital Converters with 3-State-Latched Outputs . . . . . 13 – 59
SPA1695 Synchro/Resolver Power Amplifier . . . . . 13 – 63
SSCT/RSCT1621 Solid State Control Transformer . . . . . 13 – 65
TSL1612 Processors for 2-Speed Synchro-to-Digital Conversion . . . . . 13 – 69

## Sample/Track-Hold Amplifiers – Section 14

Selection Guide . . . . . 14 – 2
General Information . . . . . 14 – 8
Definitions . . . . . 14 – 9
ADSHM-5 Ultra-Fast 0.01% Track/Sample-Hold Amplifiers . . . . . 14 – 11
SHA1144 Module, High-Resolution Sample-Hold Amplifier . . . . . 14 – 15
THS/THC Modules, Ultra-High Speed Track-Hold Amplifier Series . . . . . 14 – 19

•New product since publication of *1982–1983 Databook Update.*
Inductosyn is a registered trademark of Farrand Industries, Inc.
MULTIBUS is a registered trademark of Intel Corporation.

## Data Acquisition Subsystems – Section 15


Page

Selection Guide . . . . . 15 – 2
DAS1128 16/8-Channel 12-Bit Data Acquisition Module . . . . . 15 – 5
DAS1152/1153 14-Bit and 15-Bit Sampling Analog-to-Digital Converters . . . . . 15 – 13
DAS1155/1156 14-Bit and 15-Bit Low Level Data Acquisition Systems . . . . . 15 – 17


## Digital Panel Instruments – Section 16


Selection Guides
- Logic (+5V) Powered Digital Panel Meters . . . . . 16 – 2
- AC-Powered Digital Panel Meters . . . . . 16 – 3
- Digital Temperature Meters . . . . . 16 – 4

General Information . . . . . 16 – 5
Definitions – Terms & Specifications . . . . . 16 – 6

**DIGITAL PANEL METERS**

AD2004 High Performance 4 1/2 Digit DPM for System Applications . . . . . 16 – 9
AD2006 AC Powered 3 1/2 Digit DPM with Sperry Display . . . . . 16 – 11
AD2010 Low Cost 3 1/2 Digit DPM for OEM Applications . . . . . 16 – 15
AD2016 Low Cost 3 1/2 Digit Line Powered DPM with LED Display . . . . . 16 – 19
AD2021 Low Cost 3 1/2 Digit Logic Powered DPM with LED Displays . . . . . 16 – 23
AD2024/AD2027 Low Cost 4 1/2 Digit DPMs with LED Displays . . . . . 16 – 25
AD2025/AD2028 Low Cost 4 3/4 Digit DPMs with LED Displays . . . . . 16 – 29
AD2026 Low Cost 3 Digit Analog Panel Meter Replacement . . . . . 16 – 33

**TEMPERATURE MEASUREMENT AND SIGNAL CONDITIONING COMPONENTS**

AD2036 6 Channel Scanning Digital Thermometer . . . . . 16 – 35
AD2037/AD2038 6 Channel Scanning Digital Voltmeter/Thermometer . . . . . 16 – 37
AD2040 Low Cost Temperature Indicator . . . . . 16 – 39
AD2050/AD2051 Microprocessor-Based Thermocouple Meters . . . . . 16 – 43
•AD2060/AD2061 Microprocessor-Based RTD/Thermistor Meters . . . . . 16 – 45


•New product since publication of *1982–1983 Databook Update*.

## Microcomputer Analog I/O Subsystems – Section 17


| | Page |
|---|---|
| Selection Guide | 17 – 2 |
| •RTI-600 VME-Compatible Analog Input Board | 17 – 5 |
| •RTI-602 VME-Compatible Analog Output Board | 17 – 5 |
| •RTI-711 MULTIBUS™ Compatible Analog Input Board | 17 – 7 |
| •RTI-724 MULTIBUS™ Compatible Analog Output Board | 17 – 7 |
| •RTI-732 MULTIBUS™ Compatible Combination I/O Board | 17 – 7 |
| RTI-1225 STD Bus-Compatible Combination I/O Board | 17 – 9 |
| RTI-1226 STD Bus-Compatible Analog Input Board | 17 – 9 |
| RTI-1230 Motorola-Compatible Analog Input Board | 17 – 11 |
| RTI-1231 Motorola-Compatible Analog I/O Board | 17 – 11 |
| RTI-1232 Motorola-Compatible Analog-Digital Output Board | 17 – 11 |
| RTI-1240 Texas Instruments-Compatible Analog Input Board | 17 – 13 |
| RTI-1241 Texas Instruments-Compatible Analog I/O Board | 17 – 13 |
| RTI-1242/3 Texas Instruments-Compatible Output Boards | 17 – 13 |
| RTI-1250 DEC LSI-11/2-Compatible Analog Input Board | 17 – 15 |
| RTI-1251 DEC LSI-11/2-Compatible Combination I/O Board | 17 – 15 |
| RTI-1252 DEC LSI-11/2-Compatible Output Board | 17 – 15 |
| RTI-1260 STD Bus-Compatible Analog Input Board | 17 – 17 |
| RTI-1262 STD Bus-Compatible Analog Output Board | 17 – 17 |
| •RTI-1270 STD Bus-Compatible Sensor Based Data Acquisition Subsystem | 17 – 19 |

## μMAC Measurement and Control Subsystems – Section 18

## MACSYM Measurement and Control Systems – Section 19

## Power Supplies – Section 20


•New product since publication of *1982–1983 Databook Update*.
MULTIBUS is a registered trademark of Intel Corporation.

# Ordering Guide



## INTRODUCTION

This Ordering Guide should make it easy to order Analog Devices products, whether you're buying one IC op amp, a multi-option subsystem, or 1000 each of 15 different items. It will help you:

1. Find the correct part number for the options you want.
2. Get a price quotation and place an order with us.
3. Know our warranty for components and subsystems.

For answers to further questions, call the nearest sales office (listed at the back of the book) or our main office in Norwood, Mass. U.S.A. (617-329-4700).

## MODEL NUMBERING

Many of the data sheets in the Databook have an Ordering Guide. Use it to specify the correct part number for the exact combination of options you want. Part numbering systems for ICs and hybrids will be found in Volume I, Section 3. If there is any question, call us.

## ORDERING FROM ANALOG DEVICES

When placing an order, please provide specific information regarding model type, number, option designations, quantity, ship-to and bill-to address. Prices quoted are list; they do not include applicable taxes, customs, or shipping charges. All shipments are F.O.B. factory. Please specify if air shipment is required.

Place your orders with our local sales office or representative, or directly with Norwood. Orders and requests for quotations may be telephoned, sent via TWX or TELEX, or mailed. Orders will be acknowledged when received; billing and delivery information is included.

Payments for new accounts, where open-account credit has not yet been established, will be C.O.D. or prepaid. On all orders under fifty dollars ($50.00), a five-dollar ($5.00) processing charge is required.

When prepaid, orders should include $2.50 additional for packaging and postage (and a 5% sales tax on the price of the goods if you are ordering for delivery to a destination in Massachusetts).

## WARRANTY AND REPAIR CHARGE POLICIES

All Analog Devices, Inc., products are warranted against defects in workmanship and materials under normal use and service for one year from the date of their shipment by Analog Devices, Inc., except that components obtained from others are warranted only to the extent of the original manufacturers' warranties, if any, except for component test systems, which have a 180-day warranty, and μMAC and MACSYM systems, which have a 90-day warranty. This warranty does not extend to any products which have been subjected to misuse, neglect, accident, or improper installation or application, or which have been repaired or altered by others. Analog Devices' sole liability and the Purchaser's sole remedy under this warranty is limited to repairing or replacing defective products. (The repair or replacement of defective products does not extend the warranty period. This warranty does not apply to components which are normally consumed in operation or which have a normal life inherently shorter than one year.) Analog Devices, Inc., shall not be liable for consequential damages under any circumstances.

**THE FOREGOING WARRANTY AND REMEDY ARE IN LIEU OF ALL OTHER REMEDIES AND ALL OTHER WARRANTIES, WRITTEN OR ORAL, STATUTORY, EXPRESS, OR IMPLIED, INCLUDING ANY WARRANTY OF MERCHANTABILITY OR FITNESS FOR A PARTICULAR PURPOSE.**

# Operational Amplifiers

## Contents




| | Page |
|---|---|
| Selection Guides | |
| General-Purpose Op Amps | 4–2 |
| High-Accuracy Op Amps | 4–3 |
| Fast/Wideband Op Amps | 4–4 |
| General Information | 4–5 |
| Selection Principles | 4–5 |
| Definitions of Specifications | 4–12 |
| Bibliography on Op Amps | 4–16 |
| 50J/K Fast-Slewing and Settling Amplifiers | 4–17 |
| 51A/B Fast Wide-Temperature-Range Amplifiers | 4–17 |
| 52J/K High-Accuracy Low-Bias FET-Input Amplifiers | 4–19 |
| 171J/K High-Output-Voltage Amplifiers | 4–21 |
| 234J/K/L Low-Noise Chopper-Stabilized Amplifiers | 4–23 |
| 235J/K/L Inverting Economy Low-Noise Chopper-Stabilized Amplifiers | 4–23 |

# Selection Guide
## Operational Amplifiers

**General Purpose**

| | | 171 | AD503 | AD506 | AD542 | AD642 | AD644 | AD544 | AD611 | AD101 Series | AD741 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | FET INPUT | | | | WIDEBAND | | |
| Monolithic Technology | Bipolar Input | | | | | | | | | • | • |
| | J-FET | | | | • | | | • | • | | |
| | Dual J-FET | | | | | • | • | | | | |
| Multi-Device Technology | Hybrid | | • | • | | | | | | | |
| | Module | • | | | | | | | | | |
| High Open Loop Gain | ⩾100dB | • | | | • | • | | | | | |
| | ⩾140dB | | | | | | | | | | |
| High CMR | >100dB | • | | | | | | | | | |
| Low Offset Voltage | ⩽5mV | | | • | • | • | • | • | • | • | • |
| | ⩽1mV | • | | | • | • | • | • | • | | |
| | ⩽50μV | | | | | | | | | | |
| Low Offset V, vs. Temp | ⩽5μV/°C | | | | • | • | • | • | | | |
| | ⩽1μV/°C | | | | | | | | | | |
| | ⩽0.6μV/°C | | | | | | | | | | |
| Low Bias Current | ⩽50pA | • | • | • | • | • | • | • | • | | |
| | ⩽5pA | | | | | | | | | | |
| | ⩽0.5pA | | | | | | | | | | |
| Fast Settling | ⩽1μs to 0.1% | | | | | | • | • | • | | |
| | ⩽5μs to 0.01% | | | | | | • | • | • | | |
| Wideband (Unity Gain) | ⩾2MHz | • | | | | | • | • | • | • | |
| | ⩾10MHz | | | | | | | | | | |
| High Slew Rate | ⩾10V/μs | • | | | | | • | • | • | • | |
| | ⩾30V/μs | | | | | | | | | | |
| | ⩾100V/μs | | | | | | | | | | |
| | ⩾1000V/μs | | | | | | | | | | |
| Low Noise (0.1 to 10Hz) 2μV p-p | | | | | • | • | • | • | • | • | |
| High Voltage Out | ⩾100V | • | | | | | | | | | |
| High Current Out | ⩾20mA | | | | | | | | | | |
| Low Power | ⩽75mW | | | | • | • | • | • | • | • | • |
| Second Source | | | | | | | | | | • | • |
| Temperature Range 0 to +70°C | | • | • | • | • | • | • | • | • | • | • |
| -25°C to +85°C | | | | | | | | | | • | |
| -55°C to +125°C | | | • | • | • | • | • | • | • | • | • |
| Dice Availability | | | | | • | • | • | • | | | |
| Volume | | II | I | I | I | I | I | I | I | I | I |
| Page | | 4–21 | 4–35 | 4–35 | 4–75 | 4–95 | 4–99 | 4–79 | 4–91 | 4–17 | 4–107 |

Shading indicates new product since publication of *1982–1983 Databook Update*.

## High Accuracy

| | | LOW $V_{OS}$ DRIFT | | | | | | LOW BIAS CURRENT | | FET INPUT | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | AD504 | AD510 | AD OP-07 | AD OP-27 | AD OP-37 | AD517 | 234[1] | 235[1] | AD545 | AD547 | AD647 | AD515 | 52 |
| Monolithic Technology | Bipolar Input | • | • | • | • | • | • | | | | | | | |
| | J-FET | | | | | | | | | | • | | | |
| | Dual J-FET | | | | | | | | | | | • | | |
| Multi-Device Technology | Hybrid | | | | | | | | | • | | | • | |
| | Module | | | | | | | • | • | | | | | • |
| High Open Loop Gain | ≥100dB | • | • | • | • | • | • | • | • | | • | • | | • |
| | ≥140dB | | | | | | | • | • | | | | | |
| High CMR | >100dB | • | • | • | • | • | • | | | | | | | • |
| Low Offset Voltage | ≤5mV | • | • | • | • | • | • | | | • | | | • | • |
| | ≤1mV | | | | | | | | | | • | • | | • |
| | ≤50μV | | | • | • | • | • | • | • | | | | | |
| Low Offset V, vs. Temp | ≤5μV/°C | • | • | • | • | • | • | | | • | • | • | | • |
| | ≤1μV/°C | | | | | | | • | • | | • | • | | • |
| | ≤0.6μV/°C | • | • | • | • | • | | • | • | | | | | |
| Low Bias Current | ≤50pA | | | | | | | | • | • | • | • | • | |
| | ≤5pA | | | | | | | | | • | | | • | • |
| | ≤0.5pA | | | | | | | | | | | | • | |
| Wideband (Unity Gain) | >500kHz | | | | | | | | • | | | | | |
| | >2MHz | | | | • | • | | • | | | | | | |
| High Slew Rate | ≥10V/μs | | | | | • | | | | | | | | |
| | ≥30V/μs | | | | | | | • | | | | | | |
| | ≥100V/μs | | | | | | | | | | | | | |
| | ≥1000V/μs | | | | | | | | | | | | | |
| Low Noise (0.1 to 10Hz) | | | | | | | | | | | | | | |
| ≤4μV p-p | | | | | | | | | | | • | • | | |
| ≤2μV p-p | | | • | • | | | • | | • | | | | | • |
| ≤1μV p-p | | • | | | • | • | | • | • | | | | | |
| High Voltage Out | ≥100V | | | | | | | | | | | | | |
| High Current Out | ≥20mA | | | | | | | | | | | | | |
| Low Power | ≤75mW | | | | | | | | | • | • | • | • | |
| Second Source | | | | • | • | • | | | | | | | | |
| Temperature Range | | | | | | | | | | | | | | |
| 0 to +70°C | | • | • | • | • | • | • | | • | • | • | • | • | • |
| -25°C to +85°C | | | | | | | | | | | | | | |
| -55°C to +125°C | | • | • | • | • | • | • | | | | • | • | | |
| Dice Availability | | | | • | | | • | | | | • | | | |
| Volume | | I | I | I | I | I | I | II | II | I | I | I | I | II |
| Page | | 4–39 | 4–55 | 4–129 | 4–135 | 4–143 | 4–65 | 4–23 | 4–23 | 4–83 | 4–87 | 4–103 | 4–59 | 4–19 |

NOTE

[1] Chopper Stabilized

Shading indicates new product since publication of *1982–1983 Databook Update*.

# Selection Guide
## Operational Amplifiers

**Fast/Wideband**

| | | FET INPUT | | | | | | | | | | | UNITY GAIN BUFFER | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | AD507 | AD509 | AD518 | AD380 | AD381 | AD382 | AD3554 | 50, 51 | HOS-050 | HOS-060 | ADLH0032 | ADLH0033 | HOS-100 |
| Monolithic Technology | Bipolar Input | • | • | • | | | | | | | | | | |
| | J-FET | | | | | | | | • | | | | | |
| | Dual J-FET | | | | | | | | | | | | | |
| Multi-Device Technology | Hybrid | | | | • | • | • | • | | • | • | • | • | • |
| | Module | | | | | | | | • | | | | | |
| High Open Loop Gain | ⩾100dB | • | | | | • | • | • | | • | • | | | |
| | ⩾140dB | | | | | | | | | | | | | |
| High CMR | >100dB | | | | | | | | | | | | | |
| Low Offset Voltage | ⩽5mV | • | • | | • | | • | • | • | | | • | • | |
| | ⩽1mV | | | | | • | | | | | • | | | |
| | ⩽50μV | | | | | | | | | | | | | |
| Low Offset V, vs. Temp | ⩽5μV/°C | | | | | • | • | | | | | | | |
| | ⩽1μV/°C | | | | | | | | | | | | | |
| | ⩽0.6μV/°C | | | | | | | | | | | | | |
| Low Bias Current | ⩽50pA | | | | | • | • | • | | | | • | • | |
| | ⩽5pA | | | | | | | | | | | | | |
| | ⩽0.5pA | | | | | | | | | | | | | |
| Fast Settling | ⩽1μs to 0.1% | • | • | • | | • | • | | • | • | • | • | • | • |
| | ⩽5μs to 0.01% | | | | • | | | • | • | • | • | • | | |
| Wideband (Unity Gain) | ⩾2MHz | | | | | • | • | | | | | | | |
| | ⩾10MHz | • | • | • | • | | | • | | • | • | • | • | • |
| | ⩾50MHz | | | | | | | | • | | | | | |
| High Slew Rate | ⩾10V/μs | • | | • | | | | | | | | | | |
| | ⩾30V/μs | | | | | • | • | | | | | | | |
| | ⩾100V/μs | | • | | • | | | | • | • | • | • | • | • |
| | ⩾1000V/μs | | | | | | | • | | | | | | |
| Low Noise (0.1 to 10Hz) ⩾2μV p-p | | | | | | • | • | | | | | | | |
| High Voltage Out | ⩾100V | | | | | | | | | | | | | |
| High Current Out | ⩾20mA | • | | | • | | • | • | • | • | • | | • | • |
| Low Power | ⩽75mW | | | | | | | | | | | | | |
| Second Source | | • | • | | | | | • | | | | • | • | |
| Temperature Range | | | | | | | | | | | | | | |
| 0 to +70°C | | • | • | • | • | • | • | | • | | | | | |
| -25°C to +85°C | | | | | | | | • | | | | • | • | |
| -55°C to +125°C | | • | • | • | • | • | • | • | | • | • | • | • | • |
| Dice Availability | | | | • | | | | | | | | | | |
| Volume | | I | I | I | I | I | I | I | II | I | I | I | I | I |
| Page | | 4-47 | 4-51 | 4-71 | 4-21 | 4-27 | 4-27 | 4-111 | 4-17 | 4-147 | 4-153 | 4-121 | 4-125 | 4-157 |

# Orientation
## Operational Amplifiers



The amplifiers listed in the two volumes of this catalog are intended to provide cost-effective solutions to the bulk of op-amp requirements in precision measurement and control, as well as to more-general requirements in electronic circuits. The technical data included in these books* cover the properties of some 36 op-amp families, comprising more than 100 distinct types. Some are general purpose, others provide near-optimum performance for specific classes of applications.

They differ in a variety of ways, for example, circuit technology, circuit architecture, input properties, output properties, operating temperature range, degree of isolation, and in terms of the many performance specifications. Some are high-performance modules, most are monolithic ICs (including precision dual devices), some are hybrid ICs.

The technical data in this volume embrace exceptionally high-performance (low-drift and high-speed) operational amplifiers, in the form of small encapsulated modules. As the Selection Guide indicates, there is also a universe of technical data, to be found in Volume I, on a wide range of monolithic and hybrid operational amplifiers—including devices screened to the requirements of MIL-STD-883B and chips for hybrid assembly.

### BACKGROUND

The operational amplifier is today the most-widely used analog subassembly. It is safe to say that its *basic* properties and applications are sufficiently understood by most circuit designers and builders. However, the basis for choice, the subtleties of using op amps in circuits for best results (especially in precision measurement and control), and the varieties of possible applications are less clearly understood by op amp users, in varying degrees.

In these few pages, we shall address the question of making a proper choice of op amp type for an application, in relation to the extensive array of device properties presented in the data sheets that follow.

For those users requiring basic tutorial material, and detailed information on getting the most out of op amps, we have provided on page 4–16 a bibliography that should make available up to 99% of information need now and then, with "fanout" to the vast body of literature that – with some redundancy – will provide the remainder. It should come as no surprise to successful users of Analog Devices op amps that a number of the references are to the applications sections of data sheets included in Volume I or Volume II of this catalog.

### SELECTION PRINCIPLES

In selecting the right device for a specific application, you should have clearly in mind your design objectives and a firm understanding of what published specifications mean. Beyond this, you should detail the significant variables that are pertinent to your application. The purpose of this section is to put these many decision factors into perspective to help you make the most meaningful buying decisions.

To properly choose an operational amplifier for any given set of requirements, the designer must have:

1. *A complete definition of the design objectives.* Signal levels, accuracy desired, bandwidth requirements, circuit impedance, environmental conditions and other factors must be well defined before selection can be effectively undertaken.

2. *Firm understanding of what the manufacturer means by the numbers published for the parameters.* Frequently, any two manufacturers may have comparable published specifications, which may have been arrived at using differing measurement techniques. This creates a pitfall in op amp selection. To avoid these difficulties, the designer must know what the published specifications mean and how these parameters are measured and then must be able to interpret these published specifications in terms meaningful to the design requirements.

There are three fundamental aspects to the rational selection of an operational amplifier for a given application: (1) establishing the circuit architecture, (2) defining the performance levels, and (3) choosing the amplifier(s).

1. To obtain a circuit building block to implement a defined functional job, the principal choices are either to purchase a committed functional device or to design a circuit employing op amps to perform the function. For example, to obtain a difference between two voltages, one may either purchase an instrumentation or isolation amplifier, or design a suitable subtraction circuit using op amps. If a committed functional building block, with appropriate specs and price, is not available, the circuit designer must start by developing schematic diagrams of circuits that will perform the function simply using "ideal" operational amplifiers. Many commonly used circuits can be found in textbooks, "cookbooks", and linear circuit books, as well as in application notes and data sheets.

2. Recognizing that the choice of an op amp depends on both the overall circuit requirements and the characteristics of available op amps, the designer should interpret the desired overall performance in terms of the parameters of op amps, and establish acceptable ranges of parameters, and their variation with time, temperature, supply voltage, etc. Examples of the key parameters are the input offset voltage, input bias and offset currents, and the high-frequency performance and transient behavior of the op-amp block (and its effect on the closed-loop circuit) for large and small signals. It will be helpful to develop an application checklist, which includes such considerations as the character of the input signals and their impedance, the output load, the desired accuracy – static and dynamic – and the environmental conditions.

3. The designer must then relate acceptable performance of the op-amp building block to the specifications and prices of available devices from preferred suppliers, bearing in mind a

*In addition to the products listed in the Selection Guide, which are recommended for new designs, a number of older products are still available; data sheets are available upon request.

firm understanding of the way in which manufacturers define their specifications, and how definitions can differ in a way that may be misleading. A set of definitions used by Analog Devices follows the next section.

**APPLICATION CHECKLIST**

By way of an application checklist, the designer will need to account for the following:

*Character of the application:* The character of the application (inverter, follower, differential amplifier, etc.) will often influence the choice of amplifier.

Chopper stabilized amplifiers, for example, have not often been generally applicable where differential inputs are required.

*Accurate description of the input signal:* It is extremely important that the input signal be thoroughly characterized. Is the input a voltage source or a current source? Range of amplitude? Source impedance? Time/frequency characteristics?

*Environmental conditions:* What is the maximum range of temperature, time, and supply voltage over which the circuits must operate (to the required accuracy) without readjustment?

*Accuracy desired:* The accuracy requirement determines the extent to which the foregoing considerations are critical, and ultimately points the way to a device (or series of devices) which are acceptable. Accuracy must, of course, be defined in terms meaningful to the application with regard to bandwidth, dc offset, and other parameters.

**SELECTION PROCESS**

In general, the objective of amplifier selection should be to choose the least expensive device which will meet the physical, electrical, and environmental requirements imposed by the application. This suggests that a "General Purpose" amplifier will be the best choice in all applications where the desired performance requirements can be met. Where this is not possible, it is generally because of limitations encountered in two areas – bandwidth requirements, and/or offset and drift parameters.

To make it easier to relate bandwidth requirements with the drift and offset characteristics, a capsule view of bandwidth considerations precedes the DC discussions below. The reader is then returned to an expanded discussion of gain-bandwidth considerations.

**Gain Bandwidth Considerations, A Capsule View**

Although all selection criteria must be met simultaneously, determination of the bandwidth requirements is a logical starting point because:

A) If DC information is not of interest, a suitable blocking capacitor can be connected at the amplifier input and all of the "drift" specifications may usually be ignored, and

B) Where high frequency (>10MHz) characteristics are of primary importance, the choice will be limited to those amplifiers designated "Wide Bandwidth/Fast Settling."

Where DC information is required and where frequency requirements are relatively modest (full power response below 100kHz, unity gain of less than 1.5MHz) other criteria will probably influence the final choice. It is important, however, to choose an amplifier with which an adequate value of loop gain is assured (at the maximum frequency of interest) to obtain the desired accuracy. Loop gain is the excess of open loop gain over closed loop gain, and is responsible for the diminishing error due to fluctuations in the open loop gain due to time, temperature, etc. For example, if the closed-loop gain is 1000, the open-loop gain must be at least 100,000 to yield an error of no more than 1%, and 1,000,000 to yield an error no greater than 0.1%. Where undistorted response is required, the specifications for full linear response and slewing rate should be chosen such that they are not exceeded at the highest frequency of operation.

**Offset and Drift Considerations**

In the majority of op-amp applications, final selection is determined by the DC offset and drift characteristics. To undertake amplifier selection in these cases, it is necessary to translate the requirements listed earlier as follows. (It is assumed that bandwidth requirements and temperature range have been established at this point.)

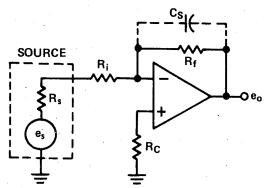
1. *What input impedance must the circuit present to the signal source?* This depends primarily on the source impedance, $R_s$, and the amount of loading error which is acceptable. Most amplifier circuits are designed around either the inverting or noninverting circuit of Figure 1. The choice is often made between the two to accommodate the impedance requirement. Input impedance for the inverting circuit is approximately equal to the summing impedance, $R_i$ and the upper limit on the magnitude of $R_i$ is determined by the allowable drift error because of input bias current as discussed below. The noninverting circuit offers inherently higher input impedance than the inverting circuit (due to "bootstrapping" feedback) and in this case input impedance is approximately equal to the common mode impedance of the amplifier $R_{cm}$.

2. *How much drift error can be tolerated?* The question is related to the input signal level, $e_s$, and the required accuracy For example, to amplify or otherwise manipulate a DC input signal of one volt with an accuracy of 0.1%, the offset drift error, $V_d$, must be one millivolt or less. (This assumes that other sources of error such as input loading, noise and gain error have already been allowed for.) By the same reasoning, the allowable drift error for a 1 volt signal and 0.01% accuracy would be 100$\mu$V.

When this has been defined, the allowable limits of offset

voltage ($e_{os}$), bias current ($i_b$), and difference current can be calculated by the equations of Figure 1. These equations relate offset voltage ($e_{os}$), bias current ($i_b$), difference current ($i_d$) and the external circuit impedances to the drift error, $V_d$, for both the inverting and the noninverting circuits. From these equations it can be seen how the input impedance requirements of the foregoing paragraphs are related to the drift error.

For example, in the case of the inverting circuit, a referred offset error voltage, $i_b R_i = e_{out}\left(\frac{R_i}{R_f}\right)$, is generated by the bias current flowing through the feedback impedance. This error increases for increasing $R_i$. Since $R_i$ also sets the input impedance, there is a conflict between high input impedance and low offset errors. Likewise, for a given offset error, higher values for $R_i$ can be used with an amplifier which has lower bias current.




$$e_o = -\frac{R_f}{R_i}\left[e_s + e_{os}\left(\frac{R_f + R_i}{R_f}\right) + I_b R_i\right]$$ For $R_C = 0$ and $R_s \ll R_i$

Signal | Input Drift Error = $V_d$

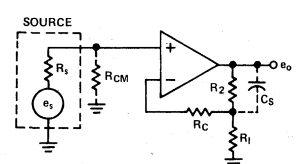
$$e_o = -\frac{R_f}{R_i}\left[e_s + e_{os}\frac{R_f + R_i}{R_f} + i_d R_i\right]$$ For $R_C = R_i R_f/(R_i + R_f)$ and $R_s \ll R_i$

Signal | Input Drift Error = $V_d$

Input Impedance $R_{IN} \approx R_i$

% Drift Error = $\frac{100V_d}{e_s}$

*Figure 1A. Inverting Configuration*




$$e_o = \frac{R_2 + R_i}{R_i}\left[e_s + e_{os} + i_b R_s\right]$$ for $R_C = 0$

Signal | Drift Error = $V_d$

$$e_o = \frac{R_2 + R_i}{R_i}\left[e_s + e_{os} + i_d R_s\right]$$ for $R_C = R_s - \frac{R_i R_2}{R_i + R_2}$

Signal | Drift Error = $V_d$

Input Impedance $R_{IN} \approx R_{CM}$

% Drift Error = $\frac{100V_d}{e_s}$

*Figure 1B. Noninverting Configuration*

Where it will otherwise function properly, the noninverting circuit generally makes a better choice for high input impedance circuits. Also, for the same source and input impedance requirement, a given amplifier will generate lower offset errors for the noninverting circuit than for the inverting circuit. This is so because the bias current flows only through $R_s$ for the noninverter and this will always be less than the input impedance, $R_i$, of the inverter. Input impedance of the noninverter (approximately $R_{CM}$) is typically $10^7$ ohms even for the least expensive bipolar amplifiers and up to $10^{11}$ ohms for FET types.

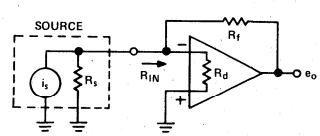
Unfortunately, however, the noninverting configuration cannot always be used since it is not convenient to use for many circuit functions such as integration or summation. A further limitation occurs in high accuracy applications, where common mode errors may rule out this circuit configuration.

Initial offset can usually be zeroed at room temperature so that only the maximum temperature excursion ($\Delta T$) from +25°C need be considered. For example, over the range of -25°C to +85°C, the maximum temperature excursion ($\Delta T$) from +25°C would be 60°C. As a practical matter, offset errors due to supply voltage and time drift can generally be neglected since errors due to temperature drift are usually much greater.

**Current Amplifier Considerations**

Before leaving the subject of offset errors, we shall discuss briefly the current amplifier configuration which is shown in Figure 2A. The obvious approach to measuring current is to develop a voltage drop across a load resistor, $R_f$, and to measure this potential with a high impedance amplifier as shown in Figure 2B.

This approach has several disadvantages as compared to the circuit of Figure 2A. First the noninverting amplifier introduces common mode errors which do not occur for Figure 2A. Second, an ideal current meter would have zero impedance whereas, $R_f$ in Figure 2B may become very large since this resistor determines the sensitivity of the measurement. Third, the changes of input impedance, $R_{cm}$, for the noninverting amplifier with temperature will cause variable loading on $R_f$ and hence a change in sensitivity.




$$e_o = -R_f\left[i_s + e_{os}\left(\frac{R_f + R_s}{R_s R_f}\right) + i_b\right]$$

Signal | Drift error = $I\epsilon$

Input Impedance $R_{IN} = \left(\frac{R_f R_d}{R_f + R_d}\right)\left(\frac{1}{1 + A\beta}\right)$

where $1/\beta = 1 + \frac{R_f (R_s + R_d)}{R_s R_d}$ % Drift Error = $\frac{100\, I\epsilon}{i_s}$

*Figure 2A. Current Amplifier*

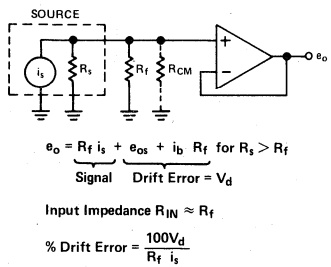



*Figure 2B. Voltage Amplifier with Sampling Resistor*

The current amplifier of Figure 2A circumvents all of these difficulties and approaches an ideal current meter; that is, there is essentially no voltage drop across the measuring circuit, since with enough open loop gain, A, the input impedance $R_{IN}$ becomes very small.

In selecting a current amplifier, the most important consideration is current noise, and bias current drift. Measuring accuracy is largely the ratio of current noise and drift to signal current, $i_s$. To obtain the drift of error current $I_\epsilon$ referred to the input, use the following expression.

$$\Delta I_\epsilon = \left[\frac{\Delta e_{os}}{\Delta T}\left(\frac{R_f + R_s}{R_f R_s}\right) + \frac{\Delta i_B}{\Delta T}\right]\Delta T$$

Now, to make a proper selection you must pick an amplifier with an error current, $I_\epsilon$, over the operating temperature which is small compared to the signal current, $i_s$. Do not overlook current noise which may be more important than current drift in many applications.

**Gain Bandwidth Considerations, Expanded Discussion**

From the previous discussion, it is apparent that most general purpose operational amplifiers will usually give adequate performance for the DC and audio frequency range applications. However, to obtain unity gain bandwidth above 2MHz, full power response above 20kHz and slewing rate above 6V/$\mu$sec, in general, requires special design techniques. All amplifiers with wideband, fast response characteristics have been listed in the wide bandwidth group to simplify the selection for higher frequency applications.

One factor often overlooked is that stray capacitance and impedance levels of the external feedback circuit can be the major limitation in high frequency applications. For example, in Figure 1A, if $R_f$ were one megohm, and stray capacitance, $C_S$, were one picofarad then the closed loop bandwidth would be limited to 160kHz ($1/(2\pi R_F C_S)$) regardless of how fast the amplifier is. Moreover, output slewing rate will be limited by how fast $C_S$ can be charged which in turn is related to signal level, $e_s$, and input impedance, $R_i$, by $de_o/dt = -e_s/R_iC_s$. For these reasons it is usually not possible to obtain both fast response and high input impedance for an inverting circuit since both $R_i$ and $R_f$ must be large to obtain high input impedance.

Another advantage of the noninverting circuit (Figure 1B) is that input impedance, being determined by potentiometric feedback, does not depend on the impedance levels for $R_1$ and $R_2$. Therefore, a low impedance can be used for $R_2$ so that stray capacitance of $C_s$ will not limit the circuit's bandwidth. In this case the minimum value for $R_2$ is constrained only by the output current rating of the amplifier. Again the trade-off between the frequency response and input impedance of the inverting and noninverting circuits must be evaluated in light of the common mode rejection error introduced by the noninverter.

For greater emphasis wideband applications can be separated into two categories – steady state and transient. Since the amplifier requirements for the two are somewhat different, these categories will be discussed separately.

**A. Steady State Applications**

Steady state applications involve amplifying or otherwise manipulating *continuous* sinusoidal, complex or random waveforms. In these applications the significant issues in choosing an amplifier are as follows:

1. *Is DC coupling required?* If DC information is of no consequence, then the offset drift errors are not usually important and a capacitor can be used if necessary to block the output DC offset. Your only concern here is that DC offset at the output does not become so large, as might be the case with a high gain stage, that the output is saturated or the dynamic swing for AC signals is limited. One way to circumvent the latter problem is to use feedback to limit the gain at DC as shown in Figure 3. The gain of these circuits can be small at DC but large at high frequencies.

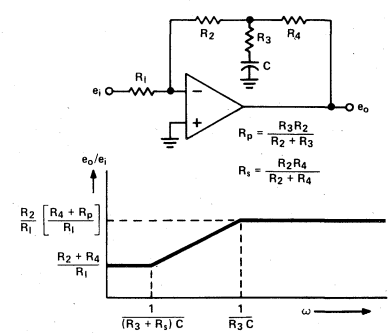



*Figure 3. DC Feedback Minimizes Output Offset for AC Applications*

2. *What closed loop gain and bandwidth are required?* Closed loop gain, G, is dictated by the application. To a first approximation the intersection of the open and closed loop gain curves in Figure 4 gives the closed loop bandwidth, $f_{c1}$(–3dB). For high gain, wideband requirements, it may be necessary, or more economical, to use two amplifiers in cascade, each at lower gain.

3. *What loop gain is required or alternatively what gain stability, output impedance and/or linearity are necessary?* The available loop gain at a particular frequency or over a range of frequencies is very often more important than closed loop bandwidth in selecting an amplifier. Loop gain as illustrated in Figure 4, is defined as the difference, in dB, or as the ratio, arithmetically, of the open to closed loop gain ($A\beta$ = A/G). You will find in most of the equations defining the closed loop characteristic of a feedback amplifier that the loop gain ($A\beta$) is the determining factor in performance. Some of the more notable examples of this point are as follows:

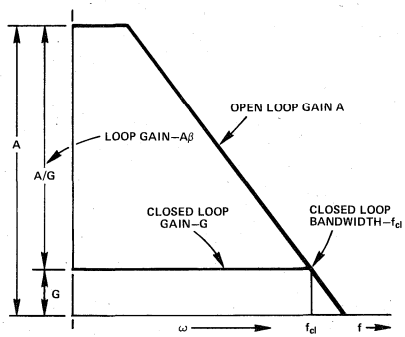



*Figure 4. Closed Loop Bandwidth and Loop Gain*

a. Closed loop gain stability = $\triangle G/G$
$\triangle G/G = (\triangle A/A)\ [1/(1 + A\beta)]$ where $\triangle A/A$ is the open loop gain stability, usually about 1%/°C.

b. Closed loop output impedance = $Z_{ocl} = Z_o/(1 + A\beta)$, where $Z_o$ is the open loop output impedance, often 200 to 5000 ohms.

c. Closed loop nonlinearity = $L_{cl} = L_{ol}/(1 + A\beta)$, where $L_{ol}$ is the open loop linearity, usually less than 5%.

Loop gain of 100, or 40dB, is adequate for most applications and this is readily achievable at DC and low frequencies. But note that loop gain decreases with increasing frequency which makes it difficult to obtain large loop gains at high frequencies. For this reason it may be necessary to use a 10MHz unity gain amplifier in order to obtain adequate feedback over a 10kHz bandwidth.

4. *What full power response and/or slew rate are required?* You should examine your expected output waveform and select an amplifier whose slewing rate exceeds the maximum rate of change of output signal. For a sinusoidal waveform with a peak voltage output equal to the rated amplifier output the frequency should not exceed $f_p$, the full power response of the amplifier. As the output signal voltage is reduced below the rated output voltage, the usable maximum frequency can be extended proportionately. If you do not observe these restrictions you will get distortion and unexpected DC offsets at the output of the amplifier.

For some monolithic amplifier designs available today their frequency response is not a simple 6dB roll-off; the response may be shaped with external RC components for improved performance, using a *compensation* terminal provided. Using feedforward or phase lag compensation networks, gain-bandwidth product and/or full power response may be shaped to meet varying design requirements. Most internally compensated op amps offer a stable 6dB per octave roll-off with specified unity gain-bandwidth and slew rate thereby limiting maximum speed and response to those published specifications.

### B. Transient Applications

In applications such as A/D and D/A converters and pulse amplifiers, the *transient response* of the wideband amplifier is generally more important than the *gain bandwidth* characteristic described above. Slewing rate, overload recovery and settling time are the specifications which determine the transient response.

When applying the high frequency amplifier, it is important to understand how amplifier performance is affected by component selection as well as impedance levels used around the amplifier.

#### Settling Time

*Settling time* is defined as the time elapsed from the application of a perfect step input to the time when the amplifier output has entered and remained within a specified error band symmetrical about the final value (Figure 5). Settling time therefore includes the time required for the amplifier to slew from the initial value, recover from slew rate limited overload, and settle to a given error in the linear range.

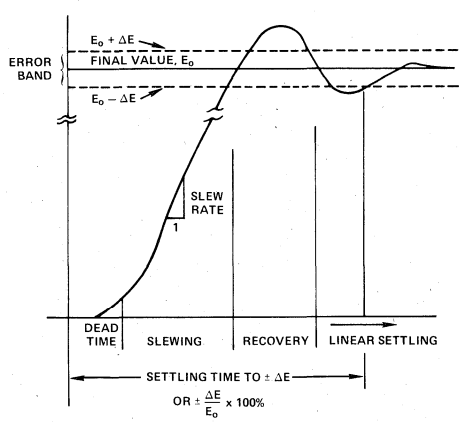



*Figure 5. Typical Settling Time Characteristics*

The time and frequency response of a linear, bilateral network or amplifier are related by well known mathematics. For example, the step response for a well behaved, ideally linear, 6dB/octave amplifier with a closed loop bandwidth of $\omega_{cl}$ is shown in Figure 6.

However, since settling time is determined by a combination of amplifier characteristics (both linear and nonlinear) and because it is a closed loop parameter, it cannot be readily predicted from the open loop specifications such as slew rate, small signal bandwidth, etc.

Analog Devices specifies settling time for the condition of unity gain, relatively low impedance levels, and no capacitive loading. A full-scale step input is used to determine settling time and the step is generally unipolar – i.e.: from zero to plus or minus full scale. The settling time indicated is generally the longest time resulting from a step of either polarity and is given as a percentage of the full scale step transition.

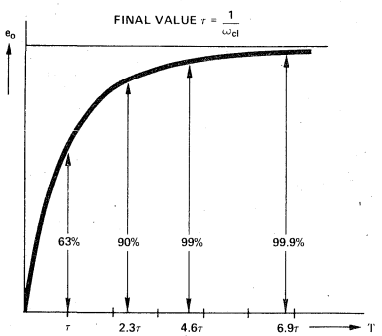



*Figure 6. Step Response for Linear 6dB/Octave Amplifier*

Settling time is a nonlinear function. It varies with the input signal level and it is greatly affected by impedances external to the amplifier.

## ERRORS DUE TO NOISE

A major criterion in the selection of an amplifier for low level signals is the amplifier input noise, since this is usually the limiting factor on system resolution. In the general case, amplifier noise can be characterized by a voltage source in series with the summing junction and a current source in parallel with the summing junction. Whenever high source impedance is encountered, current noise flowing through the source impedance will appear as an additional voltage noise, combining with the amplifier voltage noise. The root-square sum of these (uncorrelated) noise sources will then be amplified along with the desired signal. For this reason, selection of a particular amplifier must consider both the amplifier noise performance as well as the source impedance.

Consideration must also be given to noise sources other than the amplifier whenever determining total system noise. RF noise may be fed into an amplifier through any connecting wire, including power supply and output leads. A quiet power supply (nonswitching), adequate shielding, and low-pass filters on all incoming leads will usually prevent noise pick-up.

Thermal noise is generated in any conductor or resistor as a result of thermal agitation of the electrons. This noise voltage source, sometimes referred to as "Johnson Noise", is generated in the resistive component of any impedance and has a value:

$e_n = \sqrt{4KTBR}$

where $e_n$ = the rms value of the noise voltage

K = Boltzmann's Constant ($1.38 \times 10^{-23}$ joules/kelvin)

T = absolute temperature of the resistance, kelvin

B = the bandwidth in which the noise is measured

Since noise is related to the bandwidth over which the measurement is made, no noise specification is meaningful unless the bandwidth for the specification is given. Although the Thermal Noise equation may appear unwieldy for practical noise calculations, all that is required to enable rapid approximations is to apply a few simple rules of thumb.

### Rules of Thumb

(1) Remember that a 100kΩ resistor generates 40nV rms in a 1Hz bandwidth. The noise voltages generated by other values of resistances in other bandwidths can be calculated by remembering that the noise is proportional to the square root of the resistance and the bandwidth; i.e.

$$e_n \text{ (rms)} = (40nV/\sqrt{Hz})\left(\sqrt{\frac{R}{100k\Omega}\ (BW)}\right)$$

(2) To convert the rms noise to a p-p value, a conversion factor of 6.6μV p-p/μV rms is applied for less than 0.1% probability of noise peaks exceeding calculated limits.

(3) The total rms noise contribution due to several uncorrelated random noise sources is determined by the square root of the sum of the squares (RSS):

$$e_t = \sqrt{e_a^2 + e_b^2 + e_c^2 + \ldots e_n^2}$$

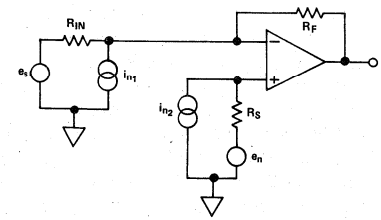
If any noise source is less than a third of another, it may be neglected. The resulting error will be approximately 5%.

(4) Restricting the bandwidth of a system to the minimum usable and using the lowest impedances possible are ways to reduce noise.

## DESIGN EXAMPLE

Figure 7A illustrates a typical circuit with noise calculations shown for each noise source. The total of the noise sources is obtained by adding each of the individual sources in RSS fashion.

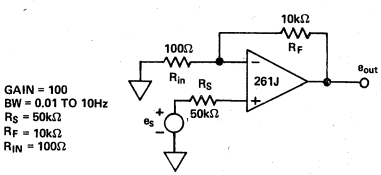
Figure 7B illustrates how the Rules of Thumb may be applied in a practical case to approximate the total output noise. In this example, model 261J, the lowest noise non-inverting chopper type amplifier is being used with a 50kΩ source impedance. The two major noise sources, in addition to the 261J input voltage noise of 1μV p-p, are the Johnson noise (58μV p-p) and current noise (100μV p-p).




| COMPONENT | CAUSE | OUTPUT CONTRIBUTION |
|---|---|---|
| $R_{IN}$ | Johnson Noise | $\sqrt{4KTBR_{IN}}\ (R_F/R_{IN})$ |
| $R_S$ | Johnson Noise | $\sqrt{4KTBR_S}\ (R_F/R_{IN}+1)$ |
| $R_F$ | Johnson Noise | $\sqrt{4KTBR_F}$ |
| $i_{n_1}$ | Amp. Current Noise | $i_{n_1} R_F$ |
| $i_{n_2}$ | Amp. Current Noise | $(i_{n_2} R_S)\ (R_F/R_{IN}+1)$ |
| $e_n$ | Amp. Voltage Noise | $e_n\ (R_F/R_{IN}+1)$ |

$$\text{TOTAL NOISE} = \sqrt{(e_{R_{IN}}\ G)^2 + [e_{R_S}\ (G+1)]^2 + e^2_{R_F} + [(i_{n_1} R_F)^2] + [(i_{n_2} R_S)\ (G+1)]^2 + [e_n\ (G+1)]^2}$$

*Figure 7A. Noise Components*




1) RESISTOR NOISE: $R_F \rightarrow 13nV/\sqrt{Hz}$
$R_{IN} \rightarrow (1.3nV/\sqrt{Hz})\ 100$
$R_S \rightarrow (28nV/\sqrt{Hz})\ 101 = 2.8\mu V/\sqrt{Hz}$
TOTAL RESISTOR NOISE IN 10Hz BW =
$(2.8\mu V/\sqrt{Hz})\ \sqrt{10Hz}\ 6.6\mu V$ p-p/$\mu V$ rms = 58$\mu V$ p-p

2) AMPLIFIER CURRENT NOISE: (20pA p-p) (50k) (101) = 100$\mu V$ p-p
(20pA p-p) (10k) = 0.2$\mu V$ p-p

3) AMPLIFIER VOLTAGE NOISE: (1$\mu V$ p-p) (101) = 100$\mu V$ p-p

TOTAL OUTPUT NOISE = $\sqrt{(100)^2 + (100)^2 + (58)^2} \approx 150\mu V$ p-p

*Figure 7B. Design Example*

## THE SELECTION GUIDE

To assist the designer in rapidly distinguishing among the many types available from Analog Devices, and to narrow the field of further study to just a few types, the Selection Guide takes the form of a "bullet chart". One axis comprises a list of key op-amp characteristics—including manufacturing technology—and specification ranges; the other is the complete set of op-amp families catalogued in both volumes. For any specification level that can be satisfied by members of a given device family, a bullet (●) is placed at the appropriate intersection.

Once the required performance has been established, the Selection Guide is used to find the family, or families, coming closest to the requirements—or to determine quickly whether a particular family is suitable. The exact volume, section, and page location of each type is included in the table, so that the detailed technical and application data can be consulted with a minimum of effort.

An effort has been made to group the amplifiers by their most salient application areas, i.e., General Purpose (low cost), High Accuracy, and Fast/Wideband, and by appropriate subclasses within those major classes.

## THE AMPLIFIERS IN THIS SECTION IN BRIEF

*High-Accuracy Low-Drift Differential-Input Modules.* "Chopperless" low-drift designs with differential FET inputs, optimized for voltage offset and drift, bias current, dc open-loop gain, and CMR, should be considered for high-accuracy instrumentation, low-level transducer bridge circuits, precision voltage comparators, and for impedance buffer designs. The best overall performer in this group in high-impedance applications is the model 52K, which combines low offset and drift (0.5mV and 1$\mu V/^\circ C$) with 3pA bias current.

*High-Accuracy Modules Using Chopper Techniques.* The amplifiers in this class are widely accepted as the best choice when it is essential to maintain low voltage offsets and bias currents with time and temperature or whenever external offset adjustments are not practical in the application. Using carrier modulation techniques, these designs achieve drifts to 0.1$\mu V/^\circ C$ and long-term stability to ½$\mu V$/mo. Typical applications include error-summing amplifiers for servo loops, precision regulators, and input amplifiers for laboratory-grade metering instruments and test equipment.

Two forms of amplifier are available. The *noninverting chopper-amplifier* (261 family) is a high gain feedback amplifier, containing a MOSFET chopper, optimized for follower-with-gain applications. The chopper converts the difference between the dc or low-frequency input voltage, at high impedance, and the feedback voltage to a high-frequency square-wave, amplifies it with no drift, and demodulates and filters the result to produce an output waveform that is an amplified version of the input. The closed-loop gain is determined by the attenuation ratio of the feedback resistor-pair.

The initial offset is ±25$\mu V$ max (trimmable to zero), with average drift-vs.-temperature of 0.1$\mu V/^\circ C$ max (model 261K). Bias current is respectable, at 300pA max, with a tempco of 10pA/°C max, to minimize errors with high-impedance sources.

Maximum noise voltage is 0.4$\mu V$ peak-to-peak, from 0.01 to 1.0Hz, and 1.0$\mu V$, from 0.01 to 10Hz. Small-signal bandwidth, established by an external compensating capacitor that is chosen as a function of gain, is 100Hz.

*Inverting chopper-stabilized amplifiers* (234/235 family) employ narrow-band chopper amplifiers to measure the summing-point voltage of the main amplifier (which should be at a null), chop, amplify, filter, and feed to the positive input of the main amplifier an amplified correction signal. Thus, the offset voltage and drift of the main amplifier (including the effects of input bias current) are reduced by the gain of the chopper amplifier, without a corresponding reduction of bandwidth.

Chopper and chopper-stabilized amplifiers should be considered when long-term stability must be maintained with time and temperature, and wherever maintenance-free operation of instruments and remote circuits is essential. Typical applications include amplification of microvolt-level signals, precision integration, and analog computing.

*Wide Bandwidth, Fast-Settling Modules.* High-speed op amps are characterized by high slewing rates, fast settling time, and wide bandwidth. Fast settling time is especially important in applications with rapidly changing or switched analog data, in buffers, d/a converters, and multiplexer circuitry; wide small-signal bandwidth is important in preamplification and in handling low-level wideband ac signals; high slewing rate is associated with fast settling time and is also important in handling ac signals having large magnitudes with minimal distortion, since the large-signal bandwidth is closely related to the slewing rate.

The products in this category with outstanding specifications are models 50J/K and 48J/K. Model 50's max slewing rate is 500V/$\mu$s inverting, 400V/$\mu$s noninverting, and small-signal unity-gain bandwidth is 70MHz; full-power bandwidth is 8MHz, min. In addition, these devices will deliver ±100mA of output current at ±10V, an important factor in video and line-driver circuitry, and in driving capacitive loads. For example, the current required to sustain 500V/$\mu$s in a 100pF load is I = C dV/dt = 50mA. Model 48J/K is optimized for settling time: 500ns maximum to 0.01%, inverting or noninverting, with output of ±20mA at ±10V.

*Differential FET-Input High-Out Modules.* This beefy group includes models 50, 51, and 171. Models 50 and 51 will furnish up to ±100mA at ±10V out. In addition both are excellent wideband amplifiers. Besides the applications suggested for them in the wide-bandwidth category, they are useful for such applications as current booster/buffer for op amps dealing with low-level signals—either outside the loop or inside the loop. They are protected against short circuits.

For extended-temperature-range operation, model 51A/B operates from −25°C to +85°C.

The model 171 has a large output voltage swing, ±140V at ±10mA, when used with ±150V supplies. However, it need not operate symmetrically; any combination of power-supply voltages between the limits of 15 to +300V for the positive side and −15 to −300V for the negative side is acceptable (including single-supply operation), provided that the total voltage across the amplifier is within the range of 30 to 300V. The output will swing to within 10V of the $V_S^+$ and $V_S^-$ supply rails. The output and both inputs are protected against short circuits to common or to either supply. Model 171K has an open-loop gain of $10^6$ min, offset of 1mV, drift of 15$\mu$V/°C max, bias current of 20pA max, CMR of 100dB min, unity-gain small-signal bandwidth of 3MHz, and slewing rate of 10V/$\mu$s. Typical applications include high compliance-voltage current source, high-voltage follower-with-gain, high-voltage integrator, differential amplifier for high-common-mode-voltage bridge applications, and high-voltage reference supply.

*Isolated Operational Amplifier Module.* Model 277 (see Section 5) combines a high-performance uncommitted operational-amplifier input stage with a precision, isolated output stage, an isolated dual ±15V power supply, and transformer-coupled isolation circuitry, to form a versatile isolation amplifier. It is rated to withstand input/output common-mode voltage of 3500V rms max (60Hz, 1 minute), and peak continuous ac or dc of ±2500V max, and has input-output CMR of 160dB min at dc and 120dB min at 60Hz, with leakage current of 1$\mu$A @ CMV of 115V rms, 60Hz ($Z_L = 10^{12}\Omega \| 16pF$).

The input-stage performance makes many op-amp applications feasible: ±1$\mu$V/°C max offset tempco (trimmed, model 277K), bias current of ±20nA max, open-loop gain of 106dB min. In addition, isolated power output of ±15mA max at ±15V, referred to input common, is available for auxiliary front-end circuitry. The output stage has gain of 1V/V, nonlinearity of 0.05% max, 1.5kHz full-power bandwidth, and 50$\mu$V/°C offset tempco.

Typical applications for the 277 include general isolated op-amp circuitry, programmable-gain isolated amplifier, isolated power source and amplifier for bridge measurements, instrumentation amplifier, instrumentation-grade process-signal isolator, and current-shunt measurements.

The extended-temperature-range equivalent of models 277J/K is model 277A.

## DEFINITIONS OF SPECIFICATIONS

*Absolute Maximum Differential Voltage*
Under most operating conditions, feedback maintains the error voltage between inputs to nearly zero volts. However, in some applications, such as voltage comparators, the voltage between the inputs can become large. This specification defines the maximum voltage which can be applied between inputs without causing permanent damage to the amplifier.

*Common-Mode Rejection*
An ideal operational amplifier responds only to the difference voltage between inputs ($e^+ - e^-$) and produces no output for a *common-mode voltage*, that is, when both inputs are at the same potential. However, due to slightly different gains between the plus and minus inputs, or variations in offset voltage as a function of common-mode level, common-mode input voltages are not eliminated at the output. If the output error voltage, due to a known magnitude of common-mode voltage, is referred to the input (dividing by the closed-loop gain), it reflects the equivalent *common-mode error voltage* (CME) between the inputs. Common-mode rejection ratio (CMRR) is defined as the ratio of common-mode voltage to the resulting common-mode error voltage. Common-mode rejection is often expressed logarithmically: CMR (in dB) = 20 $\log_{10}$ (CMRR).

The precise specification of CMR is complicated by the fact that the common-mode voltage error can be a highly nonlinear function of common-mode voltage and also varies with temperature. As a consequence, CMR data published by Analog Devices are average figures, assuming an end-point measure-

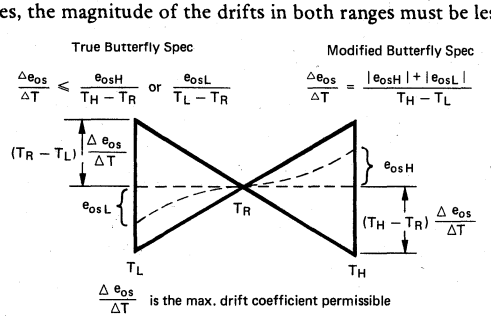
ment over the common-mode range specified. The incremental CMR about small values of common-mode voltage may be greater than the average CMR specified (on the other hand, the incremental CMR may be less in the neightborhood of large CMV). Published CMR specifications for op amps pertain to very low-frequency voltages, unless specified otherwise; CMR decreased with increasing frequency.

*Common-Mode Voltage, Maximum*
For differential-input amplifiers, the voltage at both inputs can swing about ground (power-supply common) level. *Common-mode voltage* is defined as any voltage (above or below ground) that could be observed at both inputs. The maximum common-mode voltage is defined as that voltage which will produce less than a specified value of common-mode error. This establishes the maximum input voltage for the voltage-follower connection.

*Drift vs. Supply*
Offset voltage, bias current, and difference current vary as supply voltage is varied. Usually, dc errors due to this effect are negligible compared to drift with temperature. No inference may be drawn from this low-frequency specification concerning the effects of rapid variation of voltage at the supply terminals.

*Drift vs. Temperature*
Offset voltage, bias current, and difference current all change, or "drift", from their initial values with temperature. This is by far the most important source of error in most precision applications. The temperature coefficients (tempcos) of those parameters are all defined as the average slope over a specified temperature range. Drift can be a nonlinear function of temperature (though it is often quite linear over limited temperature ranges); the slopes generally are greater at the extremes of temperature than around normal ambient (+25°C), which generally means that for small temperature excursions in the vicinity of +25°C, the specification is conservative.

Analog Devices precision operational amplifiers are specified by three- (or more-) point measurements, at 25°C and at the high and low extremes of the range ($T_H$, $T_L$), with the amplifier adjusted to zero at room temperature. The sum of the magnitudes of the drifts in the two ranges must be less than the specified drift rate (μV/°C or nA/°C) multiplied by the total temperature range (modified "butterfly"), or, in some cases, the magnitude of the drifts in both ranges must be less than the specified drift rate multiplied by the respective temperature ranges ("true butterfly").




The lowest-cost second-source IC amplifiers are specified only in terms of the maximum value of the parameter (e.g., offset voltage) over temperature in the specified range.

*Drift vs. Time*
Offset voltage, bias current, and difference current change with time as components age. It is important to realize that drift with time is random, and rarely — if ever — accumulates linearly for healthy devices. For example, voltage drift for a chopper-stabilized amplifier might be quoted at 1μV/day, whereas cumulative drift over 30 days might not exceed 5μV, or 15μV in a year (e.g., model 235). A convenient rule of thumb for extrapolation is to divide the drift for a stated interval by the square root of its ratio to any other interval of interest.

*Full-Power Response*
The large-signal and small-signal response characteristics of operational amplifiers differ substantially. An amplifier's output will not respond to large signal changes as fast as the small-signal bandwidth characteristics would predict, primarily because of slew-rate limiting in the output stages. Full-power response is specified in two ways: full linear response and full peak response. Full linear response is specified in terms of the maximum frequency, at unity closed-loop gain, for which a sinusoidal input signal will produce full output at rated load without exceeding a pre-determined distortion level. There is no industry-wide accepted value for the distortion level which determines the full-linear-response limitation, but we use 3% as a maximum acceptable limit for modules.

In many applications, the distortion caused by exceeding the full linear response can be comfortably ignored, but a more-serious effect (often overlooked) is an effect equivalent to a dc offset voltage that can be generated when full linear response is exceeded, due to rectification of the asymmetrical feedback waveform or overloading of the input stage by large distortion signals at the summing junction.

Another frequency response that is often of interest is the maximum frequency at which full output swing may be obtained, irrespective of distortion. This is termed "full peak response" and can often be found in a plot of output voltage swing vs. frequency.

*Initial Bias Current*
Bias current is defined as the current required at either input from an infinite source impedance to drive the output to zero (assuming zero common-mode voltage). For differential amplifiers, bias current is present at both the negative and the positive input. All Analog Devices specifications pertain to the *larger* of the two, *not the average.* For single-ended amplifiers (i.e., chopper types), bias current refers to the current at the input terminal.

Analog Devices specifies initial bias current, $I_b$, as the bias current at either input, specified at +25°C ambient with the input junctions *at normal operating temperature* (some manufacturers specify initial bias current at power turn-on. Such

specifications may be misleading. For example, in FET-input amplifiers, bias current is doubled for each 10°C increase; since junction temperatures may warm up to 20°C or more above ambient, the "initial bias current" spec used by some manufacturers may be met only during a brief interval after the power is burned on, and $I_b$ may be quadrupled under ordinary operation conditions.)

*Initial Difference Current*

Difference current is defined as the difference between the bias currents at the two inputs. The input circuitry of differential amplifiers is generally symmetrical, so that bias currents at both inputs tend to be equal and tend to track with changes in temperature and supply voltage. Therefore, difference current is often about 0.1 times the bias current at either input, assuming that initial bias current has not been compensated at the input terminals. For amplifiers in which bias currents track, it is often possible to reduce voltage errors due to bias current and its variations by the use of equal resistance loads at both inputs.

*Input Impedance*

Differential input impedance is defined as the impedance between the two input terminals at +25°C, assuming that the error voltage is nulled or very near zero volts. To a first approximation, dynamic impedance can be represented by a capacitor in parallel with a resistor.

Common-mode impedance, expressed as a resistance in parallel with a capacitance, is defined as the impedance between each input and power-supply common, specified at +25°C. For most circuits, common-mode impedance on the negative input has little significance, except for the capacitance which it adds at the summing junction (one exception is electrometer circuitry). However, common-mode impedance on the plus input sets the upper limit on closed-loop input impedance for the non-inverting configuration. Common-mode impedance is a nonlinear function of both temperature and common-mode voltage. For FET-input amplifiers, common-mode resistance is reduced by a factor of two for each 10° of temperature rise. As a function of common-mode voltage, the resistive component is defined as the average resistance for a common-mode change from zero to the maximum common-mode voltage. Incremental resistance may be less than the specified average value, especially at full-scale for some FET-input amplifiers.

*Input Offset Voltage*

Offset voltage is defined as the voltage required at the input from zero source impedance to drive the output to zero; its magnitude is measured by closing the loop (using low values of resistance) to establish a large fixed gain, measuring the amplified error at the output, and dividing the measured value by the gain.

The initial offset voltage is specified at +25°C and rated supply voltage. In most amplifiers, provisions are made to adjust initial offset to zero with an external trim potentiometer.

*Input Noise*

Input voltage- and current-noise characteristics can be specified and analyzed in much the same way as offset-voltage and bias-current characteristics. In fact, long-term drift can be considered as noise which occurs at very low frequencies. The primary difference is that, when evaluating noise performance, bandwidth must be considered. Also rms noise from different sources is summed by root-sum-of-squares, rather than linear, addition. Depending on the amplifier design, noise may have differing characteristics as a function of frequency, being dominated by "1/f noise", resistor noise, or junction noise, at various frequencies.

For this reason, several noise specifications are given. Low-frequency noise in the band 0.01 to 1Hz (or 0.1 to 10Hz) is specified as peak-to-peak, with a $3.3\sigma$ uncertainty, signifying that 99.9% of the observed peak-to-peak excursions will fall within the specified limits. Wideband noise is specified as rms. For some types, spectral-density plots or "spot noise", at specific frequencies, in $\mu V/\sqrt{Hz}$ or $pA/\sqrt{Hz}$, are provided.

*Open-Loop Gain*

Open-loop gain is defined as the ratio of a change of output voltage to the voltage applied between the amplifier inputs to produce the change. Gain is specified at dc. In many applications, the frequency dependence of gain is important; for this reason, the typical open-loop gain as a function of frequency is published for each amplifier type. See also *unity gain small-signal response.*

*Overload Recovery*

Overload recovery is defined as the time required for the output voltage to recover to the rated output voltage from a saturated condition caused by a 50% overdrive. Published specifications apply for low impedances and contain the assumption that overload recovery is not degraded by stray capacitance in the feedback network.

*Rated Output*

Rated output *voltage* is the minimum peak output voltage which can be obtained at rated current or a specified value of resistive load before clipping or out-of-spec nonlinearity occurs. Rated output *current* is the minimum guaranteed value of current supplied at the rated output voltage (or other specified voltage). Load impedances less than the specified (or implied) value can be used, but the maximum output voltage will decrease, distortion may increase, and the open-loop gain will be reduced. (All models are short-circuit protected to ground, and many are safe against shorts to the supplies.)

*Settling Time*

Settling time is defined as the time elapsed from the application of a perfect step input to the time when the amplifier output has entered and remained within a specified error band symmetrical about the final value. Settling time, therefore, includes the time required: for the signal to propagate through the amplifier, for the amplifier to slew from the initial value, recover from slew-rate-limited overload (if it occurs), and settle to a given error in the linear range. It may also include a "long tail" due to the time required to reach thermal equilibrium, or the settling time of compensation circuits. Settling

time is usually specified for the condition of unity gain, relatively low impedance levels, and no (or a specified value of) capacitive loading, and any specified compensation. A full-scale unipolar step input is used, and both polarities are tested.

Although settling time can generally be grossly inferred from the other amplifier specifications (an amplifier that has extra-wide small-signal bandwidth, extra-fast slewing, and excellent full-power response may reasonably – but not always – be expected to have fast settling), the settling time cannot usually be rationally predicted from the other dynamic specifications.

*Slewing Rate*

The slewing rate of an amplifier, usually in volts per microsecond (V/μs), defines the maximum rate of change of output voltage for a large input step change.

*Unity-Gain Small-Signal Response*

Unity-gain small-signal response is the frequency at which the open-loop gain falls to 1V/V, or 0dB under a specified compensation condition. "Small signal" indicates that, in general, it is not possible to obtain large output voltage swing at high frequencies because of distortion due to slew-rate limiting or signal rectification. For amplifiers with symmetrical response for signals applied to either input, the dynamic behavior will be consistent for both inverting and non-inverting configurations. However, if feedforward compensation is used, fast response will be available only on the negative input, restricting fast applications of the device to the inverting mode.

## A BRIEF BIBLIOGRAPHY ON OP AMPS

*BOOKS (Not available from Analog Devices except where noted)*

*IC Op-Amp Cookbook* by Walter Jung, Howard Sams & Co., Second Edition, 1980, down-to-earth and practical paperback

*Linear Integrated Circuit Applications* by George B. Clayton, The Macmillan Press Ltd., London, 1975

*Modern Operational Circuit Design,* by J. I. Smith, John Wiley & Sons, Inc., 1971

*Nonlinear Circuits Handbook,* edited by D. H. Sheingold. 1976. $5.95. Analog Devices, Box 796, Norwood, MA 02062

*Operational Amplifiers and Linear IC's,* by R. F. Coughlin and F. F. Driscoll, Prentice-Hall, Second Edition, 1982. Practical textbook

*Operational Amplifiers, Theory and Practice,* by J. K. Roberge, J. Wiley & Sons, 1975. Authoritative book on op amp principles and circuitry; contains extensive material on compensation to optimize dynamic performance

*Transducer Interfacing Handbook,* edited by D. H. Sheingold. 1980. $14.50. Analog Devices, Box 796, Norwood, MA 02062

*ARTICLES AND APPLICATION NOTES (Available Upon Request; ask for specific issue of Analog Dialogue)*

"Analog Signal Handling for High Speed and Accuracy" by A. P. Brokaw, ANALOG DIALOGUE 11-2

"Current Inverter with Wide Dynamic Range" by Barrie Gilbert, ANALOG DIALOGUE 9-1, 1975

"How to Select Operational Amplifiers", Application Note Section 20 of Volume I

"An IC-Amplifier User's Guide to Decoupling, Grounding, and Making Things Go Right for a Change," by A. P. Brokaw, Application Note Section 20 of Volume I

"Laser-Trimming on the Wafer, A Powerful New Tool for IC's" by R. Wagner, ANALOG DIALOGUE 9-3, 1975

"Simple Rules for Choosing Resistance Values in Adder-Subtractor Circuits" by D. Sheingold, ANALOG DIALOGUE 10-1, 1976

"Specifying and Measuring a Low-Noise FET-Input IC Op Amp" by Bill Maxwell, ANALOG DIALOGUE 8-2, 1974

"How to Test Operational Amplifier Parameters", Application Note Section 20 of Volume I

*USEFUL TUTORIAL MATERIAL IN DATA SHEETS*

Electrometer Circuitry, see AD515

High-Speed Amplifiers, see AD518 and Models 50/51

Low-Drift Differential Op Amp Performance, see AD504

Low-Level Applications of Chopper-Stabilized Amplifiers:
Inverting, see Models 234, 235
Non-Inverting, see Model 261

# Fast Settling, Wideband, 100mA Output, FET Amplifiers

# MODELS 50 & 51

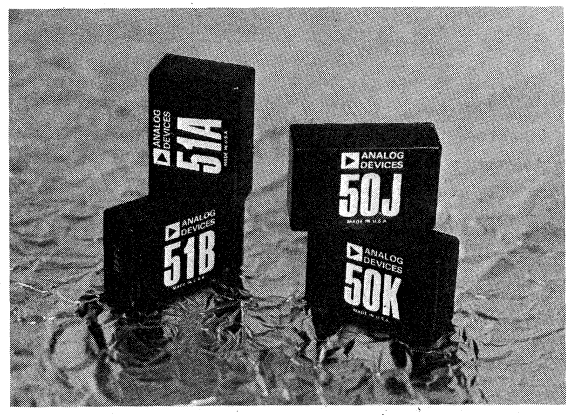


**FEATURES**

**Fast Settling: 200ns max, 0.05% (50J/K)**
**100ns max, 0.1% (50J/K)**
**100mA Output: dc to 8MHz (50J/K)**
**dc to 6MHz (51A/B)**
**All Hermetically Sealed Semiconductors (51A/B)**
**-55°C to +125°C Temperature Range (51A/B)**
**100MHz Gain Bandwidth (50J/K)**

**APPLICATIONS**

**A to D Input Amplifier**
**D to A Current Converter**
**Video Pulse Amplifier**
**CRT Deflection Amplifier**
**Wideband Current Booster**




## GENERAL DESCRIPTION

Models 50 and 51 are ultra fast, wideband differential FET amplifiers, designed for applications requiring fast settling time with high output current in closed loop gain configurations of 2 or greater. Model 50 offers guaranteed settling time of 100ns maximum to ±0.1% accuracy and 200ns maximum to ±0.05% accuracy. Model 51 features all hermetically sealed semiconductors for greater reliability and wide operating temperature range (-55°C to +125°C) with guaranteed settling times of 140ns maximum to ±0.1% and 250ns maximum to ±0.05%.

Model 50 is available in two input voltage drift selections. Model 50J is ±50μV/°C max, model 50K is ±15μV/°C max. Other outstanding features of models 50J/K are 100MHz gain bandwidth product, slew rate of 500V/μs and output current of ±100mA from dc to 8MHz.

Model 51 is also available in two input voltage drift selections; model 51A is ±50μV/°C max, model 51B is ±20μV/°C max. Models 51A/B offer 80MHz gain bandwidth product, slew rate of 400V/μs and ±100mA output current from dc to 6MHz. Both models 50 and 51 offer significant improvement over previous designs with lower input voltage noise (6μV rms, 5Hz to 2MHz bandwidth), particularly important in display system D/A converter applications.

## FAST SETTLING APPLICATIONS

D/A converters require fast settling output amplifiers since conversion speed is often dictated by the settling time of the amplifier. Models 50 and 51 offer fast settling time performance at closed loop gains from 2 to 6. This characteristic is extremely important for D/A applications requiring fast current to voltage conversion from less than ideal current sources.

The circuit shown in Figure 1 is that of a typical current to voltage converter. The output of the D/A converter is often considered an ideal current source ($R_{out} = \infty$) which is converted to a voltage by the amplifier's feedback resistor. Although it may appear that in this application the amplifier is being operated in a closed loop gain of 1, a closer look at the D/A's specifications may show an output impedance of 800 to 2500 ohms. For this condition, the amplifier is operated in a closed loop gain of 2 to 6. This is then the range of gains over which settling time is important.

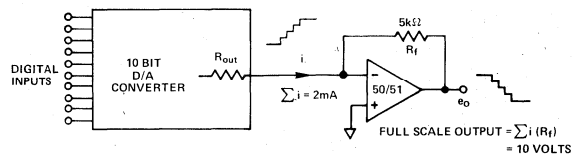



*Figure 1. High Speed Current to Voltage Buffer*

High speed amplifiers typically suffer significant degradation in settling time when operated in closed loop gains greater than unity. Model 50, with 100MHz gain bandwidth and model 51 with 80MHz gain bandwidth achieve fast settling time since they are far from the point of bandwidth limitations. For example, at a gain of 4, model 50 has a bandwidth of 20MHz, which represents a time constant of 8ns. For 0.1% settling, the bandwidth limitation is 6.9 time constants or approximately 55ns.

**For detailed information, contact factory.**

# SPECIFICATIONS (typical @ +25°C and ±15V unless otherwise noted)

| MODEL | 50J | 50K | 51A | 51B |
|---|---|---|---|---|
| OPEN LOOP GAIN | | | | |
| DC, Load = 100 ohm | 88dB min | * | 94dB min | ** |
| DC, Load = 2k ohm | 94dB min | * | 97dB min | ** |
| RATED OUTPUT[1] | | | | |
| Voltage, $R_L \geq 100\Omega$ | ±10V min | * | * | * |
| Current | ±100mA min | * | * | * |
| Impedance, Open Loop dc | 200Ω | * | * | * |
| Load Capacitance, max | | | | |
| Inverting | 100pF max | * | * | * |
| Noninverting | 50pF max | * | * | * |
| FREQUENCY RESPONSE | | | | |
| Small Signal, Unity Gain | 70MHz | * | 56MHz | ** |
| Small Signal, -3dB, Unity Gain | 100 MHz | * | 80MHz | ** |
| Full Power | 8MHz min | * | 6MHz min | ** |
| Slew Rate, Noninverting | 400V/μs, min | * | 300V/μs, min | ** |
| Slew Rate, Inverting | 500V/μs, min | * | 400V/μs, min | ** |
| Overload Recovery | 200ns | * | * | * |
| SETTLING TIME | | | | |
| Inverting, Gain = 2 | | | | |
| ±0.1%, ±10 Volt Step | 100ns max | * | 140ns max | ** |
| ±0.05%, ±10 Volt Step | 200ns max | * | 250ns max | ** |
| Noninverting, Gain = 2 | | | | |
| ±0.1%, ±10 Volt Step | 150ns max | * | 200ns max | ** |
| ±0.05%, ±10 Volt Step | 300ns max | * | 400ns max | ** |
| INPUT OFFSET VOLTAGE | | | | |
| Initial, @ +25°C | Adjust to Zero | * | * | * |
| Trim Potentiometer | 1kΩ | * | * | * |
| With 499Ω Fixed Resistor | ±3mV | * | * | * |
| vs. Temperature | ±50μV/°C max | ±15μV/°C max | ±50μV/°C max | ±20μV/°C max |
| vs. Supply Voltage | ±15μV/% | * | * | * |
| vs. Time | ±500μV/month | * | * | * |
| Warm up Drift, 20 Minutes | ±2mV | * | * | * |
| INPUT BIAS CURRENT | | | | |
| Initial, @ +25°C | 0, 0-2nA max | * | * | * |
| vs. Temperature | Double/+10°C | * | * | * |
| vs. Supply Voltage | 10pA/% | * | * | * |
| INPUT DIFFERENCE CURRENT | | | | |
| Initial, @ +25°C | ±100pA | * | * | * |
| vs. Temperature | Double/+10°C | * | * | * |
| INPUT IMPEDANCE | | | | |
| Differential | $10^{10}\Omega \| 3.5pF$ | * | * | * |
| Common Mode | $10^{10}\Omega \| 3.5pF$ | * | * | * |
| INPUT NOISE | | | | |
| Voltage, 0.1Hz to 10Hz | 5μV, p-p | * | * | * |
| 5Hz to 2MHz | 6μV, rms | * | * | * |
| Current, 0.1Hz to 10Hz | 1pA, p-p | * | * | * |
| INPUT VOLTAGE RANGE | | | | |
| Common Mode Voltage | ±10V min | * | * | * |
| Max Safe Differential Voltage | $\pm V_S$ | * | * | * |
| Common Mode Rejection, CMV = ±10V | 60dB, min | * | * | * |
| Common Mode Rejection, CMV = ±5V | 70dB, min | * | * | * |
| POWER SUPPLY | | | | |
| Voltage, Rated Performance[2] | ±15V dc | * | * | * |
| Voltage, Operating | ±(12 to 18)V dc | * | * | * |
| Current, Quiescent | ±40mA | * | * | * |
| TEMPERATURE RANGE | | | | |
| Rated Specifications | 0 to +70°C | * | -25°C to +85°C | ** |
| Operating[3] | -25°C to +85°C | * | -55°C to +125°C | ** |
| Storage | -55°C to +125°C | * | * | * |
| MECHANICAL | | | | |
| Case Size, mm | 1.8" x 1.2" x 0.6" | * | * | * |
| Weight, grams | 31 | * | * | * |
| Mating Socket | AC1034 | * | * | * |

NOTES

*Specifications same as Model 50J.

**Specifications same as Model 51A.

[1] Short circuit protected to ground.

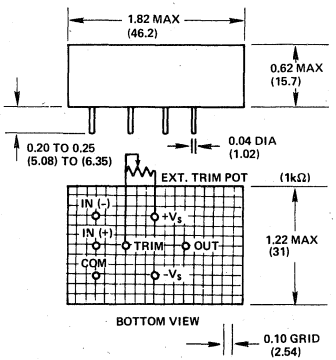
[2] Recommended power supply ADI Model 920, ±15V @ 200mA.

[3] Model 51A and 51B have an operating temperature range of -55°C to +100°C when operating in the differential mode.

Specifications subject to change without notice.

## OUTLINE DIMENSIONS

Dimensions shown in inches and (mm).




## MATING SOCKET AC1034

## UNITY GAIN APPLICATIONS

Models 50 and 51 have been optimized for fast settling inverting applications, such as current to voltage conversion at the output of D/A converters. In these configurations the high speed amplifier is usually operating in a noise gain of about 5. (Noise Gain = $1 + R_f/R_{out}$ of D/A). They have also been designed as fast non-inverting amplifiers and offer excellent performance at noise gains of 2 or higher. For unity gain applications the circuits shown in Figure 2 and Figure 3 are recommended.

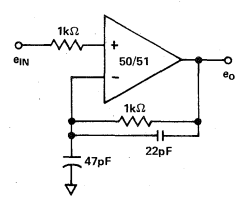



*Figure 2. Recommended Circuit for Unity Gain Noninverting Buffer*

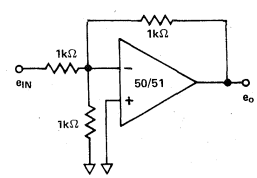



*Figure 3. Recommended Circuit for Unity Gain Inverter*

# ANALOG DEVICES

# Low Noise, Low Drift Precision FET Amplifier

# MODEL 52

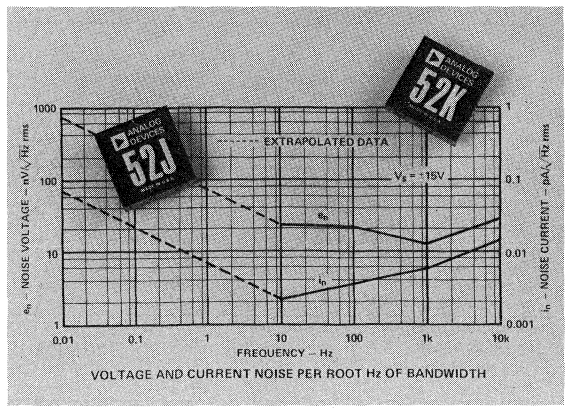


## FEATURES

**Guaranteed Low Noise: 1.5μV p-p max (52K)**
**Low Voltage Drift: 1μV/°C max (52K)**
**Low Bias Current: 3pA, max**
**High CMR: 100dB, min**
**High Voltage Gain: 120dB, min**
**Wide Power Supply Range: ±9V to ±18V**
**Excellent Long Term Stability: 5μV/month**
**Fast Thermal Response**

## APPLICATIONS

**Low Level Instrumentation Preamp**
**High Impedance Precision Buffer**
**Long Term Integrator**
**Current to Voltage Converter**
**Precision Voltage Regulator**
**Preamp for 16-Bit Resolution V/F Converters**



VOLTAGE AND CURRENT NOISE PER ROOT Hz OF BANDWIDTH

## GENERAL DESCRIPTION

Model 52, a low noise, high accuracy FET input operational amplifier was designed for handling microvolt signals from high impedance (>100kΩ) sources. It features guaranteed low voltage noise (1.5μV p-p max, 0.01 to 1Hz bandwidth 52K) with low input offset voltage drift (3μV/°C max, 52J; 1μV/°C max 52K). Unlike most available low drift amplifiers, model 52 voltage drift is unaffected by trimming the initial offset voltage (0.5mV max). The low input bias current (3pA max) is held constant over the entire ±10V common mode voltage range. High voltage gain (120dB, min) and high CMR (100dB, min) complete the performance profile. Model 52 is an excellent choice for high accuracy, high resolution linear signal processing applications.

By incorporating a new low noise N-channel monolithic FET input stage, thermal stability, voltage noise and differential signal performance are improved to a level previously obtainable only in the best bipolar amplifier designs. Model 52 is an excellent choice to replace chopper stabilized amplifiers where significant sources of error are introduced from zero beating, "chopper spikes" and ground loop currents.

The guaranteed accuracy performance of model 52 suggests critical applications such as low noise, low drift "front-end" preamplifiers for A to D converters and DVM's. For high impedance buffering applications, model 52 offers low input bias current, high linear common mode rejection, complete protection from input transients (offset voltage and bias current will not degrade due to reverse breakdown) and freedom from latch up when the common mode voltage range is exceeded. Model 52 is supplied in a reliable, compact epoxy module package. Output is protected from shorts to ground and/or supply voltage and is capable of driving up to 0.01μF load capacitance.

## IMPROVED OFFSET VOLTAGE STABILITY

Model 52 has been designed for the lowest possible input voltage drift over the 0 to +70°C temperature range. In most operational amplifier designs, trimming is accomplished by unbalancing the current in the input stage. This trimming technique introduces an additional 2 to 12μV/°C for each millivolt of $E_{OS}$ that is nulled. To provide performance consistent with low offset voltage drift, model 52 incorporates a three-point trim (see connection diagram) whereby a compensating voltage is introduced without unbalancing the input stage currents. By virtue of this trim scheme, there is no degradation in T.C. when $E_{OS}$ is nulled and the specified performance is achieved.

## IMPROVED NOISE PERFORMANCE

Input noise limits signal resolution in low level signal processing applications. The FET input stage of model 52 reduces noise current significantly from that of bipolar amplifiers, permitting high source impedance applications. Model 52 also offers voltage noise levels appreciably below that of other FET amplifiers. To illustrate the excellent low noise performance of model 52, Figure 1 shows typical input voltage noise in a 0.01 to 1Hz bandwidth. Noise is typically less than 1μV p-p and is free of noise spikes.

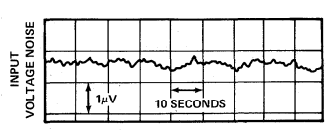



*Figure 1. Voltage Noise 0.01 to 1Hz Bandwidth*

**For detailed information, contact factory.**

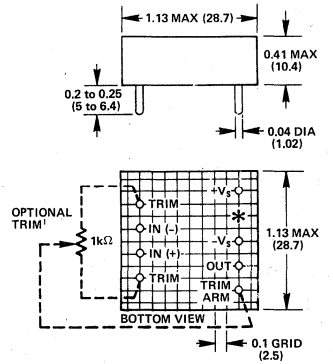
# SPECIFICATIONS (typical @ +25°C and ±15V unless otherwise noted)

| MODEL | 52J | 52K |
|---|---|---|
| OPEN LOOP GAIN | | |
| DC 2kΩ Load | 120dB min (130dB typ) | * |
| RATED OUTPUT[1] | | |
| Voltage, 2kΩ Load | ±10V min | * |
| Current | ±5mA min | * |
| Maximum Load Capacitance | 0.01μF | * |
| Impedance, Open Loop | 75Ω | * |
| FREQUENCY RESPONSE | | |
| Unity Gain, Small Signal | 500kHz | * |
| Full Power | 4kHz min | * |
| Slew Rate | 0.25V/μs min | * |
| Overload Recovery | 130μs | * |
| Settling Time, ±0.1%, ±10V Step | 100μs | * |
| Settling Time, ±0.01%, ±10V Step | 150μs | * |
| INPUT OFFSET VOLTAGE | | |
| Initial[2], @ +25°C | ±500μV max | * |
| With External Trim Potentiometer | Adjustable to Zero | * |
| vs. Temperature (0 to +70°C) | ±3μV/°C max | ±1μV/°C max |
| vs. Supply Voltage | ±2μV/% | * |
| vs. Time | ±5μV/Month | * |
| Warm-Up Drift, 5 Minutes | ±5μV | * |
| INPUT BIAS CURRENT | | |
| Initial, @ +25°C | -3pA max (-1pA typ) | * |
| vs. Temperature (0 to +70°C) | x2/+10°C | * |
| vs. Supply Voltage | ±0.01pA/% | * |
| INPUT DIFFERENCE CURRENT | | |
| Initial, @ +25°C | ±1pA | * |
| vs. Temperature (0 to +70°C) | x2/+10°C | * |
| INPUT IMPEDANCE | | |
| Differential | $10^{12}\Omega$\|\|3.5pF | * |
| Common Mode | $10^{12}\Omega$\|\|3.5pF | * |
| INPUT NOISE | | |
| Voltage, 0.01Hz to 1Hz | 3.0μV p-p | 1.5μV p-p max |
| 10Hz to 10kHz | 5.0μV rms | 3.0μV rms max |
| f = 1Hz | 70nV/√Hz rms | * |
| f = 10Hz | 25nV/√Hz rms | * |
| f = 100Hz | 20nV/√Hz rms | * |
| f = 1kHz | 13nV/√Hz rms | * |
| Current, 0.01Hz to 1Hz | 0.1pA p-p | * |
| f = 1Hz | 7fA/√Hz rms | * |
| f = 10Hz | 2.5fA/√Hz rms | * |
| f = 100Hz | 3.5fA/√Hz rms | * |
| f = 1kHz | 6fA/√Hz rms | * |
| INPUT VOLTAGE RANGE | | |
| Common Mode Voltage | ±10V min | * |
| Common Mode Rejection, CMV = ±10V | 100dB min (106dB typ) | * |
| Max Safe Differential Voltage | $\pm V_S$ | * |
| POWER SUPPLY[3] | | |
| Voltage, Rated Performance | ±15V | * |
| Voltage, Operating | ±(9 to 18)V | * |
| Current, Quiescent | ±5mA | * |
| TEMPERATURE RANGE | | |
| Rated Performance | 0 to +70°C | * |
| Operating | -25°C to +85°C | * |
| Storage | -55°C to +125°C | * |
| MECHANICAL | | |
| Case Size | 1.12" x 1.12" x 0.4" | * |
| Weight | 16g | * |
| Mating Socket | AC1008 | * |

NOTES
*Specifications same as model 52J.
[1] Protected for short circuit to ground.
[2] With no external trim potentiometer connected.
[3] Recommended power supply, ADI model 904, ±15V @ 50mA output.
Specifications subject to change without notice.

## OUTLINE DIMENSIONS

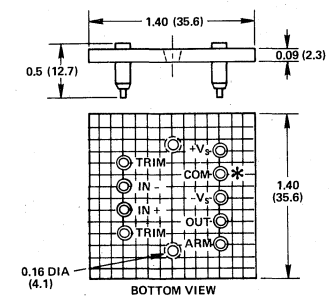
Dimensions shown in inches and (mm).




**[1] Optional 1kΩ external trim pot. Input offset voltage may be adjusted to zero with trim pot connected as shown. With trim pins left open, input offset voltage will be ±0.5mV, maximum.**

***Common Supply connection not required.**

### MATING SOCKET AC1008




*No connection required on Model 52.

### FREQUENCY RESPONSE

From the plot of Open Loop Voltage Gain and Phase Shift (see Figure 2) versus Frequency, it can be seen that model 52 is stable for all closed loop gains. Even at the crossover frequency of 500kHz, model 52 has a phase margin of 75°.

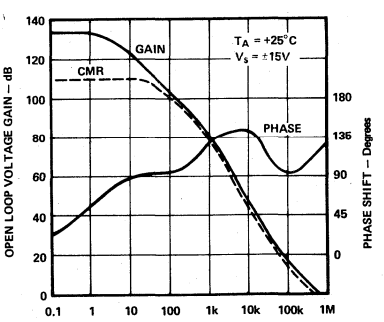



*Figure 2. Open Loop Frequency Response and CMR*

# ANALOG DEVICES

# High Voltage Differential FET Amplifier

# MODEL 171



**FEATURES**
- High Output Voltage: ±140V
- High CMR: 100dB min
- Operates With a Wide Range of Power Supplies
- High CMV: ±(|$V_S$| - 10V)

**APPLICATIONS**
- High Voltage Compliance Current Source
- High Voltage Follower With Gain
- High Voltage Integrator
- Diff. Amp for High CMV Bridge Applications
- Reference Power Supply




## GENERAL DESCRIPTION

Model 171 is a high performance FET input op amp designed for operation over a wide range of supply voltages. This module features an output range of ±15V to ±140V at 10mA, a minimum CMRR of 100dB and a high common mode voltage rating of ±($V_S$ - 10V) min. DC offset is less than ±1mV, and maximum drift of either ±50 or ±15μV/°C is available in the J or K versions. Bias current is less than 50pA (171J) or 20pA (171K), doubling per +10°C increase of temperature. The model 171 also features small signal bandwidth of 3MHz for unity gain, full-power bandwidth of 15kHz, and slew rate of 10V/μs. These operating characteristics make model 171 an excellent choice for high voltage buffer applications, followers with gain, off-ground signal measurements and reference power supplies.

Excellent power supply rejection of 7μV/V enables model 171 to be powered by inexpensive, low regulation supplies, without sacrificing any of the 171's inherent high performance. The supplies also need not be symmetrical. Any combination of power supply voltages between the limits of 15 to +300V for the positive side and 15 to -300V for negative side is acceptable provided the total voltage across the amplifier is within the range of 30 to 300V.

Model 171's output is completely short circuit protected by the use of a current limit scheme. This type of protection provides a short circuit output that is only slightly greater than the rated output current for normal operation. With this design the module and external circuitry are protected, internal heat dissipation and the associated high temperature rise are limited, and added reliability is built in.

## POWER SUPPLY VOLTAGES

Model 171 offers the flexibility of operating with an extensive range and combination of power supply voltages. Figure 1 shows a chart of permissible combinations of supply voltages for the 171. The model 171 maintains its normal operating characteristics when using asymmetrical power supply configurations.

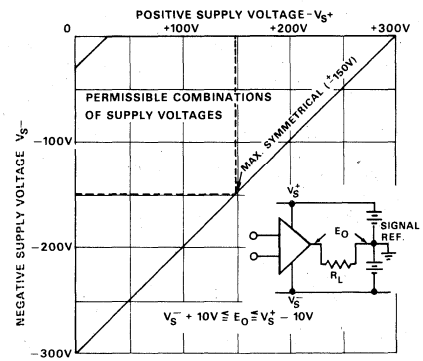



*Figure 1. Power Supply Voltage Combinations*

For detailed information, contact factory.

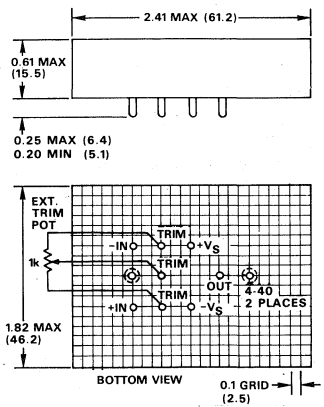
# SPECIFICATIONS (typical @ +25°C and ±125V unless otherwise noted)

| MODEL | 171J | 171K |
|---|---|---|
| OPEN LOOP GAIN | $10^6$ min | * |
| RATED OUTPUT | | |
| Voltage | ±(\|$V_S$\|-10V) min | * |
| Current | ±10mA min | * |
| Maximum Load Capacitance | 1000pF | * |
| FREQUENCY RESPONSE | | |
| Unity Gain, Small Signal | 3MHz | * |
| Slewing Rate | 10V/μs min | * |
| Full Power | 15kHz min | * |
| Settling Time to ±0.1%, ±10V Step | 25μs | * |
| Overload Recovery | 5μs | * |
| INPUT OFFSET VOLTAGE | | |
| Initial Offset, +25°C[1] | ±1mV | * |
| Avg. vs. Temp (0 to +70°C) | ±50μV/°C max | ±15μV/°C max |
| vs. Supply Voltage | ±7μV/V | * |
| vs. Time | ±250μV/mo | * |
| INPUT BIAS CURRENT | | |
| Initial Bias, +25°C | -50pA max | -20pA max |
| vs. Temp (0 to +70°C) | x 2/10°C | * |
| Difference Current | ±10pA | ±5pA |
| INPUT IMPEDANCE | | |
| Differential | $10^{11}\ \Omega \| 3.5$pF | * |
| Common Mode | $10^{11}\ \Omega \| 3.5$pF | * |
| INPUT NOISE | | |
| Voltage, 0.01 to 1.0Hz | 4μV p-p | * |
| 10Hz to 10kHz | 2.5μV rms | * |
| 5Hz to 50kHz | 6μV rms | * |
| INPUT VOLTAGE RANGE | | |
| Common Mode Voltage | ±(\|$V_S$\|-10V) min | * |
| Common Mode Rejection | 100dB min | * |
| Common Mode Rejection | 114dB | * |
| Max Safe Differential Voltage | ±$V_S$ | * |
| POWER SUPPLY | | |
| Voltage, Rated Specification | ±25 to ±150V dc | * |
| Voltage, Operating | ±15 to ±150V dc | * |
| Current, Quiescent | ±6mA typ | * |
| TEMPERATURE RANGE | | |
| Rated Specification | 0 to +70°C | * |
| Operating | -25°C to +85°C | * |
| Storage | -40°C to +100°C | * |
| MECHANICAL | | |
| Case Size | 2.41" x 1.82" x 0.61" | * |
| Weight | 80g | * |
| Mating Socket | AC1037 | * |

NOTES
*Specifications same as 171J.
[1] No external trim connection required.
Specifications subject to change without notice.

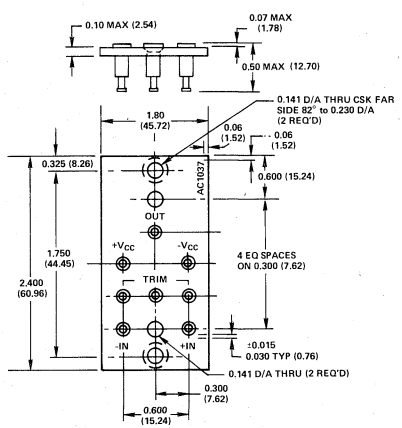
## OUTLINE DIMENSIONS

Dimensions shown in inches and (mm).




## MATING SOCKET

Dimensions shown in inches and (mm).




## MATING SOCKET AC1037

## SINGLE SUPPLY OPERATION

As shown in Figure 1, the model 171 requires at least ±15 volts applied across it in order to operate properly. The 171 may be operated from a single floating supply voltage by using the power supply offsetting scheme shown in Figure 2. When this configuration is used, the 171 is capable of operating over its specified input and output voltage range.

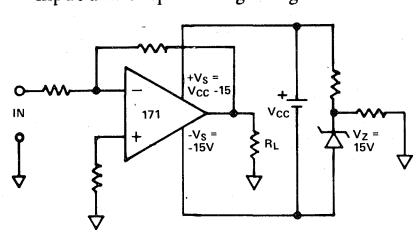



*Figure 2. Single Supply Operation*

# ANALOG DEVICES

# Low Noise Chopper Stabilized Amplifiers

## MODELS 234, 235

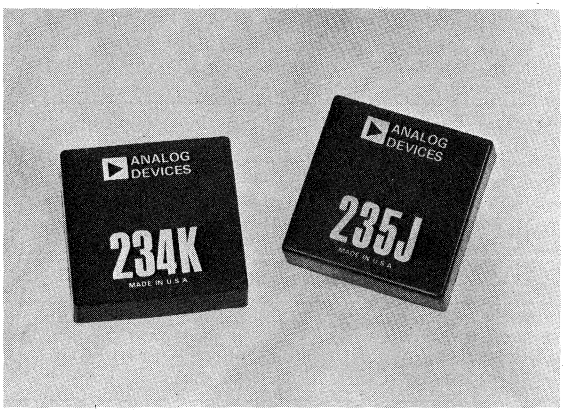


### FEATURES

**Ultra-Low Noise: 0.7μV p-p, 0.01Hz to 1Hz BW (234)**
**0.5μV p-p, 0.01Hz to 1Hz BW (235)**
**Very Low Offset Drift: 0.1μV/°C, 1pA/°C (234L)**
**0.1μV/°C, 0.5pA/°C (235L)**
**Excellent Long Term Stability: 5μV/year (235)**
**Fast Settling: 4μs to 0.01%, 2.5MHz BW (235)**

### APPLICATIONS

**Precision Integration**
**Servo/Null Detector Loops**
**Microvolt/Picoamp Measurements**
**Bridge Amplifier**
**Controlled Current Source**
**Balance Scales and Weighing Instruments**




### GENERAL DESCRIPTION

Analog Devices' models 234, 235 are high performance, economy chopper-stabilized op amps that meet the demands of critical laboratory and industrial applications requiring ultra-low noise, exceptional long term offset stability and versatility. Both models feature compact plug-in modular design, and are ideally suited for new design applications, or upgrading of existing systems, where both improved performance and cost savings can be realized.

**Model 234:** The model 234 is designed for wideband applications and features $10^7$ V/V open loop gain, 2.5MHz unity gain bandwidth, full power response to 500kHz and settling time of 4μs (to 0.01%, 10V step, 20kΩ load). The model 234 also features low input voltage noise of 0.7μV p-p (0.01Hz to 1Hz BW), low offset voltage drift of 1μV/°C (234J), 0.03μV/°C (234K) or 0.1μV/°C (234L) and long term stability of ±2μV/month.

Incorporating MOSFET choppers and discrete components (vs. IC op amps) for the main and stabilizing amplifier channels, this inverting design is virtually free of input chopper spikes and offers reduced modulation ripple for quieter wideband performance. These characteristics are especially desirable when operating from high source impedances (above 100kΩ) at wide bandwidths. To illustrate the improvements in noise and bandwidth performance, over previous Analog Devices' designs, comparative data is set forth in the following sections comparing models 232 and 233 with 234.

**Model 235:** The model 235 is recommended for applications where lowest cost and lowest noise are required. The model 235 features low input voltage noise of 0.5μV p-p (0.01Hz to 1Hz BW), low offset voltage drift of 0.5μV/°C (235J), 0.25μV/°C (235K), 0.1μV/°C (235L) and a long term stability of 5μV/year.

This combination of noise and drift performance makes model 235 ideally suited for demanding applications such as balance scales and weighing instruments requiring high accuracy and excellent long-term stability without the use of "front panel" balance pots or periodic internal adjustment.

Model 235 has been designed to virtually eliminate intermodulation problems caused by "beating" against power line frequencies. The chopper's ultra-stable oscillator is precisely set at the factory to a frequency that minimizes ineractions with harmonics of 50Hz, 60Hz and 400Hz power lines.

### APPLICATIONS

In general, the models 234, 235 inverting amplifiers should be considered where long term stability of offset voltage must be maintained with time and temperature for precision designs, or wherever maintenance-free operation of instruments and remote circuits is essential. Typical applications include low drift amplification of microvolt signals, integration of low duty-cycle pulse trains and analog computing for general purpose designs. Low input noise and stable offset voltages also make 234, 235 an ideal preamp for precision low frequency applications such as DVMs, 12- to 16-bit A to D converters, and for error amplifiers in servo and null detector systems.

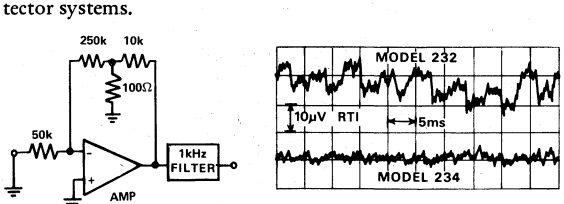



*Figure 1. Model 234 Comparative Input Noise (RTI) Performance in a dc to 1kHz Bandwidth*

**For detailed information, contact factory.**

# SPECIFICATIONS (typical @ +25°C and ±15V unless otherwise noted)

| MODEL | 234J | 234K | 234L | 235J | 235K | 235L |
|---|---|---|---|---|---|---|
| OPEN LOOP GAIN | | | | | | |
| DC, 2k ohm load | $10^7$ V/V min | * | * | 5 x $10^7$V/V min | ** | ** |
| RATED OUTPUT | | | | | | |
| Voltage | ±10V min | * | * | * | * | * |
| Current | ±5mA min | * | * | * | * | * |
| Load Capacitance Range | 0–1000pF min | * | * | 0.01µF | ** | ** |
| FREQUENCY[1] | | | | | | |
| Unity Gain, Small Signal | 2.5MHz | * | * | 1MHz | ** | ** |
| Full Power Response | 500kHz min | * | * | 5kHz min | ** | ** |
| Slew Rate | 30V/µs | * | * | 0.3V/µs min | ** | ** |
| SETTLING TIME to 0.01% | | | | | | |
| 20kΩ load, 10V step | 4µs | * | * | N/A | N/A | N/A |
| INPUT OFFSET VOLTAGE | | | | | | |
| Initial Offset[2] | ±50µV max | ±20µV max | ±20µV max | ±25µV max | ** | ±15µV max |
| vs. Temp, 0 to +70°C | ±1.0µV/°C max | ±0.3µV/°C max | ±0.1µV/°C max | ±0.5µV/°C max | ±0.25µV/°C max | ±0.1µV/°C max |
| vs. Supply Voltage | ±0.2µV/% | * | * | ±0.1µV/% | ** | ** |
| vs. Time | ±2µV/month | * | * | ±5µV/year | ** | ** |
| vs. Turn On, 10 sec to 10 min | ±3µV | * | * | * | * | * |
| INPUT BIAS CURRENT | | | | | | |
| Initial, @ +25°C | ±100pA max | * | * | * | ±50pA max | ±50pA max |
| vs. Temp, 0 to +70°C | ±4pA/°C max | ±2pA/°C max | ±1pA/°C max | 1pA/°C max | 0.5pA/°C max | 0.5pA/°C max |
| vs. Supply Voltage | ±0.5pA/% | * | * | 0.2pA/% | ** | ** |
| INPUT IMPEDANCE | | | | | | |
| Inverting Input to Signal Ground | 300k ohms | * | * | * | * | * |
| INPUT NOISE | | | | | | |
| Voltage, 0.01 to 1Hz | 0.7µV p-p | * | * | 0.5µV p-p | 2µV p-p max | 2µV p-p max |
| 0.1 to 10Hz | 1.5µV p-p | * | * | 3.5µV p-p | ** | ** |
| 10Hz to 10kHz | 2µV rms | * | * | 5µV rms | ** | ** |
| Current, 0.01 to 1Hz | 2pA p-p | * | * | 10pA p-p | ** | ** |
| 0.1 to 10Hz | 4pA p-p | * | * | 30pA p-p | ** | ** |
| INPUT VOLTAGE RANGE | | | | | | |
| (–) Input to Signal Ground | ±15V max | * | * | * | * | * |
| POWER SUPPLY (V dc)[3] | | | | | | |
| Rated Performance | ±15V @ 5mA | * | * | * | * | * |
| Operating | ±(12 to 18)V | * | * | * | * | * |
| TEMPERATURE RANGE | | | | | | |
| Rated Specifications | 0 to +70°C | * | * | * | * | * |
| Operating | -25°C to +85°C | * | * | * | * | * |
| Storage | -25°C to +100°C | * | * | -55°C to +125°C | ** | ** |

NOTES
*Specifications same as model 234J.
**Specifications same as model 235J.
[1] Model 235 overload recovery, 10 sec typ.
[2] Externally adjustable to zero.
[3] Recommended power supply: Analog Devices model 904, ±15V dc @ 50mA.
Specifications subject to change without notice.

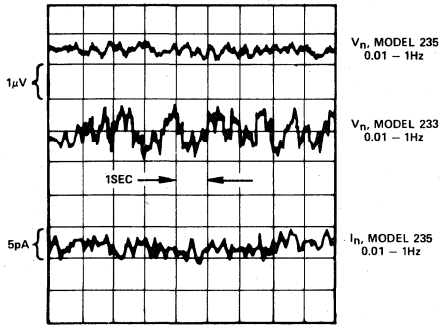
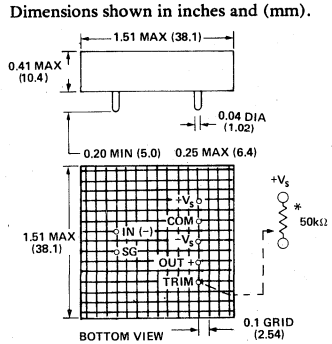



*Figure 2. Model 235 Voltage and Current Noise. Model 233 Voltage Noise Shown for Comparison.*

## OUTLINE DIMENSIONS

Dimensions shown in inches and (mm).



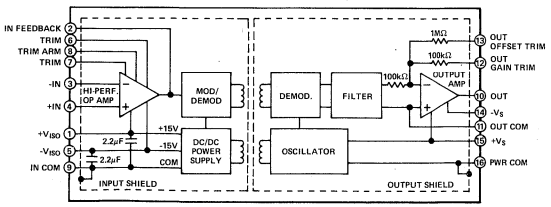

NOTES:
*Connect Trim Terminal to Common if Trim Pot is not used.
1. SG Tied to Common.
2. Mating Socket AC1010.
3. Weight: 27 grams.

# Isolation Amplifiers

## Contents


| | Page |
|---|---|
| Selection Guide | 5-2 |
| General Information | 5-6 |
| Definition of Specifications | 5-8 |
| 277J/K/A Isolated Operational Amplifier | 5-9 |
| 281 Synchronizable Drive-Oscillator for 286J and 292A | 5-11 |
| 284J Stand-Alone Isolator | 5-11 |
| 286J Driven Isolator for Multichannel Applications | 5-11 |
| 289J/K/L High-Performance Synchronizable Self-Contained Isolation Amplifier | 5-17 |
| 290A Lowest-Cost Stand-Alone Isolator | 5-21 |
| 292A Lowest-Cost Driven Isolator for Multichannel Applications | 5-21 |

# Selection Guide
## Isolation Amplifiers




## MODEL 277

Page

Versatile Op Amp Front End: Inverting, Noninverting, Differential Applications — Vol. II 5–9

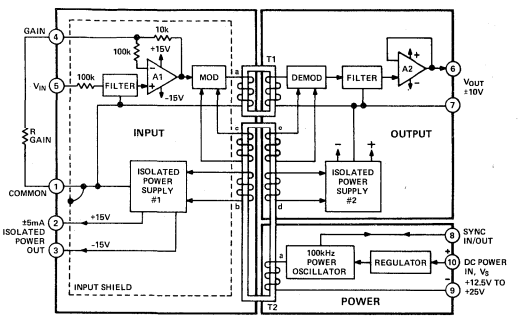
Low Nonlinearity: 0.025% max, Model 277K

Low Input Offset Voltage Drift: 1µV/°C max, Model 277K

Floating Power Supply: ±15V dc @ ±15mA

High CMR: 160dB min @ dc

High CMV: 3500$V_{rms}$




## MODEL 289

Low Nonlinearity: ±0.012% max (289L) — Vol. II 5–17

Frequency Response: (−3dB) dc to 20kHz (Full Power) dc to 5kHz

Gain Adjustable 1 to 100V/V, Single Resistor

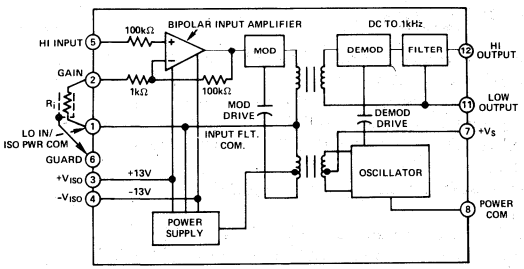
3-Port Isolation: ±2500V CMV Isolation Input/Output

Low Gain Drift: ±0.005%/°C max

Floating Power Output: ±15V @ ±5mA

120dB CMR at 60Hz: Fully Shielded Input Stage

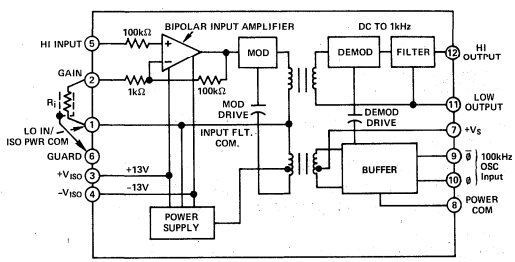
Meets UL Std. 544 Leakage: 2µA rms max, @ 115V ac, 60Hz




## MODEL 290A

Page

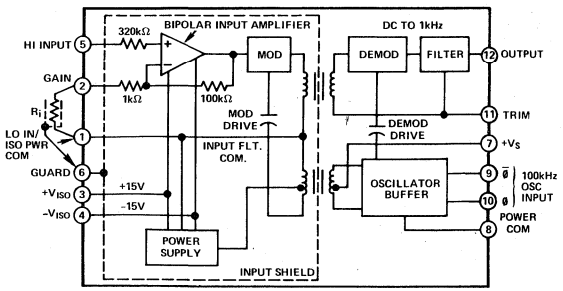
- **Isolated Power Supply: ±13V dc @ ±5mA (290A)** Vol. II 5-21
- **Low Nonlinearity: 0.1% @ 10V pk-pk Output**
- **High Gain Stability: 0.001%/1000 Hours; 0.01%/°C**
- **Small Size: 1.5″ × 1.5″ × 0.62″**
- **Low Input Offset Voltage Drift: 10μV/°C (Gain = 100V/V)**
- **Wide Input/Output Dynamic Range: 20V pk-pk**
- **High CMV Isolation: 1500V dc, Continuous**
- **Wide Gain Range: 1 to 100V/V**




## MODEL 292A

- **Multichannel Capability Using External Oscillator (292A)** Vol. II 5-21
- **Isolated Power Supply: ±15mA (292A)**
- **Low Nonlinearity: 0.1% @ 10V pk-pk Output**
- **High Gain Stability: 0.001%/1000 Hours; 0.01%/°C**
- **Small Size: 1.5″ × 1.5″ × 0.62″**
- **Low Input Offset Voltage Drift: 10μV/°C (Gain = 100V/V)**
- **Wide Input/Output Dynamic Range: 20V pk-pk**
- **High CMV Isolation: 1500V dc, Continuous**
- **Wide Gain Range: 1 to 100V/V**

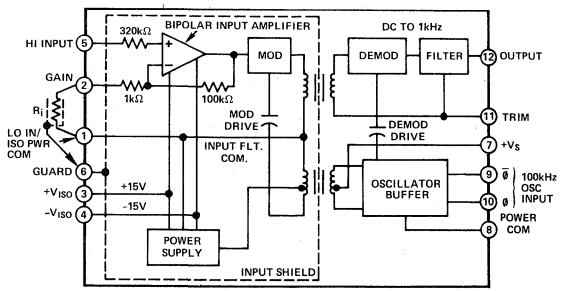
# Selection Guide
## Isolation Amplifiers




## MODEL 284

Page
Vol. II
5-11

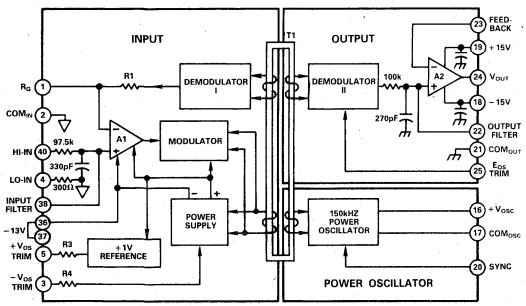
**High CMV Isolation: ±5000V pk, 10ms Pulse; ±2500V dc Continuous**
**High CMR: 110dB min with 5kΩ Imbalance**
**Low Nonlinearity: 0.05% @ 10V pk-pk Output**
**High Gain Stability: ±0.0075%/°C, ±0.001%/1000 hours**
**Low Input Offset Voltage Drift: 10μV/°C, G = 100V/V**
**Resistor Programmed Gain: 1 to 10V/V (284J)**
**Isolated Power Supply: ±8.5V dc @ ± 5mA (284J)**
**Meets IEEE Std 472: Transient Protection (SWC)**
**Meets UL Std 544 Leakage @ 115V ac, 60Hz: 2.0μA max (284J)**




## MODEL 286

Vol. II
5-11

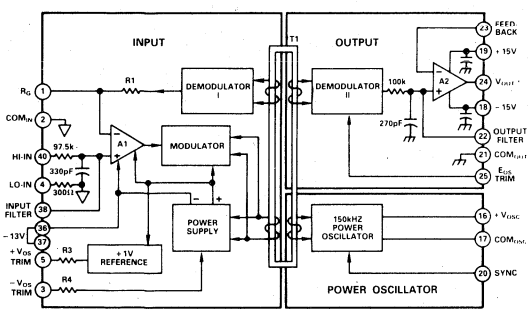
**High CMV Isolation: ±5000V pk, 10ms Pulse; ±2500V dc Continuous**
**High CMR: 110dB min with 5kΩ Imbalance**
**Low Nonlinearity: 0.05% @ 10V pk-pk Output**
**High Gain Stability: ±0.0075%/°C, ±0.001%/1000 hours**
**Low Input Offset Voltage Drift: 10μV/°C, G = 100V/V**
**Resistor Programmed Gain: 1 to 100V/V (286J)**
**Isolated Power Supply: ±15V dc @ ± 15mA (286J)**
**Meets IEEE Std 472: Transient Protection (SWC)**
**Meets UL Std 544 Leakage @ 115V ac, 60Hz: 2.5μA max (284J)**




## AD293

Page
Vol. I
5-13

**High Common-Mode Voltage: AD293 ±2500V peak max**
**Nonlinearity: ±0.05% max (AD293B)**
**Adjustable Input & Output Gain: 1V/V to 1000V/V**
**Complies with NEMA ICS1-111**
**Hermetically Sealed Hybrid Construction**




## AD294

Vol. I
5-13

**High Common-Mode Voltage: ±8000V peak max**
**Nonlinearity: ±0.05% of max**
**Adjustable Input & Output Gain: 1V/V to 1000V/V**
**Complies with NEMA ICS1-111**
**Meets UL Std 544 Leakage: 2.0μA max @ 115V ac, 60Hz**
**Hermetically Sealed Hybrid Construction**

# Orientation
# Isolation Amplifiers

The *isolation amplifier* (or *isolator*) has an input circuit that is galvanically isolated from the power supply and the output circuit. Isolators are intended for applications requiring safe, accurate measurement of dc and low-frequency voltage or current in the presence of high common-mode voltage (to thousands of volts) with high CMR, line-receiving of signals transmitted at high impedance in noisy environments, and for safety in general-purpose measurements where dc and line-frequency leakage must be maintained at levels well below certain mandated minima.* Principal applications are in electrical environments of the kind associated with medical equipment, conventional and nuclear power plants, automatic test equipment, and industrial process-control systems.

Analog Devices Isolators described in this section use electromagnetically coupled high-frequency carrier techniques for communication of power to and signals from the input circuit.

**CHOOSING AN ISOLATOR**

The choice of an isolator depends on the desired *functional characteristics* and the required *specifications*. Functional characteristics include such considerations as number of channels, range of output common-mode (output to power supply), nature of the front-end amplifier (amplification only or general op-amp functioning), and the availability of isolated power for additional external front-end circuitry. Key specifications include performance specs and "absolute max/min" mandated safety specifications. Definitions of specifications follow this section. In addition to the products listed here, which are recommended for new designs, a number of older products are still available; data sheets are available upon request. In addition to the useful applications information on the data sheets published here, an applications guide[1], available upon request, provides information useful to the circuit designer.

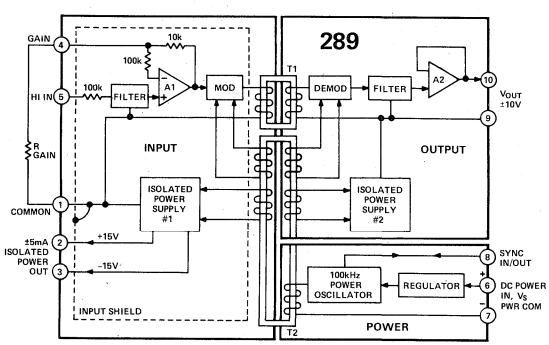
The devices described in this section are all voltage-output isolation amplifiers, useful in general-purpose circuit applications for instrumentation amplifiers or op amps where isolation is a necessity. In addition to these devices, there are a growing number of isolators available from Analog Devices that perform dedicated functions, for use where isolation is necessary or desirable. Some of their applications can be seen in the *Transducer Interfacing Handbook*[2].

Data for other products employing isolation techniques may be found in these sections of this Volume: Transducers and Signal Conditioners, Digital-to-Analog Converters, Synchro/Resolver-Digital Converters, Digital Panel Instruments, Intelligent Measurement-and-Control Subsystems, Linear Test Systems, and MACSYM. Power Supplies and DC-DC Converters, being transformer-coupled, also provide isolation.

Examples of such products include the 2B54 Thermocouple/mV 4-Channel Multiplexer/Amplifier, the 2B22 Voltage-or-Current-to 4-to-20mA Converter, the DAC1423 10-bit Digital-to-4-to-20mA Converter, the AD2036, AD2037, and AD2038 Scanning Panel Instruments, and the μMAC-5000 Intelligent Measurement-and-Control Subsystems.

*Functional Characteristics* The figure shows the circuit architecture of a self-contained isolator, Model 289. The various models differ, but their properties can be discussed in terms of the device shown. An isolator of this type requires power from a two-terminal dc supply. An internal oscillator converts the dc power to ac, which is transformer-coupled to the shielded input section, then converted to dc for the input stage and the auxiliary power output. The ac carrier is also modulated by the amplifier output, transformer-coupled to the output stage, demodulated by a phase-sensitive demodulator (using the carrier as the reference), filtered, and amplified, using isolated dc power, derived from the carrier.

The amplifier in this example is a resistor-protected op amp (actually, the protection works both ways – it protects the amplifier against differential overloads (120V rms continuous) and it protects sensitive input sources from supply voltage if the amplifier malfunctions), connected for a programmable gain from 1 to 100V/V, as determined by a single external resistor. Since both input terminals are floating, the amplifier functions effectively as an instrumentation amplifier. All but one of the amplifiers in this series function in the instrumentation-amplifier mode, but with various gain ranges. The 277 is an exception; its input stage is an uncommitted high-gain low-drift, low-noise op amp, and the output terminal of the input stage is available for feedback connections to perform a wide range of single-ended or differential operations. Because of the transformer coupling, the outputs of all these devices are isolated from their input stages.




In the figure, it can be seen that the demodulator drive is magnetically coupled from the oscillator to the output stage.

*Examples of such requirements may be found in UL STD 544 and SWC (Surge Withstand Capability) in IEEE Standard for Transient Voltage Protection 472-1974.

[1] *Analog Devices "Applications Guide to Isolation Amplifiers"* (1984)

[2] Sheingold, D. H., ed. *Transducer Interfacing Handbook—A guide to analog signal conditioning.* Norwood MA 02062 (P.O. Box 796): Analog Devices, Inc., 1980, $14.50

This permits the output to operate at a dc common-mode potential with respect to power common. An isolator of this type is said to provide *three-port* isolation, because there are three isolated ports: input, power supply, and output. The AD293 and AD294 have 3 isolated sections, but the op amp supply is tied to output common. The data sheets carry block diagrams, which show the architecture of each device; 3-port devices, in general, have an output common-mode voltage spec in the "Rated Output" section. Two-port devices are those in which there is a dc connection between the oscillator power supply and the output stage.

The 289, as can be seen, is a completely self-contained device. There are applications for which a degree of "unbundling" can lead to economy and improved performance. For example, if there are many input channels to be isolated, economies can be realized by the use of a common oscillator. In addition, the common oscillator makes it possible to avoid the possibility of small errors due to beat frequencies developed by small amounts of crosstalk.

Several synchronized multichannel devices are available. Model 292A is essentially a 290A with a power amplifier instead of an oscillator. It requires a dc power input and a pair of leads for a low-power oscillator input, which can be furnished by a 281 synchronizable oscillator. The 281 will drive from one to 16 292As, and it will also synchronize additional 281s for increments of up to 16 292s per 281.



**SPECIFICATIONS**

The illustration on the next page shows a typical specification block and defines the specifications of key interest.

**NONLINEARITY** – This is the peak deviation from a best straight line, expressed as a % of peak-to-peak output. Should be considered when signal fidelity is of prime importance.

**MAX SAFE DIFFERENTIAL INPUT** – Max voltage that can be safely applied across input terminals. Important to consider for fail-safe designs in the presence of high voltages.

**OVERLOAD RESISTANCE** – This is the apparent input impedance under conditions of amplifier saturation. It limits differential fault currents.

**INPUT NOISE** – Total noise, referred to the input. Facilitates comparison with expected signal input levels.

**ISOLATED SUPPLY** – Dual supply voltages, completely isolated from the input power supply terminals, provide the capability to excite floating input signal conditioners, front-end amplifiers, as well as remote transducers.

| Model | 289K |
|---|---|
| GAIN (NONINVERTING) | |
| Range | 1 to 100V/V |
| Formula | $G = 1 + \frac{10k\Omega}{R_G(k\Omega)}$ |
| Deviation from Formula | ±1.5% max |
| vs. Temperature (0 to +70°C)[1] | 15ppm/°C typ (50ppm/°C max) |
| Nonlinearity, (±5V Swing)[2,3] | ±0.025% max |
| INPUT VOLTAGE RATINGS | |
| Linear Differential Range (G = 1V/V) | ±10V min |
| Max Safe Differential Input | |
| Continuous | 120V rms |
| 1 Minute | 240V rms |
| Max CMV (Inputs to Outputs) | |
| Continuous ac or dc | ±2500V peak max |
| ac, 60Hz, 1 Minute Duration | 2500V rms |
| CMR, Inputs to Outputs 60Hz | |
| $R_S \leq 1k\Omega$, Balanced Source Impedance | 120dB |
| $R_S \leq 1k\Omega$, HI IN Lead Only | 104dB min |
| Max Leakage Current, Input to Output @ 115V rms, 60Hz ac | 2μA rms max |
| INPUT IMPEDANCE | |
| Differential | $33pF \| 10^8 \Omega$ |
| Overload | 100kΩ |
| Common Mode | $20pF \| 5 \times 10^{10} \Omega$ |
| INPUT DIFFERENCE CURRENT | |
| Initial @ +25°C | 10nA (75nA max) |
| vs. Temperature (0 to 70°C) | 0.15nA/°C |
| INPUT NOISE (GAIN = 100V/V) | |
| Voltage | |
| 0.05Hz to 100Hz | 8μV p-p |
| 10Hz to 1kHz | 3μV rms |
| Current | |
| 0.05Hz to 100Hz | 3pA rms |
| FREQUENCY RESPONSE | |
| Small Signal -3dB | |
| G = 1V/V | 20kHz |
| G = 100V/V | 5kHz |
| Full Power, 10V p-p Output | |
| G = 1V/V | 5kHz |
| G = 100V/V | 3.5kHz |
| Full Power, 20V p-p Output | |
| G = 1V/V | 2.3kHz |
| G = 100V/V | 2.3kHz |
| Slew Rate | 0.14V/μs |
| Settling Time[4], ±0.05%, ±10V Step | 400μs |
| OFFSET VOLTAGE, REFERRED TO INPUT | |
| Initial, @ +25°C | $\pm 5 \pm \frac{10}{G}$ mV max |
| vs. Temperature (0 to +70°C) | $\pm 15 \pm \frac{100}{G}$ max |
| vs. Supply Voltage (+15V to +20V change) | $\pm 2 \pm \frac{10}{G}$ μV/V |
| RATED OUTPUT | |
| Voltage, 2kΩ Load | ±10V min |
| Output Impedance | <1Ω(dc to 100Hz) |
| Output Ripple, 0.1MHz Bandwidth | |
| No Signal IN | 5mV p-p |
| $+10V_{IN}$ | 50mV p-p |
| ISOLATED POWER SUPPLY | |
| Voltage | ±15V dc |
| Accuracy | ±10% |
| Current | ±5mA, min |
| Regulation No Load to Full Load | ±5% |
| Ripple, 0.1MHz Bandwidth, No Load | 25mV p-p |
| Full Load | 75mV p-p |
| POWER SUPPLY, SINGLE POLARITY[5] | |
| Voltage, Rated Performance | +14.4V to +25V |
| Voltage, Operating | +8.5V to +25V |
| Current, Quiescent (@ $V_S$ = +15V) | +25mA |
| TEMPERATURE RANGE | |
| Rated Performance | 0 to +70°C |
| Operating | -15°C to +75°C |
| Storage | -55°C to +85°C |
| CASE DIMENSIONS | 1.5" X 2.0" X 0.75" |

NOTES:
[1] Gain temperature drift is specified as a percentage of output signal level.
[2] Gain nonlinearity is specified as a percentage of 10V pk-pk output span.
[3] When isolated power output is used, nonlinearity increases by ±0.002%/mA of current drawn.
[4] G = 1V/V; with 2-pole, 5kHz output filter.
[5] Recommended power supply, ADI model 904, ±15V @ 50mA output.
Specifications subject to change without notice.

**CMV, INPUTS TO OUTPUTS** – Voltage that may be safely applied to *both* inputs with respect to outputs or power common. Necessary consideration in applications with high CMV input or when high voltage transients may occur at the input.

**CMR, INPUTS TO OUTPUTS** – Indicates ability to reject common mode voltages between inputs and outputs. Important when processing small signals riding on high common mode voltages.

**LEAKAGE CURRENT** – Maximum input leakage current when power-line voltage is impressed on inputs. Vital consideration for patient safety in medical applications.

**OFFSET VOLTAGE REFERRED TO INPUT** – Total input drift is composed of two sources (input and output stage drifts) and is gain (G) dependent. Referring offsets to the input allows them to be compared to signal levels.

# ANALOG DEVICES

# Precision Isolation Amplifier
# High CMV/CMR, ±15V Floating Power
# MODEL 277

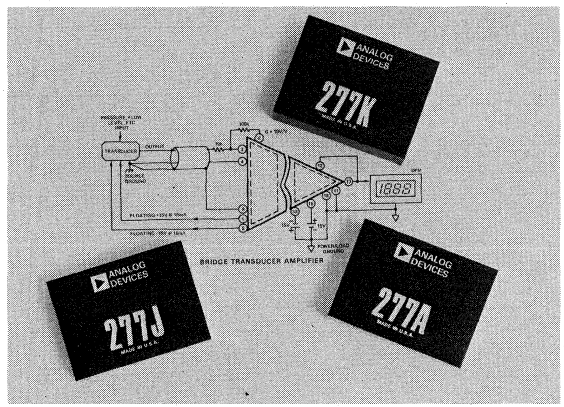


## FEATURES

**Versatile Op Amp Front End: Inverting, Non-Inverting, Differential Applications**
**Low Nonlinearity: 0.025% max, Model 277K**
**Low Input Offset Voltage Drift: 1μV/°C max, Model 277K**
**Floating Power Supply: ±15V dc @ ±15mA**
**High CMR: 160dB min @ dc**
**High CMV: 3500$V_{rms}$**

## APPLICATIONS

**Programmable Gain Isolated Amplifier**
**Isolated Power Source and Amplifier for Bridge Measurements**
**Instrumentation Amplifier**
**Instrumentation Grade Process Signal Isolator**
**Current Shunt Measurements**




## GENERAL DESCRIPTION

Model 277 is a versatile isolation amplifier which combines a high-performance, uncommitted operational amplifier front end with a precision, isolated output stage and a floating power supply section. This configuration, shown in Figure 1, makes the 277 ideally suited to instrumentation applications where the need for various forms of signal conditioning, high CMV protection and isolated transducer power requirements are encountered.

The input stage is a low drift (±1μV/°C max, model 277K) differential op amp that may be connected for use in inverting, non-inverting and differential configurations. The circuitry employed around the operational amplifier input stage can be designed by the user to suit each application's particular signal processing needs. A full ±10V signal range is available at the output of the front end amplifier.

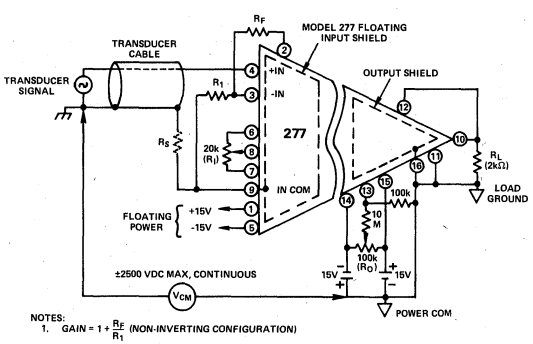



*Figure 1. Transducer, Power, Gain Resistors, and Shielding Interconnection*

The isolated output stage includes a special modulator/demodulator technique which provides the 277 with 160dB minimum dc common mode rejection between input and output common and an input-to-output CMV rating of 3500$V_{rms}$. When combined with the output stage's low nonlinearity (0.05%, models 277J/A and 0.025% model 277K), these high CMR and CMV ratings facilitate accurate measurements in the presence of noisy electrical equipment such as motors and relays. In addition, model 277A offers a -25°C to +85°C rated operating temperature range. All versions of model 277 have a ±10 volt output range.

The floating power supply section provides isolated ±15 volt outputs capable of delivering currents up to ±15mA. This feature permits model 277 to power transducers and auxiliary isolated circuitry, thereby eliminating the need for a separate isolated dc/dc converter.

All of the features of the model 277 isolation amplifier are packaged in a compact (3″ x 2.2″ x 0.59″) module. As an assurance of high performance reliability, every model 277 is factory tested for CMV rating by application of 3500$V_{rms}$ (±4900V peak) between input and output common terminals for one minute (meets NEMA and CSA requirements for 660$V_{rms}$ service.) In addition, the 277 has a calculated MTBF of 133,000 hours.

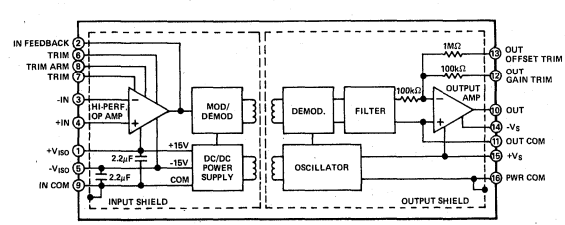



*Figure 2. Model 277 Functional Block Diagram*

For detailed information, contact factory.

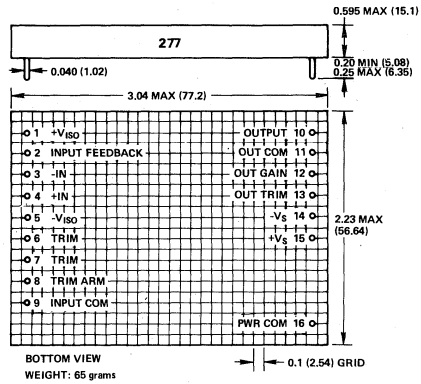
# SPECIFICATIONS (typical at +25°C and ±15V unless otherwise noted)

| MODEL | 277J | 277K | 277A |
|---|---|---|---|
| **INPUT STAGE PERFORMANCE**[1,2] | | | |
| OPEN LOOP GAIN | 106dB min | * | * |
| INPUT OFFSET VOLTAGE | | | |
| Initial, @ +25°C (Adjustable to Zero) | ±1.5mV max | * | * |
| vs. Temperature | | | |
| Offset Untrimmed | ±5μV/°C max | * | ±5μV/°C |
| Offset Trimmed to Zero | ±3μV/°C max | ±1μV/°C max | * |
| vs. Supply Voltage | ±30μV/V | * | * |
| vs. Time | ±3.5μV/mo | * | * |
| INPUT BIAS CURRENT | | | |
| Initial, @ +25°C | ±20nA max | * | * |
| vs. Temperature | ±50pA/°C | * | * |
| vs. Supply Voltage | ±100pA/V | * | * |
| INPUT DIFFERENCE CURRENT | | | |
| Initial, @ +25°C | ±6nA | * | * |
| vs. Supply Voltage | ±50pA/V | * | * |
| INPUT IMPEDANCE | | | |
| Differential | 4MΩ | * | * |
| Common Mode[3] | 100MΩ‖4pF | * | * |
| INPUT NOISE | | | |
| Voltage, 0.01Hz to 10Hz | 1μV p-p | * | * |
| 10Hz to 1kHz | 3μV rms | * | * |
| Current, 0.01Hz to 10Hz | 35pA p-p | * | * |
| INPUT VOLTAGE RANGE | | | |
| Common Mode Voltage[3] | ±10V min | * | * |
| Common Mode Rejection[3], CMV = ±10V, 60Hz | 100dB | * | * |
| Max Safe Differential Voltage | ±13V | * | * |
| ISOLATED POWER SUPPLY[4] | | | |
| Voltage/Current[2] | ±15V @ ±15mA max | * | * |
| Load Regulation (No Load – Full Load) | +0, -6% | * | * |
| Line Regulation | 1V/V | * | * |
| Ripple, Full Load | 30mV p-p @ 70kHz | * | * |
| **OUTPUT STAGE PERFORMANCE** | | | |
| GAIN | 1V/V | * | * |
| Gain Error | ±0.5% max | * | * |
| vs. Temperature | ±50ppm/°C max | * | * |
| Nonlinearity, ±10V Output | ±0.05% max | ±0.025% max | * |
| VOLTAGE RATINGS[5] | | | |
| Max CMV, Output Com/Input Com | | | |
| ac, 60Hz, 1 Minute | $3500V_{rms}$ max | * | * |
| Nonrecurring Spike (<1 Second) | ±5000V pk max | * | * |
| Peak ac or dc, Continuous | ±2500V max | * | * |
| CMR, Output Com/Input Com[5] | | | |
| dc | 160dB min | * | * |
| 60Hz | 120dB min | * | * |
| Leak. Cur., Input/output $115V_{rms}$, 60Hz | 1μA rms max | * | * |
| ISOLATION IMPEDANCE[5] | | | |
| Input Com/Output Com | $10^{12}Ω‖16pF$ | * | * |
| OUTPUT OFFSET VOLTAGE | | | |
| Initial, @ +25°C (Adjustable to Zero) | ±10mV max | * | * |
| vs. Temperature | ±100μV/°C max | ±50μV/°C max | ±100μV/° C max |
| vs. Supply Voltage | ±1mV/V | * | * |
| vs. Time | ±100μV/mo | * | * |
| FREQUENCY RESPONSE | | | |
| Small Signal, -3dB | 2.5kHz | * | * |
| Full Power, 20V p-p Output | 1.5kHz | * | * |
| Settling Time ±10V Step to 0.1% | 1ms | * | * |
| RATED OUTPUT | | | |
| Voltage/Current | ±10V min @ ±5mA min | * | * |
| OUTPUT NOISE | | | |
| Voltage, 0.01Hz to 10Hz | 7μV p-p | * | * |
| 10Hz to 1kHz | 25μV rms | * | * |
| POWER SUPPLY[6] | | | |
| Voltage, Rated Performance | ±15V dc | * | * |
| Voltage, Operating | ±(14 to 16)V dc | * | * |
| Current, Quiescent | +35, -5mA | * | * |
| TEMPERATURE RANGE | | | |
| Rated Performance | 0 to +70°C | * | -25°C to +85°C |
| Operating | -25°C to +85°C | * | * |
| Storage | -55°C to +85°C | * | * |
| CASE SIZE | 3.0" x 2.2" x 0.59" | * | * |

NOTES:
[1] Current drawn from INPUT FEEDBACK terminal must be ≤5mA.
[2] Total current drawn from IN FEEDBACK and either $+V_{ISO}$ or $-V_{ISO}$ must be ≤15mA.
[3] Input common mode specifications are measured at +IN and -IN terminals with respect to INPUT COM.
[4] Protected for momentary shorts to IN COM.
[5] Isolation specifications are measured at INPUT COM with respect to OUT COM and PWR COM.
[6] Recommended power supply, ADI model 904, ±15V @ ±50mA.
*Specifications same as model 277J.
Specifications subject to change without notice.

## OUTLINE DIMENSIONS

Dimensions shown in inches and (mm)




## MATING SOCKET – AC1053

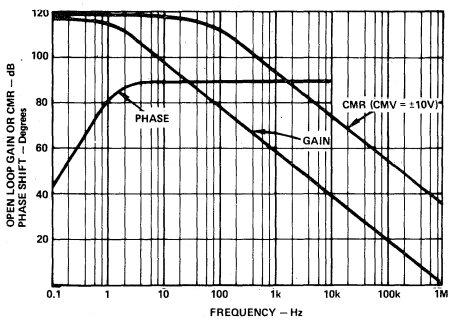



*Figure 3. Input Stage Gain, CMR and Phase vs. Frequency*

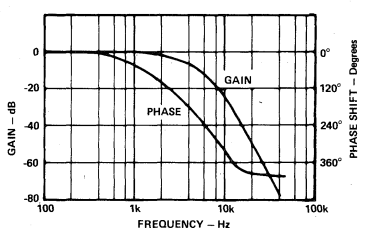



*Figure 4. Output Stage Gain and Phase vs. Frequency*

# ANALOG DEVICES

# High CMV, High Performance Isolation Amplifiers

# MODELS 284J, 286J, 281

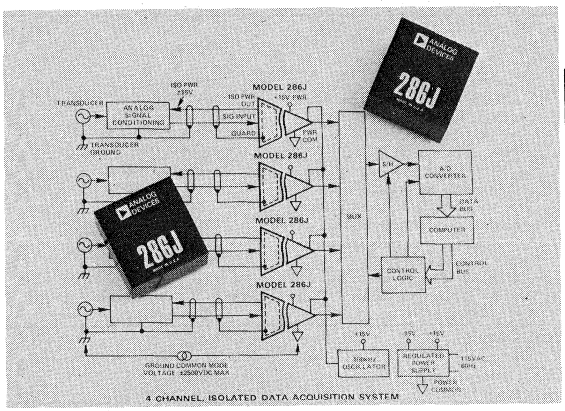


## FEATURES

- High CMV Isolation: ±5000V pk, 10ms Pulse; ±2500V dc Continuous
- High CMR: 110dB min with 5kΩ Imbalance
- Low Nonlinearity: 0.05% @ 10V pk-pk Output
- High Gain Stability: ±0.0075%/°C, ±0.001%/1000 hours
- Low Input Offset Voltage Drift: 10μV/°C, G = 100V/V (Model 286J)
- Resistor Programmed Gain: 1 to 10V/V (284J)
  1 to 100V/V (286J)
- Isolated Power Supply: ±8.5V dc @ ±5mA (284J)
  ±15V dc @ ±15mA (286J)
- Meets IEEE Std 472: Transient Protection (SWC)
- Meets UL Std 544 Leakage @ 115V ac, 60Hz:
  2.0μA max (284J)
  2.5μA max (286J)

## APPLICATIONS

- Fetal Heartbeat Monitoring
- Multi-Channel ECG Recording
- Ground Loop Elimination in Industrial and Process Control
- High Voltage Protection in Data Acquisition Systems
- 4-20mA Isolated Current Loop Receiver



4 CHANNEL, ISOLATED DATA ACQUISITION SYSTEM

## GENERAL DESCRIPTION

The models 284J, 286J are low cost, high performance isolation amplifiers designed for high CMV isolation and low leakage in biomedical, industrial and data acquisition systems. Using modulation techniques with reliable transformer isolation, the models 284J, 286J protect both patients and ultrasensitive equipment from high CMV transients up to ±5000V pk (10ms pulse) or 2500V dc continuous, high CMR of 110dB (5kΩ imbalance) and feature maximum leakage current of less than 3μA rms, @ 115V ac, 60Hz (inputs to power common).

The model 284J is a self-contained isolation amplifier for single channel applications. For multi-channel applications, the model 286J combined with an external synchronizing oscillator such as the model 281 may be used; up to 16 model 286J amplifiers can be driven from 1 model 281 oscillator. Additional channels may be obtained by configuring an unlimited number of 284Js with several ganged 281 oscillators.

Both models also provide resistor-programmable gain of 1 to 10V/V (284J) or 1 to 100V/V (286J), high gain stability of 0.0075%/°C, low nonlinearity of 0.05% @ 10V pk-pk output and isolated power supply outputs of ±15V dc @ ±15mA (286J) or ±8.5V dc @ ±5mA (284J).

## WHERE TO USE MODELS 284J, 286J

**Industrial Applications:** In data acquisition systems, computer interface systems, process signal isolators and high CMV instrumentation, models 284J, 286J offer complete galvanic isolation and protection against damage from transients and fault voltages. High level transducer interface capability is afforded with model 286J's 20V pk-pk or model 284J's 10V pk-pk input signal range at a gain of 1V/V operation. In portable field designs, single supply, wide range operation (+8V to +16V) offers simple battery operation.

**Medical Applications:** In biomedical and patient monitoring equipment such as multi-channel VCG, ECG, and polygraph recorders, models 284J, 286J offer protection from lethal ground fault currents as well as 5kV defibrillator pulse inputs. Low level bioelectric signal recording is achieved with low input noise (8μV pk-pk @ G = max gain) and high CMR (110dB, min @ 60Hz).

## DESIGN FEATURES AND USER BENEFITS

**High Reliability:** Models 284J, 286J are conservatively designed, compact modules, capable of reliable operation in harsh environments. Models 284J, 286J have calculated MTBF of over 390,000 hours and are designed to meet MIL-STD-202E environmental testing as well as the IEEE Standard for Transient Voltage Protection (472-1974: Surge Withstand Capability). As an additional assurance of reliability, every model 284J and 286J is factory tested for CMV and input ratings by application of 5kV pk, 10ms pulses, between input terminals as well as input/output terminals.

**Isolated Power Supply:** Dual regulated supplies, completely isolated from the input power terminals (±2500V dc isolation), provides the capability to excite floating signal conditioners, front end buffer amplifiers as well as remote transducers such as thermistors or bridges.

**Adjustable Gain:** A single external resistor enables gain adjustment from 1V/V to 100V/V (286J) or 1V/V to 10V/V (284J) providing the flexibility of applying models 284J, 286J in both high-level transducer interfacing as well as low-level sensor measurements.

# SPECIFICATIONS (typical @ +25°C and $V_S$ = +15V dc unless otherwise noted)

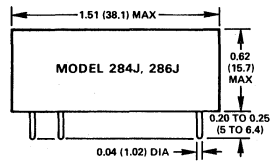
| MODEL | 284J | 286J[1] |
|---|---|---|
| GAIN (NON-INVERTING) | | |
| Range (50kΩ Load) | 1 to 10V/V | 1 to 100V/V |
| Formula | $\text{Gain} = [1 + \frac{100k\Omega}{10.7k\Omega + R_i(k\Omega)}]$ | $\text{Gain} = [1 + \frac{100k\Omega}{1k\Omega + R_i(k\Omega)}]$ |
| Deviation from Formula | ±3% | ±4% |
| vs. Time | ±0.001%/1000 Hours | * |
| vs. Temperature (0 to +70°C)[2] | ±0.0075%/°C | * |
| Nonlinearity, 10V pk-pk Output[2] | ±0.05% | * |
| INPUT VOLTAGE RATINGS | | |
| Linear Differential Range, G = 1V/V | ±5V min | ±10V min |
| Max Safe Differential Input | | |
| Continuous | $240V_{rms}$ | * |
| Pulse, 10ms duration, 1 pulse/10 sec | $\pm 6500V_{pk}$ max | * |
| Max CMV, Inputs to Outputs | | |
| AC, 60Hz, 1 minute duration | $2500V_{rms}$ | * |
| Pulse, 10ms duration, 1 pulse/10 sec | $\pm 2500V_{pk}$ max | * |
| With 510kΩ in series with Guard | $\pm 5000V_{pk}$ max | * |
| Continuous, AC or DC | $\pm 2500V_{pk}$ max | * |
| CMR, Inputs to Outputs, 60Hz, $R_S \leq 5k\Omega$ | | |
| Balanced Source Impedance | 114dB | * |
| 5kΩ Source Impedance Imbalance | 110dB min | * |
| CMR, Inputs to Guard, 60Hz | | |
| 1kΩ Source Impedance Imbalance | 78dB | * |
| Max Leakage Current, Inputs to Power Common | | |
| @ 115VAC, 60Hz | 2.0μA rms max | 2.5μA rms max |
| INPUT IMPEDANCE | | |
| Differential | $10^8\Omega \| 70pF$ | $10^8\Omega \| 150pF$ |
| Overload | 300kΩ | * |
| Common Mode | $5x10^{10}\Omega \| 20pF$ | * |
| INPUT DIFFERENCE CURRENT | | |
| Initial, @ +25°C | ±7nA max | * |
| vs. Temperature (0 to +70°C) | ±0.1nA/°C | * |
| INPUT NOISE | | |
| Voltage[3] | | |
| 0.05Hz to 100Hz | 8μV pk-pk | * |
| 10Hz to 1kHz | 10μV rms | 3μV rms |
| Current | | |
| 0.05Hz to 100Hz | 5pA pk-pk | * |
| FREQUENCY RESPONSE | | |
| Small Signal, -3dB | 1kHz | * |
| Slew Rate | 25mV/μs | * |
| Full Power, 10V p-p Output | 200Hz | 900Hz |
| Full Power, 20V p-p Output | N/A | 400Hz |
| Recovery Time, to ±100μV after Application of $\pm 6500V_{pk}$ Differential Input Pulse | 200ms | * |
| OFFSET VOLTAGE REFERRED TO INPUT | | |
| Initial, @ +25°C, Adjustable to Zero | ±(5 + 20/G)mV | ±(5 + 45/G)mV |
| vs. Temperature (0 to +70°C) | ±(1 + 150/G)μV/°C | ±(7 + 250/G)μV/°C |
| vs. Supply Voltage | ±1mV/% | * |
| RATED OUTPUT | | |
| Voltage, 50kΩ Load | ±5V min | ±10V min |
| Output Impedance | 1kΩ | * |
| Output Ripple, 1MHz Bandwidth | 5mV pk-pk | 20mV pk-pk |
| ISOLATED POWER OUTPUTS | | |
| Voltage, ±5mA Load | ±8.5V dc | ±15V dc |
| Accuracy | ±5% | 0, -6% |
| Current | ±5mA min | ±15mA min |
| Regulation, No Load to Full Load | +0, -15% | +0, -10% |
| Ripple, 100kHz Bandwidth | 100mV pk-pk | 200mV pk-pk |
| POWER SUPPLY, SINGLE POLARITY[4] | | |
| Voltage, Rated Performance | +15V dc | * |
| Voltage Operating | +(8 to 15.5)V dc | * |
| Current, Quiescent | +10mA | +13mA |
| TEMPERATURE RANGE | | |
| Rated Performance | 0 to +70°C | * |
| Operating | -25°C to +85°C | * |
| Storage | -55°C to +85°C | * |
| CASE DIMENSIONS[5] | 1.5" x 1.5" x 0.62" | * |

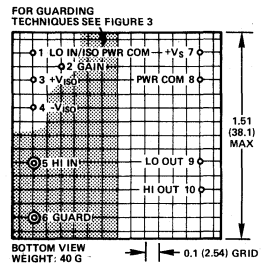
NOTES
*Specifications same as model 284J.
[1] Specifications for model 286J apply when driven by ADI model 281 oscillator.
[2] Gain temperature drift and gain nonlinearity are specified as a percentage of output signal level.
[3] Model 284J: Gain = 10V/V; Model 286J: Gain = 100V/V.
[4] Recommended power supply, ADI model 904, ±15V @ 50mA.
[5] Recommended mounting sockets – model 284J: ADI Part Number AC1049; model 286J: ADI Part Number AC1054.

Specifications subject to change without notice.

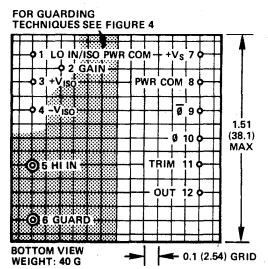
## OUTLINE DIMENSIONS

Dimensions shown in inches and (mm).




*Model 284J*




*Model 286J*

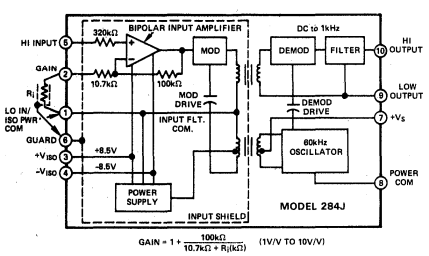



*Figure 1. Block Diagram – Model 284J*

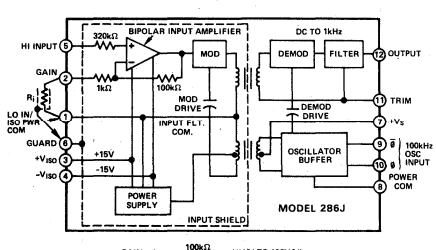
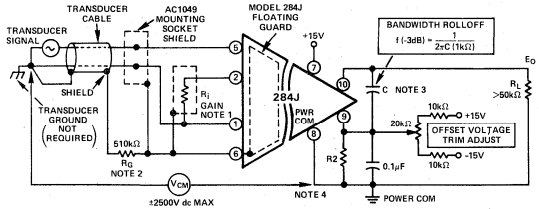



*Figure 2. Block Diagram – Model 286J*

## INTERCONNECTION AND GUARDING TECHNIQUES

Models 284J, 286J can be applied directly to achieve rated performance as shown in Figures 3 and 4. To preserve the high




NOTE 1. GAIN RESISTOR, $R_i$, 1%, 50ppm/°C METAL FILM TYPE IS RECOMMENDED.
FOR GAIN = 1V/V, LEAVE TERMINAL 2 OPEN.
FOR GAIN = 10V/V, SHORT TERMINAL 2 TO TERMINAL 1

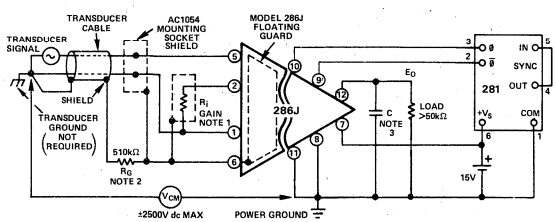
$$GAIN = 1 + \frac{100k\Omega}{10.7k\Omega + R_i(k\Omega)}$$

NOTE 2. GUARD RESISTOR, $R_G$, REQUIRED ONLY FOR CMV > ±2500$V_{PK}$ (±5k$V_{PK}$ MAX).
$R_G$ MAY BE MOUNTED ON AC1049 MOUNTING SOCKET USING STANDOFF PROVIDED.
(USE ¼ WATT, 5%, CARBON COMPOSITION TYPE; ALLEN BRADLEY RECOMMENDED).

NOTE 3. OUTPUT FILTER CAPACITOR, C. SELECT TO ROLLOFF NOISE AND OUTPUT RIPPLE: (e.g. SELECT C = 1.5μF FOR dc TO 100Hz BANDWIDTH).

NOTE 4. R2 ~ 200Ω, G = 1; R2 ~ 2kΩ, G≥1

*Figure 3. Model 284J Basic Isolator Interconnection*




NOTE 1. GAIN RESISTOR, $R_i$, USE 50ppm/°C, METAL FILM TYPE.
FOR GAIN = 1V/V, LEAVE TERMINAL 2 OPEN.
FOR GAIN = 100V/V, SHORT TERMINAL 2 TO TERMINAL 1
FOR GAINS FROM 1V/V TO 100V/V:

$$GAIN = 1 + \frac{100k\Omega}{1k\Omega + R_i\ (k\Omega)}$$

NOTE 2. OPTIONAL GUARD RESISTOR, $R_G$, REQUIRED ONLY FOR CMV > ±2500$V_{PK}$
$R_G$ MAY BE CONVENIENTLY MOUNTED ON AC1054 MOUNTING SOCKET USING THE STANDOFF PROVIDED ($R_G$). USE 1/4 WATT, 5% CARBON COMPOSITION TYPE; (ALLEN BRADLEY RECOMMENDED).

NOTE 3. OUTPUT FILTER CAPACITOR C. SELECT TO ROLL-OFF NOISE AND OUTPUT RIPPLE: (e.g. SELECT C=1.5μF FOR dc TO 100Hz BANDWIDTH)

$$F\ (-3dB) = \frac{1}{2\pi C\ (1k\Omega)}$$

*Figure 4. Model 286J Basic Isolator Interconnection*

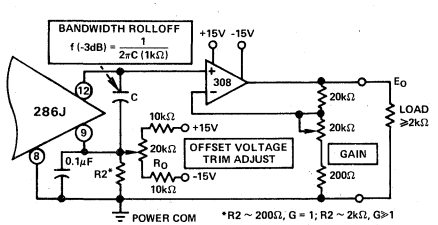



*Figure 5. Model 286J Optional Connection: Offset Voltage Trim Adjust, Bandwidth (-3dB) Rolloff and Gain Adjust (G>100V/V)*

CMR performance, care must be taken to keep the capacitance balanced about the input terminals. A shield should be provided on the printed circuit board under model 284J or 286J. The GUARD (Pin 6) should be connected to this shield. The guard-shield is provided with the mounting socket. To reduce effective cable capacitance, cable shield should be connected to the common mode signal source by connecting the shield as close as possible to the signal low.

**Offset Voltage Trim Adjust:** The trim adjust circuits shown in Figures 3 and 5 can be used to zero the output offset voltage over the specified gain range. The output terminals, HI OUT and LO OUT, can be floated with respect to PWR COM up to ±50$V_{pk}$ max, offering three-port isolation. A 0.1μF capacitor is required from LO OUT to PWR COM whenever the output terminals are floated with respect to PWR COM. LO OUT can be connected directly to PWR COM when output offset trimming is not required.

## INTERELECTRODE CAPACITANCE, TERMINAL RATINGS AND LEAKAGE CURRENTS LIMITS

**Capacitance:** Interelectrode terminal capacitance arising from stray coupling capacitance effects between the input terminals and the signal output terminals are each shunted by leakage resistance values exceeding 50kMΩ. Figures 6 and 8 illustrate the CMR ratings at 60Hz and 5kΩ source imbalance between signal input/output terminals, along with their respective capacitance.

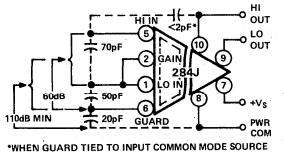



*Figure 6. Model 284J Terminal Capacitance and CMR Ratings*

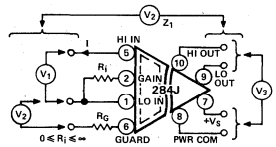



*Figure 7. Model 284J Terminal Ratings*

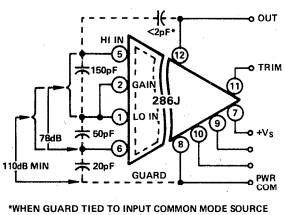



*Figure 8. Model 286J Terminal Capacitance and CMR Ratings*

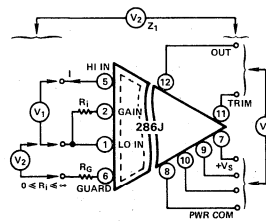



*Figure 9. Model 286J Terminal Ratings*

**Terminal Ratings:** CMV performance is given in both peak pulse and continuous ac or dc peak ratings. Pulse ratings are intended to support defibrillator and other transient voltages. Continuous peak ratings apply from dc up to the normal full power response frequencies. Figures 7 and 9 and Table I illustrate models 284J, 286J ratings between terminals.

| SYMBOL | RATING | REMARKS |
|---|---|---|
| V1 (pulse) | ±6500$V_{PK}$ (10ms) | Withstand Voltage, Defibrillator |
| V1 (cont.) | ±240$V_{RMS}$ | Withstand Voltage, Steady State |
| V2 (pulse) | ±2500$V_{PK}$ (10ms) $R_G$ = 0 | Transient |
| V2 (pulse) | ±5000$V_{PK}$ (10ms) $R_G$ = 510kΩ | Isolation, Defibrillator |
| V2 (cont.) | ±2500$V_{PK}$ | Isolation, Steady State |
| V3 (cont.) | ±50$V_{PK}$ | Isolation, dc |
| Z1 | 50kMΩ‖20pF | Isolation Impedance |
| I (286J) | 50μA rms | Input Fault Limit, dc to 200kHz |
| I (284J | 35μA rms | Input Fault Limit, dc to 60kHz |

*Table I. Isolation Ratings Between Terminals*

**Leakage Current Limits:** The low coupling capacitance between inputs and output yields a ground leakage current of less than 2.0μA rms (284J) and 2.5μA rms (286J) at 115V ac, 60Hz (or 0.02μA/V ac). As shown in Figures 10 and 11, the transformer coupled modulator signal, through stray coupling, also creates an internally generated leakage current. Line frequency leakage current levels are unaffected by the power on or off condition of models 284J, 286J.

For medical applications, models 284Jand 286J are designed to improve on patient safety current limits proposed by F.D.A., U.L., A.A.M.I. and other regulatory agencies (e.g., model 286J complies with leakage requirements for the Underwriters Laboratory STANDARD FOR SAFETY, MEDICAL AND DENTAL EQUIPMENT as established under UL544 for type A and B patient connected equipment – reference *Leakage Current,* paragraph 27.5).

In patient monitoring equipment, such as ECG recorders, models 284J, 286J will provide adequate isolation without exposing the patient to potentially lethal microshock hazards. Using passive components for input protection, this design limits input fault currents even under amplifier failure conditions.

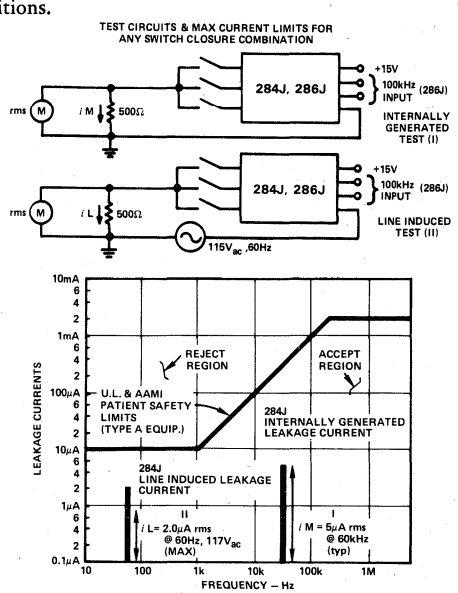



*Figure10. Model 284J Leakage Current Performance from Line Induced and Internally Generated (Modulator) Operating Conditions*

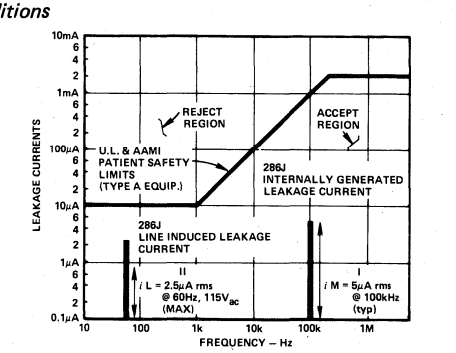



*Figure 11. Model 286J Leakage Current Performance from Line Induced and Internally Generated (Modulator) Operating Conditions*

**GAIN AND OFFSET TRIM PROCEDURE, MODEL 284J**

1. Apply $e_{IN}$ = 0 volts and adjust $R_O$ for $e_O$ = 0 volts.
2. Apply $e_{IN}$ = +1.000V dc and adjust $R_G$ for $e_O$ = +5.000V dc.
3. Apply $e_{IN}$ = −1.000V dc and measure the output error (see curve a).
4. Adjust $R_G$ until the output error is one half that measured in step 3 (see curve b).
5. Apply $e_{IN}$ = +1.000V dc and adjust $R_O$ until the output error is one half that measured in step 4 (see curve c).

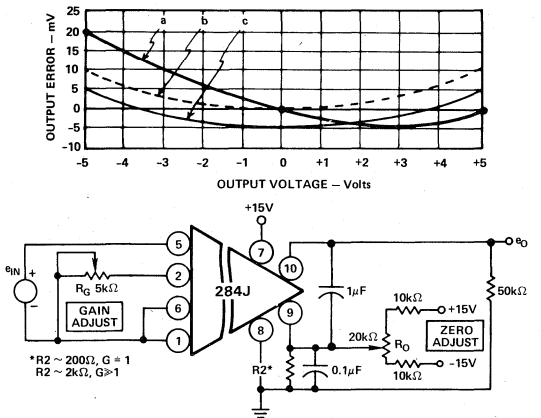



*Figure 12. Gain and Offset Adjustment*

**GAIN AND OFFSET TRIM PROCEDURE, MODEL 286J**

In applying the isolation amplifier, highest accuracy is achieved by adjustment of gain and offset voltage to minimize the peak error encountered over the selected output voltage span. The following procedure illustrates a calibration technique which can be used to minimize output error. In this example, the output span is +5V to −5V and operation at Gain = 10V/V is desired.

1. Apply $e_{IN}$ = 0 volts and adjust $R_O$ for $e_O$ = 0 volts.
2. Apply $e_{IN}$ = +0.500V dc and adjust $R_G$ for $e_O$ = +5.000V dc.
3. Apply $e_{IN}$ = −0.500V dc and measure the output error (see curve a).
4. Adjust $R_G$ until the output error is one half that measured in step 3 (see curve b).
5. Apply +0.500V dc and adjust $R_O$ until the output error is one half that measured in step 4 (see curve c).

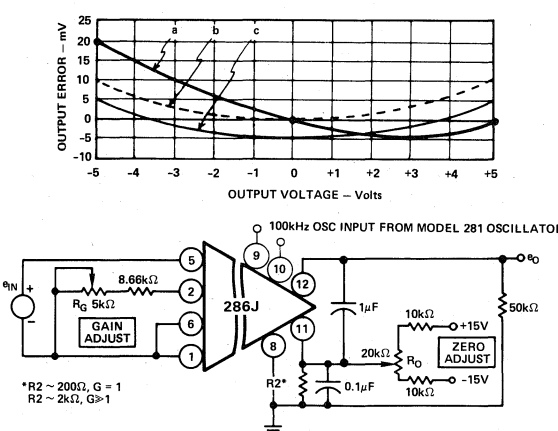



*Figure 13. Gain and Offset Adjustment*

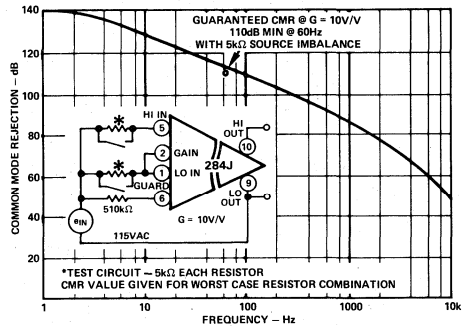



*Figure 14. Model 284J Common Mode Rejection vs. Frequency*

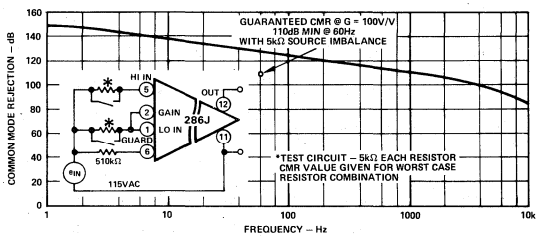



*Figure 15. Model 286J Common Mode Rejection vs. Frequency*

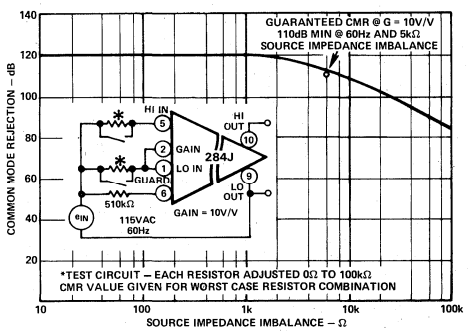



*Figure 16. Model 284J Common Mode Rejection vs. Source Impedance Imbalance*

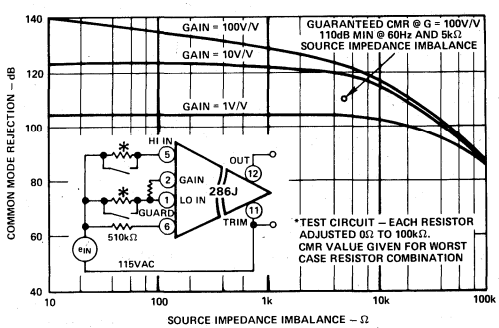



*Figure 17. Model 286J Common Mode Rejection vs. Source Impedance Imbalance*

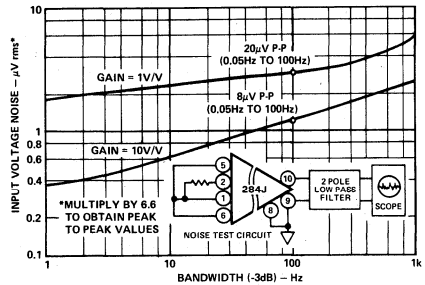



*Figure 18. Model 284J Input Voltage Noise vs. Bandwidth*

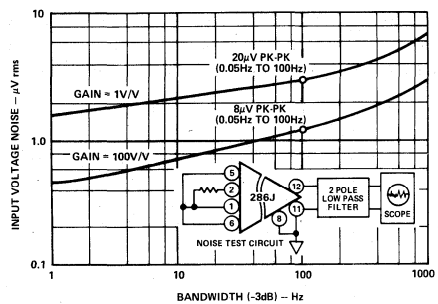



*Figure 19. Model 286J Input Voltage Noise vs. Bandwidth*

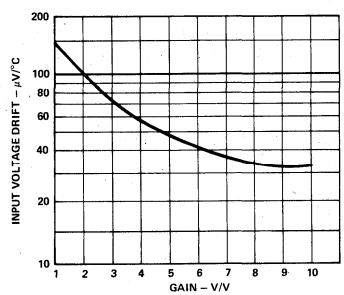



*Figure 20. Model 284J Input Offset Voltage Drift vs. Gain*

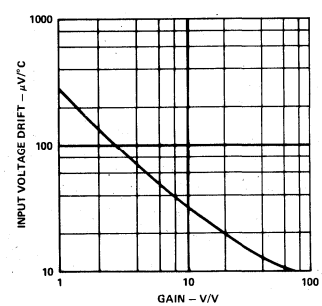



*Figure 21. Model 286J Input Offset Voltage Drift vs. Gain*

# Applying the Multi-Channel Isolation Amplifier

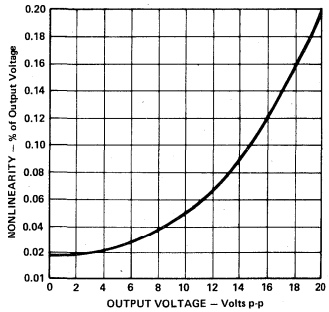
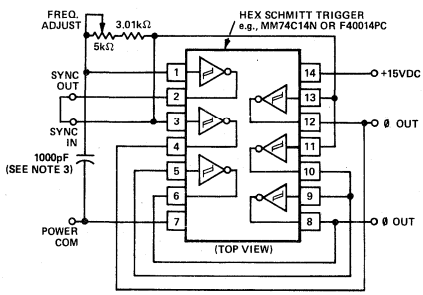



*Figure 22. Model 286J Gain Nonlinearity vs. Output Voltage*

**REFERENCE EXCITATION OSCILLATOR***

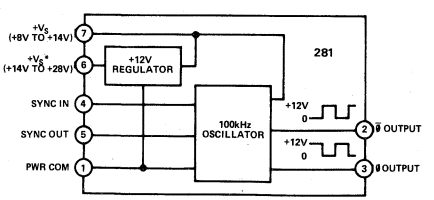
When applying model 286J, the user has the option of building a low cost 100kHz excitation oscillator, as shown in Figure 23, or purchasing a module from Analog Devices – model 281.




NOTES:
1. FREQ. ADJUST: ADJUST TRIM POT FOR OUTPUT FREQUENCY OF 100kHz ±5%.
2. FOR SLAVE OPERATION, REMOVE JUMPER FROM SYNC OUT AND SYNC IN PINS.
3. USE CERAMIC CAPACITOR, "COG" OR "NPO" CHARACTERISTIC.

*Figure 23. Model 281 100kHz Oscillator – Logic and Interconnection Diagram*

The block diagram of model 281 is shown in Figure 24. An internal +12V dc regulator is provided to permit the user the option of operating over two, pin selectable, power input ranges; terminal 6 offers a range of +14V dc to +28V dc; terminal 7 offers an input range of +8V dc to +14V dc.




*LEAVE TERMINAL 6 OPEN, WHEN POWER IS APPLIED TO TERMINAL 7.

*Figure 24. Model 281 Block Diagram*

Model 281 oscillator is capable of driving up to 16 model 286Js as shown in Figure 25. An additional model 281 may be driven in a slave-mode, as shown in Figure 26 to expand the total system channels from 16 to 32. By adding additional model 281's in this manner, systems of over 1000 channels may be easily configured.

**EXTERNAL OSCILLATOR INTERCONNECTION**

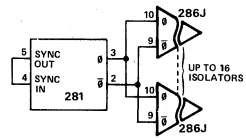



*Figure 25. Model 281/286 Connection for Driving from 1 to 16 Isolators*

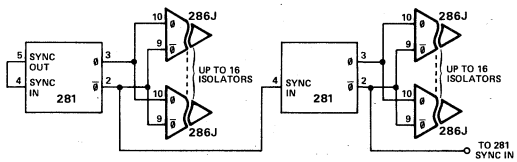



*Figure 26. Model 281/286 Connection for Driving > 16 Isolators*

**SPECIFICATIONS**

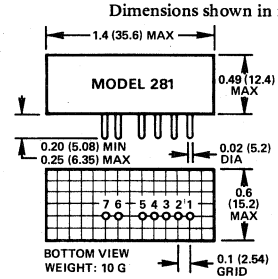
**(typical @ +25°C and $V_S$ = +15V dc unless otherwise noted)**

| MODEL | 281* |
|---|---|
| OUTPUT | |
| Frequency | 100kHz ±5% |
| Waveform | Squarewave |
| Voltage (ø and ø̄ terminals) | 0 to +12V pk |
| Fan-Out[1,2] | 16 max |
| POWER SUPPLY RANGE[3] | |
| High Input, Pin 6 | +(14 to 28)V dc |
| Quiescent Current, N.L. | +5mA |
| F.L. | +16mA |
| Low Input, Pin 7 | +(8 to 14)V dc |
| Quiescent Current, N.L. | +12mA |
| F.L. | +33mA |
| TEMPERATURE | |
| Rated Performance | 0 to +70°C |
| Storage | -55°C to +85°C |
| MECHANICAL | |
| Case Size | 1.4" x 0.6" x 0.49" |
| Weight | 10 grams |

NOTES
[1] Model 286J oscillator drive input represents unity oscillator load.
[2] For applications requiring more than 16 286Js, additional 281s may be used in a master/slave mode. Refer to Figure 26.
[3] Full load consists of 16 model 286Js and 281 oscillator slave.
Specifications subject to change without notice.

**OUTLINE DIMENSIONS**

Dimensions shown in inches and (mm).




PIN TERMINAL IDENTIFICATION
1 POWER COMMON
2 ø̄ OUTPUT
3 ø OUTPUT
4 SYNC INPUT
5 SYNC OUTPUT
6 $+V_S$: HIGH RANGE +(14 to 28)$V_{dc}$
7 $+V_S$: LOW RANGE +(8 to 14)$V_{dc}$

**MATING SOCKET: Cinch #16 DIP or Equivalent**

***CAUTION:**

ESD(Electro-static-discharge) sensitive device. Permanent damage may occur on unconnected devices subjected to high-energy electrostatic fields. Unused devices must be stored in conductive foam or shunts. The protective foam should be discharged to the destination socket before devices are removed.



# ANALOG DEVICES

# Precision, Wide Bandwidth, Synchronized Isolation Amplifier

# MODEL 289

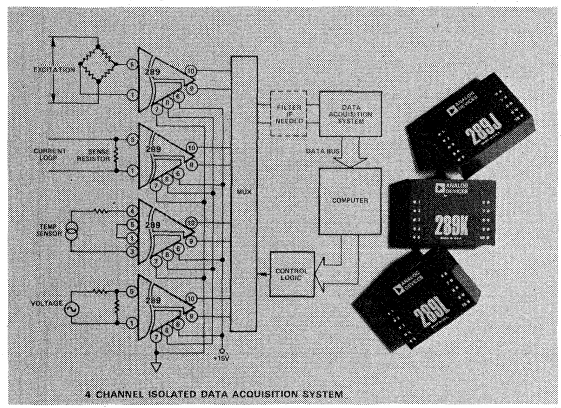


**FEATURES**

**Low Nonlinearity: ±0.012% max (289L)**
**Frequency Response: (–3dB) dc to 20kHz**
**(Full Power) dc to 5kHz**
**Gain Adjustable 1 to 100V/V, Single Resistor**
**3-Port Isolation: ±2500V CMV Isolation Input/Output**
**Low Gain Drift: ±0.005%/°C max**
**Floating Power Output: ±15V @ ±5mA**
**120dB CMR at 60Hz: Fully Shielded Input Stage**
**Meets UL Std. 544 Leakage: 2μA rms max, @ 115V ac, 60Hz**

**APPLICATIONS**

**Multi-Channel Data Acquisition Systems**
**Current Shunt Measurements**
**Process Signal Isolator**
**High Voltage Instrumentation Amplifier**
**SCR Motor Control**



4 CHANNEL ISOLATED DATA ACQUISITION SYSTEM

## GENERAL DESCRIPTION

Model 289 is a wideband, accurate, low cost isolation amplifier designed for instrumentation and industrial applications. Three accuracy selections are available offering guaranteed gain nonlinearity error at 10V p-p output: ±0.012% max (289L), ±0.025% max (289K), ±0.05% max (289J). All versions of the 289 provide a small signal frequency response from dc to 20kHz (–3dB) and a large signal response from dc to 5kHz (full power) at a gain of 1V/V. This new design offers true 3-port isolation, ±2500V dc between inputs and outputs (or power inputs), as well as 240V rms between power supply inputs and signal outputs. Using carrier modulation techniques with transformer isolation, model 289 interrupts ground loops and leakage paths and minimizes the effect of high voltage transients. It provides 120dB Common Mode Rejection between input and output common. The high CMV and CMR ratings of the model 289 facilitate accurate measurements in the presence of noisy electrical equipment such as motors and relays.

## WHERE TO USE THE MODEL 289

The model 289 is designed to interface single and multichannel data acquisition systems with dc sensors such as thermocouples, strain gauges and other low level signals in harsh industrial environments. Providing high accuracy with complete galvanic isolation, and protection from line transients of fault voltages, model 289's performance is suitable for applications such as process controllers, current loop receivers, weighing systems, high CMV instrumentation and computer interface systems.

Use the model 289 when data must be acquired from floating transducers in computerized process control systems. The photograph above shows a typical multichannel application allowing potential differences or interrupting ground loops, among transducers, or between transducers and local ground.

## DESIGN FEATURES AND USER BENEFITS

**Isolated Power:** The floating power supply section provides isolated ±15V outputs @ ±5mA. Isolated power is regulated to within ±5%. This feature permits model 289 to excite floating signal conditioners, front-end buffer amplifiers and remote transducers such as thermistors or bridges, eliminating the need for a separate isolated dc/dc converter.

**Adjustable Gain:** A single external resistor adjusts the model 289's gain from 1V/V to 100V/V for applications in high and low level transducer interfacing.

**Synchronized:** The model 289 provides a synchronization terminal for use in multichannel applications. Connecting the synchronization terminals of model 289s synchronizes their internal oscillators, thereby eliminating the problem of oscillator "beat frequency" interference that sometimes occurs when isolation amplifiers are closely mounted.

**Internal Voltage Regulator:** Improves power supply rejection and helps prevent carrier oscillator spikes from being broadcast via the isolator power terminal to the rest of the system.

**Buffered Output:** Prevents gain errors when an isolation amplifier is followed by a resistive load of low impedance. Model 289 can drive a 2kΩ load.

**Three-Port Isolation:** Provides true galvanic isolation between input, output and power supply ports. Eliminates need for power supply and output ports being returned through a common terminal.

**Reliability:** Model 289 is conservatively designed to be capable of reliable operation in harsh environments. Model 289 has a calculated MTBF of 271,835 hours. In addition, the model 289 meets UL Std. 544 leakage, 2μA rms @ 115V ac, 60Hz.

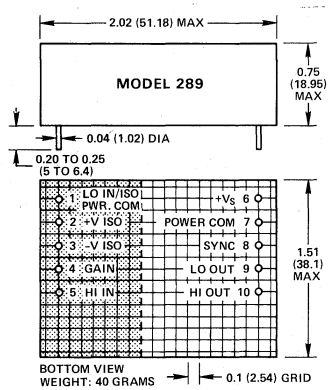
# SPECIFICATIONS (typical @ +25°C and $V_S$ = +14.4V to +25V dc unless otherwise noted)

| Model | 289J | 289K | 289L |
|---|---|---|---|
| GAIN (NONINVERTING) | | | |
| Range | | 1 to 100V/V | |
| Formula | | $G = 1 + \frac{10k\Omega}{R_G (k\Omega)}$ | |
| Deviation from Formula | | ±1.5% max | |
| vs. Temperature (0 to +70°C)[1] | | 15ppm/°C typ (50ppm/°C max) | |
| Nonlinearity, (±5V Swing)[2,3] | ±0.05% max | ±0.025% max | ±0.012% max |
| INPUT VOLTAGE RATINGS | | | |
| Linear Differential Range (G = 1V/V) | | ±10V min | |
| Max Safe Differential Input | | | |
| Continuous | | 120V rms | |
| 1 Minute | | 240V rms | |
| Max CMV (Inputs to Outputs) | | | |
| Continuous ac or dc | | ±2500V peak max | |
| ac, 60Hz, 1 Minute Duration | | 2500V rms | |
| CMR, Inputs to Outputs 60Hz | | | |
| $R_S \leq 1k\Omega$, Balanced Source Impedance | | 120dB | |
| $R_S \leq 1k\Omega$, HI IN Lead Only | | 104dB min | |
| Max Leakage Current, Input to Output @ | | | |
| 115V rms, 60Hz ac | | 2μA rms max | |
| INPUT IMPEDANCE | | | |
| Differential | | $33pF \| 10^8 \Omega$ | |
| Overload | | 100kΩ | |
| Common Mode | | $20pF \| 5 \times 10^{10} \Omega$ | |
| INPUT DIFFERENCE CURRENT | | | |
| Initial @ +25°C | | 10nA (75nA max) | |
| vs. Temperature (0 to 70°C) | | 0.15nA/°C | |
| INPUT NOISE (GAIN = 100V/V) | | | |
| Voltage | | | |
| 0.05Hz to 100Hz | | 8μV p-p | |
| 10Hz to 1kHz | | 3μV rms | |
| Current | | | |
| 0.05Hz to 100Hz | | 3pA rms | |
| FREQUENCY RESPONSE | | | |
| Small Signal -3dB | | | |
| G = 1V/V | | 20kHz | |
| G = 100V/V | | 5kHz | |
| Full Power, 10V p-p Output | | | |
| G = 1V/V | | 5kHz | |
| G = 100V/V | | 3.5kHz | |
| Full Power, 20V p-p Output | | | |
| G = 1V/V | | 2.3kHz | |
| G = 100V/V | | 2.3kHz | |
| Slew Rate | | 0.14V/μs | |
| Settling Time[4] ±0.05%, ±10V Step | | 400μs | |
| OFFSET VOLTAGE, REFERRED TO INPUT | | | |
| Initial, @ +25°C | | $\pm 5 \pm \frac{10}{G}$ mV max | |
| vs. Temperature (0 to +70°C) | $\pm 20 \pm \frac{200}{G}$ max | $\pm 15 \pm \frac{100}{G}$ max | $\pm 10 \pm \frac{50}{G}$ μV/°C max |
| vs. Supply Voltage (+15V to +20V change) | | $\pm 2 \pm \frac{10}{G}$ μV/V | |
| RATED OUTPUT | | | |
| Voltage, 2kΩ Load | | ±10V min | |
| Output Impedance | | <1Ω(dc to 100Hz) | |
| Output Ripple, 0.1MHz Bandwidth | | | |
| No Signal IN | | 5mV p-p | |
| $+10V_{IN}$ | | 50mV p-p | |
| ISOLATED POWER SUPPLY | | | |
| Voltage | | ±15V dc | |
| Accuracy | | ±10% | |
| Current | | ±5mA, min | |
| Regulation No Load to Full Load | | ±5% | |
| Ripple, 0.1MHz Bandwidth, No Load | | 25mV p-p | |
| Full Load | | 75mV p-p | |
| POWER SUPPLY, SINGLE POLARITY[5] | | | |
| Voltage, Rated Performance | | +14.4V to +25V | |
| Voltage, Operating | | +8.5V to +25V | |
| Current, Quiescent (@ $V_S$ = +15V) | | +25mA | |
| TEMPERATURE RANGE | | | |
| Rated Performance | | 0 to +70°C | |
| Operating | | -15°C to +75°C | |
| Storage | | -55°C to +85°C | |
| CASE DIMENSIONS | | 1.5" X 2.0" X 0.75" | |

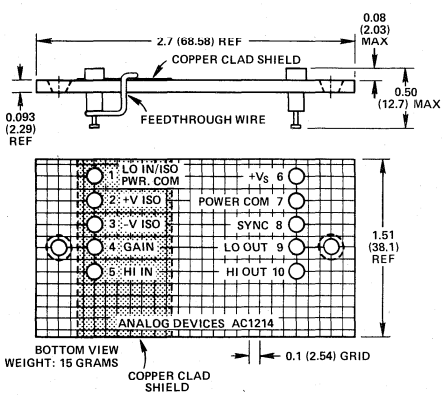
NOTES
[1] Gain temperature drift is specified as a percentage of output signal level.
[2] Gain nonlinearity is specified as a percentage of 10V pk-pk output span.
[3] When isolated power output is used, nonlinearity increases by ±0.002%/mA of current drawn.
[4] G = 1V/V; with 2-pole, 5kHz output filter.
[5] Recommended power supply, ADI model 904, ±15V @ 50mA output.
Specifications subject to change without notice.

## OUTLINE DIMENSIONS

Dimensions shown in inches and (mm).



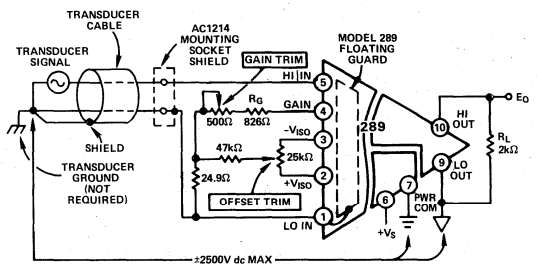

## SHIELDED MATING SOCKET AC1214




## INTERCONNECTIONS AND SHIELDING TECHNIQUE

To preserve the high CMR performance of model 289, care must be taken to keep the capacitance balanced about the input terminals. A shield should be provided on the printed circuit board under model 289 as illustrated in the outline drawing above (screened area). The LO IN/ISO PWR COM (pin 1) must be connected to this shield. This shield is provided with the mounting socket, model AC1214 (solder feedthrough wire to the socket pin 1 and copper foil surface). A recommended shielding technique using model AC1214 is illustrated in Figure 1.

Best CMR performance will be achieved by using twisted, shielded cable for the input signal to reduce inductive and capacitive pickup. To further reduce effective cable capacitance, the cable shield should be connected to the common mode signal source as close to signal low as possible (see Figure 1).




NOTE:
GAIN RESISTOR $R_G$, 1% 50ppm/°C METAL FILM TYPE IS RECOMMENDED.
FOR GAIN = 1V/V, LEAVE PIN 4 OPEN
FOR GAIN > 1V/V, CONNECT GAIN RESISTOR ($R_G$) BETWEEN PIN 4 AND PIN 1

$$\text{GAIN} = 1 + \frac{10k\Omega}{R_G(k\Omega)}$$

*Figure 1. Basic Isolator Interconnection*

## THEORY OF OPERATION

The remarkable performance of the model 289 is derived from the carrier isolation technique used to transfer both signal and power between the amplifier's input stage and the rest of the circuitry. A block diagram is shown in Figure 2.

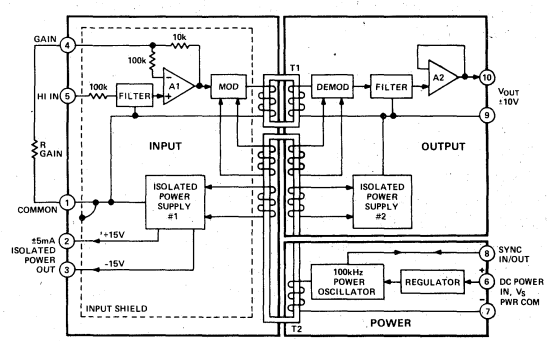



*Figure 2. Model 289 Block Diagram*

The input signal is filtered and appears at the input of the non-inverting amplifier, A1. This signal is amplified by A1, with its gain determined by the value of resistance connected externally between the gain terminal and the input common terminal. The output of A1 is modulated, carried across the isolation barrier by signal transformer T1, and demodulated. The demodulated voltage is filtered, amplified and buffered by amplifier A2, and applied to the output terminal. The voltage applied to the $V_S$ terminal is set by the regulator to +12V which powers the 100kHz symmetrical square wave power oscillator. The oscillator drives the primary winding of transformer T2. The secondary windings of T2 energize both input and output power supplies, and drives both the modulator and demodulator.

## INTERELECTRODE CAPACITANCE AND TERMINAL RATINGS

**Capacitance:** Interelectrode terminal capacitance, arising from stray coupling capacitance effects between the input terminals and the signal output terminals, are each shunted by leakage resistance values exceeding 50GΩ. Figure 3 illustrates model 289's capacitance, between terminals.

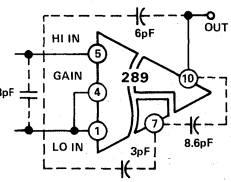



*Figure 3. Model 289 Terminal Capacitance*

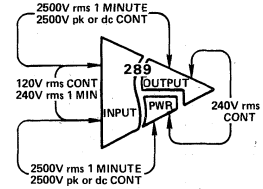


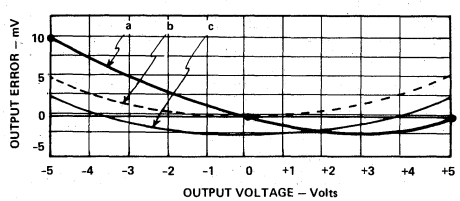

*Figure 4. Model 289 Terminal Ratings*

**Terminal Ratings:** CMV performance is given in both peak pulse and continuous ac, or dc peak ratings. Continuous peak ratings apply from dc up to the normal full power response frequencies. Figure 4 illustrates model 289 ratings between terminals.

## GAIN AND OFFSET TRIM PROCEDURE

The following procedure illustrates a calibration technique which can be used to minimize output error. In this example, the output span is +5V to −5V and Gain = 10V/V.

1. Apply $E_{IN}$ = 0 volts and adjust $R_O$ for $E_O$ = 0 volts.
2. Apply $E_{IN}$ = +0.500V dc and adjust $R_G$ for $E_O$ = +5.000V dc.
3. Apply $E_{IN}$ = −0.500V dc and measure the output error (see curve a).
4. Adjust $R_G$ until the output error is one-half that measured in step 3 (see curve b).
5. Apply +0.500V dc and adjust $R_O$ until the output error is one-half that measured in step 4 (see curve c).



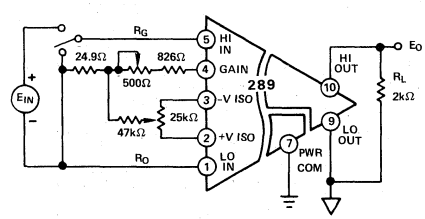




*Figure 5a. Recommended Offset and Gain Adjustment for Gains > 1*

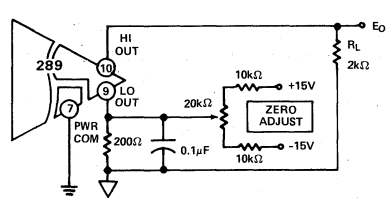



*Figure 5b. Recommended Offset Adjustment for G = 1V/V*

## PERFORMANCE CHARACTERISTICS

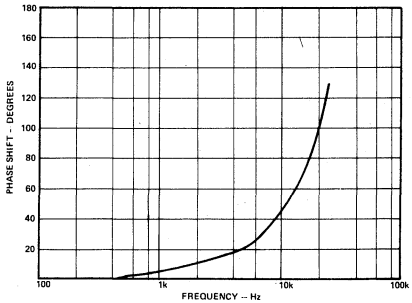



*Figure 6. Typical 289 Phase vs. Frequency*

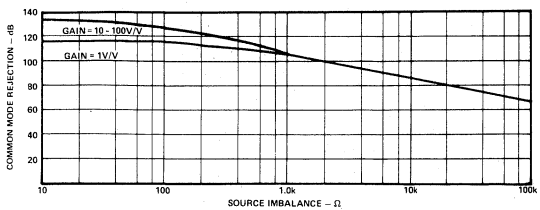



*Figure 7. Typical 289 Common Mode Rejection vs. Source Impedance*

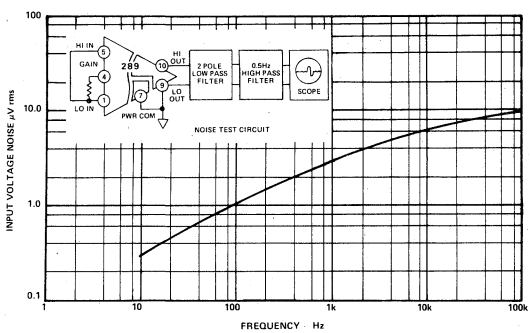



*Figure 8. Typical Input Voltage Noise vs. Bandwidth*

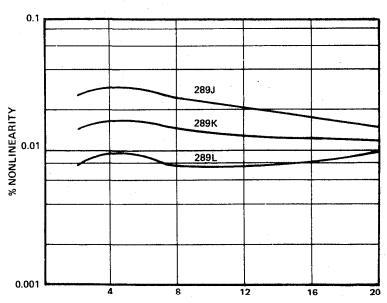



*Figure 9. Typical Gain Nonlinearity vs. Output Swing*

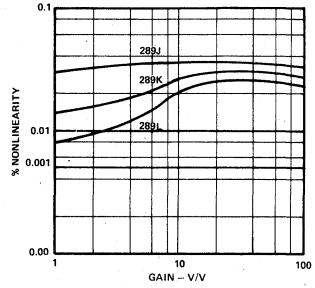



*Figure 10. Typical Gain Nonlinearity vs. Gain*

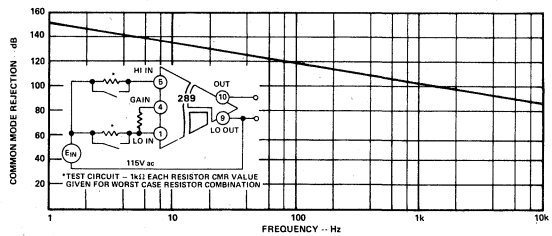



*Figure 11. Typical Common Mode Rejection vs. Frequency at a Gain of 1V/V, CMR is typically 6dB Lower than at a Gain of 100V/V*

## MULTICHANNEL APPLICATIONS

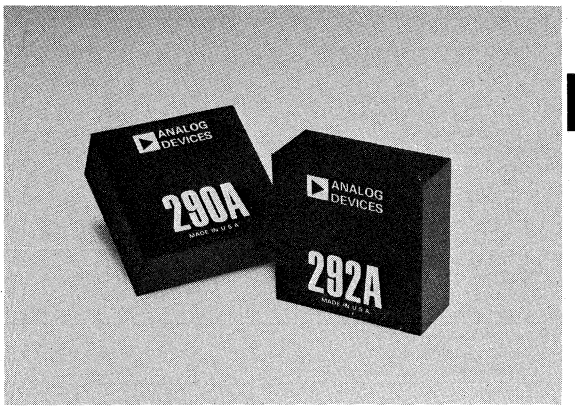
Isolation amplifiers containing internal oscillators may exhibit a slowly varying offset voltage at the output when used in multichannel applications. This offset voltage is the result of adjacent internal oscillators beating together. For example, if two adjacent isolation amplifiers have oscillator frequencies of 100.0kHz and 100.1kHz respectively, a portion of the difference frequency may appear as a slowly varying output offset voltage error. Model 289 eliminates this problem by offering a synchronization terminal (pin 8). When this terminal is interconnected with other model 289 synchronization terminals, the units are synchronized. Alternately, one or more units may be synchronized to an external 100kHz ±2% square-wave generator by the connection of synchronization termial(s) to that generator. The generator output should be 2.5V–5.0V p-p with 1kΩ source impedance to each unit. Use an external oscillator when you need to sync to an external 100kHz source, such as a sub-multiple of a microprocessor clock. A differential line driver, such as SN75158, can be used to drive large clusters of model 289. When using the synchronization pin, keep leads as short as possible and do not use shielded wire. These precautions are necessary to avoid capacitance from the synchronization terminal to other points. It should be noted that units synchronized must share the same power common to ensure a return path.

# ANALOG DEVICES

# Low Cost, Single and Multichannel Isolation Amplifier

# MODELS 290A, 292A






**FEATURES**

**Low Cost**
**Multichannel Capability Using External Oscillator (292A)**
**Isolated Power Supply: ±13V dc @ ±5mA (290A) or ±15mA (292A)**
**Low Nonlinearity: 0.1% @ 10V pk-pk Output**
**High Gain Stability: 0.001%/1000 Hours; 0.01%/°C**
**Small Size: 1.5″ X 1.5″ X 0.62″**
**Low Input Offset Voltage Drift: 10μV/°C (Gain = 100V/V)**
**Wide Input/Output Dynamic Range: 20V pk-pk**
**High CMV Isolation: 1500V dc, Continuous**
**Wide Gain Range: 1 to 100V/V**

**APPLICATIONS**

**Ground Loop Elimination in Industrial and Process Control**
**High Voltage Protection in Data Acquisition Systems**
**Off-Ground Signal Measurements**

## GENERAL DESCRIPTION

Models 290A and 292A are low cost, compact, isolation amplifiers that are optimized for single and multichannel industrial applications, respectively. The model 290A has a self-contained oscillator and is intended for single channel applications. A single external synchronizing oscillator can drive up to 16 model 292As or, a virtually limitless number of model 292As can be configured using multiple oscillators. The user can supply the external oscillator circuit or specify model 281 oscillator module, which includes a voltage regulator for operation over a wide single supply voltage range of +8V to +28V.

Models 290A and 292A design features include: adjustable gain, from 1 to 100V/V, dual isolated power, ±13V dc, ±1500V dc off ground isolation, 100dB minimum CMR at 60Hz, 1kΩ source imbalance, in a compact 1.5″ X 1.5″ X 0.6″ module. Models 290A and 292A achieve low input noise of 1μV pk-pk (10Hz bandwidth, G = 100V/V), nonlinearity of ±0.1% @ 10V pk-pk output, and an input/output dynamic range of 20V pk-pk.

Using modulation techniques with reliable transformer isolation, models 290A and 292A will interrupt ground loops, leakage paths, and voltage transients, while providing dc to 2kHz (–3dB) response.

## WHERE TO USE MODELS 290A AND 292A

**Industrial Applications:** In data acquisition systems, computer interface systems, process signal isolators and high CMV instrumentation, models 290A and 292A offer complete galvanic isolation and protection against damage from transients and fault voltages. High level transducer interface capability is afforded with 20V pk-pk input signal range at a gain of 1V/V operation. In portable single or multichannel designs, single power supply operation (+8V to +16V) enables battery operation.

## DESIGN FEATURES AND USER BENEFITS

**Isolated Power:** Dual ±13V dc output, completely isolated from the input power terminals (±1500V dc isolation), provides the capability to excite floating signal conditioners, front end buffer amplifiers and remote transducers such as thermistors or bridges.

**Adjustable Gain:** Models 290A and 292A adjustable gain offers compatibility with a wide class of input signals. A single external resistor enables gain adjustment from 1V/V to 100V/V providing flexibility in both high level transducer interfacing as well as low level sensor measurement applications.

**Floating, Guarded Front-End:** The input stage of models 290A and 292A can directly accept floating differential signals or it may be configured as a high performance instrumentation front-end to accept signals having CMV with respect to input power common.

**High Reliability:** Models 290A and 292A are conservatively designed, compact modules, capable of reliable operation in harsh environments. They have a calculated MTBF of over 400,000 hours and are designed to meet MIL-STD-202E environmental testing as well as the IEEE Standard for Transient Voltage Protection (472-1974: Surge Withstand Capability).

**For detailed information, contact factory.**

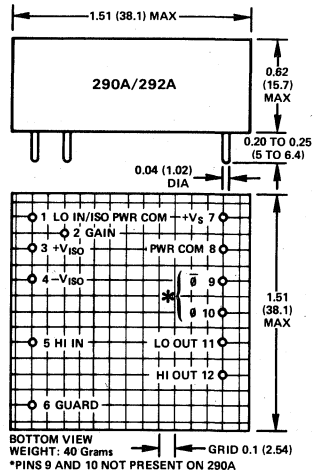
# SPECIFICATIONS (typical @ +25°C; G = 100V/V and $V_S$ = +15V dc, unless otherwise noted)

| MODEL | 290A | 292A |
|---|---|---|
| **GAIN (NONINVERTING)** | | |
| Range (50kΩ Load) | | 1 to 100V/V |
| Formula | | $\text{Gain} = \left[1 + \frac{100k\Omega}{1k\Omega + R_i(k\Omega)}\right]$ |
| Deviation from Formula | | ±3% |
| vs. Time | | ±0.001%/1000 Hours |
| vs. Temperature (-25°C to +85°C)[1] | | ±0.0075%/°C |
| Nonlinearity, G = 1V/V to 100V/V[2] | | ±0.1% (±0.25%)[3] |
| **INPUT VOLTAGE RATINGS** | | |
| Linear Differential Range, G = 1V/V | | ±5V min (±10V min)[3] |
| Max Safe Differential Input | | |
| Continuous, 1 min | | 110V rms |
| Max CMV, Inputs to Outputs | | |
| ac, 60Hz, 1 Minute Duration | | 1500V rms max |
| Continuous, ac | | ±1000V pk max |
| Continuous, dc | | ±1500V pk max |
| CMR, Inputs to Outputs, 60Hz, $R_S \leq 1k\Omega$ | | |
| Balanced Source Impedance | | 106dB |
| 1kΩ Hi In Lead Only | | 100dB min |
| Max Leakage Current, Inputs to Power Common | | |
| @ 115V ac, 60Hz | | 10μA rms max |
| **INPUT IMPEDANCE** | | |
| Differential | | $10^8\Omega \| 70pF$ |
| Overload | | 100kΩ |
| Common Mode | | $5 \times 10^{10}\Omega \| 100pF$ |
| **INPUT DIFFERENCE CURRENT** | | |
| Initial, @ +25°C | | +3nA |
| vs. Temperature (-25°C to +85°C) | | ±0.1nA/°C |
| **INPUT NOISE** | | |
| Voltage, G = 100V/V | | |
| 0.01Hz to 10Hz | | 1μV p-p |
| 10Hz to 1kHz | | 1.5μV rms |
| Current | | |
| 0.05Hz to 100Hz | | 5pA p-p |
| **FREQUENCY RESPONSE** | | |
| Small Signal, -3dB, G = 1V/V | | 2.5kHz |
| Slew Rate | | 50mV/μs |
| Full Power, 10V p-p Output | | |
| Gain - 1V/V thru 100V/V | 2.0kHz(1.0kHz)[3] | 3.0kHz(1.0kHz)[3] |
| **OFFSET VOLTAGE REFERRED TO INPUT** | | |
| Initial, @ +25°C, Adjustable to Zero | | ±(5 + 50/G)mV |
| vs. Temperature (-25°C to +85°C) | ±(10 + 150/G)μV/°C | ±(8 + 250/G)μV/°C |
| vs. Supply Voltage | | ±1mV/% |
| **RATED OUTPUT** | | |
| Voltage, 50k Load | | ±5V min (±10V min)[3] |
| Output Impedance | | 1kΩ |
| Output Ripple, 1MHz Bandwidth | | 10mV pk-pk |
| **OSCILLATOR DRIVE INPUT** | | |
| Input Voltage | N/A | 8 to 16V pk-pk |
| Input Frequency | N/A | 100kHz ±5%, max |
| **ISOLATED POWER OUTPUTS** | | |
| Voltage Full Load | | ±13V dc |
| Accuracy | | ±5% |
| Current[4] | ±5mA min | ±15mA min |
| Regulation, No Load to Full Load | | +0, -15% |
| Ripple, 100kHz Bandwidth | 200mV p-p | 250mV p-p |
| **POWER SUPPLY, SINGLE POLARITY** | | |
| Voltage, Rated Performance | | +15V dc |
| Voltage, Operating | | +8V dc to +15.5V dc |
| Current, Quiescent | | +20mA |
| **TEMPERATURE RANGE** | | |
| Rated Performance | | -25°C to +85°C |
| Storage | | -55°C to +85°C |
| **CASE DIMENSIONS** | | 1.5" X 1.5" X 0.62" |

NOTES
[1] Gain temperature drift is specified as a percentage of output signal level.
[2] Gain nonlinearity is specified as a percentage of 10V pk-pk output span.
[3] These specs apply for a 20V pk-pk output span.
[4] Do not load $V_{ISO}$ when operating at output spans greater than 10V pk-pk.
Specifications subject to change without notice.

## OUTLINE DIMENSIONS

Dimensions shown in inches and (mm).



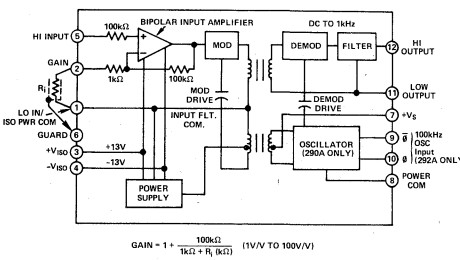




*Figure 1. Block Diagram — Models 290A and 292A*

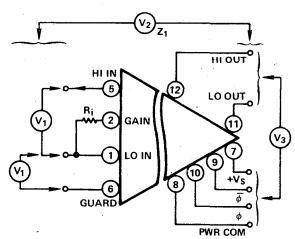



*Figure 2. Model 290A and 292A Terminal Ratings*

| Symbol | Rating | Remarks |
|---|---|---|
| $V_1$ | ±110V rms (cont.) | Withstand Voltage, Steady State |
| $V_2$ | ±1000V pk (cont.) | Isolation, Steady State, ac |
| $V_2$ | ±1500V pk (cont.) | Isolation, Steady State, dc |
| $V_2$ | ±1500V rms (1 min) | Isolation, ac, 60Hz |
| $V_3$ | ±50V pk (cont.) | Isolation, dc |
| $Z_1$ | 50GΩ\|\|20pF | Isolation Impedance |

*Table I. Isolation Ratings Between Terminals*

**CAUTION:**

ESD(Electro-static-discharge) sensitive device. Permanent damage may occur on unconnected devices subjected to high-energy electrostatic fields. Unused devices must be stored in conductive foam or shunts. The protective foam should be discharged to the destination socket before devices are removed.



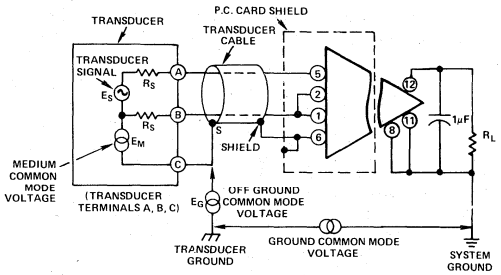
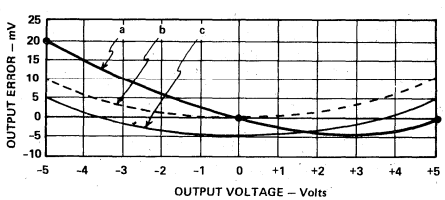


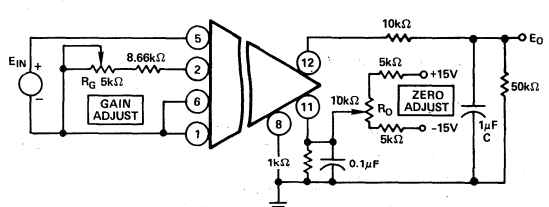

*Figure 3. Transducer – Amplifier Interface*

## GAIN AND OFFSET TRIM PROCEDURE

In applying the isolation amplifier, highest accuracy is achieved by adjustment of gain and offset voltage to minimize the peak error encountered over the selected output voltage span. The following procedure illustrates a calibration technique which can be used to minimize output error. In this example, the output span is +5V to -5V and operation at Gain = 10V/V is desired.

1. Apply $E_{IN}$ = 0 volts and adjust $R_O$ for $E_O$ = 0 volts.
2. Apply $E_{IN}$ = +0.5V dc and adjust $R_G$ for $E_O$ = +5.0V dc.
3. Apply $E_{IN}$ = –0.5V dc and measure the output error (see curve a).
4. Adjust $R_G$ until the output error is one half that measured in step 3 (see curve b).
5. Apply +0.5V dc and adjust $R_O$ until the output error is one half that measured in step 4 (see curve c).




GAIN RESISTOR, $R_I$, 1%, 50ppm/°C METAL FILM TYPE IS RECOMMENDED.
FOR GAIN = 1V/V, LEAVE TERMINAL 2 OPEN.
FOR GAIN = 100V/V, SHORT TERMINAL 2 TO TERMINAL 1

$$\text{GAIN} = 1 + \frac{100k\Omega}{1k\Omega + R_I(k\Omega)}$$

OUTPUT FILTER, 10kΩ RESISTOR AND CAPACITOR, C.
SELECT C TO ROLL-OFF NOISE AND OUTPUT RIPPLE:

$$f = (-3dB) = \frac{1}{2\pi C\,(11k\Omega)}$$

*Figure 4. Gain and Offset Adjustment*

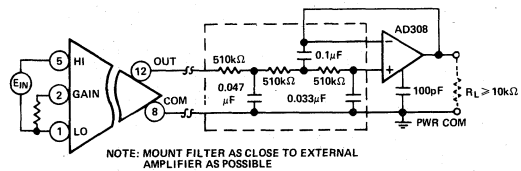



*Figure 5. Selecting Bandwidth with a 3-Pole 5Hz Active Filter for Improved 60Hz Noise Reduction (typ 150dB @ 60Hz and 1kΩ Imbalance)*

5

## PERFORMANCE CHARACTERISTICS

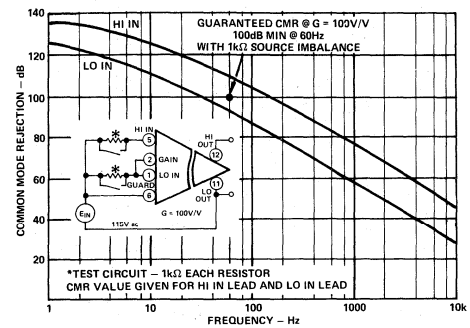



*Figure 6. Typical Common Mode Rejection vs. Frequency*

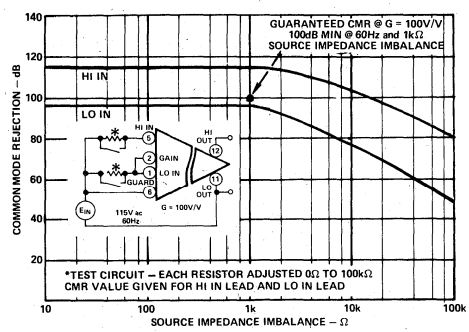



*Figure 7. Typical Common Mode Rejection vs. Source Impedance Imbalance*

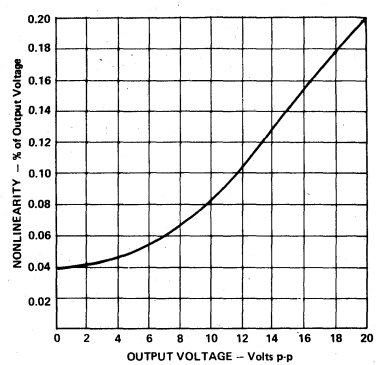



*Figure 8. Typical Gain Nonlinearity vs. Output Voltage*

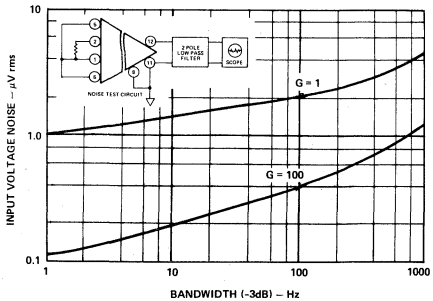



*Figure 9. Typical Input Voltage Noise vs. Bandwidth*

**Input Offset Voltage Drift:** Total input drift is composed of two sources, input and output stage drifts and is gain dependent. The curve of Figure 10 illustrates total input drift over the gain range of 1 to 100V/V.

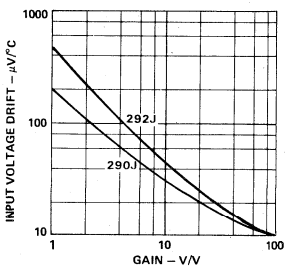
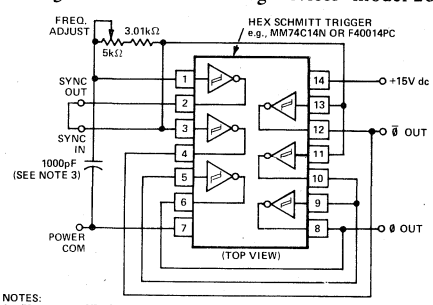



*Figure 10. Typical Input Offset Voltage Drift vs. Gain*

## REFERENCE EXCITATION OSCILLATOR, MODEL 281

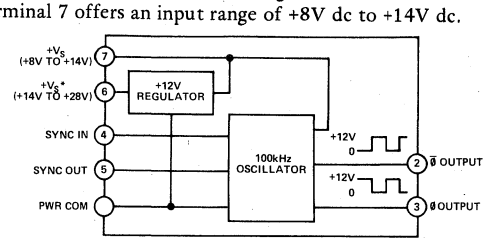
When applying model 292A, the user has the option of building a low cost 100kHz excitation oscillator, as shown in Figure 11, or purchasing a module from Analog Devices–model 281.




NOTES:
1. FREQ. ADJUST: ADJUST TRIM POT FOR OUTPUT FREQUENCY OF 100kHz ±5%.
2. FOR SLAVE OPERATION, REMOVE JUMPER FROM SYNC OUT AND SYNC IN PINS.
3. USE CERAMIC CAPACITOR, "COG" OR "NPO" CHARACTERISTIC.

*Figure 11. 100kHz Oscillator Interconnection Diagram*

The block diagram of model 281 is shown in Figure 12. An internal +12V dc regulator is provided to permit the user the option of operating over two, pin selectable, power input ranges; terminal 6 offers a range of +14V dc to +28V dc; terminal 7 offers an input range of +8V dc to +14V dc.




*LEAVE TERMINAL 6 OPEN, WHEN POWER IS APPLIED TO TERMINAL 7.

*Figure 12. Model 281 Block Diagram*

Model 281 oscillator is capable of driving up to 16 model 292As. As shown in Figure 13, an additional model 281 may be driven in a slave-mode to expand the total system channels from 16 to 32. By adding additional model 281s in this manner, systems of over 1000 channels may be easily configured.

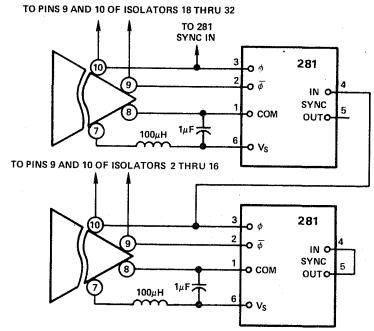



*Figure 13. External Oscillator Interconnection*

## SPECIFICATIONS

**(typical @ +25°C and $V_S$ = +15V dc unless otherwise noted)**

| MODEL | 281 |
|---|---|
| OUTPUT | |
| Frequency | 100kHz ±5% |
| Waveform | Squarewave |
| Voltage ($\phi$ and $\bar{\phi}$ terminals) | 0 to +12V pk |
| Fan-Out[1,2] | 16 max |
| POWER SUPPLY RANGE[3] | |
| High Input, Pin 6 | +(14 to 28)V dc |
| Quiescent Current, N.L. | +5mA |
| F.L. | +16mA |
| Low Input, Pin 7 | +(8 to 14)V dc |
| Quiescent Current, N.L. | +12mA |
| F.L. | +33mA |
| TEMPERATURE | |
| Rated Performance | 0 to +70°C |
| Storage | -55°C to +85°C |

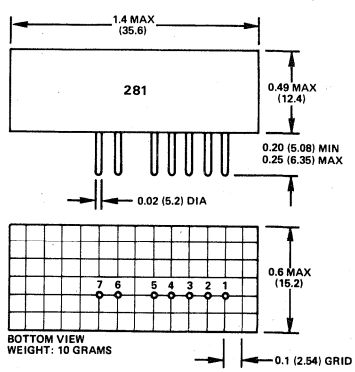
NOTES
[1] Model 292A oscillator drive input represents unity oscillator load.
[2] For applications requiring more than 16 292As, additional 281s may be used in a master/slave mode. Refer to Figure 13.
[3] Full load consists of 16 model 292As and 281 oscillator slave.

Specifications subject to change without notice.

See Caution note on specifications table.

## OUTLINE DIMENSIONS

**Dimensions shown in inches and (mm).**




PIN TERMINAL IDENTIFICATION

| | | | |
|---|---|---|---|
| 1 | POWER COMMON | 5 | SYNC OUTPUT |
| 2 | $\bar{\phi}$ OUTPUT | 6 | $+V_S$: HIGH RANGE +(14 to 28)V dc |
| 3 | $\phi$ OUTPUT | 7 | $+V_S$: LOW RANGE +(8 to 14)V dc |
| 4 | SYNC INPUT | | |

**MATING SOCKET:**
**CINCH #16 DIP OR EQUIVALENT**

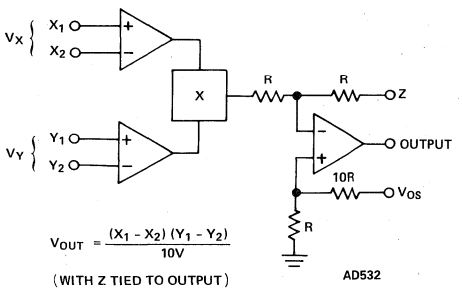
# Analog Multipliers/Dividers

## Contents


| | Page |
|---|---|
| Selection Guide | 6-2 |
| General Information | 6-5 |
| Definition of Specifications | 6-7 |
| 429A/B Wideband 4-Quadrant Multiplier | 6-9 |


6

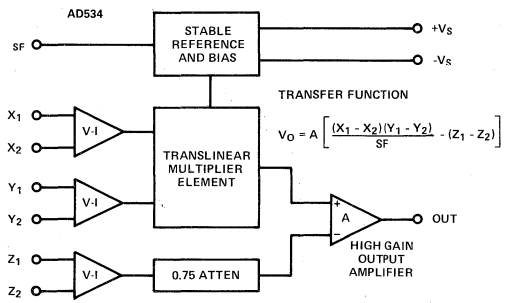
# Selection Guide
## Analog Multipliers/Dividers




### AD532

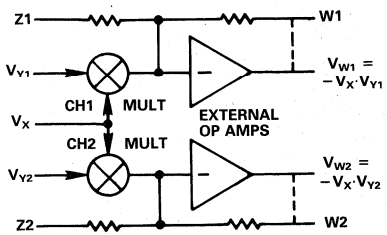
Page

Pretrimmed to ±1.0% (AD532K) — Vol. I 6-17
No External Components Required
Guaranteed ±1.0% max 4-Quadrant Error (AD532K)
Diff Inputs for $(X_1-X_2)(Y_1-Y_2)/10$ Transfer Function
Monolithic Construction




### AD534

Pretrimmed to ±0.25% max 4-Quadrant Error (AD534L) — Vol. I 6-27
All Inputs (X, Y and Z) Differential, High Impedance for $[(X_1-X_2)(Y_1-Y_2)/10V] + Z_2$ Transfer Function
Scale-Factor Adjustable to Provide up to X100 Gain
Low Noise Design: 90μV rms, 10Hz–10kHz
Low Cost, Monolithic Construction
Excellent Long Term Stability

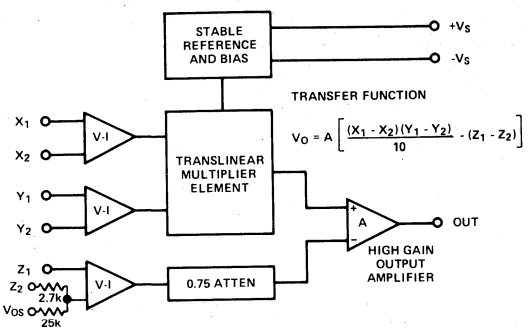



## AD539

Page
Vol. I
6-49

**Two Quadrant Multiplication/Division**
**Two Independent Signal Channels**
**Signal Bandwidth of 60MHz ($I_{OUT}$)**
**Linear Control-Bandwidth of 5MHz**
**Full-Calibrated, Monolithic Circuit**

6

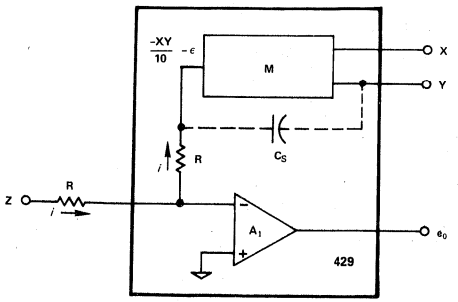



## AD632

Vol. I
6-67

**Pretrimmed to ±0.5% max 4-Quadrant Error**
**All Inputs (X, Y and Z) Differential, High Impedance for $[(X_1 - X_2)(Y_1 - Y_2)/10V] + Z_2$ Transfer Function**
**Scale-Factor Adjustable to Provide up to X10 Gain**
**Low Noise Design: 90μV rms, 10Hz–10kHz**
**Low Cost, Monolithic Construction**
**Excellent Long Term Stability**

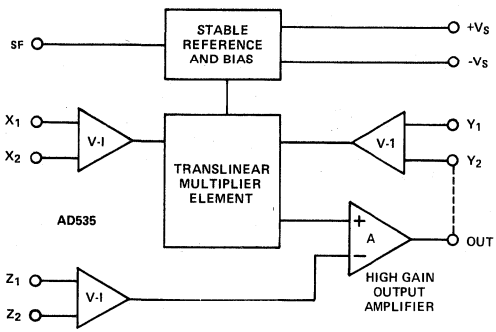
# Selection Guide
## Analog Multipliers/Dividers




### MODEL 429

Page Vol. II 6-9

**1.0%/0.5% Accuracy Without Trimming (429A/B)**
**Low Drift to 1.0mV/°C max**
**Wideband – 10MHz**
**0.2% Nonlinearity max (429B)**
**External Amplifiers not Required**
**MTBF: 169, 268 Hours**




### AD535

Vol. I 6-37

**Pretrimmed to ±0.5% max Error, 10:1 Denominator Range (AD535K)**
**±2.0% max Error, 50:1 Denominator Range (AD535K)**
**All Inputs (X, Y and Z) Differential**
**Monolithic Construction**

# Orientation
## Analog Multipliers/Dividers



The devices catalogued in this section are high-performance modules that accept analog voltages and multiply, divide, square, and/or square-root them, depending on device properties and connections. As the Selection Guide indicates, a variety of additional devices performing comparable functions using IC technologies may be found in Volume I.

*Multiplication* For two inputs, $V_x$ and $V_y$, a multiplier will provide the output, $E_{out} = V_x V_y / E_{ref}$, where $E_{ref}$ is a dimensional constant, usually of 10V nominal value. If $E_{ref}$ = 10V, $E_{out}$ = 10V when $V_x$ and $V_y$ are 10V. Multipliers are used for modulation and demodulation, fixed and variable remote gain adjustment, power measurement, and mathematical operations in analog computing, curve fitting, and linearizing.

If the inputs may be of either positive or negative polarity, and the output polarity is in a correct relationship for multiplication, the device is called a "four-quadrant" multiplier, reflecting the 4 quadrants of the X-Y plane.

*Squaring* If $V_x = V_y = V_{in}$, a multiplier's output will be $V_{in}^2 / E_{ref}$. A four-quadrant multiplier, used as a squarer, will have an output that is positive, whether $V_{in}$ is positive or negative. Squarers are useful in frequency doubling, power measurement of constant loads, and mathematical operations.

*Division* For a numerator input, $V_z$, and a denominator input, $V_x$, an analog divider will provide the output, $E_{out} = E_{ref}(V_z/V_x)$. If $E_{ref}$ = 10V, $E_{out}$ will be 10V or less for $V_z \leqslant V_x$. $V_x$ is of a single polarity and will not provide meaningful results if it approaches zero too closely. If $V_z$ may be of either positive or negative polarity, the device is described as a "two-quadrant" divider, and the output will reflect the polarity of $V_z$. Analog dividers are used to compute ratios—such as efficiency, attenuation, or gain; they are also used for fixed and variable remote gain adjustment, ratiometric measurements, and for mathematical operations in analog computing.

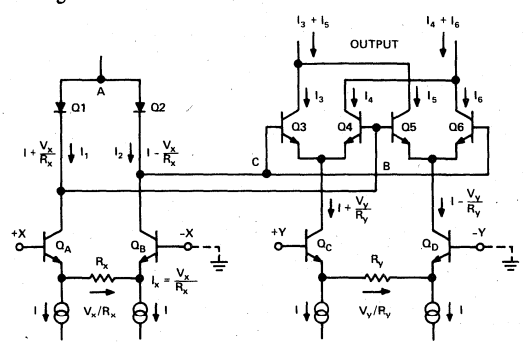
*Square rooting* For a numerator input, $V_{in}$, and a denominator input, $E_o$ (the output fed back to the denominator input), the output of a divider is $E_o = E_{ref}(V_{in}/E_o)$; hence $E_o = \sqrt{E_{ref} V_{in}}$. A square-rooter works in one quadrant; some devices require external diode circuitry to prevent latchup if the input polarity changes, even momentarily. Square roots are used in vector and rms computation, to linearize flowmeters, and for mathematical operations in analog computing.

### CHOOSING A MULTIPLIER, DIVIDER, etc.

A number of devices are listed here, differing in internal architecutre, external functional configuration, and performance specifications. Most have essentially fixed references; the model 433 is a *multifunction device* that performs the one-quadrant operation, $E_o = V_z(V_y/V_x)^m$, where m is an exponent adjustable from 1/5 to 5. With one exception (model 436 precision 2-quadrant divider), all of the devices listed here can be used for any of the functions defined above.

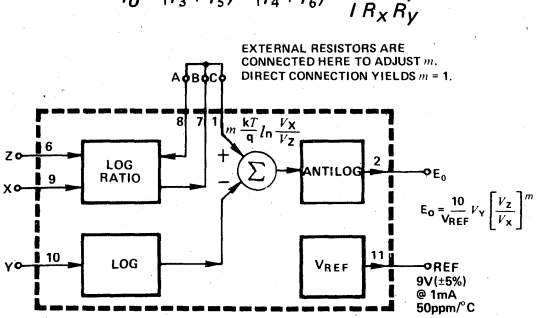
Considerable information on these functions, the nature of devices to perform them, and extensive discussions of their applications can be found in two publications available from Analog Devices.[1,2] A wealth of information is also to be found in the data sheets for the individual devices, published in this section. In addition to the products listed here, a number of popular earlier products are still available; data sheets are available upon request.

*Internal Architecture* All of the devices in this section rely on the logarithmic properties of silicon P-N junctions. With the exception of models 433 and 436, the circuit employed is basically like that of the "Gilbert cell" (its 4-quadrant-multiplying circuitry and performance are described in (1) and (2), with further references to original sources). The input voltages are converted to currents, the currents are multiplied together and divided by a reference, and the net output current, $I_x I_y / I_{ref}$, is converted to voltage by feedback around the output amplifier. The feedback terminals are available as inputs for applications involving division.




*Basic 4-Quadrant Variable-Transconductance Multiplier Circuit*

$$I_O = (I_3 + I_5) - (I_4 + I_6) = \frac{2 V_X V_Y}{I R_X R_Y}$$




*Functional Block Diagram of Model 433*

In multifunction devices like Model 433, the feedback currents of the input op amps are used to develop logarithmic

[1] *Multiplier Application Guide*, available upon request
[2] *Nonlinear Circuits Handbook*, D. H. Sheingold, ed., 1976, 536pp., $5.95, P.O. Box 796, Norwood MA 02062

voltages across transistor base-emitter junctions; these voltages are summed and differenced and produce an exponential current proportional to $V_yV_z/V_x$ via another transistor junction in the input path of the output amplifier. Thus, the output voltage is proportional to $V_yV_z/V_x$; an internally generated reference voltage is available as a fixed reference for the odd input in two-variable operations. In the 433, the internal emitter-voltage difference proportional to log $(V_z/V_x)$ can be amplified or attenuated by the appropriate connection of a resistive attenuator with an attenuation ratio, m; since the antilog of m(log $V_z/V_x$) is $(V_z/V_x)^m$, the output of the 433 is proportional to $V_y(V_z/V_x)^m$. In the model 436 divider, the inputs are scaled and linearly combined, before the log-antilog computation takes place; the result is that the numerator (of $V_z/V_x$) may have positive or negative values. The 436 circuit is optimized and trimmed for performance as a dedicated divider; it has a fixed reference.

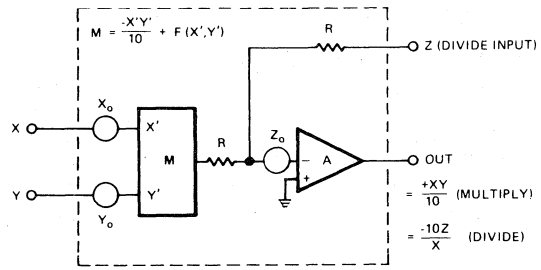
*External functional configuration* As noted earlier, with the exception of the model 436 dedicated divider, all of the devices listed here can be used for multiplication, division, squaring, and/or square-rooting (MDSSR), by the appropriate connection of external jumpers. Performance of pretrimmed devices is optimized in specified modes of operation. The data sheets show how devices are connected for the various modes of operation; where appropriate, the trim circuits and procedures for optimizing performance are provided.

*Technologies* The devices described in these two volumes are either monolithic integrated circuits or high-performance modules. For any application, the user will evaluate a device on the basis of its performance in the desired mode(s). The modules in Volume II provide the highest performance: speed (model 429), accuracy as a divider (436), and accuracy in multifunction applications (433). On the other hand, the ICs in Volume I provide economy of cost and space, and the availability of "mil-temp" range (−55°C to +125°C) versions. The pretrimmed IC's (AD534, AD535 and AD532) use laser trimming of thin-film-on-silicon chips at the wafer stage and buried-Zener reference circuitry, as well as thermally balanced input stages and "core" circuitry, for overall maximum errors to 0.25%, and linearities as yet unmatched in the industry.

*Performance* Multiplier performance, specifications and test circuitry are described in great detail in the NONLINEAR CIRCUITS HANDBOOK. Here is a brief digest of the factors relating to low-frequency performance.

In theory, a multiplier has an output which is ideally the product of two input variables, X and Y, divided by the 10V scaling voltage. However, the practical multiplier is subject to various offset errors and nonlinearities, which must be accounted for in its application. This discussion is intended to assist the designer in understanding and interpreting multiplier and divider specifications and obtaining insight into device performance.

In practice (see the figure), the multiplier may be considered as having two parts, one (M) contains the input circuitry and the multiplying cell; the other is the gain-conditioning op amp, A.




*Functional Block Diagram of Typical Multiplier/Divider*

Also summed at the op-amp input is the feedback variable, Z. In multiplication, Z is connected to the output circuit. In division, Z and X are the inputs, and Y is connected to the output. The figure shows a model used for considering errors. $X_o$ and $Y_o$ are input offset voltages, $Z_o$ is the offset-referred-to-the-input of the output amplifier, and $F(X', Y')$ is the nonlinearity, viewed as the departure from the ideal multiplication, $\frac{X'Y'}{10R}$. The output equation, including the errors is of the form

$$E_o = \frac{XY}{10B} \pm \left[\frac{X_oY}{10B} \pm \frac{XY_o}{10B} \pm Z_o + f(X,Y)\right]$$

Product; $X_{offset}$, $Y_{offset}$ (Linear "Y", Feedthrough "X"); Output offset; Nonlinearity and feedthrough

The errors are included in the bracketed term, except for gain error, which is the departure of "B", the gain-error term, from its nominal value of unity. The effects of input offsets (called "linear feedthrough") can be set to zero by applying external input biases, the output offset can be set to zero by biasing the output amplifier, and the gain can be externally calibrated by adjusting the reference or the feedback resistance. The remaining departure from the ideal output for any combination of input values is the irreducible *linearity error*, or *nonlinearity*, a function of X and Y that differs from device to device and, with temperature, within a given device. The component of nonlinearity for X = 0 is called "Y feedthrough" and for Y = 0, it is called "X feedthrough".

The "total error" specification includes the effects of all these errors. Although a guide to performance, it may produce an excessively conservative design in some applications. For example, output offset is not important if the output is to be capacitively coupled or the initial offset is nulled. Gain error is not important if system gain is to be adjusted elsewhere in the system or if gain is not a critical factor in system performance. If frequent calibration of offset and scale-factor errors is available (e.g., in a "smart" instrument, via software) non-

linearity becomes the limiting parameter. In such cases, improvements in predicted error can be achieved by using the approximate linearity equation:

$$f(X,Y) \cong |V_x|\epsilon_x + |V_y|\epsilon_y$$

were $\epsilon_x$ and $\epsilon_y$ are the specified fractional linearity errors (%/100) and $V_x$ and $V_y$ are the input signals.

When multipliers are fed back for use in division applications, it is important to recognize that maximum multiplication errors are increased approximately in proportion to the inverse of the denominator voltage ($10V/V_x$), and bandwidth is decreased in proportion to denominator voltage. Pretrimmed multipliers used in such applications, with wide dynamic range of X (e.g., 10:1), will always benefit greatly by the trimming of offsets, especially $Z_o$ (affects offsets) and $X_o$ (affects gain), for small values of X.

## DEFINITIONS OF SPECIFICATIONS*

*Accuracy* is defined in terms of *total error* of the multiplier at room temperature and constant nominal supply voltage. *Total error* includes the sum of the effects of input and output dc offsets, nonlinearity, and feedthrough. *Temperature dependence* and *supply-voltage effects* are specified separately.

*Scale Factor* The *scale-factor error* (or *gain* error) is the difference between the average scale factor and the ideal scale factor (e.g., $(10V)^{-1}$). It is expressed in percent of the output signal. *Temperature dependence* is specified.

*Output Offset* refers to the offset voltage at the output-amplifier stage. This offset is usually minimized at manufacture and can be trimmed where high accuracy is desired. Output *offset vs. temperature* is also specified.

*Linearity Error* or *Nonlinearity* is the maximum difference between actual and "best-straight-line" theoretical output, for all pairs of input values, expressed as a percentage of full scale, with all other dc errors nulled. It is the irreducible minimum error. It is usually expressed in terms of X and Y nonlinearity, with the named input swinging over its full-scale range and the other input at (±) 10V. Y nonlinearity is considerably less than X nonlinearity in "Gilbert-cell" multipliers. This specification includes nonlinear feedthrough.

*X or Y Feedthrough* is the signal at the output for any value of X or Y input in the rated range, when the other input is zero. It has two components, a linear one, corresponding to an *input offset* at the zero input, which can be trimmed out (but can drift and has a *temperature specification*), and a nonlinear one, which is irreducible. *Feedthrough* is usually specified at one frequency (50Hz) for a 20V p-p sine wave input. It increases with frequency, and plots of typical feedthrough vs. frequency are provided on multiplier data sheets.

*Noise* is specified and measured with both inputs at zero signal and zero impedance (i.e., shorted). For low-frequency applications, filtering the output of the multiplier may improve small-signal resolution significantly.

*Dynamic Parameters* include: *small-signal bandwidth, full-power response, slew(ing) rate, small-signal amplitude error,* and *settling time.*

*Small-signal bandwidth* is the frequency at which the output is down 3dB from its low-frequency value (i.e., by about 30%) for a nominal output amplitude of 10% of full scale.

*Full-power response* is the maximum frequency at which the multiplier can produce full-scale voltage into its rated load without noticeable distortion.

*Slew(ing) rate* is the maximum rate of change of output voltage for the product of a full-scale dc voltage and a full-scale step input.

*Small-signal amplitude error* is defined in relation to the frequency at which the amplitude response, or scale factor, is in error by 1%, measured with a small (10% of full-scale) signal.

*Settling time,* for the product of a ±10V step and 10Vdc, is the total length of time the output takes to respond to an input change and stay within some specified error band of its final value. Settling time cannot be accurately predicted from any other dynamic specifications; it is specified in terms of a prescribed measurement.

*Vector error* is the most-sensitive measure of dynamic error. It is usually specified in terms of the frequency at which a phase error of 0.01 radians (0.57°) occurs.

*These are general definitions. Further definitions are provided as footnotes to the specification tables; they should be read carefully.

# ANALOG DEVICES

# Accurate, Wideband, Multiplier, Divider, Square Rooter

# MODEL 429



**FEATURES:**
- 1.0%/0.5% Accuracy without Trimming (429A/B)
- Low Drift to 1.0mV/°C max
- Wideband – 10MHz
- 0.2% Nonlinearity max (429B)
- External Amplifiers not Required
- MTBF: 169, 268 Hours

**APPLICATIONS:**
- Fast Divider
- Modulation and Demodulation
- Phase Detection
- Instrumentation Calculations
- Analog Computer Functions
- Adaptive Process Control
- Trigonometric Computations




## GENERAL DESCRIPTION

The model 429, an extremely fast multiplier/divider, should be considered if bandwidth, temperature coefficient, or accuracy are critical parameters. Based on the transconductance principle to achieve high speed, the model 429 offers a unique combination of features, those being ½% max error (429B) and 10MHz small signal bandwidth.

Both models 429A and 429B are internally trimmed achieving max errors of 1.0% and 0.5% respectively. By fine trimming the offset and feedthrough with external trim potentiometers typical performance may be improved to 0.5% for the 429A and 0.2% for the 429B.

In addition to high accuracy and high bandwidth, the model 429 offers exceptionally good stability for changes in ambient temperature. Model 429B is 100% temperature tested in order to guarantee an overall accuracy temperature coefficient of only 0.04%/°C max. Additionally, offset drift is held to only 1mV/°C max. To satisfy OEM requirements of low cost, the 429 uses transconductance principles with the latest design techniques and components to achieve guaranteed performance at competitive prices.

## MULTIPLICATION ACCURACY

Multiplication accuracy is generally specified as a percentage of full scale output. This implies that error is independent of signal level. However, for signal levels less than 2/3 of full scale, error tends to decrease roughly in proportion to the input signal. A good approximation of error behavior is:

$f(X, Y) \cong |X|\,\epsilon_x + |Y|\,\epsilon_y$, where $\epsilon_x$ and $\epsilon_y$ are the fractional nonlinearities specified for the X and Y inputs

*EXAMPLE:* For model 429A, $\epsilon_x = 0.5\%$, $\epsilon_y = 0.3\%$. What maximum error can one expect for x = 5V, y = 1V, providing the offset is zeroed out? Can one get less by interchanging inputs?

1. Nominal output is XY/10 = (5)(1)/10 = 500mV
2. Expected error is (5) (0.5%) + (1) (0.3%) = 28mV, 5.6% of output (0.28% of F.S.)
3. Interchanging inputs (1) (0.5%) + (5) (0.3%) = 20mV, 4.0% of output (0.20% of F.S.)

Compare this with the overly conservative error predicted by the overall 1% of full scale specification: 100mV, or 20% of output.

## FREQUENCY RELATED SPECIFICATIONS

Accuracy, and its components, feedthrough, linearity, gain, (and phase shift) are frequency dependent. Feedthrough is constant up to 100kHz for the Y input, and up to 400kHz for the X input. Beyond these frequencies it rises at approximately a 6dB/octave rate due to distributed capacitive coupling. A plot of typical feedthrough vs. frequency is shown in Figure 1. For this measurement one input is driven with a 20V p-p sine wave while the other input is grounded and the feedthrough is measured at the output. This error will decrease roughly in proportion to the input signal, and will also vary with temperature (about 0.01%/°C of the nonzero input). Low frequency feedthrough error can be further reduced from the internally trimmed limits by the use of optional external potentiometers.

Nonlinearity likewise increases with frequency at a 6dB/octave rate above the break frequency. With the Y input driven at 10V p-p, and the X input anywhere between ±10V dc, the break frequency is 25kHz. For corresponding X input conditions, the break occurs at 60kHz. Figure 2 is a plot of the typical nonlinearity vs. frequency for the model 429.

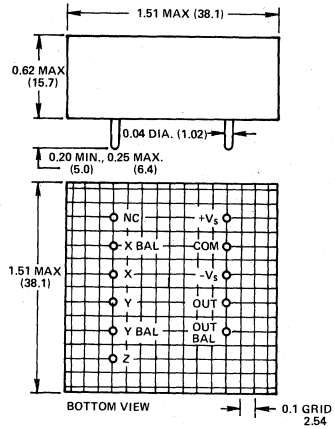
# SPECIFICATIONS (typical @ +25°C and ±15VDC unless otherwise noted)

| MODEL | 429A | 429B |
|---|---|---|
| MULTIPLICATION CHARACTERISTICS | | |
| Output Function | XY/10 | * |
| Error, with Internal Trim, at +25°C | ±1% max | ±0.5% max |
| Error, with External Trim, at +25°C | ±0.7% | ±0.3% |
| Avg. vs. Temp (-25°C to +85°C) | ±0.05%/°C | ±0.04%/°C max |
| Avg vs. Supply | ±0.05%/% | * |
| SCALE FACTOR | | |
| Initial Error at +25°C | 0.5% | 0.25% |
| Avg vs. Temp (-25°C to +85°C) | 0.03%/°C | 0.02%/°C |
| Avg vs. Supply | 0.03%/% | * |
| OUTPUT OFFSET | | |
| Initial at +25°C (Adjustable to Zero) | ±20mV max | ±10mV max |
| Avg vs. Temp (-25°C to +85°C) | ±2mV/°C | ±1mV/°C max |
| Avg vs. Supply | ±1mV/% | * |
| NONLINEARITY | | |
| X Input | | |
| (X = 20V p-p 50Hz, Y = ±10V) | 0.5% max | 0.2% max |
| Y Input | | |
| (Y = 20V p-p 50Hz, X = ±10V) | 0.3% max | 0.2% max |
| FEEDTHROUGH | | |
| X = 0, Y = 20V p-p, 50Hz | 50mV p-p, max | 20mV p-p, max |
| With External Trim | 16mV p-p | 10mV p-p |
| Y = 0, X = 20V p-p, 50Hz | 100mV p-p, max | 30mV p-p, max |
| With External Trim | 50mV p-p | 20mV p-p |
| BANDWIDTH | | |
| -3dB | 10MHz | * |
| Full Power Response | 2MHz min | * |
| Slew Rate | 120V/μs min | * |
| 1% Amplitude Error | 300kHz min | * |
| 1% Vector Error (0.57°) | 50kHz min | * |
| Differential Phase Shift ($\theta_x - \theta_y$) | 1° @ 1MHz | * |
| Small Signal Rise Time 10-90% | 40ns | * |
| Settling to ±1% (±10V step) | 500ns | * |
| Overload Recovery | 0.2μs | * |
| OUTPUT NOISE | | |
| 5Hz to 10kHz | 0.6mV rms | * |
| 5Hz to 10MHz | 3.0mV rms | * |
| OUTPUT CHARACTERISTICS | | |
| Voltage, 1kΩ load | ±11V min | * |
| Current | ±11mA min | * |
| Load Capacitance | 0.01μF max | * |
| INPUT RESISTANCE | | |
| X Input | 10kΩ±5% | * |
| Y Input | 11kΩ±2% | * |
| Z Input | 27kΩ±10% | * |
| INPUT BIAS CURRENT | | |
| Input X, Y, Z | ±100nA | * |
| Z | ±20μA | * |
| MAXIMUM INPUT VOLTAGE | | |
| For Rated Accuracy | ±10.5V | * |
| Maximum Safe | ±16V | * |
| WARM UP | | |
| To Rated Specifications | 1 second | * |
| POWER SUPPLY[1] | | |
| Rated Performance | ±(14.8 to 15.3)V dc | * |
| Operating | ±(14 to 16)V dc | * |
| Quiescent Current | ±12mA | * |
| TEMPERATURE RANGE | | |
| Rated Performance | -25°C to +85°C | * |
| Operating | -25°C to +85°C | * |
| Storage | -55°C to +125°C | * |
| MECHANICAL | | |
| Weight | 2 oz. | * |
| Socket | AC1023 | * |
| Case Dimensions | 1.5" x 1.5" x 0.62" | * |

NOTES
*Specifications same as model 429A.
[1] Recommended power supply, ADI model 904, ±15V @ 50mA output.
Specifications subject to change without notice.

## OUTLINE DIMENSIONS

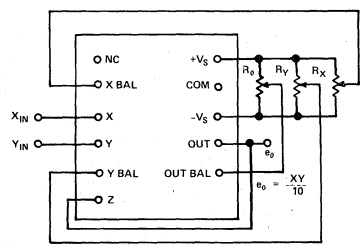
Dimensions shown in inches and (mm).



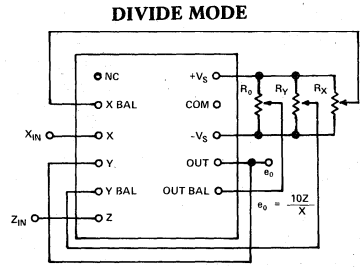

## PIN CONNECTIONS

Bottom View Shown in all Figures.
Optional Trim Pots
Shown are not Required
for Rated Accuracy.

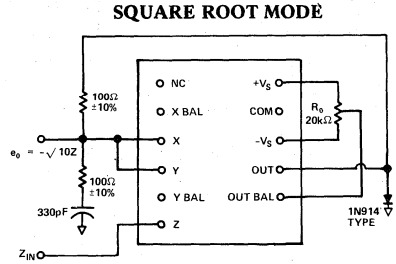
### MULTIPLY MODE




### DIVIDE MODE




### SQUARE ROOT MODE




All trim pots 20kΩ.

Gain and input to output phase shift for the model 429 are shown in Figure 2. Naturally, no multiplier will maintain accuracy at frequencies approaching the small signal bandwidth. For the model 429, the 1% amplitude error will occur at 500kHz. If input to output phase shift is a criterion, then the 1% "vector" error occurs at 50kHz.

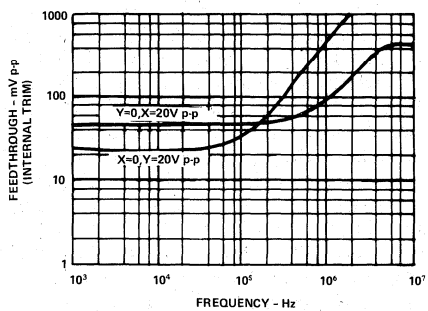



*Figure 1. Feedthrough vs Frequency*

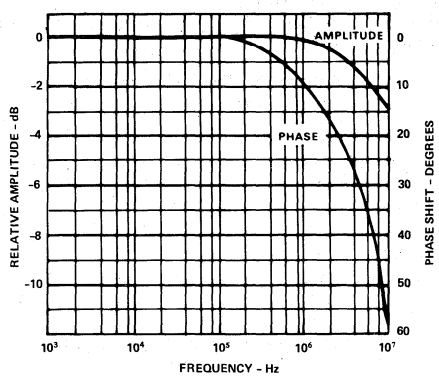



*Figure 2. Typical Amplitude and Phase vs Frequency*

**OPTIONAL TRIM — MULTIPLY MODE**

As shipped, the multiplier meets its listed specifications without use of any external trim potentiometers. Terminals are provided for optional feedthrough and offset adjustments. Using these adjustments overall static multiplication error may be reduced to only 0.2%. The 20kΩ trim potentiometers should be connected across the ± supply voltage terminals with the arm of each potentiometer connected to the desired balance terminal (see Specifications page).

**ADJUSTMENT PROCEDURE FOR OFFSET**

1. Jumper X input and Y input to ground.
2. Adjust $R_0$ for an output of zero volts.
3. Remove jumper from X and Y inputs.

**ADJUSTMENT PROCEDURE FOR FEEDTHROUGH**

1. Jumper Y input to ground and apply 20V p-p at 1kHz to X input.
2. Adjust $R_Y$ for minimum output voltage.
3. Remove jumper from Y input.
4. Jumper X input to ground and apply 20V p-p at 1kHz to Y input.
5. Adjust $R_X$ for minimum output voltage.
6. Remove jumper from X terminal.

**DIVISION**

The high bandwidth and excellent linearity of model 429 allows it to be used in divider applications achieving high performance in the dc to 8MHz region. Restrictions imposed on divide operation, and the contribution of error terms are illustrated in the error analysis below.

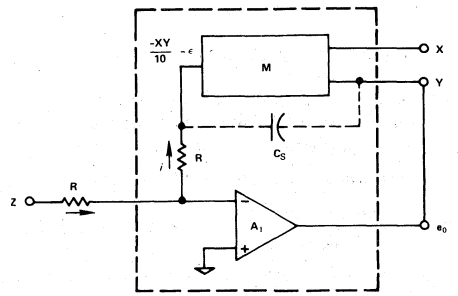



*Figure 3. Divider Circuit*

Shown in Figure 3 is a typical multiplier/divider which has been connected for divide operation by inserting the multiplier cell, M, in the op amp's feedback loop. Errors associated with the op amp, $A_1$, are incorporated in $\epsilon$, which represents all errors. In order to insure negative feedback, the X input range is restricted to negative values.

Summing currents at the op amp's summing junction:

$$\frac{Z}{R} = \frac{\frac{XY}{10} + \epsilon}{R}$$

Solving for Y, which is also $\epsilon_0$:

$$Y = \frac{10\,(Z - \epsilon)}{X}$$

or,

$$\epsilon_0 = \frac{10Z}{X} - \frac{10\epsilon}{X}$$

And now breaking $\epsilon$ into its constituents

$$\epsilon_0 = \underbrace{\frac{10Z}{X}}_{\text{ideal divider}} - \underbrace{\frac{10E_{NV}}{X}}_{\text{noise error}} - \underbrace{\frac{10E_{OS}}{X}}_{\text{offset error}} - \underbrace{\frac{10E_{OS}/^{\circ}C}{X}}_{\text{offset drift error}} - \underbrace{\frac{10E_{NLX}}{X}}_{\text{X nonlinearity error}} - \underbrace{\frac{10E_{NLY}}{X}}_{\text{Y nonlinearity error}}$$

These errors can be broken down into two categories, static errors and signal dependent errors. All of the static errors associated with the divide mode are inversely proportional to the denominator signal level. The signal dependent errors are the X and Y nonlinearities. For model 429B nonlinearity errors are 0.2% for both the X and Y inputs. Substituting these values in the error terms yields:

$$-\frac{10\,(0.2\%)\,X}{X} - \frac{10\,(0.2\%)\,Y}{X}$$

The importance of using the terminal with largest nonlinearity for the denominator is revealed by the above expression. Effects of X nonlinearity are virtually independent of signal level and may be trimmed out. Nonlinearities of Y typically contribute 200mV for X = Z = 1V i.e., (10 [0.2%] 10V) = 200mV. This error can be reduced if external trims are used to optimize divider performance.

Bandwidth is also degraded with a decrease in denominator level, due to the increase in system gain;

i.e.) for X = Z = 1V, $e_0$ = 10V

and $\frac{e_0}{Z} = \frac{10}{1} = 10$

Since the gain bandwidth product is constant, a bandwidth of 1/10 of that obtained for full scale denominator levels will be obtained for division at 1V levels.

For other denominator levels, bandwidth is determined by:

$$\text{B. W.} = \frac{\text{Denominator Level}}{\text{Full Scale Denominator}} \times (\text{Multiplier B.W.}) \times K$$

where K is a constant having a value less than unity. It is introduced due to a combination of stray capacitance paralleling the multiplier cell and effects of feedthrough. For model 429

$$\text{B.W.} = \left(\frac{X}{10}\right) 8\text{MHz}$$

Before selecting a multiplier/divider for divide applications, errors resulting from the lowest anticipated denominator signal should be considered. After such considerations have been made, one can further appreciate the importance of starting with an accurate, high speed multiplier such as model 429. It is also highly recommended that the optional trim procedure for division be performed.

### OPTIONAL TRIMMING – DIVIDE MODE

Connections are made as shown on Specifications page.

The suggested trim procedure is (starting with centered adjust adjustments):

*1. With Z = 0, trim $R_0$ to hold output constant, as X is varied from -10V toward -1.0V.
2. With Z = 0, trim $R_Y$ for zero at X = -10V.
3. With Z = X and/or Z = -X, trim $R_X$ for minimum worst-case variation as X is varied from -10V to -1.0V.
4. Repeat 1 and 2 if step 3 required large initial adjustment.

*For best accuracy X should be allowed to vary from -10V to lowest expected denominator.

### SQUARE ROOTING

When connected as shown on Specifications page, the model 429 will provide the square root of $Z_{IN}$.

By summing currents at the op amp's summing junction:

$$\frac{Z}{R} = \frac{XY}{10R} + \frac{\epsilon}{R} = \frac{Y^2}{10R} + \frac{\epsilon}{R}$$

where $\epsilon$ represents all errors associated with the multiplier. Solving for the output voltage, Y.

$$e_0 = \pm \sqrt{10\,(Z - \epsilon)}$$

There are two values of $e_0$ for every value of Z. However, only negative values of $e_0$ will provide the negative feedback necessary for circuit stability. To restrict the output from going positive, a diode is connected as shown on Specifications page. The output is then:

$$e_0 = -\sqrt{10\,(Z - \epsilon)}$$

Errors, $\epsilon$, associated with the multiplier, are inside the square root and consequently their effect, for large values of Z, is reduced. The reason for the improved performance can be seen by inspecting the circuit. The output is fed back to both the X and Z terminals, resulting in twice the feedback as would be obtained for the divide mode. An alternative method of considering error performance is to consider errors as being at the Z terminal. By differentiating the ideal transfer function with respect to Z, errors for various values of Z may be determined:

$$\frac{de_0}{dZ} = \frac{d}{dZ}\sqrt{10Z} = \tfrac{1}{2}\sqrt{\frac{10}{Z}}$$

The factor of ½ has the advantage of reducing errors by a factor of 2 for Z = 10, but also introduces the potential problem of instability. Since the feedback gain is the reciprocal of the forward gain, the slope of the forward gain is 2. Additional phase margin is required to support the increased gain in the feedback path. Model 429 is optimized for phase margin in the multiply and divide modes producing minimum vector errors at high frequencies. To avoid the potential problem of instability, the RC network shown previously is recommended. This network restricts the bandwidth and guarantees stability for all positive values of Z.

### OPTIONAL ADJUSTMENT PROCEDURE – SQUARE ROOT

1. Apply a voltage to the Z terminal equal to the lowest anticipated input voltage.
2. Adjust $R_0$ such that $e_0 = -\sqrt{10Z}$, where Z is the voltage applied in step 1.

### DIVISION SPECIFICATIONS (TYPICAL)

| | |
|---|---|
| OUTPUT FUNCTION | 10(Z)/X |
| Numerator Range | ±10V |
| Denominator Range, 1% Accuracy | -1 to -10V |
| Denominator Range, 5% Accuracy | -0.2V to -10V |
| Bandwidth Formula, (Hz, -3dB) | (8MHz)(X)/10 |

### SQUARE ROOTING SPECIFICATIONS (TYPICAL)

| | |
|---|---|
| OUTPUT FUNCTION | $-\sqrt{10(Z)}$ |
| Dynamic Range | 1000 to 1 (+0.010V ≤Z≤+10V) |
| Accuracy (% of Full Scale) | 0.5% |
| Bandwidth Formula, (Hz, -3dB) | $(5\text{MHz})\sqrt{\lvert X\rvert/10}$ |

*Table I. Division & Square Rooting Specifications*

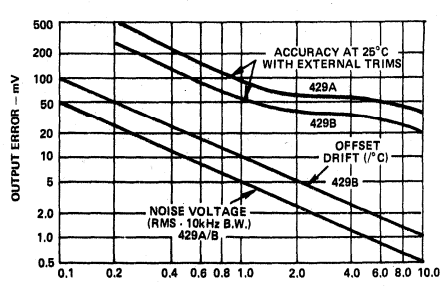



*Figure 3. Typical Error Performance of Model 429 in Divide Mode for Worst Case of $|e_0| = 10V$*

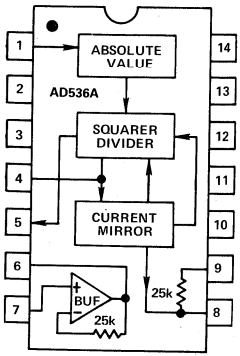
# RMS-to-DC Converters

## Contents


| | Page |
|---|---|
| Selection Guide | 7–2 |
| General Information | 7–4 |
| Performance Specifications | 7–5 |
| 442J/K/L 8MHz-Bandwidth rms-to-dc Converters | 7–7 |


7

# Selection Guide
## RMS-to-DC Converters



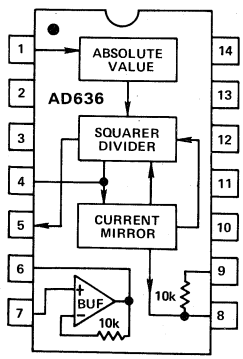

### AD536A

Page
Vol. I
6-43

True rms-to-dc Conversion
Laser-Trimmed to High Accuracy
- 0.2% max Error (AD536AK)
- 0.5% max Error (AD536AJ)

Wide Response Capability:
- Computes rms of ac and dc Signals
- 300kHz Bandwidth: $V_{rms}$>100mV
- 2MHz Bandwidth: $V_{rms}$>1V
- Signal Crest Factor 7 for 1% Error

dB Output with 60dB Range
Low Power: 1mA Quiescent Current
Single or Dual Supply Operation
Monolithic Integrated Circuit
−55°C to +125°C Operation (AD536AS)



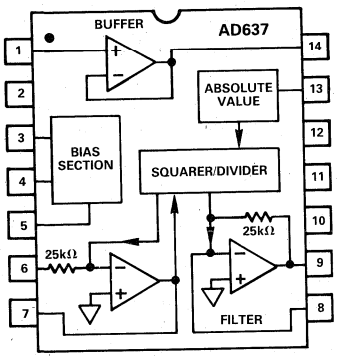

### AD636

Vol. I
6-71

True rms-to-dc Conversion
200mV Full Scale
Laser-Trimmed to High Accuracy
- 0.5% max Error (AD636K)
- 1.0% max Error (AD636J)

Wide Response Capability:
- Computes rms of ac and dc Signals
- 1MHz −3dB Bandwidth: $V_{rms}$>100mV
- Signal Crest Factor of 6 for 0.5% Error

dB Output with 50dB Range
Low Power: 800μA Quiescent Current
Single or Dual Supply Operation
Monolithic Integrated Circuit




## AD637

Page
Vol. I
6-77

High Accuracy
- 0.02% Max Nonlinearity, 0 to 2V rms Input
- 0.10% Max Error to Crest Factor of 3

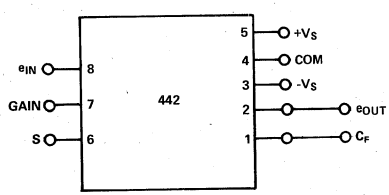
Wide Bandwidth
- 8MHz at 2V rms Input
- 600kHz at 100mV rms

Computes:
- True rms
- Square
- Mean Square
- Absolute Value

dB Output (−60dB Range)

Chip Select-Power Down Feature Allows:
- Analog "3-State" Operation
- Quiescent Current Reduction from 2.2mA to 350μA






## MODEL 442

Vol. II
7-7

DC to 8MHz Response (−3dB)

High Accuracy:
- With No Ext. Trim: ±2mV ±0.15% of Rdg., max
- With Ext. Trim: ±1mV ±0.05% of Rdg., max

Low Drift: ±(35μV ±0.01% of Reading)/°C max, 442L

Fast Settling Time: 5ms to 1%

All Hermetically Sealed Semiconductors

No External Components Required to Meet Specifications

# Orientation
## RMS-to-DC Converters

The 442 is a high-accuracy wide-bandwidth true-rms-to-dc-conversion module. As the Selection Guide indicates, additional devices to perform rms-to-dc conversion, employing IC technology, may be found in Volume I. Devices of this class compute the instantaneous square of the input signal, average it, and take the square root of the result, to provide a dc voltage that is proportional to the rms of the input (and, in the case of the AD536A and AD636 ICs, an auxiliary dc voltage that is proportional to the *log* of the rms, for dB measurements).

Excellent pre-trimmed performance, improvable by simple optional trims, makes these devices ideal for all types of laboratory and OEM rms instrumentation where amplitude measurements must be made with high accuracy, independently of waveshape.

An alternative to rms that has been widely used in the past, principally for measurements on sine waves, is mean absolute-deviation, or "ac average." It is performed by taking the absolute value of (i.e., full-wave or half-wave rectifying) a signal, filtering it, and scaling it by the ratio of rms to m.a.d. for sine waves, 1.111, so that it reads correctly (for undistorted sine waves). Unfortunately, this ratio varies widely as a function of the waveform and will give grossly incorrect results in many cases. The table shows a few representative examples comparing rms with m.a.d.

Examples of applications include noise measurement – for example, thermal noise, transistor noise, and switch-contact noise. True-rms measurement is a technique that provides consistent theoretically valid measurements of noise amplitude (standard deviation) from different sources having different properties.

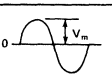
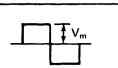
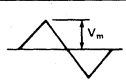
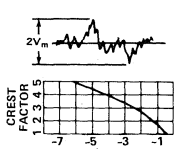
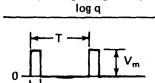
True-rms devices are also useful for measuring electrical signals derived from mechanical phenomena, such as strain, stress, vibration, shock, expansion, bearing noise, and acoustical noise. The electrical signals produced by these mechanical actions are often noisy, non-periodic, nonsinusoidal, and superimposed on dc levels, and require true-rms for consistent, valid, accurate measurements. RMS converters are also useful for accurate measurements on low-repetition-rate pulse-trains having high *crest factors* (ratio of peak to rms), and for measurements of the energy content of SCR waveforms at differing firing angles.

The basic approach used in these converters for computing the rms is to take the absolute value, square it, and divide by the fed-back output (using the logarithmic characteristics of transistor junctions), and filter the result. The resulting approximation

$$E_o = \text{Avg.}\left[\frac{V_{in}^2}{E_o}\right] \cong \sqrt{\text{Avg.}\,(V_{in}^2)}$$

is valid if the averaging time-constant is sufficiently long compared with the periods of the lowest-frequency ac components of the signal.

The simplest form of averaging involves a single-pole filter, using an external filtering capacitance. Increased values of capacitance for filtering will improve the accuracy for low frequency rms measurements and provide reduced ripple at the output, but at the cost of increased settling time. For fastest settling and minimum ripple, an additional stage of 2-pole filtering is useful. The additional filtering permits improvement of settling time or reduction of ripple (or both) because of substantial reduction of $C_{ext}$.

| WAVEFORM | | RMS | MAD | $\frac{\text{RMS}}{\text{MAD}}$ | CREST FACTOR |
|---|---|---|---|---|---|
|  | SINE WAVE | $\frac{V_m}{\sqrt{2}}$ 0.707 $V_m$ | $\frac{2}{\pi} V_m$ 0.637 $V_m$ | $\frac{\pi}{2\sqrt{2}} = 1.111$ | $\sqrt{2} = 1.414$ |
|  | SYMMETRICAL SQUARE WAVE OR DC | $V_m$ | $V_m$ | 1 | 1 |
|  | TRIANGULAR WAVE OR SAWTOOTH | $\frac{V_m}{\sqrt{3}}$ | $\frac{V_m}{2}$ | $\frac{2}{\sqrt{3}} = 1.155$ | $\sqrt{3} = 1.732$ |
|  | GAUSSIAN NOISE<br>CREST FACTOR IS THEORETICALLY UNLIMITED. q IS THE FRACTION OF TIME DURING WHICH GREATER PEAKS CAN BE EXPECTED TO OCCUR | RMS | $\sqrt{\frac{2}{\pi}}$ RMS = 0.798 RMS | $\sqrt{\frac{\pi}{2}}$ 1.253 | C.F. / q<br>1 / 32%<br>2 / 4.6%<br>3 / 0.37%<br>3.3 / 0.1%<br>3.9 / 0.01%<br>4 / 63ppm<br>4.4 / 10ppm<br>4.9 / 1ppm<br>6 / $2 \times 10^{-9}$ |
|  | PULSE TRAIN<br>$\eta$: "DUTY CYCLE" | $V_m\sqrt{\eta}$ | $V_m\eta$ | $\frac{1}{\sqrt{\eta}}$ | $\frac{1}{\sqrt{\eta}}$ |

| $\eta$ | MARK/SPACE | $V_m\sqrt{\eta}$ | $V_m\eta$ | $\frac{1}{\sqrt{\eta}}$ | $\frac{1}{\sqrt{\eta}}$ |
|---|---|---|---|---|---|
| 1 | ∞ | $V_m$ | $V_m$ | 1 | 1 |
| 0.25 | 0.3333 | $0.5V_m$ | $0.25V_m$ | 2 | 2 |
| 0.0625 | 0.0667 | $0.25V_m$ | $0.0625V_m$ | 4 | 4 |
| 0.0156 | 0.0159 | $0.125V_m$ | $0.0156V_m$ | 8 | 8 |
| 0.01 | 0.0101 | $0.1V_m$ | $0.01V_m$ | 10 | 10 |

PERFORMANCE SPECIFICATIONS

Considerable information regarding rms-to-dc converter circuit design, performance, selection, and applications is to be found in the NONLINEAR CIRCUITS HANDBOOK.[1] In addition, useful applications information on auxiliary filtering can be found in the article "Measure RMS with Less Ripple in Less Time."[2]

The most-salient feature of a true rms-to-dc converter is that *it ideally has no error due to an indirect approximation to the rms*. Static errors are due only to scale-factor, linearity, and offset errors; dynamic errors are due to insufficient averaging time at the low end and finite bandwidth and slewing rate at the upper end. Linearity errors affect crest factor in midband. Dynamic errors are also a function of signal amplitude, due in part to the variation of bandwidth of the "log" transistors with signal level.

*Total Error* A specification for quick reference, this is the maximum deviation of the dc component of the output voltage from the theoretical output value over a specified range of signal amplitude and frequency. It is shown as the sum of a fixed error and a component proportional to the theoretical output ("% of reading"). It is specified for a sinusoidal input in a given frequency and amplitude range. The fixed error-component includes all offset errors and irreducible nonlinearities; the %-of-reading component includes the linear scale-factor error.

*Total Error, external adjustment* is the amount by which the output may differ from the theoretical value when the output offset and scale factor have been trimmed. Note that the fixed error-component cannot be reduced to zero, even though the output offset can be nulled at zero input. This is because of residual input offsets and inherent nonlinearities in the converter.

*Total Error vs. Temperature* is the average change of %-of-full-scale error component plus the average change of percent of reading error component per degree Celsius, over the rated temperature range.

*Frequency for 1%-of-Reading Error* is the minimum value of frequency (at the high end) at which the error increases from the midband value by 1% of reading. It is a function of peak-to-peak input amplitude.

*Frequency for -3dB Reading Error* is the minimum value of frequency (at the high end) at which the error may equal -30% of reading. It is a function of amplitude.

*Crest Factor* (a property of the signal) is the ratio of peak signal voltage to the ideal value of rms; the specified value of crest factor is that for which the error is maintained within specified limits at a given rms level for a worst-case — rectangular pulse — input signal.

*Filter Time Constant and External Capacitor:* The time constant of the internal averaging filter, and the increase of time constant per μF of added external capacitance.

*Input:* The voltage range over which specified operation is obtained, the maximum voltage for which the unit operates, the maximum safe input voltage, and the effective input resistance.

*Output:* The maximum output range for rated performance, the minimum current guaranteed available at full-scale output voltage, and the source resistance of the output circuit.

*Power Supply:* Power-supply range for specified performance, power-supply range for operation, and quiescent current drain.

*Temperature Range:* The range of temperature variation for operation within specifications. Temperature coefficients are determined by three-point measurements ($T_H - 25°C$), ($25°C - T_L$), when measured.

[1] *Nonlinear Circuits Handbook*, Analog Devices, Inc., 1974, 1976, 536pp, edited by D. H. Sheingold.
[2] ANALOG DIALOGUE 9-3, 1975, pp 21-22

# ANALOG DEVICES

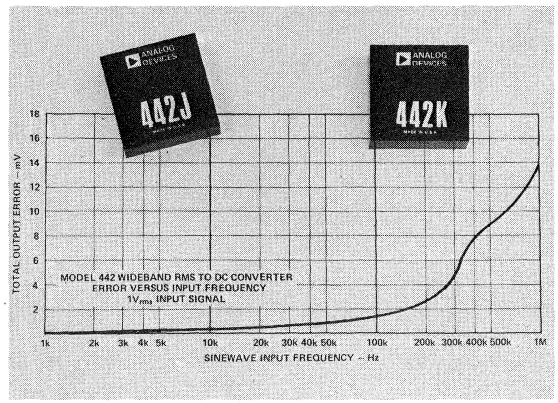
# Wideband, High Accuracy True rms-to-dc Converter

# MODEL 442



**FEATURES**
- DC to 8MHz Response (-3dB)
- High Accuracy:
  - With No Ext. Trim: ±2mV ±0.15% of Rdg., max
  - With Ext. Trim: ±1mV ±0.05% of Rdg., max
- Low Drift: ±(35μV ±0.01% of Reading)/°C max, 442L
- Fast Settling Time: 5ms to 1%
- Small Size: 1.5" x 1.5" x 0.4"
- All Hermetically Sealed Semiconductors

**APPLICATIONS**
- Wideband rms Instrumentation
- Telephone, Telegraph & Modem Test Equipment
- Vibration Analysis
- Sound & Noise Level Instrumentation
- Mean Square Measurements




## GENERAL DESCRIPTION

Model 442 is a high performance true rms-to-dc converter featuring 8MHz bandwidth, low drift to ±35μV/°C ±0.01% of reading/°C maximum, and ±1% reading error to 800kHz. Unlike competing designs, model 442 achieves its high accuracy over a very wide input signal range. With no external adjustment, accuracy is held to within ±2mV ±0.15% of reading for input signals of 0 to 2V$_{rms}$. If optional adjustments are performed, this accuracy can be improved to ±1mV ±0.05% of reading. Model 442 is designed to be used in high performance instrumentation where response to low level, high speed signals, is of greatest importance.

The compact, log-antilog circuit design of model 442 results in high accuracy measurements on sinewave signals and complex waveforms such as pulse trains. Reading error increases 0.2% for signals with crest factors up to 7. In addition, true rms measurement can be performed directly on signals containing both ac and dc components.

Model 442 is available in three low drift selections offering maximum drift performance over 0 to +70°C range; model 442L: ±(35μV ±0.01% of rdg.)/°C max; model 442K: ±(50μV ±0.01% of rdg.)/°C max; model 442J: ±(100μV ±0.01% of rdg.)/°C max.

## WHERE TO USE MODEL 442

Excellent untrimmed performance along with simple, optional trims make model 442 the ideal component for all types of laboratory and OEM rms instrumentation where wideband measurements must be made with high accuracy. Model 442 is ideally suited for measuring thermal noise, transistor noise and switch contact noise. True rms measurement is the only technique to accurately measure system noise and thereby assist the designer in reducing this noise. Model 442 is also useful for measuring mechanical phenomena such as strain, stress, vibration, shock, expansion and contraction. The electrical signals produced by these mechanical actions are often noisy, nonperiodic, nonsinusoidal and superimposed on dc levels, therefore requiring true rms devices for accurate measurements.

Model 442 is also required for accurate measurements on low repetition rate pulse trains. For pulse trains with crest factors of 10, a 3dB bandwidth of 400 times the pulse rate is required to achieve 1% accuracy and 4000 times the pulse rate is needed for 0.1% accuracy.

Model 442 may also be connected (see Figure 3) to measure the MEAN SQUARE of a signal ($e_o = \overline{e_{in}^2}/V_R$). The Mean Square of a random signal is equal to the variance ($\sigma^2$).

## TOTAL ACCURACY

Total output error is specified as the sum of two components; a fixed term plus a percentage of output signal. Model 442 has a rated sinewave accuracy of ±1mV ±0.05% max (externally trimmed), which for a one volt rms sinewave, results in a ±1.5mV maximum error (±1mV fixed error plus ±0.5mV reading error). The fixed error component is comprised of output offsets and linearity errors. Both of these error terms have been minimized in the model 442 as a result of special output circuit design and sophisticated factory offset trim procedures. Output offset can be adjusted for minimum error by means of an external adjustment (see Figure 2). The % of reading error is attributed to nonlinearity and scale factor errors. Scale factor error may also be reduced by external adjustment of an optional 5kΩ potentiometer (see Figure 2).

**For detailed information, contact factory.**

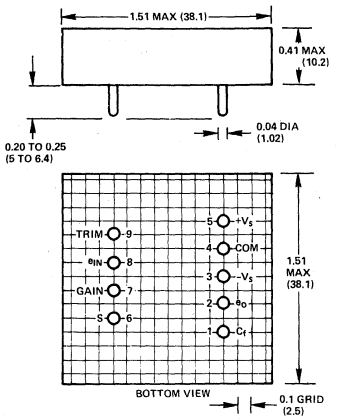
# SPECIFICATIONS** (typical @ +25°C and $V_S$ = ±15V dc, unless otherwise noted)

| MODEL | 442J | 442K | 442L |
|---|---|---|---|
| TRANSFER EQUATION | $e_o = \sqrt{avg\ (e_{in})^2}$ | * | * |
| ACCURACY[1] | | | |
| Total Error, Sinewave Input, f ≤ 20kHz | | | |
| No External Adjustment | | | |
| Input Range: 0 to 2$V_{rms}$ | ±2mV ±0.15% of Rdg., max | * | * |
| External Adjustment | | | |
| Input Range: 0 to 2$V_{rms}$ | ±1mV ±0.05% of Rdg., max | * | * |
| 10m$V_{rms}$ to 2$V_{rms}$ | ±0.5mV ±0.05% of Rdg., max | * | * |
| Additional Error, Sinewave Input, 20kHz ≤ f ≤ 500kHz | | | |
| With or Without External Adjustment | | | |
| For Any Input Range | $(\pm 25\mu V \pm 0.0025\%\ of\ Rdg) \times \left(\frac{f(kHz) - 20kHz}{1kHz}\right)$, max | * | * |
| vs. Temperature (0 to +70°C), max | ±100μV/°C plus ±0.01% of Rdg./°C | ±50μV/°C plus ±0.01% of Rdg./°C | ±35μV/°C plus ±0.01% of Rdg./°C |
| vs. Supply Voltage | ±0.1mV/% | * | * |
| Warm-Up Time | 5 minutes | * | * |
| FREQUENCY RESPONSE, SINEWAVE INPUT | | | |
| ±1% Reading Error | | | |
| Input: 7$V_{rms}$ | 500kHz | * | * |
| 2$V_{rms}$ | 700kHz | * | * |
| 1$V_{rms}$ | 800kHz | * | * |
| 0.2$V_{rms}$ | 120kHz | * | * |
| 0.1$V_{rms}$ | 80kHz | * | * |
| 0.01$V_{rms}$ | 25kHz | * | * |
| -3dB Reading Error | | | |
| Input: 7$V_{rms}$ | 5MHz | * | * |
| 2$V_{rms}$ | 8MHz | * | * |
| 1$V_{rms}$ | 7MHz | * | * |
| 0.2$V_{rms}$ | 3MHz | * | * |
| 0.1$V_{rms}$ | 2MHz | * | * |
| 0.01$V_{rms}$ | 300kHz | * | * |
| Internal Filter Time Constant | 1.5ms | * | * |
| External Filter Time Constant[2] | 15ms/μF | * | * |
| Total Averaging Time Constant[2] | 1.5ms + 15ms/μF | * | * |
| CREST FACTOR | | | |
| ±0.2% Additional Reading Error | 7 | * | * |
| ±0.5% Additional Reading Error | 10 | * | * |
| INPUT SPECIFICATIONS | | | |
| Voltage | | | |
| Signal Range | ±10$V_{peak}$ min | * | * |
| Safe Input | ±$V_S$ | * | * |
| Impedance | 2.5kΩ ±10% | * | * |
| OUTPUT SPECIFICATIONS[3] | | | |
| Rated Output | | | |
| Voltage | +10.0V min | * | * |
| Current | +5mA min | * | * |
| Impedance | 0.1Ω | * | * |
| Offset Voltage, @ +25°C | ±2mV max | * | * |
| With External 20kΩ Trim Pot | Adjustable to Zero | * | * |
| POWER SUPPLY[4] | | | |
| Voltage, Rated Specifications | ±15V dc | * | * |
| Voltage, Operating | ±(6 to 18)V dc | * | * |
| Current, Quiescent | ±12mA | * | * |
| TEMPERATURE RANGE | | | |
| Rated Performance | 0 to +70°C | * | * |
| Operating | -25°C to +85°C | * | * |
| Storage | -55°C to +125°C | * | * |
| CASE SIZE | 1.5" x 1.5" x 0.4" | * | * |

NOTES
*Specifications same as model 442J.
**Contact sales office for complete 4 page data sheet.
[1] Error is specified as the sum of two components: a fixed term plus a percentage of output signal (reading). Refer to TOTAL ACCURACY.
[2] Connect optional filter capacitor between pin 1 and pin 2 (see Figure 2). Pin 1 is protected for shorts to ground and the positive supply voltage. Pin 1 is not protected for negative voltage greater than 1 volt.
[3] Protected for short circuit to ground and/or either supply voltage.
[4] Recommended power supply: Analog Devices' model 904.
Specifications subject to change without notice.

## OUTLINE DIMENSIONS

Dimensions shown in inches and (mm).




Weight: 40 grams

## MATING SOCKET AC1016

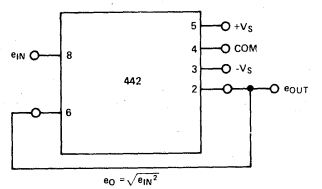



*Figure 1. Wiring Connections for rms Measurements (No External Trim)*

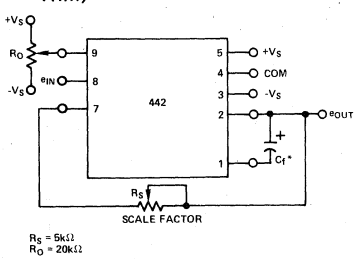



*Figure 2. Optional External Adjustment for rms Measurements*

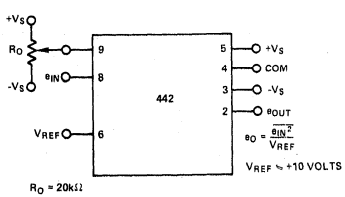


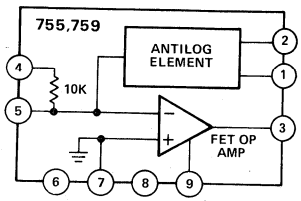

*Figure 3. Wiring Connections for Mean Square Measurements with Adjustable Scale Factor ($V_{REF}$)*

# Log-Antilog Amplifiers

## Contents


| | Page |
|---|---|
| Selection Guide | 8–2 |
| General Information | 8–3 |
| Definitions of Specifications | 8–5 |
| 755N/P High dc Performance Log-Antilog Amplifier Module | 8–7 |
| 757N/P Log-Ratio Amplifier Module | 8–11 |
| 759N/P Low-Cost, Widest-Bandwidth Log-Antilog Amplifier Module | 8–7 |

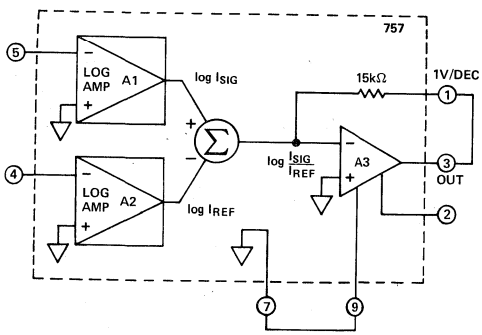
# Selection Guide
## Log-Antilog Amplifiers




### MODEL 755, MODEL 759

Page

- High Accuracy: Models 755N, 755P — Vol. II 8–7
- Low Cost: Models 759N, 759P
- Complete Log-Antilog Amplifiers: External Components not Required
- Temperature-Compensated Internal Reference
- 6 Decades Current Operation: 1nA to 1mA
- 1% max Error: 1nA to 1mA (755)
  20nA to 200μA (759)
- 4 Decades Current Operation: 1mV to 10V
- 1% max Error: 1mV to 10V (755)
  1mV to 2V (759)




### MODEL 757

- 6 Decade Operation – 1nA to 1mA — Vol. II 8–11
- 1/2% Log Conformity – 10nA to 100μA
- Symmetrical FET Inputs
- Voltage or Current Operation
- Temperature Compensated
- Complete Log Ratio Amplifier: External Components not Required

# Orientation
## Log-Antilog Amplifiers

The devices catalogued in this section are complete, self-contained modules that provide output voltage proportional to the logarithm or the antilogarithm (exponential) of an input quantity. These modules operate on the instantaneous values of inputs from dc to an upper cutoff frequency below 1MHz.

LOGS AND LOG RATIOS

In the *logarithmic* mode, the ideal output equation is

$$E_o = -K \log_{10} \left(\frac{I_{in}}{I_{ref}}\right)$$

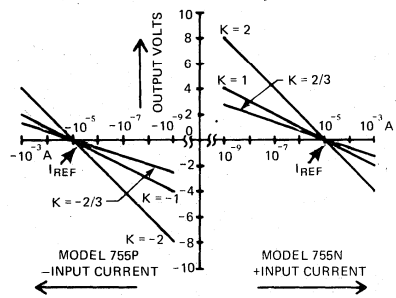
$E_o$ can be positive or negative; it is zero when the ratio is unity, i.e., $I_{in} = I_{ref}$. K is the output scale constant; it is equal to the number of output volts corresponding to a decade* change of the ratio. In the 755 and 759 log amplifiers, K is pin-programmable to be either 1V, 2V, or 2/3V, or externally adjustable to any value $\geq$ 2/3V; in the model 757 log-ratio amplifier, K may be either a preset value of 1V, or an arbitrary value adjustable by an external resistance ratio.

$I_{in}$ is a unipolar input current within a 6-decade range (1nA to 1mA); it may be applied directly, as a current, or derived from an input voltage via an input resistor (in which case, the ratio becomes $E_{in}/(R_{in}I_{ref}) = E_{in}/E_{ref}$. In models 755 and 759, the magnitude of $I_{ref}$ is internally fixed at 10μA ($E_{ref}$ = 0.1V) or externally adjusted; but model 757 is a *log-ratio* amplifier, in which both $I_{in}$ and $I_{ref}$ (or $E_{in}$ and $E_{ref}$, using external scaling resistors) are input variables.

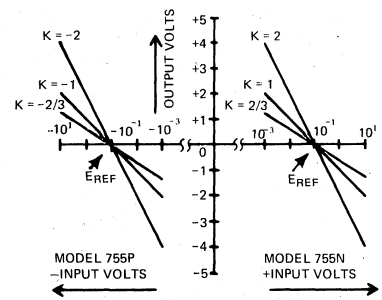
Each of the log amplifiers is available as a "P" or "N" option, depending on the polarity of the input voltage. Logarithms may be computed only for positive arguments, therefore the reference current must be of appropriate polarity to make the ratio positive. "N" indicates that the input current (or voltage) for the log mode is *positive;* "P" indicates that only *negative* voltage or current may be applied in the log mode. The polarity of K also differs: K is positive for "N" versions and negative for "P" versions. Thus, +10V applied to model 759N, with K = +1V, would produce an output voltage, $E_o = -1V \log (100) = -2V$; on the other hand, -10V applied to model 759P, with K = 1V, would produce an output voltage, $E_o = -(-1V) \log (100) = +2V$. The figure shows, in condensed form, the outputs of P and N log-amps, with differing K values, for voltage and current inputs.

Log amplifiers in the log mode are useful for applications requiring *compression* of wide-range analog input data, *linearization* of transducers having exponential outputs, and *analog computing*, ranging from simple translation of natural relationships in log form (e.g., computing absorbance as the log-ratio of input currents), to the use of logarithms in facilitating analog computation of terms involving arbitrary exponents and multi-term products and ratios.

*A *decade* is a 10:1 ratio, two decades is 100:1, etc. For example, if K = 2, and the ratio is 10, the magnitude of the output would be 2V, and its polarity would depend on whether the ratio were greater or less than unity. If the input signal then changed by a factor of 1000 (3 decades), the output would change by 6V.




*Log of Current*




*Log of Voltage*

*Output vs. Input of Model 755N & 755P in Log Connection (Log Input Scales), Showing Voltages, and Polarity Relationships*

ANTILOGS

In the *antilogarithmic* (exponential) mode, the ideal output equation is

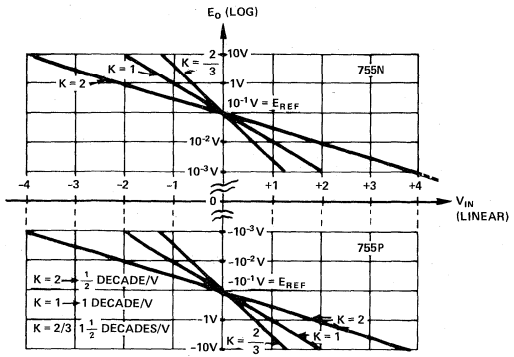
$$E_o = E_{ref} \exp_{10} (-E_{in}/K)$$

$E_{in}$ can be positive or negative; when it is zero, $E_o = E_{ref}$. However, $E_o$ is always of single polarity, positive for "N" versions, negative for "P" versions. Thus, for 759P, connected for K = -2V, if $E_{in}$ = +4V, and $E_{ref}$ = -0.1V, then

$E_o = -0.1V \cdot 10^{-4/-2}$, or -10V; if $E_{in} = -4V$, then

$E_o = -0.1V \cdot 10^{-(-4)/-2} = -1mV$. The figure on the next page shows, in condensed form, the outputs of P and N log amps, connected for antilogarithmic operation, with different K values.

Antilog amplifiers are useful for applications requiring *expansion* of compressed data, *linearization* of transducers having logarithmic outputs, *analog function fitting* or function generation, to obtain relationships or generate curves having voltage-programmable rates of growth or decay, and in *analog computing*, for such functions as compound multiplication and division of terms having differing exponents.



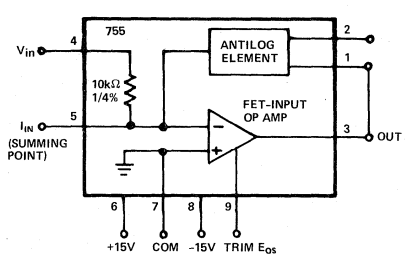

*Antilog Operator Response Curves, Semilog Scale*
$E_O = E_{REF}\ 10^{V_{IN}/-K}$

LOG-ANTILOG AMPLIFIER PERFORMANCE

Considerable information regarding log- and antilog-amplifier circuit design, performance, selection, and applications is to be found in the NONLINEAR CIRCUITS HANDBOOK[1]. Several salient points will be covered here, and specifications will be defined.

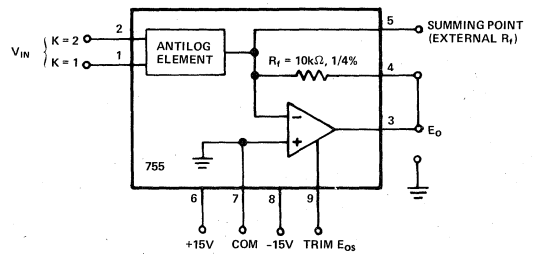
A log/antilog amplifier consists of an operational amplifier and an element with antilogarithmic transconductance (i.e., the voltage into the element produces a current that is an exponential function of the voltage). As the figure shows, for logarithmic operations, the input current is applied at the op-amp summing point, and the feedback circuit causes the amplifier output to produce whatever voltage is required to provide a feedback current that will exactly balance the input current.

In antilog operation, the input voltage is applied directly to the input of the antilog element, producing an exponential input current to the op-amp circuit. The feedback resistance transduces it to an output voltage.




*a) Log/Antilog Amplifier Connected in the Log Mode (K = 1)*

[1] *Nonlinear Circuits Handbook*, Analog Devices, Inc., 1974, 1976, 536pp, edited by D. H. Sheingold, $5.95; send check or complete MasterCard data to P.O. Box 796, Norwood MA 02062




*b) Log/Antilog Amplifier Connected in the Exponential Mode*

The wide range of log/exponential behavior is made possible by the exponential current-voltage relationship of transistor base-emitter junctions,

$$I = I_o(e^{qV/kT} - 1) \cong I_o e^{qV/kT}$$

and $V = (kT/q) \ln (I/I_o)$

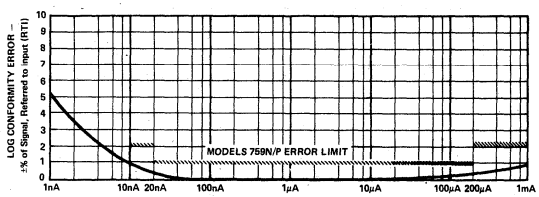
where I is the collector current, $I_o$ is the extrapolated current for V = 0, V is the base-emitter voltage, q/k (11605° K/V) is the ratio of charge of an electron to Boltzmann's constant, and T is junction temperature kelvin. In log/antilog devices, two matched transistors are connected so as to subtract the junction voltages associated with the input and reference currents, making the ratio independent of $I_o$'s variation with temperature.

$$\begin{aligned}\Delta V &= (kT/q) \ln (I_{in}/I_o) - (kT/q) \ln (I_{ref}/I_o)\\ &= (kT/q) (\ln I_{in} - \ln I_{ref}) + (kT/q) (\ln I_o - \ln I_o)\\ &= (kT/q) \ln (I_{in}/I_{ref})\end{aligned}$$

The temperature-dependence of gain is compensated for by a resistive attenuator that uses a temperature-sensitive resistor for compensation. The attenuator also produces amplification of K to the specified nominal values, e.g., from the basic 59mV/decade (kT/q) ln10 at room temperature) to 1V/decade.

Errors are introduced by the offset current of the amplifier, and the offset voltage, for voltage inputs; by inaccuracy of the reference current (or the effective reference voltage, for voltage inputs) in fixed-reference devices; and by inaccuracy of setting K. Additional errors are introduced by drift of these parameters with temperature. At any temperature, if these parameters are nulled out, there remains a final irreducible difference between the actual output and the theoretical output, called *log-conformity error*, which is manifested as a "nonlinearity" of the input-output plot on semilog paper. Best log conformity is realized away from the extremities of the rated signal range. For example, log-conformity error of model 755 is ±1% maximum, referred to the input, over the entire 6-decade range from 1nA to 1mA; but it is only ±0.5% maximum over the 4-decade range from 10nA to 100μA. A plot of log conformity error for model 759 is shown here.

Errors occurring at the input, and log-conformity errors, can only be observed at the output, but it is useful to refer them to the input (RTI). Equal percentage errors at the input, at what-




*Log Conformity Error for Models 759N and 759P*

ever input level, produce equal incremental errors at the output, for a given value of K. For example, if K = 1, and the RTI log-conformity error is +1%, the magnitude of the output error will be

Error = Actual output – ideal output
= $1V \cdot \log(1.01\ I/I_{ref}) - 1V \cdot \log(I/I_{ref})$
= $1V \cdot \log 1.01 = 0.0043V = 4.3mV$

If, in this example, the input range happens to be 5 decades, the corresponding output range will be 5 volts, and the 4.3mV log-conformity error, as a percentage of total *output* range, will be less than 0.1%. Because this ambiguity can prove confusing to the user, it is important that a manufacturer specify whether the error is referred to the input or the output. The table below indicates the conversion between RTI percentage and output error-magnitudes, for various percent errors, and various values of K.

LOG OUTPUT ERROR (mV)

| % ERROR RTI | K = 1V | K = 2V | K = (2/3)V |
|---|---|---|---|
| 0.1 | 0.43 | 0.86 | 0.28 |
| 0.5 | 2.2 | 4.3 | 1.4 |
| 1.0 | 4.3 | 8.6 | 2.9 |
| 2.0 | 8.6 | 17. | 5.7 |
| 3.0 | 13. | 26. | 8.6 |
| 4.0 | 17. | 34. | 11. |
| 5.0 | 21. | 42. | 14. |
| 10.0 | 41. | 83. | 28. |

For antilog operations, input and output errors are interchanged.

To arrive at the total error, an error budget should be made up, taking into account each of the error sources, and its contribution to the total error, over the temperature range of interest.

Dynamic response of log amps is a function of the input level. Small-signal bandwidths of ac input signals biased at currents above 1μA tend to be roughly comparable. However, below 1μA, bandwidth tends to be in rough proportion to current level. Similarly, rise time depends on step magnitude and direction – step changes in the direction of increasing current are responded to more quickly than step decreases of current.

## DEFINITIONS OF SPECIFICATIONS

*Log-Conformity Error* When the parameters have been adjusted to compensate for offset, scale-factor, and reference errors, the *log-conformity error* is the deviation of the resulting function from a straight line on a semilog plot over the range of interest.

*Offset Current* ($I_{os}$) is the bias current of the amplifier, plus any stray leakage currents. This parameter can be a significant source of error when processing signals in the nanoampere region. Its contribution in antilog operation is negligible.

*Offset Voltage* ($E_{os}$) depends on the operational amplifier used for the log operation. Its effect is that of a small voltage in series with the input resistor. For current-logging operations, with high-impedance sources, its error contribution is negligible. However, for voltage logging, it modifies the value of $V_{in}$. Though it can be adjusted to zero at room temperature, its drift over the temperature range should be considered. In antilog operation, $E_{os}$ appears at the output as an essentially constant voltage; its percentage effect on error is greatest for small outputs.

*Reference Current* ($I_{ref}$) is the effective internally-generated current-source output to which all values of input current are compared. $I_{ref}$ tolerance appears as a dc offset at the output; it can be adjusted towards zero by adjusting the reference current, adding a voltage to the output by injecting a current into the scale-factor attenuator, or simply by adding a constant bias at the output's destination.

*Reference Voltage* ($E_{ref}$) is the effective internally generated voltage to which all input voltages are compared. It is related to $I_{ref}$ by the equation: $E_{ref} = I_{ref}R_{in}$, where $R_{in}$ is the value of input resistance. Typically, $I_{ref}$ is less stable than $R_{in}$; therefore, practically all the tolerance is due to $I_{ref}$.

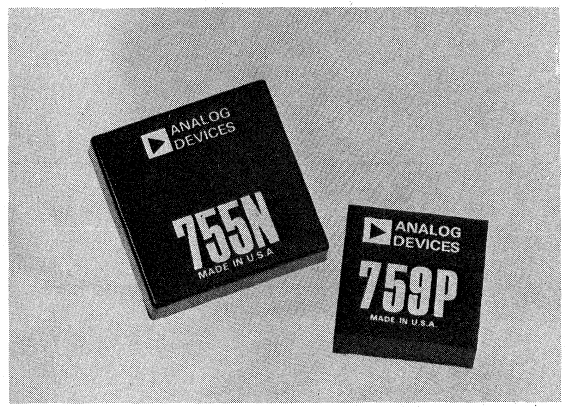
*Scale Factor* (K) is the voltage change at the output for a decade (i.e., 10:1) change at the input, when connected in the log mode. Error in scale factor is equivalent to a change in gain, or slope (on a semilog plot), and is specified in percent of the nominal value.

# 6-Decade, High Accuracy and Wideband Log, Antilog Amplifiers

# MODELS 755N, 755P, 759N, 759P

**FEATURES**

**High Accuracy: Models 755N, 755P**
**Wideband: Models 759N, 759P**
**Complete Log/Antilog Amplifiers: External Components Not Required**
**Temperature-Compensated Internal Reference**
**6 Decades Current Operation: 1nA to 1mA**
**1% max Error: 1nA to 1mA (755)**
**20nA to 200μA (759)**
**4 Decades Voltage Operation: 1mV to 10V**
**1% max Error: 1mV to 10V (755)**
**1mV to 2V (759)**
**Small Size: 1.1" X 1.1" X 0.4"**




8

## GENERAL DESCRIPTION

The models 755N, 755P and 759N, 759P are low cost dc logarithmic amplifiers offering conformance to ideal log operation over 6 decades of current (1nA to 1mA) and 4 decades of voltage (1mV to 10V). For high accuracy requirements, models 755N, 755P offer maximum nonconformity of 0.5%, from 10nA to 1mA, and 1mV to 1V. For wideband applications, the models 759N, 759P provide fast response (300kHz @ $I_{SIG}$ = 10μA to 1mA) and feature maximum nonconformity of 1% from 20nA to 200μA, and 1mV to 2V. The models 755N and 759N compute the log of positive (+) input signals, while the models 755P, 759P compute the log of negative (–) signals.

Designed for ease of use, the models 755N/P and 759N/P are complete, temperature compensated log/antilog amplifiers packaged in a compact epoxy-encapsulated module. External components are not required for logging currents over the complete 6 decade range of 1μA to 1mA. Both the scale factor (K=2, 1, or 2/3 volt/decade) and log/antilog operation are selected by simple pin connection. In addition, both the internal 10μA reference current as well as the offset voltage may be externally adjusted to improve overall accuracy.

The models 755 and 759 are ideally suited as an alternative to in-house designs of OEM applications. Advanced design techniques and superior performance place the 755 and 759 ahead of competitive designs in terms of price, performance and package design.

## APPLICATIONS

When connected in the current or voltage logging configuration, as shown in Figure 1, the models 755 and 759 may be used in several key applications. A plot of input current versus output voltage is also presented to illustrate the log amplifier's transfer characteristics.

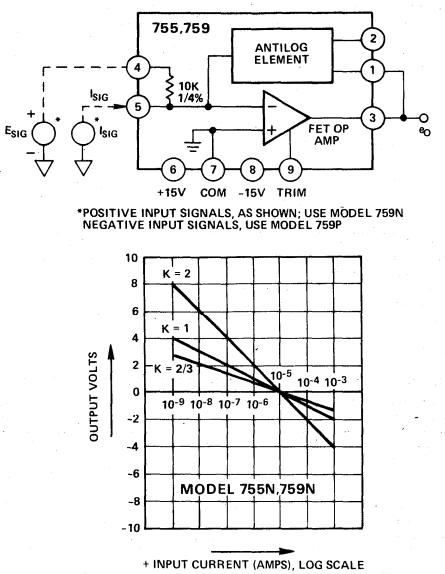



*Figure 1. Functional Block Diagram and Transfer Function*

# SPECIFICATIONS (typical @ +25°C and ±15V dc unless otherwise noted)

| MODEL | 755N/P | 759N/P |
|---|---|---|
| TRANSFER FUNCTIONS | | |
| Current Mode | $e_O = -K\log_{10}\frac{I_{SIG}}{I_{REF}}$ | * |
| Voltage Mode | $e_O = -K\log_{10}\frac{E_{SIG}}{E_{REF}}$ | * |
| Antilog Mode | $e_O = E_{REF}\,10^{-\left(\frac{E_{SIG}}{K}\right)}$ | * |
| TRANSFER FUNCTION PARAMETERS | | |
| Scale Factor (K) Selections[1, 2] | 2, 1, 2/3 Volt/Decade | * |
| Error @ +25°C | ±1% max | * |
| vs. Temperature (0 to +70°C) | ±0.04%/°C max | * |
| Reference Voltage ($E_{REF}$)[2] | 0.1V | * |
| Error @ +25°C | ±3% max | ±4% max |
| vs. Temperature (0 to +70°C) | ±0.1%/°C max | ±0.05%/°C |
| Reference Current ($I_{REF}$)[2] | 10μA | * |
| Error @ +25°C | ±3% max | * |
| vs. Temperature (0 to +70°C) | ±0.1%/°C max | ±0.05%/°C |

| MAXIMUM LOG CONFORMITY ERROR | | | | | |
|---|---|---|---|---|---|
| $I_{SIG}$ RANGE | $E_{SIG}$ RANGE | RTI | RTO (K=1) | RTI | RTO (K=1) |
| 1nA to 10nA | – | ±1% | ±4.3mV | ±5% | ±21mV |
| 10nA to 20nA | – | ±0.5% | ±2.17mV | ±2% | ±8.64mV |
| 20nA to 100μA | 1mV to 1V | ±0.5% | ±2.17mV | ±1% | ±4.3mV |
| 100μA to 200μA | 1V to 2V | ±1% | ±4.3mV | ±1% | ±4.3mV |
| 200μA to 1mA | 2V to 10V | ±1% | ±4.3mV | ±2% | ±8.64mV |

| INPUT SPECIFICATIONS | | |
|---|---|---|
| Current Signal Range | | |
| Model 755N, 759N | +1nA to +1mA min | * |
| Model 755P, 759P | −1nA to −1mA min | * |
| Max Safe Input Current | ±10mA max | * |
| Bias Current @ +25°C | (0, +) 10pA max | (0, +) 200pA max |
| vs. Temperature (0 to +70°C) | x2/+10°C | * |
| Voltage Signal Range (Log Mode) | | |
| Model 755N, 759N | +1mV to +10V min | * |
| Model 755P, 759P | −1mV to −10V min | * |
| Voltage Signal Range, Antilog Mode Model 755N, 755P | $-2 \leq \frac{E_{SIG}}{K} \leq 2$ | * |
| Offset Voltage @ +25°C (Adjustable to 0) | ±400μV max | ±2mV max |
| vs. Temperature (0 to +70°C) | ±15μV/°C max | ±10μV/°C |
| vs. Supply Voltage | ±15μV/% | * |

| FREQUENCY RESPONSE, Sinewave | | |
|---|---|---|
| Small Signal Bandwidth, −3dB | | |
| $I_{SIG}$ = 1nA | 80Hz | 250Hz |
| $I_{SIG}$ = 1μA | 10kHz | 100kHz |
| $I_{SIG}$ = 10μA | 40kHz | 200kHz |
| $I_{SIG}$ = 1mA | 100kHz | 200kHz |

| RISE TIME | | |
|---|---|---|
| Increasing Input Current | | |
| 10nA to 100nA | 100μs | 20μs |
| 100nA to 1μA | 7μs | 3μs |
| 1μA to 1mA | 4μs | 2.5μs |
| Decreasing Input Current | | |
| 1mA to 1μA | 7μs | 3μs |
| 1μA to 100nA | 30μs | 10μs |
| 100nA to 10nA | 400μs | 80μs |

| INPUT NOISE | | |
|---|---|---|
| Voltage, 10Hz to 10kHz | 2μV rms | 10μV rms |
| Current, 10Hz to 10kHz | 2pA rms | 10pA rms |

| OUTPUT SPECIFICATIONS[3] | | |
|---|---|---|
| Rated Output | | |
| Voltage | ±10V min | * |
| Current | | |
| Log Mode | ±5mA | * |
| Antilog Mode | ±4mA | * |
| Resistance | 0.5Ω | * |

| POWER SUPPLY[4] | | |
|---|---|---|
| Rated Performance | ±15Vdc | * |
| Operating | ±(12 to 18)Vdc | * |
| Current, Quiescent | ±7mA | ±4mA |

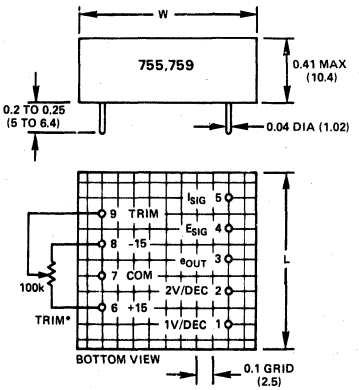
| TEMPERATURE RANGE | | |
|---|---|---|
| Rated Performance | 0 to +70°C | * |
| Operating | −25°C to +85°C | * |
| Storage | −55°C to +125°C | * |

| CASE SIZE[5] (W x L x H) | 1.5″ x 1.5″ x 0.4″ (38 x 38 x 10.4) | 1.125″ x 1.125″ x 0.4″ (29 x 29 x 10.4) |
|---|---|---|

NOTES
*Specifications same as 755N/P.
[1] Use terminal 1 for K = 1V/decade; terminal 2 for K = 2V/decade; terminals 1 or 2 (shorted together) for K = 2/3V/decade.
[2] Specification is + for models 755N, 759N; − for 755P, 759P.
[3] No damage due to any pin being shorted to ground.
[4] Recommended power supply, model 904, ±15V @ ±50mA output.
[5] Case size in inches (mm).
Specifications subject to change without notice.

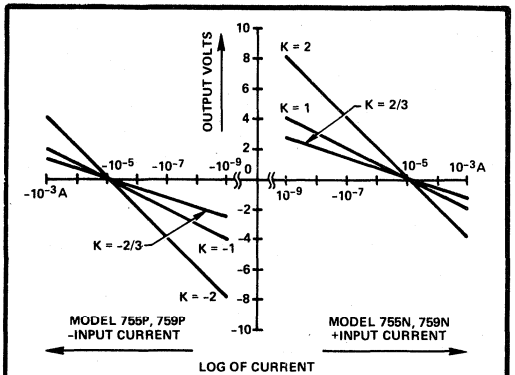
## OUTLINE DIMENSIONS

Dimensions shown in inches and (mm).

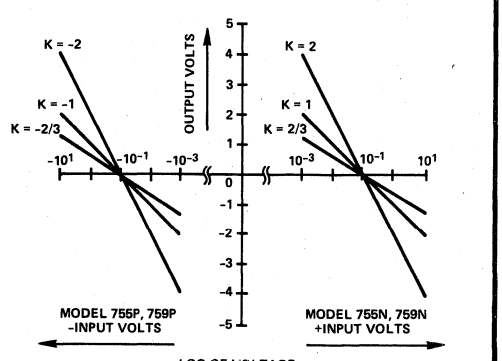



*Optional 100kΩ external trim pot. Input offset voltage may be adjusted to zero with trim pot connected as shown. With trim terminal 9 left open, input offset voltage will be ±0.4mV (755) or ±2mV (759) maximum.

## MATING SOCKET AC1016




*Plot of Output Voltage vs Input Current for Model 755 Connected in the Log Mode*




*Plot of Output Voltage vs Input Voltage for Models 755, 759 Connected in the Log Mode*

*Figure 2. Transfer Curves*

## PRINCIPLE OF OPERATION

Log operation is obtained by placing the antilog element in the feedback loop of the op amp as shown in Figure 1. At the summing junction, terminal 5, the input signal current to be processed is summed with the output current of the antilog element. To attain a balance of these two currents, the op amp provides the required output voltage to the antilog feedback element. Under these conditions the ideal transfer equation (K = 1) is:

$$e_{OUT} = 1V \log_{10} I_{SIG}/I_{REF}$$

The log is a mathematical operator which is defined only for numbers, which are dimensionless quantities. Since an input current would have the dimensions of amperes it must be referenced to another current, $I_{REF}$, the ratio being dimensionless. For this purpose a temperature compensated reference of 10μA is generated internally.

The scale factor, K, is a multiplying constant. For a change in input current of one decade (decade = ratio of 10:1), the output changes by K volts. K may be selected as 1V or 2V by connecting the output to pin 1 or 2, respectively. If the output is connected to both pins 1 and 2, K will be 2/3V.

## REFERRING ERRORS TO INPUT

A unique property of log amplifiers is that a dc error of any given amount at the output corresponds to a constant percent of the input, regardless of input level. To illustrate this, consider the output effects due to changing the input by 1%.

The output would be:

$$e_{OUT} = 1V \log_{10} (I_{SIG}/I_{REF})(1.01) \text{ which is equivalent to:}$$

$$e_{OUT} = \underbrace{1V \log_{10} (I_{SIG}/I_{REF})}_{\text{Initial Value}} \quad \underbrace{\pm 1V \log_{10} (1.01)}_{\text{Change}}$$

The change in output, due to a 1% input change is a constant value of ±4.3mV. Conversely, a dc error at the output of ±4.3mV is equivalent to a change at the input of 1%. An abbreviated table is presented below for converting between errors referred to output (R.T.O.), and errors referred to input (R.T.I.).

| | ERROR R.T.O. | | |
|---|---|---|---|
| ERROR R.T.I. | K = 1 | K = 2 | K = 2/3 |
| 0.1% | 0.43mV | 0.86mV | 0.28mV |
| 0.5 | 2.17 | 4.34 | 1.45 |
| 1.0 | 4.32 | 8.64 | 2.88 |
| 3.0 | 12.84 | 25.68 | 8.56 |
| 4.0 | 17.03 | 34.06 | 11.35 |
| 5.0 | 21.19 | 42.38 | 14.13 |
| 10.0 | 41.39 | 82.78 | 27.59 |

*Table I. Converting Output Error in mV to Input Error in %*

## SOURCES OF ERROR

**Log Conformity Error** – Log conformity in logarithmic devices is a specification similar to linearity in linear devices. Log conformity error is the difference between the value of the transfer equation and the actual value which occurs at the output of the log module, after scale factor, reference and offset errors are eliminated to taken into account. The best linearity performance for the models 755, 759 are obtained in the 5 decades from 10nA to 1mA. To obtain optimum performance, the input data should be scaled to this range.

**Offset Voltage** – The offset voltage, $E_{os}$, of models 755, 759 is the offset voltage of the internal FET amplifier. This voltage appears as a small dc offset voltage in series with the input terminals. For current logging applications, its error contribution is negligible. However, for log voltage applications, best performance is obtained by an offset trim adjustment.

**Bias Current** – The bias current of models 755, 759 is the bias current of the internal FET amplifier. This parameter can be a significant source of error when processing signals in the nanoamp region. For this reason, the bias current for model 755 is 10pA, maximum, and 200pA maximum for model 759.

**Reference Current** – $I_{REF}$ is the internally generated current source to which all input currents are compared. $I_{REF}$ tolerance errors appear as a dc offset at the output. The specified value of $I_{REF}$ is ±3% referred to the input, and, from Table I, corresponds to a dc offset of ±12.84mV for K = 1. This offset is independent of input signal and may be removed by injecting a current into terminal 1 or 2.

**Reference Voltage** – $E_{REF}$ is the effective internally generated voltage to which all input voltages are compared. It is related to $I_{REF}$ through the equation:
$E_{REF} = I_{REF} \times R_{IN}$, where $R_{IN}$ is an internal 10kΩ, precision resistor. Virtually all tolerance in $E_{REF}$ is due to $I_{REF}$. Consequently, variations in $I_{REF}$ cause a shift in $E_{REF}$.

**Scale Factor** – Scale factor is the voltage change at the output for a decade (i.e., 10:1) change at the input, when connected in the log mode. Error in scale factor is equivalent to a change in gain, or slope, and is specified in per cent of the nominal value. An external adjustment may be performed if fine trimming is desired for improved accuracy.

## OPTIONAL EXTERNAL ADJUSTMENTS FOR LOG OPERATION

**Trimming $E_{OS}$** – The amplifier's offset voltage, $E_{OS}$, may be trimmed for improved accuracy with the models 755, 759 connected in its log circuit. To accomplish this, a 100kΩ, 10 turn pot is connected as shown in Figure 3. The input terminal, Pin 4, is connected to ground. Under these conditions the output voltage is:

$$e_{OUT} = -K \log_{10} E_{OS}/E_{REF}$$

To obtain an offset voltage of 100μV or less, for K = 1, the trim pot should be adjusted until the output voltage is between +3 and +4 volts for models 755N, 759N, and -3V to -4V for models 755P, 759P.

For other values of K, the trim pot should be adjusted for an output of $e_{OUT}$ = 3 x K to 4 x K where K is the scale factor.

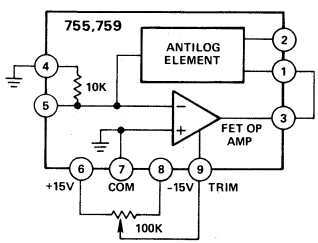



*Figure 3. Trimming $E_{OS}$ in Log Mode*

**Reference Current or Reference Voltage** – The reference current or voltage of models 755, 759 may be shifted by injecting a constant current into the unused scale factor terminal (Pin 1 or Pin 2). The current injected will shift the reference one decade, in accordance with the expression: $I_I = 66\mu A \log 10\mu A/I_{REF}$ (755), $I_I = 330\mu A \log 10\mu A/I_{REF}$ (759), where $I_I$ = current to be injected and $I_{REF}$ = the desired reference current.

By changing $I_{REF}$, there is a corresponding change in $E_{REF}$ since, $E_{REF} = I_{REF} \times R_{IN}$. An alternate method for rescaling $E_{REF}$ is to connect an external $R_{IN}$, at the $I_{IN}$ terminal (Pin 5) to supplant the 10kΩ supplied internally (leaving it unconnected). The expression for $E_{REF}$ is then, $E_{REF} = R_{IN} I_{REF}$. Care must be taken to choose $R_{IN}$ such that $(e_{SIG}\ max)/R_{IN} \leq 1mA$.

**Scale Factor (K) Adjustment** – Scale factor may be increased from its nominal value by inserting a series resistor $R_S$ between the output terminal, Pin 3, and either terminal 1 or 2. The table below should be consulted when making these scale factor changes.

| RANGE OF K | CONNECT SERIES R TO PIN | VALUE OF $R_S$ | NOTE |
|---|---|---|---|
| 2/3V to 1.01V | 1 | R x (K - 2/3) | use pins 1, 2 |
| 1.01V to 2.02V | 1 | R x (K - 1) | use pin 1 |
| >2.02V | 2 | R x (K - 2) | use pin 2 |

R = 15kΩ (755); 3kΩ (759)

*Table 2. Resistor Selection Chart for Shifting Scale Factor*

## ANTILOG OPERATION

The models 755 and 759 may be used to develop the antilog of the input voltage when connected as shown in Figure 4. The antilog transfer function (an exponential), is:

$$e_{OUT} = E_{REF}\ 10^{-e_{IN}/K} \qquad [-2 \leq e_{IN}/K \leq 2]$$

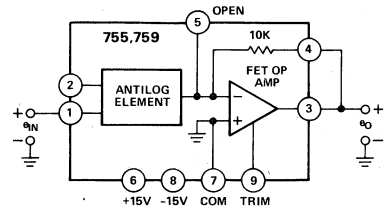



*Figure 4. Functional Block Diagram*

**Principle of Operation** – The antilog element converts the voltage input, appearing at terminal 1, to a current which is proportional to the antilog of the applied voltage. The current-to-voltage conversion is then completed by the feedback resistor in a closed-loop op amp circuit.

A more complete expression for the antilog function is:

$$e_{OUT} = E_{REF}\ 10^{-e_{IN}/K} + E_{OS}$$

The terms K, $E_{OS}$, and $E_{REF}$ are those described previously in the LOG section.

**Offset Voltage ($E_{OS}$) Adjustment** – Although offset voltage of the antilog circuit may be balanced by connecting it in the log mode, and using the technique described previously, it may be more advantageous to use the circuit of Figure 5. In this configuration, offset voltage is equal to $e_{OUT}/100$. Adjust for the desired null, using the 100k trim pot. After adjusting, turn power off, remove the external 100Ω resistor, and the jumper from Pin 1 to +15V. For 755P, 759P use the same procedure but connect Pin 1 to -15V.

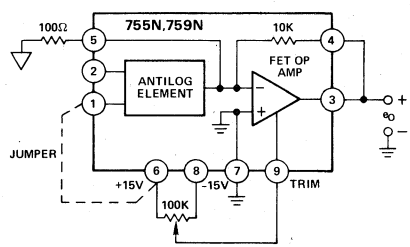



*Figure 5. Trimming $E_{OS}$ in Antilog Mode*

**Reference Voltage ($E_{REF}$) Adjustment** – In antilog operation, the voltage reference appears as a multiplying constant. $E_{REF}$ adjustment may be accomplished by connecting a resistor, R, from Pin 5 to Pin 3, in place of the internal 10kΩ. The value of R is determined by:

$$R = E_{REF}\ \text{desired}/10^{-5}\ A$$

**Scale Factor (K) Adjustment** – The scale factor may be adjusted for all values of K greater than 2/3V by the techniques described in the log section. If a value of K less than 2/3V is desired for a given application, an external op amp would be required as shown in Figure 6. The ratio of the two resistors is approximately:

$$R1/R_G = (1/K - 1) \text{ where K = desired scale factor}$$

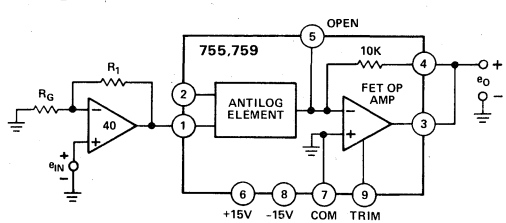



*Figure 6. Method for Adjusting K< 2/3V*

# ANALOG DEVICES

# 6-Decade, High Accuracy Log Ratio Amplifiers

# MODEL 757N, 757P

**FEATURES**
**6 Decade Operation – 1nA to 1mA**
**1/2% Log Conformity – 10nA to 100μA**
**Symmetrical FET Inputs**
**Voltage or Current Operation**
**Temperature Compensated**

**APPLICATIONS**
**Absorbence Measurements**
**Log Ratios of Voltages or Currents**
**Data Compression**
**Transducer Linearization**




8

## GENERAL DESCRIPTION

Model 757 is a complete, temperature compensated, dc-coupled log ratio amplifier. It is comprised of two input channels for processing signals spanning up to 6 decades in dynamic range (1nA to 1mA). By virtue of its symmetrical FET input stages, the 757 can accommodate this 6 decade signal range at either channel. Log conformity is maintained to within 1/2% over 4 decades of input (10nA to 100μA) and to within 1% over the full input range. Unlike other log ratio designs, model 757 does not restrict the relative magnitude of the two signal inputs to achieve rated performance. Either input can be operated within the specified range regardless of the signal level at the other channel.

The model 757 log-ratio amplifier design makes available both input amplifier summing junctions. As a result, it can directly interface with photo diodes operating in the short-circuit current mode without the need of additional input circuitry.

The excellent performance of model 757 can be further improved by means of external scale factor and output offset adjustments. A significant feature of model 757 not found on competing devices is that, when the offset adjustment is used to establish a fixed bias at the output, the output offset level does not vary as a function of input signal magnitude. On other designs, the sensitivity of output offset to input levels results in output effects resembling log conformity errors.

Model 757 can operate with either current or voltage inputs. Its excellent performance makes it ideally suited for log ratio applications such as blood analysis, chromatography, chemical analysis of liquids and absorbence measurements.

## CURRENT LOG RATIO

Current log ratio is accomplished by model 757 when two currents, $I_{SIG}$ and $I_{REF}$, are applied directly to the input terminals (see Figure 1). The two log amps process these signals providing

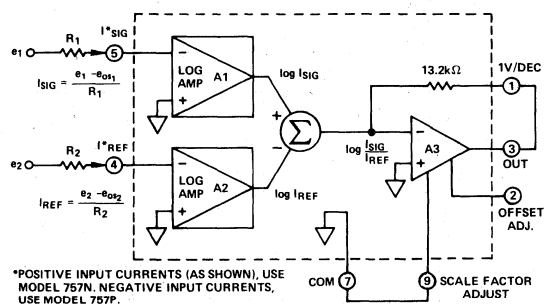



*Figure 1. Functional Block Diagram of Model 757*

voltages which are proportional to the log of their respective inputs. These voltages are then subtracted and applied to an output amplifier. The scale factor, when connected as shown, is 1V/dec. However, higher scale factors may be achieved by connecting external scale factor adjusting resistors. (See section on optional adjustments and trims.)

## VOLTAGE LOG RATIO

The principle of operation for voltage log ratio is identical to that of current log ratio after the voltage signal has been converted to a current. To accomplish this conversion, an external resistor is attached from the voltage signal to the appropriate input current terminal of the 757. Input currents are then determined by:

$$I_{SIG} = \frac{e_1 - e_{os_1}}{R_1}, \quad I_{REF} = \frac{e_2 - e_{os_2}}{R_2}$$

$e_{os_1}$ = Input Offset Voltage ($I_{SIG}$ Channel)

$e_{os_2}$ = Input Offset Voltage ($I_{REF}$ Channel)

# SPECIFICATIONS (typical @ +25°C and $V_S$ = ±15V dc unless otherwise noted)

| MODEL | 757N/P |
|---|---|
| TRANSFER FUNCTION [1] | |
| Current Mode | $e_o = -K \log_{10} \frac{I_{SIG}}{I_{REF}}$ |
| Voltage Mode | $e_o = -K \log_{10} \left[ \frac{(e_1 - e_{os_1})}{(e_2 - e_{os_2})} \times \frac{R_2}{R_1} \right]$ |
| ACCURACY | |
| Log Conformity [2] | |
| $I_{SIG}$, $I_{REF}$ = 10nA to 100μA | ±0.5%, max |
| $I_{SIG}$, $I_{REF}$ = 1nA to 1mA | ±1%, max |
| Scale Factor (1V/Dec) | (+0, -2%) max |
| vs. Temperature (0 to +70°C) | ±0.04%/°C max |
| INPUT SPECIFICATIONS – Both Input Channels | |
| Current | |
| Signal Range, Rated Performance | |
| Model 757N | +1nA to +1mA min |
| Model 757P | -1nA to -1mA min |
| Max Safe | ±10mA max |
| Bias Current, @ +25°C | (0, +) 10pA max |
| vs. Temperature (0 to +70°C) | x2/+10°C |
| Offset Voltage, @ +25°C | ±1mV max |
| vs. Temperature (0 to +70°C) | |
| $I_{SIG}$ Channel | ±25μV/°C max |
| $I_{REF}$ Channel | ±25μV/°C max |
| vs. Supply Voltage | ±5μV/% |
| FREQUENCY RESPONSE, Sinewave | |
| Small Signal Response (-3dB) | |
| Signal Channel | |
| $I_{SIG}$ = 1nA | 250Hz |
| $I_{SIG}$ = 1μA | 25kHz |
| $I_{SIG}$ = 100μA | 40kHz |
| Reference Channel | |
| $I_{REF}$ = 1nA | 100Hz |
| $I_{REF}$ = 1μA | 25kHz |
| $I_{REF}$ = 100μA | 40kHz |

| RISE TIME | Signal Channel ($I_{REF}$ = 10μA) | Reference Channel ($I_{SIG}$ = 10μA) |
|---|---|---|
| Increasing Input Current | | |
| 1nA to 10nA | 250μs | 80μs |
| 10nA to 100nA | 50μs | 40μs |
| 100nA to 1μA | 30μs | 30μs |
| 1μA to 100μA | 25μs | 25μs |
| Decreasing Input Current | | |
| 100μA to 1μA | 25μs | 25μs |
| 1μA to 100nA | 30μs | 30μs |
| 100nA to 10nA | 100μs | 40μs |
| 10nA to 1nA | 600μs | 70μs |

| | |
|---|---|
| INPUT NOISE | |
| Voltage (10Hz to 10kHz) | 3μV rms |
| Current (10Hz to 10kHz) | 0.1pA rms |
| OUTPUT SPECIFICATIONS | |
| Rated Output | |
| Voltage | ±10V min |
| Current | ±5mA min |
| Resistance | 0.1Ω |
| Offset Voltage [3] (K = 1V/Decade) | ±15mV max |
| vs. Temperature (0 to +70°C) | ±0.3mV/°C |
| vs. Supply | ±5μV/V |
| POWER SUPPLY [4] | |
| Rated Performance | ±15V dc |
| Operating | ±(12 to 18)V dc |
| Current, Quiescent | ±8mA |
| TEMPERATURE RANGE | |
| Rated Performance | 0 to +70°C |
| Operating | -25°C to +85°C |
| Storage | -55°C to +125°C |
| MECHANICAL | |
| Case Size | 1.5" x 1.5" x 0.4" |
| Weight | 21 grams |

NOTES

[1] For model 757N, K = +1V/Decade and input currents must be positive. For model 757P, K = -1V/Decade and input currents must be negative. (Input currents are defined as positive when flowing into the input terminals, 4 and 5. Refer to TRANSFER CURVES.)

[2] The log conformity error is referred to input (RTI). 1% error RTI is equivalent to 4.3mV of error at the output for K = 1V/Dec.

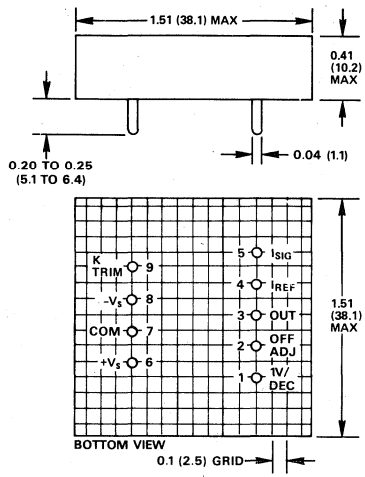
[3] Externally adjustable to zero.

[4] Recommended power supply: Analog Devices model 904, ±15V @ 50mA.

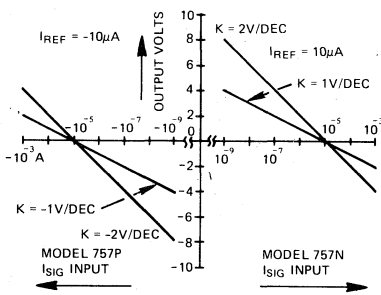
Specifications subject to change without notice.

## OUTLINE DIMENSIONS

Dimensions shown in inches and (mm).




## TRANSFER CURVES




**Log mode output voltage vs. input current for $I_{REF}$ = 10μA.**

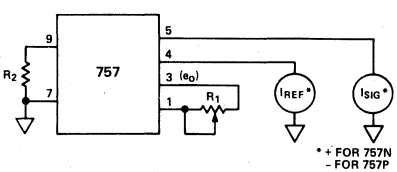



*Figure 2. Scale Factor Adjustment*

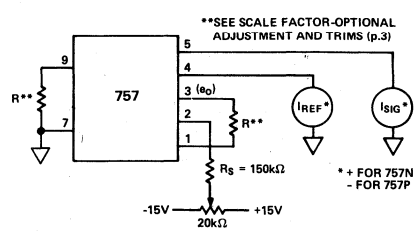



*Figure 3. Output Voltage Offset Adjustments*

## OPTIONAL ADJUSTMENTS AND TRIMS

**Scale Factor** – A one volt per decade scale factor is available when pin 1 is tied to 3 and pin 7 is connected to 9. Higher scale factors are possible by using a potentiometer, $R_1$, between pins 1 and 3 and a resistor, $R_2$, between pins 7 to 9 as shown in Figure 2. The value of the required resistor is (13.2kΩ) (K-1) where K is the desired scale factor. The approximate potentiometer value is also (13.2kΩ) (K-1). The scale factor adjustment procedure is as follows:

1. Connect the appropriate value of resistor between pins 7 and 9.
2. Set $I_{REF}$ = 1μA, $I_{SIG}$ = 10μA. Measure $e_O$.
3. Set $I_{REF}$ = 1μA, $I_{SIG}$ = 100μA. Adjust $R_1$ until the difference in $e_O$ corresponding to steps 2 and 3 is K volts.
4. Repeat steps 2 and 3 until the change in $e_O$ = K volts.

**Output Voltage Offset** – Output voltage offset must be adjusted after the desired scale factor is established as indicated above. To adjust the offset, inject equal dc input currents into the reference and signal channels. The value of the input currents should approximate the average input current levels expected to be encountered in normal operation. Adjust the potentiometer shown in Figure 3 until the output voltage is zero.

## LOG CONFORMITY

Log conformity in logarithmic devices is a specification similar to linearity in linear devices. Log conformity error is the difference between the theoretical value of the log of a ratio and the actual value that appears at the output of the log-ratio module after scale factor errors have been eliminated. Measurement of this error is made after initially zeroing the module at unity-ratio and adjusting the desired scale factor.

Figure 4 shows the log conformity performance of model 757 over a 6 decade input range. Log conformity for each channel does not vary noticeably as the current is varied in the other channel.

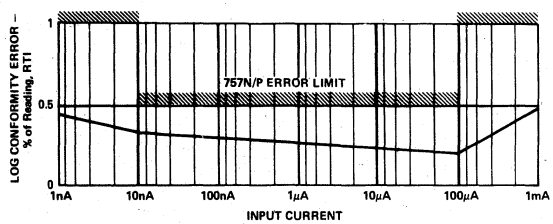



*Figure 4. Log Conformity Error for Model 757. Curve is for Either Input Channel with Current Held Constant at 10μA On Other Channel.*

## FREQUENCY CHARACTERISTICS

Figure 5 shows a plot of small signal response (-3dB) as a function of input signal current. The graph demonstrates the frequency response performance for each input channel over the range of 1nA to 1mA, independent of current on the other channel.

As shown in the graph, the reference channel is faster than the signal channel at low input levels. If an application requires higher speed in the input signal channel than in the reference channel, then the channels can be interchanged with a resulting polarity reversal of the output signal

$$\log \frac{I_{SIG}}{I_{REF}} = \log I_{SIG} - \log I_{REF} = -\log \frac{I_{REF}}{I_{SIG}} .$$

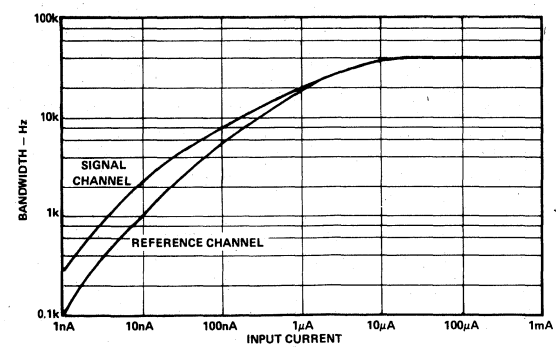



*Figure 5. Small Signal Bandwidth (-3dB) vs. Input Signal Level*

## APPLICATIONS

**Data Compression** – Processing signals with wide dynamic range is a common problem in instrumentation and data transmission. For example, digitizing an analog signal with a range of 10nA to 100μA with 1% accuracy requires a 20 bit A/D converter. (Required resolution = 1/100 x 1/10,000 = $1/10^6 \cong 1/2^{20}$).

By using the 757 with $I_{REF}$ adjusted to 10nA and K set for 5/4 V/decade, the input data can be compressed into a 5 volt output range. For a 1% resolution of any signal, the allowable output error is 4.32mV x K. Log conformity contributes 2.17mV x K (0.5%) over this range. The remaining error with K = 5/4 is 2.69mV and should correspond to less than the LSB of the converter. With a 5 volt output range 2.69mV corresponds just over the LSB of an 11-bit converter. Thus the 757 module can compress the data for use with a 12 bit A/D (such as Analog Devices AD574JD) to obtain the desired 1% resolution.

**Absorbence Measurements** – Critical properties of materials which are of particular interest in the fields of chemistry, medicine, spectrometry and pollution control are characterized by absorbence. The relationship between absorbence, A, and light intensity, I, is: $A = \log I_O/I_T$ where $I_O$ = intensity of incident light, and $I_T$ = intensity of transmitted light.

Figure 6 shows the 757 log-ratio module used in such a photometer application. Two inputs represent the intensities of light transmitted through space and through a medium that absorbs light. The absorbence of the medium is given by the formula

$$A = \log \frac{I_{SIGNAL}}{I_{REFERENCE}}$$

where $I_{SIGNAL}$ and $I_{REFERENCE}$ are the currents representing the light intensities.

The transducers used in this application are photodiodes, which provide a short-circuit current proportional to the intensity of applied light. The lowest value of absorbence is determined by the value of $I_{REF}$, since when $I_{SIG} = I_{REF}$, A = 0. The output of the log-ratio module is externally trimmed to 1V/decade and applied to the input of a 3½-digit DPM through the scaling network R1 and R2.

Model 757 was chosen for this design because it makes available both amplifier summing junctions. When the photodiodes are connected to the summing junctions, they are operated in the short-circuit mode, that is, with zero volts across the diodes. Short-circuit loading is necessary, because accuracy of the photodiodes can be degraded several percent when operated with as little as 100mV across the diode junction.

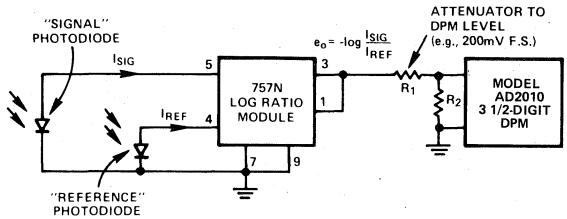



*Figure 6. Model 757N Applied to Absorbence Measurements*

## INTERCONNECTION GUIDELINES

Model 757 is a complete log ratio amplifier that requires no additional frequency compensation for proper operation.

**Input Capacitance** – Model 757 is able to operate with 1000pF at both input terminals. Therefore, the 757 can be used in applications requiring long cable lengths between the module and the signal transducers.

**Input-to-Output Capacitance** – When using a log ratio module the user should take care in system configurations to avoid excessive stray capacitance between input and output terminals. Such precautions include avoiding running input and output signal lines close together. If long cable runs are required where inputs and output are closely bundled together, it is advisable to enclose the inputs and/or output in separate, grounded electrostatic shields. By observing simple rules of good circuit layout, problems with oscillations that may result from excessive input-to-output capacitance can easily be avoided. Model 757 can accommodate up to 33pF of input-to-output capacitance without oscillation.

**Leakage Resistance** – Since model 757 can operate at extremely low input current levels, precautions must be taken to prevent current leakage into the input terminals. Such leakage can cause errors when small input or reference currents are used. This problem may arise on printed circuit layouts if the inputs are run too close to the power supply busses. Providing an etched guard around the input lines, connected to analog signal ground will also reduce unwanted current leakage.

# Temperature Transducers & Signal Conditioners

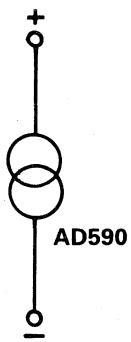
## Contents


| | Page |
|---|---|
| Selection Guides | |
| Temperature Transducers | 9–2 |
| Signal Conditioners | |
| Temperature Transducer Signal Conditioners | 9–3 |
| Voltage-to-Current Converters | 9–4 |
| Strain Gage/RTD Conditioners | 9–5 |
| Isolated Transducer Signal Conditioners | 9–6 |
| Two-Wire Transmitters | 9–7 |
| 3B Series I/O Subsystems | 9–9 |
| 4B Series Alarm Limit System | 9–10 |
| General Information | 9–11 |
| AC2626J/K/L Stainless-Steel Temperature Probe (AD590) | 9–13 |
| 2B20A/B Voltage (0 to +10V) to Current (4-to-20mA) Converter | 9–15 |
| 2B22J/K/L Isolated Voltage (0 to +1V to 0 to +10V) to Current (4-to-20mA) Converter | 9–19 |
| 2B23J/K Programmable Output Isolated Voltage-to-Current Converter | 9–23 |
| 2B24A/B Loop Powered Isolator | 9–27 |
| 2B30J/K/L Strain Gage/RTD Signal Conditioner | 9–29 |
| 2B31J/K/L Self-Powered Strain Gage/RTD Signal Conditioner | 9–29 |
| 2B34J Four-Channel RTD/Strain Gage Signal Conditioner | 9–35 |
| 2B35J/K Triple-Output Transducer/Conditioner Power Supply | 9–39 |
| 2B50A/B Isolated Thermocouple Signal Conditioner | 9–41 |
| 2B52A Isolated Thermocouple Temperature Transmitter | 9–45 |
| 2B53A Thermocouple Temperature Transmitter | 9–45 |
| 2B54A/B Four-Channel Isolated Low-Level Thermocouple/mV Conditioners/Multiplexers | 9–47 |
| 2B55A Four-Channel Isolated High- or Low-Level Signal Conditioner/Multiplexer | 9–47 |
| 2B56A Four-Function Thermocouple Cold-Junction Compensation | 9–53 |
| 2B57A 4-to-20mA Current Transmitter for AD590 Temperature Transducer | 9–57 |
| 2B58A Linearized RTD Temperature Transmitter | 9–61 |
| 2B59A Low-Cost RTD Temperature Transmitter | 9–63 |
| 3B Series Signal Conditioning I/O Subsystem | 9–65 |
| •4B Series Alarm Limit Subsystem | 9–69 |


•New product since publication of *1982–1983 Databook Update*

9

# Selection Guide
## Temperature Transducers




### AD590

Page

- Linear Current Output: 1μA/K
- Wide Range: −55°C to +150°C
- Probe Compatible Ceramic Sensor Package
- Two-Terminal Device: Voltage In/Current Out
- Laser Trimmed to ±0.5°C Calibration Accuracy (AD590M)
- Excellent Linearity: ±0.3°C Over Full Range (AD590M)
- Wide Power Supply Range: +4V to +30V
- Sensor Isolation from Case

Vol. I 8-15

### AD592

- High Precalibrated Accuracy: 0.5°C max @ 25°C
- Excellent Linearity: 0.2°C max (0 to +70°C)
- Wide Operating Temperature Range: −25°C to +105°C
- Single Supply Operation: +4V to +30V
- Excellent Repeatability and Stability
- High Level Output Signal: 1μA/°C
- Two Terminal Monolithic IC: Temperature In/Current Out
- Minimal Self-Heating Errors
- Low Cost Plastic Package

Vol. I 8-23

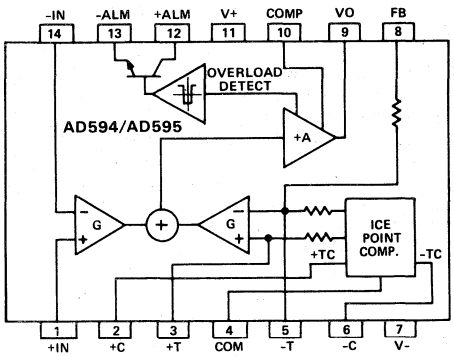
### AC2626

- Linear Current Output: 1μA/K
- Wide Range: −55°C to +150°C
- Laser Trimmed Sensor (AD590) to ±0.5°C Calibration Accuracy (AC2626M)
- Excellent Linearity: ±0.3°C Over Full Range (AC2626M)
- 6 Inch or 4 Inch Standard, Stainless Steel Sheath
- 3/16 Inch in Outside Diameter
- 3 Feet Teflon Coated Lead Wire
- Wide Power Supply Range +4V to +30V
- Fast Response: 2 Seconds (In Stirred Water)
- Sensor Isolated from Sheath

Vol. II 9-13

# Signal Conditioners

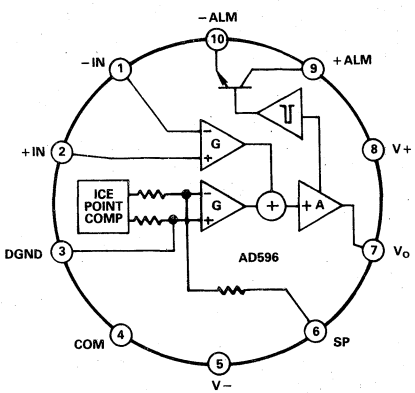
## Temperature Transducer Signal Conditioners




### AD594/AD595


| | Page |
|---|---|
| Pretrimmed for Type J (AD594) or Type K (AD595) Thermocouples | Vol. I 8-31 |


- Can Be Used with Type T Thermocouple Inputs
- Low Impedance Voltage Output: 10mV/°C
- Built-In Ice Point Compensation
- Wide Power Supply Range: +5V to ±15V
- Low Power: <1mW typical
- Thermocouple Failure Alarm
- Laser Wafer Trimmed to 1°C Calibration Accuracy
- Set-Point Mode Operation
- Self-Contained Celsius Thermometer Operation
- High Impedance Differential Input




### AD596

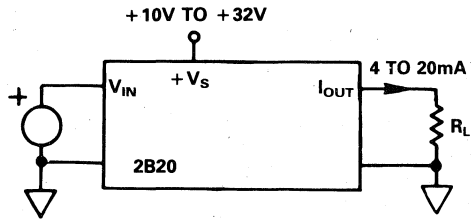

| | |
|---|---|
| Monolithic Temperature Set-Point Controller | Vol. I 8-39 |


- Built-In Ice Point Compensation for Type J Thermocouples
- Self-Contained Temperature Sensor for Stand-Alone Operation
- Programmable Dead Band
- Wide Power Supply Range +5V to ±15V
- 4°C Calibration Accuracy
- Low Power: ±1mW typ

9

# Selection Guide
## Signal Conditioners

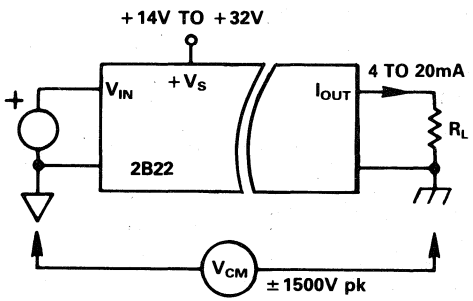
## Voltage-to-Current Converters




### 2B20

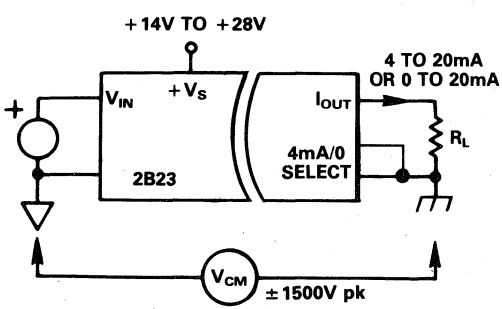
Page

- Complete, No External Components Needed — Vol. II 9-15
- Small Size: 1.1″ × 1.1″ × 0.4″ Module
- Input: 0 to +10V; Output: 4 to 20mA
- Low Drift: 0.005%/°C max; Nonlinearity: 0.005% max (2B20B)
- Wide Temperature Range: −25°C to +85°C
- Single Supply: +10V to +32V
- Meets ISA Std. 50.1 for Type 3, Class L and U, Nonisolated Current Loop Transmitters




### 2B22

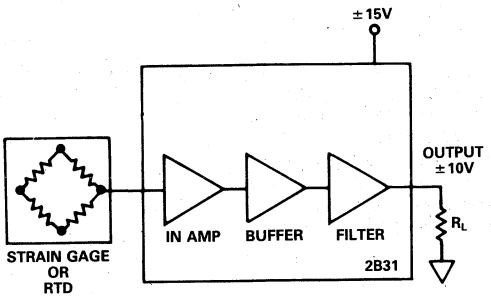
- Wide Input Range: 0 to +1V to 0 to +10V — Vol. II 9-19
- Standard Output Range: 4 to 20mA
- High CMV Input/Output Isolation: 1500V dc Continuous
- Low Nonlinearity: 0.05% max, 2B22L
- Low Span Drift: 0.005%/°C max, 2B22L
- Single Supply: +14V to +32V
- Meets IEEE Std. 472: Transient Protection (SWC)
- Meets ISA Std. 50.1: Isolated Current Loop Transmitters




### 2B23

- Wide Input Range, Resistor Programmable — Vol. II 9-23
- Pin Programmable Output: 4 to 20mA or 0 to 20mA
- High CMV Input/Output Isolation: ±1500V pk Continuous
- Low Nonlinearity: ±0.05% max (2B23K)
- Low Span Drift: ±0.005%/°C max (2B23K)
- Single Supply Operation: +14V to +28V
- Small Size: 1.8″ × 2.4″ × 0.6″
- Meets IEEE Std. 472: Transient Protection (SWC)
- Meets ISA ST. 50.1: Isolated Current Loop Transmitters

# Strain Gage/RTD Conditioners

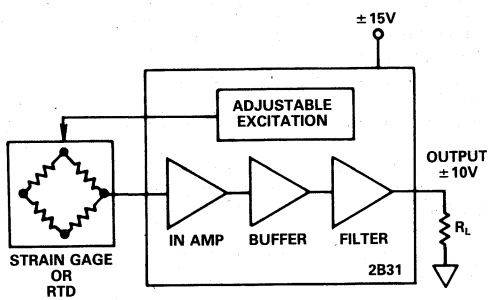



## 2B30

Page
Vol. II
9-29

**Complete Signal Conditioning Function**
**Low Drift: 0.5μV/°C max ("L"); Low Noise: 1μV p-p max**
**Wide Gain Range: 1 to 2000V/V**
**Low Nonlinearity: 0.0025% max ("L")**
**High CMR: 140dB min (60Hz, G = 1000V/V)**
**Input Protected to 130V rms**
**Adjustable Low Pass Filter: 60dB/Decade Roll-Off (from 2Hz)**

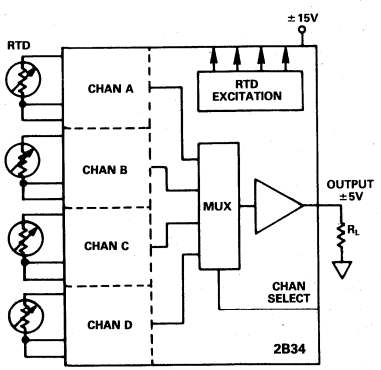





## 2B31

Vol. II
9-29

**Complete Signal Conditioning Function**
**Low Drift: 0.5μV/°C max ("L"); Low Noise: 1μV p-p max**
**Wide Gain Range: 1 to 2000V/V**
**Low Nonlinearity: 0.0025% max ("L")**
**High CMR: 140dB min (60Hz, G = 1000V/V)**
**Input Protected to 130V rms**
**Adjustable Low Pass Filter: 60dB/Decade Roll-Off (from 2Hz)**
**Programmable Transducer Excitation: Voltage (4V to 15V @ 100mA) or Current (100μA to 10mA)**



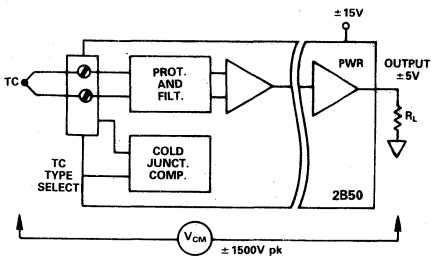

## 2B34

Vol. II
9-35

**Low Input Offset Drift: ±1.0μV/°C**
**Low Gain Drift: ±25ppm/°C**
**Low Nonlinearity: ±0.01% max (±0.005% typ)**
**Differential Input Protection: ±130V rms**
**Channel Multiplexing: 3000 chan/sec Scanning Speed**
**Solid State Reliability**
**Internal RTD Excitation/Lead Wire Compensation**

# Selection Guide
## Signal Conditioners

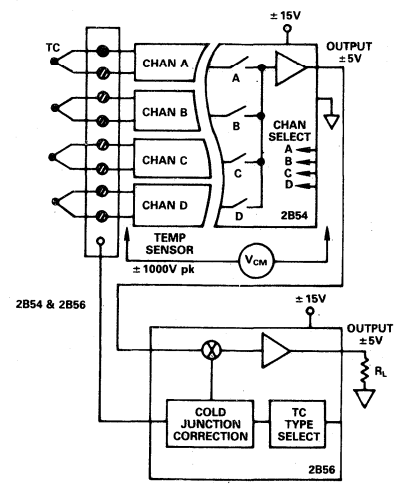
## Isolated Transducer Signal Conditioners




### 2B50

Page Vol. II 9-41

- Accepts J, K, T, E, R, S or B Thermocouple Types
- Internally Provided Cold Junction Compensation
- High CMV Isolation: ±1500V pk
- High CMR: 160dB min @ 60Hz
- Low Drift: ±1μV/°C max (2B50B)
- High Linearity: ±0.01% max (2B50B)
- Input Protection and Filtering
- Screw Terminal Input Connections




### 2B54

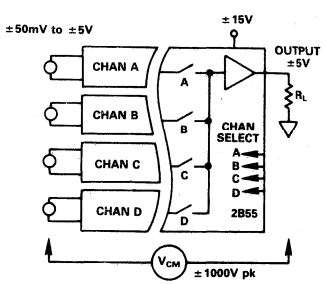
Vol. II 9-47

- Low Cost
- Wide Input Span Range: ±5mV to ±100mV
- 12-Bit Systems Compatible
- High CMV Isolation: ±1000V dc; CMR = 156dB min @ 60Hz
- Low Input Offset Voltage Drift: ±1μV/°C max (2B54B)
- Low Gain Drift: ±25ppm/°C max (2B54B)
- Low Nonlinearity: ±0.02% max (±0.012% typ)
- Normal Mode Input Protection (130V rms) and Filtering
- Channel Multiplexing: 400 chan/sec Scanning Speed
- Solid State Reliability

### 2B56

Vol. II 9-53

- Universal Thermocouple Compensation
  - Internally Provided: Types J, K, T
  - User Configurable: Types E, R, S, B
- Digitally Programmable
- High Accuracy: ±0.8°C max over +5°C to +45°C
- High Ambient Rejection: 50 to 1 min
- Low Cost
- Small Size: 1.5″ × 2″ × 0.4″

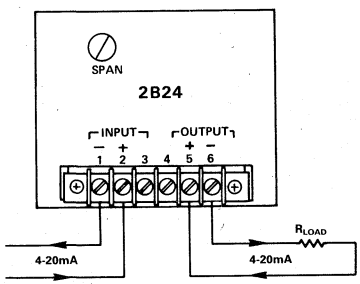



### 2B55

Vol. II 9-47

- Low Cost
- Wide Input Span Range: ±50mV to ±5V
- 12-Bit Systems Compatible
- High CMV Isolation: ±1000V dc; CMR = 145dB min @ 60Hz
- Low Input Offset Voltage Drift: ±5μV/°C max
- Low Gain Drift: ±25ppm/°C max
- Low Nonlinearity: ±0.02% max (G = 1 to 100)
- Normal Mode Input Protection (130V rms) and Filtering
- Channel Multiplexing: 400 chan/sec Scanning Speed
- Solid State Reliability

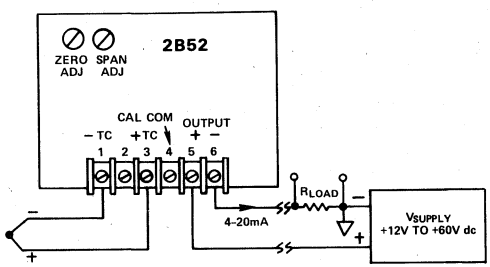
# Two-Wire Transmitters




## 2B24

Page
Vol. II
9–27

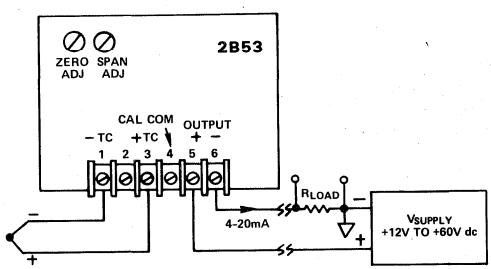
**Self-Powered**
**Wide Input Range: 1-50mA (2B24B)**
**High CMV Isolation: ±1500V pk; CMR: 120dB**
**High Accuracy: ±0.1%**
**RFI/EMI Immunity**
**Low Cost**




## 2B52

Vol. II
9–45

**Accepts Type J, K or T Thermocouple Inputs**
**Compatible with Standard 4-20mA Loops**
**High Accuracy: ±0.1%**
**High CMV Isolation: 600V rms; CMR = 160dB**
**High Noise Rejection and RFI Immunity**
**Internal Cold Junction Compensation**
**Open Thermocouple Detection**
**Millivolt Signal Transmission**
**Low Cost**
**FM Approved**

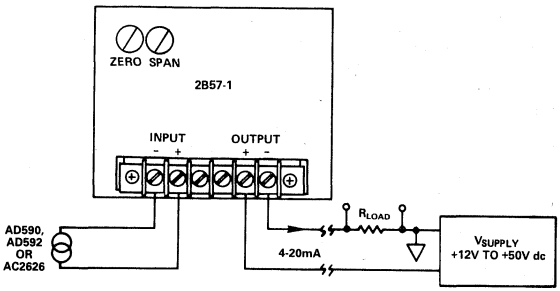



## 2B53

Vol. II
9–45

**Accepts Type J, K or T Thermocouple Inputs**
**Compatible with Standard 4-20mA Loops**
**High Accuracy: ±0.1%**
**High Noise Rejection and RFI Immunity**
**Internal Cold Junction Compensation**
**Open Thermocouple Detection**
**Millivolt Signal Transmission**
**Low Cost**

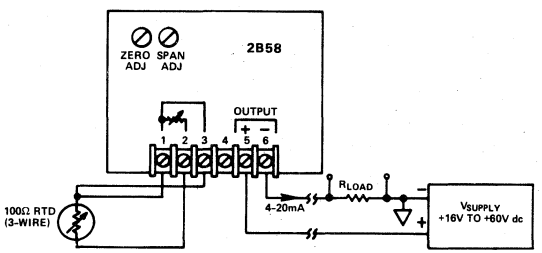
# Selection Guide
## Signal Conditioners
## Two-Wire Transmitters




### 2B57

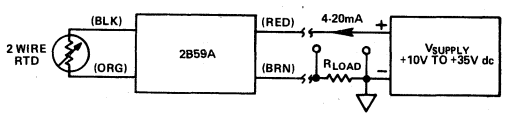
Page

**Low Cost** Vol. II
**Compatible with Standard 4-20mA Loops** 9–57
**Low Span Drift: ±0.005%/°C max**
**Low Nonlinearity: ±0.05% max**
**RFI Immunity**
**Small Size: 1.5″ × 1.5″ × 0.4″**




### 2B58

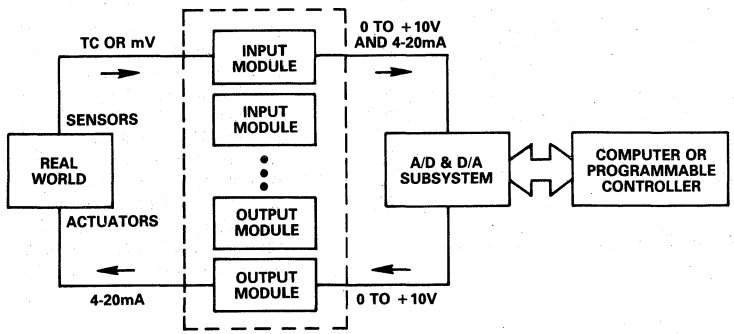
**Platinum RTD Input** Vol. II
**Linearized 4-20mA Output** 9–61
**High Accuracy: ±0.1%**
**Low Drift: ±0.01°C/°C max**
**RFI Immunity**
**Low Cost**
**FM Approved**




### 2B59

**Low Cost** Vol. II
**Standard RTD Input** 9–63
**Linearized 4-20mA Output**
**High Accuracy: ±0.1%**
**Small Size**
**Ease of Installation**

# 3B Series I/O Subsystems






**Input Module Selection**

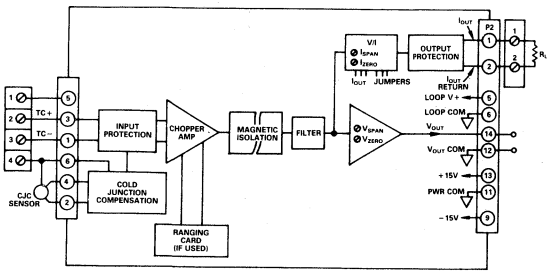
| Input Type/Span | Voltage Output | Current Output | Nonisolated Modules | Isolated Modules |
|---|---|---|---|---|
| dc, ± 10mV, ± 50mV, ± 100mV | ± 10V | 4-20mA/0-20mA | 3B10 | 3B30 |
| dc, ± 1V, ± 5V | ± 10V | 4-20mA/0-20mA | 3B10 | 3B31 |
| dc, ± 10V | ± 10V | 4-20mA/0-20mA | 3B11 | 3B31 |
| dc, 4-20mA, 0-20mA | 0 to + 10V | 4-20mA/0-20mA | 3B12 | 3B32 |
| Thermocouple Types J, K, T, E, R, S, B | 0 to + 10V | 4-20mA/0-20mA | | 3B37 |
| 100Ω Platinum RTD, 2-, 3-, 4-Wire $\alpha = 0.00385$ (linearized) | 0 to + 10V | 4-20mA/0-20mA | 3B14 | 3B34 |
| 100Ω Platinum RTD, Kelvin 4-Wire $\alpha = 0.00385$ (linearized) | 0 to + 10V | 4-20mA/0-20mA | 3B15 | |
| Strain Gage ± 30mV, ± 100mV | ± 10V | 4-20mA/0-20mA | 3B16 | |
| AD590/AD592/AC2626 Solid State Temperature Transducer | 0 to + 10V | 4-20mA/0-20mA | 3B13 | |
| Wideband Strain Gage | ± 10V | 4-20mA/0-20mA | 3B18 | |
| Wideband mV, V | ± 10V | 4-20mA/0-20mA | | 3B40/1 |
| AC Input | 0 to + 10V | 4-20mA/0-20mA | | 3B42/3/4 |
| Frequency Input | 0 to + 10V | 4-20mA/0-20mA | | 3B45/6 |

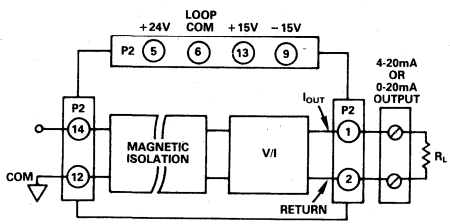
**Output Module Selection**

| Input Type/Span | Current Output | Nonisolated Modules | Isolated Modules |
|---|---|---|---|
| 0 to + 10V, ± 10V | 4-20mA/0-20mA | 3B19 | 3B39 |

# Selection Guide
## Signal Conditioners

## 3B Series I/O Subsystems




## Input Modules

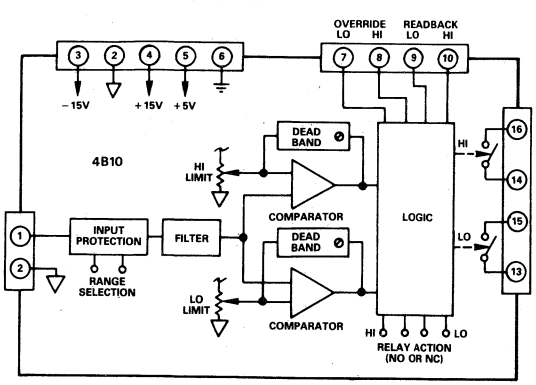
Page

- Wide Variety of Sensor Inputs: Thermocouples, RTD's, Strain Gages, AD590/AD592/AC2626 — Vol. II 9–65
- Dual High Level Outputs
  - Voltage: 0 to +10V or ±10V
  - Current: 4-20mA/0-20mA
- Mix and Match Input Capability
  - Sensor Signals, mV, V, 4-20mA, 0-20mA
- High Accuracy: ±0.1%
- High Noise Rejection and RFI/EMI Immunity
- Reliable Transformer Isolation: ±1500V CMV
- Meets IEEE-STD 472: Transient Protection (SWC)
- Input Protection: 130V or 220V rms Continuous

## Output Modules

- High Level Voltage Input: (0 to +10V, ±10V) — Vol. II 9–65
- Process Current Output: (4-20mA/0-20mA)
- High Accuracy: ±0.1%
- Reliable Transformer Isolation: ±1500V CMV, CMR = 90dB
- Meets IEEE-STD 472: Transient Protection (SWC)
- Output Protection: 130V or 220V rms Continuous

## 4B Series Alarm Limit Subsystem




## Features/Benefits

- Low Cost, Completely Integrated 12-Channel Modular Alarm Limit Subsystem — Vol. II 9–69
  - Selection of Alarm Limit Modules
  - Rugged Industrial Chassis, Rack or Surface Mounted
  - On-Board Power Supplies Available
- Alarm Modules Accept High Level Voltage and Process Current Inputs
- Complete Alarm Function per Module
  - High Accuracy of ±0.1%
  - Two Set Points, Adjustable Over 100% Span
  - Dead Band Adjustment per Set Point, Adjustable Over 0.5%–10.0% Span
  - Alarm Types are Configurable for HI or LO Operation
  - Two Relay Outputs
  - Display Indicates Set Points and Process Variable
  - LED per Set Point Provides Local Alarm Indication
  - Input Protection
  - High RFI/EMI Immunity
- Specifications Valid Over the 0 to +70°C Temperature Range
- Easy to Install Calibrate and Service

# Orientation
# Temperature Transducers & Signal Conditioners

In this section are listed a wide variety of cost-effective *analog-to-analog* signal conditioners for laboratory and industrial applications, and a set of linear high-output-level semiconductor temperature transducers, manufactured by Analog Devices.

The signal conditioners are intended to provide a variety of system interfaces for signals originating from input transducers or destined for output transducers.

They accept low or high-level signal inputs from millivolts to volts, low- or high-level current inputs from microamperes to 4-to-20mA loops, and direct inputs from transducers, such as strain gages and other bridge devices, RTDs, thermocouples, thermistors, and semiconductor temperature sensors. One of these modules (2B35) is a triple-output power supply that accepts ac line voltage and provides voltage and programmable current excitation for transducers and signal conditioners.

Outputs from these devices include 0-to-20mA, 4-to-20mA and 10-to-50mA transmitter loop current, and normalized voltage at ±5V or ±10V levels for inputs to analog and digital data-acquisition systems. Most of the devices that operate with current loops derive their power directly from the loop supply.

The many useful functions of these devices include—and often combine—voltage-to-current conversion; input-to-output and channel-to-channel isolation; current-to-current conversion; amplification, offsetting, and filtering; transducer voltage and current excitation; all-solid-state isolation, gain, filtering, protection, and multiplexing; thermocouple open-input detection and cold-junction compensation; RTD linearizing.[1]

**SELECTION GUIDE**

These many functions are sorted out and arranged for easy access in the Selection Guide so that a device having the desired combination of performance characteristics can be readily found. Device types are classified in broad categories, and the key attributes of each device are listed next to a functional block diagram. A quick glance at the Selection Guide allows you to choose the product(s) with your desired functionality. At this point, you may turn to the appropriate data sheet(s) to compare performance, starting the process of considering the specific device(s) for your application.

**THAT'S NOT ALL**

Besides the signal conditioners in this section, this databook has technical data on many other products that perform signal-conditioning functions. They are to be found in these sections of this Volume:

*Isolation Amplifiers.*

*D/A Converters* (DACs having 4-to-20mA output current, isolation, and other useful features).

*Data-Acquisition Subsystems* (including programmable-gain amplifiers, differential inputs, etc.).

*Digital Panel Instruments* (with isolation, low-level signal-handling capability, digital readout and BCD system output: scanning multi-channel voltmeters, intelligent thermocouple thermometers, low-cost digital thermometers, etc.).

*Microcomputer Interface Boards* (with input multiplexing and programmable gain, 4-to-20mA output options, etc.).

*μMAC-4000 Single-Board Intelligent Measurement-and-Control Subsystems* (with direct sensor inputs, isolation, signal conditioning, microcomputer-based linearization, ASCII 20mA/RS-232C communications, on-board power supply, and digital I/O).

*MACSYM Complete BASIC-Programmable Minicomputer-Based Measurement-And-Control SYsteMs* (with a wide selection of input signal conditioning cards and direct connection to sensor field wiring).

9

[1] Many of these issues are discussed in *Transducer Interfacing Handbook, a guide to analog signal conditioning,* published by Analog Devices, Inc., 1980, $14.50, available from P.O. Box 796, Norwood MA 02062.

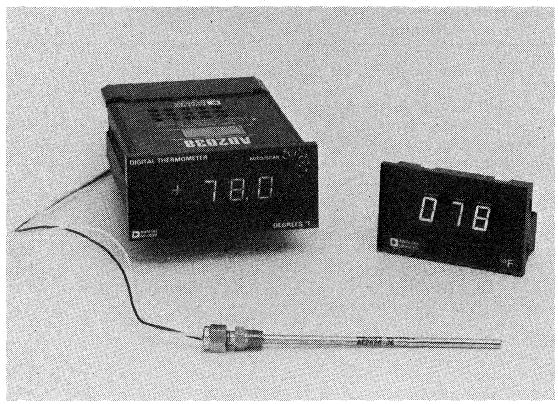
# ANALOG DEVICES

# General Purpose Temperature Probe

# AC2626

**FEATURES**

- **Linear Current Output: 1μA/K**
- **Wide Range: -55°C to +150°C**
- **Laser Trimmed Sensor (AD590) to ±1.0°C Calibration Accuracy (AC2626L)**
- **Excellent Linearity: ±0.4°C Over Full Range (AC2626L)**
- **6 Inch or 4 Inch Standard, Stainless Steel Sheath**
- **3/16 Inch in Outside Diameter**
- **3 Feet Teflon Coated Lead Wire**
- **Wide Power Supply Range +4V to +30V**
- **Low Cost**
- **Fast Response: 2 Seconds (In Stirred Water)**
- **Sensor Isolated From Sheath**



9

## PRODUCT DESCRIPTION

The AC2626 is a stainless steel tubular probe measuring 3/16 inch (4.76mm) in outside diameter and is available in 6 inch (152.4mm or 4 inch (101.6mm) lengths. The probe is available in linearity grades of 0.4°C, 0.8°C or 1.5°C.

The probe is designed for both liquid and gaseous immersion applications as well as temperature measurements in refrigeration or any general temperature monitoring application.

For taking measurements in pipes or other closed vessels, the AC2629 compression fitting is available. The AC2629 may be applied anywhere along the probe and is supplied in two materials. The low cost AC2629B is constructed of brass and the higher priced AC2629SS is made of stainless steel.

## PRODUCT HIGHLIGHTS

The AC2626 is based on the AD590 temperature transducer, a two terminal integrated circuit which produces an output current linearly proportional to absolute temperature.

Costly linearization circuitry, precision voltage amplifiers, resistance measuring circuitry and cold junction compensation are not needed in applying the AC2626.

Due to the high impedance current output of the AD590, the AC2626 is particularly useful in remote sensing applications, because of its insensitivity to voltage drops over lines. The output characteristics also make the AC2626 easy to multiplex.

In addition to temperature measurement, applications include temperature compensation, biasing proportional to absolute temperature, flow rate measurement, level detection of fluids and anemometry.

## DIRECT INTERFACE PRODUCTS

For display and/or control applications, two companion products are available. The AD2038, 6 channel digital thermometer, and the AD2040, low cost temperature indicator, were designed to be used in conjunction with the AC2626.

1. The AD2038 is a low cost, ac line powered 6 channel digital scanning thermometer designed to interface to printers, computers, serial data transmitters, etc., for display, control, logging or transmission of multi-point temperature data. Channel selection is made via three methods: manual, using the switch provided on the front; auto/scan, where the AD2038 cycling on an internal clock can continually scan the six input channels or external selection, where control inputs provided on the rear connector enable channel selection via external BCD coding.
2. The AD2040 is a low cost, 3 digit temperature indicator. An internal precision voltage reference, resistor network and span and zero adjusts allow the AD2040 to read out directly in °C, °F, K or R. User selectable readout as well as all other connections, i.e., +5V dc power and AC2626 interface are all made via the terminal block on the rear.

## APPLICATION HINTS

1. Under all operating conditions, a minimum 4V dc must be present across the AC2626.
2. Use of twisted pair wiring is recommended, particularly for remote applications or in high noise environments. Shielded wire is desirable in severe noise environments.
3. For the lowest cost, the J and K grades are recommended. Where probe interchangeability is desired, grade L is recommended.

# SPECIFICATIONS (typical @ +25°C and +5V unless otherwise specified)

| MODEL | AC2626J | AC2626K | AC2626L |
|---|---|---|---|
| ABSOLUTE MAXIMUM RATINGS[1] | | | |
| Forward Voltage ($V_S$) | +44V | * | * |
| Reverse Voltage ($V_S$) | -20V | * | * |
| Breakdown Voltage (Case to Leads) | ±200V | * | * |
| Rated Performance Temp. Range | -55°C to +150°C | * | * |
| Storage Temperature Range | -60°C to +160°C | * | * |
| POWER SUPPLY | | | |
| Operating Voltage Range | +4V to +30V | * | * |
| OUTPUT | | | |
| Nominal Current Output @ +25°C (298.2°K) | 298.2μA | * | * |
| Nominal Temperature Coefficient | 1μA/°C | * | * |
| Calibration Error @ +25°C | ±5.0°C max | ±2.5°C max | ±1.0°C max |
| Absolute Error (over rated performance temperature range) | | | |
| Without External Calibration Adjustment | ±10.0°C max | ±5.5°C max | ±3.0°C max |
| With +25°C Calibration Error Set to Zero | ±3.0°C max | ±2.0°C max | ±1.6°C max |
| Nonlinearity | ±1.5°C max | ±0.8°C max | ±0.4°C max |
| Repeatability[2] | 0.1°C | * | * |
| Long Term Drift[3] | 0.1°C max/month | * | * |
| Time Constant[4] (in stirred water) | 2 sec. | * | * |
| Current Noise | 40pA$\sqrt{Hz}$ | * | * |
| Power Supply Rejection | | | |
| +4V≤$V_S$≤+5V | 0.5μA/V | * | * |
| +5V≤$V_S$≤+15V | 0.2μA/V | * | * |
| +15V≤$V_S$≤+30V | 0.1μA/V | * | * |
| Electrical Turn-On Time | 20μs | * | * |
| + Lead Color | yellow | orange | blue |

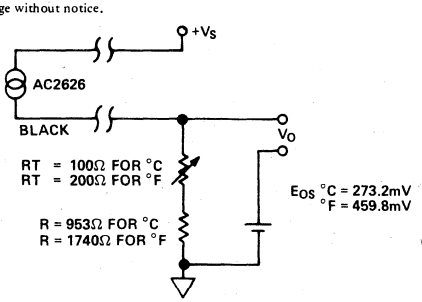
**ORDERING GUIDE**

AC2626
- GRADE: J, K, L — ENTER
- LENGTH: 4, 6 — ENTER

AC2629
- BRASS: B — ENTER
- TYPE 316 STAINLESS: SS — ENTER

NOTES
[1] Maximum safe recommended pressure: 7500psi (5.17 × $10^4$ Kpa).
[2] Maximum deviation between +25°C readings after temperature cycling between -55°C and +150°C; guaranteed, not tested.
[3] Conditions: constant +5V, constant +125°C; guaranteed, not tested.
[4] The time constant is defined as the time required to reach 63.2% of an instantaneous temperature change.
*Specifications same as AC2626J.
Specifications subject to change without notice.

## CALIBRATION



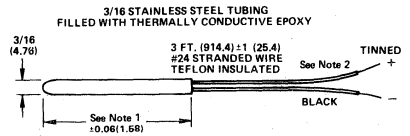

For most applications, a single point calibration is sufficient. With the probe at a known temperature, adjust $R_T$ so that $V_O$ corresponds to the known temperature.

If more detailed information is desired, see the AD590 data sheet and application note.

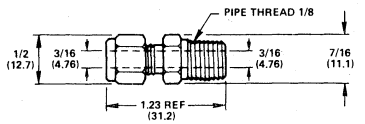
## MECHANICAL OUTLINE

Dimensions shown in inches and (mm).

### AC2626




### AC2629




NOTE 1 Probes are available in 4-inch or 6-inch lengths.
NOTE 2 + lead wire is color coded: J, yellow; K, orange; L, blue.
NOTE 3 When assembling compression fitting (AC2629) to probe, tighten the 1/2" nut 3/4's of a turn from finger tight.

# High Performance, 4-20mA Output Voltage-to-Current Converter

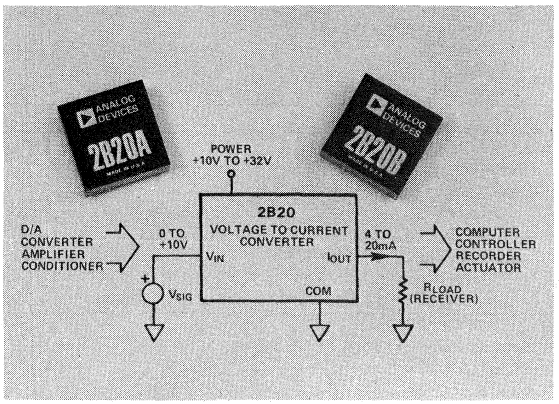
# MODEL 2B20

**FEATURES**

- **Complete, No External Components Needed**
- **Small Size: 1.1″ x 1.1″ x 0.4″ Module**
- **Input: 0 to +10V; Output: 4 to 20mA**
- **Low Drift: 0.005%/°C max; Nonlinearity: 0.005% max (2B20B)**
- **Wide Temperature Range: -25°C to +85°C**
- **Single Supply: +10V to +32V**
- **Meets ISA Std 50.1 for Type 3, Class L and U, Nonisolated Current Loop Transmitters**
- **Economical**

**APPLICATIONS**

- **Industrial Instrumentation and Control Systems**
- **D/A Converter – Current Loop Interface**
- **Analog Transmitters and Controllers**
- **Remote Data Acquisition Systems**




9

## GENERAL DESCRIPTION

Model 2B20 is a complete, modular voltage-to-current converter providing the user with a convenient way to produce a current output signal which is proportional to the voltage input. The nominal input voltage range is 0 to +10V. The output current range is 4 to 20mA into a grounded load.

Featuring low drift (0.005%/°C max, 2B20B) over the -25°C to +85°C temperature range and single supply operation (+10V to +32V), model 2B20 is available in two accuracy grades. The 2B20B offers precision performance with nonlinearity error of 0.005% (max) and guaranteed low offset error of ±0.1% max and span error of ±0.2% max, without external trims. The 2B20A is an economical solution for applications with lesser accuracy requirements, featuring nonlinearity error of 0.025% (max), offset error of ±0.4% (max), span error of ±0.6% (max), and span stability of 0.01%/°C max.

The 2B20 is contained in a small (1.1″ x 1.1″ x 0.4″), rugged, epoxy encapsulated package. For maximum versatility, two signal input ($V_{IN1}$ and $V_{IN2}$) and two reference input ($REF_{IN1}$ and $REF_{IN2}$) terminals are provided. Utilizing terminals $V_{IN1}$ and $REF_{IN1}$ eliminates the need for any external components, since offset and span are internally calibrated. If higher accuracy (up to ±0.01%) is required, inputs $V_{IN2}$ and $REF_{IN2}$ with series trim potentiometers may be utilized.

## APPLICATIONS

Model 2B20 has been designed for applications in process control and monitoring systems to transmit information between subsystems or separated system elements. The 2B20 can serve as a transmission link between such elements of process control system as transmitters, indicators, controllers, recorders, computers, actuators and signal conditioners.

In a typical application, model 2B20 may act as an interface between the D/A converter output of a microcomputer based system and a process control device such as a variable position valve. Another typical application of the 2B20 may be as a current output stage of a proportional controller to interface devices such as current-to-position converters and current-to-pneumatic transducers.

## DESIGN FEATURES AND USER BENEFITS

**Process Signal Compatibility:** To provide output signal compatibility, the 2B20 meets the requirements of the Instrument Society of America Standard S50.1, "Compatibility of Analog Signals for Electronic Industrial Process Instruments" for Type 3, Class L and U, nonisolated current loop transmitters.

**External Reference Use:** For increased flexibility, when ratiometric operation is desired, the 2B20 offers a capability of connecting an external reference (i.e., from multiplying D/A converter) to the $REF_{IN2}$ terminal.

**Wide Power Supply Range:** A wide power supply range (+10V to +32V dc) allows for operation with either a +12V battery, a +15V powered data acquisition system, or a +24V powered process control instrumentation.

# SPECIFICATIONS (typical @ +25°C and $V_S$ = +15V, unless otherwise noted)

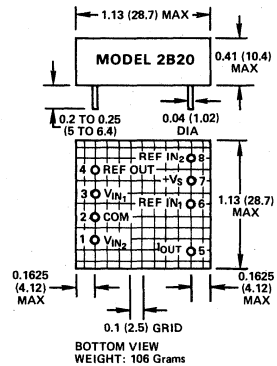
| Model | 2B20A | 2B20B |
|---|---|---|
| INPUT SPECIFICATIONS | | |
| Voltage Signal Range | 0 to +10V | * |
| Input Impedance | 10kΩ | * |
| OUTPUT SPECIFICATIONS | | |
| Current Output Range[1] | 4 to 20mA | * |
| Load Resistance Range[2] | | |
| $V_S$ = +12V | 0 to 350Ω max | * |
| $V_S$ = +15V | 0 to 500Ω max | * |
| $V_S$ = +24V | 0 to 950Ω max | * |
| NONLINEARITY (% of Span) | ±0.025% max | ±0.005% max |
| ACCURACY[3] | | |
| Warm-Up Time to Rated Specs | 1 minute | * |
| Total Output Error @ +25°C[3,4] | | |
| Offset ($V_{IN}$ = 0 volts) | ±0.4% max | ±0.1% max |
| Span ($V_{IN}$ = +10 volts) | ±0.6% max | ±0.2% max |
| vs. Temperature (-25°C to +85°C) | | |
| Offset ($V_{IN}$ = 0 volts) | ±0.01%/°C max | ±0.005%/°C max |
| Span ($V_{IN}$ = +10 volts) | ±0.01%/°C max | ±0.005%/°C max |
| DYNAMIC RESPONSE | | |
| Settling Time – to 0.1% of F.S. for 10V Step | 25μs | * |
| Slew Rate | 2.5mA/μs | * |
| REFERENCE INPUT[5] | | |
| Voltage | +2.5V dc | * |
| Input Impedance | 10kΩ | * |
| POWER SUPPLY | | |
| Voltage, Rated Performance | +15V dc | * |
| Voltage, Operating | +10V to +32V dc max | * |
| Supply Change Effect (% of Span)[6] | | |
| on Offset | ±0.005%/V | * |
| on Span | ±0.005%/V | * |
| Supply Current | 6mA + $I_{LOAD}$ | * |
| TEMPERATURE RANGE | | |
| Rated Performance | -25°C to +85°C | * |
| Storage | -55°C to +125°C | * |
| CASE SIZE | 1.125" X 1.125" X 0.4" | * |

NOTES
*Specifications same as 2B20A.
[1] Current output sourced into a grounded load over a supply voltage range of +10V to +32V.
[2] See Figure 1 for the maximum load resistance value over the power supply range.
[3] Accuracy is guaranteed with no external trim adjustments when $REF_{IN}$ is connected to $REF_{OUT}$.
[4] All accuracy is specified as % of output span where output span is 16mA (±0.1%=±0.016mA output error).
[5] Reference input is normally connected to the reference output (+2.5V dc).
[6] Optional trim pots may be used for calibration at each supply voltage.

Specifications subject to change without notice.

## OUTLINE DIMENSIONS

Dimensions shown in inches and (mm).




**MATING SOCKET: AC1016**

## LOAD RESISTANCE RANGE

The load resistance is the sum of the resistances of all connected receivers and the connection lines. The 2B20 operating load resistance is power supply dependent and will decrease by 50 ohms for each 1 volt reduction in the power supply. Similarly, it will increase by 50 ohms per volt increase in the power supply, but must not exceed the safe voltage capability of the unit.

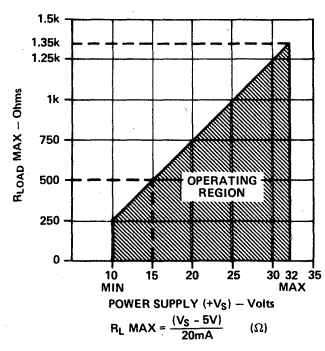



*Figure 1. Maximum Load Resistance vs. Power Supply*

## PRINCIPLE OF OPERATION

The design of the 2B20 is comprised of high performance op amps, precision resistors and a high stability voltage reference to develop biasing and output drive capability. The 2B20 is designed to operate from a single positive power supply over a wide range of +10V to +32V dc and accepts a single ended, 0 to +10V voltage input. The internal reference has nominal output voltage of +2.5V ($REF_{OUT}$) and is used to develop 4mA output current for a zero volts input when $REF_{IN}$ is connected to $REF_{OUT}$.

The output stage of the 2B20 utilizes a sensing resistor in the feedback loop, so the output current is linearly related to the voltage input and independent of the load resistance. There is no minimum resistance for the loads driven by the 2B20; it can drive even a short circuit with no damage to the unit. The maximum resistance of the load as seen by the unit (resistance of the load plus the resistance of the connecting wire) is limited. The maximum external loop resistance, $R_L$, is given by:

$$R_L\ (\Omega)\ \text{max} = \left(\frac{+V_S - 5V}{20mA}\right)$$

Figure 1 shows the operating region of the 2B20. The load must be returned to power supply common. The voltage appearing between $I_{OUT}$ (pin 5) and COM (pin 2) should not exceed $V_{max} = +V_S - 5V$. Exceeding this value (up to +32V dc) will not damage the unit, but it will result in a loss of linearity.

The basic connections of the 2B20 are shown in Figure 2.

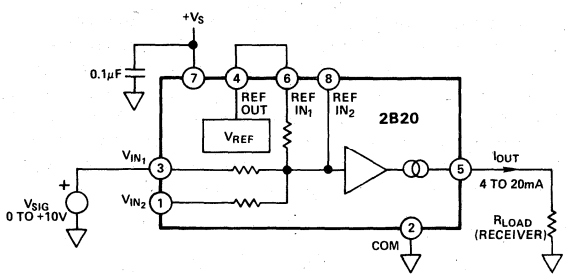



*Figure 2. Basic Connections Diagram*

## OPTIONAL CALIBRATION AND TRIM PROCEDURE

Model 2B20's factory trimmed offset error is ±0.1% max and span error is ±0.2% max (2B20B). In most applications, further trimming will not be required. If it is necessary to obtain calibrated accuracy of up to ±0.01%, or, if a high signal source resistance (with respect to 10kΩ) introduces calibration error, inputs $V_{IN2}$ and $REF_{IN2}$ and optional trim pots should be used with $V_{IN1}$ and $REF_{IN1}$ open. To perform external trims, connect 500Ω potentiometers in series with $V_{IN2}$ (span trim) and $REF_{IN2}$ (offset trim) as shown in Figure 3. Adjust span pot, monitoring voltage drop across $R_{LOAD}$, to obtain an output voltage of 5.000V ($I_{OUT}$ = 20mA) for a +10V input. Next, with 0 volts input, adjust offset pot to obtain 1.000V output ($I_{OUT}$ = 4mA). Check both offset and span and retrim if necessary after each adjustment.

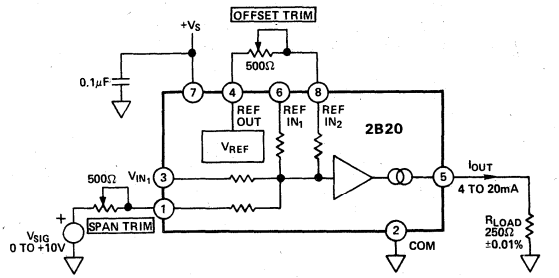



*Figure 3. Model 2B20 Connections Using Optional Offset and Span Trims*

## CONNECTING THE 2B20 FOR 0 TO 10mA OUTPUT

The 2B20 may be utilized in applications requiring 0 to 10mA current output for a 0 to 10V input voltage range. To obtain 0mA output for 0V input, $REF_{IN1}$ (pin 6) and $REF_{IN2}$ (pin 8) terminals should be left open. A typical output current error for a zero volts input (without trimming) is 0.1mA. The 2B20 span calibration may be adjusted by a 1kΩ potentiometer in series with the $V_{IN2}$ input. Basic connections of the 2B20 used to obtain a 0 to 10mA output are shown in Figure 4a.



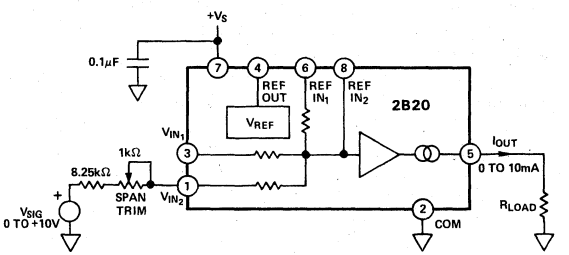



*Figure 4a. Model 2B20 Connected for 0 to 10mA Output Range*

## CONNECTING THE 2B20 FOR 0 TO 20mA OUTPUT

The 2B20 may also be configured for use in applications requiring 0 to 20mA output for a 0 to +10 volt input range. $REF_{IN1}$ (pin 6) is left open, and $REF_{IN2}$ (pin 8) is connected to $V_{IN2}$ (pin 1) through a 32.4kΩ resistor. The typical output current error for 0V input (without trimming) is 0.1mA. The 2B20 span may be adjusted by a 2kΩ potentiometer in series with the $V_{IN2}$ input to provide 9% FSR adjustment range. Basic connections for 0-20mA operation are shown in Figure 4b.

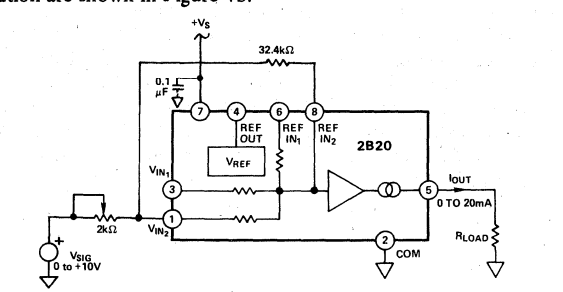



*Figure 4b. Model 2B20 Connected for 0 to 20mA Output Range*

## OUTPUT PROTECTION

In many industrial applications, it may be necessary to protect the 4 to 20mA output from accidental shorts to ac line voltages. The circuit shown in Figure 5 can be used for this purpose. The maximum permissible load resistance will be lowered by a fuse resistance value when protection circuitry is utilized.

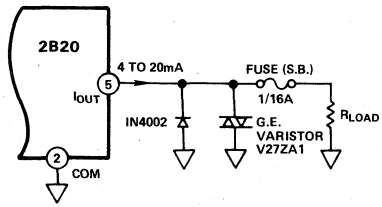



*Figure 5. Output Protection Circuitry Connections*

## APPLICATIONS

**Interfacing Voltage Output D/A Converters:** The 2B20 is well suited in applications requiring 4 to 20mA output from D/A converters. The voltage necessary to power the current loop can be derived from the same +15V supply that is used to power the converter. The D/A converter, such as the 12-bit AD DAC80, should be connected for operation on the unipolar 0 to +10V output range. This is shown in Figure 6. After the load resistor connection has been made, the current loop can be calibrated using the offset and span adjustment potentiometers associated with the 2B20 (or the AD DAC80). First, a digital input code of all ones is loaded into the D/A, and the offset adjustment potentiometer is adjusted for a current output of exactly 4mA. Then, a digital code of all 0s is loaded into the D/A, and the span adjustment potentiometer is adjusted for a voltage across the load that corresponds to a current of 20mA −1LSB = 19.9961mA.

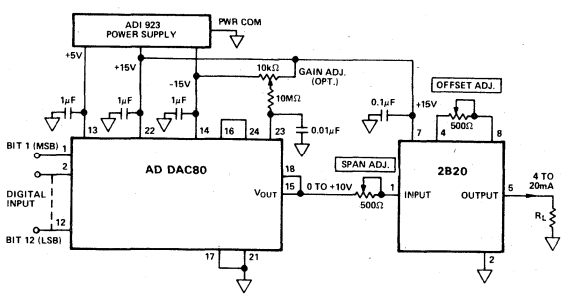



*Figure 6. AD DAC80 – 4 to 20mA Current Loop Interface*

**Interfacing Current Output D/A Converters:** To interface current output D/A converters, such as the AD562, a circuit configuration illustrated in Figure 7 should be used. Since the AD562 is designed to operate with an external +10V reference, the same external reference may be utilized by the 2B20 for ratiometric operation. The output of the AD562 is used to drive the summing junction of an operational amplifier to produce an output voltage. Using the internal feedback resistor of the AD562 provides a 0 to +10V output voltage range suitable to drive the 2B20.

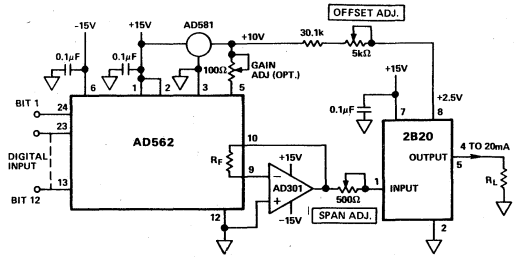



*Figure 7. 12-Bit – 4 to 20mA Current Loop Interface*

**Microcomputer – Current Loop Interface:** Figure 8 shows a typical application of the 2B20 in a multichannel microcomputer analog output system. When a microcomputer is to control a final control element, such as a valve positioner, servomechanism or motor, an analog output board with 4 to 20mA outputs is often necessary. The output boards typically have from one to eight channels, each with its own D/A converter. The 2B20, in a compact package, allows for an easy installation without any additional components and offers a 12-bit system compatible performance.

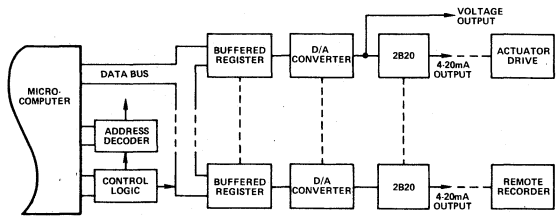



*Figure 8. Microcomputer Analog Output Subsystem*

**Pressure Control System:** In Figure 9, model 2B20 is used in a proportional pressure control system. The 3-15psi working pressure of a system is monitored with a pressure transducer interfaced by the model 2B31 signal conditioner. The high level voltage output of the 2B31 is converted to a 4 to 20mA to provide signal to the limit alarm and proportional control circuitry. A current-to-position converter controlling a motorized valve completes the pressure-control loop.

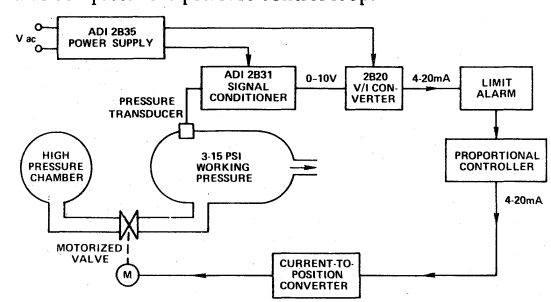



*Figure 9. Proportional Pressure Control System*

**Isolated 4 to 20mA Output:** For applications requiring up to ±1500V dc input to output isolation, consider using Analog Devices' model 2B22 isolated voltage-to-current converter.

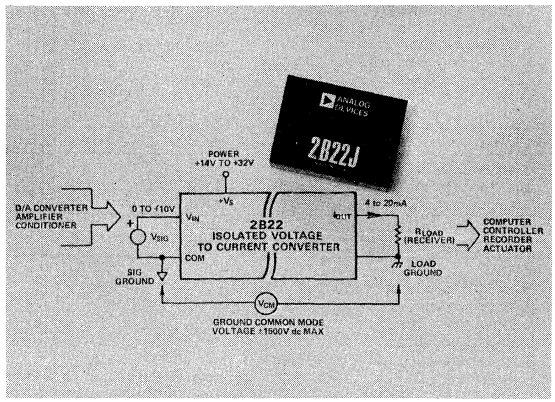
# ANALOG DEVICES

# High Performance, Isolated Voltage-to-Current Converter

# MODEL 2B22

**FEATURES**
- Wide Input Range: 0 to +1V to 0 to +10V
- Standard Output Range: 4 to 20mA
- High CMV Input/Output Isolation: 1500V dc Continuous
- Low Nonlinearity: 0.05% max, 2B22L
- Low Span Drift: 0.005%/°C max, 2B22L
- Single Supply: +14V to +32V
- Meets IEEE Std 472: Transient Protection (SWC)
- Meets ISA Std 50.1: Isolated Current Loop Transmitters

**APPLICATIONS**
- Industrial Instrumentation and Process Control
  - Ground Loop Elimination
  - High Voltage Transient Protection
- D/A Converter – Current Loop Interface
- Analog Transmitters and Controllers
- Remote Data Acquisition Systems




9

## GENERAL DESCRIPTION

Model 2B22 is a high performance, compact voltage-to-current converter offering 1500V dc input to output isolation in interfacing standard process signals. The input stage of the model 2B22 is single resistor programmable to accept voltage ranges from 0 to +1V to 0 to +10V. The isolated output current range is 4 to 20mA, and the 2B22 can be operated with 0 to 1000Ω grounded or floating loads.

Using modulation techniques with transformer isolation for reliable performance, the 2B22 is available in three accuracy selections offering guaranteed nonlinearity error (2B22L: ±0.05% max, 2B22K: ±0.1% max, and 2B22J: ±0.2% max) and guaranteed low span drift: ±0.005%/°C max, ±0.01%/°C max, and ±0.015%/°C max, respectively. The internally trimmed span and offset errors are ±0.1% max for the 2B22L and ±0.25% max for the 2B22J/2B22K. Both span and offset are adjustable by the optional external potentiometers.

Featuring a wide range, single supply operation (+14V to +32V), the 2B22 provides isolated +28V loop power and is capable of delivering rated current into an external 0 to 1000Ω load resistance. The unique output stage configuration also allows the user to utilize an optional external loop power supply to interface systems designed for a two-wire operation.

## APPLICATIONS

Model 2B22 has been specifically designed for high accuracy applications in process control and monitoring systems to offer complete galvanic isolation and protection against damage from transients and fault voltages in transmitting information between subsystems or separated system elements. The 2B22 meets the requirements of the Instrument Society of America Std. 50.1 "Compatibility of Analog Signals for Electronic Industrial Process Instruments" for Type 4, Class U isolated current loop transmitters.

In the industrial environment, model 2B22 can serve as a transmission link between such system elements as transmitters, indicators, controllers, recorders, computers, actuators and signal conditioners. In data acquisition and control systems, the 2B22 may act as an isolated interface between the D/A converter output of a microcomputer and standard 4 to 20mA analog loops.

## DESIGN FEATURES AND USER BENEFITS

**High Reliability:** Model 2B22 is a conservatively designed, compact, epoxy encapsulated module capable of reliable operation in harsh environments. To assure high reliability, the 2B22 has a calculated MTBF of over 270,000 hours and has been designed to meet the IEEE Standard for Transient Voltage Protection (472-1974: Surge Withstand Capability).

**Process Signal Compatibility:** The versatile input stage design with a single resistor gain adjustment enables the 2B22 to accept any one of the standard inputs—0-1V, 0-10V, 1-5V; or 1-5mA, 4-20mA, 10-50mA; and provide standard, isolated 4-20mA output.

**Isolated Loop Power:** Internal 28V dc loop supply, completely isolated from the input power terminals (±1500V dc isolation), provides the capability to drive 0 to 1000Ω loads and eliminates the need for an external dc/dc converter.

# SPECIFICATIONS (typical @ +25°C and $V_S$ = +15V unless otherwise noted)

| Model | 2B22J | 2B22K | 2B22L |
|---|---|---|---|
| INPUT SPECIFICATIONS | | | |
| Voltage Signal Range, G = 1.6mA/V | 0 to +10V | * | * |
| G = 16mA/V | 0 to +1V | * | * |
| Gain Range | 1.6 to 16mA/V | * | * |
| Maximum Safe Input | +15V | * | * |
| Input Impedance | 10MΩ | * | * |
| OUTPUT SPECIFICATIONS | | | |
| Current Output Range | 4 to 20mA | * | * |
| Load Resistance Range, $V_S$ = +14V to +32V, Internal Loop Power | 0 to 1000Ω max | * | * |
| Maximum Output Current, @ Input Overload | 25mA | * | * |
| Output Ripple, 100Hz Bandwidth G = 1.6mA/V | 60μA pk-pk | * | * |
| NONLINEARITY (% of Span) | ±0.2% max | ±0.1% max | ±0.05% max |
| CMV, INPUT TO OUTPUT | | | |
| ac, 60Hz, 1 Minute Duration | 1500V rms | * | * |
| Continuous, ac or dc | ±1500V pk max | * | * |
| CMR, INPUT TO OUTPUT | | | |
| 60Hz, 1kΩ Source Imbalance | 90dB | * | * |
| ACCURACY[1] | | | |
| Warm Up Time to Rated Performance 5 Minutes | | | |
| Total Output Error @ +25°C[1,2] | | | |
| Offset ($V_{IN}$ = 0V) | ±0.25% max | ±0.25% max | ±0.1% max |
| Span ($V_{IN}$ = +10V) | ±0.25% max | ±0.25% max | ±0.1% max |
| vs. Temperature (0 to +70°C, G = 1.6mA/V) | | | |
| Offset ($V_{IN}$ = 0V) | ±0.01%/°C max | ±0.005%/°C max | ±0.0025%/°C max |
| Span ($V_{IN}$ = +10V) | ±0.015%/°C max | ±0.01%/°C max | ±0.005%/°C max |
| vs. Temperature (0 to +70°C) | | | |
| Offset ($V_{IN}$ = 0V, G = 1.6mA/V to 16mA/V) | ±0.01%/°C | ±0.005%/°C | ±0.0025%/°C |
| Span (G = 1.6mA/V to 16mA/V)[3] | ±0.015%/°C | ±0.01%/°C | ±0.005%/°C |
| DYNAMIC RESPONSE | | | |
| Settling Time – to 0.1% of F.S. for 10V Step | 300μs | * | * |
| Slew Rate | 0.06mA/μs | * | * |
| REFERENCE INPUT | | | |
| Voltage | +2.5V dc | * | * |
| Input Impedance | 6kΩ | * | * |
| OSCILLATOR | | | |
| Frequency, Internal Oscillator | 100kHz ± 10% | * | * |
| External Sync Input | | | |
| Frequency | 100kHz ± 10% max | * | * |
| Waveform | Square wave, 50% duty cycle | * | * |
| Voltage | 20V p-p | * | * |
| POWER SUPPLY | | | |
| Voltage, Rated Performance | +15V dc | * | * |
| Voltage, Operating | +14V to +32V dc | * | * |
| Supply Current (at Full Scale Output) | | | |
| Using Internal Loop Power | 100mA | * | * |
| Using External Loop Power | 50mA | * | * |
| Supply Change Effect (% of Span) | | | |
| on Offset ($V_{IN}$ = 0V) | ±0.0005%/V | * | * |
| on Span ($V_{IN}$ = +10V) | ±0.0005%/V | * | * |
| TEMPERATURE RANGE | | | |
| Rated Performance | 0 to +70°C | * | * |
| Operating | -25°C to +75°C | * | * |
| Storage | -55°C to +85°C | * | * |
| CASE SIZE | 2.2" X 3" X 0.6" | * | * |

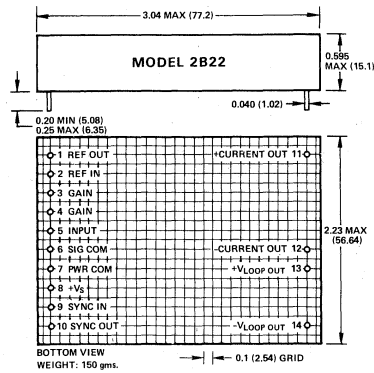
NOTES
[1] Accuracy is guaranteed at G = 1.6mA/V with no external trim adjustments when connected as shown in Figure 1.
[2] All accuracy is % of span where span is 16mA (±0.1% = ±0.016mA error).
[3] Span T.C. for gains higher than 1.6mA/V is $R_G$ dependent – a low T.C. (±10ppm/°C) $R_G$ is recommended for best performance.

*Specifications same as 2B22J.

Specifications subject to change without notice.

## OUTLINE DIMENSIONS

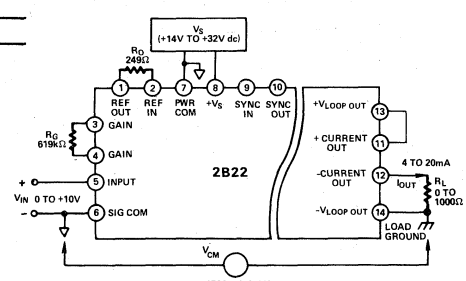
Dimensions shown in inches and (mm).




## MATING SOCKET: AC1579

## INTERCONNECTION DIAGRAM

Model 2B22 can be applied directly to achieve rated performance as shown in Figure 1 below. The input stage gain of 1.6mA/V, to convert a 0 to +10V signal into a 4 to 20mA output current, is obtained with the values shown. A single polarity power supply (+14V to +32V dc) should be connected to pin 8. To eliminate ground loops, the user should ensure that the signal return (common) lead does not carry the power supply current. Power common (pin 7) and signal common (pin 6) should be tied at the power supply common terminal. The voltage difference between pins 6 and 7 should not exceed 0.2V. An internal dc-dc converter provides isolated output loop power (pins 13 and 14), which is connected externally to the current output terminals (pins 11 and 12) and a load resistance. The standard 4 to 20mA current output signal is delivered into any external load between zero and 1000Ω.




NOTE: Resistors $R_O$ and $R_G$ are 1%, 50ppm/°C Metal Film Type. Values shown are for G = 1.6mA/V. For G = 16mA/V, use 10ppm/°C $R_G$ and 50ppm/°C $R_O$.

*Figure 1. Basic Connections*

## FUNCTIONAL DESCRIPTION

The high performance of model 2B22 is derived from the carrier isolation technique which is used to transfer both signal and power between the V/I converter's input circuitry and the output stage. High CMV isolation is achieved by the transformer coupling between the input amplifier, modulator section and the current output circuitry. The block diagram for model 2B22 is shown in Figure 2 below.

The 2B22 produces an isolated 4 to 20mA output current which is proportional to the voltage input and independent of the load resistance. The input amplifier operates single-ended and accepts a positive voltage within 0 to +10V range. Gain can be set from 1.6mA/V to 16mA/V by changing the gain resistor $R_G$ to accommodate input ranges from 0 to +1V (G = 16mA/V) to 0 to +10V (G = 1.6mA/V). The transfer function is $I_{OUT} = (4mA + G \times V_{IN})$.

An internal, high stability reference has nominal output voltage of +2.5V (REF OUT) and is used to develop a 4mA output current for a 0 volts input. The terminals REF OUT (pin 1) and REF IN (pin 2) should be connected via the offset setting resistor $R_O$. For ratiometric operation, an external reference voltage can be connected to the REF IN terminal.

The 2B22 is designed to operate from a single positive power supply over a wide range of +14V to +32V dc. An internal dc-dc converter provides isolated +28V loop power which is independent of $+V_S$. The maximum resistance of the load $R_L$ (resistance of the receivers plus the resistance of the connecting wire) is 1000Ω. Since the loop power is derived from the input side, the current capability of the power supply ($+V_S$) must be 100mA min to supply full output signal current.

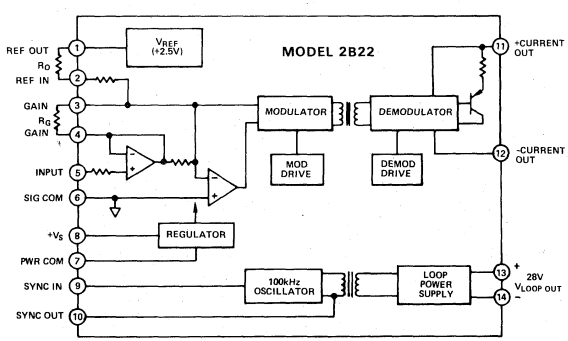



*Figure 2. Block Diagram – Model 2B22*

## OPTIONAL TRIM ADJUSTMENTS

Model 2B22 is factory calibrated for a 0 to +10V input range (G = 1.6mA/V). As shipped, the 2B22 meets its listed specifications without use of any external trim potentiometers. Additional trim adjustment capability, to reduce span and offset errors to ±0.05% max, is easily provided as shown in Figure 3. The span and offset trim pots are adjusted while monitoring the voltage drop across a precision (or known) load resistor. The following trim procedure is recommended:

1. Connect model 2B22 as shown in Figure 3.
2. Apply $V_{IN}$ = 0 volts and adjust $R_O$ (Offset Adjust) for $V_{OUT}$ = +2V ± 4mV.
3. Apply $V_{IN}$ = +10.00V and adjust $R_G$ (Span Adjust) for $V_{OUT}$ = +10V ± 4mV.

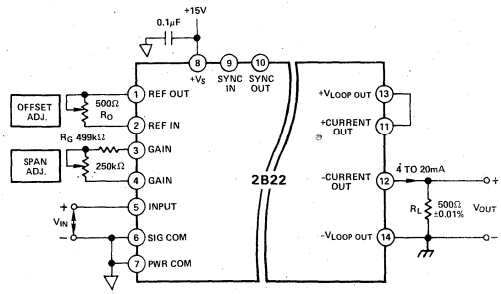



*Figure 3. Optional Span and Offset Adjustment*

## GAIN AND OFFSET SETTING

The gain of the 2B22 is a scale factor setting that establishes the nominal conversion relationship to accommodate +1V to +10V full scale inputs ($V_{IN}$). The value of the gain setting resistor $R_G$ is determined by: $R_G(k\Omega) = 6.314SF/(10.1 - SF)$ where SF is a scale factor equal to the value of $V_{IN}$ F.S. Example: to convert a 0 to +1V input to the 4 to 20mA output, SF = 1 and $R_G$ = 693Ω. Due to device tolerances, allowance should be made to vary $R_G$ by ±5% using the potentiometer.

The value of the offset resistor $R_O$ is independent from the gain setting and given by the relationship: $R_O(k\Omega) = 2.5(V_{REF} - 2.4)$ where $V_{REF}$ is the reference voltage applied. For example, the reference provided by the 2B22 is +2.5V and therefore $R_O$ = 250Ω. The accuracy of the $R_O$ calculation from from the above formula is ±5%. When an external reference operation is desired (i.e. for ratiometric operation), connect the reference voltage via $R_O$ to pin 2 and leave pin 1 open.

## EXTERNAL LOOP POWER OPERATION

For maximum versatility, the 2B22's output stage is designed to operate from the optional, isolated external loop power supply. This feature allows the user to interface systems wired for a two-wire operation. As shown in Figure 4, the same wiring is used for loop power and output. The load resistance is connected in series with an external dc power supply (+6V to +32V), and the current drawn from the supply is the 4 to 20mA output signal. The input stage of the 2B22 still requires $+V_S$ power, but the current drain from $+V_S$ is limited to 50mA. Use of an external loop power may require gain and offset trimming to obtain specified accuracy. The maximum series load resistance depends on the loop supply voltage as shown in Figure 4.

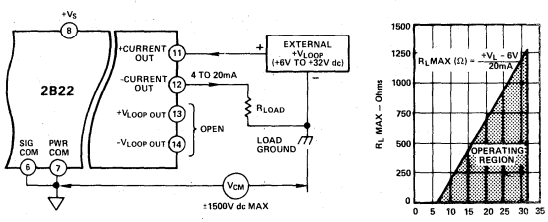



*Figure 4. Optional External Loop Power Operation*

## SYNCHRONIZING MULTIPLE 2B22'S

In applications where multiple 2B22's are used in close proximity, radiated individual oscillator frequencies may cause "beat frequency" related output errors. These errors can be eliminated by synchronizing multiple units by connecting the SYNC OUT (pin 10) terminal to the SYNC IN (pin 9) terminal of the adjacent 2B22. The SYNC OUT terminal of this "slaved" unit can be used to drive another adjacent 2B22 (Figure 5). For best accuracy, each 2B22 should be retrimmed when synchronizing connections are used.

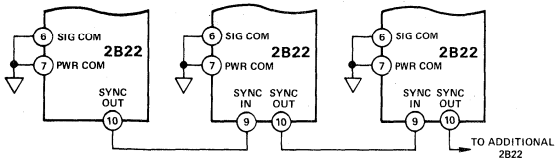



*Figure 5. Multiple 2B22's Synchronization*

## OUTPUT PROTECTION

The current output terminals (pins 11 and 12) are protected from shorts up to +32V dc but in many industrial applications, it may be necessary to protect the 4 to 20mA output from accidental shorts to ac line voltages. The circuit shown in Figure 6 can be used for this purpose. The maximum permissible load resistance will be lowered by a fuse resistance value when protection circuitry is utilized.

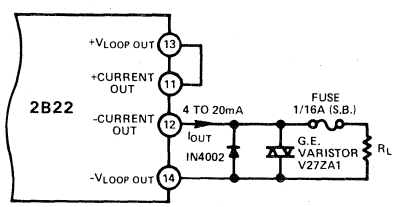



*Figure 6. Output Protection Circuitry Connections*

## APPLICATIONS IN INDUSTRIAL MEASUREMENT AND CONTROL SYSTEMS

**Process Signal Isolator:** In process control applications, model 2B22 can be applied to interface standard process signals (e.g. 1 to 5mA, 4 to 20mA, 10 to 50mA, 1 to 5V) and convert them to isolated 4 to 20mA output. A typical hook-up of model 2B22 is illustrated in Figure 7, showing input resistor $R_C$ converting the current from a remote loop to a voltage input, and a span adjustment resistor $R_G$. A value of $R_C$ should be selected to develop a minimum of +1V signal with full scale input current applied. For example, a 50Ω resistor converts the 4 to 20mA current input to a 200mV to 1V voltage input, which the 2B22 isolates and converts to a 4 to 20mA output. The reference input (pin 2) is not connected since the process signal provides a desired offset.

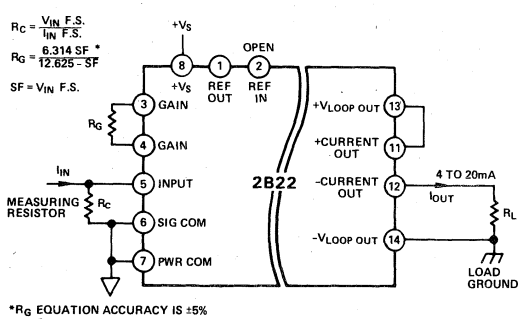



*Figure 7. Process Signal Current Isolator*

**Isolated D/A Converter:** Model 2B22 offers total ground isolation and protection from high voltage transients in interfacing D/A converters to standard 4 to 20mA current loops. This requirement is common in a microcomputer-based control system. The voltage necessary to power the current loop can be derived from the same +15V supply that is used to power the D/A converter. The D/A converter, such as the 12-bit AD DAC80, should be connected for operation on the unipolar 0 to +10V output range. This is shown in Figure 8. After the load resistor connection has been made, the current loop can be calibrated using the offset and span adjustment potentiometers associated with the 2B22. First, a digital input code of all one's is loaded into the D/A, and the offset adjustment potentiometer is adjusted for a current output of exactly 4mA. Then, a digital code of all zero's is loaded into the D/A, and the span adjustment potentiometer is adjusted for a voltage across the load that corresponds to a current of 20mA less 1LSB (19.9961mA).

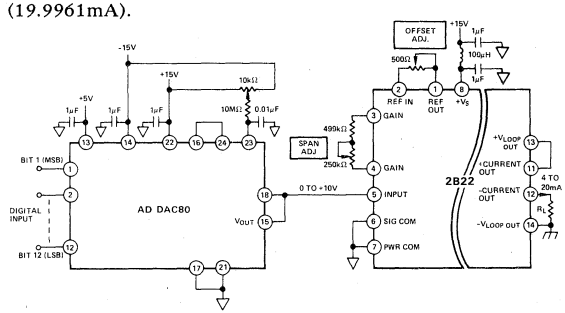



*Figure 8. D/A Converter – Isolated 4 to 20mA Interface*

**Pressure Transmitter:** In Figure 9, model 2B22 is used in a pressure transmitter application to provide complete input-output isolation and avoid signal errors due to ground loop currents. The process pressure is monitored with a strain gage type pressure transducer interfaced by the Analog Devices' model 2B30 transducer conditioner. The bridge excitation and system power is provided by the model 2B35 triple output power supply. The high level voltage output of the 2B30 is converted to the isolated 4 to 20mA current for transmission to a remote recorder or indicator.

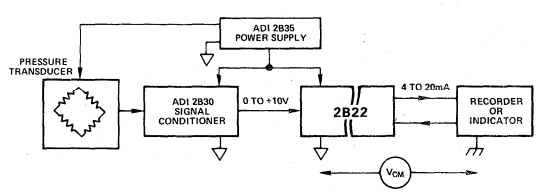


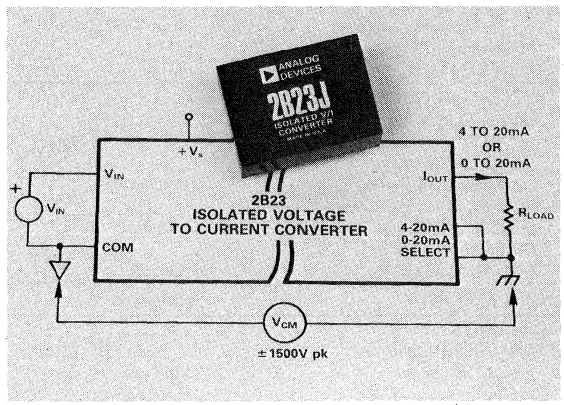

*Figure 9. Isolated Pressure Transmitter*

# Programmable Output, Isolated Voltage-to-Current Converter

# MODEL 2B23

**FEATURES**
- **Wide Input Range, Resistor Programmable**
- **Pin Programmable Output: 4 to 20mA or 0 to 20mA**
- **High CMV Input/Output Isolation: ±1500V pk Continuous**
- **Low Nonlinearity: ±0.05% max (2B23K)**
- **Low Span Drift: ±0.005%/°C max (2B23K)**
- **Single Supply Operation: +14V to +28V**
- **Small Size: 1.8″ × 2.4″ × 0.6″**
- **Meets IEEE Std. 472: Transient Protection (SWC)**
- **Meets ISA Std. 50.1: Isolated Current Loop Transmitters**

**APPLICATIONS**
- **Industrial Instrumentation and Process Control**
  - **Ground Loop Elimination**
  - **Transient Voltage Protection**
- **Analog Transmitters and Controllers**
- **Remote Data Acquisition Systems**




9

## GENERAL DESCRIPTION

The model 2B23 is a high performance, low cost voltage to current converter featuring ±1500V pk input to output isolation for interfacing with standard process signals. The input stage of the 2B23 may be single resistor programmed to accept voltages within a 0 to +10V range (+0.1V to +10V full scale). The isolated output is pin programmable to provide current in the range of 4 to 20mA or 0 to 20mA and can be operated with 0 to 800Ω grounded or floating loads.

The 2B23 uses reliable transformer isolation techniques and is available in two accuracy selections offering guaranteed nonlinearity error (2B23K: ±0.05% max, 2B23J: ±0.1% max) and guaranteed low span drift (2B23K: ±0.005%/°C max, 2B23J: ±0.01%/°C max). The internally trimmed span and offset errors are ±0.1% for the 2B23K and ±0.25% for the 2B23J. Both span and offset may be adjusted using optional external potentiometers.

Featuring wide range, single supply operation (+14V to +28V dc), the 2B23 provides isolated loop power, thus eliminating the need for an external dc/dc converter.

## APPLICATIONS

Model 2B23 has been designed to provide high accuracy, versatility and low cost in industrial and laboratory system applications requiring isolated current transmission. The 2B23 meets the requirements of the Instrument Society of America Std. 50.1 "Compatibility of Analog Signals for Electronic Industrial Process Instruments" and may serve as a transmission link between such system elements as computers, controllers, actuators, recorders and indicators.

In data acquisition and control systems, the 2B23 may act as an isolated interface between the D/A converter output of a microcomputer analog I/O and standard 4 to 20mA or 0 to 20mA analog loops. In process control systems, the 2B23 may be used as a current output stage of a proportional controller to interface devices such as current-to-position converters and current-to-pneumatic transducers.

## DESIGN FEATURES AND USER BENEFITS

**High CMV Isolation:** The 2B23 features high input to output galvanic isolation to eliminate ground loops and offer protection against damage from transients and fault voltages. Its isolation barrier will withstand continuous CMV of ±1500V pk and 1500V rms @ 60Hz for 60 seconds.

**High Reliability:** To assure high reliability in harsh industrial environments, reliable magnetic isolation is used. The 2B23 meets the IEEE Standard for Transient Voltage Protection (472–1974: Surge Withstand Capability) and offers reliable operation over −25°C to +85°C temperature range.

**Versatility:** The 2B23 can be easily tailored to the user's application, accommodating a wide range of input voltages, providing pin programmable, standard current outputs and offering wide range, single supply operation.

**Small Size:** To conserve board space, the 2B23 is packaged in a compact, 1.8″ × 2.4″ × 0.6″ module.

# SPECIFICATIONS (typical @ +25°C and $V_S$ = +15V unless otherwise noted)

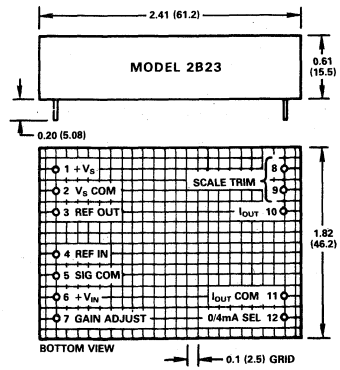
| Model | 2B23J | 2B23K |
|---|---|---|
| INPUT SPECIFICATIONS | | |
| Input Voltage Range | | |
| Factory Calibrated | 0 to +10V | * |
| Full Scale Input | +0.1V min to +10V max | * |
| Transfer Function (TF) | | |
| Factory Calibrated | 1.6mA/V | * |
| User Programmable | 1.6mA/V to 200mA/V | * |
| Maximum Safe Input | ±15V | * |
| Input Impedance | 10MΩ | * |
| OUTPUT SPECIFICATIONS | | |
| Current Output Range | | |
| User Selectable | 4 to 20mA, 0 to 20mA | * |
| Load Resistance Range | | |
| Internal Loop Power | 0 to 800Ω max | * |
| Maximum Output Current | | |
| @ Input Overload | 22mA typ | * |
| Output Noise | | |
| 100Hz Bandwidth | 1.5μA pk-pk | * |
| NONLINEARITY | ±0.1% max | ±0.05% max (±0.02% typ) |
| ISOLATION | | |
| CMV, Input to Output | | |
| ac, 60Hz, 1 min | 1500V rms | * |
| Continuous, ac or dc | ±1500V pk | * |
| Transient Protection | IEEE Std. 472 (SWC) | * |
| CMR | | |
| @ 60Hz, 1kΩ Source Imbalance | 86dB | * |
| ACCURACY[1] | | |
| Warm Up Time to Rated Performance | 5 Minutes | * |
| Total Output Error @ +25°C[2,3] | | |
| Offset ($V_{IN}$ = 0V) | ±0.25% max | ±0.1% max |
| Span ($V_{IN}$ = +10V) | ±0.25% max | ±0.1% max |
| vs. Temperature (0 to +70°C) | | |
| Offset, 4-20mA Mode | ±0.01%/°C max | ±0.005%/°C max |
| 0-20mA Mode | ±0.01%/°C typ | ±0.005%/°C typ |
| Span, Both Modes | ±0.01%/°C max | ±0.005%/°C max |
| DYNAMIC RESPONSE | | |
| Settling Time to 0.1% of FS for 10V Step | 5ms | * |
| Small Signal Bandwidth | 400Hz | * |
| POWER SUPPLY | | |
| Voltage, Rated Performance (+$V_S$) | +15V dc | * |
| Voltage, Operating | +14V min to +28V max | * |
| Supply Current (@ 20mA Output) | 75mA | * |
| Supply Change Effect | | |
| on Offset and Span | ±0.0015%/V | * |
| ENVIRONMENTAL | | |
| Temperature Range | | |
| Rated Performance | 0 to +70°C | * |
| Operating | −25°C to +85°C | * |
| Relative Humidity | | |
| per MIL-STD 202, Method 103B | ±0.2% Error | * |
| RFI Immunity | | |
| 27MHz @ 5W @ 3ft | ±0.1% Error | * |
| CASE SIZE | 1.8″ × 2.4″ × 0.6″ | * |

NOTES
[1]Accuracy is guaranteed @ TF = 1.6mA/V with no external trim adjustments when connected in the basic configuration.
[2]All accuracy is % of span where span is 16mA (i.e., ±0.1% = 0.016mA error).
[3]Span T.C. for transfer functions higher than 1.6mA/V is $R_G$ dependent – low T.C. (±10ppm/°C) $R_G$ recommended for best performance.

*Specifications same as 2B23J.
Specifications subject to change without notice.

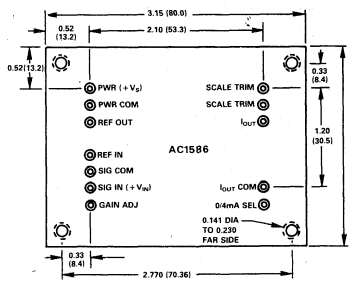
## OUTLINE DIMENSIONS

Dimensions shown in inches and (mm).




## MATING SOCKET: AC1586

Dimensions shown in inches and (mm).



## FUNCTIONAL DESCRIPTION

The high performance of model 2B23 is derived from the carrier isolation technique which is used to transfer both signal and power between the V/I converter's input circuitry and the output stage. High CMV isolation is achieved by the transformer coupling between the input amplifier stage, modulator, and current output circuitry. A block diagram of the 2B23 is shown in Figure 1.

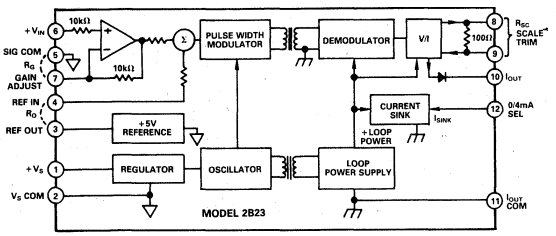



*Figure 1. 2B23 Functional Block Diagram*

The model 2B23 produces an isolated 4 to 20mA or 0 to 20mA output current which is proportional to the input voltage and independent of the output load resistance. The input amplifier accepts a positive voltage within the range of 0 to +10V. The transfer function of the input stage may be set from 1.6mA/V to 200mA/V (dependent upon the output current range desired) by changing the gain resistor $R_G$ connected between pins 5 and 7.

An internal, high stability reference having a nominal output voltage of +5V (REF OUT) is used to develop a 4mA output current for a 0 volts input. REF OUT (Pin 3) and REF IN (Pin 4) should be connected via the offset scaling resistor $R_O$. An output current bypass section allows scaling of the nominal 4 to 20mA output current to a range of 0 to 20mA. This is accomplished by connecting the output range select pin (Pin 12) to the $I_{OUT}$ pin (Pin 10) thereby providing a bypass for the 4mA. For 4-20mA operation, the bypass pin is connected to $I_{OUT}$ COMMON (Pin 11).

The 2B23 is designed to operate from a single positive power supply ($+V_S$) over a range of +14V to +28V dc. The power supply section consists of an input voltage regulator, a dc/dc converter, plus associated rectifying and filtering circuitry. The dc/dc converter generates isolated loop power which is independent of $V_S$ and capable of driving the maximum load resistance (resistance of receivers plus the resistance of connecting wire) of 800Ω. The current capability of the power supply ($+V_S$) must be 75mA minimum to supply full output signal current.

## BASIC INTERCONNECTIONS

The 2B23 may be applied to achieve rated performance as shown in Figure 2. The transfer function of 1.6mA/V, for conversion of the 0 to +10V input signal into a 4 to 20mA output current, is obtained using the values shown ($R_O$ = 10kΩ, $R_{SC}$ = 301Ω, $R_G$ open). For best performance, $R_{SC}$ should be a metal film, ±0.1% tolerance, 25ppm/°C resistor and $R_O$ should be ±1%, 100ppm/°C.

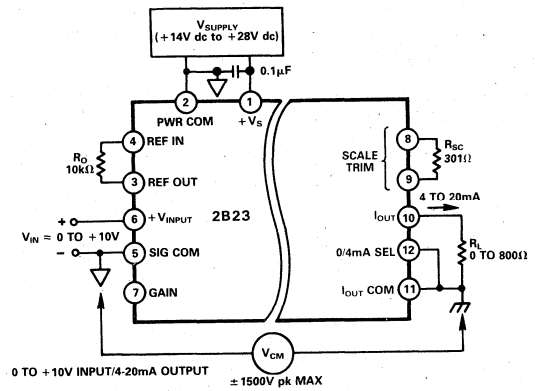



*Figure 2. Basic Interconnections*

A power supply ($+V_S$) is connected to Pin 1. To avoid ground loops, the user should ensure that the input signal return (SIG COM) does not carry the power supply return current. Power common (Pin 2) and signal common (Pin 5) should be tied at the power supply common terminal.

9

## OPTIONAL TRIM ADJUSTMENTS

Model 2B23 is factory calibrated for a 0 to +10V input range and an output of 4 to 20mA, meeting its listed specifications without use of any external trim potentiometers. If desired, optional span and zero trim adjustments may be easily accomplished as described in the following sections.

**Input Gain Adjustment:** The input gain of the 2B23 is a scale factor setting that establishes the nominal conversion relationship to accommodate +1V to +10V full scale inputs ($V_{IN}$). In addition, full scale inputs as low as 100mV may be accommodated.

The value of the gain setting resistor $R_G$ is determined by: $R_G$ (kΩ) = 10kΩ/(G − 1) where G represents a ratio of 10V/$V_{IN}$(V) F.S. For example, to convert a 0 to +1V input to 4 to 20mA output, $V_{IN}$ F.S. = +1V and G = 10V/1V = 10, therefore $R_G$ = 10kΩ/9 = 1.1kΩ. Due to resistor tolerances, allowance should be made to vary $R_G$ by using a series cermet type potentiometer (Figure 3). For best performance, $R_G$ should be a metal film, 1% tolerance, 25ppm/°C resistor.

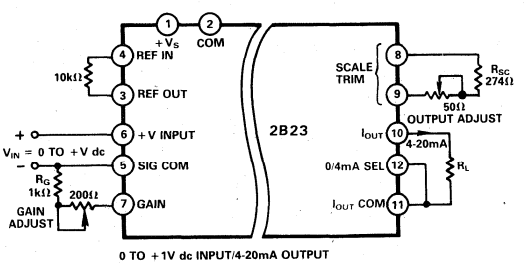
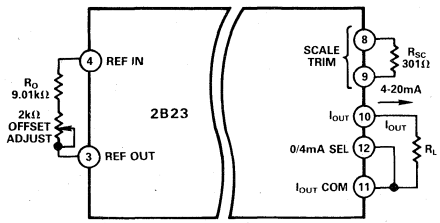


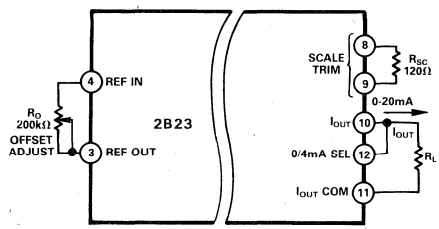

*Figure 3. Input Gain Adjustment*

**Offset and Output Scaling Adjustments:** After selecting the required input stage gain, the 2B23 must then be configured for either 4 to 20mA or 0 to 20mA output current range. Figures 4a and 4b illustrate the respective methods for each. The value of the offset resistor $R_O$ is independent from the gain setting and may be adjusted by a series cermet pot.

For fine adjustment of the output current, $R_{SC}$ value should be trimmed as shown in Figure 3.




*4a. 4-20mA Output Connections*




*4b. 0-20mA Output Connections*

*Figure 4. 4-20mA/0-20mA Scaling Connections*

## USING MULTIPLE 2B23s

Unlike other transformer-based isolators, the 2B23 does not require any synchronizing circuits to eliminate beat frequency related output errors in multichannel applications. This is due to the use of pulse-width modulation technique in the 2B23. Radiated individual oscillator frequencies will have no effect upon performance, even in situations requiring multiple 2B23s to be located in close proximity to one another. For this reason, no provisions for external synchronization are necessary.

## OUTPUT PROTECTION

The current output terminals (Pins 10 and 11) are protected for reverse voltage and shorts up to +32V dc but in many industrial applications it may be necessary to protect the 4 to 20mA from accidental shorts to ac line voltages. The circuit shown in Figure 5 may be employed for this purpose. The maximum permissible load resistance will be lowered by a fuse resistance value when protection circuitry is utilized.

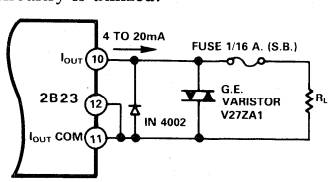



*Figure 5. Output Protection Circuitry*

## APPLICATIONS

In Figure 6, model 2B23 is used in multiloop application of the data acquisition and control system to provide isolated current interface to a recorder, indicator and a valve positioner.

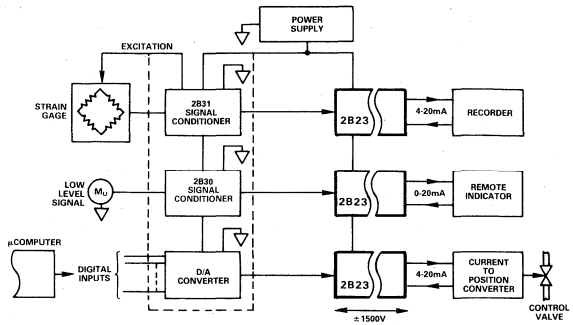



*Figure 6. Multiloop Isolation*

In applications requiring current to voltage conversion, the 2B23 may be used as shown in Figure 7. An external −10V reference is used to provide necessary input offset. This circuit will provide ±1500V isolation in converting 4-20mA into a 0 to +10V output. The output measurement device must have a high input impedance to avoid loading errors.

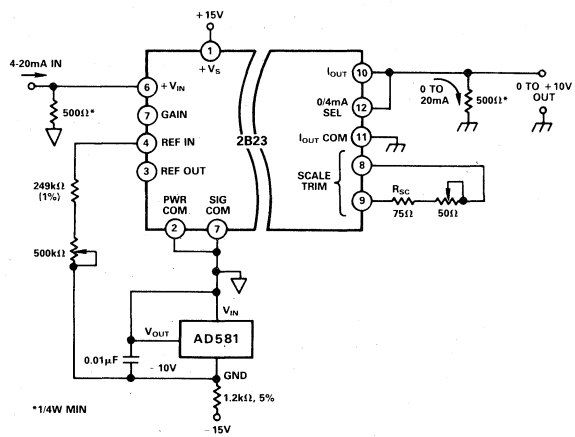



*Figure 7. 4-20mA to 0 to +10V Isolated Converter*

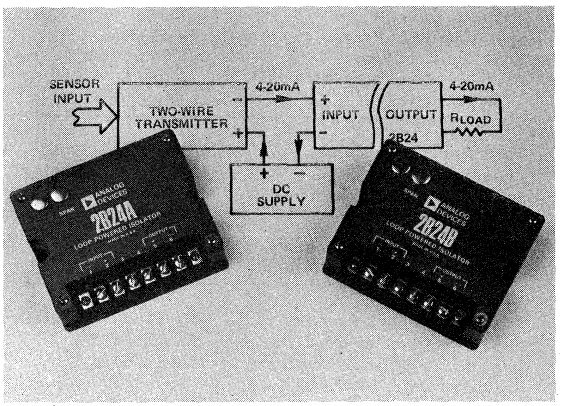
ANALOG DEVICES

# Loop Powered Isolator

# MODEL 2B24

**FEATURES**
**Self-Powered**
**Wide Input Range: 1-50mA (2B24B)**
**High CMV Isolation: ±1500V pk; CMR: 120dB**
**High Accuracy: ±0.1%**
**RFI/EMI Immunity**
**Low Cost**

**APPLICATIONS**
**Ground Loop Elimination**
**Transient Voltage Protection**




9

## GENERAL DESCRIPTION

The model 2B24 is a low cost, loop-powered isolator designed to accept input current in the range of 1-50mA and provide an isolated output current proportional to the input. The 2B24 is powered by the input signal and does not require an external power supply.

Two basic models are available for signal ranges of 4-20mA (2B24A) and 4-20mA or 10-50mA (2B24B). Both feature high accuracy (±0.1%), high input to output isolation (±1500V pk, continuous), and high CMR (120dB). Other features include low input signal loop burden, low sensitivity to variations in load, as well as excellent stability (±0.01%/°C) over a wide ambient temperature range (-30°C to +85°C).

A rugged metal enclosure, suitable for field mounting, offers environmental protection and screw terminal input and output connections. This enclosure may be either surface or relay track mounted.

## APPLICATIONS

The 2B24 is designed to eliminate ground loop problems and high common mode noise interference in process control, monitoring and factory automation systems. It is especially useful for providing individual isolation of many current loop outputs operating from a common source of dc power.

## OPERATION

The 2B24 is factory calibrated to accuracy of ±0.1% of span. A user accessible span trim potentiometer providing ±3% adjustment range permits precise field calibration. This may be accomplished by connecting normal operating load resistance and adjusting SPAN for a 20.00mA output when an input is 20.00mA.

A wide range of load resistance (up to 600Ω @ 20mA and 240Ω @ 50mA) may be accommodated by the 2B24. The transmitter supplying power to the 2B24 must be capable of furnishing the necessary input voltage for the given load and desired maximum output current.

## DESIGN FEATURES AND USER BENEFITS

**High Isolation:** Input to output isolation eliminates ground loops and allows ±1500V potential difference between the input and the output.

**Loop Powered:** All power required for the 2B24 is derived from the process loop, eliminating the need for an external supply and therefore reducing installation cost.

**High Noise Rejection:** The 2B24 features internal filtering to eliminate errors caused by EMI/RFI and line noise pickup.

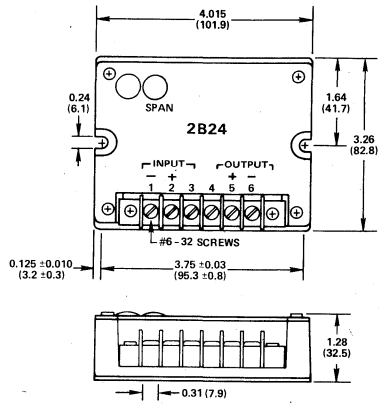
# SPECIFICATIONS (typical @ +25°C and $I_{IN}$ = 20mA unless otherwise noted)

| Model | 2B24A | 2B24B |
|---|---|---|
| **INPUT SPECIFICATIONS** | | |
| Input Signal | 4-20mA | 4-20mA, 10-50mA |
| Maximum Input Range | 1-30mA | 1-50mA |
| Input Voltage Requirement[1] | 3.5V+ $I_{OUT}$ RL | * |
| **OUTPUT SPECIFICATIONS** | | |
| Output Signal | 4-20mA | 4-20mA, 10-50mA |
| Maximum Output Range | 1-30mA | 1-50mA |
| Span Adjustment Range | ±3% of Span | * |
| Load Resistance Range | 0 to 600Ω @ 20mA | 0 to 240Ω @ 50mA |
| Load Resistance Change Effect per 10Ω Change | ±0.15% of Span | * |
| **ACCURACY** | | |
| Total Output Error[2] | ±0.1% @ $R_L$ = 300Ω | ±0.1% @ $R_L$ = 120Ω |
| Linearity | ±0.05% @ $R_L$ = 300Ω | ±0.05% @ $R_L$ = 120Ω |
| Span Stability vs. Temperature | ±0.01%/°C | * |
| **ISOLATION** | | |
| CMV, Input to Output, Continuous | ±1500V pk | * |
| Common Mode Rejection @ 60Hz | 120dB @ $R_L$ = 300Ω | 120dB @ $R_L$ = 120Ω |
| **ENVIRONMENTAL** | | |
| Temperature Range, Operating | -30°C to +85°C | * |
| Storage Temperature Range | -55°C to +125°C | * |
| Humidity Effect, Span Error[3] | ±0.2% of Span | * |
| RFI Effect (5W @ 470MHz @ 3 ft.) Error | ±0.5% of Span | * |
| **PHYSICAL** | | |
| Case Size | 4" X 3.25" X 1.25" | * |
| Weight | 8.5 oz (240g) | * |

NOTES
[1] Includes 3.5V plus voltage drop across output load.
[2] Accuracy is specified as a percent of output span and includes combined effects of repeatability, hysteresis, and linearity.
[3] Per MIL-STD-202, Method 103.
*Specifications same as 2B24A.
Specifications subject to change without notice.

## OUTLINE DIMENSIONS (MAX)

Dimensions shown in inches and (mm).



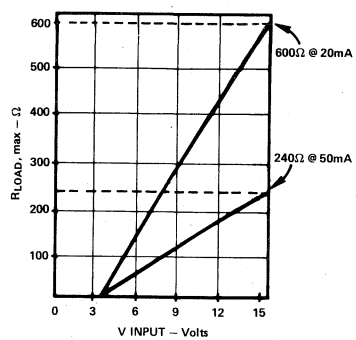




*Figure 2. Required $V_{INPUT}$ vs. $R_{LOAD}$ (max) - 2B24A & B*

## BASIC APPLICATIONS

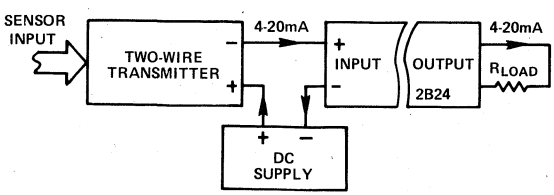



*Figure 1a. Two-Wire Transmitter Application*

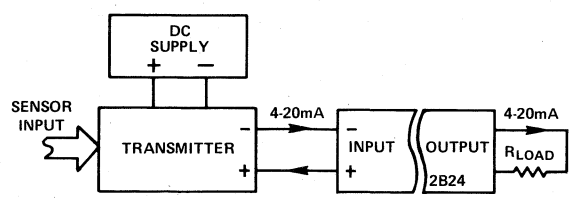



*Figure 1b. Four-Wire Transmitter Application*

# High Performance, Economy Strain Gage/RTD Conditioners

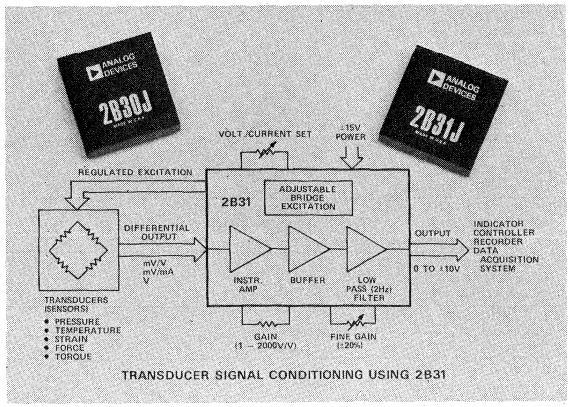
# MODELS 2B30 AND 2B31

**FEATURES**

- Low Cost
- Complete Signal Conditioning Function
- Low Drift: 0.5μV/°C max ("L"); Low Noise: 1μV p-p max
- Wide Gain Range: 1 to 2000V/V
- Low Nonlinearity: 0.0025% max ("L")
- High CMR: 140dB min (60Hz, G = 1000V/V)
- Input Protected to 130V rms
- Adjustable Low Pass Filter: 60dB/Decade Roll-Off (from 2Hz)
- Programmable Transducer Excitation: Voltage (4V to 15V @ 100mA) or Current (100μA to 10mA)

**APPLICATIONS**

- Measurement and Control of: Pressure, Temperature, Strain/Stress, Force, Torque
- Instrumentation: Indicators, Recorders, Controllers
- Data Acquisition Systems
- Microcomputer Analog I/O



TRANSDUCER SIGNAL CONDITIONING USING 2B31

9

## GENERAL DESCRIPTION

Models 2B30 and 2B31 are high performance, low cost, compact signal conditioning modules designed specifically for high accuracy interface to strain gage-type transducers and RTD's (resistance temperature detectors). The 2B31 consists of three basic sections: a high quality instrumentation amplifier; a three-pole low pass filter, and an adjustable transducer excitation. The 2B30 has the same amplifier and filter as the 2B31, but no excitation capability.

Available with low offset drift of 0.5μV/°C max (RTI, G = 1000V/V) and excellent linearity of 0.0025% max, both models feature guaranteed low noise performance 1μV p-p max, and outstanding 140dB common mode rejection (60Hz, CMV = ±10V, G = 1000V/V) enabling the 2B30/2B31 to maintain total amplifier errors below 0.1% over a 20°C temperature range. The low pass filter offers 60dB/decade roll-off from 2Hz to reduce normal-mode noise bandwidth and improve system signal-to-noise ratio. The 2B31's regulated transducer excitation stage features a low output drift (0.015%/°C max) and a capability of either constant voltage or constant current operation.

Gain, filter cutoff frequency, output offset level and bridge excitation (2B31) are all adjustable, making the 2B30/2B31 the industry's most versatile high-accuracy transducer-interface modules. Both models are offered in three accuracy selections, J/K/L, differing only in maximum nonlinearity and offset drift specifications.

## APPLICATIONS

The 2B30/2B31 may be easily and directly interfaced to a wide variety of transducers for precise measurement and control of pressure, temperature, stress, force and torque. For applications in harsh industrial environments, such characteristics as high CMR, input protection, low noise, and excellent temperature stability make 2B30/2B31 ideally suited for use in indicators, recorders, and controllers.

The combination of low cost, small size and high performance of the 2B30/2B31 offers also exceptional quality and value to the data acquisition system designer, allowing him to assign a conditioner to each transducer channel. The advantages of this approach over low level multiplexers include significant improvements in system noise and resolution, and elimination of crosstalk and aliasing errors.

## DESIGN FEATURES AND USER BENEFITS

**High Noise Rejection:** The true differential input circuitry with high CMR (140dB) eliminating common-mode noise pickup errors, input filtering minimizing RFI/EMI effects, output low pass filtering ($f_c$=2Hz) rejecting 50/60Hz line frequency pickup and series-mode noise.

**Input and Output Protection:** Input protected for shorts to power lines (130V rms), output protected for shorts to ground and either supply.

**Ease of Use:** Direct transducer interface with minimum external parts required, convenient offset and span adjustment capability.

**Programmable Transducer Excitation:** User-programmable adjustable excitation source-constant voltage (4V to 15V @ 100mA) or constant current (100μA to 10mA) to optimize transducer performance.

**Adjustable Low Pass Filter:** The three-pole active filter ($f_c$=2Hz) reducing noise bandwidth and aliasing errors with provisions for external adjustment of cutoff frequency.

# SPECIFICATIONS (typical @ +25°C and $V_S$ = ±15V unless otherwise noted)

| MODEL | 2B30J<br>2B31J | 2B30K<br>2B31K | 2B30L<br>2B31L |
|---|---|---|---|
| GAIN[1] | | | |
| Gain Range | 1 to 2000V/V | * | * |
| Gain Equation | $G = (1 + 94k\Omega/R_G)$ [$20k\Omega/(R_F + 16.2k\Omega)$] | * | * |
| Gain Equation Accuracy | ±2% | * | * |
| Fine Gain (Span) Adjust. Range | ±20% | * | * |
| Gain Temperature Coefficient | ±25ppm/°C max (±10ppm/°C typ) | * | * |
| Gain Nonlinearity | ±0.01% max | ±0.005% max | ±0.0025% max |
| OFFSET VOLTAGES[1] | | | |
| Total Offset Voltage, Referred to Input | | | |
| Initial, @ +25°C | Adjustable to Zero (±0.5mV typ) | * | * |
| Warm-Up Drift, 10 Min., G = 1000 | ±5µV RTI | * | * |
| vs. Temperature | | | |
| G = 1V/V | ±150µV/°C max | ±75µV/°C max | ±50µV/°C max |
| G = 1000V/V | ±3µV/°C max | ±1µV/°C max | ±0.5µV/°C max |
| At Other Gains | ±(3 ± 150/G)µV/°C max | ±(1 ± 75/G)µV/°C max | ±(0.5 ± 50/G)µV/°C max |
| vs. Supply, G = 1000V/V | ±25µV/V | * | * |
| vs. Time, G = 1000V/V | ±3µV/month | * | * |
| Output Offset Adjust. Range | ±10V | * | * |
| INPUT BIAS CURRENT | | | |
| Initial @ +25°C | +200nA max (100nA typ) | * | * |
| vs. Temperature (0 to +70°C) | -0.6nA/°C | * | * |
| INPUT DIFFERENCE CURRENT | | | |
| Initial @ +25°C | ±5nA | * | * |
| vs. Temperature (0 to +70°C) | ±40pA/°C | * | * |
| INPUT IMPEDANCE | | | |
| Differential | 100MΩ‖47pF | * | * |
| Common Mode | 100MΩ‖47pF | * | * |
| INPUT VOLTAGE RANGE | | | |
| Linear Differential Input | ±10V | * | * |
| Maximum Differential or CMV Input Without Damage | 130V rms | * | * |
| Common Mode Voltage | ±10V | * | * |
| CMR, 1kΩ Source Imbalance | | | |
| G = 1V/V, dc to 60Hz[1] | 90dB | * | * |
| G = 100V/V to 2000V/V, 60Hz[1] | 140dB min | * | * |
| dc[2] | 90dB min (112 typ.) | * | * |
| INPUT NOISE | | | |
| Voltage, G = 1000V/V | | | |
| 0.01Hz to 2Hz | 1µV p-p max | * | * |
| 10Hz to 100Hz[2] | 1µV p-p | * | * |
| Current, G = 1000 | | | |
| 0.01Hz to 2Hz | 70pA p-p | * | * |
| 10Hz to 100Hz[2] | 30pA rms | * | * |
| RATED OUTPUT[1] | | | |
| Voltage, 2kΩ Load[3] | ±10V min | * | * |
| Current | ±5mA min | * | * |
| Impedance, dc to 2Hz, G = 100V/V | 0.1Ω | * | * |
| Load Capacitance | 0.01µF max | * | * |
| DYNAMIC RESPONSE (Unfiltered)[2] | | | |
| Small Signal Bandwidth | | | |
| -3dB Gain Accuracy, G = 100V/V | 30kHz | * | * |
| G = 1000V/V | 5kHz | * | * |
| Slew Rate | 1V/µs | * | * |
| Full Power | 15kHz | * | * |
| Settling Time, G = 100, ±10V Output Step to ±0.1% | 30µs | * | * |
| LOW PASS FILTER (Bessel) | | | |
| Number of Poles | 3 | * | * |
| Gain (Pass Band) | +1 | * | * |
| Cutoff Frequency (-3dB Point) | 2Hz | * | * |
| Roll-Off | 60dB/decade | * | * |
| Offset (at 25°C) | ±5mV | * | * |
| Settling Time, G = 100V/V, ±10V Output Step to ±0.1% | 600ms | * | * |
| BRIDGE EXCITATION (See Table 1) — Page 4 | | | |
| POWER SUPPLY[4] | | | |
| Voltage, Rated Performance | ±15V dc | * | * |
| Voltage, Operating | ±(12 to 18)V dc | * | * |
| Current, Quiescent | ±15mA | * | * |
| TEMPERATURE RANGE | | | |
| Rated Performance | 0 to +70°C | * | * |
| Operating | -25°C to +85°C | * | * |
| Storage | -55°C to +125°C | * | * |
| CASE SIZE | 2" x 2" x 0.4" (51 x 51 x 10.2mm) | * | * |

NOTES

*Specifications same as 2B30J/2B31J.

[1] Specifications referred to output at pin 7 with 3.75k, 1%, 25ppm/°C fine span resistor installed and internally set 2Hz filter cutoff frequency.

[2] Specifications referred to the unfiltered output at pin 1.

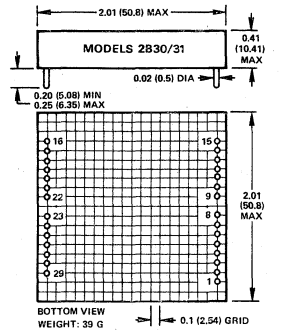
[3] Protected for shorts to ground and/or either supply voltage.

[4] Recommended power supply ADI model 902-2 or model 2B35 transducer power supply (for 2B30).

Specifications subject to change without notice.

## OUTLINE DIMENSIONS

Dimensions shown in inches and (mm).

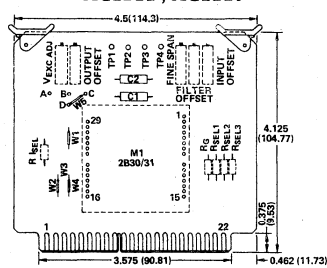



## PIN DESIGNATIONS

| PIN | FUNCTION | PIN | FUNCTION |
|---|---|---|---|
| 1 | OUTPUT 1 (UNFILTERED) | 16 | EXC SEL 1 |
| 2 | FINE GAIN (SPAN) ADJ. | 17 | I SEL |
| 3 | FINE GAIN (SPAN) ADJ. | 18 | $V_{EXC\ OUT}$ |
| 4 | FILTER OFFSET TRIM | 19 | $I_{EXC\ OUT}$ |
| 5 | FILTER OFFSET TRIM | 20 | SENSE HIGH (+) |
| 6 | BANDWIDTH ADJ. 3 | 21 | EXC SEL 2 |
| 7 | OUTPUT 2 (FILTERED) | 22 | REF OUT |
| 8 | BANDWIDTH ADJ. 2 | 23 | SENSE LOW (-) |
| 9 | BANDWIDTH ADJ. 1 | 24 | REGULATOR $+V_{R\ IN}$ |
| 10 | $R_{GAIN}$ | 25 | REF IN |
| 11 | $R_{GAIN}$ | 26 | $-V_S$ |
| 12 | -INPUT | 27 | $+V_S$ |
| 13 | INPUT OFFSET TRIM | 28 | COMMON |
| 14 | INPUT OFFSET TRIM | 29 | OUTPUT OFFSET TRIM |
| 15 | + INPUT | | |

Note: Pins 16 thru 25 are not connected in Model 2B30

## MOUNTING CARDS AC1211 ; AC1213




## AC1211/AC1213 CONNECTOR DESIGNATIONS

| PIN | FUNCTION | PIN | FUNCTION |
|---|---|---|---|
| A | REGULATOR $+V_{R\ IN}$ | 1 | EXC SEL 1 |
| B | SENSE LOW (-) | 2 | I SEL |
| C | REF OUT | 3 | $V_{EXC\ OUT}$ |
| D | REF IN | 4 | $I_{EXC\ OUT}$ |
| E | | 5 | SENSE HIGH (+) |
| F | | 6 | EXC SEL 2 |
| H | | 7 | OUTPUT OFFSET TRIM |
| J | | 8 | |
| K | $-V_S$ | 9 | $-V_S$ |
| L | $+V_S$ | 10 | $+V_S$ |
| M | | 11 | |
| N | COMMON | 12 | COMMON |
| P | | 13 | |
| R | FINE GAIN ADJ. | 14 | |
| S | FINE GAIN ADJ. | 15 | |
| T | FILTER OFFSET TRIM | 16 | |
| U | FILTER OFFSET TRIM | 17 | $R_{GAIN}$ |
| V | OUTPUT 2 (FILTERED) | 18 | $R_{GAIN}$ |
| W | - INPUT | 19 | OUTPUT 1 (UNFILTERED) |
| X | INPUT OFFSET TRIM | 20 | BANDWIDTH ADJ. 1 |
| Y | INPUT OFFSET TRIM | 21 | BANDWIDTH ADJ. 3 |
| Z | + INPUT | 22 | BANDWIDTH ADJ. 2 |

The AC1211/AC1213 mounting card is available for th 2B30/2B31. The AC1211/AC1213 is an edge connector card with pin receptacles for plugging in the 2B30/2B31 In addition, it has provisions for installing the gain resistors and the bridge excitation, offset adjustment and filter cutoff programming components. The AC1211/ AC1213 is provided with a Cinch 251-22-30-160 (or equivalent) edge connector. The AC1213 includes the adjustment pots; no pots are provided with the AC1211.

## FUNCTIONAL DESCRIPTION

Models 2B30 and 2B31 accept inputs from a variety of full bridge strain gage-type transducers or RTD sensors and convert the inputs to conditioned high level analog outputs. The primary transducers providing direct inputs may be 60Ω to 1000Ω strain gage bridges, four-wire RTD's or two- or three-wire RTD's in the bridge configuration.

The 2B30 and 2B31 employ a multi-stage design, shown in Figure 1, to provide excellent performance and maximum versatility. The input stage is a high input impedance ($10^8$ Ω), low offset and drift, low noise differential instrumentation amplifier. The design is optimized to accurately amplify low level (mV) transducer signals riding on high common mode voltages (±10V), with wide (1-2000V/V), single resistor ($R_G$), programmable gain to accommodate 0.5mV/V to 36mV/V transducer spans and 5Ω to 2000Ω RTD spans. The input stage contains protection circuitry for accidental shorts to power line voltage (130V rms) and RFI filtering circuitry.

The inverting buffer amplifier stage provides a convenient means of fine gain trim (0.8 to 1.2) by using a 10kΩ potentiometer ($R_F$); the buffer also allows the output to be offset by up to ±10V by applying a voltage to the noninverting input (pin 29). For dynamic, high bandwidth measurements—the buffer output (pin 1) should be used.

The three-pole active filter uses a unity-gain configuration and provides low-pass Bessel-type characteristics-minimum overshoot response to step inputs and a fast rise time. The cutoff frequency (-3dB) is factory set at 2Hz, but may be increased up to 5kHz by addition of three external resistors ($R_{SEL_1}$ - $R_{SEL_3}$).

## INTERCONNECTION DIAGRAM AND SHIELDING TECHNIQUES

Figure 1 illustrates the 2B31 wiring configuration when used in a typical bridge transducer signal conditioning application. A recommended shielding and grounding technique for preserving the excellent performance characteristics of the 2B30/2B31 is shown.

Because models 2B30/2B31 are direct coupled, a ground return path for amplifier bias currents must be provided either by direct connection (as shown) or by an implicit ground path having up to 1MΩ resistance between signal ground and conditioner common (pin 28). The sensitive input and gain setting terminals should be shielded from noise sources for best performance, especially at high gains. To avoid ground loops, signal return or cable shield should never be grounded at more than one point.

The power supplies should be decoupled with 1μF tantalum and 1000pF ceramic capacitors as close to the amplifier as possible.

## TYPICAL APPLICATION AND ERROR BUDGET ANALYSIS

Models 2B30/2B31 have been conservatively specified using min-max values as well as typicals to allow the designer to develop accurate error budgets for predictable performance. The error calculations for a typical transducer application, shown in Figure 1 (350Ω bridge, 1mV/V F.S., 10V excitation), are illustrated below.

Assumptions: 2B31L is used, G = 1000, ΔT = ±10°C, source imbalance is 100Ω, common mode noise is 0.25V (60Hz) on the ground return.

Absolute gain and offset errors can be trimmed to zero. The remaining error sources and their effect on system accuracy (worst case) as a % of Full Scale (10V) are listed:

| Error Source | Effect on Absolute Accuracy % of F.S. | Effect on Resolution % of F.S. |
|---|---|---|
| Gain Nonlinearity | ±0.0025 | ±0.0025 |
| Gain Drift | ±0.025 | |
| Voltage Offset Drift | ±0.05 | |
| Offset Current Drift | ±0.004 | |
| CMR | ±0.00025 | ±0.00025 |
| Noise (0.01 to 2Hz) | ±0.01 | ±0.01 |
| Total Amplifier Error | ±0.09175 max | ±0.01275 max |
| Excitation Drift | ±0.15 (±0.03 typ) | |
| Total Output Error (Worst Case) | ±0.24175 max (±0.1 typ) | ±0.0127 max |

The total worst case effect on absolute accuracy over ±10°C is less than ±0.25% and the 2B31 is capable of 1/2 LSB resolution in a 12 bit, low input level system. Since the 2B31 is conservatively specified, a typical overall accuracy error would be lower than ±0.1% of F.S.

In a computer or microprocessor based system, automatic recalibration can nullify gain and offset drifts leaving noise, nonlinearity and CMR as the only error sources. A transducer excitation drift error is frequently eliminated by a ratiometric operation with the system's A/D converter.

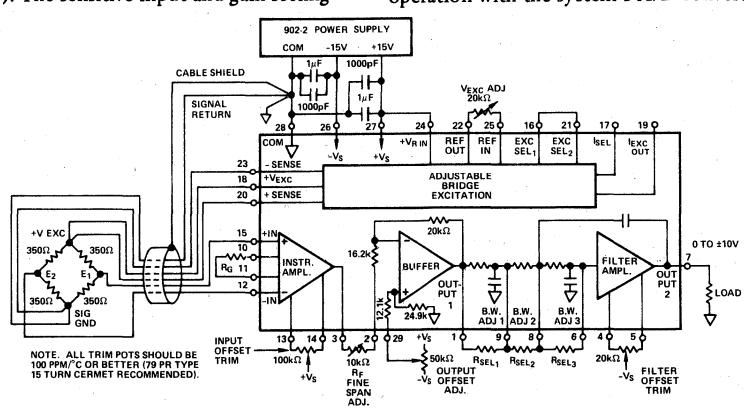



*Figure 1. Typical Bridge Transducer Application Using 2B31*

## BRIDGE EXCITATION (2B31)

The bridge excitation stage of the model 2B31 is an adjustable output, short circuit protected, regulated supply with internally provided reference voltage (+7.15V). The remote sensing inputs are used in the voltage output mode to compensate for the voltage drop variations in long leads to the transducer. The regulator circuitry input (pin 24) may be connected to $+V_S$ or some other positive dc voltage (pin 28 referenced) within specified voltage level and load current range. User-programmable constant voltage or constant current excitation mode may be used. Specifications are listed below in Table I.

| MODEL | 2B31J | 2B31K | 2B31L |
|---|---|---|---|
| Constant Voltage Output Mode | | | |
| Regulator Input Voltage Range | +9.5V to +28V | * | * |
| Output Voltage Range | +4V to +15V | * | * |
| Regulator Input/Output Voltage Differential | 3V to 24V | * | * |
| Output Current[1] | 0 to 100mA max | * | * |
| Regulation, Output Voltage vs. Supply | 0.05%/V | * | * |
| Load Regulation, $I_L$ = 1mA to $I_L$ = 50mA | 0.1% | * | |
| Output Voltage vs. Temperature (0 to +70°C) | 0.015%/°C max<br>0.003%/°C typ | *<br>* | *<br>* |
| Output Noise | 1mV rms | * | * |
| Reference Voltage (Internal) | 7.15V ±3% | * | * |
| Constant Current Output Mode | | | |
| Regulator Input Voltage Range | +9.5V to +28V | * | * |
| Output Current Range | 100μA to 10mA | * | * |
| Compliance Voltage | 0 to 10V | * | * |
| Load Regulation | 0.1% | * | * |
| Temperature Coefficient (0 to +70°C) | 0.003%/°C | * | * |
| Output Noise | 1μA rms | * | * |

[1] Output Current derated to 33mA max for 24V regulator input/output voltage differential.

*Table I. Bridge Excitation Specifications*

## OPERATING INSTRUCTIONS

**Gain Setting:** The differential gain, G, is determined according to the equation:

$$G = (1 + 94k\Omega/R_G)\ [20k\Omega/(R_F + 16.2k\Omega)]$$

where $R_G$ is the input stage resistor shown in Figure 1 and $R_F$ is the variable 10kΩ resistor in the output stage. For best performance, the input stage gain should be made as large as possible, using a low temperature coefficient (10ppm/°C) $R_G$, and the output stage gain can then be used to make a ±20% linear gain adjustment by varying $R_F$.

**Input Offset Adjustment:** To null input offset voltage, an optional 100kΩ potentiometer connected between pins 13 and 14 (Figure 1) can be used. With gain set at the desired value, connect both inputs (pins 12 and 15) to the system common (pin 28), and adjust the 100kΩ potentiometer for zero volts at pin 3. The purpose of this adjustment is to null the internal amplifier offset and it is not intended to compensate for the transducer bridge unbalance.

**Output Offset Adjustment:** The output of the 2B30/2B31 can be intentionally offset from zero over the ±10V range by applying a voltage to pin 29, e.g., by using an external potentiometer or a fixed resistor. Pin 29 is normally grounded if output offsetting is not desired. The optional filter amplifier offset null capability is also provided as illustrated in Figure 1.

**Filter Cutoff Frequency Programming:** The low pass filter cutoff frequency may be increased from the internally set 2Hz by the addition of three external resistors connected as shown in Figure 1. The values of resistors required for a desired cutoff frequency, $f_c$, above 5Hz are obtained by the equation below:

$$R_{SEL_1} = 11.6 \times 10^6/(2.67f_c - 4.34);$$

$$R_{SEL_2} = 27.6 \times 10^6/(4.12f_c - 7)$$

$$R_{SEL_3} = 1.05 \times 10^6/(0.806f_c - 1.3)$$

where $R_{SEL}$ is in ohms and $f_c$ in Hz. Table II gives the nearest 1% $R_{SEL}$ for several common filter cutoff (-3dB) frequencies.

| $f_c$ (Hz) | $R_{SEL1}$ (kΩ) (Pin 1 to 9) | $R_{SEL2}$ (kΩ) (Pin 9 to 8) | $R_{SEL3}$ (kΩ) (Pin 8 to 6) |
|---|---|---|---|
| 2 | Open | Open | Open |
| 5 | 1270.000 | 2050.00 | 383.000 |
| 10 | 523.000 | 806.00 | 154.000 |
| 50 | 90.000 | 137.00 | 26.700 |
| 100 | 44.200 | 68.10 | 13.300 |
| 500 | 8.660 | 13.30 | 2.610 |
| 1000 | 4.320 | 6.65 | 1.300 |
| 5000 | 0.866 | 1.33 | 0.261 |

*Table II. Filter Cutoff Frequency vs. $R_{SEL}$*

**Voltage Excitation Programming:** Pin connections for a constant voltage output operation are shown in Figure 2. The bridge excitation voltage, $V_{EXC}$, is adjusted between +4V to +15V by the 20kΩ (50ppm/°C) $R_{VSEL}$ potentiometer. For ratiometric operation, the bridge excitation can be adjusted by applying an external positive reference to pin 25 of the 2B31. The output voltage is given by: $V_{EXC\ OUT} = 3.265V_{REF\ IN}$. The remote sensing leads should be externally connected to the excitation leads at the transducer or jumpered as shown in Figure 2 if sensing is not required.

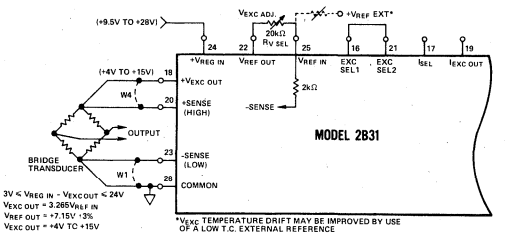



*Figure 2. Constant Voltage Excitation Connections*

**Current Excitation Programming:** The constant current excitation output can be adjusted between 100μA to 10mA by two methods with the 2B31. Figure 3 shows circuit configuration for a current output with the maximum voltage developed across the sensor (compliance voltage) constrained to +5V. The value of programming resistor $R_{ISEL}$ may be calculated from the relationship: $R_{ISEL} = (V_{REG\ IN} - V_{REF\ IN})/I_{EXC\ OUT}$.

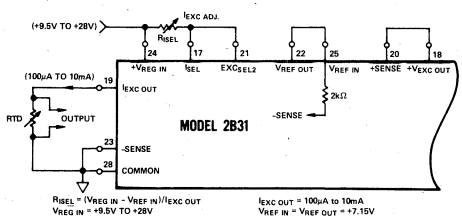



*Figure 3. Constant Current Excitation Connections ($V_{COMPL}$ = 0 to +5V)*

A compliance voltage range of 0 to +10V can be obtained by connecting the 2B31 as shown in Figure 4. The 2kΩ potentiometer $R_{ISEL}$ is adjusted for desired constant current excitation output.

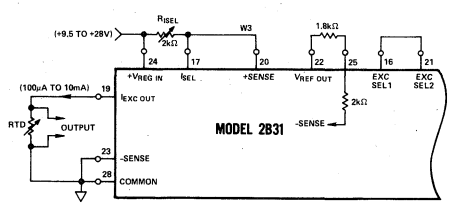



*Figure 4. Constant Current Excitation Connections ($V_{COMPL}$ = 0 to +10V)*

## APPLICATIONS

**Strain Measurement:** The 2B30 is shown in Figure 5 in a strain measurement system. A single active gage (120Ω, GF = 2) is used in a bridge configuration to detect small changes in gage resistance caused by strain. The temperature compensation is provided by an equivalent dummy gage and two high precision 120Ω resistors complete the bridge. The 2B35 adjustable power supply is set to a low +3V excitation voltage to avoid the self-heating error effects of the gage and bridge elements. System calibration produces a 1V output for an input of 1000 microstrains. The filter cutoff frequency is set at 100Hz.

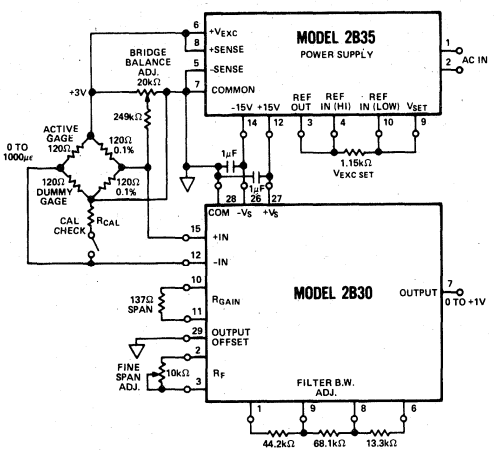



*Figure 5. Interfacing Half-Bridge Strain Gage Circuit*

**Pressure Transducer Interface:** A strain gage type pressure transducer (BLH Electronics, DHF Series) is interfaced by the 2B31 in Figure 6. The 2B31 supplies regulated excitation (+10V) to the transducer and operates at a gain of 333.3 to achieve 0-10V output for 0-10,000 p.s.i. at the pressure transducer. Bridge Balance potentiometer is used to cancel out any offset which may be present and the Fine Span potentiometer adjustment accurately sets the full scale output. Depressing the calibration check pushbutton switch shunts a system calibration resistor ($R_{CAL}$) across the transducer bridge to give an instant check on system calibration.

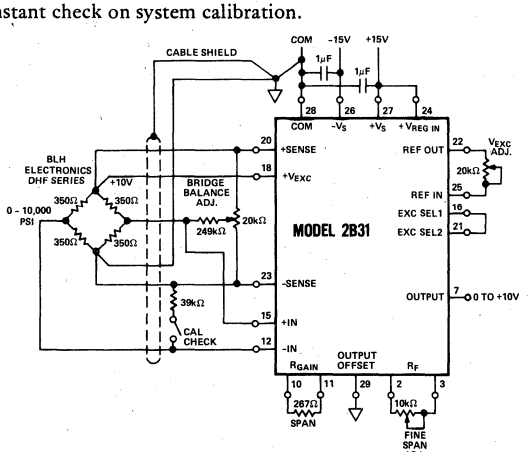



*Figure 6. Pressure Transducer Interface Application*

**Platinum RTD Temperature Measurement:** In Figure 7 model 2B31 provides complete convenient signal conditioning in a wide range (−100°C to +600°C) RTD temperature measurement system. YSI - Sostman four-wire, 100Ω platinum RTD (PT139AX) is used. The four wire sensor configuration, combined with a constant current excitation and a high input impedance offered by the 2B31, eliminates measurement errors resulting from voltage drops in the lead wires. Offsetting may be provided via the 2B31's offset terminal. The gain is set by the gain resistor for a +10V output at +600°C.

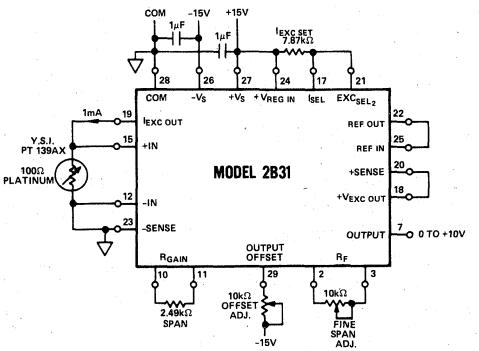



*Figure 7. Platinum RTD Temperature Measurement*

**Interfacing Three-Wire Sensors:** A bridge configuration is particularly useful to provide offset in interfacing to a platinum RTD and to detect small, fractional sensor resistance changes. Lead compensation is employed, as shown in Figure 8, to maintain high measurement accuracy when the lead lengths are so long that thermal gradients along the RTD leg may cause changes in line resistance. The two completion resistors (R1, R2) in the bridge should have a good ratio tracking (±5ppm/°C) to eliminate bridge error due to drift. The single resistor (R3) in series with the platinum sensor must, however, be of very high absolute stability. The adjustable excitation in the 2B31 controls the power dissipated by the RTD itself to avoid self-heating errors.

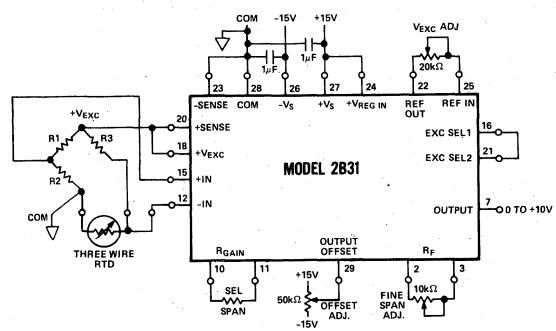



*Figure 8. Three-Wire RTD Interface*

**Linearizing Transducer Output:** To maximize overall system linearity and accuracy, some strain gage-type and RTD transducer analog outputs may require linearization. A simple circuit may be used with the 2B31 to correct for the curvature in the input signal. Consult factory for the application assistance.

**Data Acquisition System:** Figure 9 shows a typical application of the 2B30/2B31 in a low level, high speed microcomputer based data acquisition system. The advantages of this configuration are improvement in CMR enhanced by a low pass filter/channel provided by the 2B31, elimination of aliasing errors and crosstalk noise between input channels, improvement in system noise and resolution, and optimized, individual bridge excitation source for each channel.

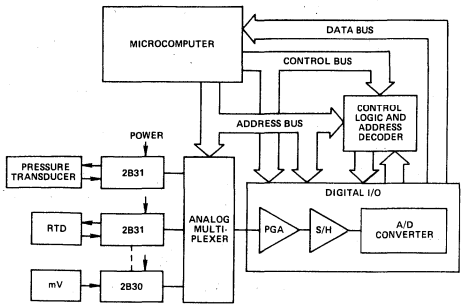



*Figure 9. Use of the 2B30/2B31 in Data Acquisition System*

## PERFORMANCE CHARACTERISTICS

**Input Offset Voltage Drift:** Models 2B30/2B31 are available in three drift selections: ±0.5, ±1 and ±3μV/°C (max, RTI, G = 1000V/V). Total input drift is composed of two sources (input and output stage drifts) and is gain dependent. Figure 10 is a graph of the worst case total voltage offset drift vs. gain for all versions.

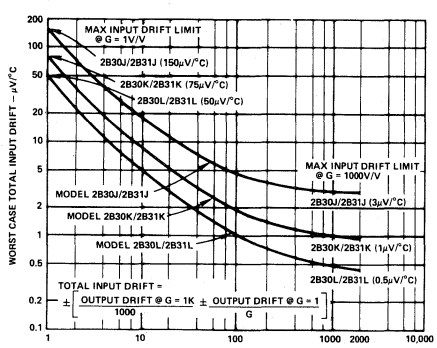



*Figure 10. Total Input Offset Drift (Worst Case) vs. Gain*

**Gain Nonlinearity and Noise:** Nonlinearity is specified as a percent of full scale (10V), e.g. 0.25mV RTO for 0.0025%. Three maximum nonlinearity selections offered are: ±0.0025%, ±0.005% and ±0.01% (G = 1 to 2000V/V). Models 2B30/2B31 offer also an excellent voltage noise performance by guaranteeing maximum RTI noise of 1μV p-p (G = 1000V/V, $R_S \leq 5k\Omega$) with noise bandwidth reduced to 2Hz by the low pass filter.

**Low Pass Filter:** The three pole Bessel-type active filter attenuates unwanted high-frequency components of the input signal above its cutoff frequency (-3dB) with 60dB/decade roll-off. With a 2Hz filter, attenuation of 70dB at 60Hz is obtained, settling time is 600ms to 0.1% of final value with less than 1% overshoot response to step inputs. Figure 11 shows the filter response.

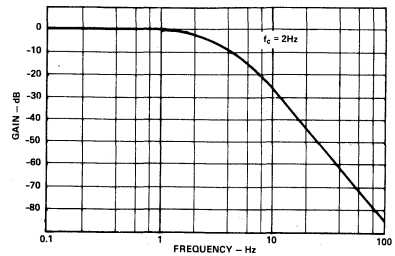



*Figure 11. Filter Amplitude Response vs. Frequency*

**Common Mode Rejection:** CMR is rated at ±10V CMV and 1kΩ source imbalance. The CMR improves with increasing gain. As a function of frequency, the CMR performance is enhanced by the incorporation of low pass filtering, adding to the 90dB minimum rejection ratio of the instrumentation amplifier. The effective CMR at 60Hz at the output of the filter ($f_c$ = 2Hz) is 140dB min. Figure 12 illustrates a typical CMR vs. Frequency and Gain.

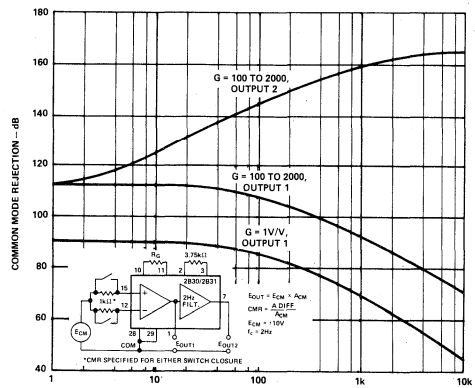



*Figure 12. Common Mode Rejection vs. Frequency and Gain*

**Bridge Excitation (2B31):** The adjustable bridge excitation is specified to operate over a wide regulator input voltage range (+9.5V to +28V). However, the maximum load current is a function of the regulator circuit input-output differential voltage, as shown in Figure 13. Voltage output is short circuit protected and its temperature coefficient is ±0.015% $V_{OUT}$/°C max (±0.003%/°C typ). Output temperature stability is directly dependent on a temperature coefficient of a reference and for higher stability requirements, a precision external reference may be used.

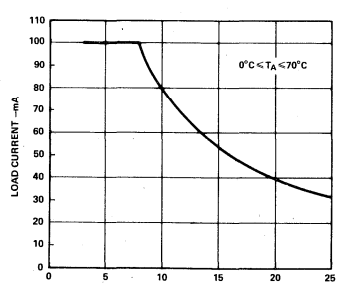



*Figure 13. Maximum Load Current vs. Regulator Input-Output Voltage Differential*

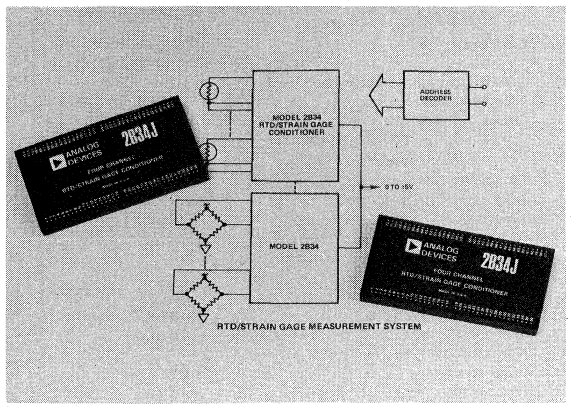
# ANALOG DEVICES

# Four Channel RTD/Strain Gage Conditioner

# MODEL 2B34

**FEATURES**
**Low Input Offset Drift: ±1.0μV/°C**
**Low Gain Drift: ±25ppm/°C**
**Low Nonlinearity: ±0.01% max (±0.005% typ)**
**Differential Input Protection: ±130V rms**
**Channel Multiplexing: 3000 chan/sec Scanning Speed**
**Solid State Reliability**
**Internal RTD Excitation/Lead Wire Compensation**

**APPLICATIONS**
**Multichannel Signal Conditioning**
**Data Acquisition**
**Industrial Process Monitoring**




9

## GENERAL DESCRIPTION

The model 2B34 is a four channel signal conditioner providing input protection, multiplexing, and amplification in a single, low cost package. A multi-purpose device, the 2B34 is designed to effectively condition low level signals (±30mV to ±100mV) such as those produced by RTD and strain gage sensors. The superior design of the 2B34 provides low input drift (±1.0μV/°C), high common mode rejection (94dB @ 60Hz), and extremely stable gain (±25ppm/°C). Other features include low nonlinearity (±0.01% max), excitation and lead wire compensation for RTD inputs, and a wide operating temperature range (-25°C to +85°C).

## APPLICATIONS

The 2B34 is a superior alternative to the relay multiplexing technique used in multichannel data acquisition systems, computer interface systems, and measurement and control instrumentation. Advantages over relay circuits include functional versatility, superior signal conditioning, and solid state speed and reliability.

## DESIGN FEATURES AND USER BENEFITS

**Solid State Design:** Complete solid state construction offers both high performance and reliability.

**Ease of Use:** The multichannel, functionally complete design in a compact (2″ X 4″ X 0.4″) module, conserves board space and eliminates the need for a number of discrete components that would otherwise be required.

**Low Cost:** The 2B34 offers the lowest cost per channel for solid state, low level sensor signal conditioning.

**Wide Operating Temperature Range:** The 2B34 has been designed to operate over -25°C to +85°C ambient temperature range.

## FUNCTIONAL DESCRIPTION

The internal structure of the 2B34 is shown in Figure 1. Four individual input channels are multiplexed into a single, low

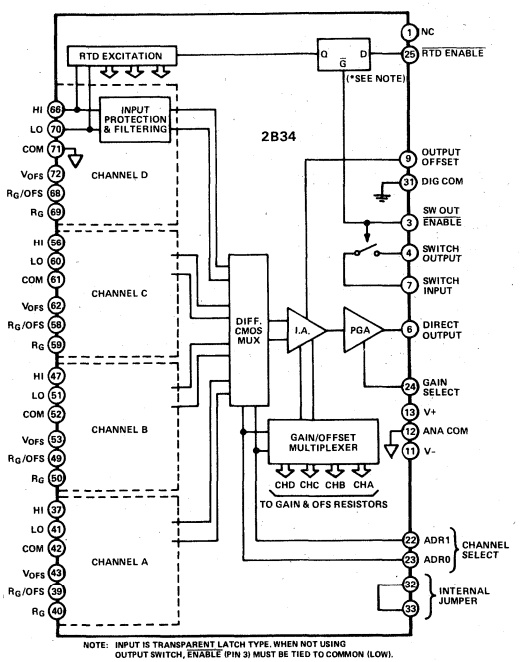



*Figure 1. 2B34 Functional Diagram*

# SPECIFICATIONS (typical @ +25°C, $V_S$ = ±15V, unless otherwise noted)

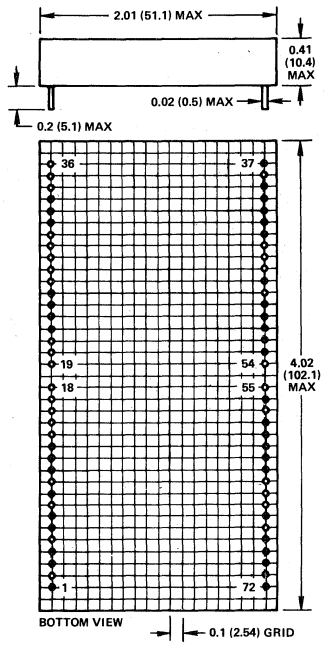
| Model | 2B34J Strain Gage Mode | 2B34J RTD Mode |
|---|---|---|
| **ANALOG INPUT** | | |
| Number of Channels | 4 | * |
| Input Range | ±30mV & ±100mV | 25-175Ω & 0-350Ω |
| Gain Range ($R_G$ =945Ω) | 166.6V/V & 50V/V | * |
| Expanded[1] | 50V/V to 1000V/V | * |
| Transfer Function | N/A | $V_{OUT} = [0.4 \times 10^{-3} \times (R_{RTD}) - 0.04]$ G |
| Gain Error | ±0.6% max (G = 50) | * |
| | ±0.8% max (G = 166.6) | * |
| Gain Temperature Coefficient[2] | ±25ppm/°C | * |
| Gain Nonlinearity | ±0.01% of Span, max | * |
| Offset Voltage | | |
| Input Offset, Initial[3] (Adj. to Zero) | ±150µV | * |
| vs. Temperature | ±1µV/°C | ±0.015 deg/deg |
| Channel to Channel Offset | ±25µV | * |
| Total Offset Drift (RTI) | ±1µV/°C | * |
| Input Noise Voltage | | |
| 0.01Hz-100Hz, $R_S$ = 1kΩ | 1.5µV p-p | * |
| Common Mode Voltage | ±6V | N/A |
| Common Mode Rejection | | |
| $R_S$ = 100Ω, f = 60Hz | 94dB (@ G = 166.6) | N/A |
| $R_S$ = 1kΩ, f = 60Hz | 86dB (@ G = 166.6) | |
| Maximum Safe Differential Input (10 min) | 130V rms | * |
| Normal Mode Rejection @ 60Hz | 24dB | * |
| Input Resistance | 20MΩ | * |
| Input Bias Current | 10nA max | * |
| Lead Resistance Effect | N/A | ±0.03 deg/Ω |
| **ANALOG OUTPUT** | | |
| Output Voltage Swing | ±5V @ 1mA | * |
| Output Resistance | | |
| Direct Output | 0.1Ω | * |
| Switched Output | 35Ω, +0.5%/°C | * |
| Maximum Switched Voltage | ±9V, no load | * |
| **SENSOR EXCITATION** | | |
| Excitation Level (per channel) | NA | 0.4mA ±1% (±1.7% max) |
| vs. Temperature | NA | ±10ppm/°C |
| **CHANNEL SELECTION** | | |
| Channel Selection Time to ±0.01% F.S. | 300µs | * |
| Channel Scanning Speed | >3000 chan/sec | * |
| **DYNAMIC RESPONSE** | | |
| Input Settling Time to ±0.01% F.S. | 0.4 sec | * |
| Bandwidth | 4Hz | * |
| **POWER SUPPLY** | | |
| Voltage, ±$V_S$, Rated Performance | ±15V dc ±5% | * |
| Current | +35mA, -15mA, max | * |
| Supply Effect on Offset | ±0.003%/% | ±0.02%/% |
| **ENVIRONMENTAL** | | |
| Temperature | | |
| Rated Performance | 0 to +70°C | * |
| Operating | -25°C to +85°C | * |
| Storage | -55°C to +85°C | * |
| **CASE SIZE** | 2" X 4" X 0.4" | |

NOTES
[1] Gain range may be expanded by use of external amplifier as shown in Figure 3.
[2] Does not include effects of sensor excitation drift.
[3] With no induced offset, using circuit shown in Figure 2 (pots centered).
*Specifications same as Strain Gage Mode.

Specifications subject to change without notice.

## OUTLINE DIMENSIONS

Dimensions shown in inches and (mm).




NOTE: TERMINAL PINS INSTALLED ONLY IN SHADED HOLE LOCATIONS

## 2B34 PIN DESIGNATIONS

| PIN | FUNCTION | PIN | FUNCTION | |
|---|---|---|---|---|
| 1 | NC | 37 | HI | CHANNEL A |
| 2 | | 38 | | |
| 3 | SW'D OUTPUT ENABLE | 39 | $R_G$/OFS | |
| 4 | SW'D OUTPUT | 40 | $R_G$ | |
| 5 | | 41 | LO | |
| 6 | DIRECT OUTPUT | 42 | COM | |
| 7 | SW'D INPUT | 43 | $V_{OFS}$ (+10V) | |
| 8 | | 44 | | |
| 9 | OUTPUT OFFSET | 45 | | |
| 10 | | 46 | | |
| 11 | -15V | 47 | HI | CHANNEL B |
| 12 | ANA COM | 48 | | |
| 13 | +15V | 49 | $R_G$/OFS | |
| 14 | | 50 | $R_G$ | |
| 15 | | 51 | LO | |
| 16 | | 52 | COM | |
| 17 | | 53 | $V_{OFS}$ (+10V) | |
| 18 | | 54 | | |
| 19 | | 55 | | |
| 20 | | 56 | HI | CHANNEL C |
| 21 | | 57 | | |
| 22 | ADR1 } CHANNEL | 58 | $R_G$/OFS | |
| 23 | ADR0 } SELECT | 59 | $R_G$ | |
| 24 | GAIN SELECT | 60 | LO | |
| 25 | RTD ENABLE | 61 | COM | |
| 26 | | 62 | $V_{OFS}$ (+10V) | |
| 27 | | 63 | | |
| 28 | | 64 | | |
| 29 | | 65 | | |
| 30 | | 66 | HI | CHANNEL D |
| 31 | DIG COM | 67 | | |
| 32 | SYNC IN } * | 68 | $R_G$/OFS | |
| 33 | SYNC OUT } * | 69 | $R_G$ | |
| 34 | | 70 | LO | |
| 35 | | 71 | COM | |
| 36 | | 72 | $V_{OFS}$ (+10V) | |

*SHORTED INTERNALLY FOR FEEDTHROUGH FOR USE WITH 2B54/55 MODELS.

drift differential instrumentation amplifier, with the desired channel specified by the two digital channel select inputs. This signal is then fed to a digitally controlled programmable gain amplifier (PGA). The appropriate gain for a particular sensor type is selected by the gain select input.

User selectable direct or switched output permits direct output connection of several modules, should more than four channels be required.

An internally selectable constant current excitation source provides direct connection of 2 or 3 wire RTDs, thus eliminating the need for external excitation sources. Each channel contains an input protection and filtering network to preserve signal integrity in the presence of series mode 50/60Hz noise.

## OPERATING INSTRUCTIONS

Connection of the 2B34 with three wire RTD inputs is shown in Figure 2 and will be all that is needed in most cases. The following sections describe the basic application, as well as detail some optional connections that enhance the module's performance in more complex applications. All unused inputs should be shorted to common.

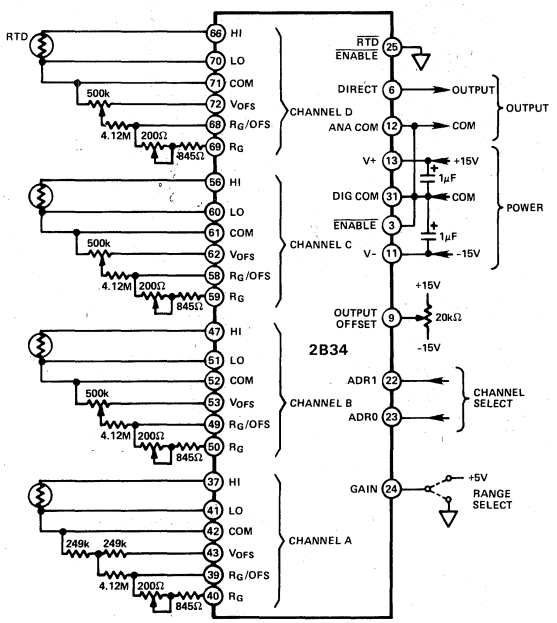



*Figure 2. Basic RTD Application*

**Channel Selection:** Each channnel of the 2B34 is turned on and off by applying the proper binary code to channel select inputs (ADR0, ADR1). Channels may be selected in any order and there are no restrictions on rate other than the 300μs settling time for access to a channel (Table I, channel select truth table).

**Gain Selection:** The 2B34 is designed to provide signal conditioning of both RTD and strain gage sensor inputs. To accommodate both of these sensor types, the 2B34 is precalibrated to provide gains of 50 and 166.6, with gain components shown in Figure 2. This provides proper amplification of input signals over the span of ±30mV to ±100mV. Selection of the desired gain and sensor input mode is achieved by applying the appropriate binary codes shown in Table II. A 200Ω pot provides ±3% full scale span adjustment.

| AD1 | AD0 | Channel |
|---|---|---|
| 0 | 0 | A |
| 0 | 1 | B |
| 1 | 0 | C |
| 1 | 1 | D |

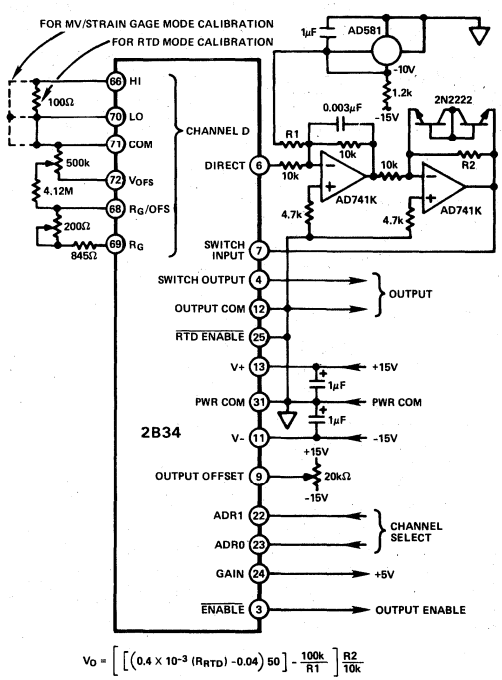
*Table I. Channel Selection*

| (Pin 24) Gain Select Input | Selected Gain |
|---|---|
| 0 | 166.6 |
| 1 | 50 |

| (Pin 25) RTD ENABLE | Selected Mode |
|---|---|
| 0 | RTD |
| 1 | Strain Gage |

*Table II. Gain and Mode Selection*

**Zero Suppression & Gain:** In most instances, the gain capability of the 2B34 will be sufficient. However, in the case of input signals that may require gains greater than 166, the




$$V_O = \left[ \left[ (0.4 \times 10^{-3} (R_{RTD}) - 0.04) 50 \right] - \frac{100k}{R1} \right] \frac{R2}{10k}$$

*Figure 3. Zero Suppressed Switched Output RTD Application*

gain range of the 2B34 may be supplemented by use of an external amplifier (Figure 3). A low drift, operational amplifier (such as the AD741K) should be used to maintain signal integrity.

**Optional Offset Adjustment:** All channels of the 2B34 are typically within ±150μV (RTI) offset. For use in more demanding applications, the module has provisions for fine adjustment of the input offset (RTI) of each input as well as the output offset (RTO) of the entire module. None of the offset adjustments will affect drift performance.

In some applications, where ±25μV channel-to-channel offset voltage can be tolerated, adjustment of only the output offset will be sufficient. The offset circuit shown in Figure 2 (for channel "A") is required when a potentiometer is not used to adjust input offset. The output offset adjustment may then be used to null the 150μV (RTI) offset, leaving an offset difference between channels of ±25μV. If input offset adjustment is desired, the input offset circuitry shown in Figure 3 should be used. This provides approximately ±140mV (RTO) of adjustment, and should be adequate, in most cases, for elimination of sensor offset errors.

To calibrate in the mV (strain gage) mode, (Figure 3), short the signal inputs (for example, pins 66, 70 for channel "D") to common and center the input offset adjustment potentiometer. Adjust the output offset potentiometer until the output is nulled for that channel at the appropriate gain. The input offset pots on each channel may then be used to eliminate any errors on subsequent channels that are selected.

To calibrate in the RTD mode, follow the same procedure, but replace the short with a 100Ω resistance standard.

**Channel Expansion:** The 2B34 has provisions for directly interconnecting several modules when more than four channels are required. The series switched outputs of the modules are connected together, the channel select inputs are driven in parallel, and the switched output of the desired module is selected using the $\overline{\text{ENABLE}}$ pin. This technique is shown in Figure 4. Channel address and $\overline{\text{ENABLE}}$ (active low) inputs are CMOS/TTL compatible with an input current of 100μA each.

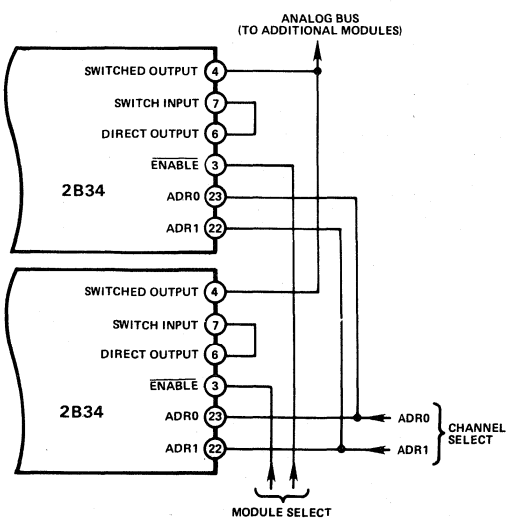



*Figure 4. Channel Expansion*

**2B34 Strain Gage Application:** Figure 5 shows a four channel strain gage input system utilizing the multiplexing feature of the 2B34. Input offset and gain adjustments are used to eliminate inherent sensor errors. The model 2B35 triple output supply may be used to provide power for the 2B34 as well as excitation for the strain gage sensors.

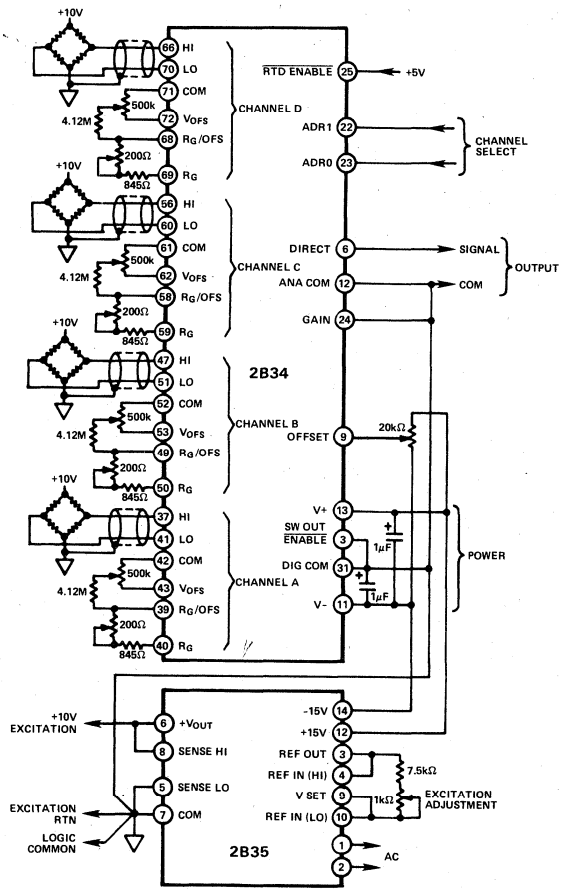



*Figure 5. 2B34 Strain Gage Application*

# Precision, Triple Output Transducer Power Supply

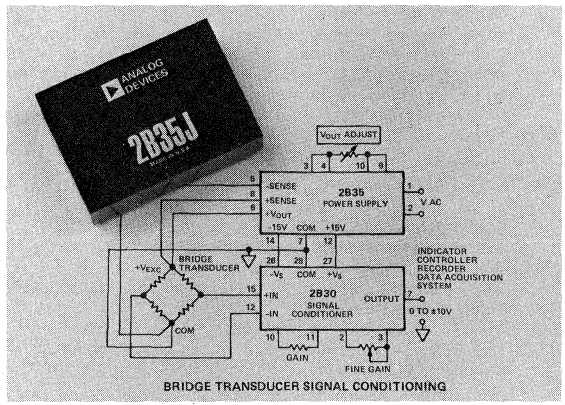
# MODEL 2B35

## FEATURES

**Resistor Programmable Voltage or Current Output**
**Voltage: +1V dc to +15V dc @ 125mA max**
**Current: 100μA to 10mA ($V_{COMPL}$ = +10V)**
**Dual Fixed Output: ±15V dc @ ±65mA max**
**Excellent Regulation: Line ±0.01% max; Load ±0.02% max**
**Low Drift: 0.006%/°C max (2B35K)**
**No Derating Over -25°C to +71°C Operating Range**

## APPLICATIONS

**Measurement and Control Instruments and Systems**
**Excitation Source For:**
**Strain Gages, Pressure Transducers, Load Cells, Torque Transducers, RTD's**



BRIDGE TRANSDUCER SIGNAL CONDITIONING

9

## GENERAL DESCRIPTION

The 2B35 is a triple output modular power supply designed to provide regulated excitation to a wide variety of transducers as well as ±15V power for amplifiers and other analog circuits of an instrumentation system. The single-resistor programmable transducer excitation output may be operated in two modes: constant voltage, providing a +1V to +15V output or a constant current, adjustable from 100μA to 10mA.

The programmable output in the voltage mode features current rating of 0 to 125mA, suitable to excite four 350Ω transducers at 10V. Current limiting protects the output against accidental overload and remote sensing corrects for the transducer cable resistance variations. In the constant current mode, externally set 100μA to 10mA output offers a 0 to +10V compliance voltage range. The ±15V outputs feature 0.5% tracking accuracy and current rating of 0 to ±65mA max.

Two accuracy selections are available offering guaranteed low temperature coefficient; 2B35K: 0.006%/°C max and 2B35J: 0.05%/°C max. Line and load regulation are also guaranteed; 2B35K: 0.01% and 0.02%, and 2B35J: 0.08% and 0.1%, max, respectively.

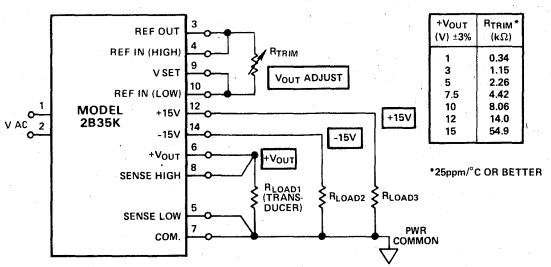
## APPLICATIONS

The 2B35 is designed for ac powered signal conditioning instrumentation applications used for data acquisition, control, indication or recording. This compact module may be applied as a power source for the model 2B30 strain gage transducer/RTD signal conditioner in a high accuracy transducer interface application. Some typical applications involve strain gages for stress/strain measurements, pressure transducers, load cells, torque transducers and RTD's.

## OPERATION

Figure 1 illustrates operation of the 2B35K providing an adjustable voltage output and dual 15V dc outputs. The resistor programmable output (+$V_{OUT}$) is set between +1V to +15V by the $R_{TRIM}$. $R_{TRIM}$ may be determined by using either the table shown in Figure 1 or the graph shown in Figure 2. For example, to provide an adjustable range from +1V to +6V, $R_{TRIM}$ should be a 5kΩ pot.

The remote sensing inputs (pins 5 and 8) are connected at the transducer (load) to the voltage output (SENSE HIGH to +$V_{OUT}$ and SENSE LOW to COMMON).




| +VOUT (V) ±3% | RTRIM* (kΩ) |
|---|---|
| 1 | 0.34 |
| 3 | 1.15 |
| 5 | 2.26 |
| 7.5 | 4.42 |
| 10 | 8.06 |
| 12 | 14.0 |
| 15 | 54.9 |

*Figure 1. Model 2B35K Connection Diagram for Dual 15V dc and Adjustable +1V to +15V Output*

**For optional input voltage ranges, see note 1, next page.**

# SPECIFICATIONS (typical @ +25°C and 115V ac 60Hz unless otherwise noted)

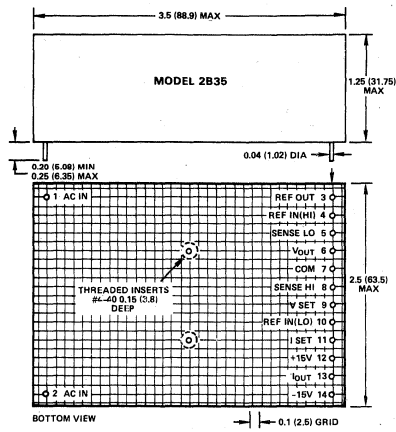
| Model | 2B35J | 2B35K |
|---|---|---|
| INPUT | | |
| Input Voltage Range[1] | 105V ac to 125V ac | * |
| Input Frequency Range | 50Hz to 400Hz | * |
| ADJUSTABLE OUTPUT | | |
| Voltage Mode | | |
| Output Voltage Range | +1V to +15V dc | * |
| Output Voltage Stability | | |
| vs. Temperature – % $V_{OUT}$/°C max | ±0.05 | ±0.006 |
| vs. Time – % $V_{OUT}$/month | ±0.01 | * |
| Output Current (–25°C to +71°C)[2] | 0 to 125mA max | * |
| Output Impedance – @ dc, max | 0.1Ω | * |
| Noise and Ripple (dc to 1MHz) – mV p-p max | 1 | * |
| – mV rms max | 0.25 | * |
| Regulation | | |
| Line (full range) – % $V_{OUT}$ max | ±0.08 | ±0.01 |
| Load (no load to full load) – % $V_{OUT}$ max | ±0.1 | ±0.02 |
| Remote Sensing Impedance | 30kΩ | * |
| Short Circuit Current Limit[3] (–25°C to +71°C) | 200mA | * |
| Current Mode | | |
| Output Current Range | 100µA to 10mA | * |
| Output Current Stability | | |
| vs. Temperature – % $I_{OUT}$/°C max | ±0.05 | ±0.006 |
| vs. Time – % $I_{OUT}$/month | ±0.01 | * |
| Compliance Voltage Range | 0 to +10V | * |
| Noise and Ripple (dc to 1MHz) –µA p-p | 0.1 | * |
| Line Regulation (full range) – % $I_{OUT}$ max | ±0.08 | ±0.01 |
| DUAL FIXED OUTPUTS | | |
| Output Voltage | ±15V dc | * |
| Voltage Error – mV max | –0, +300 | * |
| Accuracy Tracking (–15V Ref to +15V) – % max | ±0.5 | * |
| Stability vs. Temperature – %/°C max | ±0.02 | ±0.006 |
| Output Current[4] | 0 to ±65mA max | * |
| Output Impedance – @ dc, max | 0.1Ω | * |
| Noise and Ripple (dc to 1MHz) – mV p-p | 1 | * |
| – mV rms | 0.25 | * |
| Regulation | | |
| Line (full range) – % max | ±0.08 | ±0.01 |
| Load (no load to full load) – % max | ±0.1 | ±0.02 |
| Short Circuit Current Limit[3] (–25°C to +71°C) | ±180mA | * |
| INPUT TO OUTPUT ISOLATION | | |
| Breakdown Voltage – Continuous, ac or dc | ±500V pk max | * |
| Isolation Resistance | 50MΩ | * |
| TEMPERATURE RANGE | | |
| Operating, Rated Performance | –25°C to +71°C | * |
| Storage | –25°C to +85°C | * |
| MECHANICAL | | |
| Case Dimensions – Inches | 2.5 x 3.5 x 1.25 | * |
| Weight – Grams | 550 | * |
| Mating Socket | AC1212 | * |

NOTES
*Specifications same as model 2B35J.
[1] Optional input voltage ranges: "E" Option; 205-240V ac, 50 to 400Hz
"F" Option; 90-110V ac, 50 to 400Hz
"H" Option; 220-260V ac, 50 to 400Hz
Order option desired as a suffix to model number.
[2] Maximum output current available over the entire output voltage and temperature range without derating.
[3] Output protected for continuous short circuit over the temperature range.
[4] Unbalanced load operation is permissible for any combination of $+I_O$ and $|-I_O|$ which does not exceed a total of 130mA.

Specifications subject to change without notice.

## OUTLINE DIMENSIONS

Dimensions shown in inches and (mm).




## MATING SOCKET: AC1212

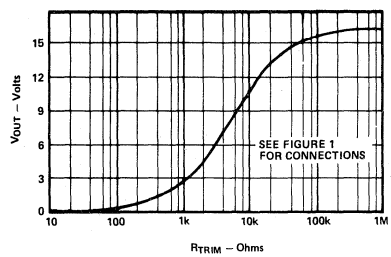



*Figure 2. Voltage Output vs. $R_{TRIM}$*

## ADJUSTABLE CURRENT OUTPUT WITH DUAL 15V dc OUTPUTS

Pin connections to provide dual 15V dc and a constant current output are shown in Figure 3. The current output is adjusted from 100µA to 10mA via $R_{TRIM}$. The value of programming resistor $R_{TRIM}$ may be calculated from the relationship: $R_{TRIM} = 2.46/I_{OUT}$ where $R_{TRIM}$ is in kΩ and $I_{OUT}$ in mA.

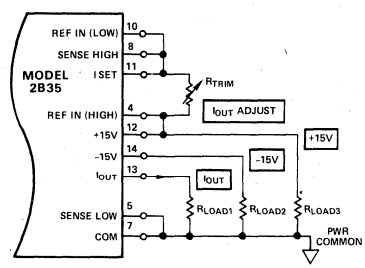



*Figure 3. Model 2B35 Connection Diagram to Provide Dual 15V dc and Adjustable 100µA to 10mA Current Output*

# ANALOG DEVICES

# Isolated, Thermocouple Signal Conditioner

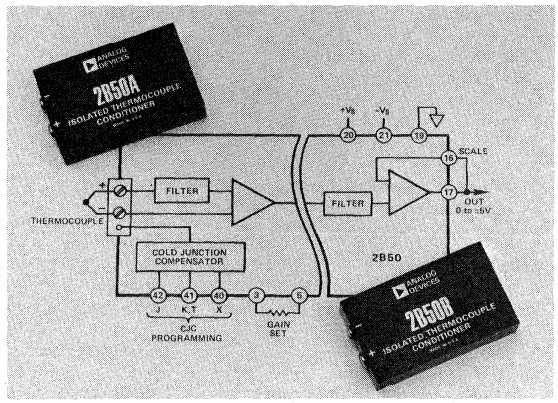
# MODEL 2B50

**FEATURES**

**Accepts J, K, T, E, R, S or B Thermocouple Types**
**Internally Provided Cold Junction Compensation**
**High CMV Isolation: ±1500V pk**
**High CMR: 160dB min @ 60Hz**
**Low Drift: ±1μV/°C max (2B50B)**
**High Linearity: ±0.01% max (2B50B)**
**Input Protection and Filtering**
**Screw Terminal Input Connections**

**APPLICATIONS**

**Precision Thermocouple Signal Conditioning For:**
**Process Control and Monitoring**
**Industrial Automation**
**Energy Management**
**Data Acquisition Systems**




9

## GENERAL DESCRIPTION

The model 2B50 is a high performance thermocouple signal conditioner providing input protection, isolation and common mode rejection, amplification, filtering and integral cold junction compensation in a single, compact package.

The 2B50 has been designed to condition low level analog signals, such as those produced by thermocouples, in the presence of high common mode voltages. Featuring direct thermocouple connection via screw terminals and internally provided reference junction temperature sensor, the 2B50 may be jumper programmed to provide cold junction compensation for thermocouple types J, K, T, and B, or resistor programmed for types E, R, and S.

The high performance of the 2B50 is accomplished by the use of reliable transformer isolation techniques. This assures complete input to output galvanic isolation (±1500V pk) and excellent common mode rejection (160dB @ 60Hz).

Other key features include: input protection (220V rms), filtering (NMR of 70dB @ 60Hz), low drift amplification (±1μV/°C max - 2B50B), and high linearity (±0.01% max - 2B50B).

## APPLICATIONS

The 2B50 has been designed to provide thermocouple signal conditioning in data acquisition systems, computer interface systems, and temperature measurement and control instrumentation.

In thermocouple temperature measurement applications, outstanding features such as low drift, high noise rejection, and 1500V isolation make the 2B50 an ideal choice for systems used in harsh industrial environments.

## DESIGN FEATURES AND USER BENEFITS

**High Reliability:** To assure high reliability and provide isolation protection to electronic instrumentation, the 2B50 has been conservatively designed to meet the IEEE Standard for transient voltage protection (472-1974: SWC) and provide 220V rms differential input protection.

**High Noise Rejection:** The 2B50 features internal filtering circuitry for elimination of errors caused by RFI/EMI, series mode noise, and 50Hz/60Hz pickup.

**Ease of Use:** Internal compensation enables the 2B50 to be used with seven different thermocouple types. Unique circuitry offers a choice of internal or remote reference junction temperature sensing. Thermocouple connections may be made either by screw terminals or, in applications requiring PC Board connections, by terminal pins.

**Small Package:** 1.5″ X 2.5″ X 0.6″ size conserves board space.

# SPECIFICATIONS (typical @ +25°C and $V_S$ = ±15V unless otherwise noted)

| MODEL | 2B50A | 2B50B |
|---|---|---|
| **INPUT SPECIFICATIONS** | | |
| Thermocouple Types | | |
| Jumper Configurable Compensation | J, K, T, or B | * |
| Resistor Configurable Compensation | R, S, or E | * |
| Input Span Range | ±5mV to ±100mV | * |
| Gain Range | 50V/V to 1000V/V | * |
| Gain Equation | $1 + (200k\Omega/R_G)$ | * |
| Gain Error | ±0.25% | * |
| Gain Temperature Coefficient | ±35ppm/°C max | ±25ppm/°C max |
| Gain Nonlinearity[1] | ±0.025% max | ±0.01% max |
| Offset Voltage | | |
| Input Offset (Adjustable to Zero) | ±50μV | * |
| vs. Temperature | ±2.5μV/°C max | ±1μV/°C max |
| vs. Time | ±1.5μV/month | * |
| Output Offset (Adjustable to Zero) | ±10mV | * |
| vs. Temperature | ±30μV/°C | * |
| Total Offset Drift | $\pm\left(2.5 + \frac{30}{G}\right)$ μV/°C | $\pm\left(1 + \frac{30}{G}\right)$ μV/°C |
| Input Noise Voltage | | |
| 0.01Hz to 100Hz, $R_S$ = 1kΩ | 1μV p-p | * |
| Maximum Safe Differential Input Voltage | 220V rms, Continuous | * |
| CMV, Input to Output | | |
| Continuous, ac or dc | ±1500V pk max | * |
| Common Mode Rejection | | |
| @ 60Hz, 1kΩ Source Unbalance | 160dB min | * |
| Normal Mode Rejection @ 60Hz | 70dB min | * |
| Bandwidth | dc to 2.5Hz (-3dB) | * |
| Input Impedance | 100MΩ | * |
| Input Bias Current[2] | ±5nA | * |
| Open Input Detection | Downscale | * |
| Response Time[3], G = 250 | 1.4sec | * |
| Cold Junction Compensation | | |
| Initial Accuracy[4] | ±0.5°C | * |
| vs. Temperature[5] (+5°C to +45°C) | ±0.01°C/°C | * |
| **OUTPUT SPECIFICATIONS** | | |
| Output Voltage Range[6] | ±5V @ ±2mA | * |
| Output Resistance | 0.1Ω | * |
| Output Protection | Continuous Short to Ground | * |
| **POWER SUPPLY** | | |
| Voltage | | |
| Output ±$V_S$ (Rated Performance) | ±15V dc ±10% @ ±0.5mA | * |
| (Operating) | ±12V to ±18V dc max | * |
| Oscillator +$V_{OSC}$ (Rated Performance) | +13V to +18V @ 15mA | * |
| **ENVIRONMENTAL** | | |
| Temperature Range, Rated Performance | 0 to +70°C | * |
| Operating | -25°C to +85°C | * |
| Storage Temperature Range | -55°C to +85°C | * |
| RFI Effect (5W @ 470MHz @ 3ft) | | |
| Error | ±0.5% of Span | * |
| **PHYSICAL** | | |
| Case Size | 1.5" X 2.5" X 0.6" | * |

NOTES

*Specifications same as 2B50A.

[1] Gain nonlinearity is specified as a percentage of output signal span representing peak deviation from the best straight line; e.g., nonlinearity at an output span of 10V pk-pk (±5V) is ±0.01% or ±1mV.

[2] Does not include open circuit detection current of 20nA (optional by jumper connection).

[3] Open input response time is dependent upon gain.

[4] When used with internally provided CJC sensor.

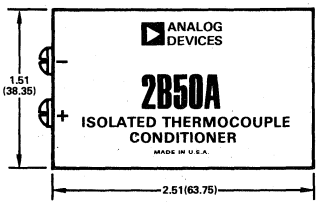
[5] Compensation error contributed by ambient temperature changes at the module.

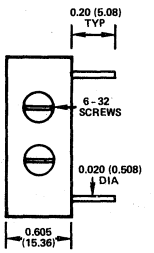
[6] Output swing of ±10V may be obtained through output scaling (Figure 5).

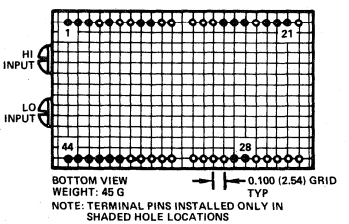
Specifications subject to change without notice.

## OUTLINE DIMENSIONS

Dimensions shown in inches and (mm).




## PIN DESIGNATIONS

| PIN | FUNCTION | PIN | FUNCTION |
|---|---|---|---|
| 1 | INPUT LO | 23 | |
| 2 | INPUT HI | 24 | |
| 3 | $R_G$ | 25 | |
| 4 | | 26 | |
| 5 | $R_G$/COM | 27 | |
| 6 | | 28 | +V OSC |
| 7 | | 29 | OSC COM |
| 8 | +V ISO OUT | 30 | |
| 9 | -V ISO OUT | 31 | |
| 10 | | 32 | |
| 11 | | 33 | |
| 12 | | 34 | |
| 13 | | 35 | |
| 14 | | 36 | |
| 15 | OUTPUT OFFSET ADJUST | 37 | |
| | | 38 | |
| 16 | OUTPUT SCALE | 39 | OPEN INPUT DET. |
| 17 | OUTPUT | 40 | X |
| 18 | | 41 | K, T ‡ TYPE PROGRAMMING |
| 19 | OUTPUT COM | 42 | J |
| 20 | +$V_S$ | 43 | CJC SENSOR IN |
| 21 | -$V_S$ | 44 | CJC SENSOR OUT |
| 22 | | | |

**MATING SOCKET: AC1218**

## FUNCTIONAL DESCRIPTION

The internal structure of the 2B50 is shown in Figure 1. An input filtering and protection network precedes a low drift, high performance amplifier whose gain is set by a user supplied resistor ($R_G$) for gains of 50 to 1000V/V. Isolated power is brought out to permit convenient adjustment of the input offset voltage, if desired.

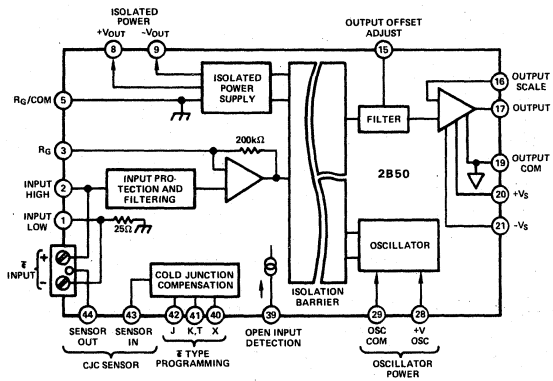



*Figure 1. 2B50 Functional Block Diagram*

Internal circuitry provides reference junction compensation. An integral reference junction sensor is provided for direct thermocouple connections, or an external reference sensor (2N2222 transistor) may be used in applications having remote thermocouple termination. Compensating networks for thermocouple types J, K, and T are built into the 2B50. A fourth compensation (X) may be programmed with a single resistor for any other thermocouple type. The 2B50 can be programmed for uncompensated output when used with inputs other than thermocouples.

Transformer coupling is used to achieve stable, reliable input to output galvanic isolation, as well as elimination of ground loop error effects.

Normally, the full scale output of the 2B50 is ±5V. However, with the addition of an external resistive divider, the output buffer amplifier may be scaled for a gain of up to 2, providing a full scale output swing of ±10V.

## OPERATING INSTRUCTIONS

The connections shown in Figure 2 are common to most applications using the 2B50, and, in many cases, will be all that is required.

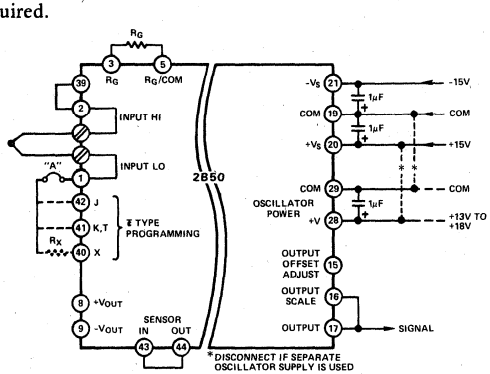



*Figure 2. Basic 2B50 Application*

Two sets of parallel thermocouple input connections are provided. The thermocouple input may be connected by screw terminals (Input +, Input −) or to terminal pins 1 (−) and 2 (+) in cases where thermocouples are to be remotely terminated. The following sections describe a basic thermocouple application, as well as detail some optional connections to enhance performance in more demanding applications. Jumper A (Figure 2) is used to disconnect cold junction compensation circuitry during offset adjustments.

## INTERCONNECTION GUIDELINES

All power supply inputs should be decoupled with 1μF capacitors as close to the unit as possible. Any jumpers installed for programming purposes should also be installed as close as possible to minimize noise pickup effects.

Since the oscillator section of the 2B50 accounts for most of the power consumption but can accept a wide range of voltages (+13V to +18V), it may be desirable to power this section from a convenient source of unregulated power.

If the same supply is to be used for both amplifier and oscillator circuitry, the power supply returns should be brought out separately so that oscillator power supply currents do not flow in the low lead of the signal output. In either case, a 1μF capacitor must be connected from $+V_{OSC}$ (Pin 28) to Oscillator COM (Pin 29).

The oscillator and amplifier sections are completely isolated; therefore, a dc power return path is not required between the two power supply commons.

## GAIN SETTING

The gain of the 2B50 is set by a user-supplied resistor ($R_G$) connected as shown in Figure 2. Gain will normally be selected so that the maximum output of the signal source will result in a plus full scale output swing. The resistor value required is determined by the equation: $R_G = 200k\Omega/(G-1)$.

A series trim on the gain setting resistor can be used to trim out the resistor tolerance and module gain error (Figure 3). Since addition of a series resistance will always decrease gain, the value of the gain-setting resistor should be selected to provide a gain somewhat higher than the desired trimmed gain. A good quality (e.g., 10ppm/°C), metal-film resistor should be used for $R_G$, since drift of $R_G$ will add to the overall gain drift of the 2B50. A cermet pot is suitable for the trim. Note that a minimum gain of 50 is required for guaranteed operation.

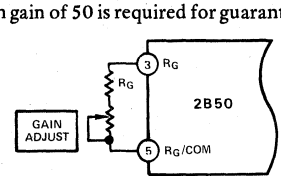



*Figure 3. Gain Adjustment*

## INPUT AND OUTPUT OFFSET ADJUSTMENTS

The 2B50 has provisions for adjusting input and output offset errors of the module. None of the offset adjustments will affect drift performance, and adjustments need not be used unless the particular application calls for lower offsets than those specified.

Connections for offset adjustments are shown in Figure 4. Isolated supply voltages are brought out for input trimming convenience only and are not for use as a power supply for external components.

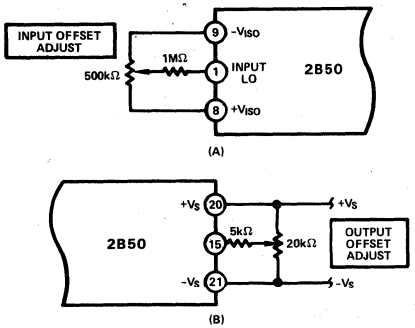



*Figure 4. (A) Input and (B) Output Offset Adjustment*

## OFFSET CALIBRATION

1. Short Input + and Input - together.
2. Disconnect cold junction compensation circuitry by removing Jumper "A" (Figure 2).
3. Adjust input offset trim pot (±250μV range, RTI) to zero output while operating at the desired gain. In most applications, adjustment of the input offset alone will be sufficient. Output offset adjustment (±30mV range) may be performed if it is desired to adjust output offset on the nonisolated side.

## OPEN INPUT DETECTION

Connecting the open input detection pin (PIN 39) to input high (PIN 2) creates a 20nA bias current which will provide a negative overscale response if the input is opened, or in case of thermocouple "burn out". The speed at which this occurs is dependent on gain, with a typical response time of 1.4sec @ G = 250.

## OUTPUT SCALING

With the output scale (PIN 16) connected to the output (PIN 17), the full scale output range is ±5V and the total gain is equal to the gain set by $R_G$. For applications requiring a full scale output of ±10V, a resistive divider may be connected to provide a gain of 2 at the output amplifier (see Figure 5). In this configuration, total gain will be twice the gain set by $R_G$. Output gains greater than 2 cannot be used.

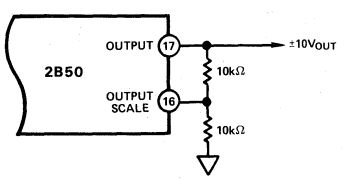



*Figure 5. Output Scaling Connections*

## COLD JUNCTION COMPENSATION

The 2B50 may be programmed to provide cold junction compensation for types J, K and T thermocouples by connecting a jumper from input low (PIN 1) to the appropriate programming points (PIN 42 for J, PIN 41 for K or T). To compensate other thermocouple types, a resistor ($R_X$) is connected from the "X" programming point (PIN 40) to Input Low (PIN 1). Table I shows the appropriate $R_X$ values for types E, R, and S. $R_X$ should be a 50ppm/°C, 1% tolerance resistor.

Type B thermocouples are unique, in that they have almost no output in the +5°C to +45°C range, and, therefore, do not require cold junction compensation at all. To accommodate a type B thermocouple, resistor $R_X$ must be left open. Error due to cold junction temperature will be less than ±1°C for any measurement above 260°C. In the measurement range above 1000°C (where type B thermocouples are normally used) the error will be less than ±0.3°C.

| T/C Type | $R_X$ (kΩ) |
|---|---|
| E | 1.87 |
| R,S | 19.6 |
| B | Open |

*Table I. Compensation Values for Thermocouple Types E, R, S and B*

## REMOTE REFERENCE SENSING

In applications requiring termination of thermocouple leads at a point located remotely from the 2B50, with connections brought to the 2B50 (PINS 1,2) by copper wires, reference temperature sensing at the remote location will be necessary. The 2B50 has provisions for connection of a 2N2222 transistor (metal can version) for use as a reference junction sensor. The connections are shown in Figure 6. The remote sensing transistor is calibrated by adjusting $R_{CAL}$ to obtain the value of $V_{CAL}$ as specified in Table II.

(Example: $V_{CAL}$ = 570.0mV @ 25°C)

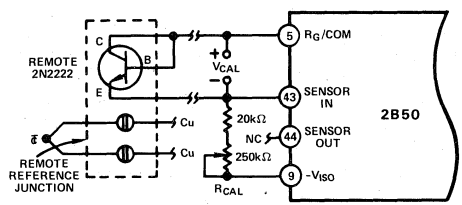



*Figure 6. Remote Reference Junction Sensing*

| Sensor Temp (°C) | $V_{CAL}$ (mV) |
|---|---|
| 5 | 616.5 |
| 10 | 604.9 |
| 15 | 593.3 |
| 20 | 581.6 |
| 25 | 570.0 |
| 30 | 558.4 |
| 35 | 546.8 |
| 40 | 535.1 |
| 45 | 523.5 |

(Values may be interpolated)

*Table II. Calibration Voltages vs. Sensor Temperature*

Proper sensor placement is important. Close thermal contact of the sensor and thermocouple termination point (reference junction) is essential for accurate operation of the 2B50. The sensor may be placed any distance from the 2B50. When the sensor leads are more than ten feet long, or in the presence of strong noise signal sources, shielded cable should be used.

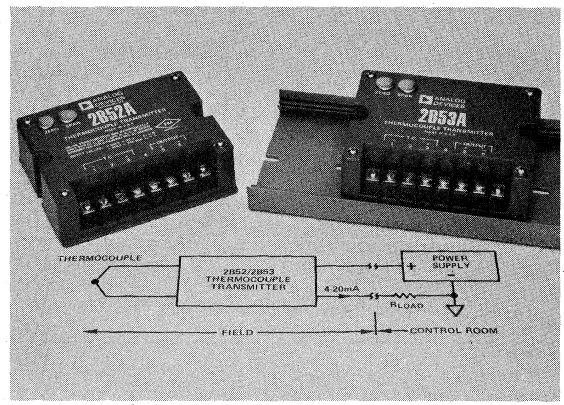
# ANALOG DEVICES

# Two-Wire, Thermocouple Temperature Transmitters

# MODELS 2B52 and 2B53

**FEATURES**
**Accept Type J, K or T Thermocouple Inputs**
**Compatible with Standard 4-20mA Loops**
**High Accuracy: ±0.1%**
**High CMV Isolation: 600V rms; CMR = 160dB (2B52)**
**High Noise Rejection and RFI Immunity**
**Internal Cold Junction Compensation**
**Open Thermocouple Detection**
**Millivolt Signal Transmission**
**Low Cost**
**FM Approved (2B52)**

**APPLICATIONS**
**Thermocouple Temperature Monitoring and Control In:**
**Process Control**
**Factory Automation**
**Energy Management**




9

**GENERAL DESCRIPTION**
Models 2B52 and 2B53 are high performance, low cost temperature transmitters designed to accept a thermocouple input from types J, K or T and produce a standard 4–20mA output current proportional to the measured temperature.

Two basic models are available. The 2B52 features high input to output isolation (600V rms) and high CMR (160dB @ 60Hz). The 2B53 offers a functionally equivalent design without input to output isolation. Both models were designed to operate as two-wire transmitters and are compatible with standard 4–20mA loops. The 2B52 is approved by Factory Mutual for intrinsically safe use in hazardous locations.

The 2B52 and 2B53 offer high noise rejection, RFI immunity and automatic cold junction compensation to assure accurate operation in noisy industrial environments over a wide ambient temperature range. Other features include open thermocouple detection, fast response time and a low bias current to minimize errors induced by thermocouple extension wires.

A rugged metal enclosure, suitable for field mounting, offers environmental protection and screw terminal input and output connections. This enclosure may be either surface or standard relay track mounted.

**APPLICATIONS**
The 2B52 and 2B53 have been specifically designed to provide low cost, reliable and accurate thermocouple temperature measurement and transmission in a wide array of industries, including chemical, petrochemical, power generation and food processing.

These models are especially useful in process control and monitoring applications where the process sensor is located remotely from the receiver. The 2B52 and 2B53 may then be used to provide signal conditioning near the point of temperature measurement and to transmit an accurate, noise immune, high level current signal over conventional copper wires, resulting in improved performance and reduced cost.

**DESIGN FEATURES AND USER BENEFITS**
**Low Cost:** Low transmitter cost, two-wire operation and the use of inexpensive copper wire for transmission result in lower total installation cost.

**High Isolation (2B52):** Input to output isolation eliminates ground loop errors in installations requiring grounded sensors and permits direct transmission of signal to a receiver where common mode voltages up to 600V rms may exist.

**High Noise Rejection:** The 2B52 and 2B53 feature internal filtering circuitry to eliminate errors caused by RFI/EMI and line frequency pickup.

**Environmental Protection:** High quality electronic components, protective coating and mechanical packaging combine to provide a high degree of reliability and protection against temperature, humidity and noise interference.

**Millivolt Transmission:** Unique circuitry of the 2B52 and 2B53 allows both models to be used as mV signal transmitters.

**Ease of Calibration:** Both models can be quickly, easily and accurately calibrated in the field to operate over any input span between 5 and 100 millivolts.

# SPECIFICATIONS (typical @ +25°C and $V_S$ = +24V dc unless otherwise noted)

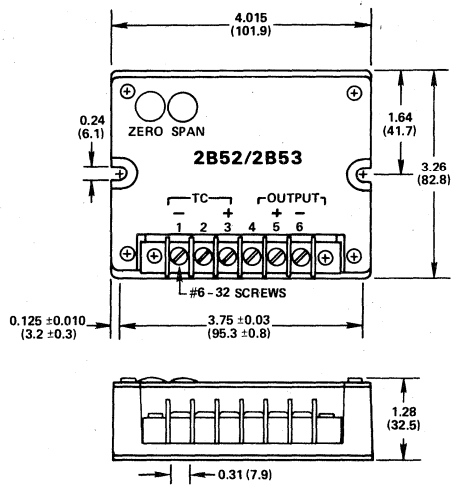
| Model | 2B52A | 2B53A |
|---|---|---|
| **INPUT SPECIFICATIONS** | | |
| Thermocouple Types | J, K, T | * |
| Input Span Range | 5mV min, 100mV max | * |
| Input Impedance | 5MΩ | * |
| Input Bias Current[1] | 85nA | 30nA |
| Zero and Span Adj. Range | ±5% of Span | * |
| Open Input Detection | Upscale | * |
| **OUTPUT SPECIFICATIONS** | | |
| Output Span | 4–20mA | * |
| Minimum Output Current | 3.3mA, typ | 2mA, typ |
| Maximum Output Current | 42mA, typ | 28mA, typ |
| Load Resistance Range Equation | $R_L$ max = (+$V_S$ -12V)/20mA | * |
| @ +24V Supply | 0 to 600Ω max | * |
| Output Protection[2] | +60V | * |
| **ACCURACY** | | |
| Total Output Error[3] | ±0.1% | * |
| Stability vs. Ambient Temperature | | |
| Zero, for Ambient 0 to +50°C[4] | ±0.015°C/°C | * |
| 0 to +85°C[4] | ±0.025°C/°C | * |
| -30°C to 0°C[4] | ±0.06°C/°C | * |
| Span, for Ambient -30°C to +85°C | ±0.005%/°C | * |
| Warm-up Time to Rated Performance | 5 min | 3 min |
| **ISOLATION** | | |
| CMV, Input to Output, Continuous | 600V rms | NA |
| Common Mode Rejection, @ 60Hz | 160dB | NA |
| Normal Mode Rejection, @ 60Hz | 60dB | NA |
| **RESPONSE TIME** | | |
| to 90% of Span | 0.3 sec | 0.1 sec |
| **INTRINSICALLY SAFE OPERATION** | | |
| Use in Class I, Division 1, Groups A,B,C, and D Hazardous Locations | FM Approved | NA |
| **POWER SUPPLY** | | |
| Voltage, Operating Range | +12V to +60V dc | * |
| Supply Change Effect, % of Span | | |
| on Zero | 0.005%/V | * |
| on Span | 0.001%/V | * |
| **ENVIRONMENTAL** | | |
| Temperature Range, Rated Performance | -30°C to +85°C | * |
| Storage Temperature Range | -55°C to +125°C | * |
| Relative Humidity, Noncondensing[5] | 0 to 90% | * |
| RFI Effect (5W @ 470MHz @ 3 ft.) | | |
| Error, % of Span | ±0.5% | * |
| **PHYSICAL** | | |
| Case Size | 4" X 3.25" X 1.25" | * |
| Weight | 8.5 oz. (240g) | 8 oz. (227g) |

NOTES
[1] Includes thermocouple burnout detection current.
[2] Protected for reverse polarity and for any combination of input and output pins.
[3] Accuracy is specified as a percent of output span (16mA). Accuracy spec includes combined effects of transmitter repeatability, hysteresis and linearity. Does not include sensor error.
[4] Includes combined effects of cold junction compensation and amplifier offset drift.
[5] Per MIL-STD-202E method 103.

*Specifications same as 2B52A.
Specifications subject to change without notice.

## OUTLINE DIMENSIONS (MAX)

Dimensions shown in inches and (mm).




## ORDERING INFORMATION

**Example:** MODEL 2B52A - 1 - J - 03

Select Model
2B52A (Isolated)
2B53A (Nonisolated)

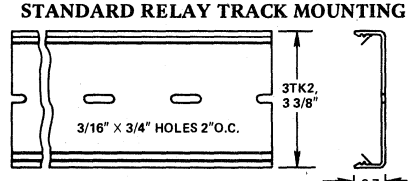
Select Housing
1 – Standard Enclosure

Select Thermocouple Type
J, K or T

Select Temperature Range
01 through 06

| Range in °C(°F) | TC Type | No. |
|---|---|---|
| -100 to +300 (-148 to +572) | J, K, T | 01 |
| 0 to +200 (+32 to +392) | T | 02 |
| 0 to +500 (+32 to +932) | J | 03 |
| 0 to +600 (+32 to +1112) | K | 04 |
| 0 to +750 (+32 to +1382) | J | 05 |
| 0 to +1000 (+32 to +1832) | K | 06 |

## STANDARD RELAY TRACK MOUNTING




Both 2B52 and 2B53 may be conveniently mounted in a standard relay mounting channel (3.25" wide) such as Reed Devices Inc. (RDI) model 3TK2–6 or equivalent.

# ANALOG DEVICES

# Four-Channel, Isolated Thermocouple/mV Conditioners

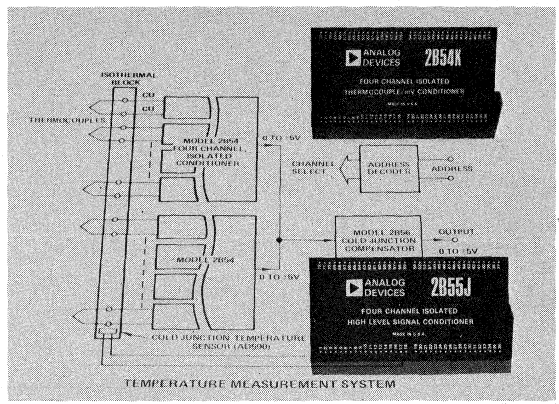
# MODELS 2B54 AND 2B55

**FEATURES**

**Low Cost Per Channel**
**Wide Input Span Range: ±5mV to ±100mV (2B54)**
**±50mV to ±5V (2B55)**
**12-Bit Systems Compatible**
**High CMV Isolation: ±1000V dc; CMR = 156dB min @ 60Hz**
**Low Input Offset Voltage Drift: ±1μV/°C max (2B54B)**
**Low Gain Drift: ±25ppm/°C max (2B54B)**
**Low Nonlinearity: ±0.02% max (±0.012% typ)**
**Normal Mode Input Protection (130V rms) and Filtering**
**Channel Multiplexing: 400 chan/sec Scanning Speed**
**Solid State Reliability**

**APPLICATIONS**

**Multichannel Thermocouple Temperature Measurements**
**Low and High Level Data Acquisition Systems**
**Industrial Measurement and Control Systems**



TEMPERATURE MEASUREMENT SYSTEM

9

**GENERAL DESCRIPTION**

Models 2B54 and 2B55 are low cost, high performance, four-channel signal conditioners. Both models are functionally complete, providing input protection, isolation and common mode rejection, multiplexing, filtering and amplification.

The 2B54 has been designed to condition low level signals (±5mV to ±100mV), like those generated by thermocouples or strain gages, in the presence of high common mode voltages. The 2B55 is optimized to condition ±50mV to ±5V or 4 to 20mA transmitter signals as inputs. The four-channel structure of both models results in significant cost and size reduction.

The high performance of the 2B54 and 2B55 is accomplished by the use of reliable transformer isolation techniques and an amplifier-per-channel architecture. Each of the input channels is galvanically isolated (±1000V dc) from the other input channels and from output ground. The amplifier-per-channel structure is used to obtain low input drift (±1μV/°C max, 2B54B), high common mode rejection (156dB @ 60Hz), and very stable gain (±25ppm/°C max). Other key features include low input noise (1μV p-p), low nonlinearity (±0.02% max) and open-thermocouple detection (2B54).

**APPLICATIONS**

Models 2B54 and 2B55 were designed to serve as a superior alternative to the relay multiplexing circuits used in multi-channel data acquisition systems, computer interface systems, process signal isolators, and temperature measurement and control instrumentation. Advantages over relay circuits include functional versatility, superior performance, and solid state reliability.

In thermocouple temperature measurement applications, outstanding low drift, high noise rejection, high throughput and 1000V isolation make the 2B54 a natural choice over flying capacitor multiplexers in conditioning any thermocouple type. When cold junction compensation is required in measurement of temperature with thermocouples, the 2B54 may be used directly with the model 2B56 Universal Cold Junction Compensator.

**DESIGN FEATURES AND USER BENEFITS**

**High Reliability:** To assure high reliability and provide isolation protection to electronic instrumentation, reliable transformer isolation and solid state switching are used. Both models have been conservatively designed to meet the IEEE standard for Transient Voltage Protection (472-1974:SWC) and offer 130V rms normal mode input protection.

**High Noise Rejection:** To preserve high system accuracy in electrically noisy industrial environments, the 2B54 and 2B55 provide excellent common mode noise rejection, RFI/EMI immunity, and low pass filtering for rejection of series mode noise and 50Hz/60Hz pickup.

**Ease of Use:** The multichannel, functionally complete design in a compact (2" X 4" X 0.4") module, assures ease of use, conserves board space and eliminates the need for a number of discrete components necessary in relay multiplexing circuits.

**Low Cost:** The 2B54 and 2B55 offer the lowest cost per channel for isolated, solid state, low level signal conditioners.

# SPECIFICATIONS (typical @ +25°C, $V_S$ = ±15V and $V_{OSC}$ = +15V, unless otherwise noted)

| Model | 2B54A | 2B54B | 2B55A |
|---|---|---|---|
| ANALOG INPUTS | | | |
| Number of Channels | 4 | * | * |
| Input Span Range | ±5mV to ±100mV | * | ±50mV to ±5V |
| Gain Equation | $G = 1 + 10k\Omega/R_G$ | * | * |
| Gain Error | ±0.2% max (G = 50 to 300) | * | ±0.2% max (G = 1 to 100) |
| | ±1% max (G = 1000) | * | NA |
| Gain Temperature Coefficient | ±35ppm/°C max | ±25ppm/°C max | ±25ppm/°C max |
| Gain Nonlinearity[1] | ±0.03% max (G = 50 to 300) | ±0.02% max(±0.012% typ) | ±0.02% max (G = 1 to 100) |
| | ±0.03% (G = 1000) | * | NA |
| Offset Voltage | | | |
| Input Offset, Initial (Adj. to Zero) | ±20µV max | * | ±50µV max |
| vs. Temperature | ±2.5µV/°C max | ±1µV/°C max(±0.5µV/°C typ) | ±5µV/°C max |
| vs. Time | ±1.5µV/month | * | * |
| Output Offset (Adjustable to Zero) | ±12mV max | * | * |
| vs. Temperature | ±50µV/°C max | * | * |
| Total Offset Drift (RTI), max | $\pm\left(2.5+\frac{50}{G}\right)\mu V/°C$ | $\pm\left(1+\frac{50}{G}\right)\mu V/°C$ | $\pm\left(5\mu V+\frac{50}{G}\right)\mu V/°C$ |
| Input Noise Voltage | | | |
| 0.01Hz -100Hz, $R_S$ = 1kΩ | 1µV p-p | * | * |
| CMV, Channel-to-Channel or | | | |
| Channel-to-Ground | | | |
| Continuous, ac, 60Hz | 750V rms | * | * |
| Continuous, ac or dc | ±1000V pk max | * | * |
| Common Mode Rejection | | | |
| $R_S \leq 100\Omega$, $f \geq 50Hz$ | 156dB min (G = 1000) | * | 145dB min (G = 100) |
| $R_S \leq 100\Omega$, $f \geq 50Hz$ | 128dB min (G = 50) | * | 110dB min (G = 1) |
| Normal Mode Input, Without Damage | 130V rms, 60Hz | * | * |
| Normal Mode Rejection, @ 60Hz | 55dB min (G = 1000) | * | 55dB min (G = 100) |
| Input Resistance, Power On | 100MΩ | * | * |
| Power Off | 35kΩ min | * | 74kΩ min |
| Input Bias Current | +8nA max | * | * |
| ANALOG OUPUT | | | |
| Output Voltage Swing[2] | ±5V @ ±5mA | * | * |
| Output Noise, dc - 100kHz | 0.8mV p-p | * | * |
| Output Resistance | | | |
| Direct Output | 0.1Ω | * | * |
| Switched Output | 35Ω | * | * |
| CHANNEL SELECTION | | | |
| Channel Selection Time to ±0.01% FS | 2.5ms max | * | * |
| Channel Scanning Speed | 400 chan/sec min | * | * |
| Channel Select Input Reverse Voltage | | | |
| Rating | 3V max | * | * |
| POWER SUPPLY | | | |
| Voltage | | | |
| Output $\pm V_S$ (Rated Performance) | ±15V dc ±10% | * | * |
| (Operating) | ±12V to ±18V dc max | * | * |
| Oscillator $+V_{OSC}$ | | | |
| (Rated Performance) | +13.5V to +24V | * | * |
| Absolute max $+V_{OSC}$ | +26V | * | * |
| Current | | | |
| Output $\pm V_S$ = ±15V | ±4mA max | * | * |
| Oscillator $+V_{OSC}$ = +15V | 40mA max | * | * |
| Supply Effect on Offset | | | |
| Output $\pm V_S$ | 100µV/V RTO | * | * |
| Oscillator $+V_{OSC}$ | 1µV/V RTI | * | * |
| ENVIRONMENTAL | | | |
| Temperature | | | |
| Rated Performance | 0 to +70°C | * | * |
| Operating | -25°C to +85°C | * | * |
| Storage | -55°C to +85°C | * | * |
| Relative Humidity | | | |
| Non-Condensing to +40°C | 0 to 85% | * | * |
| CASE SIZE | 2" X 4" X 0.4" | * | * |

NOTES

*Specifications same as 2B54A.

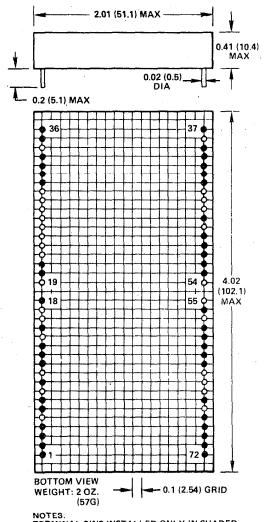
[1] Gain nonlinearity is specified as a percentage of output signal span representing peak deviation from the best straight line; e.g. nonlinearity at an output span of 10V pk-pk (±5V) is ±0.02% or ±2mV.

[2] Protected for shorts to ground and/or either supply voltage.

Specifications subject to change without notice.

## OUTLINE DIMENSIONS

Dimensions shown in inches and (mm).



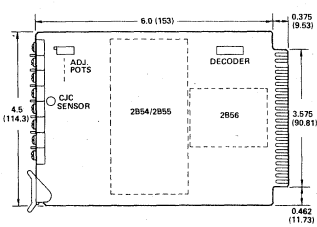

NOTES.
TERMINAL PINS INSTALLED ONLY IN SHADED HOLE LOCATIONS.

## 2B54/2B55 PIN DESIGNATIONS

| PIN | FUNCTION | PIN | FUNCTION |
|---|---|---|---|
| 1 | - SELECT CH. D | 37 | HI |
| 2 | + SELECT CH. D | 38 | |
| 3 | SW'D OUTPUT ENABLE | 39 | $R_G$ |
| 4 | SWITCHED OUTPUT | 40 | $R_G$/COM CHANNEL A |
| 5 | | 41 | LO/OFS |
| 6 | DIRECT OUTPUT | 42 | V- OUT |
| 7 | SENSE OUTPUT | 43 | V+ OUT |
| 8 | | 44 | |
| 9 | OFS. ADJ. OUTPUT | 45 | |
| 10 | | 46 | |
| 11 | $-V_S$ OUTPUT | 47 | HI |
| 12 | COM OUTPUT | 48 | |
| 13 | $+V_S$ OUTPUT | 49 | $R_G$ |
| 14 | | 50 | $R_G$/COM CHANNEL B |
| 15 | - SELECT CH. C | 51 | LO/OFS |
| 16 | | 52 | V- OUT |
| 17 | | 53 | V+ OUT |
| 18 | + SELECT CH. C | 54 | |
| 19 | | 55 | |
| 20 | - SELECT CH. B | 56 | HI |
| 21 | + SELECT CH. B | 57 | |
| 22 | | 58 | $R_G$ |
| 23 | | 59 | $R_G$/COM CHANNEL C |
| 24 | | 60 | LO/OFS |
| 25 | | 61 | V- OUT |
| 26 | | 62 | V+ OUT |
| 27 | | 63 | |
| 28 | | 64 | |
| 29 | | 65 | |
| 30 | $+V_{OSC}$ OSC. POWER | 66 | HI |
| 31 | COM OSC. POWER | 67 | |
| 32 | IN SYNC | 68 | $R_G$ |
| 33 | OUT SYNC | 69 | $R_G$/COM CHANNEL D |
| 34 | | 70 | LO/OFS |
| 35 | - SELECT CH. A | 71 | V- OUT |
| 36 | + SELECT CH. A | 72 | V+ OUT |

## AC1215 OUTLINE DIMENSIONS

Dimensions shown in inches and (mm).




**Mating Connector:**
**Cinch 251-22-30-160 or equivalent.**

## MOUNTING CARDS AC1215, AC1216

The AC1215 and AC1216 mounting cards are available to assist in evaluation of the 2B54 and 2B55. These 4 1/2" X 6" printed circuit edge connector cards have sockets that allow a 2B54/2B55 and 2B56 to be plugged directly onto them, as well as offset adjustment pots, and address decoding circuitry. The AC1215 and AC1216 differ only in input signal connections: the AC1215 includes a screw terminal block and AC1216 has an edge connector.

## FUNCTIONAL DESCRIPTION

The internal structure of the 2B54/2B55 is shown in Figure 1. Four individually isolated input channels are multiplexed into a single output buffer, with the desired channel selected by control inputs SELECT A through SELECT D. Isolated power and timing signals for the input channels are provided by an internal oscillator.

Each channel contains an input protection and filtering network and a low-drift amplifier whose gain is set by a user-supplied resistor ($R_G$). Additional filtering is provided in the amplifier circuit. This structure preserves signal integrity by taking all signal gain ahead of the isolation and multiplexing circuits. The isolated power supply for each channel is brought out to permit convenient fine adjustment of the input offset voltage if desired.

Transformer coupling is used to achieve stable, reliable galvanic isolation of each channel from all other channels and from output ground. Although the bandwidth of the input channels is small (<2Hz at high gains) to provide immunity to normal-mode noise, the multiplexing technique allows the channels to be scanned at a high rate (400 channels/sec). Thus a high revisitation rate is maintained even in systems with a large number of input channels.

The output buffer amplifier operates at unity gain with feedback provided by an external connection from the DIRECT output to the SENSE input. The DIRECT output provides a ±5V swing with low source resistance to permit error-free operation with heavy loads. In addition, a separate series-switched output with an active-low enable control is provided so that multiple modules may be combined without the use of external analog multiplexers. An offset trim point which does not affect drift is also provided on the output channel.

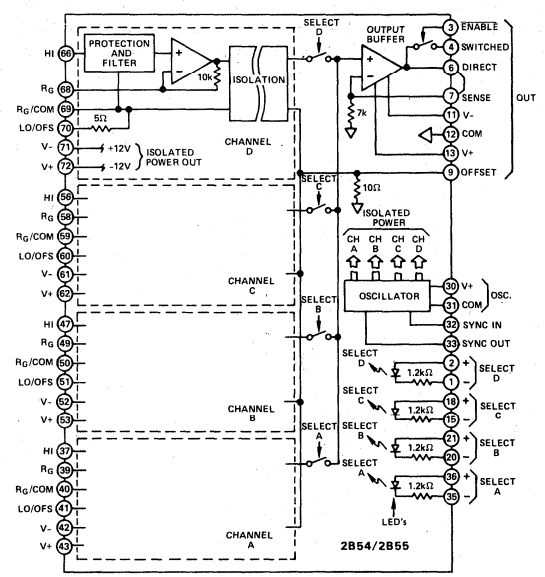



*Figure 1. 2B54/2B55 Functional Diagram*

The internal oscillator has its own power supply pins for enhanced application flexibility, and a sync mechanism is provided to eliminate beat-frequency errors when multiple 2B54/2B55's are used or when a system clock is present.

The 2B54 and 2B55 share the same design, differing only in input specifications and filter characteristics.

## OPERATING INSTRUCTIONS

The connections shown in Figure 2 are common to most applications of the 2B54/2B55, and in many cases will be all that is required. The following sections describe this basic application and also detail some optional connections which enhance the module's utility in more complex applications.

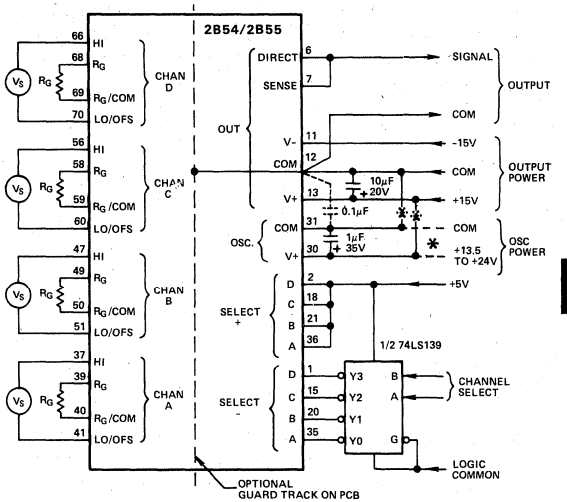



*Figure 2. Basic 2B54/2B55 Application*

### Interconnection Guidelines

In any high accuracy isolator application it is important to minimize coupling between input and output, and the 2B54/2B55 pinout has been designed to make this easy to do. For best results, keep all leads associated with signals on the input edge as far as possible from signals on the output edge. This will minimize the effects of board leakage and capacitance. The use of a guard track on both sides of the board (Figure 2) can also be helpful.

The power supplies should be decoupled with tantalum capacitors as close to the unit as possible. For lowest noise, the output grounding scheme should be as shown in Figure 2. The output signal common is connected directly to pin 12, with power supply returns brought separately to that pin so that power supply currents do not flow in the low lead of the signal output.

Since most of the power taken by the 2B54/2B55 is supplied to the internal oscillator which requires only a positive supply and can accommodate a wide range of supply voltages, it is sometimes desirable to power the oscillator from a convenient source of unregulated power (such as +24V – Figure 2). A 0.1μF capacitor should be then connected directly from pin 12 to pin 31. Since the output and oscillator circuits are not fully isolated, a dc path must exist between the two power supply commons. A small (one or two volts) potential difference between OUT COM and OSC COM will not affect operation.

### Gain Setting

The gain of each channel is independently set by a user-supplied resistor ($R_G$) connected as shown in Figure 2. Channel gain will normally be selected so that the maximum output of the signal source will result in a plus or minus full scale (±5V) output swing. The resistor value required is $R_G = 10k\Omega/(G-1)$. Thus if $R_G = 101\Omega$, the gain will be 100, and an input signal swing of ±50mV will yield an output span of ±5V.

A parallel trim on the gain-setting resistor can be used to trim out the resistor's tolerance and the module's gain error (Figure 3). Since a parallel trim will always increase the gain, the value of the gain-setting resistor should be chosen to give an untrimmed gain somewhat lower than the desired trimmed gain. Good quality metal-film resistors should be used for $R_G$ since gain accuracy and drift are a direct function of $R_G$'s characteristics. Cermet pots are suitable for the trim.

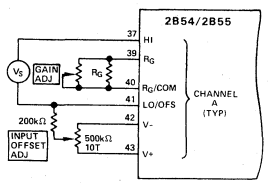



*Figure 3. Input Offset and Gain Adjustments*

### Optional Offset Adjustment

The 2B54/2B55 has provision for fine adjustment of the input offset of each channel and the output offset of the entire module. None of the offset adjustments affect offset drift, and there is no need to make any adjustment unless the application calls for tighter offsets than those specified for the module type.

Connections for input offset adjustment are shown in Figure 3. This is a fine trim with a limited range (±250μV – 2B54 and ±1mV – 2B55, RTI), used to adjust each channel for zero offset while operating at the desired gain. Since the range of the input offset trim is small, it will usually be necessary to adjust output offset first. This can be conveniently done by operating one channel with zero input at unity gain (by disconnecting the gain resistor) and adjusting the output offset control for zero output. Connections for output offset adjustment are shown in Figure 4.

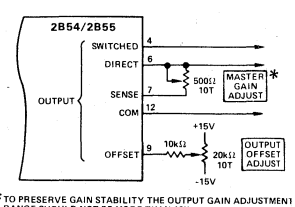



*Figure 4. Output Offset and Master Gain Adjustments*

An alternative offset adjustment procedure is appropriate in applications where the channel gains are field-selected by switching the gain-setting resistor. Here it is desirable to set the input offset so that there is no zero shift at the output when the gain is changed. To make the adjustment, switch back and forth from low to high gain with zero input and adjust the input offset control until no shift occurs at the output when changing gains. Then adjust the output offset control for zero output at the lower gain.

Stable components (a metal film resistor and a cermet pot) should be used for the input offset adjustment to avoid compromising drift. Output offset adjustment components are not critical and may be omitted altogether when a single 2B54/2B55 is followed by an A to D Converter that has a zero adjustment.

### Channel Selection

Each channel in the 2B54/2B55 is turned on and off by a SELECT input. As indicated in Figure 1, each SELECT input consists of an LED in series with a resistor, and is not connected to any other circuits in the module. Turning the LED on ($I \geq 2.5mA$) turns the channel on, and turning the LED off ($I \leq 50\mu A$) turns the channel off. This allows considerable flexibility of connection, but the easiest way to use the SELECT inputs is to tie all four SELECT + pins to +5V and drive the SELECT–inputs from TTL logic (either open-collector or totem-pole outputs can be used), as shown in Figure 2.

It is also possible to use CMOS logic to drive the SELECT inputs (Figure 5). With a +15V logic supply a standard CMOS decoder or gate can supply enough current to drive the SELECT inputs directly, but at lower supply voltages it is advisable to use a buffer such as that shown in Figure 5b. The power taken by the SELECT inputs is small, since only one is on at a time, but at the higher CMOS supply voltages more current than the required 2.5mA will flow. This does not affect operation, but if desired the current can be brought back to the minimum value with series resistors as shown in Figure 5. Use 2kΩ for 10V operation, and 3.9kΩ at 15V.

The maximum reverse voltage applied to any SELECT input must be limited to 3V to avoid damage to the LED. Maximum forward current should be kept below 25mA. Each SELECT input is isolated from all other circuits in the module and may be operated up to ±50V away from output and power ground.

Channels may be selected in any order, and there are no restrictions on rate or duty cycle except the 2.5ms settling time for access to a channel. It should be noted, however, that selecting two or more channels simultaneously for more than a few microseconds will result in a very long settling time when the conflict is resolved. Timing overlaps should therefore be avoided.

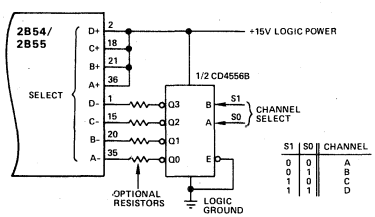



*Figure 5a.*

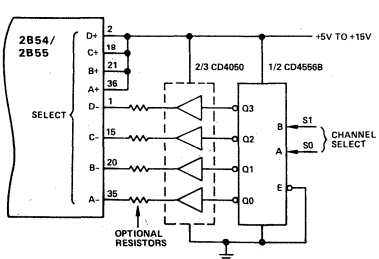



*Figure 5b.*

*Figure 5. CMOS Channel Selection*

### Channel Expansion

The 2B54/2B55 has provision for directly interconnecting several modules when more than four channels are needed. The series-switched outputs of a group of modules are connected together, the SELECT inputs are driven in parallel, and the output of the desired module is selected using the Output Enable pin. This is shown in Figure 6. A single 74LS139 decoder is used to drive the SELECT inputs of up to four modules, and also provides address expansion so that the binary coded channel address word selects the appropriate module output via the Output Enable pins. The overall operation of the series-switched outputs is analogous to three-state logic, and the output rail is thus an analog bus.

It is possible to operate up to sixteen modules in parallel, for a total of 64 input channels. Note that it will be necessary to break up the SELECT inputs into several groups to avoid overloading the decoder when many modules are used. The settling time of the output switches is <50μs to ±0.01% and is thus negligible in comparison to the channel selection times.

The Output Enable signal is active low, and is compatible with both TTL and CMOS logic. The switching threshold is +1.8V; input current at 0V is typically –0.4mA.

The output resistance of the Switched Output (typically 35Ω +0.5%/°C) is low enough to provide fast switching times but will cause gain errors when driving a heavy load. A single buffer isolating the Switched Outputs from the load will solve this problem in an "analog bus" application (Figure 6). In single-module applications the DIRECT (low impedance) output should be used. Note that in all cases the SENSE pin *must* be connected to the DIRECT output to provide feedback for the output amplifier.

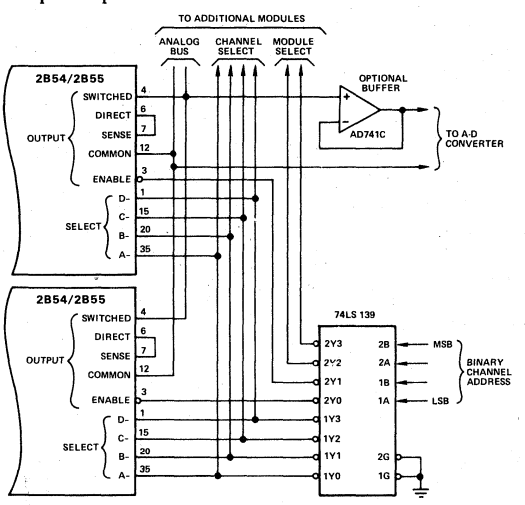



*Figure 6. Expansion to More than Four Channels*

### Synchronization

In applications where multiple 2B54/2B55's are used in close proximity or when system clock signals are present near the isolator, differences in individual oscillator frequencies may cause "beat frequency" related output errors. To eliminate these errors, multiple units may be synchronized by connecting the SYNC OUT (pin 33) terminal to the SYNC IN (pin 32) terminal of the adjacent 2B54/2B55 (Figure 7). The first of a group of modules may be synchronized to an external source via the SYNC IN pin. To minimize noise pickup, sync wiring should be separated from analog signal runs.

The frequency of the external sync source, when used, will have a small effect on the gain and output offset of the 2B54/2B55. Thus any adjustments should be made with the module synchronized.

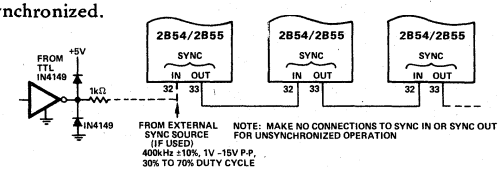



*Figure 7. Synchronization*

### Open Input Detection

The 2B54 can be programmed to respond to an open-circuit condition on a channel input with either an upscale or downscale response when the affected channel is selected. The response time to detect an open input can be in the tens of seconds, since only a few nA of input bias current are available to charge the input filter. The circuits in Figure 8 indicate the selection of either downscale or upscale response and can be used to provide shorter open-circuit response times. Either circuit will produce a bias current of approximately 20nA which can be used to aid or oppose the 3nA typically supplied by the module, as shown. The circuit of Figure 8A has the advantage of simplicity, but the high-value resistor may not be readily available. Figure 8B shows how to solve the problem at the expense of complexity. The values shown may be modified to give an optimum trade of bias current for response time in a given application. A 2 to 5 second response is typical for the values shown.

If a downscale response is desired, a resistor divider circuit like Figure 8B may be desired to prevent a negative overscale. If a negative overscale condition occurs (typically –7V), the output will saturate on all channels.

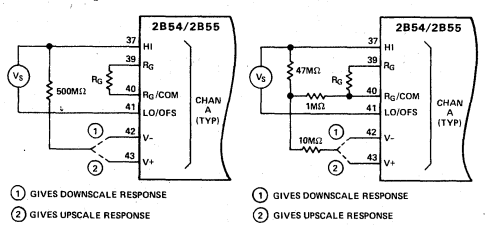



*Figure 8. High Speed or Reversed Open Input Detection*

### Output Filtering

In most applications, no output filtering will be required since the effect of the small carrier-related noise spikes on the output (<1mV p-p, 100kHz B.W.) drops off rapidly as bandwidth decreases and in many cases will be negligible. In some applications (e.g., when driving a successive-approximation A to D) the effective system bandwidth may be large enough to pass the noise. To eliminate the carrier noise (without any effect on switching times), a simple R-C filter may be used at the output (Figure 9A). Only one filter is needed even when multiple modules are used, as shown in Figure 9B. If the load to be driven has an input resistance of less than 10MΩ, a buffer will be needed.

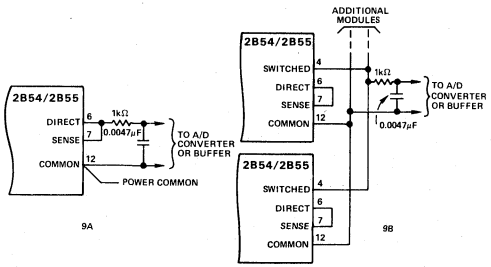



*Figure 9. Output Filtering*

## CMR AND NMR PERFORMANCE

Common mode rejection is a result of both isolation and filtering and indicates ability to reject common mode inputs while amplifying differential signal inputs. CMR is dependent on source impedance imbalance, signal frequency and conditioner gain.

Normal mode rejection is also a function of the 2B54/2B55 gain. Figures 10 and 11 illustrate typical CMR and NMR performance. Note that any additional low pass filtering (e.g., an integrating A to D converter) at the output of the 2B54/2B55 will further improve both CMR and NMR performance.

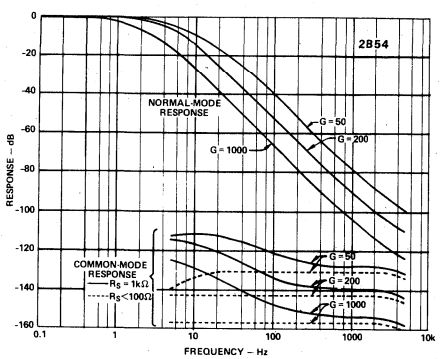



*Figure 10. Common Mode and Normal Mode Response – Model 2B54*

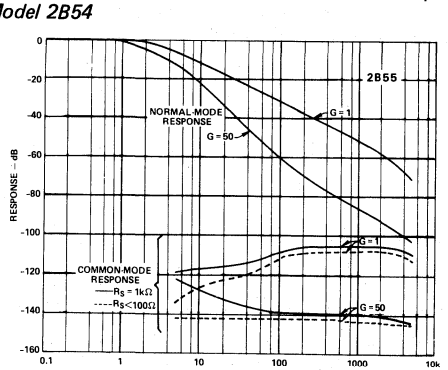



*Figure 11. Common Mode and Normal Mode Response – Model 2B55*

## APPLICATIONS

**Thermocouple Temperature Measurement:** Figure 12 shows a four-channel thermocouple input system with isolation, amplification, and multiplexing provided by the 2B54. Several different thermocouple types are used, and the gain-setting resistors on each channel have been chosen to take the standard ANSI range for each type to a 5V output span. Since thermocouples must be compensated for the temperature of the reference junction which is formed where the thermocouple leads are terminated, the 2B56 Universal Cold Junction Compensator is used. The 2B56 monitors the temperature of the reference junction (terminal block) via an external sensor and corrects the signal at the output of the 2B54 for reference temperature. Compensation for several thermocouple types is selectable via digital control inputs. Thermocouple linearization, if needed, would be typically performed in system's software.

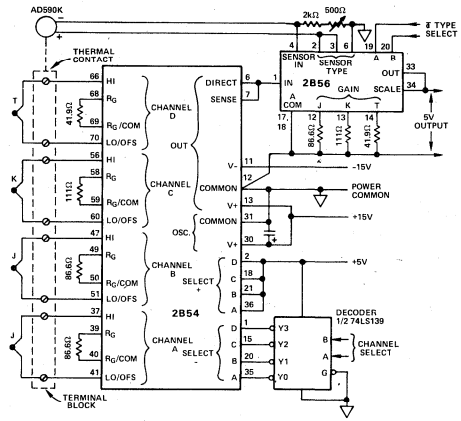



*Figure 12. Four-Channel Thermocouple Temperature Measurement with Cold Junction Compensation*

**Process Signals Interface:** In Figure 13, the 2B55 is used to provide floating inputs for four 4-20mA process signal loops. The use of floating inputs in this type of application gives protection from common-mode voltages and greatly simplifies system configuration, since additional loads in series with the loop can be connected on either side of the isolator input.

Each current input is converted into a 1 to 5 volt signal by a 250Ω resistor. The 2B55 is operated at unity gain (no gain-setting resistors) so that a 1 to 5 volt signal appears at the output. Since no gain-setting resistors are used, gain adjustment, if required, is done by connecting trims directly across the input resistors. Other current ranges can be accommodated by changing the value of the input resistors.

When there are several loads on the loop, compliance voltage at the transmitter may be at a premium. In this case it will be advantageous to reduce the voltage swing at the isolator inputs by using smaller resistors (perhaps 25Ω) and scaling the output back to a 5V span by taking an appropriate gain in the isolator.

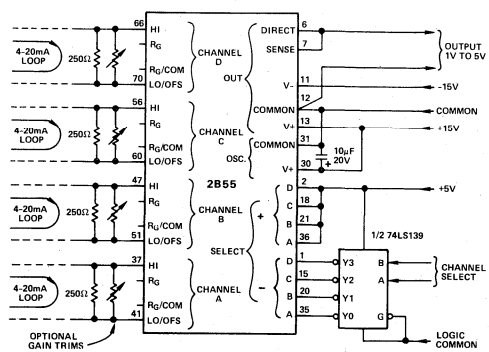



*Figure 13. Isolated 4-20mA Loop Signals Interface*

# High Accuracy, Thermocouple Cold Junction Compensator

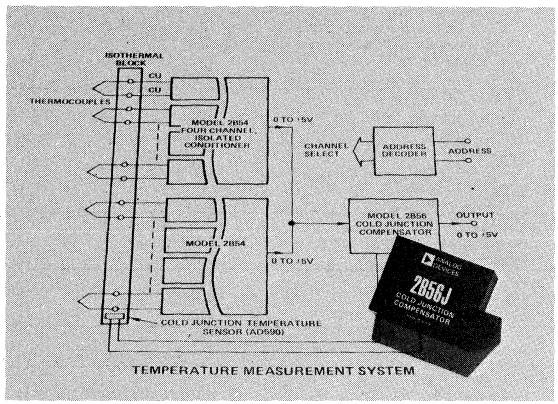
# MODEL 2B56

**FEATURES**

**Universal Thermocouple Compensation:**
**Internally Provided: Types J, K, T**
**User Configurable: Types E, R, S, B**
**Digitally Programmable Type Select**
**High Accuracy: ±0.8°C max over +5°C to +45°C**
**High Ambient Rejection: 50 to 1 min**
**Low Cost:**
**Small Size: 1.5" X 2" X 0.4"**

**APPLICATIONS**

**Thermocouple Signal Conditioning**
**Temperature Measurement and Control Systems**
**Temperature Data Acquisition and Logging**
**Temperature Controllers**



TEMPERATURE MEASUREMENT SYSTEM

9

## GENERAL DESCRIPTION

Model 2B56 is a high accuracy, universal thermocouple cold junction compensator. Designed to operate with an external temperature sensor in thermal contact with the cold junction, the 2B56 provides an automatic compensation for amplified thermocouple signals over wide ambient temperature variations. The 2B56 is calibrated to compensate the cold junction to a reference temperature of 0°C. The total compensation error is ±0.8°C max over +5°C to +45°C.

Designed to compensate seven different thermocouple types, the 2B56 may be digitally programmed to select compensation for types J, K and T, and one user programmed type (E, R, S, B or none). This feature makes the 2B56 especially suitable for multichannel applications involving several thermocouple types.

## COLD JUNCTION COMPENSATION PRINCIPLES

In thermocouple measurements, temperature is determined by measuring the potential difference between the measurement (hot) junction of two dissimilar metals and the reference (cold) junction which is formed when thermocouple leads are connected to a measuring circuit. Since this potential difference is proportional to the temperature difference between the measurement temperature and the temperature at the reference junction, the reference junction temperature must be known. Changes in reference junction temperature influence the output voltage and, therefore, cold junction compensation is required to eliminate measurement errors.

Two methods may be used to reduce errors introduced at the thermocouple connections: keep the reference junction at a known constant temperature, or measure the reference junction temperature and cancel the changes by the appropriate correction to the thermocouple output signal. The first method, accomplished by immersing the reference junction in an ice bath maintained at 0°C is not very practical. The 2B56 employs the second method and has been specifically designed to eliminate the need for ice baths by electronically simulating the desired reference point. Digital programmability, high accuracy and low cost make the 2B56 ideal for single or multichannel thermocouple temperature measurement, indication or control systems.

## FUNCTIONAL DESCRIPTION

The 2B56 compensates for cold junction temperature by adding a correction signal at the output of the user's thermocouple amplifier, as shown in Figure 1. The value of the correction signal is determined by the cold junction temperature, as measured by a sensor, and the thermocouple type in use, as specified by two digital TYPE SELECT inputs. Since compensation is done at the output of the thermocouple amplifier it is also necessary to scale the correction signal for the gain of the amplifier. This is done by a scaling circuit which has provision for a user-supplied gain-setting resistor for each thermocouple type in use.

Compensating networks for thermocouple types J, K, and T are built into the 2B56. A fourth compensation (X) can be programmed with two external resistors for any other thermocouple type. The X compensation can also be used without programming resistors to obtain an uncompensated output when sensors other than thermocouples are in use.

# SPECIFICATIONS (typical @ +25°C, $V_S$ = ±15V unless otherwise noted)

| MODEL | 2B56A |
|---|---|
| COLD JUNCTION COMPENSATION | |
| Thermocouple Types: | |
| Internally Compensated | J, K, T |
| Externally Programmable | B, E, R, S, None |
| Reference Temperature | 0°C |
| Compensation Accuracy | |
| Total Output Error @ +25°C[1] | ±0.2°C |
| vs. Ambient Temperature (+5°C to +45°C)[1] | ±0.8°C max |
| Compensation Error | |
| vs. Sensor Temperature (+5°C to +45°C)[2] | ±0.4°C max (±0.15°C typ) |
| vs. Compensator Module Temperature (0 to +70°C)[3] | ±0.02°C/°C max (0.01°C/°C typ) |
| Cold Junction Temperature Sensing Element | AD590 or 2N2222 |
| INPUT SPECIFICATIONS | |
| Voltage Signal Range | ±10V |
| Input Impedance | 100kΩ |
| Signal Gain[4] | +1V/V |
| vs. Temperature | ±10ppm/°C |
| Input Offset Voltage | ±1mV max |
| vs. Temperature | ±15μV/°C max |
| OUTPUT SPECIFICATIONS[5] | |
| Output Voltage | ±10V @ ±5mA |
| Output Impedance | 0.1Ω |
| DYNAMIC RESPONSE | |
| Selection Settling Time | 0.5ms |
| Signal Settling Time, to ±0.01% | 50μs |
| DIGITAL INPUTS | |
| Select Inputs A & B | TTL, CMOS Compatible |
| POWER SUPPLY | |
| Analog, Rated Performance | ±15V dc ±10% @ ±5mA |
| Operating | ±12V to ±18V dc |
| Digital, $V_{DD}$ | +5V to +15V dc @ 2mA max |
| TEMPERATURE RANGE | |
| Rated Performance | 0 to +70°C |
| Operating | -25°C to +85°C |
| Storage | -55°C to +125°C |
| CASE SIZE | 1.5" X 2" X 0.4" |

NOTES
[1] Total compensation error composed of errors of temperature sensor and module at the same ambient temperature.
[2] Compensation error contributed by ambient temperature changes at temperature sensor.
[3] Compensation error contributed by ambient temperature changes at the module.
[4] Signal gain of 2 is also available by jumper selection.
[5] Protected for shorts to ground or either supply voltage.

Specifications subject to change without notice.

| T/C Type | Max Gain for Sensor Temp to +45°C | Max Gain for Sensor Temp to +70°C |
|---|---|---|
| J | 1000 | 650 |
| K, T | 1300 | 820 |
| E | 870 | 550 |
| R, S | 9000 | 5500 |
| B | Any | Any |

*Table I. Maximum Gain vs. Sensor Temperature and Thermocouple Type*

| T/C Type | RX1 | RX2 |
|---|---|---|
| E | 412kΩ | 1.43kΩ |
| R, S | 412kΩ | 121Ω |

*Table II. Resistor for Compensating Types E, R and S*

| Type Sel. Logic B | Type Sel. Logic A | Compensation |
|---|---|---|
| 0 | 0 | J |
| 0 | 1 | K |
| 1 | 0 | T |
| 1 | 1 | X |

*Table III. Digital Selection of Compensation Type*

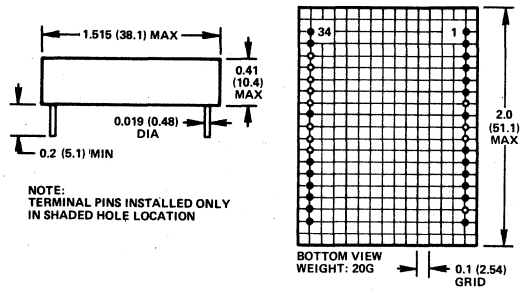
| Sensor Temp (°C) | $V_{CAL}$ (mV) 2N2222 | $V_{CAL}$ (mV) AD590 |
|---|---|---|
| 5 | 616.5 | 634.5 |
| 10 | 604.9 | 645.9 |
| 15 | 593.3 | 657.3 |
| 20 | 581.6 | 668.7 |
| 25 | 570.0 | 680.1 |
| 30 | 558.4 | 691.5 |
| 35 | 546.8 | 702.9 |
| 40 | 535.1 | 714.3 |
| 45 | 523.5 | 725.7 |

Values may be interpolated

*Table IV. Calibration Voltage vs. Sensor Temperature*

## OUTLINE DIMENSIONS

Dimensions shown in inches and (mm).




## PIN DESIGNATIONS

| PIN | FUNCTION | PIN | FUNCTION |
|---|---|---|---|
| 1 | SIGNAL INPUT | 18 | ANALOG COMMON |
| 2 | SENSOR SELECT | 19 | E TYPE SELECT |
| 3 | SENSOR SELECT | 20 | E TYPE SELECT |
| 4 | SENSOR INPUT | 21 | $+V_{DD}$ |
| 5 | SENSOR SELECT | 22 | DIGITAL COMMON |
| 6 | SENSOR SELECT | 23 | $+V_S$ |
| 7 | | 24 | |
| 8 | $V_{REF}$ | 25 | |
| 9 | | 26 | |
| 10 | | 27 | $-V_S$ |
| 11 | "X" COMPENSATION | 28 | |
| 12 | TYPE J (GAIN SELECT) | 29 | |
| 13 | TYPE K (GAIN SELECT) | 30 | |
| 14 | TYPE T (GAIN SELECT) | 31 | |
| 15 | TYPE "X" (GAIN SELECT) | 32 | |
| 16 | | 33 | OUTPUT |
| 17 | ANALOG COMMON | 34 | SCALE |

**MATING SOCKET: AC1217**

A buffer amplifier is provided at the output of the 2B56 to preserve accuracy when driving heavy loads. The gain from $V_{IN}$ to $V_{OUT}$ will be +1 when SCALE is connected to $V_{OUT}$ (see Figure 1). Input and output signal swings of up to ±10V can be accommodated with this connection. When the SCALE pin is left open, the gain from $V_{IN}$ to $V_{OUT}$ is +2. This is useful when interfacing a thermocouple amplifier with a ±5V output swing (such as the 2B54) to an A to D converter with a ±10V input range.

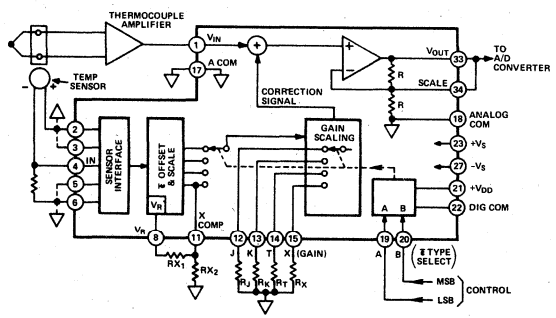



*Figure 1. 2B56 Functional Block Diagram*

It should be noted that the 2B56 is designed for use with noninverting thermocouple amplifiers. Thus a positive voltage change at the input of the 2B56 must indicate increasing temperature.

## OPERATING INSTRUCTIONS

**Temperature Sensors:** The temperature sensor used with the 2B56 can be either the Analog Devices AD590 temperature transducer or the popular 2N2222 transistor. Either sensor type can be used without loss of accuracy, but each has advantages in different applications. The 2N2222 (the metal can version must be used) is widely available at very low cost. However, an adjustment must be made whenever the sensor is replaced. The AD590 is available in several precalibrated accuracy grades, but at somewhat higher cost.

Connections are shown for both sensor types in Figure 2. Resistor $R_{CAL}$ is the calibration adjustment point. It is used only to adjust for unit-to-unit variations in the sensors. All other adjustments have been made internal to the 2B56.

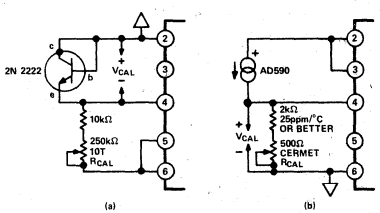



*Figure 2. Sensor Connections and Calibration*

With either sensor type, proper placement of the sensor is important. Close thermal contact of the sensor and the thermocouple termination point (reference junction) is necessary, particularly when nearby heat sources are present, since these could cause the sensor temperature to differ from the reference junction temperature. In multichannel applications, care should be taken to keep all input terminals at the same temperature to avoid channel-to-channel errors. The sensor may be placed at any distance from the 2B56. When the sensor leads are more than ten feet long, or where strong noise sources are present, shielded cable should be used with the 2N2222 sensor. The AD590 will operate properly with twisted-pair leads at distances up to a few hundred feet.

**Gain Selection:** Since the 2B56 performs cold junction compensation at the output of the user's thermocouple amplifier, it must take the gain of that amplifier into account. For this purpose, four gain-programming pins are provided: one each for the J, K, and T compensations and one for the X (user-selected) compensation. Thus the user's thermocouple amplifiers can have different gains for each thermocouple type in use, and the 2B56 gain will be selected automatically when the thermocouple type is selected at the digital TYPE SELECT inputs. Gain-programming resistors are connected as shown in Figure 1. The value of each resistor is $R = 10k\Omega/(G-1)$ where G is the gain of the user's thermocouple amplifier from the thermocouple terminals to the input of the 2B56. As an example, if the thermocouple amplifiers in use have a gain of 110 for type J, 90 for type K, and 220 for type T, then $R_J$ = 91.7Ω, $R_K$ = 112Ω, and $R_T$ = 45.7Ω. Gain resistor pins for unused thermocouple types must be grounded. The resistors used to set gain should have a tolerance of 1% or better. A 1% error in setting gain will result in a 0.01°C/°C slope error.

The gain of the thermocouple amplifier will normally be determined by the thermocouple type, temperature measurement range, and A to D converter input range, but there are some practical limits imposed by the 2B56. The minimum allowable gain for proper operation is 40. The maximum gain which can be used is limited by the dynamic range of the compensation circuits in the 2B56, and is a function of thermocouple type and the temperature range (at the sensor) over which compensation is to be effective. Table I lists the maximum gain for each thermocouple type both for the specified +5°C to +45°C sensor temperature range and for a wider (reduced accuracy) 0 to +70°C range.

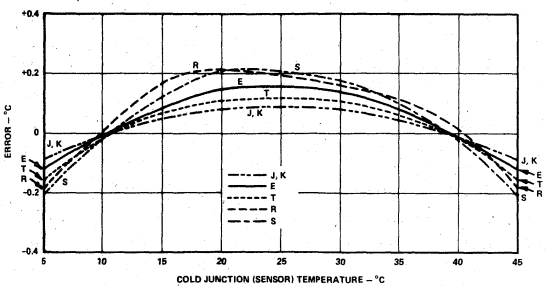



*Figure 3. Error Due to Thermocouple Nonlinearity*

**Compensation of Other Thermocouple Types:** Compensation for type J, K, and T thermocouples is built into the 2B56. A fourth compensation can be added by installing two resistors ($R_{X1}$ and $R_{X2}$) as shown in Figure 1. Table II gives the values needed for proper compensation of type E, R, and S thermocouples. Type B thermocouples are a special case, in that they have almost no output in the +5°C to +45°C range, and therefore, do not need cold junction compensation at all. To accommodate a type B thermocouple, select No Compensation (described in the next section). Errors due to cold junction temperature will be less than ±1°C for any measurement temperature above 260°C. In the measurement range beyond 1000°C (where type B thermocouples are normally used) the error will be less than ±0.3°C.

**No Compensation Operation:** In some instances it may be desirable to disable the compensation function of the 2B56, so that it functions as a straight-through amplifier with a gain of one (or two, if the output scaling feature is used). This might be done, for example, in a multichannel system with a mixture of thermocouples and strain gage signals or other sources requiring no compensation. It is also necessary when using the type B thermocouple, as described above. The X compensation can be programmed to provide no compensation by grounding pin 11 (X COMP), Figure 1. A 200Ω resistor should be used for $R_X$ (at any gain). Selecting X compensation with this connection will give an uncompensated output.

**Digital Inputs:** The TYPE SELECT inputs are compatible with TTL or CMOS logic, or may be used with jumpers or switches. Table III shows the truth table for these inputs. Each input has an internal 22kΩ pullup resistor to $V_{DD}$ and drives a single CMOS gate. For use with TTL signals, $V_{DD}$ should be connected to the +5V logic supply. When CMOS logic is used, connect $V_{DD}$ to the CMOS logic power supply (which must be in the +5V to +15V range). If jumpers or switches are used, connect $V_{DD}$ to the +15V analog power supply. Grounding a SELECT input will give a logic "0"; an open input will be at logic "1" due to the action of the internal pullups.

A separate pin is provided for logic ground to minimize ground loop problems. However, for proper operation logic ground at the module must be within ±0.3V of analog common. Failure to observe this restriction may result in damage to the module.

**Calibration:** Only one adjustment is necessary to get proper operation of the 2B56. This is shown in Figure 2 for both sensor types. $R_{CAL}$ is adjusted to obtain the correct voltage at $V_{CAL}$ for the appropriate sensor type and temperature, as listed in Table IV. Use a high-impedance voltmeter to measure $V_{CAL}$ to prevent loading errors.

The tolerance to which the calibration adjustment must be made depends on the requirements of the application. For either sensor type, and for all thermocouple types, each millivolt of calibration error will result in a temperature offset error at the 2B56 output of 0.44°C, accompanied by a slope error of 0.0015°C/°C.

**Curvature Error:** The voltage output of thermocouples is a nonlinear function of temperature, so the reference junction output which is compensated by the 2B56 is also nonlinear. The correction signal generated by the 2B56, however, is approximately linear. The 2B56 is adjusted internally to give the best fit of its linear correction to the nonlinear reference junction output over the +5°C to +45°C range. The remaining error, which is included in the specifications given on page 2, is shown for each thermocouple type in Figure 3. Note that as a result of thermocouple nonlinearity the error at +25°C will not be zero after calibration is done. The error for a particular thermocouple type could be adjusted to zero at +25°C by appropriate adjustment of the thermocouple amplifier offset, but the improvement will be at the expense of increased errors over the +5°C to +45°C range.

## APPLICATIONS

The application of the 2B56 to a single-channel system is shown in Figure 1. Because the 2B56 compensates at the output of the thermocouple amplifier, it is also very attractive for use in multiplexed multichannel systems. Three typical applications are shown in Figure 4. The amplifier-per-channel structure shown in Figure 4a is one example of a system which could have a different gain for each thermocouple type in use, with channels preassigned or switchable for thermocouple type.

The model 2B30 may be used as an amplifier for applications not requiring isolation.

In systems of this type, it is important that the ON resistance of the multiplex switches be less than 100 ohms, since larger values can create slope errors in the 2B56. If switches with higher resistance are used, a unity-gain buffer should be placed between the multiplexer and the 2B56. An AD741 or AD301-type amplifier will suffice unless the system is very fast.

Figure 4b shows an input-multiplexed system. Different gains for different channels in this type of system are sometimes provided by software control of the amplifier gain. The 2B56 can also accommodate this situation, since it can accept a different gain for each thermocouple type.

Figure 4c shows a somewhat different application of the 2B56. Here the signal input is grounded, so that the output is simply the correction signal rather than a corrected version of the input. In this case the actual summation is done elsewhere, usually in the processor following the A to D converter. The advantage of such a structure is that it allows somewhat simpler calibration of the individual channels because the compensator can be bypassed.

There is no electrical limit to the number of channels that can be served by a single 2B56 in these applications or the many others that are possible. There is, however, a thermal limit in that a single temperature sensor must accurately monitor the temperature of a number of sets of input terminals. The actual channel limit will thus be determined by the allowable error and the degree to which all the inputs can be held at the same temperature.

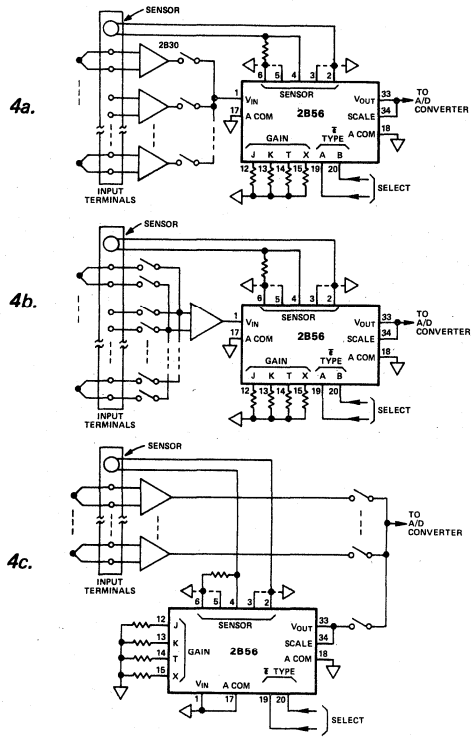



*Figure 4. Model 2B56 in Various Multichannel Applications*

Figure 5 shows the application of the 2B56 to the output of the 2B54 Four-Channel Isolator. More than one 2B54 can be served by the same 2B56 by using the built-in output switches of the 2B54 to connect several isolators to one output line. Note that the values of the gain-setting resistors for the 2B54 and 2B56 are the same, since both have the same gain formula. This permits very simple reconfiguration when the system must be tailored for new applications.

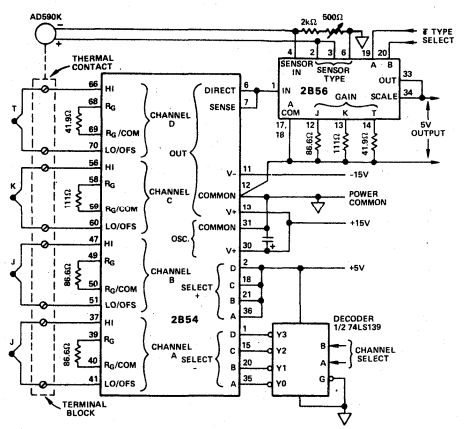


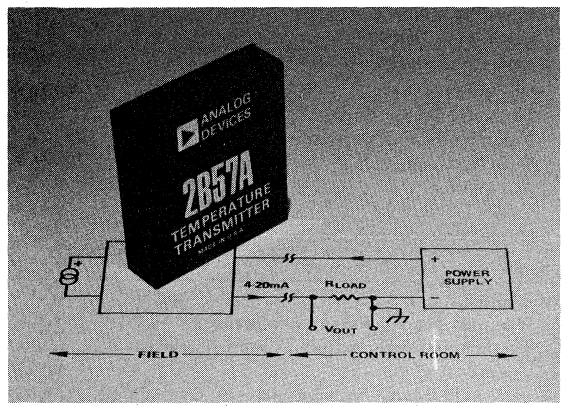

*Figure 5. Four-Channel Thermocouple Temperature Measurement with Cold Junction Compensation*

# Low Cost, Two-Wire Temperature Transmitter

# MODEL 2B57

**FEATURES**
- Low Cost
- Compatible with Standard 4-20mA Loops
- Low Span Drift: ±0.005%/°C max
- Low Nonlinearity: ±0.05% max
- RFI Immunity
- Small Size: 1.5″ × 1.5″ × 0.4″

**APPLICATIONS**
- Temperature Monitoring and Control
- Remote Temperature Sensing
- Process Control Systems
- Energy Management Systems




9

## GENERAL DESCRIPTION

The model 2B57 is a low cost, two-wire temperature transmitter designed to interface with Analog Devices' AD590 temperature transducer and produce a standard 4 to 20mA output current proportional to the measured temperature. The 2B57 can also be interfaced with Analog Devices' AD592 temperature transducer when user calibrated. The 2B57 features a low span drift of ±0.005%/°C max, a high linearity (±0.05% max) and high noise immunity to assure measurement accuracy in harsh industrial environments.

The transmitter accommodates the AD590 temperature measurement range of -55°C to +150°C. Both zero and span adjustments are provided to trim the range for input measurement spans between 20°C and 205°C. The transmitter output of 4 to 20mA and a wide range of power supply voltages make the 2B57 compatible with standard two-wire control loops.

The basic package is a small (1.5″ × 1.5″ × 0.4″), rugged, epoxy encapsulated module. For applications requiring protective housing, the 2B57 is available in a versatile metal case.

## APPLICATIONS

The 2B57 has been specifically designed to provide low cost, accurate and reliable temperature measurement in any applications below +150°C in which conventional electrical temperature sensors and transmitters are currently employed.

Industrial applications in process control and monitoring systems include chemical, petroleum, food processing, power generation and a wide variety of other industries.

In multipoint energy management applications, low cost and small size combine to make the AD590 and 2B57 ideal for mounting in standard utility or thermostat boxes for remote temperature sensing.

## DESIGN FEATURES AND USER BENEFITS

**RFI Noise Immunity:** The transmitter incorporates RFI filtering circuitry to assure protection against radio frequency interference.

**Low Cost:** The low cost of the 2B57 transmitter and two-wire operation reduce total system installation cost.

**Linear Output:** The transmitter output is linear with temperature, thus eliminating the need for linearizing circuitry.

**Standard Loop Compatibility:** The two-wire output structure conforms to the Instrument Society of America Standard ISA-S50.1 "Compatibility of Analog Signals for Electronic Industrial Process Instruments."

# SPECIFICATIONS (typical @ +25°C and $V_S$ = +24V dc, unless otherwise noted)

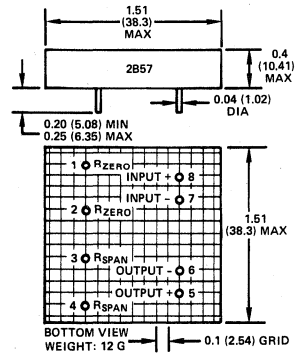
| MODEL | 2B57A |
|---|---|
| **INPUT SPECIFICATIONS** | |
| Sensor Type[1] | AD590 |
| Maximum Temperature Measurement Range | -55°C to +150°C |
| Minimum Input Span (for a 4-20mA Output) | 20°C |
| Zero Adjustment Range | -55°C to +60°C |
| Input Protection[2] | +50V dc |
| Open Input Detection | Upscale |
| **OUTPUT SPECIFICATIONS** | |
| Output Span | 4 to 20mA |
| Minimum Output Current | 2.5mA |
| Maximum Output Current | 26mA |
| Load Resistance Range | |
| Equation | $R_{LMAX} = (V_{SUPPLY} - 12V)/20mA$ |
| @ +24V Supply | 0 to 600Ω max |
| Output Protection[2] | +50V dc |
| **NONLINEARITY (% of Span)** | ±0.02% typ (±0.05% max) |
| **ACCURACY** | |
| Warm-Up Time to Rated Performance | 1 min |
| Total Output Error, without External Trims[3] | |
| Zero | ±0.2% typ (±0.5% max) |
| vs. Ambient Temperature (-30°C to +85°C) | ±0.005%/°C typ (±0.01%/°C max) |
| Span | ±0.2% typ (±0.5% max) |
| vs. Ambient Temperature (-30°C to +85°C) | ±0.001%/°C typ (±0.005%/°C max) |
| **RESPONSE TIME, to 90% of Span** | 0.15 sec |
| **POWER SUPPLY** | |
| Voltage, Rated Performance | +24V dc |
| Voltage, Operating | +12V to +50V dc |
| Supply Change Effect, % of Span | |
| on Zero | ±0.005%/V |
| on Span | ±0.001%/V |
| **ENVIRONMENTAL** | |
| Temperature Range, Rated Performance | -30°C to +85°C |
| Storage Temperature Range | -55°C to +100°C |
| Relative Humidity, to +40°C | 0 to 90% |
| RFI Effect (5W @ 420MHz @ 3 ft) | |
| Error, % of Span | ±0.5% max |
| **CASE SIZE** | 1.5" X 1.5" X 0.4" |

NOTES
[1] AD590 produces an output current proportional to absolute temperature (1μA/°K).
[2] Protected for any combination of input and output pins.
[3] Accuracy is specified as a percent of output span (16mA) for an input range of -55°C to +150°C. Accuracy spec includes combined effects of transmitter repeatability, hysteresis, and linearity. Does not include sensor error.

Specifications subject to change without notice.

## OUTLINE DIMENSIONS

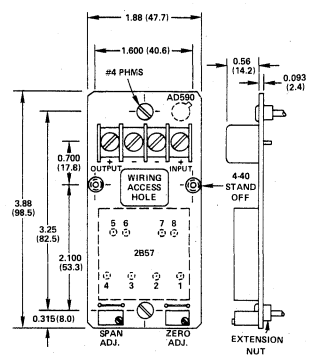
Dimensions shown in inches and (mm).




## MOUNTING CARD

## AC1583 OUTLINE DIMENSIONS

Dimensions shown in inches and (mm).




The AC1583 mounting card is available to assist in applying the 2B57. The AC1583 is suitable for mounting in a standard 2" X 4" thermostat or electrical boxes. It includes screw terminals for field wiring, provisions for plugging in the 2B57 and AD590, and 5kΩ span and zero adjustment pots.

## FUNCTIONAL DESCRIPTION

The 2B57 transmitter converts the output of an AD590 temperature transducer to a current output within a span of 4 to 20mA. The transmitter includes input protection and filtering circuitry, an amplifier, voltage regulator, precision voltage reference and an output current generator.

A precision voltage reference, resistor network, and span and zero adjusts are used in conjunction with a low current drain amplifier to scale output signal of the AD590. The amplifier drives a current generator which controls output current (Figure 1).

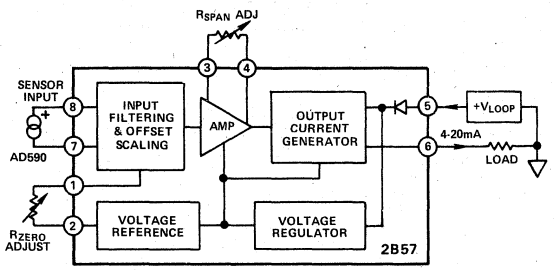



*Figure 1. Model 2B57 Functional Block Diagram*

Input power and output signal are transmitted over the same two leads. The load resistance is connected in series with a dc power supply, and the current drawn from the supply is the 4 to 20mA output signal. The maximum series load resistance depends on the supply voltage and is given by $R_{LMAX} = (+V_S - 12V)/20mA$. A wide range of power supply voltages may be used (see Figure 2).

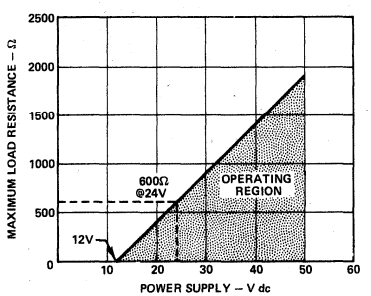



*Figure 2. Maximum Load Resistance vs. Power Supply*

## THE SENSOR

The AD590 is a calibrated two terminal temperature sensor producing a current in microamperes (1μA/°K) that is linearly proportional to absolute temperature for temperatures from -55°C to +150°C. The AD590 sensor is available in a hermetically sealed TO-52 transistor package, a miniature flat-pack, chip form and stainless steel probes (AC2626). The sensor construction assures reliable isolation from ground.

The AD590 is available in several accuracy grades, as shown in Table I. The grade selection will depend on whether the device is used uncalibrated or with calibration at a single value. For greater accuracy (in any grade), the device may be calibrated at two points.

**TABLE I. AD590 ACCURACY SPECIFICATIONS (MAX ERROR)**

| Conditions | Max Error (±°C) | | | | |
|---|---|---|---|---|---|
| Grade | I | J | K | L | M |
| Error at 25°C, as delivered | 10.0 | 5.0 | 2.5 | 1.0 | 0.5 |
| Errors over the -55°C to +150°C range: | | | | | |
| Without external calibration | 20.0 | 10.0 | 5.5 | 3.0 | 1.7 |
| With error nulled at 25°C only | 5.8 | 3.0 | 2.0 | 1.6 | 1.0 |
| Nonlinearity | 3.0 | 1.5 | 0.8 | 0.4 | 0.3 |

## OPERATING INSTRUCTIONS

Model 2B57 is factory calibrated to ±0.5% accuracy for a maximum sensor measurement range of -55°C to +150°C (205°C span) with $R_{SPAN}$ and $R_{ZERO}$ resistor values as shown in Figure 3. For this input range 4mA output corresponds to an AD590 temperature of -55°C and 20mA to +150°C. The span and zero adjustments can be used to accommodate other input ranges.

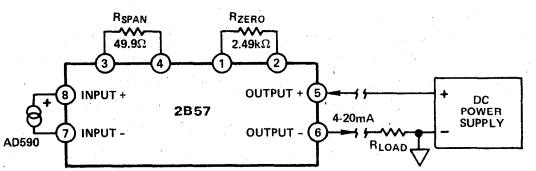



*Figure 3. Model 2B57 Basic Application*

**Span Adjustment:** The value of the span setting resistor $R_{SPAN}$ is determined by:

$$R_{SPAN}\ (\Omega) = \left(\frac{1.2V}{10^{-6}\ A \times SPAN}\right) - 5810\Omega$$

where SPAN is a desired measurement span in °C. For example, for a measurement span of 100°C $R_{SPAN}$ = $\left(\frac{1.2V}{10^{-6}\ A \times 100}\right) - 5810\Omega = 6.19k\Omega$. If a span accuracy of ±0.5% if desired, the value of the $R_{SPAN}$ resistor should be accurate to ±0.1%.

**Zero Adjustment:** Zero adjustment must be performed after installation of the $R_{SPAN}$ resistor. To select $R_{ZERO}$ an AD590 or a calibrated current source may be used as an input to the 2B57. If an AD590 is used, it must be maintained at the desired reference temperature. A resistance decade box is inserted between pins 1 and 2 of the 2B57. The decade box is adjusted to produce an output corresponding to the selected reference temperature. For example, for a sensor measurement range of 0 to 100°C and an AD590 at 0°C, the $R_{ZERO}$ is adjusted for an output current of 4mA. If a current source is used, its output must equal the AD590 output at the selected reference temperature. For example, at 0°C the current source output must equal 273.2μA.

**Sensor Calibration Trim:** The sensor calibration error is the major contributor to maximum total error in all AD590 grades. To trim this error the temperature of the AD590 is measured by a reference temperature sensor and $R_{ZERO}$ is trimmed to the calculated value of the 2B57 output current at that temperature. A reference temperature at the midpoint in the span should be selected.

For best measurement accuracy over temperature, $R_{ZERO}$ and $R_{SPAN}$ should be trimmed with the AD590 at two known temperatures. For example, with the $R_{SPAN}$ selected for a 100°C span and with the AD590 at 0°C $R_{ZERO}$ is adjusted for a 4mA output. $R_{SPAN}$ is then trimmed for a 20mA output with the sensor at 100°C. Figure 4 illustrates a typical two-trim system accuracy.

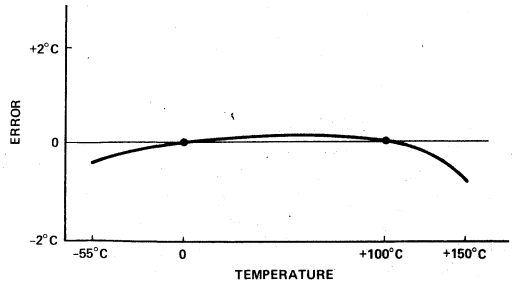


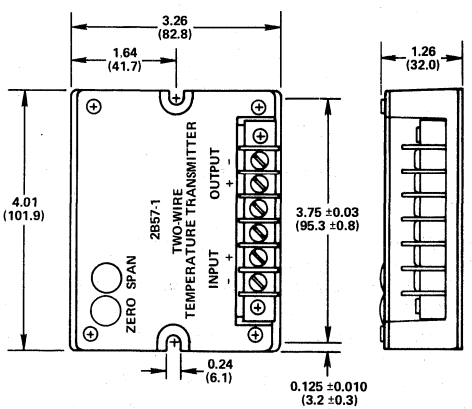

*Figure 4. Typical Two-Trim Accuracy (AD590 and 2B57)*

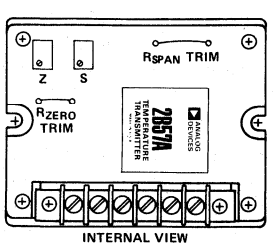
**OPTIONAL PACKAGING CONFIGURATION (2B57A-1)**

The 2B57 is available mounted in an aluminum case including screw terminals for connecting an external sensor and power. This versatile housing may be surface mounted in racks, cabinets, NEMA enclosures, etc., or snapped onto standard relay tracks. The 2B57 in a metal housing is calibrated for a -55°C to +150°C measurement range and may be ordered by specifying model 2B57A-1. Price: 2B57A-1 – $95 (1-9), $68 (100s).

**TRANSMITTER HOUSING OUTLINE DIMENSIONS**

Dimensions shown in inches and (mm).




INTERNAL VIEW

Refer to operating instructions section for suggested method of calibration.

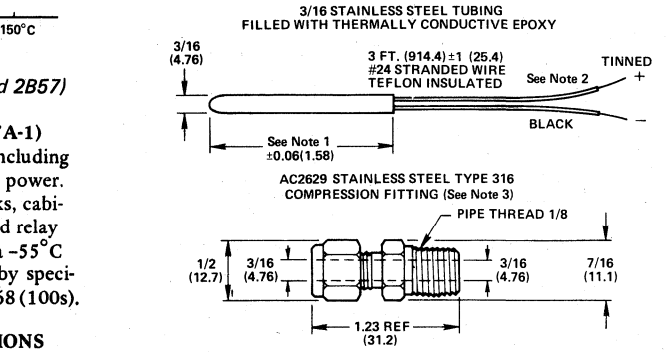
**AC2626 PROBE (AD590 PACKAGING OPTION)**

The AC2626 is a stainless steel tubular probe measuring 3/16 inch (4.76mm) in outside diameter and is available in 6 inch (152.4mm) or 4 inch (101.6mm) lengths. Based on the AD590F, the probe is available in linearity grades of 0.3°C, 0.4°C, 0.8°C or 1.5°C and is compatible with the 2B57 transmitter. The mechanical outline of the AC2626 is shown below.

The probe is designed for both liquid and gaseous immersion applications as well as temperature measurements in refrigeration or any general temperature monitoring applications.

**AC2626 MECHANICAL OUTLINE**

Dimensions shown in inches and (mm).




NOTE 1 Probes are available in 4-inch or 6-inch lengths. Other lengths are available; consult factory for price and delivery.

NOTE 2 + lead wire is color coded: J, yellow; K, orange; L, blue; M, green.

NOTE 3 When assembling compression fitting (AC2629) to probe, tighten the 1/2" nut 3/4's of a turn from finger tight.

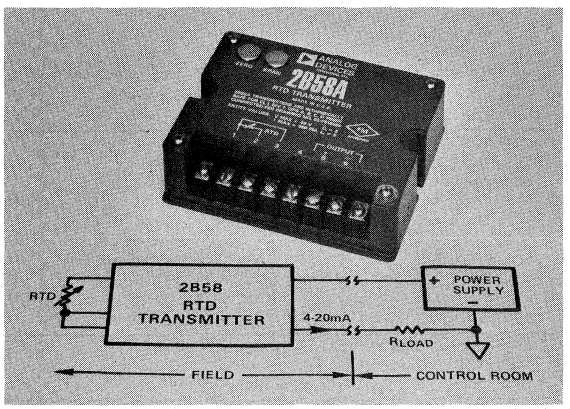
# ANALOG DEVICES

# Two-Wire, Linearized RTD Temperature Transmitter

# MODEL 2B58

**FEATURES**
**Platinum RTD Input**
**Linearized 4-20mA Output**
**High Accuracy: ±0.1%**
**Low Drift: ±0.01°C/°C Max**
**RFI Immunity**
**Low Cost**
**FM Approved**

**APPLICATIONS**
**RTD Temperature Transmission in:**
**Process Control**
**Factory Automation**
**Energy Management**




9

## GENERAL DESCRIPTION

The model 2B58 is a high accuracy, two-wire temperature transmitter designed to accept a platinum RTD (Resistance Temperature Detector) input and produce a proportional standard 4-20mA output. The RTD signal is internally linearized to provide an output which is linear with temperature. Four precalibrated ranges are available for RTD measurements from −100°C to +400°C.

The 2B58 features high accuracy of 0.1%, low drift of ±0.01°C/°C, high noise rejection and RFI immunity. Both two-wire and three-wire 100Ω sensors may be used. Lead wire compensation is provided for three-wire RTDs. The 2B58 is approved by Factory Mutual for intrinsically safe use in hazardous locations.

A rugged metal enclosure, suitable for field mounting, offers environmental protection and screw terminal input and output connections. This enclosure may be either surface or standard relay track mounted.

## APPLICATIONS

The 2B58 has been specifically designed to provide high-performance two-wire transmission of measured temperatures using RTD sensors.

Two-wire current transmission permits remote mounting of the transmitter near the sensor to minimize the effects of noise and signal degradation to which low level sensor outputs are susceptible. Transmission of the proportional current output may be accomplished by means of inexpensive copper wires. These factors make the 2B58 ideally suited for applications where accuracy, stability, and low cost installation are desired.

## DESIGN FEATURES AND USER BENEFITS

**High Accuracy:** The 2B58 offers high calibration accuracy, linearized output and conformity with the standard DIN 43760 ($\alpha$ = 0.00385) RTD sensors.

**Low Cost:** The 2B58 combines low price with a two-wire transmission, lowering total installation cost.

**High Noise Rejection:** The transmitter features internal filtering circuitry to assure protection against RFI and line frequency pickup.

**Standard Loop Compatibility:** The two-wire output structure conforms to the ISA Standard S50.1 "Compatibility of Analog Signals for Electronic Industrial Process Instruments".

**Wide Operating Temperature Range:** The 2B58 has been designed to operate over −30°C to +85°C ambient temperature range.

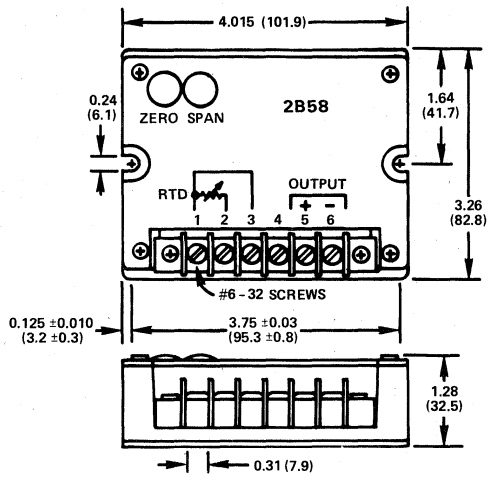
# SPECIFICATIONS (typical @ +25°C and $V_S$ = +24V dc unless otherwise noted)

| Model | 2B58A |
|---|---|
| **INPUT SPECIFICATIONS** | |
| Sensor Type | Platinum, 100Ω @ 0°C, α = 0.00385<br>2 or 3 Wire |
| Normal Mode Rejection | 56dB @ 60Hz |
| Sensor Excitation Current | 0.5mA |
| Zero and Span Adjustment Range | ±5% of Span |
| **OUTPUT SPECIFICATIONS** | |
| Output Span | 4-20mA |
| Minimum Output Current | 3.5mA, typ |
| Maximum Output Current | 40mA, typ |
| Load Resistance Range Equation | $R_L$ max = (+$V_S$ -16V)/20mA |
| @ +24V Supply | 0 to 400Ω |
| Output Protection[1] | ±60V |
| **ACCURACY** | |
| Total Output Error[2] | ±0.1% |
| Stability vs. Ambient Temperature | |
| Zero, Measurement Range 01 through 03[3] | ±0.01°C/°C max (±0.005°C/°C typ) |
| Measurement Range 04[3] | ±0.01°C/°C |
| Span | ±0.005%/°C |
| Stability vs. Time[2] | ±50ppm/Month |
| Lead Resistance Effect, to 40Ω per Lead | |
| Span Error | ±0.5% |
| Warm-Up Time to Rated Performance | 3 Minutes |
| **INTRINSICALLY SAFE OPERATION** | |
| Use in Class I, Division 1,<br>Groups A,B,C, and D Hazardous Locations | FM Approved |
| **RESPONSE TIME** | |
| To 90% of Span | 0.4 sec |
| **POWER SUPPLY** | |
| Voltage, Operating Range | +16V to +60V dc |
| Supply Change Effect, % of Span | |
| on Zero | ±0.005%/V |
| on Span | ±0.01%/V |
| **ENVIRONMENTAL** | |
| Temperature Range, Rated Performance | -30°C to +85°C |
| Storage Temperature Range | -55°C to +125°C |
| Humidity, Effect[4] | |
| Error | ±0.6% of Span |
| RFI Effect (5W @ 470MHz @ 3 ft.) | |
| Error | ±0.5% of Span |
| **PHYSICAL** | |
| Case Size | 4" X 3.25" X 1.25" |
| Weight | 8 oz (227 g) |

NOTES
[1] Protected for reverse polarity and for any input/output connection combination.
[2] Accuracy is specified as a percent of output span (16mA). Accuracy spec includes combined effects of transmitter repeatability, hysteresis and sensor linearization conformity. Does not include sensor error.
[3] See ordering information for measurement temperature ranges 01 through 04.
[4] Per MIL-STD-202E Method 103B.
Specifications subject to change without notice.

## OUTLINE DIMENSIONS (MAX)

Dimensions shown in inches and (mm).




## ORDERING INFORMATION

Example: Model 2B58A - 1 - 1 - 01

Enter Model
2B58A

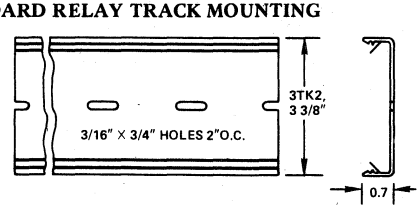
Enter Housing
1-Standard Enclosure

Enter Sensor Type
1-100Ω Platinum, α = 0.00385

Enter Temperature Range
01 Through 04

| Range in °C (°F) | No. |
|---|---|
| -100 to +100 (-148 to +212) | 01 |
| 0 to +100 (+32 to +212) | 02 |
| 0 to +200 (+32 to +392) | 03 |
| 0 to +400 (+32 to +752) | 04 |

## STANDARD RELAY TRACK MOUNTING



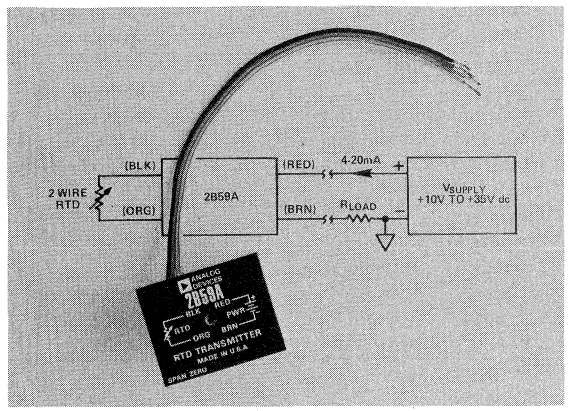

Model 2B58 may be conveniently mounted in a standard relay mounting channel (3.25" wide) such as Reed Devices Inc. (RDI) model 3TK2-6 or equivalent.

# Low Cost, Two-Wire RTD Temperature Transmitter

# MODEL 2B59

**FEATURES**
**Low Cost**
**Standard RTD Input**
**Linearized 4-20mA Output**
**High Accuracy: ±0.1%**
**Small Size**
**Ease of Installation**

**APPLICATIONS**
**Temperature Monitoring and Transmission**
**Energy Management Systems**




9

## GENERAL DESCRIPTION

The model 2B59 is a low cost temperature transmitter designed to accept an RTD sensor input and produce a 4-20mA output proportional to the measured temperature. The RTD signal is internally linearized to provide an output which is linear with temperature. The 2B59 is a true two-wire transmitter, with the same wiring used for power and output. The load resistance is connected in series with a dc power supply ($+V_S$) and the current drawn from the supply is the 4-20mA output signal.

The transmitter features high calibration accuracy of ±0.1%. Several factory-calibrated temperature measurement ranges are available for standard platinum and nickel-iron RTD sensors. Both zero and span user-accessible screwdriver adjustments are provided for fine calibration after installation, if needed.

The 2B59 is packaged in a small (1.2″ × 1.5″ × 0.5″), rugged, epoxy encapsulated module and may be easily mounted by using a single screw. Connections to the transmitter are made via four color-coded leads using standard wire nuts.

## APPLICATIONS

The 2B59 has been specifically designed to provide low cost, small size, ease of installation, and reliability in multipoint temperature monitoring applications.

In energy management and control systems, the 2B59 may be mounted in standard 2″ × 4″ utility or thermostat boxes in conjunction with a sensor and used for duct or room temperature sensing and transmission.

## CALIBRATION

The 2B59 is factory calibrated to provide zero and span accuracy of ±0.1% of span. Should field calibration of the 2B59 to the specified range be desired, the following procedure is recommended:

1. Connect the transmitter as shown in Figure 2. Substitute a resistance standard for the RTD and use a load resistor for the appropriate power supply voltage, as specified by the graph of $R_{LOAD}$ max vs. $V_{SUPPLY}$ (Figure 1).
2. Determine minimum and maximum resistance values of sensor being used from standard resistance/temperature tables. (For example, for a 100 Pt sensor, a measurement range of 0 to +100°C corresponds to the resistance range of 100.0Ω to 138.50Ω.)
3. Connect required minimum input resistance standard. Adjust ZERO potentiometer, if necessary, to obtain an output of 4 ±0.016mA.
4. Connect required maximum input resistance standard. Adjust SPAN potentiometer, if necessary, to obtain an output of 20 ±0.016mA.
5. Repeat steps 3 and 4 until readings converge.

An alternate method of calibration utilizing an RTD sensor would be to adjust the ZERO and SPAN potentiometers while alternatively maintaining the probe at the specified minimum and maximum measured temperatures. A precision thermometer, located at the temperature probe, should be used to provide an accurate point of reference.

# SPECIFICATIONS (typical @ +25°C and $V_S$ = +24V unless otherwise noted)

| MODEL | 2B59A |
|---|---|
| **INPUT SPECIFICATIONS** | |
| Sensor Type | |
| Platinum | 100Ω @0C, α = 0.00385 |
| Nickel-Iron | 1000Ω, 2000Ω @ +21.1°C (+70°F) α = 0.00527 |
| Zero and Span Adjustment Range | ±3% of Span min |
| Open Input Detection | Upscale |
| **OUTPUT SPECIFICATIONS** | |
| Output Span | 4-20mA |
| Minimum Output Current | 3.4mA |
| Maximum Output Current | 35mA |
| Load Resistance Equation | $R_L$ max = (+$V_S$ - 10V)/20mA |
| @ +24V Supply | 0 to 700Ω |
| **ACCURACY** | |
| Total Output Error[1] | ±0.1% |
| Stability vs. Ambient Temperature | |
| Zero | ±0.015%/°C |
| Span | ±0.005%/°C |
| Warm-Up Time to Rated Performance | 1 min |
| **RESPONSE TIME** | |
| To 90% of Span | 0.125ms |
| **POWER SUPPLY** | |
| Voltage, Operating Range[2] | +10V to +35V dc |
| Supply Change Effect, % of Span | ±0.001%/V |
| **ENVIRONMENTAL** | |
| Temperature Range, Rated Performance | -25°C to +85°C |
| Storage Temperature Range | -55°C to +125°C |
| Humidity Effect | |
| Error, 90% RH @ +40°C | ±0.2% of Span |
| **PHYSICAL** | |
| Case Size | 1.2" X 1.5" X 0.5" |

NOTES

[1] Accuracy is specified as a percent of output span (16mA). Accuracy spec includes combined effects of transmitter linearity, repeatability and hysteresis. Does not include sensor error.

[2] Protected for reverse polarity.

Specifications subject to change without notice.

## ORDERING INFORMATION

MODEL 2B59A - 0 - 1 - 01

ENTER MODEL
2B59A

ENTER ENCLOSURE
0 - MODULE

ENTER SENSOR TYPE
1- 100Ω Pt, α = 0.00385
2- 1000Ω NiFe, α = 0.00527
3- 2000Ω NiFe, α = 0.00527

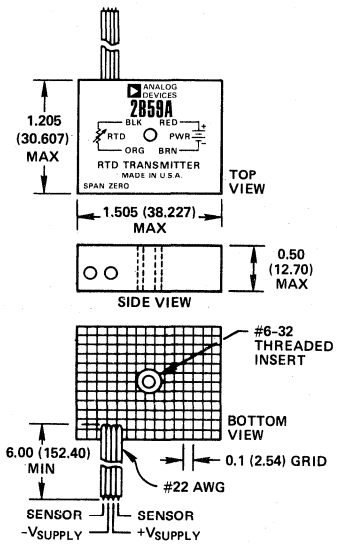
ENTER TEMPERATURE RANGE
01 through 06 → AVAILABLE TEMPERATURE RANGES IN °F (°C)

| | |
|---|---|
| 01 | 0 to +100 (-18 to +38) – Sensors 1 and 2 |
| 02 | +20 to +120 (-7 to +49) – Sensors 1, 2 and 3 |
| 03 | +50 to +150 (+10 to +66) – Sensors 1 and 2 |
| 04 | +32 to +212 (0 to +100) – Sensors 1, 2 and 3 |
| 05 | -30 to +130 (-34 to +54) – Sensor 3 |
| 06 | +200 to +400 (+93 to +204) – Sensor 3 |

(Consult factory for additional ranges.)

## OUTLINE DIMENSIONS

Dimensions shown in inches and (mm).



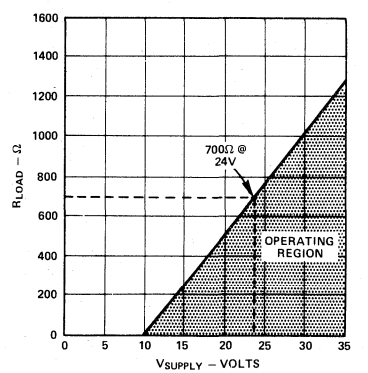




*Figure 1. $R_{LOAD}$ vs. $V_{SUPPLY}$*

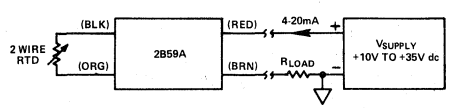



*Figure 2. Basic Application*

# ANALOG DEVICES

# The Complete Signal Conditioning I/O Subsystem

# 3B Series

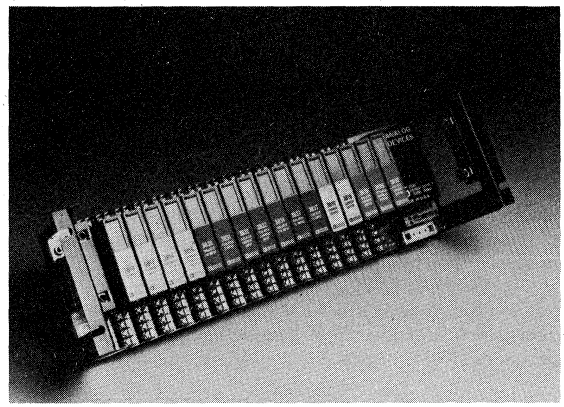
**FEATURES**

**Low Cost, Completely Integrated 16-Channel Modular Signal Conditioning Subsystem**
- **Wide Selection of Functionally Complete Input and Output Plug-In Modules,**
- **Rugged Industrial Chassis, Rack or Surface Mounted**
- **On-Board Power Supplies Available**

**Analog Input Modules Available for Direct Interface to a Wide Variety of Signal Sources**
- **Thermocouples, RTDs, Strain Gages,**
- **Millivolt and Voltage Sources,**
- **4-20mA/0-20mA Process Current Inputs**

**Current Output Modules**
- **4-20mA/0-20mA Outputs**

**Complete Signal Conditioning Function**
- **Input Protection, Filtering, Amplification,**
- **Galvanic Isolation to ±1500V,**
- **Wide-Range Zero Suppression,**
- **High Noise Rejection and RFI/EMI Immunity,**
- **Simultaneous Voltage and Current Outputs**



9

## GENERAL DESCRIPTION

The 3B Series Signal Conditioning I/O Subsystem provides a low cost, versatile method of interconnecting real world analog signals to a data acquisition, monitoring or control system. It is designed to interface directly to analog signals such as thermocouple, RTD, Strain Gage, or AD590/AC2626 solid state temperature sensor outputs or millivolt or process current signals and convert the inputs to standardized analog outputs compatible with high level analog I/O subsystems.

The 3B Series Subsystem consists of a 19″ relay rack compatible universal mounting backplane and a family of plug in (up to 16 per rack) input and output signal conditioning modules. Eight and four channel backplanes are also available. Each backplane incorporates screw terminals for sensor inputs and current outputs and a connector for high level single ended outputs to the user's equipment.

The input and output modules are offered in both isolated (±1500V peak) and nonisolated versions. The input modules feature complete signal conditioning circuitry optimized for specific sensors or analog signals and provide high level analog outputs. Each input module provides two simultaneous outputs: 0 to 10V (or ±10V) and 4-20mA (or 0-20mA). Output modules accept high level single ended signals and provide an isolated or nonisolated 4-20mA (or 0-20mA) process signal. All modules feature a universal pin-out and may be readily "mixed and matched" and interchanged without disrupting field wiring.

Each backplane contains the provision for a subsystem power supply. The 3B Series Subsystem can operate from a dc/dc converter or ac power supply mounted on each backplane or from externally provided dc power. Two LEDs are used to indicate that power is being applied.

## APPLICATIONS

The Analog Devices 3B Series Signal Conditioning Subsystem is designed to provide an easy and convenient solution to signal conditioning problems in measurement and control applications. Some typical uses are in mini- and microcomputer based systems, standard data acquisition systems, programmable controllers, analog recorders, dedicated control systems, and any other applications where monitoring and control of temperature, pressure, flow, and analog signals are required. Since each input module features two simultaneous outputs, the voltage output can be used to provide an input to a microprocessor based data acquisition or control system while the current output can be used for analog transmission, operator interface, or an analog backup system.

## DESIGN FEATURES AND USER BENEFITS

**Ease of Use:** Direct sensor interface via screw terminals, standardized high level outputs, factory precalibration of each unit and the modular design make the 3B Series Subsystem extremely easy to use. The subsystem features rugged packaging for the industrial environment and can be easily installed and maintained.

**High Protection and Reliability:** All field wired terminations offer 130V or 220V rms normal mode protection. To assure connection reliability, gold plated pin and socket connections are used throughout the system. The isolated modules offer protection against high common mode voltages and are designed to meet the IEEE Standard for Transient Voltage Protection (472–1974: SWC).

**High Performance:** The high quality signal conditioning features ±0.1% calibration accuracy and chopper-based amplification which assures low drift (±1μV/°C) and excellent long term stability. For thermocouple applications, high accuracy cold junction sensing is provided in the backplane on each channel. Low drift sensor excitation is provided for RTD and strain gage models. For RTD models, the input signal is linearized to provide an output which is linear with temperature.

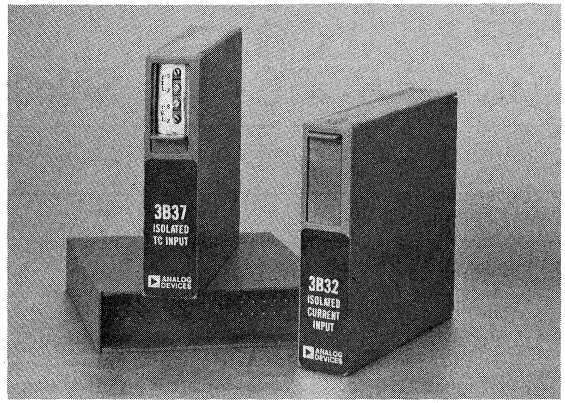
**This four-page data summary contains key specifications to speed your selection of the proper solution for your application. Additional information on this product can be obtained from your local sales office.**

**FEATURES**

**Wide Variety of Sensor Inputs**
**Thermocouples, RTDs, Strain Gages, AD590/AC2626**
**Dual High Level Outputs**
**Voltage: 0 to +10V or ±10V**
**Current: 4-20mA/0-20mA**
**Mix and Match Input Capability**
**Sensor Signals, mV, V, 4-20mA, 0-20mA**
**High Accuracy: ±0.1%**
**Low Drift: ±1μV/°C**
**Reliable Transformer Isolation:**
**±1500V CMV, CMR =160dB**
**Meets IEEE-STD 472: Transient Protection (SWC)**
**Input Protection: 130V or 220V rms Continuous**
**Low Cost Per Channel**

## GENERAL DESCRIPTION

Each input module is a single channel signal conditioner that plugs into sockets on the backplane and accepts its signal from the input screw terminals. All input modules provide input protection, amplification and filtering of the input signal, accuracy of ±0.1%, low drift of 1μV/°C (low level input modules), and feature two high level analog outputs that are compatible with most process instrumentation. The isolated input modules also provide ±1500V isolation.




The choice of a specific 3B module depends on the type of input signal and also whether an isolated or nonisolated interface is required. Input modules are available to accept millivolt, volt, process current, thermocouple, RTD, strain gage, and AD590 inputs. The voltage output of each module is available from the voltage I/O connector while the current output is available on the output screw terminals.

---

### THERMOCOUPLE INPUT MODEL 3B37

The isolated thermocouple models incorporate cold junction compensation circuitry which provides an accuracy of ±0.5°C over the +5°C to +45°C ambient temperature range. Open thermocouple detection (upscale) is also provided with the thermocouple models. Standard models are available with factory calibration for thermocouple types J, K, T, E, R, S and B. However, if another thermocouple type or a special range is desired, the 3B37-X-00 and ranging card, AC1310, can be used to satisfy the requirement. All screw terminal connections have at least 130V rms protection.

### RTD INPUT MODELS 3B14, 3B15, 3B34

Each RTD model provides a sensor excitation current of 0.25mA and produces an output signal that is linear with temperature with a conformity error of ±0.05% of span and accuracy of ±0.1% span. The lead resistance effect for the three models is ±0.02°C/Ω for the 3B14 and the 3B34, and ±.00001°C/Ω for the 3B15. All excitation input and output screw terminal connections have at least 130V rms protection.

### STRAIN GAGE INPUT MODEL 3B16

Model 3B16 is designed to accept inputs from full four arm bridge strain gage-type transducers. The 3B16 provides a constant +10V bridge excitation and can be used with a bridge resistance of 300Ω or greater. All excitation input and output screw terminal connections have 130V rms protection.

### WIDEBAND STRAIN GAGE MODEL 3B18

Model 3B18 is designed to accept inputs from full four arm bridge strain gage-type transducers. The 3B18 provides a switch selectable excitation of +3.3V or +10.0V and can be used with 100Ω to 1000Ω strain gage bridges. The module has a 20kHz bandwidth to interface to dynamic signals.

### MILLIVOLT AND VOLTAGE INPUT MODELS 3B10, 3B11, 3B30, 3B31

Models 3B10 and 3B11 are nonisolated modules that accept millivolt and voltage signals respectively. Models 3B30 and 3B31 are isolated modules that accept millivolt and voltage signals respectively. All screw terminal connections have at least 130V rms protection.

### WIDEBAND MILLIVOLT AND VOLT INPUT MODELS 3B40, 3B41

Models 3B40 and 3B41 are isolated modules that accept millivolt and voltage signals respectively. The modules have a 10kHz bandwidth to interface to dynamic signals. All screw terminal connections have at least 130V rms protection.

### CURRENT INPUT MODELS 3B12, 3B32

Models 3B12 and 3B32 are nonisolated and isolated modules respectively that accept process current signals. Both models use a 100Ω sensing resistor that is mounted on backplane terminals 2 and 3. All screw terminal connections have at least 130V rms protection.

### AD590 INPUT MODEL 3B13

Model 3B13 accepts an AD590 as its input signal. Sensor excitation is provided and a 2kΩ sensing resistor is mounted on backplane terminals 2 and 3. All excitation input and output screw terminal connections have 130V rms protection.

### AC INPUT MODELS 3B42, 3B43, 3B44

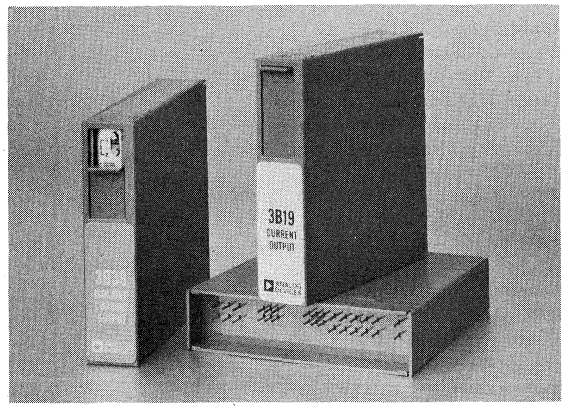
Models 3B42, 3B43 and 3B44 are designed to accept ac signals from 20mV to 450V rms. The modules are rms calibrated for sinusoidal inputs, such as ac power lines. All screw terminal connections have at least 130V rms protection.

### FREQUENCY INPUT MODELS 3B45, 3B46

Preliminary models 3B45 and 3B46 are designed to accept frequency input signals from 25Hz to 25kHz. User selectable thresholds of 1.6V and 0V (for zero crossing) are available. All screw terminal connections have at least 130V rms protection.

# Output Modules

**FEATURES**
**High Level Voltage Input (0 to +10V, ±10V)**
**Process Current Output (4-20mA/0-20mA)**
**High Accuracy: ±0.1%**
**Reliable Transformer Isolation: ±1500V CMV, CMR = 90dB**
**Meets IEEE-STD 472: Transient Protection (SWC)**
**Output Protection: 130V or 220V rms Continuous**
**Reliable Pin and Socket Connections**
**Low Cost Per Channel**




## GENERAL DESCRIPTION

Each output module accepts a high level analog signal from the system connector and provides a current output on the output screw terminals. When a +24V loop supply is used, loads up to 850Ω can be driven. If desired, +15V can be used to power the output modules with a smaller load (up to 400Ω). Each output module features high accuracy of ±0.1%. If isolation is required, the 3B39 provides ±1500V peak common mode voltage isolation protection.

## NONISOLATED OUTPUT MODEL 3B19

The 3B19 output module accepts a 0 to +10V or ±10V input signal and converts it to a proportional current output. Output ranges are jumper selectable for either 0 to 20mA or 4 to 20mA. The current output is protected to 130V rms continuous.

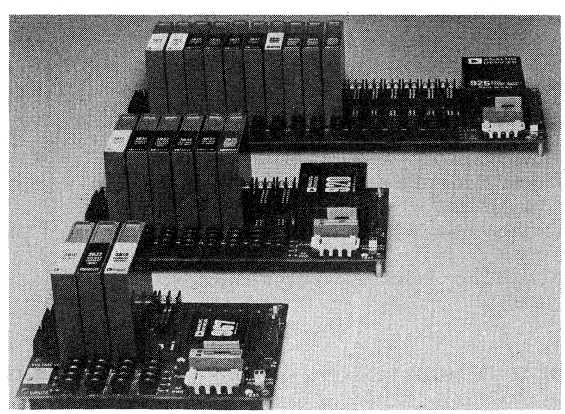
## ISOLATED OUTPUT MODEL 3B39

Model 3B39 is an isolated module that accepts a 0 to +10V or ±10V input signal and converts it to a proportional current output. Output ranges are jumper selectable for either 0 to 20mA or 4 to 20mA. Input to output isolation is rated to 1500V pk continuous.

9

# Backplanes

**FEATURE**
**4, 8, or 16-Channel Versions Available**
**ac or dc Power Supply Options**



## GENERAL DESCRIPTION

The three backplane models, 3B01, 3B02 and 3B03 are designed for 16, 8 and 4 channels, respectively, to give users the flexibility to match the size of a system to specific applications. The sixteen channel backplane can be mounted in a 19″ × 5.25″ panel space. The backplanes can be surface mounted, mounted on a rack or mounted in a NEMA enclosure.

## POWER SUPPLY

The 3B Series Subsystem can operate from a common ac power supply or dc/dc (+24V input) power supply mounted on the backplane or an externally provided ±15V and +24V supply. The power supply is bussed to all signal conditioners in the system. The current consumption is a function of the modules that are actually used.

# 3B Series Subsystem Specifications

## INPUT MODULES

**Input Types**
Thermocouples: J, K, T, E, R, S, B
RTDs: 100Ω Platinum (linearized)
Strain Gage Transducers:
±30mV and ±100mV spans
Solid State Temperature Transducers:
AD590 or AC2626
DC Voltage: ±10mV, ±50mV, ±100mV
±1V, ±5V, ±10V
DC Current: 4 to 20mA, 0 to 20mA

**Outputs (Simultaneous)**
0 to +10V or ±10V and
4 to 20mA or 0 to 20mA

**Performance**
Accuracy: ±0.1% of span
Nonlinearity: ±0.01% of span
Bandwidth: 3Hz (−3dB)

Isolated Modules
Common Mode Voltage,
Input to Output: ±1500V pk continuous
Transient Protection: Meets IEEE-Std 472 (SWC)
Normal Mode Input Protection: 220V rms continuous
Current Output Protection: 130V rms continuous
Common Mode Rejection @ 50Hz or 60Hz: 160dB
Normal Mode Rejection @ 50Hz or 60Hz: 60dB

**Nonisolated Modules**
Common Mode Voltage: ±6.5V
Normal Mode Input Protection: 130V rms continuous
Current Output Protection: 130V rms continuous
Common Mode Rejection @ 50Hz or 60Hz: 90dB
Normal Mode Rejection @ 50Hz or 60Hz: 60dB

## OUTPUT MODULES

**Input**
0 to +10V or ±10V

**Output**
4 to 20mA or 0 to 20mA

**Performance**
Accuracy: ±0.1% of span
Nonlinearity: ±0.01% of span

**Isolated Module**
Common Mode Voltage,
Input to Output: ±1500V pk continuous
Current Output Protection
Transient: Meets IEEE-Std 472 (SWC)
Continuous: 220V rms

**Nonisolated Module**
Current Output Protection: 130V rms continuous

## BACKPLANES

Channel Capacity
3B01: 16 channels
3B02: 8 channels
3B03: 4 channels

## POWER SUPPLIES

Backplane Mounted:
100, 115, 220, 240V ac, 50/60Hz
or +24V dc
External Power Option
±15V dc and +24V dc

## MECHANICAL

Input or Output Modules:
3.150″ × 0.775″ × 3.395″
(80.0mm × 19.7mm × 86.2mm)
Backplanes:
3B01: 17.40″ × 5.20″ × 4.37″
(442.0mm × 132.1mm × 111.1mm)
3B02: 11.00″ × 5.20″ × 4.37″
(279.4mm × 132.1mm × 111.1mm)
3B03: 7.80″ × 5.20″ × 4.37″
(198.1mm × 132.1mm × 111.1mm)

## ENVIRONMENTAL

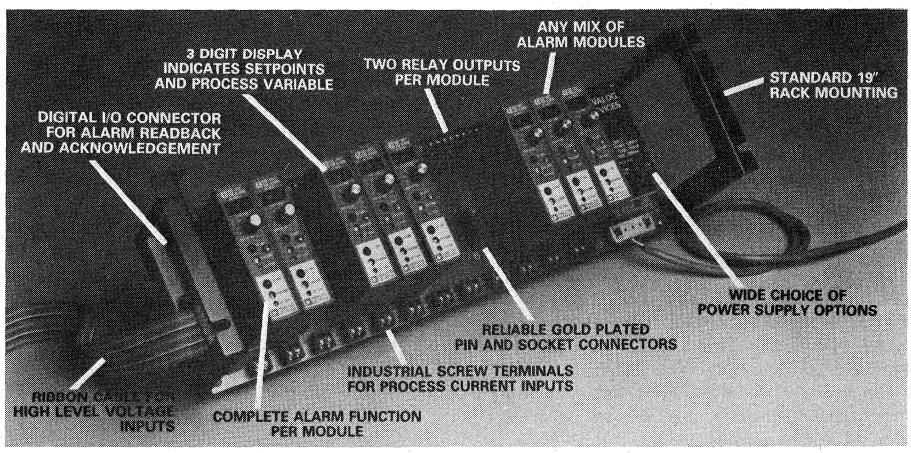
Temperature Range, Rated Performance:
−25°C to +85°C
Storage Temperature Range:
−55°C to +85°C
Relative Humidity: Conforms to MIL-STD 202, Method 103
RFI Susceptibility: ±0.5% span error, 5W @ 400MHz @ 3 ft.

Specifications subject to change without notice.

# ANALOG DEVICES

# Alarm Limit Subsystem

## 4B Series




9

### FEATURES/BENEFITS

- **Low Cost, Completely Integrated 12-Channel Modular Alarm Limit Subsystem**
  - **Selection of Alarm Limit Modules**
  - **Rugged Industrial Chassis, Rack or Surface Mounted**
  - **On-Board Power Supplies Available**
- **Alarm Modules Accept High Level Voltage and Process Current Inputs**
- **Complete Alarm Function per Module**
  - **High Accuracy of ±0.1%**
  - **Two Set Points, Adjustable Over 100% Span**
  - **Dead Band Adjustment per Set Point, Adjustable Over 0.5%–10.0% Span**
  - **Alarm Types are Configurable for HI or LO Operation**
  - **Two Relay Outputs**
  - **Three Digit Display Indicates Set Points and Process Variable as a Percent of the Input Span**
  - **LED per Set Point Provides Local Alarm Indication**
  - **Input Protection**
  - **High RFI/EMI Immunity**
- **Specifications Valid Over the 0 to +70°C Temperature Range**
- **Easy to Install, Calibrate and Service**
  - **Direct Connections to Industrial Screw Terminals**
  - **Modules Removable without Disturbing Field Wiring or Power**
  - **Front Panel Set Point and Dead Band Adjustments**
- **Convenient Connection to User's Equipment**
  - **Interfaces Directly to Analog Output Subsystems**
  - **Used for Single Board Computer Interfaces**
  - **Universal Adapter Board Allows Easy Interface to Any Equipment**

### GENERAL DESCRIPTION

The 4B Series Alarm Limit Subsystem is a low cost method of providing adjustable alarm limits to a variety of process sensors and transducers. It has been designed as a companion product to the 3B Series Signal Conditioning Subsystem, which interfaces directly to a variety of process sensors and transducers and converts the inputs to standardized high level analog outputs. The Alarm Limit Subsystem accepts the high level output from the 3B Series Subsystem or any other transmitter and provides fully independent HI and LO relay outputs.

The subsystem consists of a 19" relay rack compatible universal mounting backplane and a family of plug-in (up to 12 per rack) alarm limit modules. A four channel backplane is also available. The modules, designed for voltage or current inputs, can be readily mixed and matched and interchanged without disturbing field wiring. Each backplane incorporates screw terminals for field wiring and a connector for high level single ended inputs from the user's equipment.

Each alarm module has two set points which are fully adjustable over the 100% span. It will accept a standardized high level analog input and will provide one or two ON/OFF outputs. The allowable input ranges are ±10V, 0 to +10V, 4-20mA and 0-20mA. All input types can be connected to either the voltage input connector or the input screw terminals.

The two set points within each module can be user configured with push-on jumpers for HI-LO, HI-HI or LO-LO use. If only one limit per channel is desired, the module can be used in a HI or LO state. The value of each set point and the process variable can be viewed with a 3 digit display which is controlled with a rotary switch. Each set point has an adjustable dead band (hysteresis) which can be adjusted up to 10% of span and can be used to eliminate nuisance alarms.

**This two-page data summary contains key specifications to speed your selection of the proper solution for your application. Additional information on this product can be obtained from your local sales office.**

## DESIGN FEATURES AND USER BENEFITS

Direct interface via screw-terminals or ribbon cable, two screwdriver adjustable set points per module, adjustable dead band per set point, a three digit display that indicates the value of the process variable and set points, and the modular design make the 4B Series Subsystem extremely easy to use. The subsystem features rugged packaging for the industrial environment and can be easily installed and maintained.

All input screw terminals offer 130V rms normal mode protection. Connection reliability is assured by gold plated pin and socket connectors. The high quality alarm modules feature ±0.1% accuracy and a low drift with temperature (±0.005%/°C).

## APPLICATIONS

The Analog Devices' 4B Series Alarm Limit Subsystem is designed to provide an easy and convenient solution to alarm/annunciation problems in measurement and control applications. In a typical application, the 4B Series Alarm Subsystem provides alarm indication for any sensor input when used with the 3B Series Signal Conditioning Subsystem. The 3B Series interfaces directly to sensors and converts the inputs to the standardized high level analog signal that the 4B Series alarms. This modular approach provides a very flexible means to alarm indication since the same 4B module can be used to alarm a variety of sensors when used with the appropriate 3B module. The 4B Series can also provide alarm indication or ON/OFF control when used with field transmitters or any other device that provides a process current or high level voltage output.

## FUNCTIONAL DESCRIPTION

Each alarm module is a single channel unit that plugs into sockets on the backplane and accepts its signal from either the input screw terminals or the voltage input connector. All alarm modules provide input protection, filtering of the input signal, accuracy of ±0.1% and feature two relay outputs that are capable of driving loads up to 3A.

The choice of a specific 4B module depends on whether the input signal is a high level voltage or a process current. The voltage inputs can be connected to a 4B module by either the input screw terminals or the voltage input connectors. Process currents can also be connected through either the screw terminals or the voltage input connector, but must use a sensing resistor. The current input models are shipped with the required sense resistor, which is to be installed on the input screw terminals.

The transfer function provided by each alarm module is:

Inputs: High level voltage or process current
Outputs: Two independent ON/OFF Relay Outputs

Figure 1 shows a functional diagram for the model 4B10 alarm limit module which has been configured for HI-LO operation. The high level voltage input signal is filtered and compared against both set points. If the process variable is above the HI limit or below the LO limit, the appropriate relay is turned on.

Each set point has an adjustable dead band (0.5%–10.0% span), which is used to eliminate nuisance alarms. Dead band is the amount of signal change necessary, after an alarm has occurred, to return an alarm to its original condition. As an example, if the HI limit is set at 75% of span and the dead band is 2%, the alarm will turn on when the process variable is at 75% and will not turn off until the process variable falls to 73%. For a LO limit configuration, the dead-band relationship is reversed and the alarm would not turn off until the process variable has risen above the sum of the LO set point value and the dead-band value.

Each set point has an LED which turns on when an alarm condition occurs and provides local alarm indication.

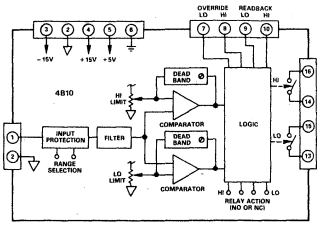



*Figure 1. 4B10 Functional Block Diagram*

The alarm status of both limits can be read externally from the digital I/O connector. When an alarm state exists which is TTL active high on the readback pins, the relay can be turned off with an external override signal (TTL active low) that connects to the digital I/O connector. The readback/override feature allows for external monitoring of the alarm states as well as for external control or alarm acknowledgement. When an override signal is used, the readback feature reads the alarm state and not the relay input signal so that the state of the process variable can still be monitored.

For the modules with a display, positive overload is indicated by ⌋ ⌋ ⌋and negative overload is indicated by a ⌊ in the left most position.

The 4B modules have five user programmable jumper options. Each unit can be configured for unipolar or bipolar inputs, both set points can be configured for HI or LO limit operation, and both relays can be configured for Normally Open (NO) or Normally Closed (NC) operation. These options allow the user to readily tailor the 4B units to his specific needs. For instance, if HI-HI operation were required, it is available by changing the appropriate jumpers. All modules are shipped from the factory configured for unipolar input, NO relay action, and HI-LO operation.

# 4B MODULE SPECIFICATIONS

**(typical @ +25°C and ±15V, + 5V dc power)**

| Model | 4B10, 4B20 | 4B11, 4B21 | 4B12, 4B22 |
|---|---|---|---|
| Inputs[1] | 0 to +10V, ±10V | 0–20mA | 4–20mA |
| Outputs (2 SPST Relays) | Resistive Rating: 3A @ 120V ac or 24V dc | * | * |
| Performance | | | |
| Accuracy[2] | ±0.1% span | * | * |
| Temperature Stability | ±0.005% span/°C | * | * |
| Bandwidth[3] | 5Hz (−3dB) | * | * |
| Normal Mode Input Protection | 130V rms | * | * |
| Normal Mode Rejection @ 50Hz or 60Hz | 20dB | * | * |
| Input Resistance[4] | 100MΩ | * | * |
| Warm-Up Time to Rated Performance | 3 Minutes | * | * |
| Features | | | |
| Two Set Points per Module | Adjustable over 100% span by 25 turn potentiometers | * | * |
| Dead band per Set Point | 0.5%–10.0% span, adjustable by 1 turn potentiometer | * | * |
| Relay Action | Field reversible by jumper change | * | * |
| Three Digit Display[5] | 0–99.9% of input span | * | * |
| Alarm Status Readback | TTL Level | * | * |
| External Override Signal | TTL Level | * | * |
| Power Supply | | | |
| Voltage, Rated Performance | ±15V, +5V | * | * |
| Voltage, Operating | ±12V to ±18V, +4.5V to 5.5V | * | * |
| Current[6] | ±12mA, +150mA | * | * |
| Size[7] | 4.020" × 1.050" × 4.020" | * | * |
| Environmental | | | |
| Temperature Range, Rated Performance | 0 to +70°C | * | * |
| Storage Temperature Range | −25°C to +85°C | * | * |
| Relative Humidity, Conforms to MIL Std 202, Method 103B | 0 to 95% @ 60°C, noncondensing | * | * |
| RFI Susceptibility | ±0.5% span error, 5W @ 400MHz @ 3 ft. | * | * |

NOTES

[1]Voltage input range is jumper selectable.
[2]Accuracy includes setability, repeatability, linearity, and hysteresis. Models 4B10, 4B11, and 4B12 have a quantization error of ±1 digit.
[3]Unipolar inputs only. Bipolar inputs have a bandwidth of 10Hz (−3dB).
[4]Unipolar inputs only. Bipolar inputs have an input resistance of 400kΩ.
[5]Only models 4B10, 4B11 and 4B12 have a three digit display.
[6]Only models 4B10, 4B11 and 4B12. Models 4B20, 4B21 and 4B22 require ±12mA for ±15V and +125mA from +5V.
[7]Only applies to models 4B10, 4B11 and 4B12. Models 4B20, 4B21 and 4B22 measure 4.020" × 1.050" × 3.530".
*Specifications same as 4B10, 4B20.

Specifications subject to change without notice.

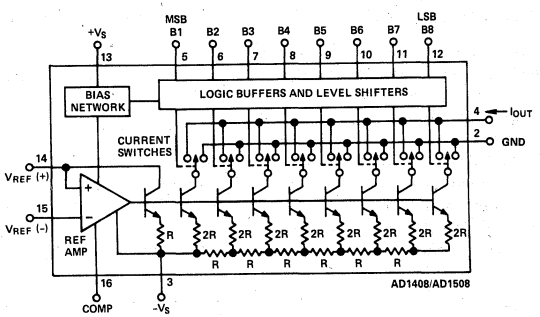
# Digital-to-Analog Converters

## Contents


| | Page |
|---|---|
| Selection Guides | |
| General Purpose 8-Bit DACs | 10–3 |
| General Purpose 10-Bit DACs | 10–4 |
| General Purpose 12-Bit DACs | 10–5 |
| High Resolution DACs | 10–6 |
| CMOS Multiplying DACs | 10–8 |
| LOG DACs | 10–11 |
| 8-Bit μP-Compatible DACs | 10–12 |
| 12-Bit μP-Compatible DACs | 10–14 |
| Video Display DACs | 10–17 |
| Video Speed Current Output DACs | 10–19 |
| Video Speed Voltage Output DACs | 10–20 |
| General Information | 10–21 |
| Specifications and Terms | 10–22 |
| DAC1136/DAC1138 High Resolution 16- and 18-Bit DAC Modules | 10–27 |
| DAC1146 Low Cost High Accuracy 18-Bit DAC Module | 10–35 |
| MDD Ultra-High-Speed Deglitched 8- and 10-Bit DAC Modules | 10–39 |
| MDMS Ultra-High-Speed 8-, 10-, and 11-Bit Multiplying DACs | 10–43 |

# Selection Guide
## Digital-to-Analog Converters

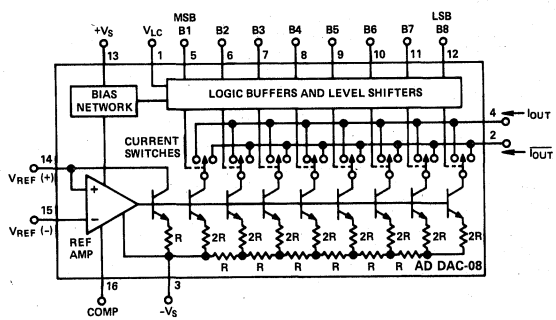
## General Purpose 8-Bit D/A Converters




### AD1408/AD1508

Page
Vol. I
9-265

- Improved Replacement for Industry Standard 1408/1508
- Improved Settling Time: 250ns typ
- Improved Linearity: ±0.1% Accuracy Guaranteed Over Temperature Range (−9 Grade)
- High Output Voltage Compliance: +0.5V to −5.0V
- Low Power Consumption: 157mW typ
- High Speed 2-Quadrant Multiplying Input: 4.0mA/μs Slew Rate
- Single Chip Monolithic Construction
- Hermetic 16-Pin Ceramic DIP



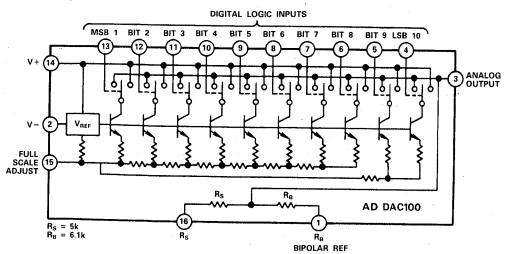

### AD DAC-08

Vol. I
9-89

- Exact Replacement for Industry Standard DAC-08
- Fast (85ns typical) Settling Time
- Linearity Error ±1/4LSB (±0.1%) Guaranteed Over Full Temperature Range
- Wide Output Voltage Compliance: −10V to +18V
- Single Chip Monolithic Construction
- 16-Pin Ceramic DIP Packaging

# Selection Guide
## Digital-to-Analog Converters

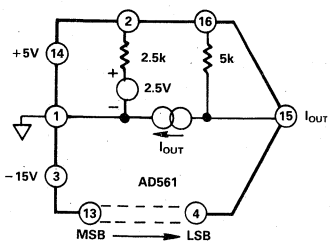
## General Purpose 10-Bit D/A Converters




### AD DAC-100

Page

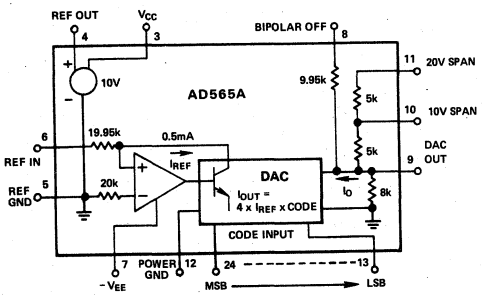
- Complete Current Output Converter — Vol. I 9–287
- High Stability Buried Zener Reference
- Single Chip Monolithic Construction
- Wide Supply Range ±6V to ±18V
- Trimmed Output Application Resistors
- Fast Settling – 225ns (8 Bits), 375ns (10 Bits)
- Guaranteed Monotonicity Over Full Operating Temperature Range
- TTL and DTL Compatible Logic Inputs
- Hermeticaly-Sealed 16-Pin Ceramic DIP (All Grades)




### AD561

- Complete Current Output Converter — Vol. I 9–43
- High Stability Buried Zener Reference
- Laser Trimmed to High Accuracy (1/4 LSB Max Error, AD561K, T)
- Trimmed Output Application Resistors for 0 to +10, ±5 Volt Ranges
- Fast Settling – 250ns to 1/2LSB
- Guaranteed Monotonicity Over Full Operating Temperature Range
- TTL/DDT and CMOS Compatible (Positive True Logic)
- Single Chip Monolithic Construction
- Hermetically-Sealed Ceramic DIP (All Grades)

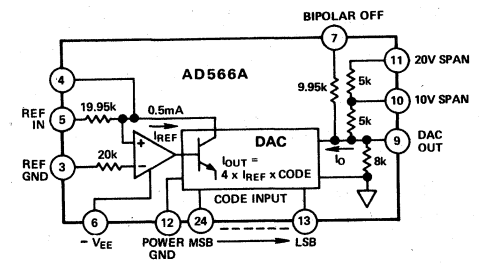
# General Purpose 12-Bit D/A Converters




## AD565A

Page
Vol. I
9-57

- Single Chip Construction
- Very High Speed: Settles to 1/2LSB in 250ns max
  Full Scale Switching Time: 30ns
- High Stability Buried Zener Reference On Chip
- Monotonicity Guaranteed Over Temperature
- Linearity Guaranteed Over Temperature: 1/2LSB max (AD565AK, T)
- Guaranteed for Operation with ±12V Supplies
- Low Power: 225mW Including Reference
- Pin-Out Compatible with AD563, AD565

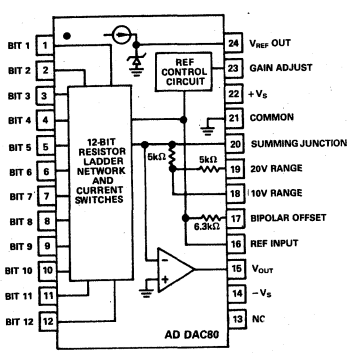



## AD566A

Vol. I
9-65

10

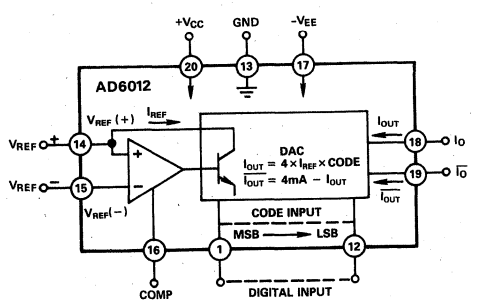
- Single Chip Construction
- Very High Speed: Settles to 1/2LSB in 350ns max
  Full Scale Switching Time: 30ns
- Guaranteed for Operation with −12V Supply
- Monotonicity Guaranteed Over Temperature
- Linearity Guaranteed Over Temperature: 1/2LSB max (AD566AK, T)
- Low Power: 180mW
- Pin-Out Compatible with AD562, AD566




## AD DAC80 SERIES

Vol. I
9-277

- Single Chip Construction
- On-Board Output Amplifier
- Low Power Dissipation: 300mW
- Monotonicity Guaranteed Over Temperature
- Guaranteed for Operation with ±12V Supplies
- Improved Replacement for Standard DAC80
- High Stability, High Current Output Buried Zener Reference
- Laser Trimmed to High Accuracy: ±1/2LSB max Nonlinearity
- Low Cost Plastic Packaging
- Current Out Models and Voltage Output Models Available

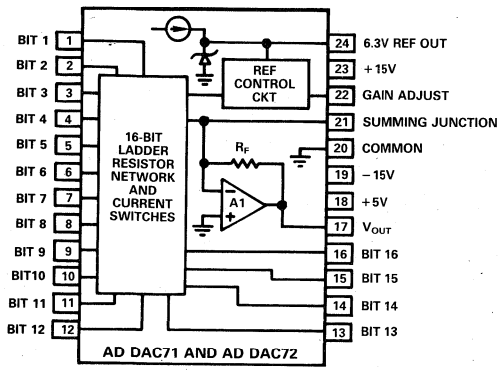



## AD6012

Vol. I
9-97

- 1/2LSB max Differential Linearity Error Over Temperature
- 250ns Typical Settling Time
- Full Scale Current 4mA
- High Speed Multiplying Capability
- TTL/CMOS/ECL/HTL Compatible
- High Output Compliance: −5V to +10V
- Complementary Current Outputs
- Low Power Consumption: 230mW

# Selection Guide
## Digital-to-Analog Converters
### High Resolution D/A Converters

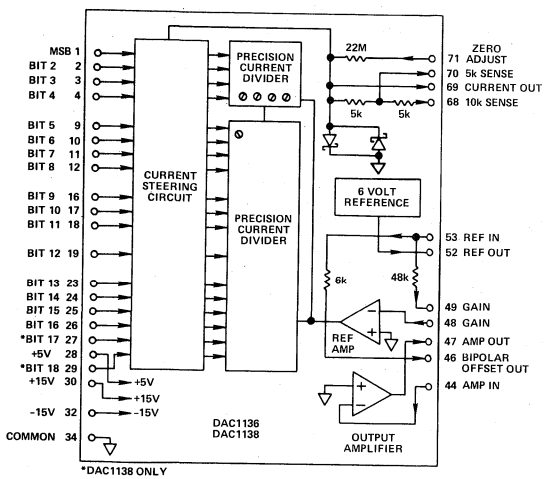


AD DAC71 AND AD DAC72

## AD DAC71/AD DAC72

Page

16-Bit Resolution — Vol. I
±0.003% Maximum Nonlinearity — 9-271
Low Gain Drift ±7ppm/°C
0 to +70°C Operation (AD DAC71, AD DAC71H, AD DAC72C)
−25°C to +85°C Operation (AD DAC72)
Current and Voltage Models Available
Improved Second-Source



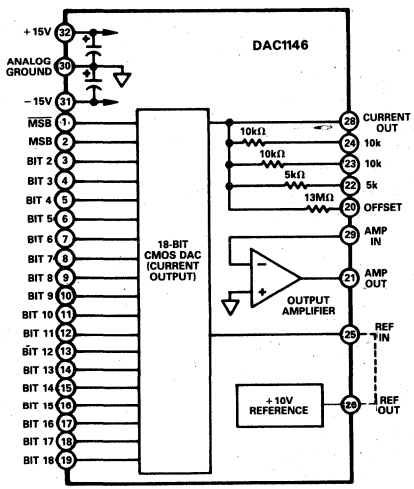
*DAC1138 ONLY

## DAC1136

16-Bit Resolution and Accuracy — Vol. II
Low Cost — 10-27
Nonlinearity 1/2LSB
Settling to 1/2LSB (0.0008%) in 6μs

## DAC1138

18-Bit Resolution and Accuracy (38μV, 1 Part in 62,144) — Vol. II
Integral Nonlinearity 1/2LSB — 10-27
Differential Nonlinearity 1/2LSB
Settling to 1/2LSB (0.002%) in 10μs
Hermetically-Sealed Semiconductors

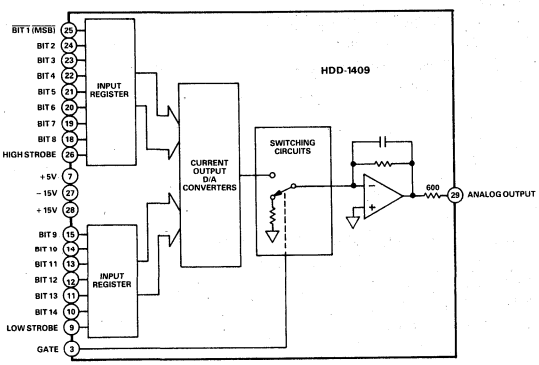



## DAC1146

Page

Low Cost, High Accuracy 18-Bit D/A Converter — Vol. II
Integral Nonlinearity: ±0.00076% FSR max — 10–35
Differential Nonlinearity: ±0.00076% FSR max
Low Differential Nonlinearity T.C.: ±1ppm/°C max
Wide Power Supply Operation: ±11.5V to ±16V
Fast Settling: 6µs to ±0.00076% FSR
Small Size 2″ × 2″ × 0.4″

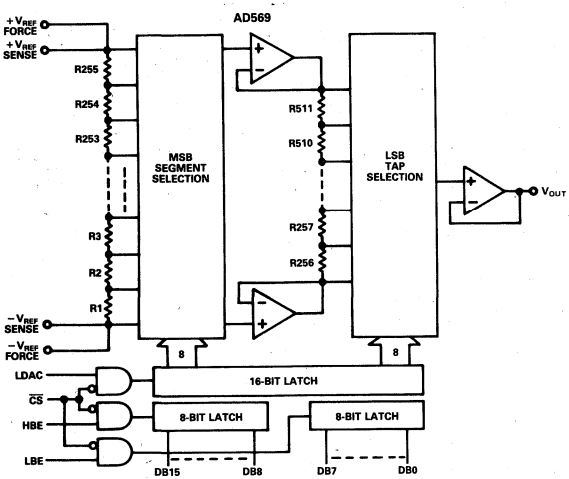
10




## HDD-1409

14-Bit Resolution
200kHz Word Rates
RZ Gated Output
32-Pin DIP

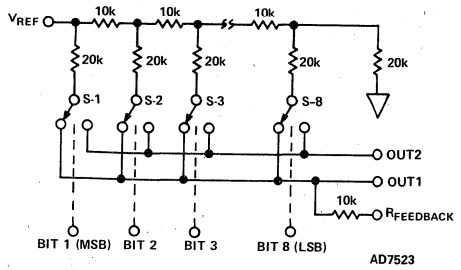
APPLICATIONS — Vol. I
FDM/TDM Transmultiplexers — 9–305
Digital Signal Processing
PCM Systems
Digital Audio




## AD569

Guaranteed 16-Bit Monotonicity
Voltage Output, 6µs Settling Time
Monolithic BIMOS Construction
±0.02% Nonlinearity
8- and 16-Bit Bus Compatible — Vol. I
6µs Settling Time — 9–81
Low Drift
Low Power: 150mW
Low Cost

# Selection Guide
## Digital-to-Analog Converters
## CMOS Multiplying D/A Converters

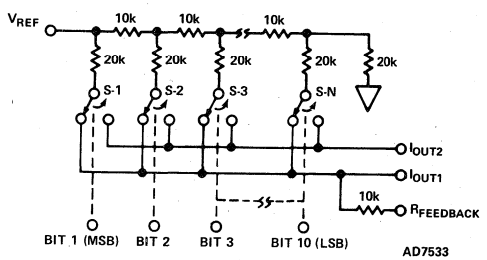



### AD7523

Page

**8 Bits of Resolution**
**Fast Settling: 100ns**
**Low Power Dissipation**
**Low Feedthrough: 1/2LSB @ 200kHz**
**Full Four-Quadrant Multiplying**

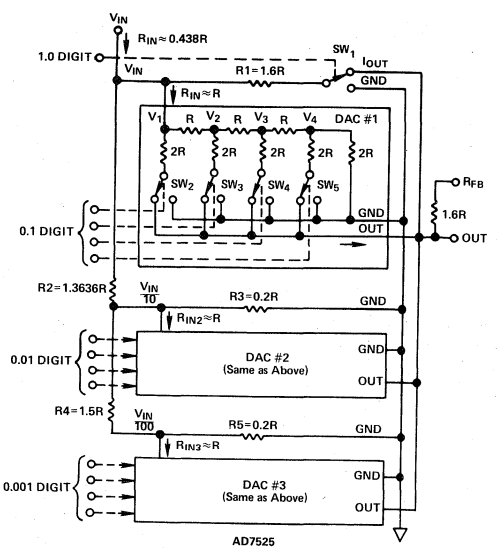
Vol. I
9-167




### AD7533

**Lowest Cost 10-Bit DAC**
**Low Cost AD7520 Replacement**
**Linearity: 1/2, 1 or 2LSB**
**Low Power Dissipation**
**Full Four-Quadrant Multiplying DAC**
**CMOS/TTL Direct Interface**
**Latch-Free (Protection Schottky Not Required)**
**End-Point Linearity**

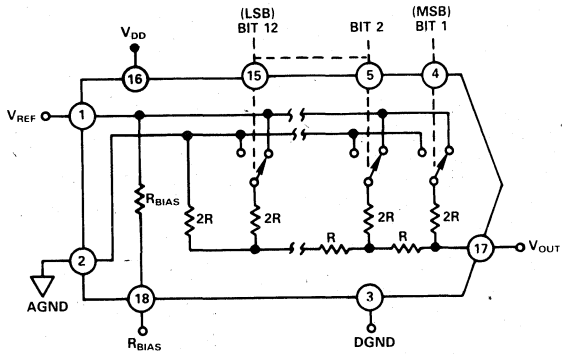
Vol. I
9-195




### AD7525

**Resolution: 3 1/2 Digit BCD (1999 Counts)**
**Nonlinearity: ±1/2LSB $T_{MIN}$ to $T_{MAX}$**
**Gain Error: ±0.05% FS**
**Excellent Repeatability Accuracy**
**Low Power Dissipation**

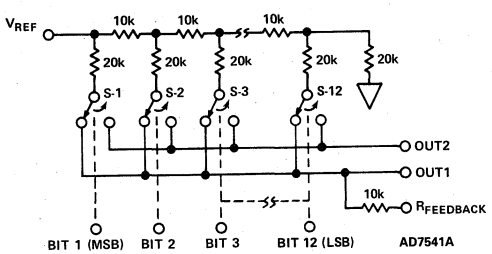
Vol. I
9-177




## AD7240

Page
Vol. I
9-145

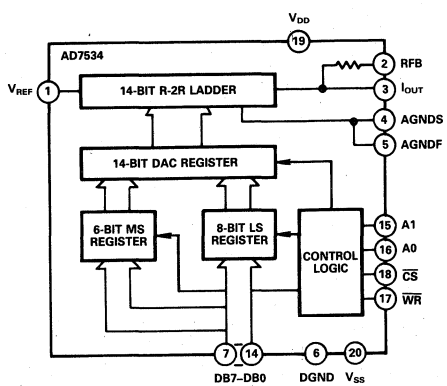
- 12 Bits of Resolution
- Fast Voltage Settling Time: 550ns to 0.01%
- Total Unadjusted Error: 1LSB max
- Single Supply Operation
- Latch-Up Proof (No Protection Schottky Required)
- Superb Differential Nonlinearity: 1/2LSB max Over Temperature
- Low Power Dissipation: 30mW




## AD7541A

Vol. I
9-209

- 12 Bits of Resolution
- Improved Version of AD7541
- Full Four Quadrant Multiplication
- 12-Bit Linearity (End-Point)
- ±1LSB Gain Error
- All Parts Guaranteed Monotonic
- TTL/CMOS Compatible
- Protection Schottky not Required
- Low Logic Input Leakage

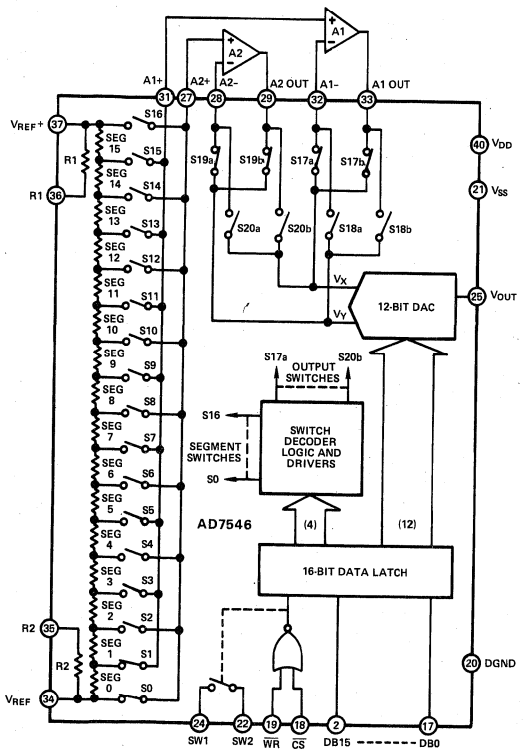



## AD7534

Vol. I
9-201

- 14 Bits of Resolution
- Full 4-Quadrnat Multiplication
- Microprocessor Compatible with Double Buffered Inputs
- Exceptionally Low Gain Temperature Coefficient, 0ppm/°C typ
- Small 20-Pin Package
- Low Output Leakage (<20nA) over the Full Temperature Range
- All Grades 14-Bit Monotonic over the Full Temperature Range

# Selection Guide
## Digital-to-Analog Converters
## CMOS Multiplying D/A Converters



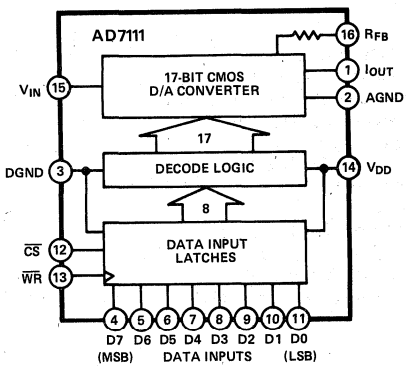

## AD7546

Page

Vol. I
9-239

**16 Bits of Resolution**
**Monotonic to 16 Bits Over Temperature**
**On-Chip Deglitch Switch**
**Unipolar and Bipolar Operation**
**Microprocessor Compatible**
**TTL/CMOS Compatible Latched Inputs**
**Voltage Output (Constant Output Impedance)**
**Low Cost**
**Low Power Consumption: 50mW typ**

# Log D/A Converters



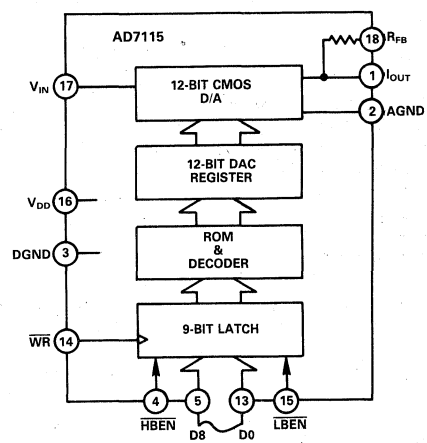

## AD7111

Page
Vol. I
9-109

**Dynamic Range: 88.5dB**
**Resolution: 0.375dB**
**On-Chip Data Latches**
**Full ±25V Input Range Multiplying DAC**
**Low Distortion**
**Single +5V Supply**
**Latch-Up Free (No Prctection Schottky Required)**

**APPLICATIONS**
**Digitally Controlled AGC Systems**
**Audio Attenuators**
**Wide Dynamic Range A/D Converters**
**Sonar Systems**
**Function Generators**

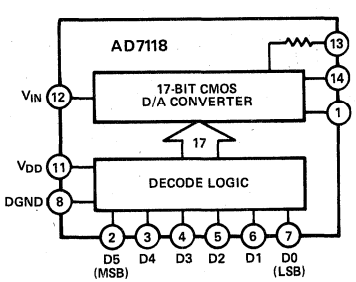





## AD7115

Vol. I
9-115

**Dynamic Range: 0 to 19.9dB Plus Full Muting**
**Resolution: 0.1dB**
**2 1/2 Digit BCD Input Coding**
**On-Chip Data Latches**
**Full ±25V Input Range**
**Low Distortion and Noise**
**Latch-Up Free (No Protection Schottky Required)**
**TTL Compatible**

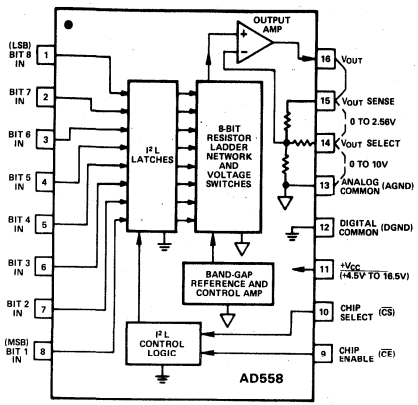



## AD7118

Vol. I
9-123

**Dynamic Range 85.5dB**
**Resolution 1.5dB**
**Full ±25V Input Range Multiplying DAC**
**Extended Temperature Range −55°C to +125°C**
**Low Distortion**
**Low Power Consumption**
**Latch-Proof Operation (Schottky Diodes Not Required)**

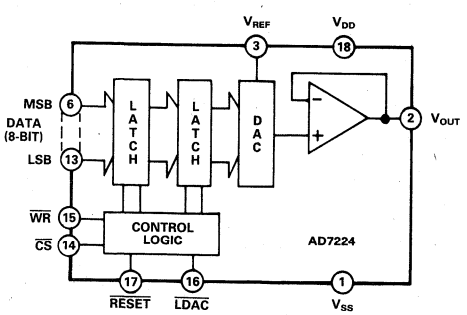
# Selection Guide
## Digital-to-Analog Converters
## 8-Bit μP-Compatible D/A Converters




### AD558

Page
Vol. I
9-35

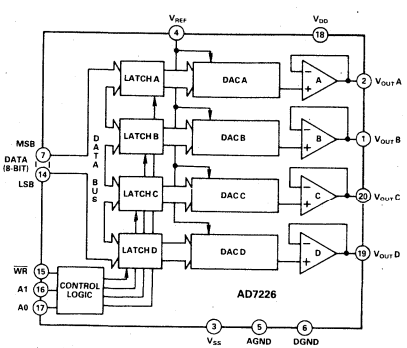
**Complete 8-Bit DAC**
**Voltage Output – 2 Calibrated Ranges**
**Internal Precision Band-Gap Reference**
**Single-Supply Operation: +5V to +15V**
**Full Microprocessor Interface**
**Fast: 1μs Voltage Settling to ±1/2LSB**
**Low Power: 75mW**
**No User Trims**
**Guaranteed Monotonic Over Temperature**
**All Errors Specified $T_{min}$ to $T_{max}$**
**Small 16-Pin DIP Package**
**Single Laser-Wafer-Trimmed Chip for Hybrids**




### AD7224

Vol. I
9-129

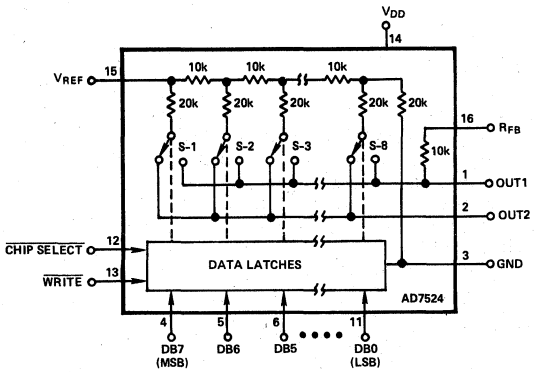
**8-Bit DAC with Output Amplifier**
**Full Double Buffering**
**Microprocessor Compatible**
**Single Supply Operation**
**Multiplying Capability**
**No User Trims**
**Low Power**
**0.3" Wide 18-Pin DIP**




### AD7226

Vol. I
9-133

**Four 8-Bit DACs with Output Amplifiers**
**0.3" Wide, 20-Pin DIP**
**Microprocessor Compatible**
**TTL/CMOS Compatible**
**No User Trims**
**Single Supply Operation Possible**

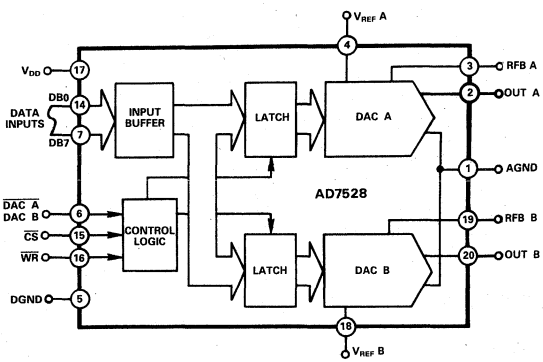



## AD7524

Page
Vol. I
9–171

- Microprocessor Compatible (6800, 8085, Z80, Etc.)
- TTL/CMOS Compatible Inputs
- On-Chip Data Latches
- End Point Linearity
- Low Power Consumption
- Monotonicity Guaranteed (Full Temperature Range)
- Latch-Free (No Protection Schottky Required)





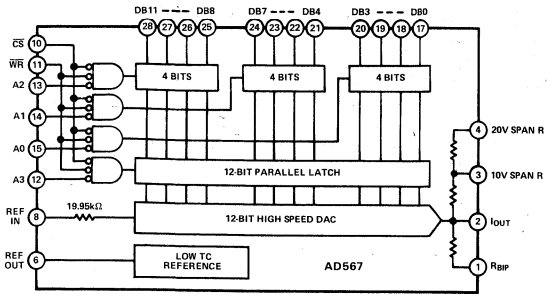

## AD7528

Vol. I
9–183

- Dual D/A Converter
- On-Chip Latches for Both DACs
- +5V to +15V Operation
- DACs Matched to 1%
- Four Quadrant Multiplication
- TTL/CMOS Compatible
- Latch-Free (Protection Schottkys Not Required)

# Selection Guide
## Digital-to-Analog Converters

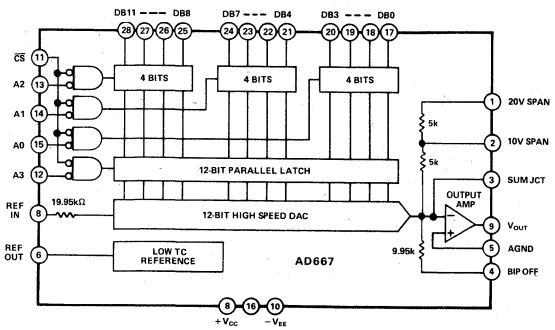
## 12-Bit µP-Compatible D/A Converters




### AD567

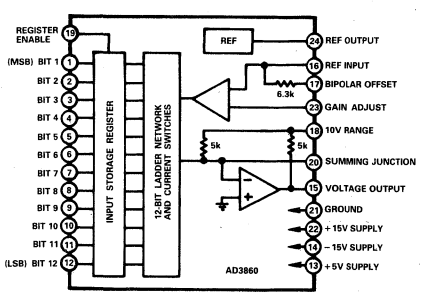
Page

- Single Chip Construction — Vol. I 9–73
- Double-Buffered Latch for 8-Bit µP Compatibility
- Fast Settling Time: 500ns max to ±1/2LSB
- High Stability Buried Zener Reference on Chip
- Monotonicity Guaranteed Over Temperature
- Linearity Guaranteed Over Temperature: 1/2LSB max (AD567K, T)
- Guaranteed for Operation with ±12V or ±15V Supplies
- Low Power: 300mW Including Reference
- TTL/5V CMOS Compatible Logic Inputs



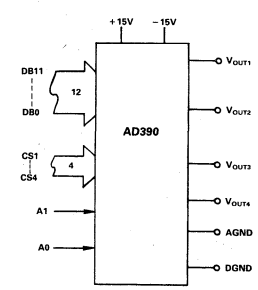

### AD667

- Voltage Output — Vol. I 9–83
- Single Chip Construction
- Double-Buffered Latch for 8-Bit µP-Compatibility
- Fast Settling Time: 5ns max to ±1/2LSB
- High Stability Buried Zener Reference On Chip
- Monotonicity Guaranteed Over Temperature
- Linearity Guaranteed Over Temperature: 1/2LSB max (AD667K, T)
- Guaranteed for Operation with ±12V or ±15V Supplies
- Low Power: 300mW Including Reference
- TTL/5V CMOS Compatible Logic Inputs



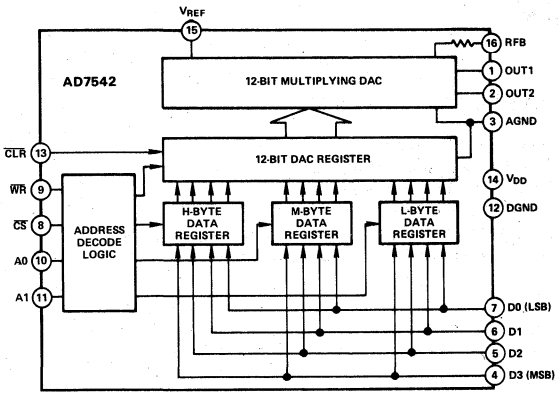

### AD3860

- Nonlinearity: ±1/2LSB $T_{min}$ to $T_{max}$ — Vol. I 9–93
- 12-Bit Input Register
- Small Size: 24-Pin DIP
- Fast Settling: 5µs to ±0.01%
- Internal Reference
- Internal Output Amplifier




### AD390

- Four Complete 12-Bit DACs in One IC Package — Vol. I 9–27
- Linearity Error ±1/2LSB $T_{min}$ – $T_{max}$ (AD390K, T)
- Factory-Trimmed Gain and Offset
- Buffered Voltage Output
- Monotonicity Guaranteed Over Full Temperature Range
- Double-Buffered Data Latches
- Includes Reference and Buffer
- Fast Settling: 8µs max to ±1/2LSB

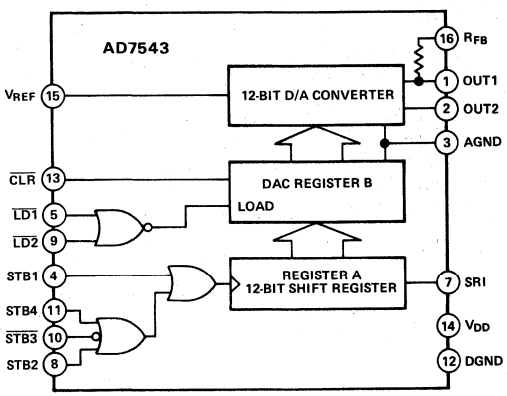



## AD7542

Page Vol. I 9-215

**Nonlinearity: ±1/2LSB $T_{min}$ to $T_{max}$**
**Low Gain Drift: 2ppm/°C typ, 5ppm/°C max**
**Microprocessor Compatible**
**Full 4-Quadrant Multiplication**
**Low Multiplying Feedthrough**
**Low Power Dissipation: 40mW max**
**Small Size: 16-Pin DIP**



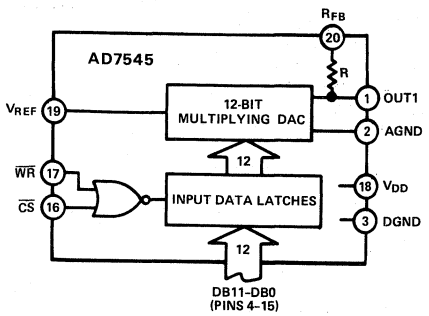



## AD7543

Vol. I 9-223

**Nonlinearity: ±1/2LSB $T_{min}$ to $T_{max}$**
**Low Gain T.C.: 2ppm/°C typ, 5ppm/°C max**
**Serial Load on Positive or Negative Strobe**
**Asynchronous CLEAR Input for Initialization**
**Full 4-Quadrant Multiplication**
**Low Multiplying Feedthrough: 1LSB max @ 10kHz**
**Requires no Schottky Diode Output Protection**
**Low Power Dissipation: 40mW max**
**+5V Supply**
**Small Size: 16-Pin DIP**

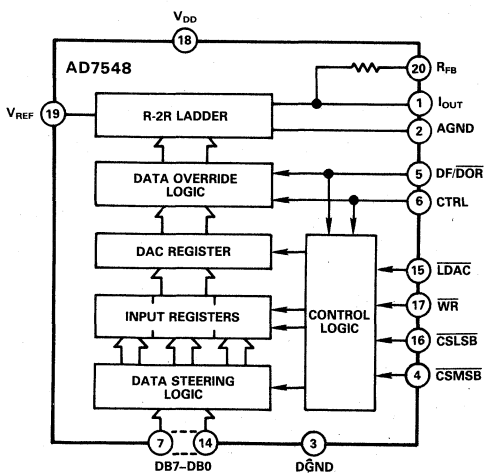
# Selection Guide
## Digital-to-Analog Converters
## 12-Bit μP-Compatible D/A Converters




### AD7545

Page
Vol. I
9-231

**Low Gain T.C.: 2ppm/°C typ**
**Fast TTL Compatible Data Latches**
**Single +5V to +15V Supply**
**Small 20-Pin 0.3″ DIP**
**Latch Free (Schottky Protection Diode Not Required)**
**Ideal for Battery Operated Equipment**

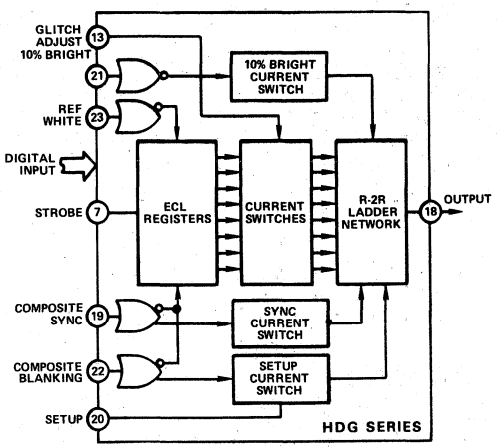



### AD7548

Vol. I
9-247

**8-Bit Bus Compatible 12-Bit DAC**
**All Grades 12-Bit Monotonic Over Full Temperature Ranges**
**Operation Specified at +5V, +12V or +15V Power Supply**
**Low Gain Drift of 5ppm/°C Maximum**
**Full 4-Quadrant Multiplication**
**Small 20-Pin Package**

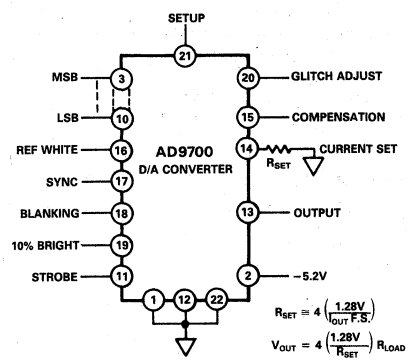
# Video Display D/A Converters




## HDG SERIES

Page
Vol. I
9-309

**Ultra Fast 7ns Settling Time to 0.4% (8ns max)**
**Low 50 pV-s max Glitch Energy**
**Operates from Single −5.2V Power Supply**
**Complete Composite Inputs**
**Designed for General Output Compatibility with EIA Standard RS-170 and RS-343, Including 10% Brightness**
**HDG-0805**
**Resolution: 8 Bits**
**% of Gray: 0.4%**
**Settling Time: 8ns**
**HDG-0605**
**Resolution: 6 Bits**
**% of Gray: 1.6%**
**Settling Time: 6ns**
**HDG-0405**
**Resolution: 4 Bits**
**% of Gray: 6.4%**
**Settling Time: 4ns**



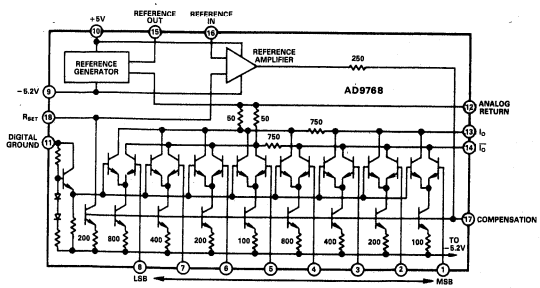

## AD9700

Vol. I
9-259

**Update Rates to 125MHz**
**2ns Rise Time**
**On-Chip Reference Voltage**
**Single −5.2V Power Supply**
**Complete Composite Inputs**

**APPLICATIONS**
**Raster Scan Displays**
**Color Graphics**
**Automated Test Equipment**
**TV Video Reconstruction**

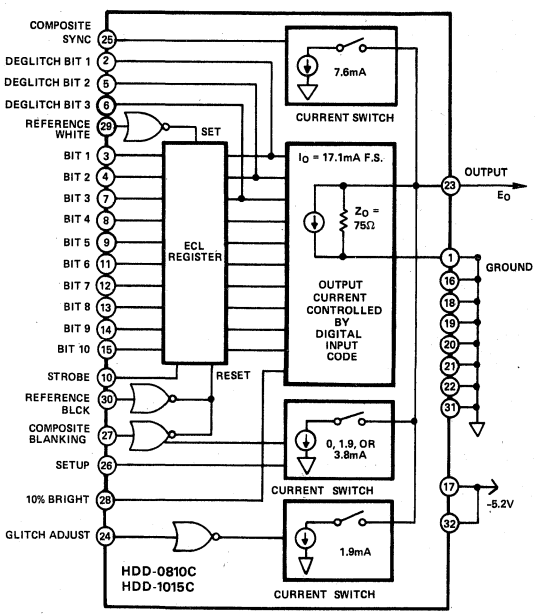
# Selection Guide
## Digital-to-Analog Converters
## Video Display D/A Converters




### AD9768

Page

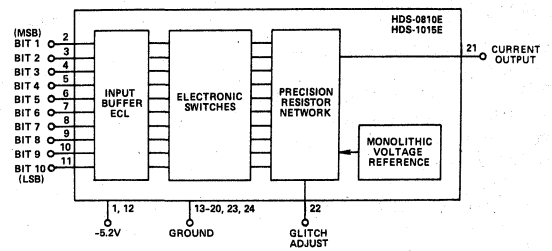
**8 Bits of Resolution** Vol. I
**5ns Settling Time** 9–261
**100MHz Update Rate**
**20mA Output Current**
**ECL-Compatible**
**40MHz Multiplying Mode**




### HDD SERIES

**HDD-0810 – 8 Bits of Resolution** Vol. I
**HDD-1015 – 10 Bits of Resolution** 9–295
**Ultra Fast 10ns Settling Time to 0.2% (HDD-0810)**
**15ns Settling Time to 0.1% (HDD-1015)**
**Internal Monolithic Reference**
**Low 200pV-s Glitch Energy**
**Single −5.2V Power Supply**
**Designed for General Output Compatibility with EIA Standards RS-170 and RS-343, Including 10% Brightness**
**Complete Composite Inputs (HDD-0810C, HDD-1015C)**

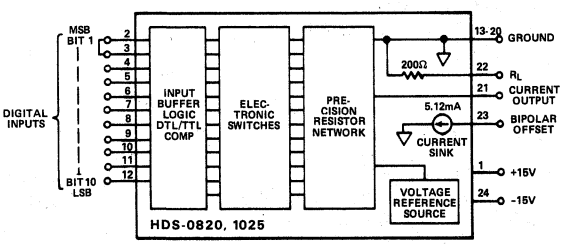
# Video Speed Current Output D/A Converters




## HDS-0810E/HDS-1015E

Page

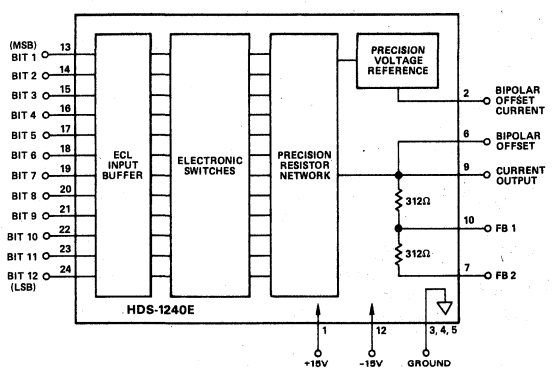
**HDS-0810E: 8 Bits** — Vol. I
**HDS-1015E: 10 Bits** — 9-321
**ECL Inputs**
**Settling Time to 10ns**
**Low Glitch Energy – 200pV-s**
**100MHz Update Rates**
**Low Power <1 Watt**




## HDS-0820/HDS-1025

**HDS-0820: 8 Bits** — Vol. I
**HDS-1025: 10 Bits** — 9-317
**25ns Current Settling to 0.1%**
**10mA Current Out**
**Guaranteed Monotonicity Over Temperature**
**No External Parts Required**
**Reliable Hybrid Construction**

10

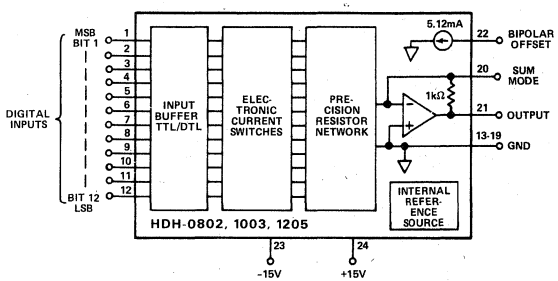



## HDS-1240E

**12 Bits of Resolution** — Vol. I
**12-Bit Settling Time to 40ns** — 9-323
**Low Glitch Energy**
**ECL Compatible**
**Replacement for ADH-030, DA-4000, DAC397**

# Selection Guide
## Digital-to-Analog Converters

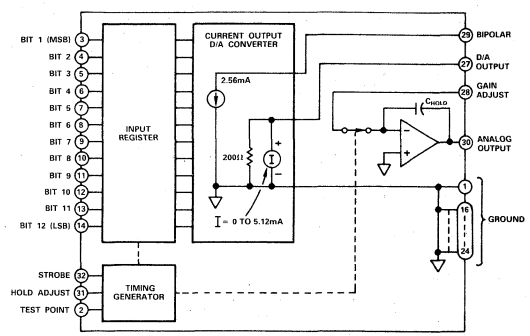
## Video Speed Voltage Output D/A Converters




### HDH SERIES

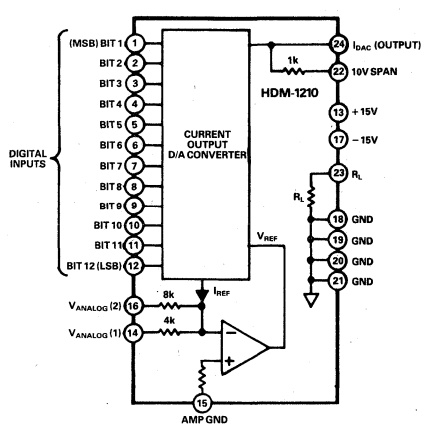
Page

**200ns Voltage Settling to 0.1%** Vol. I
**10mA Current Out** 9-317
**Guaranteed Monotonicity Over Temperature**
**No External Parts Required**
**Reliable Hybrid Construction**
**HDH-0802**
**Resolution: 8 Bits**
**Settling Time: 200ns to 0.4%**
**HDH-1003**
**Resolution: 10 Bits**
**Settling Time: 300ns to 0.1%**
**HDH-1205**
**Resolution: 12 Bits**
**Settling Time: 500ns to 0.125%**




### HDD-1206

**12 Bits of Resolution** Vol. I
**Registers, D/A, Amplifier in Single Hybrid** 9-301
**Deglitched Voltage Output**
**6MHz Update Rate**




### HDM-1210

**Small Size: 24-Pin DIP** Vol. I
**12-Bit Multiplying Accuracy** 9-315
**Good Drive: 10.24mA**
**Highest Speed Available**

# Orientation
# Digital-to-Analog Converters

## FACTORS IN CHOOSING A D/A CONVERTER

In the current issue of this two-volume catalog, there are listed some 62 different families of digital-to-analog converters (DACs). If one were to consider all the variations, there would be more than 260 types to choose among. The reason for so many different types is the number of degrees of freedom in selection—technological, functional, and performance. Complete information on converters may be found in the 250-page book, ANALOG-DIGITAL CONVERSION NOTES, published by Analog Devices and available for $5.95 from P.O. Box 796, Norwood MA 02062.

## TECHNOLOGICAL FACTORS

The technologies represented in these two volumes include modules (cards and potted circuits) and integrated circuits—monolithic and hybrid. Modules historically have provided the extremes of performance and arbitrary levels of functional completeness (e.g., the 18-bit DAC1138, the 10-bit 20MHz-word-rate deglitched MDD-1020, and the isolated 10-bit DAC1423 loop DAC), although ICs are catching up rapidly.

The technical data in this volume embrace exceptionally high performance (high-resolution and high-speed) d/a converters, in the form of encapsulated modules. As the Selection Guide indicates, there is also a universe of technical data, to be found in Volume I, on a wide range of monolithic and hybrid d/a converters, including microprocessor-compatible types with resolution through 16 bits, and chips for hybrid assembly.

## FUNCTIONAL CHARACTERISTICS

The basic structure of all conventional D/A converters involves a network of precision resistors, a set of switches, and some form of level-shifting to adapt the switch drives to the specified logic levels. In addition, the device may contain output-conditioning circuitry, an output amplifier, a reference amplifier, an on-board reference, on-board buffer-registers (single- or dual-rank), configuration conditioning, and even high-voltage isolation.

### Basic DAC

This form, which supplies a current, and consequently a small voltage across its internal impedance or an external low-impedance load, is used principally for high speed. Basic current-output DACs are inherently fast, but additional elements (such as an output op amp), furnished by the user to meet overall system specs, slow down the conversion.

While the basic DAC function is almost always linear, there are exceptions. For example, the AD7111 LOGDAC, which has linear two-quadrant analog response, has a digitally controlled exponential gain function, i.e., 0.375dB per bit, a useful function in digital audio systems.

### Output Conditioning

The analog quantity that is the "output" of a DAC, representing the input digital data, may be a "gain" (multiplying DAC), a current, and/or a voltage. In order to obtain a substantial voltage output at low impedance, an op amp is required. It is generally provided on-board in modular and hybrid DACs.

Almost all types of DACs provide one or more feedback resistors; they are matched to, and thermally track, resistances in the network, so that an external op amp, if used, will not require an external feedback resistor that might introduce tracking errors. If more than one feedback resistor is provided, a choice of analog output voltage ranges becomes available, e.g., 0–5V full-scale or 0–10V full-scale. If bipolar output-voltage ranges are specified, a bipolar-offset output is provided to subtract a half-scale value from the current flowing through the op amp summing point; it is usually derived from the DAC's reference (or analog) input to avoid additional tracking error. Multiplying DACs use an internal or external op amp for bipolar offset.

In addition to the usual zero-based current and voltage outputs, DACs are available with 4-to-20mA ISA-standard loop-current outputs, both direct-coupled (DAC1420/22) and high-voltage-isolated (DAC1423), with some additional features that are specifically useful in digital control of analog processes.

In order to avoid difficulties, the user must pay especial attention to the specified output polarity, its relationship to the reference (if external) and to the input digital code. This can be especially tricky if the output is bipolar and the input requires a complementary (negative-true) digital coding. Another such case is where a current-output DAC, specified for a particular output-voltage polarity when used with an inverting op amp, is used in a mode that develops an output voltage passively (without the op amp) across an external resistive load. In addition to polarity, in this case, the user should be aware of the output-compliance constraint and the specified resistive component of output impedance.

### Reference Input

The reference may be specified as external or internal, fixed or variable, single-polarity or bipolar. If internal, it may be permanently connected (as in the DAC1106/1108) or optionally connectible (as in the DAC1136/1138). If the DAC is a 4-quadrant multiplying type, the reference (or "analog input") is external, variable, and bipolar. The user should check a converter's specifications to determine whether the full-scale accuracy specifications are overall or subdivided into a converter-gain spec and a reference spec.

### Digital Data

There are a number of ways in which converters differ in regard to the input data: First, the *coding* must be appropriate (binary, offset-binary, two's-complement, BCD, arbitrary, etc.), and its sense should be understood (positive-true, negative-true). The *resolution* (number of bits) must be sufficient; in addition, the specifications must be checked to ascertain that the $2^n$ distinct binary input codes will not only be accepted, but that also they will (if necessary) correspond to $2^n$ output values in a monotonic progression at any temperature in the operating range, with sufficient accuracy.

The *data levels* accepted by the converter must be checked (TTL, ECL, low-voltage CMOS, high voltage CMOS), as must the input loading imposed by the converter, and the supply conditions under which the converter will respond to the data. Check the data notation (is the MSB Bit 1 or Bit (n-1)?)—misinterpretation can lead to connecting the data bits in backward order. If *buffer registers* are desired, the converter should have an appropriate buffer configuration. The data can be clocked in, while the DAC output remains unchanged.

**Controls**
If the DAC has external digital controls—for example, register strobes– their drive levels, digital sense (true or false), loading, and timing must be considered. The function and use of configuration controls (where present), such as serial/parallel, short-cycle, or chip-select decoding should be understood, and the appropriate ways of disabling them when not needed should be employed.

**Power Supplies**
Appropriate power supplies should be made available, considering the logic levels and analog output signals to be employed in the system. The appropriate degree of power-supply stability to meet the accuracy specs should be employed. Any recommended external protection circuitry (e.g., Schottky diodes, to ensure that $V_{CC}$ is never more than 0.4V above $V_{DD}$ in the AD7522) should be planned for. In many cases separate analog and digital grounds are required; ground wiring should follow best practice to minimize digital interference with high-accuracy analog signals, while ensuring that a connection between the grounds can always exist at one point, even if the "mecca" point is inadvertently unplugged from the system.

For video converters, use massive, low impedance ground systems. The analog and digital grounds are connected together inside converters of these types, so bus bars are essential for system grounding and power distribution; use lots of ground plane on PC boards.

## SPECIFICATIONS AND TERMS

Definitions of the performance specifications, and related information, are provided on the next few pages, in alphabetical order.

**Accuracy, Absolute**
Error of a D/A converter is the difference between the actual analog output and the output that is expected when a given digital code is applied to the converter. Sources of error include gain (calibration) error, zero error, linearity errors, and noise. Error is usually commensurate with resolution, i.e., less than $2^{-(n+1)}$, or "½ LSB" of full scale. However, accuracy may be much better than resolution in some applications; for example, a 4-bit reference supply having only 16 discrete digitally chosen levels would have a resolution of 1/16, but it might have an accuracy to within 0.01% of each ideal value.

Absolute-accuracy measurements should be made under a set of standard conditions with sources and meters traceable to an internationally accepted standard.

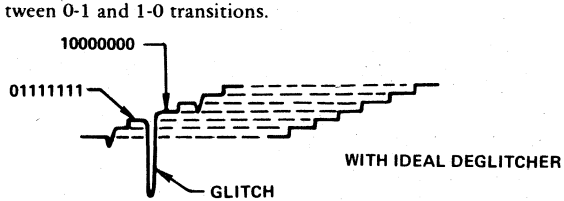
**Accuracy, Relative**
Relative accuracy error, expressed in %, ppm, or fractions of 1 LSB, is the deviation of the analog value at any code (relative to the full analog range of the device transfer characteristics) from its theoretical value (relative to the same range), after the full-scale range (FSR) has been calibrated. Since the discrete analog output values corresponding to the digital input values ideally lie on a straight line, the relative-accuracy error of a linear DAC can be interpreted as a measure of nonlinearity (see *Linearity*).

**Compliance-Voltage Range**
For a current-output DAC, the maximum range of (output) terminal voltage for which the device will provide the specified current-output characteristics.

**Common-Mode Rejection (CMR)**
The ability of an amplifier to reject the effect of voltage applied to both input terminals simultaneously. Usually a logarithmic expression representing a "common-mode rejection ratio" e.g., 1,000,000:1 (CMRR) or 120dB (CMR). A CMRR of $10^6$:1 means that a 1V common-mode voltage passes through the device as though it were a differential input signal of 1 microvolt.

**Common-Mode Voltage**
An undesirable signal picked up in a circuit by both wires making up the circuit, with reference to an arbitrary "ground." Amplifiers differ in their ability to amplify a desired signal accurately in the presence of a common-mode voltage.

**Deglitcher**
As the input code to a DAC is increased or decreased by small changes, it passes through what is known as major and minor transitions. The most major transition is at half-scale, when the DAC switches around the MSB, and all switches change state, i.e., 01111111 to 10000000. If, at major transitions, the switches are faster (or slower) to switch off than on, this means that, for a short time, the D/A will give a zero (or full-scale) output, and then return to the required 1 LSB above the previous reading. Such large transient spikes which differ widely in amplitude and are extremely difficult to filter out, are commonly known as "glitches", hence, a deglitcher is a device which removes these glitches or reduces them to a set of small, uniform pulses. It normally consists of a fast sample-hold circuit, which holds the output constant until the switches reach equilibrium. Glitch energy is smallest in fast-switching DACs driven by fast logic gates that have little time-skew between 0-1 and 1-0 transitions.



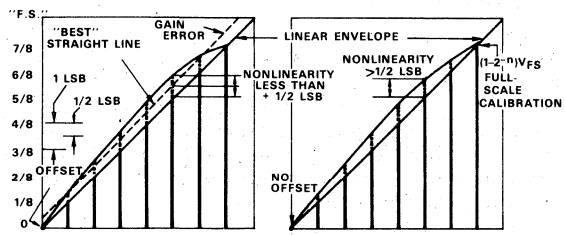
**Feedthrough**
Undesirable signal coupling around switches or other devices that are supposed to be turned off or provide isolation, e,g,. *feedthrough error* in a multiplying DAC. It is variously specified in %, ppm, fractions of 1 LSB, or fractions of 1 volt, with a given set of inputs, at a specified frequency.

**Four-Quadrant**
In a multiplying DAC, "four quadrant" refers to the fact that both the reference signal and the number represented by the digital input may be of either positive or negative polarity. A four-quadrant multiplier is expected to obey the rules of multiplication for algebraic sign.

**Gain**
The "gain" of a converter is that analog scale-factor setting that provides the nominal conversion relationship, e.g., 10V span for a full-scale code change, in a fixed-reference converter. For fixed-reference converters where the use of the internal reference is optional, the converter gain and the reference may be specified separately. Gain- and zero-adjustment are discussed under *Zero.*

**Least-Significant Bit (LSB)**
In a system in which a numerical magnitude is represented by a series of binary (i.e., two-valued) digits, the LSB is that bit that carries the smallest value, or weight. For example, in the natural-binary number 1101 (decimal 13, or $2^3 + 2^2 + 0 + 2^0$), the rightmost digit is the LSB. Its analog weight, relative to full scale, is $2^{-n}$, where n is the number of binary digits. It represents the smallest analog change that can be resolved by an n-bit converter.

**Linearity**
Linearity error of a converter (also, *integral nonlinearity*, see *Linearity, Differential*), expressed in % or ppm of full-scale range, or (sub)multiples of 1 LSB, is a deviation of the analog values, in a plot of the measured conversion relationship, from a straight line. The straight line can be either a "best straight line", determined empirically by manipulation of the gain and/or offset to equalize maximum positive and negative deviations of the actual transfer characteristics from this straight line; or it can be a straight line passing through the end points of the transfer characteristic after they have been calibrated (sometimes referred to as "end-point" linearity). End-point linearity error is similar to *relative-accuracy* error.




*a. ½LSB Nonlinearity Achieved By Arbitrary Location of "Best Straight Line".*

*b. Nonlinearity Reference is Straight Line Through End Points. Nonlinearity >½LSB for Curve of a.*

*Comparison of Linearity Criteria for 3-Bit D/A Converter. Straight Line Through End Points is Easier to Measure, Gives More-Conservative Specification.*

For multiplying D/A converters, the *analog* linearity error, at a specified digital code, is defined in the same way as for multipliers, i.e., by deviation from a "best straight line" through the plot of the analog output-input response.

**Linearity, Differential**
Any two adjacent digital codes should result in measured output values that are exactly 1 LSB apart ($2^{-n}$ of full scale for an n-bit converter). Any deviation of the measured "step" from the ideal difference is called *differential nonlinearity*, expressed in (sub)multiples of 1 LSB. It is an important specification, because a differential linearity error greater than 1 LSB can lead to non-monotonic response in a D/A converter and missed codes in an A/D converter (see *Differential Linearity* in the A/D converter section for an illustration).

**Monotonic**
A DAC is said to be monotonic if the output either increases or remains constant as the digital input increases, with the result that the output will always be a single-valued function of the input. The specification "monotonic" (over a given temperature range) is sometimes substituted for a *differential nonlinearity* specification, since differential nonlinearity less than 1 LSB is a sufficient condition for monotonic behavior.

**Most-Significant Bit (MSB)**
In a system in which a numerical magnitude is represented by a series of binary (i.e., two-valued) digits, the MSB is that digit (or bit) that carries the largest value of weight. For example, in the natural-binary number 1101 (decimal 13, or $2^3 + 2^2 + 0 + 2^0$), the leftmost "1" is the MSB, with a weight of $2^{n-1}$, or 8 LSBs. Its analog weight, relative to a DAC's full-scale span, is ½. In bipolar DACs, the MSB indicates the polarity of the number represented by the rest of the bits.

**Multiplying DAC**
A multiplying DAC differs from a fixed-reference DAC in being designed to operate with varying (or ac) reference signals. The output signal of such a DAC is proportional to the product of the "reference" (i.e., analog input) voltage and the fractional equivalent of the digital input number (see also *four-quadrant*).

**Noise, Peak and rms**
Internally generated random noise is not a major factor in D/A converters, except at extreme resolutions (e.g., DAC1138) and dynamic ranges (AD7111). Random noise is characterized by rms specifications for a given bandwidth, or as a spectral density (current or voltage per root hertz); if the distribution is Gaussian, the probability of peak-to-peak values exceeding 7x the rms value is less than 0.1% (see the waveform table in Section 7).

10

Of much greater importance in DACs is interference in the form of high-amplitude low-energy (hence low-rms) spikes appearing at the DAC's output, caused by coupling of digital signals in a surprising variety of ways; they include coupling via stray capacitance, via power supplies, via inadequate ground systems, via feedthrough, and by glitch-generation. Their presence underscores the necessity for maximum application of the designer's art, including layout, shielding, guarding, grounding, bypassing, and deglitching.

**Offset**
For almost all bipolar converters (e.g., ±10-volt output), instead of actually generating negative currents to correspond to negative numbers, a unipolar DAC is used, and the output is offset by half full scale (1 MSB). For best results, this offset voltage or current is derived from the same reference supply that determines the gain of the converter.

This makes the zero point of the converter independent of thermal drift of the reference, because the ½ scale offset cancels the weight of the MSB at zero, independently of the amplitude of both.

**Power-Supply Sensitivity**
The sensitivity of a converter to changes in the power-supply voltages is normally expressed in terms of percent-of-full-scale change in analog output value (or fractions of 1 LSB) for a 1% dc change in the power supply, e.g., $0.05\%/\%\Delta V_S$). Power supply sensitivity may also be expressed in relation to a specified dc shift of supply voltage. A converter may be considered "good" if the change in reading at full scale does not exceed ±½ LSB for a 3% change in power supply. Even better specs are necessary for converters designed for battery operation.

**Quantizing Uncertainty (or "Error")**
The analog continuum is partitioned into $2^n$ discrete ranges for n-bit processing. All analog values within a given range of output (of a DAC) are represented by the same digital code, usually assigned to the nominal midrange value. For applications in which an analog continuum is to be restored, there is an inherent quantization uncertainty of ±½ LSB, due to limited resolution, in addition to the actual conversion errors. For applications in which discrete output levels are desired (e.g., digitally controlled power supplies or digitally controlled gains), this consideration is not relevant.

**Resolution**
An n-bit binary converter should be able to provide $2^n$ distinct and different analog output values corresponding to the set of n-bit binary words. A converter that satisfies this criterion is said to have a *resolution* of n bits. The smallest output change that can be resolved by a linear DAC is $2^{-n}$ of the full-scale span. However, a nonlinear device, such as the AD7111 LOGDAC has a logarithmic gain resolution of 0.375/88.5dB= 1:256dB, which corresponds to a gain increment of 4.25/step, or 26,600:1.

**Settling Time**
The time required, following a prescribed data change, for the output of a DAC to reach and remain within a given fraction (usually ±½ LSB) of the final value. Typical prescribed changes are full-scale, 1 MSB, and 1 LSB at a major carry. Settling time of current-output DACs is quite fast. The major share of settling time of a voltage-output DAC is usually contributed by the settling time of the output op-amp circuit.

**Slew Rate (or Slewing Rate)**
Slew rate of a device or circuit is a limitation in the rate of change of output voltage, usually imposed by some basic circuit consideration, such as limited current to charge a capacitor. Amplifiers with slew rate of a few V/μs are common, and moderate in cost. Slew rates greater than about 75 volts/μs are usually seen only in more sophisticated (and expensive) devices. The output slewing speed of a voltage-output D/A converter is usually limited by the slew rate of the amplifier used at its output (if one is used).

**Stability**
Stability of a converter usually applies to the insensitivity of its characteristics to time, temperature, etc. All measurements of stability are difficult and time consuming, but stability vs. temperature is sufficiently critical in most applications to warrant universal inclusion of temperature coefficients in tables of specifications (see "Temperature Coefficient").

**Staircase**
A voltage or current, increasing in equal increments as a function of time and having the appearance of a staircase (in a time plot), generated by applying a pulse train to a counter, and the output of the counter to the input of a DAC.

A very simple A/D converter can be built by comparing a staircase from a DAC with the unknown analog input. When the DAC output exceeds the analog input by a fraction of 1 LSB, the count is stopped, and the code corresponding to the count is the digital output.

**Switching Time**
In a DAC, the switching time is the time it takes for the switch to change from one state to the other ("delay time" plus "rise time" from 10%-90%), but does not include settling time, e.g. to <½ LSB.

**Temperature Coefficients**
In general, temperature instabilities are expressed as %/°C, ppm/°C, as fractions of 1 LSB/°C, or as a change in a parameter over a specified temperature range. Measurements are usually made at room temperature and at the extremes of the specified range, and the temperature coefficient (tempco, T.C.) is defined as the change in the parameter, divided by the corresponding temperature change. Parameters of interest include *gain, linearity, offset* (bipolar), and *zero*.

**Gain Tempco:** Two factors principally affect converter gain stability with temperature.

a) In fixed-reference converters the reference source will vary with temperature. For example, the tempco of an AD581L is generally less than 5ppm/°C.

b) The reference circuitry and switches may add another 3ppm/°C in good 12-bit converters (e.g. AD566K/T).

High-resolution converters require much better tempcos for accuracy commensurate with the resolution.

**Linearity Tempco:** Sensitivity of linearity ("integral" and/or differential linearity) to temperature (in % FSR/°C or ppm FSR/°C) over the specified range. Monotonic behavior is achieved if the differential nonlinearity is less than 1 LSB at any temperature in the range of interest. The *differential nonlinearity temperature coefficient* may be expressed as a ratio, as a maximum change over a temperature range, and/or implied by a statement that the device is monotonic over the specified temperature range.

**Offset Tempco:** The temperature coefficient of the all-DAC-switches-off (minus full scale) point of a bipolar converter (in % FSR/°C or ppm FSR/°C) depends on three major factors:

a) The tempco of the reference source
b) The voltage zero-stability of the output amplifier
c) The tracking capability of the bipolar-offset resistors and the gain resistors

**Unipolar Zero Tempco (in % FSR/°C or ppm FSR/°C):** The temperature stability of a unipolar fixed-reference DAC is principally affected by current leakage (current-output DAC), and offset voltage and bias current of the output op-amp (voltage-output DAC).

**Zero- and Gain-Adjustment Principles**

The output of a unipolar DAC is set to zero volts in the all-bits-off condition. The gain is set for F.S. $(1 - 2^{-n})$ with all bits on. The "zero" of an offset-binary bipolar DAC is set to -F.S. with all bits off, and the gain is set for +F.S. $(1 - 2^{-(n-1)})$ with all bits on. The data sheet instructions should be followed.

10

# High Resolution 16- and 18-Bit Digital-to-Analog Converters

# DAC1136/1138

**FEATURES**

**DAC1138**

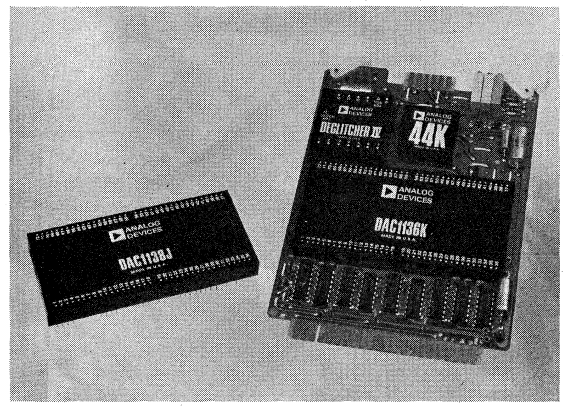
**18-Bit Resolution and Accuracy (38μV, 1 Part in 262,144)**
**Nonlinearity 1/2LSB max (DAC1138K)**
**Excellent Stability**
**Settling to 1/2LSB (0.0002%) in 10μs**
**Hermetically-Sealed Semiconductors**

**DAC1136**

**16-Bit Resolution and Accuracy (152μV, 1 Part in 65,536)**
**Low Cost**
**Nonlinearity 1/2LSB max (DAC1136K, L)**
**Settling to 1/2LSB max (0.0008%) in 6μs**

**DEGLITCHER IV**

**Eliminates DAC Glitches**
**Available on DAC1136/1138 Card-Mounted Assembly**




## GENERAL DESCRIPTION

The DAC1136/1138 are complete self-contained current or voltage output modular digital-to-analog converters with resolutions and accuracies of 16 and 18 bits.

The DAC1136/1138 combine precision current sources with state-of-the-art steering switches to produce a very linear output. Inputs to these converters are compatible with TTL levels. The converters have a current output of -2mA full scale. A voltage output can be obtained by connecting the internal amplifier to the current output by means of jumpers. By using additional jumpers, the user can select any one of the following output ranges: 0 to +5V, 0 to +10V, ±5V, or ±10V.

The DAC1136/1138 are available on Card-Mounted Assemblies. In this configuration, selectable options include: input codes, output amplifiers, and a high speed transient-suppressing Deglitcher Module, Deglitcher IV.

## WHERE TO USE HIGH RESOLUTION DACS

The DAC1136/1138 deliver exceptional accuracy for a broad range of display, test and instrumentation applications. The DAC1136, with a resolution of 16 bits or 1 part in 65,536, and the DAC1138 with a resolution of 18 bits or 1 part in 262,144 are ideally suited for applications requiring wide dynamic range measurement and control. Applications include data acquisition systems, high resolution CRT displays, automatic semiconductor testing, photo-typesetting, frequency synthesis and nuclear reactor control.

## CERTIFICATE OF CALIBRATION

Each DAC1138 has been calibrated with equipment and methods that are traceable to the National Bureau of Standards (NBS). A Certificate of Performance is sent with each unit, which includes 1000 hour stability data for the reference zener and linearity test data.

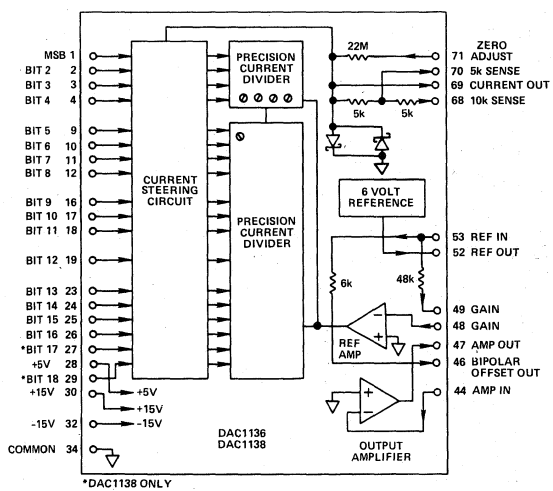



*Figure 1. Block Diagram and Pin Designations*

# SPECIFICATIONS (typical @ +25°C, rated power supplies unless otherwise noted; specifications for mounting card with amplifier/deglitcher options same as module unless otherwise noted)

| | DAC1136 Module | | | DAC1136 on Mounting Card with Amplifier/Deglitcher Options. | | |
|---|---|---|---|---|---|---|
| | J | K | L | Deglitcher IV (Internal AD542K) | Low Drift 234L w/wo Deglitcher | High Speed 44K w/wo Deglitcher |
| RESOLUTION, BITS | 16 | | | | | |
| ACCURACY | | | | | | |
| Integral Nonlinearity | ±1LSB max | ±1/2LSB max | ±1/2LSB max | | | |
| Differential Nonlinearity | ±1LSB max | ±1/2LSB max | ±1/2LSB max | | | |
| Gain and Offset Error (Externally Adjustable) | | | | Gain, offset and glitch-nulling adjustments provided on the mounting card. | | |
| ANALOG OUTPUT | | | | | | |
| Unipolar Mode | −2mA to 0mA | | | | | |
| Bipolar Mode | −1mA to +1mA | | | | | |
| Voltage Output Range (Pin Selectable) | 0 to +5V, 0 to +10V, ±5V, ±10V | | | | | |
| DIGITAL INPUTS | TTL/CMOS; See Figure 2 | | | | | |
| INPUT CODES | | | | | | |
| Unipolar Mode | Complementary Binary (COMP BIN) | | | BIN, COMP BIN, 2's COMP, COMP 2's COMP | | |
| Bipolar Mode | Complementary Offset Binary (COMP OBIN) | | | OBIN, COMP OBIN | | |
| | | | | SIGN PLUS MAG BIN, COMP SIGN PLUS MAG BIN | | |
| STROBE INPUT | None | | | One standard series 74LS load, leading-edge triggered, pulse width 100ns minimum. | | |
| DYNAMIC CHARACTERISTICS | | | | | | |
| Settling Time to 1/2LSB | | | | | | |
| Current | | | | | | |
| Full Scale Step | 8µs | | | Voltage Output, Only | | |
| LSB Step | 6µs | | | Voltage Output, Only | | |
| Voltage | | | | | | |
| Unipolar (10V Step) | 90µs | | | 80µs | 45µs | 25µs |
| Bipolar (20V Step) | 250µs | | | 90µs | 60µs | 30µs |
| LSB Step | 8µs | | | 8µs | 8µs | 8µs |
| Slew Rate | 1V/µs | | | 2V/µs | 6V/µs | 20V/µs |
| TEMPERATURE COEFFICIENTS (ppm of FSR/°C)[1] | | | | | | |
| Integral Nonlinearity | ±1 | ±1 | ±1.5 max | | | |
| Differential Nonlinearity | ±1 | ±1 | ±1.5 max | | | |
| Gain (Excluding $V_{REF}$) | ±5 | ±5 | ±8 max | | | |
| Offset | | | | | | |
| Unipolar Mode | ±0.5 | | | ±0.5 | ±0.1 | ±2 |
| Bipolar Mode | ±5 | | | | | |
| STABILITY, LONG TERM (ppm of FSR/1,000 hrs.)[2] | | | | | | |
| Gain (Excluding $V_{REF}$) | ±5 | | | | | |
| Offset | ±6 | | | ±1 | ±0.5 | ±25 |
| NOISE (Include $V_{REF}$; Double for Bipolar Mode) | | | | | | |
| Output Current (BW = 100kHz) | 0.5nA rms | | | Voltage Output, Only | | |
| Output Voltage (BW = 0.1–10Hz) | | | | | | |
| @ 0V (A11 1's Code; "ZERO") | 4µV pk-pk | | | | | |
| @ 5V (MSB = 0 Code; "Half Scale") | 6µV pk-pk | | | | | |
| @ 10V (A11 0's Code; "Full Scale") | 9µV pk-pk | | | | | |
| Output Voltage (BW = 100kHz) | 30µV rms | | | 20µV rms | 40µV rms | 35µV rms |
| VOLTAGE COMPLIANCE (Amplifier Offset, $E_{OS}$) | | | | | | |
| Max $E_{OS}$ Allowed for Rated Accuracy | ±2mV max | | | | | |
| Initial $E_{OS}$ (Factory Adj.) | ±100µV | | | ±50µV | ±20µV | ±100µV |
| $E_{OS}$ Drift | ±10µV/°C | | | ±5µV/°C | ±0.1µV/°C | ±15µV/°C |
| Current Output (pin 69) | | | | | | |
| Voltage Protection | via Internal Schottky Diodes | | | | | |
| Source Resistance | | | | | | |
| Unipolar Mode | >33kΩ | | | | | |
| Bipolar Mode | >5kΩ | | | | | |
| Source Capacitance | 150pF | | | | | |
| REFERENCE VOLTAGE ($V_{REF}$) | | | | | | |
| Voltage ($Z_{OUT}$ ≈200Ω) | +6.000V (Maximum Error, ±0.024V) | | | | | |
| Noise (BW = 0.1–10Hz) | 3µV pk-pk | | | | | |
| Tempco | 5ppm/°C | | | | | |
| POWER SUPPLY REQUIREMENTS[3] | | | | | | |
| +5V dc, ±5% | 9mA | | | | 95mA | |
| ±15V dc, ±5% | ±30mA | | | ±38mA | ±37mA | ±40mA |
| POWER SUPPLY REJECTION (±15V dc) | | | | | | |
| Gain or Offset vs. FSR | 80dB | | | 100dB | 100dB | 75dB |
| Differential Nonlinearity | ±1/4LSB per Volt $\Delta V_S$ | | | | | |
| ENVIRONMENTAL | | | | | | |
| Operating Temperature | 0 to +70°C | | | −55°C to +80°C | −55°C to +85°C | −55°C to +85°C |
| Storage Temperature | −55°C to +85°C | | | | | |
| Humidity | 5% to 95%, Noncondensing | | | | | |

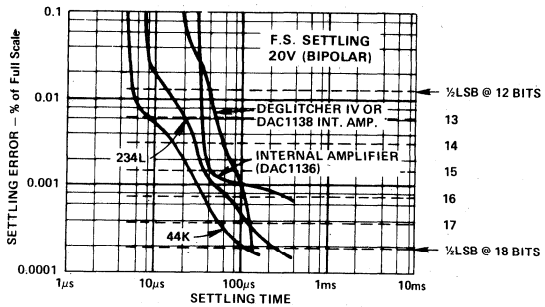
NOTES
[1]Maximum temperature coefficients guaranteed from 15°C to 35°C, typical from 0 to +70°C.
[2]Recommended DNL calibration check: 6 months.
[3]Recommended Power Supply: Analog Devices Model 923.
Specifications subject to change without notice.

# SPECIFICATIONS (typical @ +25°C, rated power supplies unless otherwise noted; specifications for mounting card with amplifier/deglitcher options same as module unless otherwise noted)

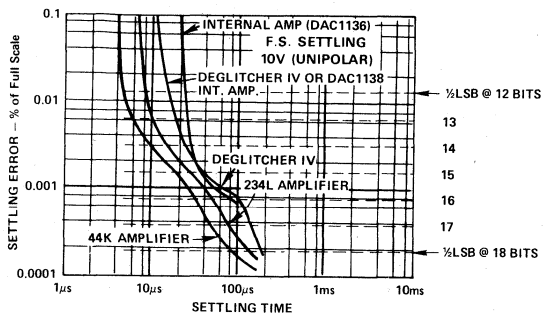
| | DAC1138 Module | | DAC1138 on Mounting Card with Amplifier/Deglitcher Options. | |
|---|---|---|---|---|
| | J | K | Deglitcher IV (Internal AD542K) | Low Drift 234L w/wo Deglitcher |
| RESOLUTION, BITS | 18 | | | |
| ACCURACY | | | | |
| Integral Nonlinearity | ±1LSB max | ±1/2LSB max | | |
| Differential Nonlinearity | ±1LSB max | ±1/2LSB max | | |
| Gain and Offset Error (Externally Adjustable) | | ±1LSB | Gain, offset and glitch–nulling adjustments provided on the mounting card. | |
| ANALOG OUTPUT | | | | |
| Unipolar Mode | −2mA to 0mA | | | |
| Bipolar Mode | −1mA to +1mA | | | |
| Voltage Output Range (Pin Selectable) | 0 to +5V, 0 to +10V, ±5V, ±10V | | | |
| DIGITAL INPUTS | TTL/CMOS; See Figure 2 | | | |
| INPUT CODES | | | | |
| Unipolar Mode | Complementary Binary (COMP BIN) | | BIN, COMP BIN, 2's COMP, COMP 2's COMP | |
| Bipolar Mode | Complementary Offset Binary (COMP OBIN) | | OBIN, COMP OBIN<br>SIGN PLUS MAG BIN, COMP SIGN PLUS MAG BIN | |
| STROBE INPUT | None | | One standard series 74LS load, leading-edge triggered, pulse width 100ns minimum. | |
| DYNAMIC CHARACTERISTICS | | | | |
| Settling Time to 1/2LSB | | | | |
| Current | | | | |
| Full Scale Step | 10μs | | Voltage Output, Only | |
| LSB Step | 8μs | | Voltage Output, Only | |
| Voltage | | | | |
| Unipolar (10V Step) | 175μs | | 80μs | 45μs |
| Bipolar (20V Step) | 140μs | | 90μs | 60μs |
| LSB Step | 18μs | | 18μs | 18μs |
| Slew Rate | 2V/μs | | 2V/μs | 6V/μs |
| TEMPERATURE COEFFICIENTS (ppm of FSR/°C)[1] | | | | |
| Integral Nonlinearity | ±0.3 | | | |
| Differential Nonlinearity | ±0.4 | | | |
| Gain (Excluding $V_{REF}$) | ±0.8 | | | |
| Offset | | | | |
| Unipolar Mode | ±0.5 | | ±0.5 | ±0.1 |
| Bipolar Mode | ±1 | | | |
| STABILITY, LONG TERM (ppm of FSR/1,000 hrs.)[2] | | | | |
| Gain (Excluding $V_{REF}$) | ±2 | | | |
| Offset | ±2 | | ±1 | ±0.5 |
| NOISE (Include $V_{REF}$; Double for Bipolar Mode) | | | | |
| Output Current (BW = 100kHz) | 0.5nA rms | | Voltage Output, Only | |
| Output Voltage (BW = 0.1–10Hz) | | | | |
| @ 0V (A11 1's Code; "ZERO") | 4μV pk-pk | | | |
| @ 5V (MSB = 0 Code; "Half Scale") | 6μV pk-pk | | | |
| @ 10V (A11 0's Code; "Full Scale") | 9μV pk-pk | | | |
| Output Voltage (BW = 100kHz) | 30μV rms | | 20μV rms | 40μV rms |
| VOLTAGE COMPLIANCE (Amplifier Offset, $E_{OS}$) | | | | |
| Max $E_{OS}$ Allowed for | | | | |
| Rated Accuracy | ±200μV max | | | |
| Initial $E_{OS}$ (Factory Adj.) | ±100μV | | ±50μV | ±20μV |
| $E_{OS}$ Drift | ±10μV/°C | | ±5μV/°C | ±0.1μV/°C |
| Current Output (pin 69) | | | | |
| Voltage Protection | via Internal Schottky Diodes | | | |
| Source Resistance | | | | |
| Unipolar Mode | >33kΩ | | | |
| Bipolar Mode | >5kΩ | | | |
| Source Capacitance | 150pF | | | |
| REFERENCE VOLTAGE ($V_{REF}$) | | | | |
| Voltage ($Z_{OUT} \approx 200\Omega$) | +6.000V (Maximum Error, ±0.024V) | | | |
| Noise (BW = 0.1–10Hz) | 3μV pk-pk | | | |
| Tempco | 5ppm/°C | | | |
| POWER SUPPLY REQUIREMENTS[3] | | | | |
| +5V dc, ±5% | 9mA | | | 95mA |
| ±15V dc, ±5% | ±30mA | | ±38mA | ±37mA |
| POWER SUPPLY REJECTION (±15V dc) | | | | |
| Gain or Offset vs. FSR | 80dB | | 100dB | 75dB |
| Differential Nonlinearity | ±1/4LSB per Volt $\Delta V_S$ | | | |
| ENVIRONMENTAL | | | | |
| Operating Temperature | 0 to +70°C | | | |
| Storage Temperature | −55°C to +85°C | | −55°C to +80°C | −55°C to +85°C |
| Humidity | 5% to 95%, Noncondensing | | | |

NOTES
[1]Maximum temperature coefficients guaranteed from 15°C to 35°C, typical from 0 to +70°C.
[2]Recommended DNL calibration check: 6 months.
[3]Recommended Power Supply Analog Devices: Model 923.
Specifications subject to change without notice.

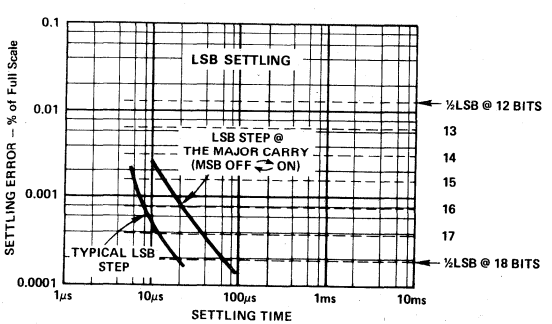
# Characteristic Curves*




*Settling Time (Voltage Output) vs. %-of-Full-Scale-Error for 20V Output Step (+10V ⇄ -10V)*




*Settling Time (Voltage Output) vs. %-of-Full-Scale-Error for 10V Output Step (0V ⇄ +10V)*

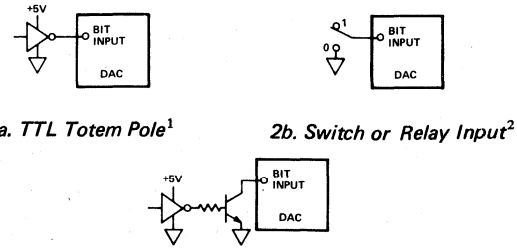



*Settling Time (Voltage Output) vs. %-of-Full-Scale-Error for LSB Steps (Essentially Independent of Amplifier Used). With Deglitcher IV, the LSB Step at the Major Carry Settles as Fast as the Typical LSB Step, Following the 11μs Hold Period.*

*NOTE: All curves typical at rated supply voltage.
F.S. = Full Scale

## INPUT CONSIDERATIONS

The DAC1136/1138 may be driven by TTL or CMOS as shown in Figure 2. Note that the TTL input is shown with inputs for both a direct "totem pole" TTL gate and open collector (or "pull-up") configurations.




*2a. TTL Totem Pole[1]*

*2b. Switch or Relay Input[2]*

*2c. CMOS Input*

1. FOR TTL WITH OPEN COLLECTOR, DO NOT USE EXTERNAL PULL-UP. CONVERTERS HAVE INTERNAL 10kΩ PULL-UP ON EACH INPUT TO 3.8V.
2. USE SPST SWITCH OR RELAY TO GROUND. WHEN SWITCH IS OPEN, THE INTERNAL 10kΩ WILL PULL INPUT UP TO 3.8V.

*Figure 2. Input Connections*

## OUTPUT CONNECTIONS AND GUARDING

The DAC1136/1138 output connections for various voltage ranges are shown in Figure 3.

Since an LSB is only 38μV (at 10 volts full scale for the DAC1138), care must be exercised to properly guard the current output of the converter from leakage current. Any connection made to the DAC's current output (pin 69) should be guarded. Suggested printed circuit board guarding is shown in Figure 3. The optional Card-Mounted Assemblies of the DAC1136/1138 have been carefully designed for optimum guarding and performance.

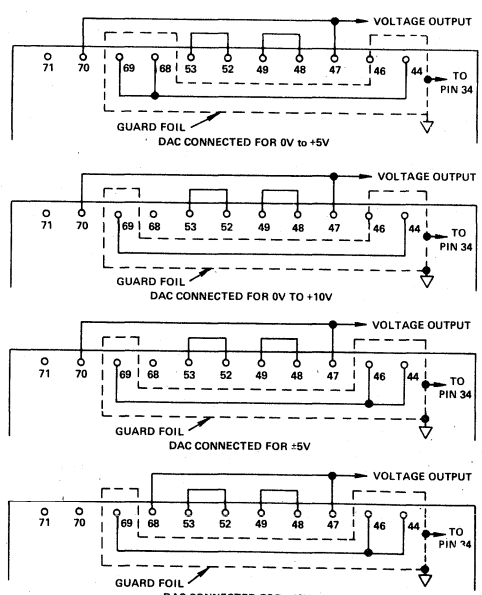
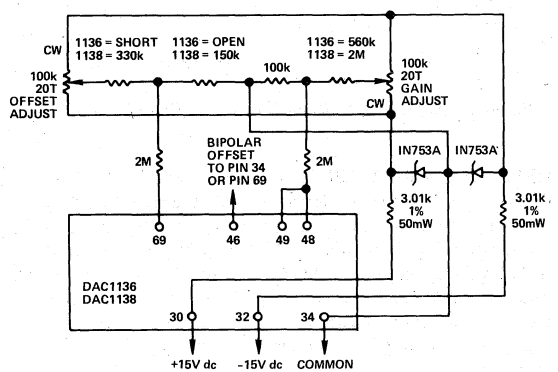



*Figure 3. Output Voltage Connections and Suggested PCB Guarding (Unipolar and Bipolar)*

## GAIN AND OFFSET ADJUSTMENTS

The gain and offset adjustments are made with external potentiometers which the user supplies. With the appropriate digital inputs applied, these potentiometers are adjusted until the desired output voltage is obtained. The proper connections for offset and gain are shown in Figure 4. The voltmeter used to measure the output should be capable of stable resolution of 1/4LSB in the region of zero and full scale. Because of the interaction between offset and gain adjustments, the adjustment procedure described below should be carefully followed. Offset adjustment affects gain, but gain adjustment does not affect offset.




NOTES:
1. ALL FIXED RESISTORS ARE 5% CARBON COMP, UNLESS OTHERWISE NOTED.
2. ALL POTENTIOMETERS ARE 20-TURN INFINITE RESOLUTION TYPE.

*Figure 4. Gain and Offset Adjustments*

For unipolar mode, apply a digital input of all "1's" (complementary binary code for zero output) and adjust the offset potentiometer until a 0.00000V output is obtained (see Table I). Once the appropriate offset adjustment has been made, apply a digital input of all "0's". Adjust the gain potentiometer until the plus full scale output is obtained (see Table I).

For bipolar mode, apply a digital input of all "1's" (complementary offset binary code for minus full scale) and adjust the offset potentiometer for the proper minus full scale output voltage (see Table I). Once the appropriate minus full scale adjustment has been made, apply a digital input of all "0's". Adjust the gain potentiometer until the plus full scale output shown below is obtained.

| RANGE | IDEAL OUTPUT | | |
|---|---|---|---|
| | | DAC1138 | DAC1136 |
| Unipolar: | All 11...1 | All 00...0 | |
| 0V→+10V | 0.00000V | +9.999962V | +9.999848V |
| 0V→+5V | 0.00000V | +4.999981V | +4.999924V |
| Bipolar: | | | |
| -10V→+10V | -10.00000V | +9.999934V | +9.999695V |
| -5V → +5V | -5.00000V | +4.999962V | +4.999848V |
| To adjust: | Adjust ZERO pot | Adjust GAIN pot | |

*Table I. Full Scale Output*

## DIFFERENTIAL LINEARITY ADJUSTMENT

Each DAC1136/1138 has been factory calibrated and tested to achieve the performance indicated in the electrical specifications. Before attempting recalibration, it is imperative that the circuit be checked to confirm that all previously described precautions have been taken to insure proper application at the 16- or 18-bit level. Basically, the DAC is trimmed by comparing a bit to the sum of all lower bits, and adjusting, if necessary, for a one LSB positive difference. The top 4 major carries, i.e., MSB minus the sum of bits 2-through-the-LSB, down through bit 4 minus the sum of bits 5-through-the-LSB, can be trimmed using the procedure outlined below. A differential voltmeter capable of 100μV Full Scale should be connected to $V_{OUT}$ of the DAC. This will resolve an LSB which at 18 bits is 38μV (10V range). A Fluke 895A or equivalent is recommended.

1. Bit 4 Trim
   a. Set bit inputs to 11110 . . . . 0.
   b. Read the output voltage by nulling the voltmeter.
   c. Set bit inputs to 11101 . . . . 1.
   d. Read voltage by nulling voltmeter. This reading should be equal to that of step 1b plus 1LSB. Adjust bit 4 if required (see B4, Figure 6).

2. Bit 3 Trim
   a. Set bit inputs to 1110 . . . . 0.
   b. Read output voltage by nulling the voltmeter.
   c. Set inputs to 1101 . . . . 1.
   d. Read voltage by nulling the voltmeter. This reading should be equal to that of step 2b plus 1LSB. Adjust bit 3 if required (see B3, Figure 6).

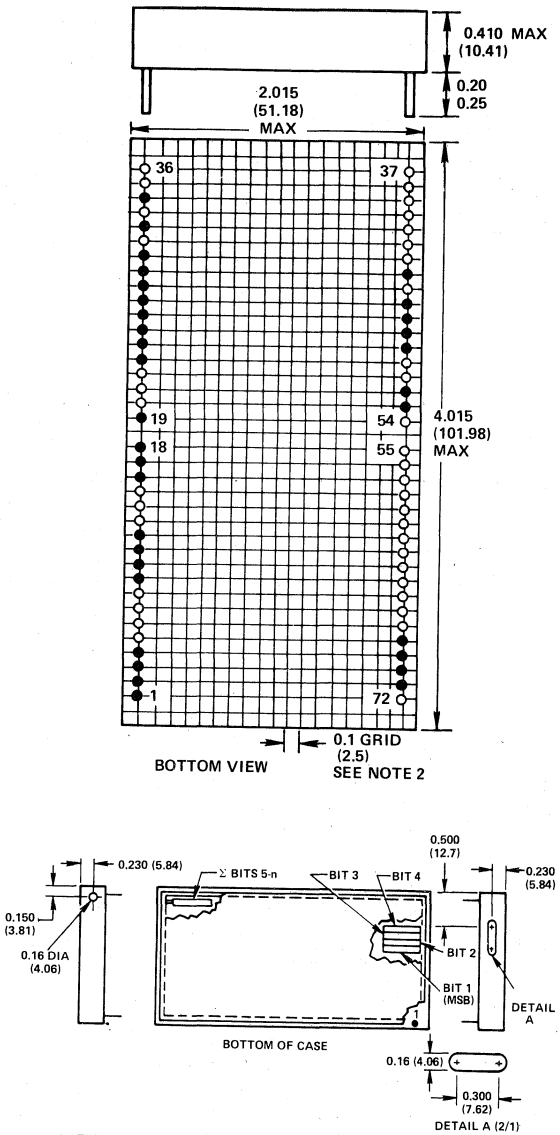
3. Bit 2 Trim
   a. Set bit inputs to 110 . . . . 0.
   b. Read output voltage by nulling the voltmeter.
   c. Set bit inputs to 101 . . . . 1.
   d. Read voltage by nulling voltmeter. This reading should be equal to that of step 3b plus 1LSB. Adjust bit 2 if required (see B2, Figure 6),

4. Bit 1 (MSB) Trim
   a. Set bit switches to 100 . . . . 0.
   b. Read output voltage by nulling the voltmeter.
   c. Set bit switches to 011 . . . . 1.
   d. Read voltage by nulling voltmeter. This reading should be equal to that of step 4b plus 1LSB. Adjust bit 1 (MSB) if required (see MSB, Figure 6).

If insufficient range exists on any adjustment, then a separate adjustment for the weight of bits 5-through-the-LSB (see Sum B5 → LSB, Figure 6) should be performed. This condition will probably not occur on bit 2, 3 and 4 but might occur on the MSB. If adjustment of the sum of bits 5-through-the-LSB is made, the trim procedure for all bits should be repeated. Obviously, since the procedure affects the weight of individual bits, it affects the overall gain of the DAC. The final step should be adjustment of gain (user supplied adjustment external to module, or pot at edge of mounting card).

## OUTLINE DIMENSIONS AND PIN DESIGNATIONS

Dimensions shown in inches and (mm).




NOTES:
1. PINS: 0.019 ±0.001 DIA.
2. GRID AND MARKINGS NEXT TO PINS ARE FOR REFERENCE ONLY AND DO NOT APPEAR ON UNIT.
3. PINS 27 AND 29 ARE NOT PRESENT ON DAC1136.

## USING AN EXTERNAL 6V REFERENCE

The DAC1136/1138 can be operated with an external reference connected to pin 53 of the module. The current drain on the external reference will be 1.125mA in bipolar mode or 0.125mA in unipolar mode (pin 46 should be left open and not grounded when using an external reference in the unipolar mode). When an external reference is used, pin 52, (the output of the internal reference) is left open.

Codi Semiconductor manufactures a reference module called Certavolt[1] with a 10 volt output accurate to 0.001%. This output is temperature compensated to within 1ppm/°C from +15°C to +55°C. The Certavolt requires a power supply of +28V dc @ 20mA. To convert the +10 volt output of the Certavolt to the +6 volt reguired by the DAC, the circuit shown in Figure 5 is recommended.

[1] Certavolt is a registered trade name by Codi Semiconductor.

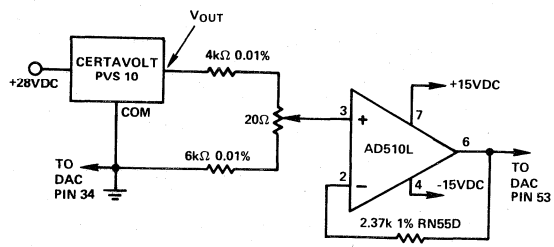
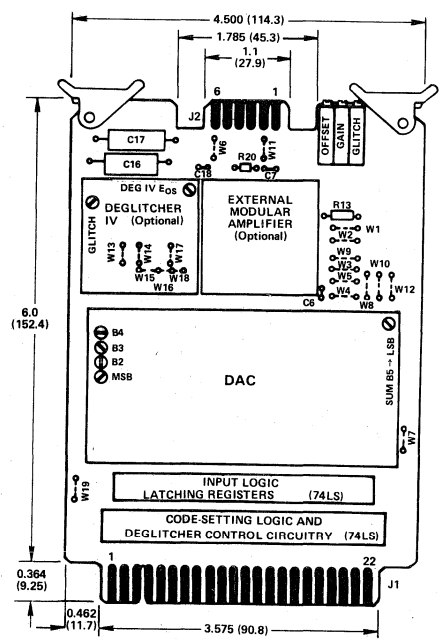



*Figure 5. DAC1136/1138 with External Precision Reference*

## OPTIONAL CARD-MOUNTED ASSEMBLY

Analog Devices offers an optional Card-Mounted Assembly designed to provide optimum performance at the 18-bit level. As shown in Figure 6, this 4 1/2" X 6" printed circuit card includes the appropriate DAC GAIN and OFFSET adjustment potentiometers, power supply bypass capacitors and input registers. The Card-Mounted Assembly can be ordered with custom code-setting logic, external output amplifiers, and a Deglitcher IV.




W'S INDICATE JUMPER POSITIONS.
TO ISOLATE ANALOG AND DIGITAL GROUND W7 IS OMITTED.
W6 AND W11 ARE NOT INSTALLED WHEN USER DESIRES 4-WIRE CONNECTION TO J2 WHEN EITHER A 44K OR 234L AMPLIFIER IS USED.

*Figure 6. Card-Mounted Assembly. Dimensions shown in inches and (mm).*

## CARD-MOUNTED ASSEMBLY JUMPER DESIGNATIONS

The output voltage range, reference source, amplifier and deglitcher configurations are programmed at the factory by means of jumpers, resistors, and capacitors (see ordering guide for details). The mounting card can be programmed by the user, if necessary, as shown below.

| Output Voltage Range | Install Jumpers |
|---|---|
| ±10V | W10, W5 |
| ±5V | W12, W5 |
| +10V | W12, W3 |

| Reference | Install Jumpers |
|---|---|
| Internal | W2 |
| External | W1 |

| Amplifier | Install Jumpers |
|---|---|
| Internal | W4, W9 |
| External[1] | W8, W13 |
| Deglitcher IV[2] | W8, W15, W17, W18 |
| Deg. IV with Ext Amp[3] | W8, W14, W16 |

NOTES:

[1] With a 234L amplifier install C7 (0.01μF, 10%, ceramic capacitor). With a 44K amplifier use a variable resistor (typ value ≈ 499Ω, 0.1W, 1%) to adjust the output voltage for a ±100μV reading as measured between pins 69 and 34 of the DAC (this step sets voltage compliance); install this value resistor (R13 position).

[2] With Deglitcher IV remove R20 (100Ω) and replace the resistor with a jumper.

[3] With Deglitcher IV and a 234L amplifier remove C6 (6.8pF Capacitor) and install: C7 (0.01μF, 10%, ceramic capacitor), C18 (100pF, 10%, ceramic capacitor), C17 (1000pF, 10%, polystyrene capacitor) and replace R20 (100Ω) with a jumper. With Deglitcher IV and a 44K amplifier perform the operation described in Note 1, remove C6 (6.8pF capacitor) and install: C18 (100pF, 10%, ceramic capacitor), C17 (1000pF, 10% polystyrene capacitor) and replace R20 (100Ω) with a jumper.

CONNECTOR J1

| PIN | FUNCTION | PIN | FUNCTION |
|---|---|---|---|
| A | BIT 1 | U | STROBE |
| B | BIT 2 | V | BIT 18[1] |
| C | BIT 3 | W | +5V |
| D | BIT 4 | X | +15V |
| E | BIT 5 | Y | -15V |
| F | BIT 6 | Z | DIGITAL GND |
| H | BIT 7 | 1-4 | NC |
| J | BIT 8 | 5 | INTERLOCK |
| K | BIT 9 | 6 | INTERLOCK |
| L | BIT 10 | 7-16 | NC |
| M | BIT 11 | 17 | BIT 17[1] |
| N | BIT 12 | 18 | |
| P | BIT 13 | 19 | |
| R | BIT 14 | 20 | |
| S | BIT 15 | 21 | |
| T | BIT 16 | 22 | |

J1 MATES WITH CINCH P.N. 251-22-30-160 (SUPPLIED).

[1] DAC1138 ONLY

CONNECTOR J2

| PIN | FUNCTION |
|---|---|
| 1 | ANALOG SENSE LOW |
| 2 | ANALOG SOURCE LOW |
| 3 | NC |
| 4 | ANALOG SOURCE HIGH |
| 5 | ANALOG SENSE HIGH |
| 6 | ANALOG REF. IN/OUT |
| A | ANALOG REF. IN/OUT |
| B | ANALOG SENSE HIGH |
| C | ANALOG SOURCE HIGH |
| D | NC |
| E | ANALOG SOURCE LOW |
| F | ANALOG SENSE LOW |

J2 MATES WITH CINCH P.N. 251-06-30-160 (SUPPLIED).

*Mounting Card Connector Designations*

## DEGLITCHER IV

The Deglitcher IV is a precision high-speed, high-isolation sample-and-hold circuit which eliminates the glitches that occur whenever a DAC is dithered through a major carry. Such momentary transients can be of concern in applications such as high-resolution CRT beam positioning, where glitch-free code transitions are often required for optimum display quality and legibility. Oscilloscope photographs in Figures 7a and 7b below show the output of a DAC1136 being dithered up and down through the major carry, between codes 1000000000000000 and 0111111111111111. In Figure 7b, the Deglitcher IV is turned on virtually elminating the glitches and allowing the 152μV LSB step to be clearly seen.

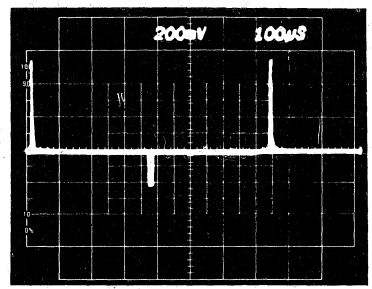



*Figure 7a. DAC1136; Major-Carry Dither without Deglitcher IV (BW = 1MHz), Vertical Scale 0.2V/Division*

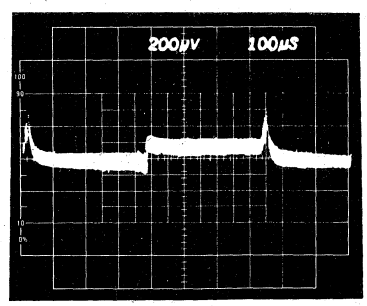



*Figure 7b. Same Major-Carry Dither with Deglitcher IV (BW = 1MHz), Vertical Scale, 200μV/Division*

The Deglitcher IV utilizes a proprietary sampling technique which isolates the output amplifier during the critical 10μs period immediately following a code change. The only discernible difference in DAC performance when used with Deglitcher IV is a delay of approximately 11μs after the strobe goes HI before the (deglitched) DAC output voltage starts slewing toward the new value.

## GLITCH ADJUSTMENT

There are two "Glitch" adjustment potentiometers, accessible on the Card-Mounted Assembly. The adjustment on the card permits nulling of any Track-to-Hold offset, whereas the adjustment internal to the Deglitcher IV allows for precise nulling of the Hold-to-Track transient. Because of the near-infinite attenuation of the actual DAC current glitches, no current-glitch transient is visible on the output. For this reason, it is easiest to null the 2 Deglitcher adjustments while strobing the Card with a static digital input.

## INPUT OPTIONS

The Card-Mounted Assembly contains input registers. The input code ordered by the user is set at the factory by means of various jumpers in the logic circuitry. See ordering guide for details.

Since the Card-Mounted Assembly contains input registers, the card requires a strobe pulse circuit. Strobe characteristics of input registers are:

1. ⌐¯¯¯

# Low Cost/High Accuracy 18-Bit D/A Converter

# DAC1146

**FEATURES**
**Integral Nonlinearity: ±0.00076% FSR max**
**Differential Nonlinearity: ±0.00076% FSR max**
**Low Differential Nonlinearity T.C.: ±1ppm/°C max**
**Wide Power Supply Operation: ±11.5V to ±16V**
**Fast Settling: 6μs to ±0.00076% FSR**
**Small Size 2″ × 2″ × 0.4″**

**APPLICATIONS**
**Automatic Test Equipment**
**Digital Audio**
**Sonar**
**Robotics**
**Nuclear Instrumentation**




## GENERAL DESCRIPTION

The DAC1146 is a low cost, 18-bit resolution (1 part in 262,144), digital-to-analog converter that provides high accuracy, high stability and is contained in a 2″ × 2″ × 0.4″ module.

Integral and differential nonlinearity are both guaranteed at ±0.00076% FSR maximum. Additional guaranteed performance features include: differential nonlinearity T.C. ±1ppm/°C maximum, offset T.C. ±30μV/°C maximum, gain T.C. ±12ppm/°C maximum, bipolar offset T.C. ±7ppm/°C maximum.

The DAC1146 makes use of CMOS integrated circuits, thin-film resistor technology and proprietary CMOS current-steering switches to obtain high resolution, high reliability and small size. The calculated MTBF for the DAC1146 is 275,445 hours, per Mil Handbook 217C.

The DAC1146 can operate with power supplies ranging from ±11.5V to ±16.0V. An internal precision reference is provided, an external reference can be used. The external reference voltage input range is −12V to +12V. The analog output ranges include: +5V, +10V, ±5V, ±10V, −2mA and ±1mA, and are selectable via pin programming (see Figure 1). Digital input coding for unipolar operation is true binary, bipolar input coding is offset binary or 2's complement.

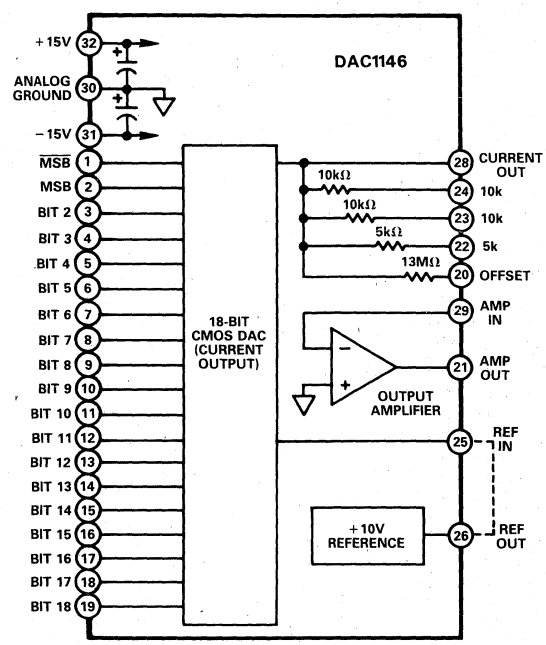



*Figure 1. DAC1146 Functional Block Diagram*

10

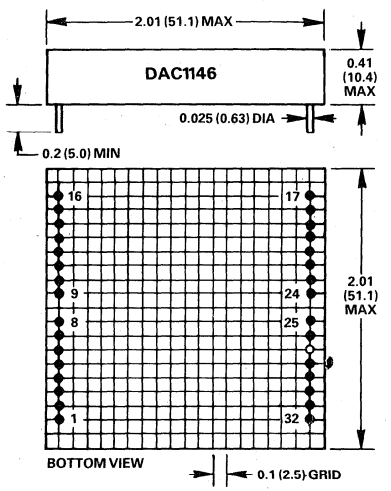
# SPECIFICATIONS (typical @ +25°C, $V_S$ = ±15V, $V_{REF}$ = +10V unless otherwise specified)

| MODEL | DAC1146 |
|---|---|
| RESOLUTION | 18 Bits |
| ACCURACY | |
| Integral Nonlinearity | ±0.00076% FSR[1](max) |
| Differential Nonlinearity | ±0.00076% FSR[1](max) |
| Monotonic (16 Bits) | Guaranteed |
| Offset[2] | Adjustable to Zero |
| Gain[2] | Adjustable to Full Scale |
| STABILITY | |
| Differential Nonlinearity | ±1ppm/°C (max) |
| Offset | ±30μV/°C (max) |
| Bipolar Offset | ±7ppm/°C (max) |
| Gain | ±12ppm/°C (max) |
| STABILITY, Long Term (ppm/1000 hr) | |
| Differential Nonlinearity | ±1ppm |
| Offset | ±3ppm |
| Bipolar Offset | ±3ppm |
| Gain | ±12ppm |
| REFERENCE VOLTAGE ($V_{REF}$) | |
| Output Voltage | +10.00V ±0.3% (max) |
| Output Current | 2mA (max) |
| Ext. Ref Voltage Range[3] | −12V to +12V |
| Input Resistance | 12kΩ |
| DYNAMIC PERFORMANCE[4] | |
| Settling Time to ±0.00076% | |
| Voltage, Full Scale Step | |
| Unipolar (10V) | 6μs |
| Bipolar (±10V) | 12μs |
| Voltage, LSB Step | 3μs |
| Current | 2μs |
| DIGITAL INPUTS | CMOS, TTL Compatible |
| Codes | |
| Unipolar | Binary (BIN) |
| Bipolar | Offset Binary (OBIN), Two's Complement |
| ANALOG OUTPUT | |
| Voltage | +5V, +10V, ±5V, ±10V |
| Current | −2mA, ±1mA |
| Voltage Compliance | +500mV |
| Noise (100kHz B.W.) | 30μV rms |
| POWER REQUIREMENTS | |
| Voltage (Rated Performance) | ±15V (±5%) |
| Voltage (Operating) | ±11.5V to ±16.0V |
| Supply Current Drain | |
| ±15V | +15mA, −25mA |
| Total Power @ $V_S$ = ±15V | 600mW |
| POWER SUPPLY SENSITIVITY | |
| Offset | 0.001%/% $V_S$ |
| Gain | 0.001%/% $V_S$ |
| TEMPERATURE RANGE | |
| Rated Performance | 0 to +70°C |
| Operating | −25°C to +85°C |
| Relative Humidity | Meets MIL STD 202E, Method 103B |
| SIZE | 2" × 2" × 0.4" (50.8 × 50.8 × 10.16mm) |
| Weight | 33g |

NOTES
[1]FSR means Full Scale Range.
[2]Offset and gain are adjustable to zero by means of external potentiometers. See Figure 2 for proper connections.
[3]Rated performance is specified with +10.0V reference.
[4]See Figure 5 for settling time curves.
Recommended Power Supply: Analog Devices Model 904.
Specifications subject to change without notice.

## OUTLINE DIMENSIONS

Dimensions shown in inches and (mm).




TERMINAL PINS INSTALLED ONLY IN SHADED HOLE LOCATIONS

## MATING CONNECTORS

**AC1584-3 (2 REQUIRED)**

## PIN DESIGNATIONS

| PIN | FUNCTION | PIN | FUNCTION |
|---|---|---|---|
| 1 | $\overline{\text{MSB}}$ | 32 | +15V |
| 2 | MSB | 31 | −15V |
| 3 | BIT 2 | 30 | ANALOG GROUND |
| 4 | BIT 3 | 29 | AMP IN |
| 5 | BIT 4 | 28 | CURRENT OUT |
| 6 | BIT 5 | 27 | N.C. |
| 7 | BIT 6 | 26 | REFERENCE OUT |
| 8 | BIT 7 | 25 | REFERENCE IN |
| 9 | BIT 8 | 24 | 10k |
| 10 | BIT 9 | 23 | 10k |
| 11 | BIT 10 | 22 | 5k |
| 12 | BIT 11 | 21 | AMP OUT |
| 13 | BIT 12 | 20 | OFFSET |
| 14 | BIT 13 | 19 | BIT 18 (LSB) |
| 15 | BIT 14 | 18 | BIT 17 |
| 16 | BIT 15 | 17 | BIT 16 |

## ANALOG OUTPUT RANGE

In the unipolar mode the DAC1146 provides an output current of −2mA. In the bipolar mode the DAC output current is offset by 1mA, (by connecting pin 25 to pin 24) for an output of ±1mA.

The DAC can be pin programmed for +5V, +10V, ±5V and ±10V by converting the DAC's current output to a voltage. To program the DAC for voltage output ranges (see Figure 1, Figure 2 and Table I).

| Output Voltage Range | Input Code[1] | Connect Pin[2] 25 to Pin | Connect Pin 28 to Pin | Connect Pin 21 to Pin(s) |
|---|---|---|---|---|
| +5V | BIN | | 29 | 22, 23, 24 |
| +10V | BIN | | 29 | 23, 24 |
| ±5V | OBIN, 2's Comp | 24 | 29 | 22 |
| ±10V | OBIN, 2's Comp | 24 | 29 | 23 |

[1]For BIN or OBIN codes connect $\overline{MSB}$ to ground.
For 2's comp code connect MSB to +5V system power.
[2]Connect Pin 25 through a 50Ω potentiometer to either internal reference (Pin 26) or an external reference.

*Table I. Analog Output Range Pin Programming*

## OFFSET AND GAIN CALIBRATION

Initial offset and gain errors can be adjusted to zero by potentiometers as shown in Figure 2. Proper offset and gain calibration requires great care and the use of extremely sensitive and accurate measurement instruments. These instruments should be capable of measuring to within 1μV of the adjusted output voltage at both ends of the range. The potentiometers selected should be good quality Cermet type. Multi-turn potentiometers having ten to fifteen turns and 100ppm/°C temperature coefficients will be adequate. The temperature coefficients contributed by these Cermet potentiometers will be less than 0.1ppm/°C.

For unipolar mode, apply a digital input code of all "0's" and adjust the offset potentiometer until a 0.00000V output is obtained (see Table II). Once the appropriate offset adjustment has been made, apply a digital input code of all "1's", and adjust the gain potentiometer until the plus full scale output is obtained (see Table II).

For bipolar mode, apply a digital input code of 100 . . . 00 and adjust the offset potentiometer until a 0.00000V output is obtained (see Table II). Once the appropriate offset adjustment has been made, apply a digital input of all "1's", and adjust the gain potentiometer until the proper plus full scale output is obtained.

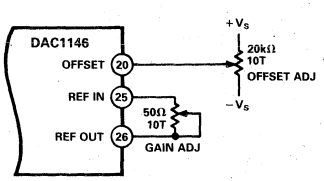



*Figure 2. Offset & Gain Calibration*

| | Code 000 . . . 00 | Code 111 . . . 11 |
|---|---|---|
| Unipolar | | |
| +5V | 0.00000V | +4.999981V |
| +10V | 0.00000V | +9.999962V |
| | **Code 100 . . . 00** | **Code 111 . . . 11** |
| Bipolar | | |
| ±5V | 0.00000V | +4.999962V |
| ±10V | 0.00000V | +9.999924V |

*Table II. Full Scale Calibrated Output Voltages*

## PRECISION LOW DRIFT VOLTAGE OUTPUT

The internal output amplifier of the DAC1146 is optimized for high speed applications like digital audio and sonar, that require fast settling time. An external precision operational amplifier like the AD OP-07 can be applied when low offset drift is important. Simply connect the current output (Pin 28) to the inverting input of the amplifier. This connection should be made as close as possible to the DAC. Connect the proper feedback resistors as shown in last two columns of Table I. To avoid decreasing the gain drift performance of the DAC always use the internal feedback resistors, since they are matched to the internal current weighting resistors of the DAC (see Figure 3).

The current drift of the DAC1146 is typically 350pA/°C from +15°C to +35°C. When using the AD OP-07, the total drift of the output signal will be less than 2μV/°C.

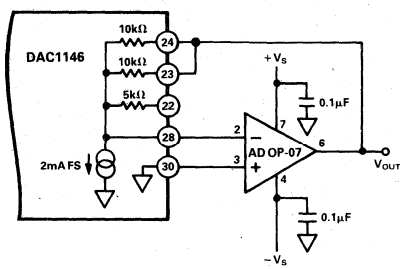



*Figure 3. Low Drift Voltage Output (+10V) Application*

## DIFFERENTIAL LINEARITY ADJUSTMENT

Each DAC1146 has been factory calibrated and tested to achieve the performance indicated in the electrical specifications. Before attempting recalibration, it is imperative that the circuit be checked to confirm that all precautions have been taken to insure proper application. The DAC is trimmed by comparing a bit to the sum of all lower bits, and adjusted if necessary, for a one LSB positive difference. The top four bits can be trimmed using the procedure outlined on next page. A differential voltmeter capable of 100μV full scale should be connected to amp out of the DAC. A Fluke 895A or equivalent is recommended (see Figure 4).

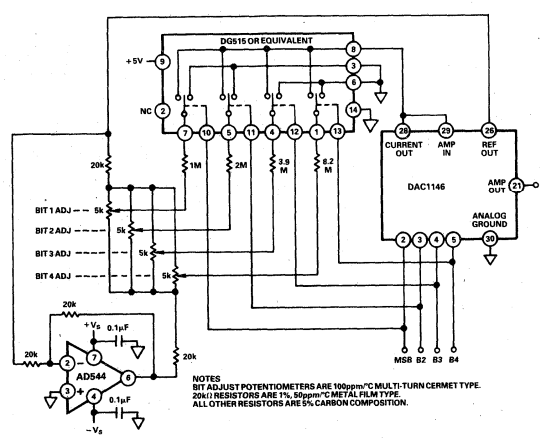



*Figure 4. Optional Differential Linearity Adjustment Circuit*

1. Start with Bit 4, proceed to Bits 3, 2 and 1 by repeating steps 2 through 5. Set Bits 17 and 18 to "0" for this entire rocedure.
2. Set all digital inputs less significant than the bit being adjusted to "1"; set all others to "0".
3. Read the output voltage by nulling the voltmeter.
4. Set the digital input for the bit being adjusted to "1", set all others to "0".
5. Read the output voltage by nulling the voltmeter. This reading should be equal to that of Step 3 plus 153μV (10V FSR). If not, adjust the bit.
6. Retrim gain.

## DIGITAL AUDIO APPLICATION

When using a DAC to reconstruct an audio signal, emphasis is placed on important audio parameters. These parameters include: Total Harmonic Distortion, Dynamic Range and Settling Time.

**Settling Time:** Settling time is the total time for the output to settle within an error band around its final value after a change in the input. Settling times for the DAC1146 are specified to ±0.00076% of full-scale for any step change (see Figure 5).

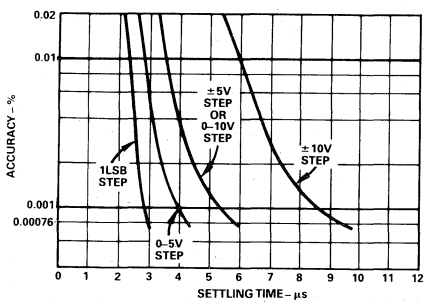



*Figure 5. Voltage Settling Time vs Accuracy*

**Dynamic Range:** The DAC1146 has a typical dynamic range of 96dB for a 16-bit input and 100dB for an 18-bit input. The theoretical dynamic range can be expressed as 6dB X N, where N is the number of bits. The theoretical limit would indicate a dynamic range of 108dB for an 18-bit input, however linearity, noise and other errors limit the useful dynamic range to 100dB at 18 bits.

**Total Harmonic Distortion:** When the DAC1146 is used at 16 bits of resolution with a deglitcher as shown in Figure 6, the Total Harmonic Distortion (THD) for a full scale signal over the entire audio range 20Hz to 20kHz is typically less than 0.002% or −94dB.

Total Harmonic Distortion is defined as the ratio of the square root of the sum of the squares of the rms harmonic value to the rms fundamental values and is expressed in percent dB.

The THD can be calculated from the following formula and verified by testing (see Figure 6).

$$\text{THD} = \frac{\text{RMS Error}}{\text{RMS Signal}} = \frac{\sqrt{\frac{1}{N}\sum_{i=1}^{N}\left[E_L(i) + E_Q(i)\right]^2}}{\text{RMS Signal}} \times 100\%$$

where N is the number of samples.
$E_L(i)$ is the linearity error of the DAC at each sample point.
$E_Q(i)$ is the quantization error of the DAC at each sample point.

## THD TESTING

When testing for THD the test equipment used must be distortion free so as not to mask the true performance of the device under test. The test circuit (see Figure 6) will produce a negligible amount of distortion when generating a test signal.

The PROM contains one cycle of a computer generated sine wave. Frequency select switches program the adder with the number of codes that it should skip on each count. This selection allows any of 2048 discrete frequencies between 12Hz and 25kHz to be generated with a constant 50kHz update rate. The DAC output is deglitched, and displayed on the spectrum analyzer. Total Harmonic Distortion can be computed by comparing the amplitude of the fundamental frequency with the amplitudes of the harmonics.

## TYPICAL THD TEST RESULTS

| Dynamic Range | 16-Bit Resolution | 18-Bit Resolution |
|---|---|---|
| Dynamic Range | 96dB | 100dB |
| THD at FS | 0.002% (−94dB) | 0.0015% (−96dB) |
| THD at −15dB | 0.01% (−80dB) | 0.0075% (−82dB) |
| THD at −20dB | 0.02% (−74dB) | 0.015% (−76dB) |
| THD at −30dB | 0.06% (−64dB) | 0.045% (−67dB) |

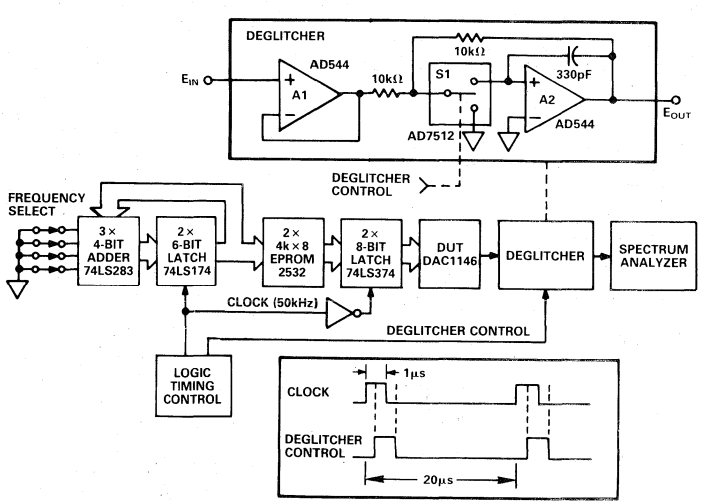


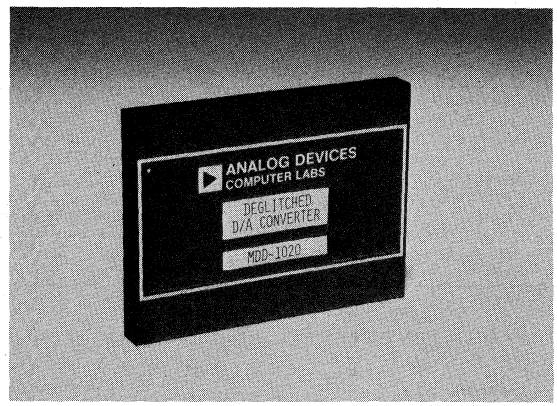

*Figure 6. Block Diagram Harmonic Distortion Test Circuit*

# Ultra High Speed Deglitched D/A Converter

# MDD SERIES

**FEATURES**
**Ultra-High Speed: 20MHz Word Rate**
**8- and 10-Bit Versions Available**
**TTL Compatible**
**Smallest Size Available: 3″ X 4″ X 0.5″**
**Completely Self-Contained with Input Register, D/A, Deglitcher, Timing, Internal References, and Output Buffering**

**APPLICATIONS**
**Color-Television Video Reconstruction, Time-Base Correction and Frame Synchronization**
**Graphic Displays**
**Deflection Systems**
**Character Generators**
**High Speed D/A Systems**




## GENERAL DESCRIPTION

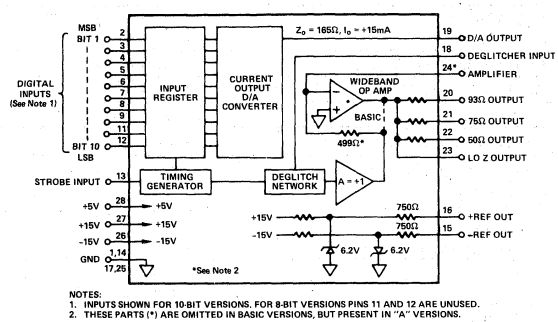
The MDD Series is a subsystem module which contains an input digital register, ultra-high speed current output D/A converter, deglitcher, output buffer amplifier, precision references, and timing circuitry within a 3″X4″X0.5″ case. The output of the device is an ultra-linear analog representation of the digital input. Requiring only external gain and offset potentiometers for final calibration, the MDD D/A solves the glitch problem associated with high-speed D/A converters. The incorporation of an internal register virtually eliminates the need for input bit time deskewing. While not totally eliminating the glitch per se, the remnant glitch is very small, and more importantly, constant (and therefore filterable) over the output range.

The MDD Series is available with 8- or 10-bit resolution and in two versions. The basic versions contain a unity gain output buffer and can deliver 2V p-p open circuit (or 1V p-p into a load) when the MDD output is both source and load terminated. The "A" versions contain a very high speed output gain amplifier to allow the MDD to deliver 4V p-p open circuit (or 2V p-p into a load) when the device is source and load terminated. Higher output voltages may be obtained—up to ±10V by external feedback resistor selection. However, settling time degradation must be expected.

## TV APPLICATION

The "A" version of the MDD Series deglitched D/A is ideally suited for color television video reconstruction. Its output can directly drive the low impedances normally associated with video baseband transmission. Since the output impedance of the internal operational amplifier is less than 1Ω, the transmission-line match obtained with the internal source terminating resistor is almost perfect. Other applications include waveform generation, automatic test equipment, and fast process control systems.

Designed primarily for PC board mounting, these D/A's may also be plugged into pin sockets. The pins are 0.04″ diameter, gold plated, and are on 0.2″ centers. For increased reliability, each module is burned in for 96 hours at +25°C before final test and shipment.




NOTES:
1. INPUTS SHOWN FOR 10-BIT VERSIONS. FOR 8-BIT VERSIONS PINS 11 AND 12 ARE UNUSED.
2. THESE PARTS (*) ARE OMITTED IN BASIC VERSIONS, BUT PRESENT IN "A" VERSIONS.

*MDD Series Block Diagram*

# SPECIFICATIONS (typical at +25°C and nominal supply voltages unless otherwise noted)

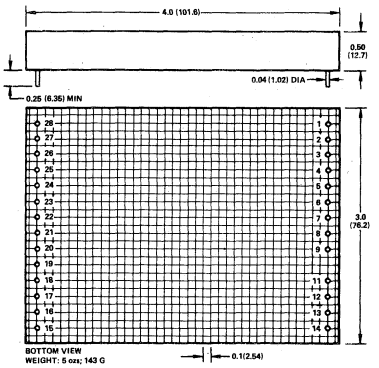
| MODEL | MDD-0820<br>MDD-0820A | MDD-1020<br>MDD-1020A |
|---|---|---|
| RESOLUTION | 8 Bits | 10 Bits |
| Accuracy (including linearity) at Maximum Word Rate of 20MHz | ±0.2% | ±0.05% |
| Monotonicity | Guaranteed 0 to +70°C | |
| **DIGITAL DATA BIT INPUTS** | | |
| Logic Level/Load | 1 Standard "S" TTL Load | |
| Positive Logic—Binary (BIN) | "1" = +2.4V to +5V<br>"0" = 0V to +0.4V | |
| **DIGITAL STROBE INPUT** | | |
| Logic Level/Load | 2 Standard "S" TTL Loads | |
| Positive Logic | "1" = +2.4V to +5V<br>"0" = 0V to +0.4V | |
| Risetime and Falltime | 10ns max | |
| Width | 15ns min | |
| Timing | Negative-Going Trailing Edge to Occur a Minimum of 20ns After Last Data Bit Change | |
| Frequency | 20MHz max | |
| **OUTPUT** | **MDD-0820<br>MDD-1020** | **MDD-0820A<br>MDD-1020A** |
| Voltage, No Load, Unipolar | 0 to +2V | Externally Programmable with Gain and Offset Resistors to ±10V max |
| Bipolar | +1V to −1V | |
| Impedance | | |
| Pin 23, Low Z | 10Ω max | 1Ω max |
| Pin 22, 50Ω | 50Ω ±5% | 50Ω ±1% |
| Pin 21, 75Ω | 75Ω ±5% | 75Ω ±1% |
| Pin 20, 93Ω | 93Ω ±5% | 93Ω ±1% |
| Amplifier Current | ±50mA for dc load = 100Ω min, dc load = $Z_{OUT} + R_{LOAD}$ | |
| DAC Current | +15mA | |
| **SETTLING TIME** | | |
| DAC Current Output (to 0.1%) | 15ns | |
| Voltage Output | 50ns to 0.1%<br>2V p-p | 120ns to 0.1%<br>4V p-p |
| **RESIDUAL GLITCH**[1] | 30mV for 2V p-p F.S. Output or 1.5% of F.S. | |
| **PEDESTAL** | 10mV for 2V p-p F.S. Output or 0.5% of F.S. | |
| **OUTPUT ZERO OFFSET** | Adjustable to Zero | |
| **OUTPUT ZERO OFFSET vs. TEMP** | 100ppm/°C | |
| **GAIN** | Adjustable | |
| **REFERENCES AVAILABLE** | ±6.2V | |
| **POWER REQUIREMENTS** | | |
| +15V ±3% | 120mA | |
| −15V ±3% | 150mA | |
| +5V ±5% | 250mA | |
| Power Supply Rejection Ratio | 0.1%/V | |
| **CASE** | Diallyl Phthalate (per MIL-M-14 type SDG-F) | |
| **TEMPERATURE RANGE** | | |
| Operating | 0 to +70°C | |
| Storage | −55°C to +85°C | |

NOTES
[1] Occurs at the update rate.

**Specifications subject to change without notice.**

## OUTLINE DIMENSIONS

Dimensions shown in inches and (mm).




PINS ARE GOLD PLATED PER MIL-G-6204 TYPE II
DOT ON TOP INDICATES POSITION OF PIN 1.

## PIN DESIGNATIONS

| PIN | FUNCTION | PIN | FUNCTION |
|---|---|---|---|
| 1 | GROUND* | 15 | -REF OUT |
| 2 | BIT 1 INPUT (MSB) | 16 | +REF OUT |
| 3 | BIT 2 INPUT | 17 | GROUND* |
| 4 | BIT 3 INPUT | 18 | DEGLITCHER INPUT |
| 5 | BIT 4 INPUT | 19 | D/A OUTPUT |
| 6 | BIT 5 INPUT | 20 | 93Ω OUTPUT |
| 7 | BIT 6 INPUT | 21 | 75Ω OUTPUT |
| 8 | BIT 7 INPUT | 22 | 50Ω OUTPUT |
| 9 | BIT 8 INPUT | 23 | LO Z OUTPUT |
| 10 | NC | 24 | AMP FEEDBACK |
| 11 | BIT 9 INPUT | 25 | GROUND* |
| 12 | BIT 10 INPUT (LSB) | 26 | -15V POWER INPUT |
| 13 | STROBE INPUT | 27 | +15V POWER INPUT |
| 14 | GROUND* | 28 | +5V POWER INPUT |

*ALL GROUNDS INTERNALLY CORRECTED

## NOTES ON "DEGLITCHING"

An MDD Series D/A converter operating with a full-scale p-p analog output of 1V will typically have a glitch, or transient, in its output which is 15mV in amplitude and is 25ns wide, at the 50% points. These typical values are independent of whether the D/A converter is an 8-bit unit or a 10-bit unit.

This glitch remains constant, regardless of the transition points. In other words, it is the same for the transition from 0000000001 to 1000000000 as it is for the transition from 1000000000 to 1000000001 or any other two input words.

A constant glitch is the purpose of the deglitcher circuits. They are intended to hold the area under the curve at a constant value; they are not intended to get rid of all glitches per se.

When the area under the transient curve is held constant, the frequency spectrum of the glitch is a fine line; i.e., a single-line spectrum at the sample rate frequency, and harmonics of the sample frequency.

If the glitch is a function of signal dynamics, as it is in the case of a D/A converter output which is not deglitched, a multitude of intermodulation products are formed. Some of these IM products appear in the video pass-band as spurious signals and increased noise level. The deglitcher circuits effectively eliminate these products. When they do, the S/N ratio approaches that of an ideally-quantized signal, where the rms noise is $Q/\sqrt{12}$, when frequencies above Nyquist are filtered out.

In summary then:

- The residual glitch for an MDD Series D/A converter is typically 15mV for a full-scale 1V p-p output; this is 1.5% of F.S.
- The glitch width is typically 25ns at the 50% points.
- The amplitude and width of the glitch are constant, and independent of:
  - –the magnitude of change in successive transitions
  - –number of bits of digital output
  - –input (update) data rates

D/A converters without deglitching circuits have smaller, shorter glitches, on the average; but this type of converter has larger glitches at the major crossings, especially at the mid-scale transition.

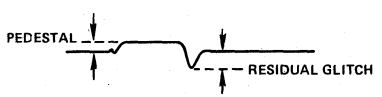



*Figure 1. Pedestal/Glitch Relationship*

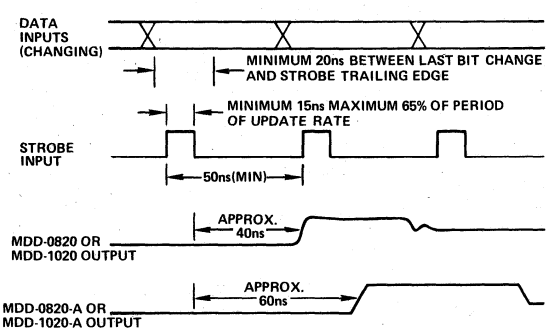



*Figure 2. MDD Series Timing Diagram*

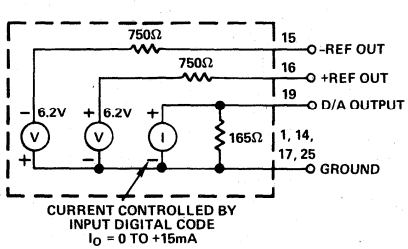



*Figure 3. D/A Current Equivalent Circuit*

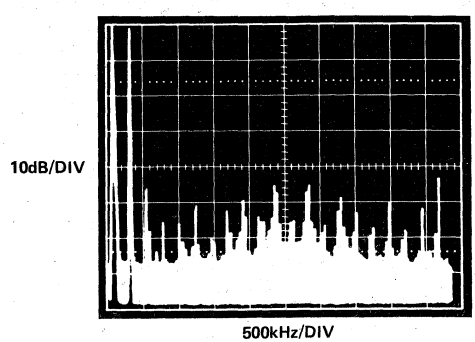



*Figure 4. Spectrum of 10-bit D/A Operating at 11MHz Update Rate Without Deglitching – Unfiltered*

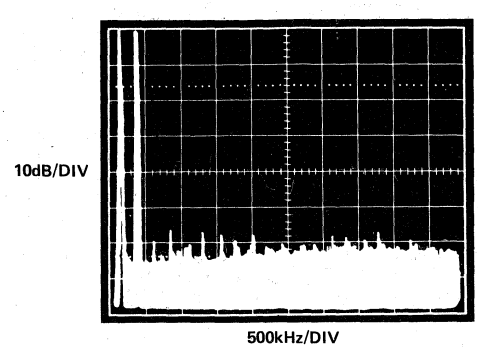



*Figure 5. Spectrum of 10-bit D/A Operating at 11MHz Update Rate With Deglitching – Unfiltered*

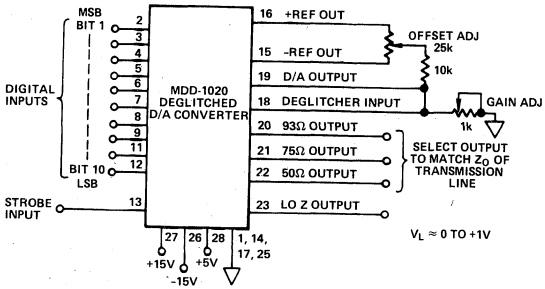



*Figure 6. Unipolar Output Configuration Basic Versions*

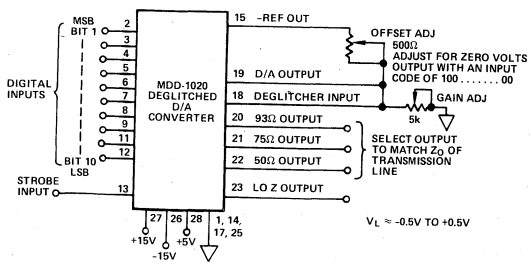
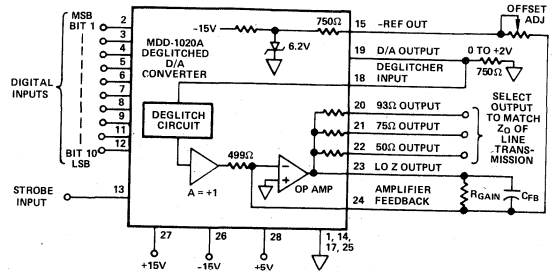



*Figure 7. Bipolar Output Configuration Basic Versions*




NOTES:
1. SELECT $R_{GAIN}$ TO GIVE DESIRED OPEN CIRCUIT OUTPUT VOLTAGE. THE INPUT VOLTAGE TO THE OP AMP IS APPROXIMATELY 0 TO +2V. THE OUTPUT OF THE OP AMP IS THEREFORE ((2 × $R_{GAIN}$)/500Ω) VOLTS p-p.
2. THE LOGIC IS INVERTED INTERNALLY FOR THE "A" VERSIONS SUCH THAT ALL "1'S" AT THE DIGITAL INPUTS YIELDS A FULL-SCALE POSITIVE VOLTAGE AT THE OP AMP OUTPUT.
3. FOR POSITIVE UNIPOLAR OPERATION, THE NOMINAL OFFSET POTENTIOMETER RESISTANCE SHOULD BE SET FOR A VALUE OF APPROXIMATELY 800Ω, MAKING A 2000Ω POTENTIOMETER IDEAL.
4. FOR BIPOLAR OPERATION, THE NOMINAL OFFSET POTENTIOMETER RESISTANCE SHOULD BE SET FOR A VALUE OF APPROXIMATELY 2300Ω, MAKING A 5000Ω POTENTIOMETER IDEAL. THE OUTPUT VOLTAGE SHOULD BE ADJUSTED FOR ZERO WITH AN INPUT CODE OF 10 . . . . . 00.
5. MAKE $C_{FB}$ NOMINALLY 10pF. SELECT FOR OPTIMUM SETTLING TIME IF DESIRED.
6. IF ADJUSTABLE GAIN IS DESIRED, ADD A LOW-VALUE, LOW-INDUCTANCE CERMET TRIMMING POTENTIOMETER IN SERIES WITH $R_{GAIN}$. BY PUTTING THE GAIN ADJUSTMENT HERE, THE GAIN AND OFFSET ADJUSTMENTS ARE INDEPENDENT OF EACH OTHER.

*Figure 8. Output Configuration — "A" Versions*

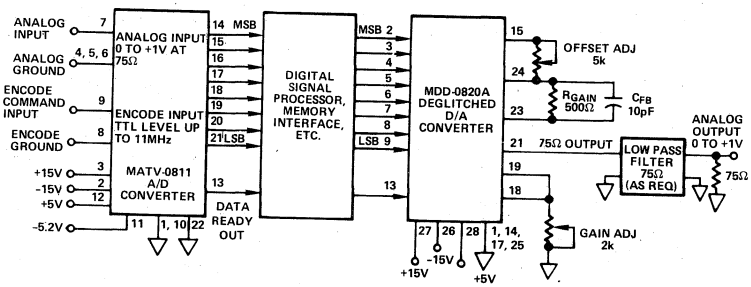



*Figure 9. Typical A/D-D/A Back-to-Back Connections for Video Applications or Testing*

The typical video differential phase and gain errors (disregarding quantization effects) for the configuration shown are 3° and 3%, respectively, using an encode command frequency of three times the NTSC color subcarrier (10.74MHz). For applications requiring digitization at frequencies of four times NTSC (14.32MHz) or three times PAL (13.29MHz) the MATV-0816 A/D Converter should be substituted. For applications requiring digitization at four times PAL (17.74MHz), the MATV-0820 A/D Converter should be substituted. Results are applicable for either NTSC or PAL test signals using the 20 IRE modulated ramp.

Due to the inherently stable characteristics of the output operational amplifier, the "A" versions are recommended for driving properly terminated video terminated lines.

## ORDERING INFORMATION

| | |
|---|---|
| For 8-Bit Models, Order: | MDD-0820 without output amplifier<br>MDD-0820A with output amplifier |
| For 10-Bit Models, Order: | MDD-1020 without output amplifier<br>MDD-1020A with output amplifier |

Mating pin socket connectors for the MDD Series is model MSB-2. Prototyping socket is MSD-1.

The MDD Series D/A's are normally burned-in at +25°C for a minimum of 96 hours. For extended burn-in, consult the factory. All of Analog Devices' data acquisition products are covered by a one-year warranty.

# ANALOG DEVICES

# Ultra High Speed Multiplying D/A Converter

## MDMS SERIES

**FEATURES**
**Small Size: 2″ X 2″ X 0.4″**
**High Multiplying Accuracy: Maintains Monotonicity and Linearity for any Analog Input within the Specified Range**
**High Current Output: 10mA Full Scale**
**High Reliability, Hybrid Microcircuit Construction**
**Guaranteed Operation: -30°C to +85°C**

**APPLICATIONS**
**CRT Displays**
**Waveform Generation**
**Vector Generation**
**Fast Digital Attenuator**




### GENERAL DESCRIPTION

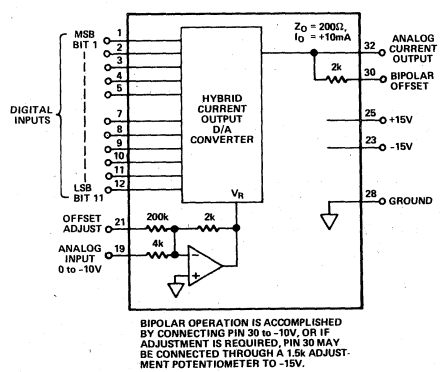
The MDMS series is an ultra-high speed, one or two-quadrant, multiplying D/A converter capable of 10MHz operation and 11-bit precision. The settling time for both analog and digital inputs is 100ns, and the large signal bandwidth of the analog input is in excess of 10MHz. The module is designed for the needs of the graphic display field and other applications requiring high-accuracy, high-speed multiplying operation.

The current output of the MDMS series D/A is precisely proportional to the analog input signal multiplied by the digital input code. The analog input signal may be any voltage between 0V and -10V, and can be a sine wave, triangle wave, sawtooth, or other waveform. The D/A output is an accurate scaled version of the input waveform, the scale factor being the digital input code. Alternatively, the analog input voltage may be used to scale a digitally generated signal. Various offsetting provisions are made so that the analog signal, digital signal, and output may be made bipolar or unipolar in order to accommodate various uses requiring one or two-quadrant operation.

The output impedance of the D/A is 200 ohms so that a two-volt output swing is possible with no load. Loading the output with 200 ohms results in a 1 volt p-p output. If an external operational amplifier such as the Analog Devices' HOS-050, HOS-050A, or HOS-060 op amp is connected to the output of the D/A, output voltages up to 20V p-p are obtainable at a small sacrifice in speed.

### ORDERING INFORMATION

Order Model Number MDMS-0801, MDMS-1001, or MDMS-1101. Ruggedized versions with extended burn-in are also available. Consult the factory.




*MDMS Series - Block Diagram*

10

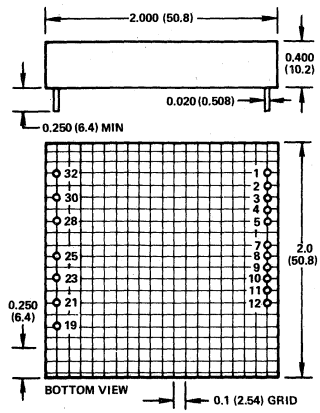
# SPECIFICATIONS (typical @ +25°C and nominal power supply voltages unless otherwise noted)

| MODEL | MDMS-0801 | MDMS-1001 | MDMS-1101 |
|---|---|---|---|
| RESOLUTION | 8 Bits | 10 Bits | 11 Bits |
| LSB Weight | 40µA | 10µA | 5µA |
| ACCURACY (ADJUSTABLE TO) | ±0.2% | ±0.05% | ±0.025% |
| Monotonicity | Guaranteed | * | * |
| Linearity | 20µA, ±1/2LSB | 5µA, ±1/2LSB | 2.5µA, ±1/2LSB |
| ANALOG INPUT | | | |
| Voltage Range | 0 to -10V | * | * |
| Impedance | 4kΩ ±2% | * | * |
| Transfer Function (inverting) | 0V input scales D/A output to minimum output; -10V input scales D/A output to maximum output. | | |
| DIGITAL INPUT (TTL) | | | |
| Positive Logic, "1" = | +2.4V to +5.0V | * | * |
| "0" = | 0V to 0.4V | * | * |
| Loading, 2 Std. TTL Loads | | | |
| "0" = | -5mA | * | * |
| "1" = | 50µA | * | * |
| CODING (PARALLEL INPUT DATA) | | | |
| Unipolar | BIN | * | * |
| Bipolar | OBN | * | * |
| All "1's" Input | Maximum Positive Output | | |
| All "0's" Input | Maximum Negative Output | | |
| OUTPUT (CURRENT) | | | |
| Unipolar | 0 to +10mA | * | * |
| Bipolar | ±5mA | * | * |
| Compliance Voltage | +1.5V, -2V | * | * |
| Impedance | 200Ω, ±1% | * | * |
| Loading | 200Ω for 0 to 1V p-p Out; 0Ω for 0 to 2V p-p Out | | |
| Zero Offset (max) | 50nA | * | * |
| DYNAMIC CHARACTERISTICS | | | |
| Settling Time (digital & analog) | 90ns to 0.2% F.S. | 100ns to 0.1% F.S. | 130ns to 0.05% F.S. |
| Bandwidth (analog in) | 10MHz | * | * |
| TEMPERATURE COEFFICIENTS | | | |
| Linearity | 2ppm/°C | * | * |
| Monotonicity | Guaranteed -30°C to +85°C | | |
| POWER REQUIREMENTS | | | |
| +15V ±10% | 60mA | * | * |
| -15V ±10% | 20mA | * | * |
| Power Supply Rejection Ratio | 0.005%/V | * | * |
| TEMPERATURE RANGE | | | |
| Operating | -30°C to +85°C | | |
| Storage | -55°C to +125°C | | |
| PHYSICAL CHARACTERISTICS | | | |
| Case | Diallyl Phthalate per MIL-M-14 Type SDG-F | | |

NOTES
*Specifications same as MDMS-0801
Specifications subject to change without notice.

## OUTLINE DIMENSIONS

Dimensions shown in inches and (mm).




NOTE: DOT ON TOP INDICATES POSITION OF PIN 1
WEIGHT: 1.6 OZ, 45.3 G
PINS ARE GOLD PLATED PER MIL-G-5204 TYPE II

## MATING SOCKET MSA-1

## PIN DESIGNATIONS

| PIN | FUNCTION |
|---|---|
| 1 | BIT 1 INPUT (MSB) |
| 2 | BIT 2 INPUT |
| 3 | BIT 3 INPUT |
| 4 | BIT 4 INPUT |
| 5 | BIT 5 INPUT |
| 7 | BIT 6 INPUT |
| 8 | BIT 7 INPUT |
| 9 | BIT 8 INPUT |
| 10 | BIT 9 INPUT |
| 11 | BIT 10 INPUT |
| 12 | BIT 11 INPUT LSB |
| 19 | ANALOG INPUT |
| 21 | OFFSET ADJ |
| 23 | -15V POWER INPUT |
| 25 | +15V POWER INPUT |
| 28 | GROUND |
| 30 | BIPOLAR OFFSET |
| 32 | ANALOG OUTPUT |

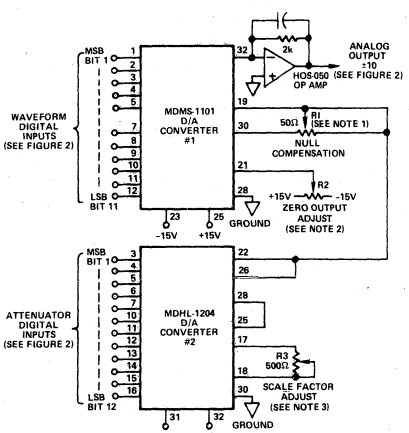
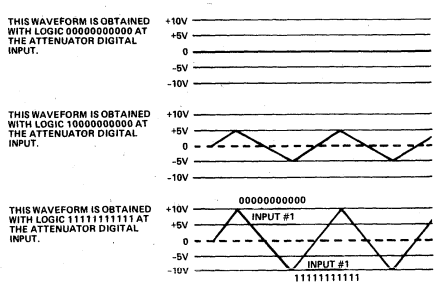



*Figure 1. The MDMS-1101 Multiplying D/A Used as a Digital Waveform Generator with Digital Attenuator Control*




NOTES
1. R1 MAY BE OMITTED IF 0.5% DC SHIFT IS PERMISSIBLE BETWEEN MINIMUM & MAXIMUM ATTENUATION.
2. ADJUST R2 FOR 0V OUTPUT WITH ATTENUATOR INPUT SET FOR 00000000000 AND WAVEFORM INPUT ACTIVE.
3. ADJUST R3 TO OBTAIN ±10V OUTPUT WITH ATTENUATOR INPUT SET FOR 11111111111 AND WAVEFORM INPUT ACTIVE.

THE ABOVE WAVEFORMS DEPICT THE ANALOG OUTPUT FOR VARIOUS VALUES OF ATTENUATOR DIGITAL INPUTS TO D/A #2 WITH A DIGITAL TRIANGLE BEING APPLIED TO THE WAVEFORM DIGITAL INPUT OF D/A #1.

PEAK POSITIVE LEVEL = 00000000000 DIGITAL INPUT
PEAK NEGATIVE LEVEL = 11111111111 DIGITAL INPUT
(THE OUTPUT OP AMP INVERTS THE SENSE OF THE INPUT BITS)

*Figure 2. Operation of Multiplying D/A Circuit*

# Analog-to-Digital Converters

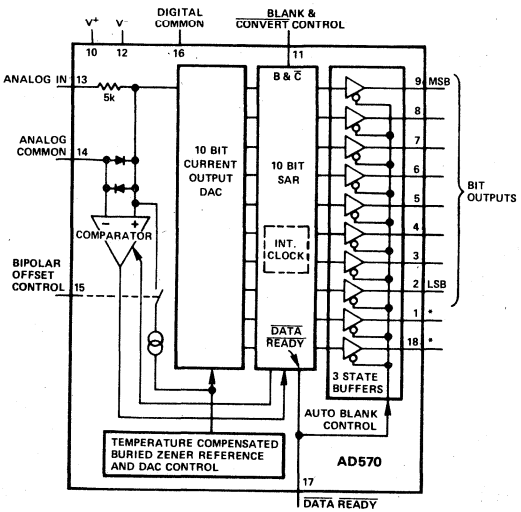
## Contents


| | Page |
|---|---|
| Selection Guides | |
| 8-Bit A/D Converters | 11-2 |
| 10-Bit A/D Converters | 11-5 |
| 12-Bit A/D Converters | 11-8 |
| High Resolution A/D Converters | 11-12 |
| Video A/D Converters | 11-15 |
| General Information | 11-20 |
| Specifications & Terms | 11-22 |
| ADC1130/ADC1131 14-Bit High-Speed ADC Modules | 11-27 |
| ADC1140 Low Cost 16-Bit Analog to Digital Converter | 11-31 |
| •ADC1143 Low Power/High Performance 16-Bit ADC | 11-35 |
| CAV-0920 9-Bit Video ADC | 11-39 |
| •CAV-1040 10-Bit Video ADC | 11-43 |
| CAV-1210 12-Bit Video ADC | 11-45 |
| MAH Ultra-High Speed 8- and 10-Bit ADC Modules | 11-49 |
| MAS Ultra-High-Speed 8-, 10-, and 12-Bit ADC Modules | 11-53 |
| MATV Video 8-Bit ADCs with Built-In Track-Hold | 11-57 |
| MOD-1005 10-Bit 5MHz Video ADC with Built-In Track-Hold | 11-61 |
| MOD-1020 10-Bit 20MHz Video ADC with Built-In Track-Hold | 11-65 |
| MOD-1205 12-Bit 5MHz Video ADC with Built-In Track-Hold | 11-69 |


•New product since publication of *1982-1983 Databook Update.*

# Selection Guide
## Analog-to-Digital Converters

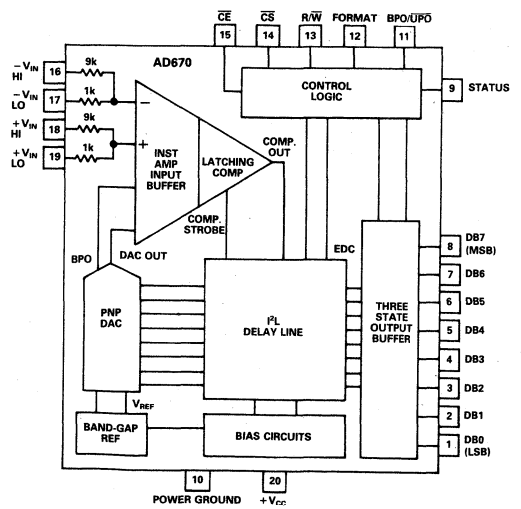
## 8-Bit A/D Converters




### AD570

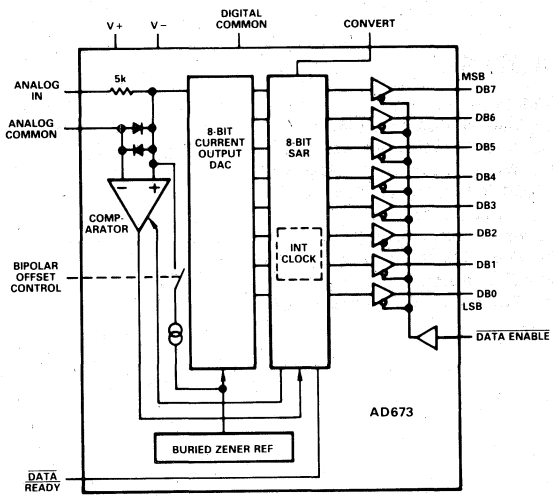
Page

Complete A/D Converter with Reference and Clock — Vol. I
Fast Successive Approximation Conversion – 25μs — 10–27
No Missing Codes Over Temperature
0 to +70°C – AD570J
−55°C to +125°C – AD570S
Digital Multiplexing – 3 State Outputs
18-Pin Ceramic DIP




### AD670

Complete 8-Bit A/D Converter — Vol. I
Fast Conversion Time: 10μs — 10–85
Full Microprocessor Bus Interface
Flexible Input Stage: Instrumentation Amp Front End Provides Differential Inputs and Good Common-Mode Rejection
No User Trims Required
No Missing Codes Over Temperature
Single +5V Supply Required
Convenient Input Ranges
Small 20-Pin Package

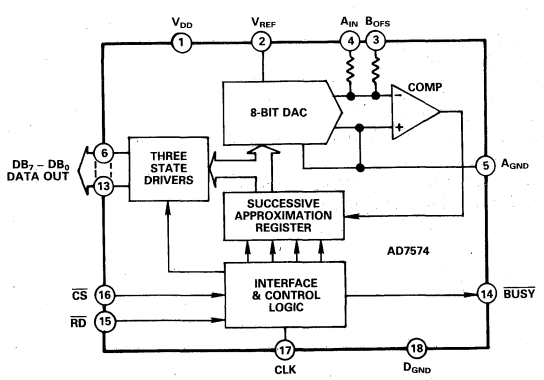



## AD673

Page

- Complete 8-Bit A/D Converter with Reference, Clock and Comparator Vol. I 10-95
- Full Microprocessor Bus Interface
- Fast Successive Approximation Conversion – 20μs
- No Missing Codes Over Temperature
- Operates on +5V and −12V to −15V Supplies

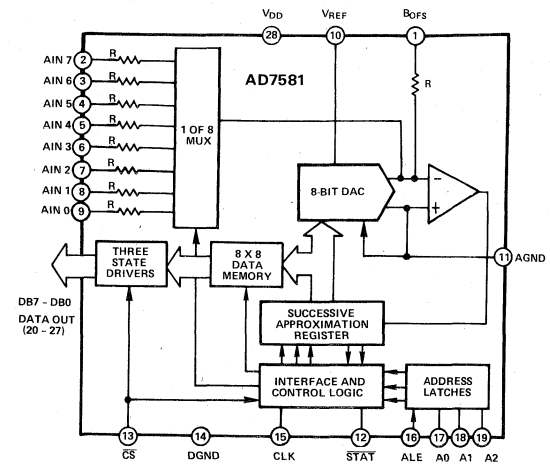





## AD7574

- No Missed Codes Over Full Temperature Range Vol. I 10-151
- Fast Conversion Time: 15μs
- Interfaces to μP like RAM, ROM or Slow Memory
- Low Power Dissipation: 30mW
- Ratiometric Capability
- Single +5V Supply

# Selection Guide
## Analog-to-Digital Converters
## 8-Bit A/D Converters

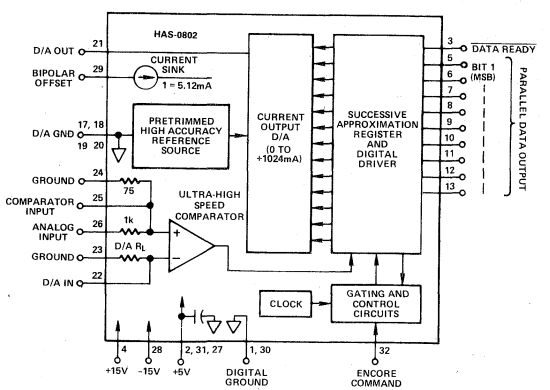



### AD7581

**Page**

Vol. I
10–159

**8-Bit Resolution**
**On-Chip 8 × 8 Dual-Port Memory**
**No Missed Codes Over Full Temperature Range**
**Interfaces Directly to Z80/8085/6800**
**CMOS, TTL Compatible Digital Inputs**
**Three-State Data Drivers**
**Ratiometric Capability**
**Interleaved DMA Operation**
**Fast Conversion**
**A/D Process Totally Transparent to µP**

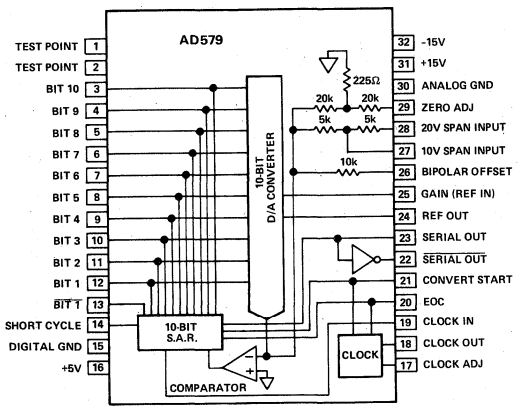



### HAS-0802

Vol. I
10–201

**Conversion Times as Low as 1.2µs**
**Resolution: 8 Bits**
**Exceptional Accuracy: 0.012% of F.S.**
**Low Power**
**Contained in Glass or Metal 32-Pin DIP**
**Adjustment-Free Operation**

# 10-Bit A/D Converters




## AD579

Page

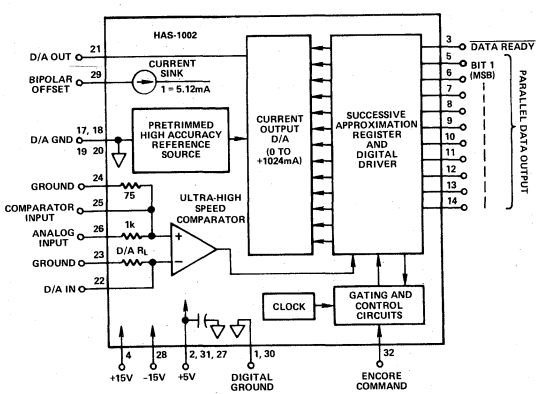
**Complete 10-Bit A/D Converter with Reference and Clock** — Vol. I 10–79

**Fast Successive Approximation Conversion: 1.8μs**

**Buried Zener Reference for Long Term Stability and Low Gain T.C.: ±40ppm/°C max**

**Max Nonlinearity: <±0.048%**

**Low Power: 775mW**




## HAS-1002

**Conversion Times as Low as 1.7μs** — Vol. I 10–201

**Resolution: 10 Bits**

**Exceptional Accuracy: 0.012% of F.S.**

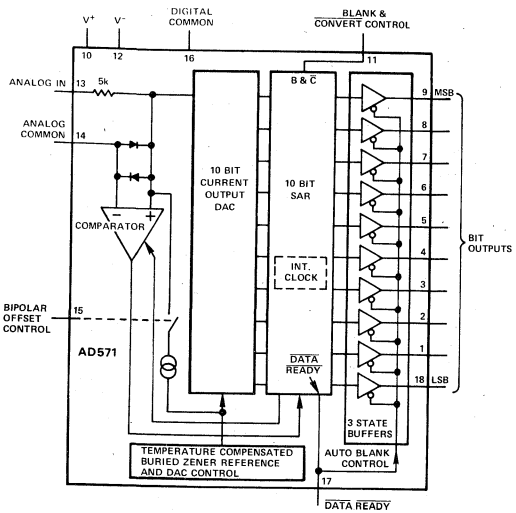
**Low Power**

**Contained in Glass or Metal 32-Pin DIP**

**Adjustment-Free Operation**

11

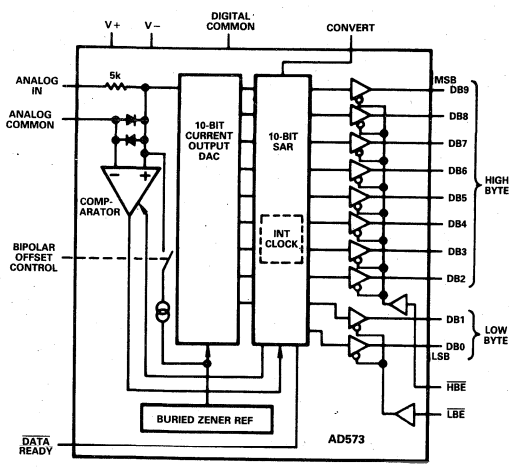
# Selection Guide
## Analog-to-Digital Converters
## 10-Bit A/D Converters




### AD571

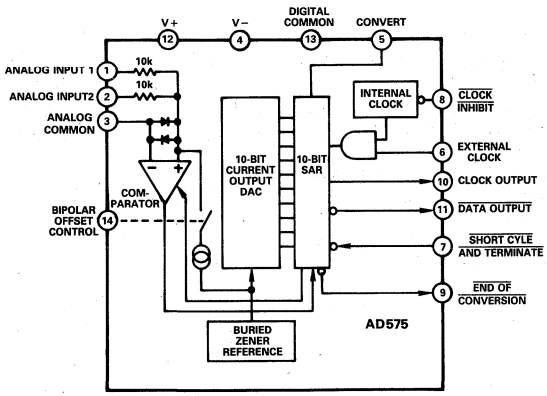
**Page**

**Complete A/D Converter with Reference and Clock** — Vol. I 10–31
**Fast Successive Approximation Conversion – 25μs**
**No Missing Codes Over Temperature**
**0 to +70°C – AD571K**
**−55°C to +125°C – AD571S**
**Digital Multiplexing – 3 State Outputs**
**18-Pin Ceramic DIP**
**Low Cost Monolithic Construction**




### AD573

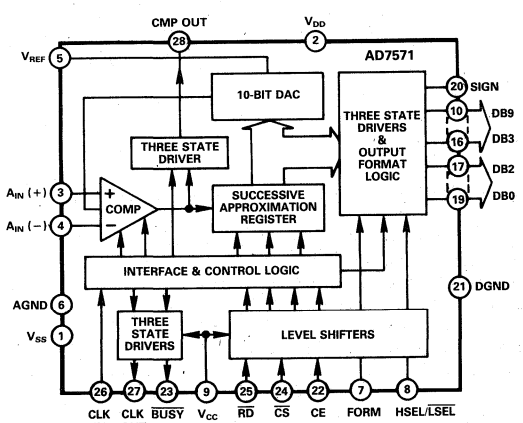
**Complete 10-Bit A/D Converter with Reference, Clock and Comparator** — Vol. I 10–47
**Full 8- or 16-Bit Microprocessor Bus Interface**
**Fast Successive Approximation Conversion – 15μs**
**No Missing Codes Over Temperature**
**Operates on +5V and −12V to −15V Supplies**




## AD575



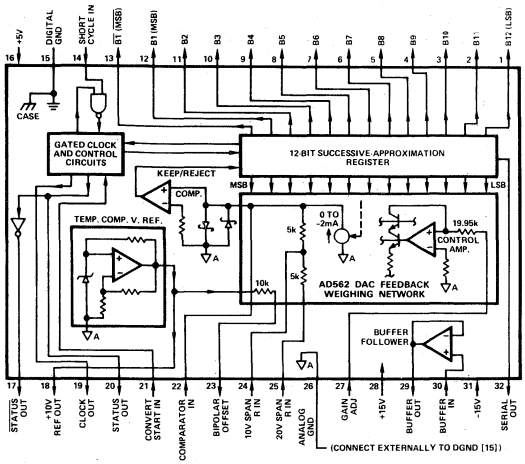
**Complete 10-Bit A/D Converter with Reference, Clock and Comparator** Vol. I 10–67
**Serial Output**
**Fast Successive Approximation Conversion – 20μs**
**No Missing Codes Over Temperature**
**Operates on +5V and −12V to −15V Supplies**
**Low Cost Monolithic Construction**
**Internal/External Clock Option**
**Triggered or Continuous Conversions**
**Automatic Shunt Cycle Option**




## AD7571

**10-Bit Plus Sign Resolution** Vol. I 10–139
**No Missed Codes Over Full Temperature Range**
**Conversion Time 80μs**
**Differential Analog Voltage Inputs, ±10V Range**
**Serial and Parallel Data Outputs**
**Easy Interface to Most Microprocessors**
**Internal Clock Oscillator**
**Single Supply Operation for Positive-Only Signals**
**Monolithic Construction**

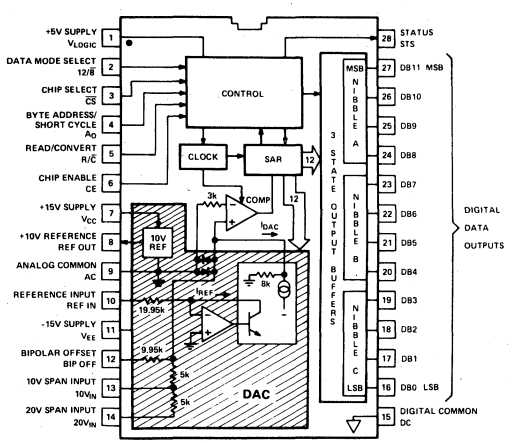
# Selection Guide
## Analog-to-Digital Converters
## 12-Bit A/D Converters




### AD572

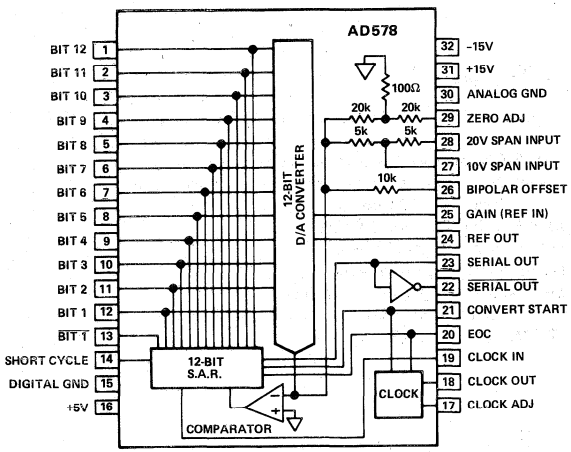
Page

**True 12-Bit Operation: Max Nonlinearity $< \pm 0.012\%$** Vol. I
**Low Gain T.C.: $< \pm 15$ppm/°C (AD572B)** 10-39
**Low Power: 900mW**
**Fast Conversion Time: $<25\mu s$**
**Monotonic Feedback DAC Guarantees No Missing Codes**




### AD574A

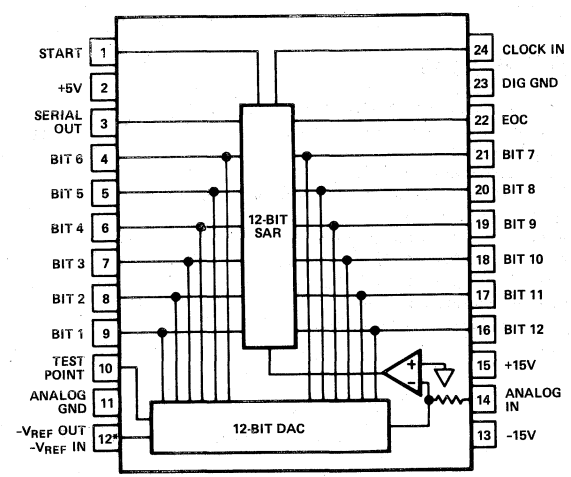
**Complete 12-Bit A/D Converter with Reference and Clock** Vol. I
**Full 8- or 16-Bit Microprocessor Bus Interface** 10-55
**250ns Bus Access Time**
**Guaranteed Linearity Over Temperature**
**0 to +70°C – AD574AJ, AK, AL**
**−55°C to +125°C – AD574AS, AT, AU**
**No Missing Codes Over Temperature**
**Fast Successive Approximation Conversion – $25\mu s$**
**Buried Zener Reference for Long-Term Stability and Low Gain T.C.**
**10ppm/°C max AD574AL**
**12.5ppm/°C max AD574AU**
**Low Profile 28-Pin Ceramic DIP**
**Low Power: 390mW**




# AD578

Page

- Complete 12-Bit A/D Converter with Reference and Clock — Vol. I 10-73
- Fast Conversion: 3μs (max)
- Buried Zener Reference for Long Term Stability and Low Gain T.C.: ±30ppm/°C max
- Max Nonlinearity: <±0.012%
- Low Power: 775mW
- Hermetic Package Available
- Positive-True Parallel or Serial Logic Outputs
- Short Cycle Capability
- Precision +10V Reference for External Applications
- Adjustable Internal Clock
- "Z" Models for ±12V Supplies

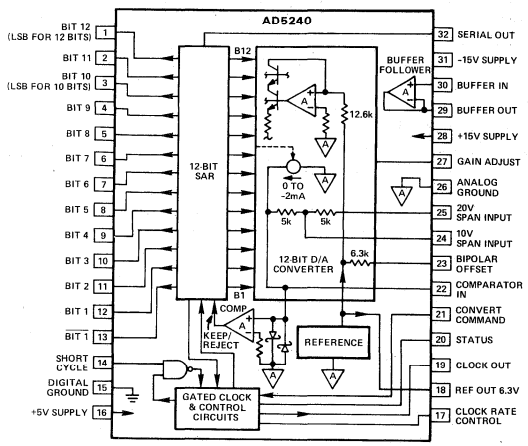



# AD5200 SERIES

- AD5200: 50μs Conversion Time — Vol. I 10-105
- AD5210: 13μs Conversion Time
- True 12-Bit Operation: ±1/2LSB max Nonlinearity
- Totally Adjustment-Free
- Guaranteed No Missing Codes Over the Specified Temperature Range
- Hermetically-Sealed Package
- Standard Temperature Range: −25°C to +85°C
- Extended Temperature Range: −55°C to +125°C
- Serial and Parallel Outputs
- Monolithic DAC with Scaling Resistors for Stability
- Low Chip Count for High Reliability
- Industry Standard Pin Out
- Small 24-Pin DIP

11

# Selection Guide
## Analog-to-Digital Converters
## 12-Bit A/D Converters

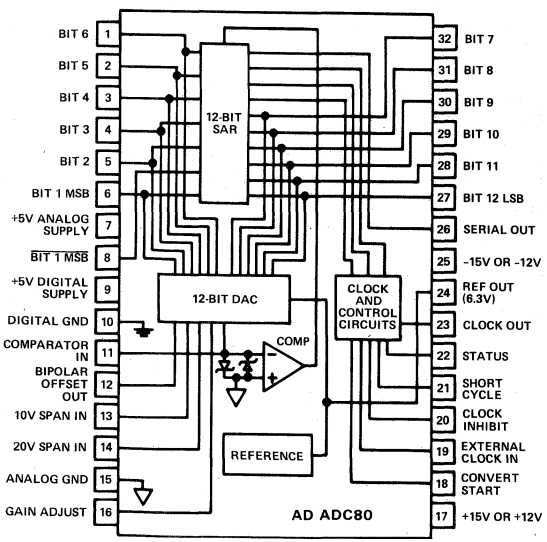



### AD5240

Page

- Complete 12-Bit A/D Converter with Reference and Clock
- Fast Successive Approximation Conversion: 5μs
- Buried Zener Reference for Long Term Stability and Low Gain T.C.: 10ppm/°C
- Max Nonlinearity: <±0.012%
- Low Power: 775mW Typical
- Hermetic Package Available
- Low Chip Count – High Reliability
- Pin Compatible with AD ADC84/AD ADC85
- "Z" Models for ±12V Supplies

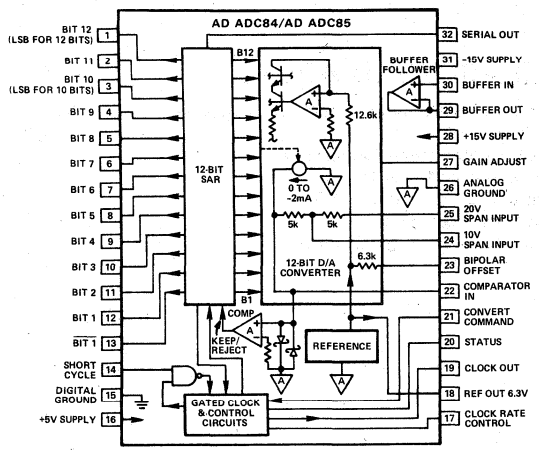
Vol. I 10–111




### AD ADC80

- True 12-Bit Operation: Max Nonlinearity ±0.012%
- Low Gain T.C.: ±30ppm/°C max
- Low Power: 800mW
- Fast Conversion Time: 25μs
- Precision 6.3V Reference for External Application
- Short-Cycle Capability
- Serial or Parallel Data Outputs
- Monolithic DAC with Scaling Resistors for Stability
- Low Chip Count – High Reliability
- Industry Standard Pin Out
- "Z" Models for ±12V Supplies

Vol. I 10–183

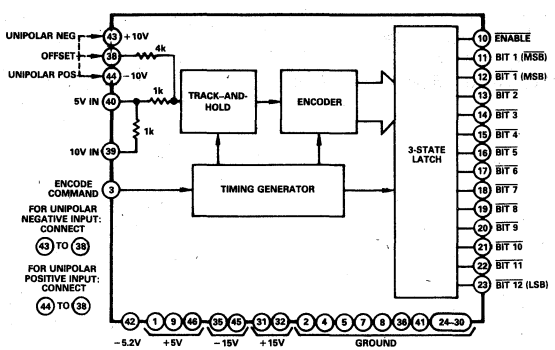



# AD ADC84/AD ADC85

Page

Vol. I
10–191

**Complete 12-Bit A/D Converter with Reference and Clock**
**Fast Successive Approximation Conversion: 10μs**
**Buried Zener Reference for Long Term Stability and Low Gain T.C.: 10ppm/°C**
**Max Nonlinearity: <±0.012%**
**Low Power: 880mW Typical**
**Hermetic Package Available**
**Low Chip Count – High Reliability**
**Industry Standard Pin Out**
**"Z" Models for ±12V Operation Available**




# HAS-1201

**12-Bit Resolution**
**1MHz Word Rate**
**T/H and Timing Circuits Included**
**Single Hybrid Package**

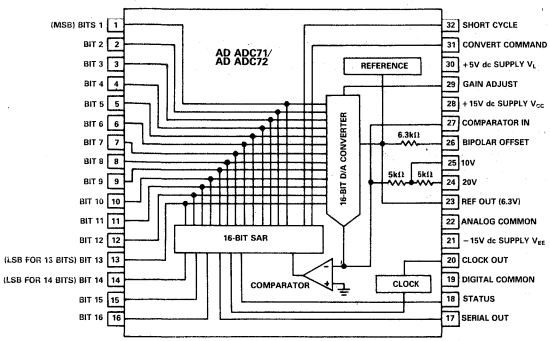
**APPLICATIONS**
**Radar Systems**
**Medical Instrumentation**
**Electro-Optics Systems**
**Test Systems**

11

Vol. I
10–205

# Selection Guide
## Analog-to-Digital Converters

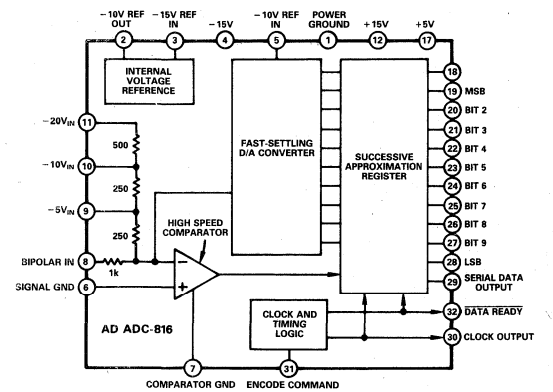
## High Resolution A/D Converters




### AD ADC71/AD ADC72

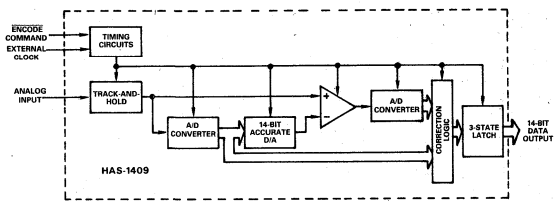
Page

**Complete 16-Bit Converter with Reference and Clock** — Vol. I 10–175
**±0.003% Maximum Nonlinearity**
**No Missing Codes to 14 Bits**
**Fast Conversion – 45μs (14 Bit)**
**Short Cycle Capability**
**Parallel or Serial Logic Outputs**




### AD ADC816

**10-Bit Resolution** — Vol. I 10–199
**800ns Conversion Time**
**Six Input Ranges**
**Unipolar and Bipolar Operation**

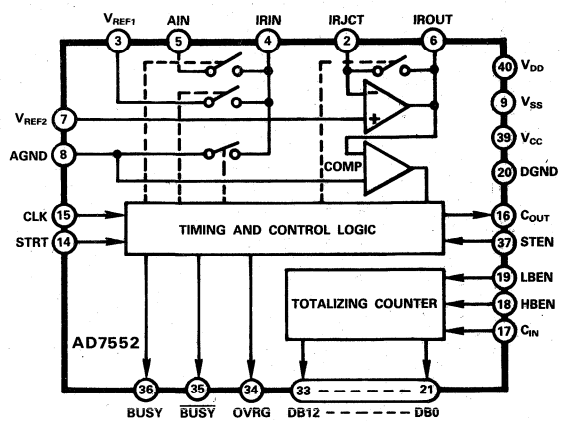



## HAS-1409



**14-Bit Resolution** Vol. I
**125kHz Word Rates** 10–207
**Internal Track-and-Hold**
**40-Pin DIP**

**APPLICATIONS**
**FDM/TDM Transmultiplexers**
**CAT/NMR Scanners**
**PCM Systems**
**Digital Audio**

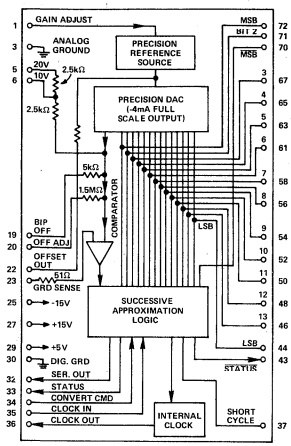



## AD7552

**12-Bit Binary with Polarity and Overrange** Vol. I
**Accuracy ±1LSB** 10–127
**Microprocessor Compatible**
**Ratiometric Operation**
**Low Power Dissipation**

11

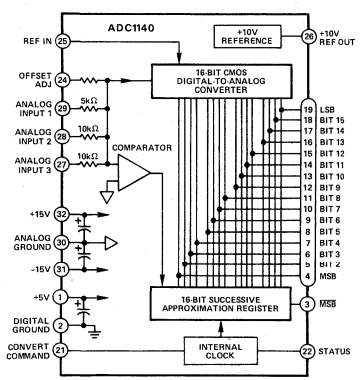
# Selection Guide
## Analog-to-Digital Converters
## High Resolution A/D Converters




### ADC1130/ADC1131

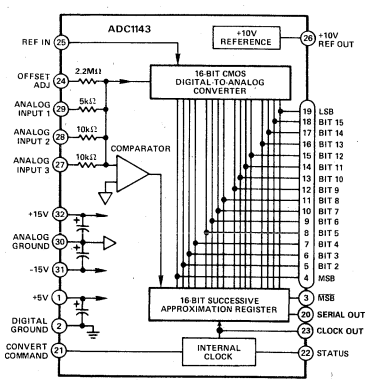
Page

- 14-Bit Resolution and Accuracy — Vol. II 11-27
- Fast 12μs Conversion Time (ADC1131J/K)
- Low 10ppm/°C Maximum Gain TC
- User Choice of Input Range
- No Missing Codes




### ADC1140

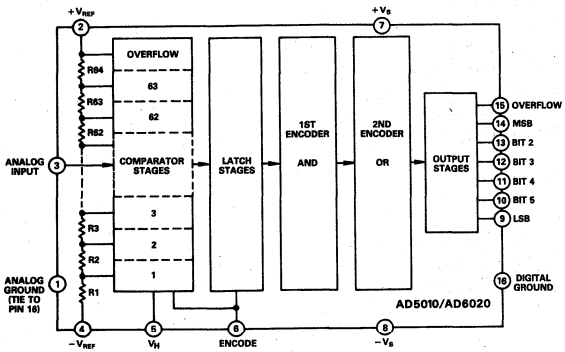
- Low Cost 16-Bit A/D Converter — Vol. II 11-31
- Guaranteed Nonlinearity: ±0.003% FSR max
- 35μs Maximum Conversion Time
- Small Size 2" × 2" × 0.4"
- Wide Power Supply Operation: ±12V to ±17V




### ADC1143

- High Performance 16-Bit A/D Converter — Vol. II 11-35
- Low Power Consumption:
  - 175mW max, $V_S$ = ±15V
  - 150mW max, $V_S$ = ±12V
- Guaranteed Nonlinearity:
  - ±0.006% FSR max (ADC1143J)
  - ±0.003% FSR max (ADC1143K)
- Guaranteed Differential Nonlinearity:
  - ±0.006% FSR max (ADC1143J)
  - ±0.003% FSR max (ADC1143K)
- Low Differential Nonlinearity T.C.:
  - ±2ppm/°C max (ADC1143J)
  - ±1ppm/°C max (ADC1143K)
- Fast Conversion Time:
  - 70μs max (ADC1143J)
  - 100μs max (ADC1143K)
- Wide Power Supply Operation:
  - $V_S$ = ±11.4V to ±18.0V
  - $V_D$ = +3.0V to +18.0V

# Video A/D Converters



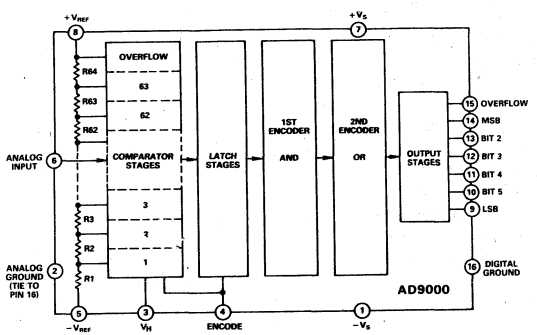

## AD5010/AD6020

Page

Vol. I
10–103

**Scan Frequency to 100MHz (AD5010KD)**
**Low 450mW Power Dissipation**
**±1/4LSB Linearity**
**ECL Logic Compatible**
**No Sample & Hold Required**
**Overflow Output for Extended Resolution**

**APPLICATIONS**
**Video Data Conversion**
**High Speed Data Acquisition**
**Radar/Sonar Data Conversion**



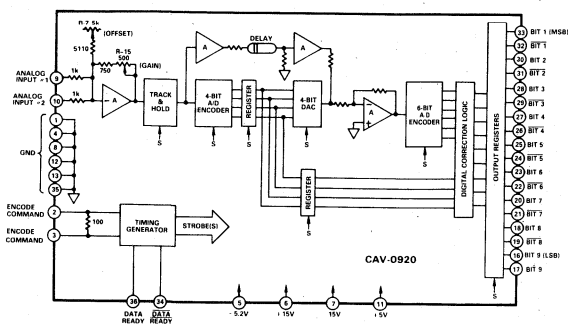

## 9000 SERIES

Vol. I
10–167

**6-Bit, 75MHz Minimum Word Rates**
**No T/H Required**
**−55°C to +125°C Temperature**
**Overflow Bit for Cascading Units**

**APPLICATIONS**
**Image Processing**
**Video Digitizing**
**Radar Digitizing**
**Military Systems**

# Selection Guide
## Analog-to-Digital Converters
## Video A/D Converters



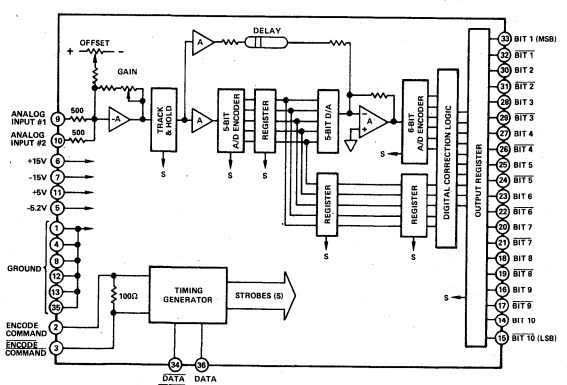

### CAV-0920

Page

Vol. II
11–39

**9-Bit Resolution**
**20MHz Word Rate**
**Single 35-In$^2$ PC Board**
**ECL Compatible**
**No External Circuits Required**

**APPLICATIONS**
**Television Digitizing**
**Radar Digitizing**
**Medical Instrumentation**
**Digital Communications**
**Spectrum Analysis**

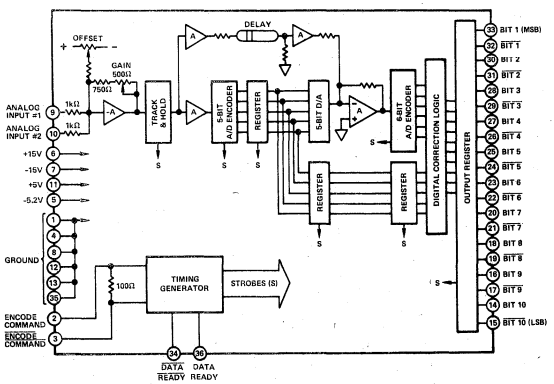



### CAV-1040

Vol. II
11–43

**10-Bit Resolution**
**40MHz Word Rate**
**Single 35-In$^2$ PC Board**
**ECL Compatible**
**No External Circuits Required**

**APPLICATIONS**
**Radar Digitizing**
**Medical Instrumentation**
**Digital Communications**
**Spectrum Analysis**




# CAV-1210

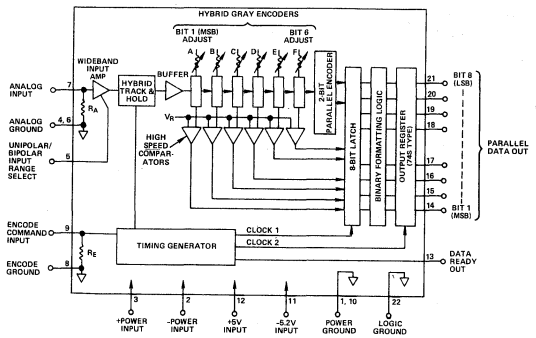
**12-Bit Resolution**
**10MHz Word Rate**
**Single 35-In$^2$ PC Board**
**ECL Compatible**
**No External Circuits Required**

**APPLICATIONS**
**Radar Digitizing**
**Medical Instrumentation**
**Digital Communications**
**Spectrum Analysis**

Page

Vol. II
11–45

# Selection Guide
## Analog-to-Digital Converters
## Video A/D Converters




## MATV-0811/MATV-0816

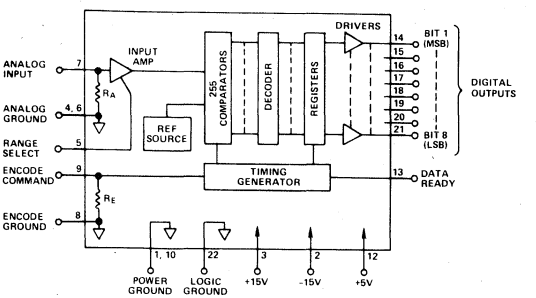
**MATV-0811: 11MHz Word Rates**
**MATV 0816: 16MHz Word Rates**

Page

**8-Bit Accuracy – Guaranteed Monotonic**
**Most Economical Video A/D**
**Smallest Available Complete A/D – 5.5″ × 4.38″ × 0.85″**
**Self Contained – Includes Input Buffer, Encoder, Reference, Timing, and Buffered Parallel Output**

Vol. II 11–57

**APPLICATIONS**
**Digitize Color Television at Up to Three or Four Times NTSC or PAL Color Subcarrier Frequencies**
**Video Time Base Correction and Frame Synchronization**
**Radar Signal Processing**
**Real Time Transient and Continuous Spectrum Analysis**

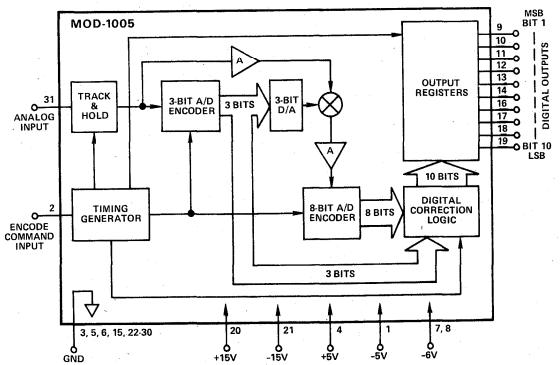



## MATV-0820

**8-Bit Accuracy – Guaranteed Monotonic**
**Ultra-High Speed – dc to 20MHz Word Rates**
**Most Economical Video A/D**
**Smallest Available Complete A/D – 5.5″ × 4.38″ × 0.85″**
**Self Contained – Includes Input Buffer, Encoder, Reference, Timing, and Buffered Parallel Output**

Vol. II 11–57

**APPLICATIONS**
**Digitize Color Television at Up to Three or Four Times NTSC or PAL Color Subcarrier Frequencies**
**Video Time Base Correction and Frame Synchronization**
**Radar Signal Processing**
**Real Time Transient and Continuous Spectrum Analysis**

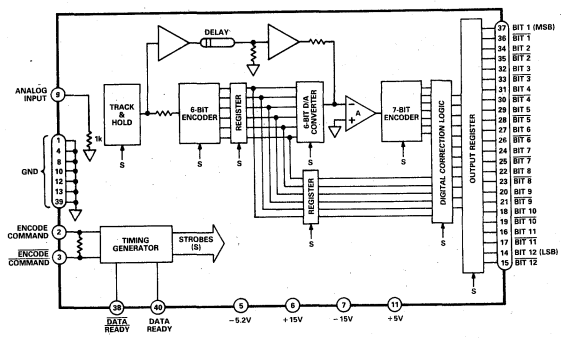



# MOD-1005

Page
Vol. II
11-61

**10 Bits @ 5MHz Word Rate**
**One-27 Sq. In. PC Board**
**Built-In Track-and-Hold – 25ps Aperture Uncertainty**
**20MHz Analog Input Bandwidth**
**TTL Compatible**
**Low (10-Watt) Power Dissipation**
**Signal-to-Noise Ratio Greater Than 58dB**
**Noise Power Ratio Greater Than 49dB**
**Completely Repairable**

**APPLICATIONS**
**Radar Digitizing**
**Digital Communications**
**Real Time Spectrum Analysis**
**High Resolution TV**

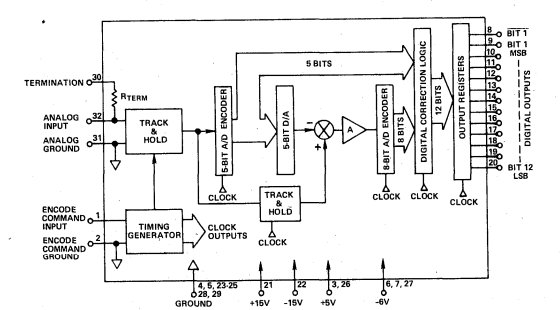



# MOD-1020

Vol. II
11-65

**10 Bits @ 20MHz Word Rates**
**One-35 Sq. In. PC Board**
**Built-In Track-and-Hold – 25ps Aperture**
**15MHz Large-Signal Input Bandwidth**
**ECL Compatible**
**Signal-to-Noise Ratio Greater Than 56dB**
**Noise Power Ratio Greater Than 45dB**

**APPLICATIONS**
**Television Digitizing**
**Radar Digitizing**
**Medical Instrumentation**
**Digital Communications**
**Spectrum Analysis**
**Sonar Digitizing**




# MOD-1205

Vol. II
11-69

**12 Bits @ 5MHz Word Rate**
**One-27 Sq. In. PC Board**
**Built-In Track-and-Hold – 25ps Aperture Uncertainty**
**15MHz Analog Input Bandwidth**
**TTL Compatible**
**Low (13-Watt) Power Dissipation**
**Signal-to-Noise Ratio Greater Than 66dB**
**Noise Power Ratio Greater Than 56dB**
**Completely Repariable**

**APPLICATIONS**
**Radar Digitizing**
**Digital Communications**
**Real Time Spectrum Analysis**
**Signature Analysis**

# Orientation
# Analog-to-Digital Converters

## FACTORS IN CHOOSING AN A/D CONVERTER

In the two volumes of this catalog, there are listed some 34 different families of analog-to-digital converters (ADCs). If one were to consider all the variations, there would be considerably more than 92 different types to choose among (excluding digital panel meters and data-acquisition systems, which are catalogued elsewhere). The reason for so many different types is the number of degrees of freedom in selection—technological, functional, performance, and package. Complete information on converters may be found in the 250-page book, *Analog-Digital Conversion Notes*, published by Analog Devices and available for $5.95 from P.O. Box 796, Norwood, MA 02062.

## TECHNOLOGICAL FACTORS

The technologies represented here include modules (cards and potted circuits) and integrated circuits—monolithic and hybrid. Modules generally can provide the extremes of performance as well as arbitrary levels of functional completeness. For example, the 12-bit 5MHz MOD-1205 is built on a card that includes a track-hold amplifier.

The technical data in this volume embrace exceptionally high performance (high-resolution and high-speed) A/D converters, in the form of encapsulated modules and printed-circuit cards. As the Selection Guide indicates, there is also a universe of technical data, to be found in Volume I, on a wide range of monolithic and hybrid A/D converters, including many microprocessor-compatible types.

Besides the products in this section, analog-to-digital conversion functions in this Volume (at various levels of system integration) are also inherent in the sections devoted to Data-Acquisition Subsystems, Digital Panel Instruments, Microcomputer Interface Boards, Intelligent Measurement-and-Control Subsystems, and MACSYM. A/D conversion functions are also performed by products in the Voltage-to-Frequency and Synchro-Digital Conversion sections.

## FUNCTIONAL CHARACTERISTICS

Block diagrams illustrating the various conversion techniques appear on individual data sheets.

The moderate-speed converters described in this volume (<1MHz) employ two fundamental techniques—*successive approximations*, for moderate-to-high resolution at moderate-to-high speed, and *integration*, for high resolution at modest speeds. The ADC1143 and ADC1140 are examples of the former, the converters used in DPMs, the latter.

Like a chemist's balance with binary weights (1/2, 1/4, 1/8, etc.), the *successive-approximation* converter compares the unknown input with sums of accurately-known binary fractions of full scale, starting with the largest ($2^{-1}$), and rejecting any that change the comparator's state ("tip the scale"). At the end of conversion (EOC), the output of the converter is a digital word, representing the ratio of the input to full scale by a fractional-binary code.

*Integrating* types count pulses for a period proportional to the input. Most-frequently used are *dual slope* types, which count off the period required for the integral of the reference to become equal to the average value of the input (over a fixed period). Integrating types can be made insensitive to drift by storing errors during an error-correcting cycle and subtracting them during the input-measuring cycle. This correction can be performed in analog fashion, using capacitance for storage, or digitally—using the information stored in a counter for correction (AD7550).

The *video converters* described here (MATV, MOD-1205, etc.) employ two basic encoding techniques: simultaneous, or *flash* conversion, and serial-Gray-code conversion. High resolution and high speed are obtained by *subranging*, i.e., by performing an n-bit conversion in two steps; Analog Devices has perfected a form of subranging, known as DCS—*digitally corrected subranging*—which permits accurate resolutions of 12 bits and more.*

In *flash* conversion, the analog signal is compared against $2^n - 1$ graded voltage levels, using as many comparators, and the comparator output logic levels are processed by a priority encoder, which converts the "thermometer" output to a binary (or Gray) code. Since the whole conversion occurs essentially simultaneously, it is the fastest means of conversion, but it requires many accurate comparators and large numbers of gates.

In *serial*-analog-parallel-digital conversion, there are a number of cascaded stages, each having a gain of +2 for signals less than one-half the reference, and a gain of −2 for signals between one-half the reference and full scale. At each stage, a decision is made as to whether the signal is larger (1) or smaller (0) than one-half the reference; the stage's analog output becomes the input to the next stage. The complete time for one conversion is determined by the propagation delay of the analog signal through all stages; however, since the decision of each stage can be latched as soon as the stage has settled (and a new conversion can, in principle, be started as soon as the first bit has been latched), the rate at which conversions come out of the pipeline is considerably faster than the time for one sample to go through the conversion process. Though fast, this process is difficult to implement accurately for more than a few bits, because of the compounding of gain (hence errors).

A *subranging* converter digitizes to a group of more-significant bits, and stores them in a latch. A fast, very-high-accuracy D/A converter converts them to an analog signal, which is then subtracted from the input. The difference, or residue, is amplified and digitized, and (in DCS) the result is combined digitally in such a way as to correct for mid-scale conversion errors.

Whatever the technique, these A/D converters comprise several essential functions: an analog section, a digital data-generating section, data outputs, and digital controls. Some video converters also include an on-board track-hold function.

*A considerable amount of useful information about video conversion can be found in "Understanding High-Speed (Video) A/D Converter Specifications", available upon request.

**Analog Section**
This section requires a reference, one or more high-gain comparators, and either a D/A converter (successive approximations and subranging) or a controllable integrator. The reference may be internal or external, fixed or variable, and of a specified polarity/sense in relation to the analog input. In ratiometric conversion, the reference is usually external and variable.

In successive-approximation converters, the comparator is generally used in the *current-summing* mode; that is, the current output of the DAC is summed with the current developed in the DAC's "feedback resistor" by the input voltage (of opposite polarity), and the balancing action of the converter tends to bring the summing junction towards a voltage null (much like that of an op amp) at the end of conversion. The typical DAC feedback options, when applied in an ADC, provide input-scaling choices. When the bipolar-offset connection is jumpered to the summing point, input signals of both polarities can be handled. The current-switching action of the DAC, at the typically fast clock-rates used in successive-approximation converters, can disturb the output of the analog signal source, especially if it is a slow high-precision op amp. In such cases, buffering may be necessary; some of the modules, have on-board analog buffer-followers, and the card-mounted video converters have on-board track-hold-buffer amplifiers.

In integrating types, absolute-value and polarity-sensing circuitry may be required at the front end to handle both polarities of input. Outputs are usually sign-magnitude BCD.

**Digital Data-Generating Section**
In successive-approximation types, this section consists of a discrete or integrated successive-approximations register (SAR), its controls, and inputs from the comparator and clock (which is on-board, but in many cases permits external clock pulses, frequency adjustment, and/or control). In integrating types, this section consists of the clock-pulse generator, the counter(s), the input from the comparator, and the associated controls.

**Data Outputs**
Factors to consider here include coding, resolution, overrange information, levels, format, validity, and timing. *Coding* is usually binary, including jumper-connected offset-binary and/or two's complement for bipolar input signals. For some types, BCD is available, with sign-magnitude for bipolar inputs. Output coding specs should always be checked for digital polarity (positive- or negative-true) of both magnitude and sign information. The *resolution* (number of output bits) must be sufficient for the application; in addition, the specifications must be checked to ascertain that not only will all $2^n$ (binary) output codes be present (no missing codes), but they must all be present at any temperature in the operating range and related to the input with sufficient accuracy. Integrating types generally have no problems with missing codes (except sometimes at zero, with sign-magnitude coding); nevertheless, nonlinear integration can cause the conversion relationship to become nonlinear. Successive-approximation types have no way of determining *overrange;* they simply fill up. However, counter types roll over and put out a carry flag to signal overrange.

The *data levels* available at the converter output must be checked (TTL, low-voltage CMOS, high-voltage CMOS, ECL), as must the load-driving capability and fanout, and the supply conditions under which appropriate output levels will be furnished. The available choice of output *formats* must also be as desired—parallel, serial, byte-serial, and/or pulse-train. If the converter is intended to communicate directly with a data bus, the output should have three-state capability, and parallel outputs must be enabled in bytes of appropriate widths. If the output is serial NRZ (non-return-to-zero), it should be accompanied by a set of synchronized clock-pulses.

A *status* (or *busy* or EOC or "*data ready*") output changes state to indicate when the data becomes *valid*. The exact nature of this transition should be specified—polarity, timing, levels, etc. For serial data, the exact relationship between the data and the synchronizing clock should be specified, to indicate when each bit becomes valid, and for how long. In general, the *timing* of the whole conversion process must be clearly understood, especially if high speeds are necessary, either for conversion, or for communication with a processor (or both). The timing diagrams on specification sheets are usually accompanied by adequate descriptions of the conversion process and specifications of the critical interface parameters.

**Controls**
The functions, action (levels or edges), polarity, and timing of all control inputs and outputs should be clearly understood, as well as their loading characteristics and dependence on the supply. In addition to the essential *start-conversion-command* input and a *status* output, various control commands may be available, such as *clock inhibit, high (low)-byte enable, status enable*, and—for speeding up conversion at the cost of resolution in successive-approximation converters—*short-cycle.*

**Power Supplies**
Appropriate power supplies should be made available, considering the logic levels and analog input signals to be employed in the system. The appropriate degree of power-supply stability to meet the accuracy specifications should be provided. Any recommended external protection circuitry should be planned for. In many cases, separate analog and digital grounds are required; ground wiring should follow best practice to minimize digital interference with high-accuracy analog signals, while ensuring that a connection between grounds can always exist at one point, even if the "mecca" point is inadvertently unplugged from the system.

For video converters, use massive, low-impedance ground systems. The analog and digital grounds are connected together inside converters of these types, so bus bars are essential for system grounding and power distribution; use lots of ground plane on PC boards.

**Application Checklist**
The designer will generally require specific information in the following categories, before proceeding to the selection process:

- Accurate description of input and output
  1. analog signal range and source or load impedance
  2. digital code needed – binary, offset binary, 2's complement, BCD, etc.
  3. logic level system, i.e., TTL/DTL/ECL compatible
- What are the needed analog bandwidth and data throughput rate?
- What are the control interface details?
- What does the system error budget allow for the converter?
- What are environmental conditions – temperature range, time, supply voltage – over which the converter should operate to the desired accuracy?

For A/D converters, the following considerations are typical.

- What is the analog input voltage range, and to what resolution must the signal be measured?
- What is the requirement for linearity error (or relative accuracy error)?
- To what extent must the various sources of error be minimized as environmental temperature changes?
- How much time can be allowed in the system for each complete conversion? What aperture uncertainty and acquisition time are needed for the sample-hold?
- How stable is the system power supply? What errors will result from power supply terminal voltage variations of this order?
- Can the system tolerate missed codes under any conditions?
- What is the character of the input signal? Is it noisy, sampled, filtered, rapidly-varying, slowly-varying? What kind of pre-processing is to be (or can be) done that will affect the choice (and cost) of the converter? Is aliasing a potential problem?

## SPECIFICATIONS & TERMS

Definitions of performance specifications, and related information, are to be found on the following pages, in alphabetical order.*

*For video converters, there are a number of additional application-oriented specifications pertaining to the device's use in a system (e.g., *noise power ratio*, *differential phase*, *differential gain*, *signal-to-noise ratio*). Some useful references for understanding such specifications can be found in the following publications, available from Analog Devices, Computer Labs Division 7810 Success Road, Greensboro NC 27409.


Kester, W.A., "PCM Signal Codecs for Video Applications", *SMPTE Journal*, Volume 88, November 1979, pp 770-778.

Pratt, W.J., "Test A/D Converters Digitally", *Electronic Design*, December 6, 1975

Smith, B.F. and Pratt, W.J., "Understanding High-Speed A/D Converter Specifications", Computer Labs, 1974


**Accuracy, Absolute**
The error of an A/D converter at a given output code is the difference between the theoretical and the actual analog input voltages required to produce that code. Since the code can be produced by any analog voltage in a finite band (see Quantizing Uncertainty), the "input required to produce that code" is defined as the midpoint of the band of inputs that will produce the code. For example, if 5 volts (±1.2mV) will theoretically produce a 12-bit half-scale code of 100000000000, then a converter for which any voltage from 4.997V to 4.999V will produce that code will have absolute error of 1/2(4.997 + 4.999) – 5 volts = –2mV.

Absolute error comprises gain error, zero error, and nonlinearity, together with noise, Absolute-accuracy measurements should be made under a set of standard conditions with sources and meters traceable to an internationally accepted standard.

**Accuracy, Relative**
Relative accuracy error, expressed in %, ppm, or fractions of an LSB, is the deviation of the analog value at any code (relative to the full analog range of the device transfer characteristic) from its theoretical value (relative to the same range), after the full-scale range (FSR) has been calibrated.

Since the discrete points on the theoretical transfer characteristic lie on a straight line, this deviation can also be interpreted as a measure of nonlinearity (see Linearity).

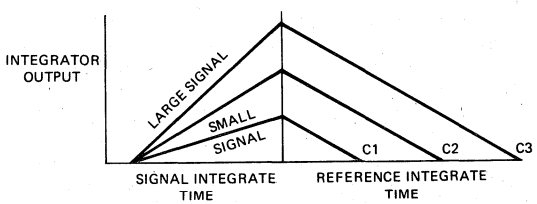
The "discrete points" of an A/D transfer characteristic may be the midpoints of the quantization bands at each code (see Accuracy, Absolute), or—for convenience— the ideal transitions, which are displaced by 1/2LSB.

**Aperture Time**
This is the interval between the application of the *hold* command to a sample/track-hold and the actual opening of the switch. The aperture time consists of a delay (which depends on the logic and the switching device—50ns for SHA1144) and an uncertainty (due to jitter—20ps max rms for HTS-0025). When a sample-hold is used in an application where timing is critical, the timing of the hold command can be advanced to compensate for the known component of aperture delay. The jitter, however, imposes the ultimate limitation on timing accuracy. When a sample-hold is used with an ADC, the timing uncertainty of the conversion process is reduced by the ratio of aperture jitter to the conversion time, i.e., the maximum frequency which can be handled with less than 1LSB error due to timing is $2^{-n}/(\pi\,\tau_{au})$ instead of $2^{-n}/(\pi\,\tau_c)$, where $\tau_{au}$ is the aperture uncertainty and $\tau_c$ is the conversion time.

**Common Mode Rejection (CMR)**
The ability of a device to reject the effect of voltage applied to both input terminals simultaneously. Usually expressed as the log of a "common-mode rejection ratio," e.g., 1,000,000:1 (CMRR) or 120dB (CMR). A CMRR of 1,000,000 to 1 means that a 1V common-mode voltage passes through the amplifier as through it were a differential signal of one microvolt at the input.

**Conversion Time and Conversion Rate**
The time required for a complete measurement by an ADC is called *conversion time*. For most converters (assuming no significant additional systemic delays), this is identical to the inverse of *conversion rate*. However, in some high-speed converters, because of pipelining, new conversions are initiated before the results of prior conversions have been determined; thus, for example, the MOD-1205 can provide 12-bit output data at a 5MHz word rate (200ns/conversion), even though the time for any one conversion, from start to finish, is two clock periods plus 275ns, or 675ns, at 5MHz.

**Dual-Slope Converter**
An integrating analog-to-digital converter in which the unknown signal is converted to a proportional time interval, which is then measured digitally. This is done by integrating the unknown for a predetermined time. Then a reference input is switched to the integrator, and integrates "down" from the level determined by the unknown until a "zero" level is reached. The time for the second integration process is proportional to the average of the unknown signal level over the predetermined integrating period. A digital time-interval meter (i.e., counter) is generally used as the output indicator.




**Feedthrough**
Undesirable signal-coupling around switches or other devices that are supposed to be turned off or provide isolation, e.g., *feedthrough error* in a multiplexer. It is variously specified in %, ppm, fractions of 1 LSB, or fractions of 1 volt, with a given set of inputs, at a specified frequency.

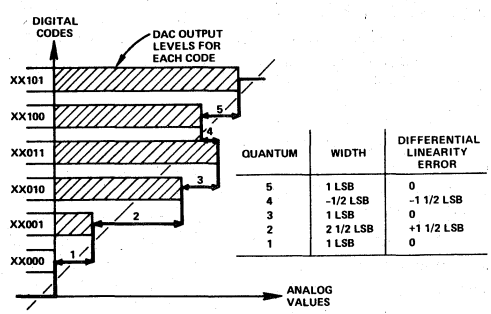
**"Flash" Converter**
A converter in which all the bit choices are made at the same time. It requires $2^n - 1$ voltage-divider taps and comparators, and a comparable amount of priority encoding logic. An extremely fast scheme, it requires large numbers of precision components. Flash converters are often used for partial conversions in *subranging converters*.

**Gain Adjustment**
The "gain" of a converter is that analog scale factor setting that provides the nominal conversion relationship, e.g., 10V full scale, in a fixed-reference converter, or 100% of full-scale in a ratiometric converter. Gain- and zero-adjustment principles are discussed under *zero*.

**Least Significant Bit (LSB)**
In a system in which a numerical magnitude is represented by a series of binary (i.e., two-valued) digits, the "least significant bit" is that digit (or "bit") that carries the smallest value or weight. For example, in the natural binary number 1101 (decimal 13, or $2^3 + 2^2 + 0 + 2^0$), the rightmost "1" is the LSB. Its analog weight, relative to full scale, is $2^{-n}$, where n is the number of binary digits. It represents the smallest change that can be resolved by an n-bit converter.

**Linearity Error**
Linearity error of a converter, expressed in percent or parts-per-million of full-scale range, or fractions of a least-significant bit, is the deviation of the analog values from a straight line, in a plot of the measured conversion relationship. The straight line can be either a "best straight line," determined empirically by manipulation of the gain and/or offset to equalize maximum positive and negative deviations of the actual transfer characteristic from this straight line; or, it can be a straight line passing through the end points of the transfer characteristic after they have been calibrated. Sometimes referred to as "end-point" nonlinearity, the latter is both a more conservative measure and is much easier to verify in actual practice. "End-point" nonlinearity is similar to relative accuracy error (see Accuracy, Relative). Linearity has two components—*differential* and *integral* nonlinearity.

**Linearity, Differential and Integral**
A digital output code should correspond to a quantum of analog input values exactly 1 LSB in width ($2^{-n}$ of full scale, for an n-bit converter). Any deviation of the measured "step" from the ideal width is called Differential Nonlinearity. It is an important specification, because a differential nonlinearity error greater than 1 LSB can lead to nonmonotonic behavior of of a D/A converter, and missed codes in an A/D converter employing such a DAC. A flagrant example of differential nonlinearity is shown here.




| QUANTUM | WIDTH | DIFFERENTIAL LINEARITY ERROR |
|---|---|---|
| 5 | 1 LSB | 0 |
| 4 | -1/2 LSB | -1 1/2 LSB |
| 3 | 1 LSB | 0 |
| 2 | 2 1/2 LSB | +1 1/2 LSB |
| 1 | 1 LSB | 0 |

In the illustration, the horizontal bars represent the measured DAC output values corresponding to 6 adjacent digital codes. The DAC is nonlinear, in that the next-least-significant bit (XX010) is 1½ LSB too large. Thus, instead of the five quanta, or steps, being all equal ( = 1 LSB), quantum 2 is 2½ LSB and quantum 4 is -½ LSB. The differential linearity error, the difference between the actual quantum width and the ideal 1 LSB, is +1½ LSB for quantum 2 and -1½ LSB for quantum 4.

When this DAC is used in successive-approximations conversion, it will lead to a missed code. Analog inputs slightly larger than the value of XX100 will be converted to XX100, and analog inputs slightly less than the value of XX100 will be converted to XX010. The code XX011 will not exist; it will be a *missed code.*

Often, instead of a maximum differential nonlinearity specification, there will be a simple specification of "no missed codes", which implies a differential nonlinearity less than 1 LSB.

While differential nonlinearity deals with errors in step size, *integral nonlinearity* has to do with deviations of the overall shape of the conversion response. Even converters that are not subject to differential linearity errors (e.g., integrating types) have integral linearity (sometimes just "linearity") errors.

**Power-Supply Sensitivity**
The sensitivity of a converter to dc changes in power-supply voltages is normally expressed in terms of percentage change in analog input value (or fractions of the analog equivalent of 1 LSB), corresponding to a given code, for a 1% dc change in the power supply, e.g., $0.05\%/\%\Delta V_S$). Power-supply sensitivity may also be expressed in relation to a specified dc shift of the supply voltage. High-accuracy ADCs intended for battery operation require excellent rejection of large supply-variations.

**Quad-Slope Converter**
This is an integrating analog-to-digital converter that goes through two cycles of *dual-slope* conversion, once with zero input and once with the analog input being measured. The errors determined during the first cycle are subtracted digitally from the result in the second cycle. The scheme results in an extremely accurate converter. For example, the 13-bit single-chip AD7550 is a CMOS quad-slope A/D converter with typical tempcos (gain and zero temperature coefficients) of 1ppm/°C.

**Quantizing Uncertainty (or "Error")**
The analog continuum is partitioned into $2^n$ discrete ranges for n-bit conversion. All analog values within a given range are represented by the same digital code, usually assigned to the nominal midrange value. There is, therefore, an inherent quantization uncertainty of ±½ LSB, in addition to the actual conversion errors. In integrating converters, this "error" is often expressed as "±1 count."

**Ratiometric Converter**
The output of an A/D converter is a digital number proportional to the ratio of (some measure of) the input to a reference. Most requirements for conversions call for an absolute measurement, i.e., against a fixed reference. In some cases, where the measurement is affected by a changing reference voltage (e.g., the voltage applied to a bridge), it is advantageous to use that same reference as the reference for the conversion, to eliminate the effect of variation. Ratiometric conversion can also serve as a substitute for analog signal division (where the denominator changes but little during the conversion).

**Stability**
Stability of a converter, usually applies to the insensitivity of its characteristics with time, temperature, etc. All measurements of stability are difficult and time consuming, but stability vs. temperature is sufficiently critical in most applications to warrant universal inclusion in tables of specifications (see "Temperature Coefficients").

**Subranging Converters**
In this type of converter, an extremely fast conversion produces the most-significant portion of the output word. This portion is converted back to analog with a fast high-accuracy D/A converter and subtracted from the input. The resulting residue is converted to digital at high speed and combined with the results of the earlier conversion to form the output word. In *digitally corrected subranging* (DCS), the two bytes are combined in a manner that corrects for the error of the LSB of the most-significant byte. For example, using 8-bit and 5-bit conversion, and this proprietary technique, a full-accuracy high-speed 12-bit converter can be built.

**Successive Approximations**
Successive approximations is a high speed method of comparing an unknown against a group of weighted references. The operation of a successive approximations A/D converter is generally similar to the orderly weighing of an unknown quantity on a precision chemical balance, using a set of weights such as: 1 gram, 1/2 gram, 1/4 gram, 1/8 gram, 1/16 gram, etc. The weights are tried in order, starting with the largest. Any weight that tips the scale is removed. At the end of the process, the sum of the weights remaining on the scale will be within one LSB of the actual weight (±½ LSB, if the scale is properly biased — see *zero*).

**Temperature Coefficients**
In general, temperature instabilities are expressed in %/°C, ppm/°C, as fractions of 1 LSB/°C, or as a change in a parameter over a specified temperature range. Measurements are usually made at room temperature and at the extremes of the specified range, and the temperature coefficient (tempco, T.C.) is defined as the change in the parameter, divided by the corresponding temperature change. Parameters of interest include *gain, linearity, offset* (bipolar), and *zero.* The last three are expressed in % or ppm of full-scale range per Celsius degree.

**Gain Tempco:** Two factors principally affect converter gain instability with temperature:

a) In fixed-reference converters, the reference source will vary with temperature. For example, the tempco of an AD581L is typically 5ppm/°C.
b) The ratiometric circuitry has a sensitivity to temperature.

**Linearity Tempco:** Sensitivity of linearity to temperature over the specified range. To avoid missed codes, it is sufficient that the differential nonlinearity error be less than 1 LSB at any temperature in the range of interest. The *differential nonlinearity temperature coefficient* may be expressed as a ratio, as a maximum change over a specified

temperature range, and/or implied by a statement that there are no missed codes when operating within a specified temperature range.

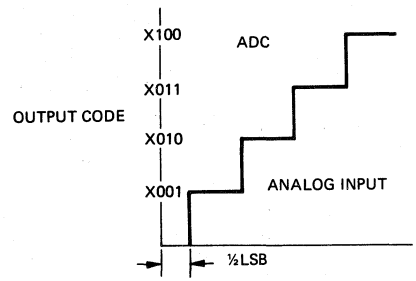
**Offset Tempco** The temperature coefficient of the all-DAC-switches-off (minus full-scale) point, of a bipolar successive-approximations converter, is dependent on three variables:

1) The tempco of the reference source
2) The voltage stability of the input buffer and the comparator
3) The tracking capability of the bipolar-offset resistors and the gain resistors.

**Unipolar Zero** The zero tempco of an ADC is dependent only on the zero stability of the integrator and/or the input buffer and the comparator. It may be expressed in $\mu V/^{\circ}C$, or in percent or ppm of full-scale per degree C.

**Zero- and Gain-Adjustment Principles**

The zero adjustment of a unipolar ADC is set so that the transition from all-bits-off to LSB-on occurs at $\frac{1}{2} \times 2^{-n}$ of nominal full-scale. The gain is set for the final transition




to all-bits-on to occur at F.S. $(1 - \frac{3}{2} \times 2^{-n})$. The "zero" of an offset-binary bipolar ADC is set so that the first transition occurs at -F.S. $(1 - 2^{-n})$ and the last transition at +F.S. $(1 - 3 \times 2^{-n})$. The data sheet instructions should be followed.

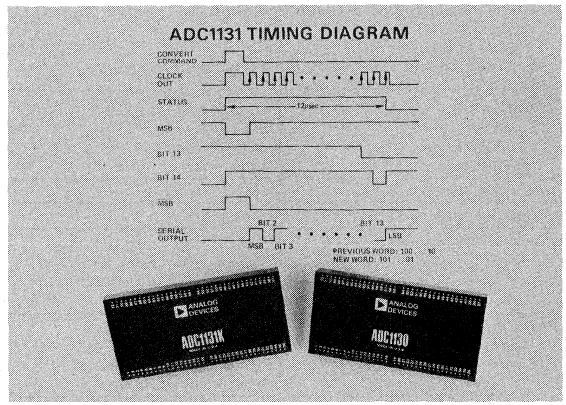
# ANALOG DEVICES

# 14-Bit High Speed Analog-to-Digital Converters

# ADC1130, ADC1131

**FEATURES**
- **14-Bit Resolution and Accuracy**
- **Fast 12μs Conversion Time (ADC1131J/K)**
- **Low 10ppm/°C Maximum Gain TC**
- **User Choice of Input Range**
- **No Missing Codes**

**APPLICATIONS**
- **Wide Band Data Digitizing**
- **Multi-Channel Computer Interface**
- **High Accuracy Data Acquisition**
- **X-Ray Tomography**
- **Nuclear Accelerator Instrumentation**




## GENERAL DESCRIPTION

The ADC1130 and ADC1131 are high speed analog-to-digital converters packaged in a small 2″ x 4″ x 0.4″ (51 x 102 x 10mm) module, which perform complete 14-bit conversions in 25μs and 12μs respectively. Using the successive approximations technique, they convert analog input voltages into natural binary, offset binary, or two's complement coded outputs. Data outputs are provided in both parallel and non-return-to-zero serial form.

Four analog input ranges are available: 0 to +20V, 0 to +10V, ±10V, ±5V. The user selects the desired range by making appropriate connections to the module terminals. The ADC1130 and ADC1131 can also be connected so as to perform conversions of less than 14 bit resolution with a proportionate decrease in conversion time.

## TIMING

As shown in Figure 1, the leading edge of the convert command set the MSB output to Logic "0" and the CLOCK OUT, STATUS, $\overline{\text{MSB}}$, and BIT 2 through BIT 12 outputs to Logic "1". Nothing further happens until the convert command returns to Logic "0", at which time the clock starts to run and the conversion proceeds.

With the MSB in the Logic "0" state, the internal digital-to-analog converter's output is compared with the analog input. If the D/A output is less than the analog input, the first "0" to "1" clock transition resets the MSB to Logic "1". If the D/A output is greater than the analog input, the MSB remains at Logic "0".

The first "0" to "1" clock transition also sets the BIT 2 output to Logic "0" and another comparison is made. This process continues through each successive bit until the BIT 14 (LSB) comparison is completed. At this point the STATUS and CLOCK OUT return to Logic "0" and the conversion cycle ends.

The serial data output is of the non-return-to-zero (NRZ) format. The data is available, MSB first, 20ns after each of the fourteen "0" to "1" clock transitions.

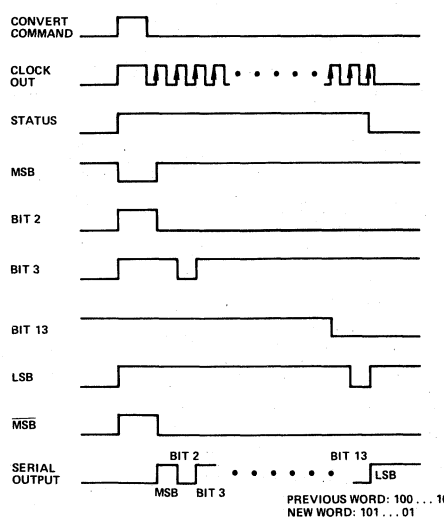



*Figure 1. Timing Diagram*

# SPECIFICATIONS (typical @ +25°C unless otherwise noted)

| MODEL | HIGH SPEED 12μs ADC1131 J | K | MEDIUM SPEED 25μs ADC1130 |
|---|---|---|---|
| RESOLUTION, BITS | 14 | 14 | 14 |
| CONVERSION TIME (max) | 12μs | 12μs | 25μs |
| ACCURACY | | | |
| Integral Nonlinearity Error (LSB) | ±1/2 (max) | * | * |
| Differential Nonlinearity | | | |
| Error (LSB) | ±1/2 (1 max) | ±1/2 (max) | ±1/2 (1 max) |
| Missing Codes | No missing codes | * | * |
| TEMPERATURE COEFFICIENTS | | | |
| Gain ppm/°C | ±12 (max) | ±7 (+10 max) | ±12 max |
| Unipolar Offset | ±0.7 (±3 max) | * | * |
| Bipolar Offset | ±3 (±7 max) | * | * |
| INPUT VOLTAGE RANGES | ±5V, ±10V, +10V, +20V | * | * |
| INPUT IMPEDANCE (10V RANGE) | 2500Ω | * | * |
| CONVERT COMMAND | Positive Pulse, 200ns min, 400ns max Leading Edge Resets, Trailing Edge Starts, TTL/DTL Compatible | * | * |
| PARALLEL DATA OUTPUT | | | |
| Unipolar | Positive True Binary | * | * |
| Bipolar | Positive True Offset Binary, Two's Complement | * | * |
| SERIAL DATA OUTPUT | | | |
| Unipolar | Positive True Binary | * | * |
| Bipolar | Positive True Offset Binary | * | * |
| STATUS OUTPUT | "1" During Conversion. Complement also available TTL/DTL Compatible. | * | * |
| LOGIC FANOUTS AND LOADINGS | | | |
| Convert Command Input | 1TTL Unit Load | * | * |
| Clock Input | 3TTL Unit Loads | * | * |
| Short Cycle Input | 1TTL Unit Load | * | * |
| Parallel Data Outputs | 3TTL Unit Loads/Bit | * | * |
| Serial Data Output | 8TTL Unit Loads | * | * |
| STATUS Output | 2TTL Unit Loads | * | * |
| $\overline{\text{STATUS}}$ Output | 12TTL Unit Loads | * | * |
| Clock Output | 4TTL Unit Loads | * | * |
| POWER REQUIREMENTS | +15V ±5% @ 40mA | * | * |
| | −15V ±5% @ 60mA | * | * |
| | +5V ±5% @ 250mA | * | * |
| POWER SUPPLY SENSITIVITY | | | |
| To ±15V Tracking Supplies | | | |
| Gain | ±4.5ppm/%Δ $V_S$ | * | * |
| Zero | ±4.5ppm/%Δ $V_S$ | * | * |
| To ±15V Non-Tracking Supplies | | | |
| Gain | ±10ppm/%Δ $V_S$ | * | * |
| Zero | ±7ppm/%Δ $V_S$ | * | * |
| TEMPERATURE RANGE | | | |
| Operating | 0 to +70°C | * | * |
| Storage | −55°C to +85°C | * | * |

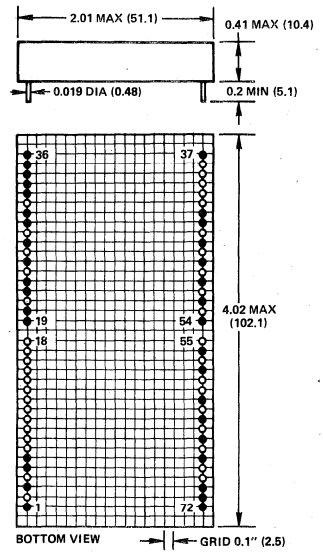
*Same Specifications as ADC1131J.

NOTES
[1] Offset (zero) and gain errors are adjustable to zero by means of external potentiometers. See Figure 5 for proper connection.
[2] Recommended power supply: Analog Devices model 923.

Specifications subject to change without notice.

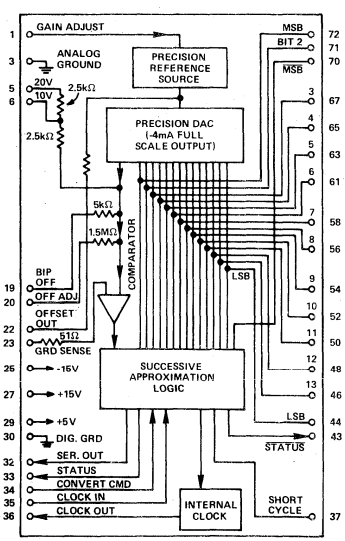
## OUTLINE DIMENSIONS

Dimensions shown in inches and (mm).




NOTE:
Terminal pins installed only in shaded hole locations.
Module weight: 3.5 ounces (99.3 grams).
All pins are gold plated half-hard brass (MIL–G–45204), 0.019" ±0.001" (0.48 ±0.03mm) dia.
For plug-in mounting card order Board No. AC1578.

## BLOCK DIAGRAM AND PIN DESIGNATIONS



## ANALOG INPUT CHARACTERISTICS

The input circuit of the ADC1130 and ADC1131 are shown in block diagram form.

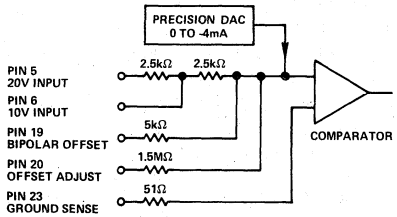



*Figure 2. Input Circuit Block Diagram*

When the converters are connected as a unipolar device, Pin 19 is left open circuit and, thus, no offset current is applied to the comparator input. The 0 to +10V input signal applied to Pin 6 (or the 0 to +20V input signal applied to Pin 5) develops a 0 to +4mA current which is compared to the 0 to -4mA output of the D/A converter. A voltage between +15V and -15V can be applied to Pin 20 from the wiper of a 100kΩ potentiometer to adjust the zero point by ±40LSB. To reduce the range of this trim padding resistors should be used.

With the offset output, Pin 22, connected to Pin 19, a +2mA offset current is applied to the comparator input. The ADC1130 and ADC1131 will then accept bipolar inputs of ±5V at Pin 6, or ±10V at Pin 5 and compare the 0 to +4mA sum of the offset and input signal currents to the 0 to -4mA D/A converter output. The offset adjustment potentiometer is once again used as described in the preceding paragraph.

Signal ground sense, Pin 23, should normally be jumpered to analog ground, Pin 3. In the event that an offset voltage is developed in the ground wiring, it may be possible to eliminate its effect by connecting Pin 23 directly to the signal or analog ground of the device feeding the analog input signal to the ADC. In any case, Pin 23 must not be left open.

If a high input impedance is required, it can be achieved by using a high speed operational amplifier as an input buffer.

## PARALLEL DATA OUTPUT

These converters produce natural Binary Coded outputs when configured as a unipolar device. As a bipolar device, they can produce either Offset Binary or Two's Complement output codes. The most significant bit is represented by Pin 72 (MSB output) for Binary and Offset Binary codes, or by Pin 70 ($\overline{\text{MSB}}$ output) for the Two's Complement code. Tables I and II illustrate the relationship between analog input and digital output for all three codes.

| ANALOG INPUT | | DIGITAL OUTPUT |
|---|---|---|
| 0 to +10V Range | 0 to +20V Range | Binary Code |
| +9.9994V | +19.9988V | 11111111111111 |
| +5.0000V | +10.0000V | 10000000000000 |
| +1.2500V | +2.5000V | 00100000000000 |
| +0.0006V | +0.0012V | 00000000000001 |
| +0.0000V | +0.0000V | 00000000000000 |

*Table I. Nominal Unipolar Input-Output Relationships*

| ±5V Range | ±10V Range | Offset Binary Code | Two's Complement Code |
|---|---|---|---|
| +4.9994V | +9.9988V | 11111111111111 | 01111111111111 |
| +2.5000V | +5.0000V | 11000000000000 | 01000000000000 |
| +0.0006V | +0.0012V | 10000000000001 | 00000000000001 |
| +0.0000V | +0.0000V | 10000000000000 | 00000000000000 |
| -5.0000V | -10.0000V | 00000000000000 | 10000000000000 |

*Table II. Nominal Bipolar Input-Output Relationships*

## SERIAL DATA OUTPUT

The serial data output, available on Pin 32, is of the non-return-to-zero format. The data is transmitted MSB first and is Binary coded for unipolar units and Offset Binary coded for bipolar units.

Figure 3, shown below, indicates one method for transmitting data serially using only three wires (plus a digital ground). The data is clocked into a receiving shift register using the delayed clock output of the converter.

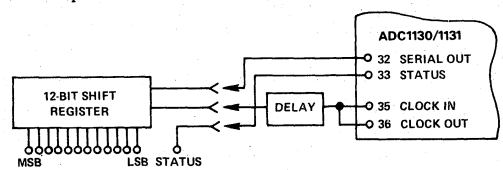



*Figure 3. Serial Data Transmission*

The timing diagram presented in Figure 4 shows that the converter's clock output must be delayed by an amount of time greater than or equal to the sum of the receiving shift register setup time plus the 20ns clock output to serial output delay.

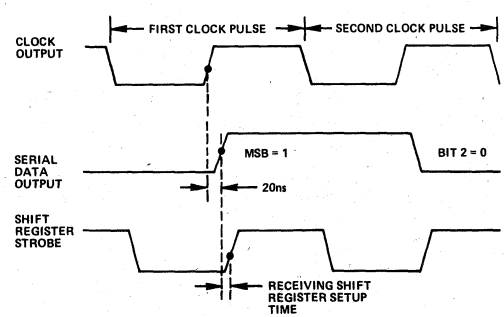



*Figure 4. Serial Data Timing Diagram*

The 50ns span between the time that the last serial output bit is available and the time that the STATUS output returns to zero insures that the data in the shift register will be valid on the "1" to "0" transition of the STATUS signal.

## GAIN AND OFFSET ADJUSTMENTS

The potentiometers used for making gain and offset adjustments are connected as shown in Figure 5. Note that a jumper

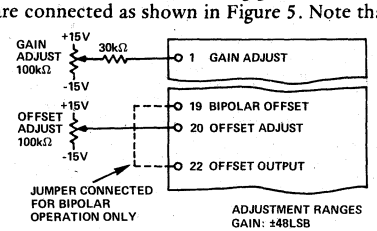



*Figure 5. Adjustment Connections*

is connected between Pin 19 and Pin 22 for bipolar operation; these pins *must* be left open for unipolar operation.

Proper gain and offset calibration requires great care and the use of extremely sensitive and accurate reference instruments. The voltage standard used as a signal source must be very stable. It should be capable of being set to within 1μV of the desired value at both ends of its range.

The gain and offset calibrations will be independent of each other if the offset adjustment is made first. These adjustments are not made with zero and full scale input signals and it may be helpful to understand why. An A/D converter will produce a given digital output for a small range of input signals, the nominal width of the range being one LSB. If the input test signal is set to a value which should cause the output of the converter to be on the verge of switching from one digital value to the adjacent digital value, the unit can be calibrated so that it does change values at just that point. With a high speed convert command rate and a visual display, these adjustments can be performed in a very accurate and sensitive way. Analog Devices' *Analog-Digital Conversion Notes* gives more detailed information on testing and calibrating A/D and D/A converters.

### OFFSET CALIBRATION

For the 0 to +10V unipolar range set the input voltage precisely to +0.0003V; for 0 to +20V units set it to +0.0006V. Adjust the zero potentiometer until the converter is just on the verge of switching from 00 . . . . 0 to 00 . . . . 1.

For the ±5V bipolar range set the input voltage precisely to −4.9997V; for ±10V units set it to −9.9994V. Adjust the zero potentiometer until offset binary coded units are just on the verge of switching from 00 . . . . 0 to 00 . . . . 1 and two's complement coded units are just on the verge of switching from 100 . . . 0 to 100 . . . 1.

### GAIN CALIBRATION

Set the input voltage precisely to +19.9982V for 0 to +20V units, +9.9991V for 0 to +10V units, +4.9991V for ±5V units, or +9.9982V for ±10V units. Note that these values are 1½LSB's less than nominal full scale. Adjust the gain potentiometer until binary and offset binary coded units are just on the verge of switching from 11 . . . 0 to 11 . . . 1 and two's complement coded units are just on the verge of switching from 011 . . . 10 to 011 . . . 11.

### POWER SUPPLY AND GROUNDING CONNECTIONS

These converters do not have an internal connection between analog power ground and digital ground and, thus, a connection must be provided in the external circuitry. The choice of an optimum "star" point for these grounds is an important consideration in the performance of the system. No strict rules can be given, only the general guidelines that the grounding should be arranged in such a manner as to avoid ground loops and to minimize the coupling of voltage drops (on the high current carrying logic supply ground) to the sensitive analog circuit sections. One suggested approach is shown in Figure 6.

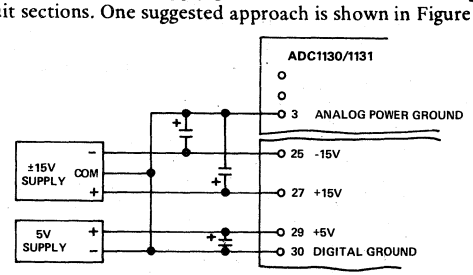



*Figure 6. Power Supply and Grounding Connections*

The ±15V and +5V power supplies must be externally bypassed with 15μF (+35V tantalum) capacitors. These capacitors should be connected between Pin 27 and Pin 3, between Pin 25 and Pin 3, and between Pin 29 and Pin 30. Capacitor connections should be made as close to the module pins as possible.

### CLOCK CONNECTIONS

When the converters are used with their own internal clock, Pin 36 is simply jumpered to Pin 35. When the internal clock is not used, Pin 36 is grounded and an external clock capable of driving three TTL loads is connected to Pin 35. The convert command should be synchronized with the external clock.

### REPETITIVE CONVERSIONS

When making repetitive conversions, a new convert command may be initiated any time after the "1" to "0" transition of the STATUS output. The $\overline{\text{STATUS}}$ output may not, however, be connected directly to the CONVERT COMMAND input for the purpose of automatically generating convert command pulses.

### SHORT CYCLE CONNECTIONS

When the converters are operated as a 14-bit device, Pin 37 is left open. If, however, it is to perform conversions of less than 14 bits, Pin 37 is connected to the N+1 bit output (where N is the number of bits in the conversion). The conversion time in this mode of operation is $T_C$ x N/14 where $T_C$ is the conversion time of the particular model when operated at 14-bit resolution.

### THE AC1578 MOUNTING CARD

The AC1578 mounting card is specifically designed to be used with Analog Devices high resolution, high speed analog-to-digital converters, models ADC1130 and ADC1131. This 4.5″ X 3.56″ (114 X 90mm) printed circuit card, shown in Figure 7, has sockets which allow the converter to be plugged directly onto it. It contains an input buffer that can be programmed using on-board jumpers to provide the input ranges of 0–10 volts, ±10 volts, or ±5 volts. Additionally, a 0–20 volt input range can be achieved by wiring the AC1578 without utilizing the buffer.

The analog information has been isolated from the digital information by the use of two separate connectors, one at the top (designated "P1") and one at the bottom (designated "P2") of the AC1578. Both connectors P1 and P2 are supplied with each card. Whenever feasible, the top connector should be used for analog interfacing to eliminate crosstalk.

Additional wiring information and calibration procedure are contained in a separate data sheet for the AC1578 which is shipped with the card and is available on request.

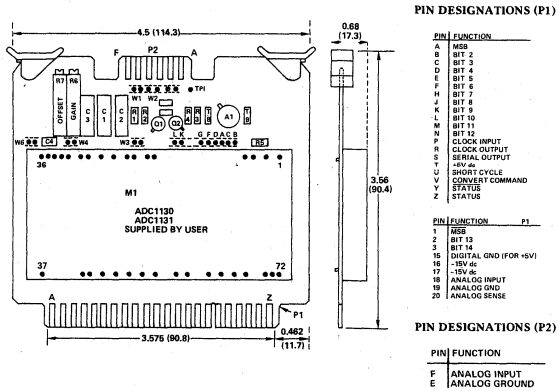



*Figure 7. AC1578 Mounting Card*

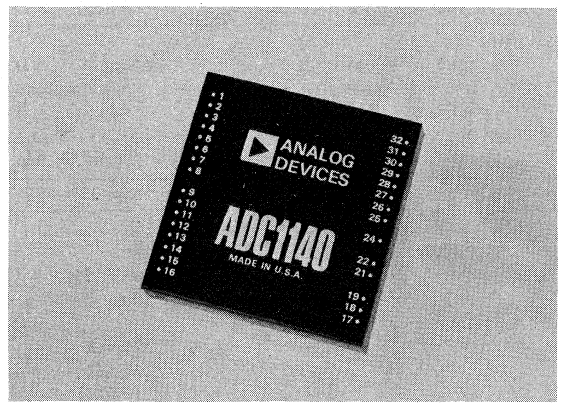
# ANALOG DEVICES

# Low Cost 16-Bit Analog-to-Digital Converter

# ADC1140

**FEATURES**
- **Guaranteed Nonlinearity: ±0.003% FSR max**
- **35μs Maximum Conversion Time**
- **Small Size 2″ × 2″ × 0.4″**
- **Wide Power Supply Operation: ±12V to ±17V**

**APPLICATIONS**
- **Process Control Data Acquisition**
- **Seismic Data Acquisition**
- **Nuclear Instrumentation**
- **Medical Instrumentation**
- **Pulse Code Modulation Telemetry**
- **Industrial Scales**
- **Robotics**




## GENERAL DESCRIPTION

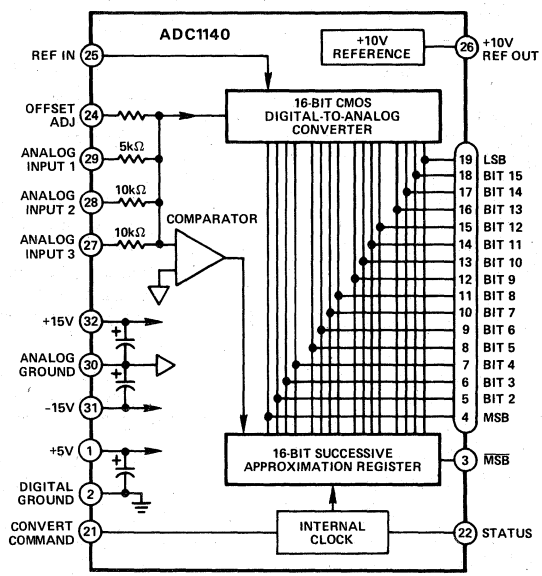
The ADC1140 is a low cost 16-bit successive-approximation analog-to-digital converter having a 35μs maximum conversion time. This converter provides high accuracy, high stability and low power consumption all in a 2″ × 2″ × 0.4″ module.

High accuracy performance such as integral and differential nonlinearity of ±0.003% FSR max are both guaranteed. Guaranteed stability such as differential nonlinearity TC of ±2ppm/°C maximum, offset TC of ±30μV/°C maximum, gain TC of ±12ppm/°C maximum and power supply sensitivity of ±0.002% of FSR/% $V_S$ are also provided by the ADC1140.

The ADC1140 makes extensive use of both integrated circuit and thin-film components to obtain excellent performance, small size and low cost. The internal 16-bit DAC incorporates Analog Devices' proprietary thin-film resistor technology and proprietary CMOS current-steering switches. A low noise reference, low power comparator and low power successive-approximation register are also used to optimize the ADC1140's design (shown in Figure 1).

The ADC1140 can operate with power supplies ranging from ±12V to ±17V and has provisions for a user supplied external reference. Four analog input voltage ranges are selectable via pin programming: ±5V, ±10V, 0 to +5V and 0 to +10V. Bipolar coding is provided in the offset binary and two's complement formats with unipolar coding displayed in true binary.

**ADC1140 FUNCTIONAL BLOCK DIAGRAM**




11

# SPECIFICATIONS (typical @ +25°C ±$V_S$ = ±15V, $V_{CC}$ = +5V, $V_{REF}$ = +10.0V unless otherwise specified)

| Model | ADC1140 |
|---|---|
| RESOLUTION | 16 Bits |
| CONVERSION TIME | 35μs max |
| ACCURACY[1] | |
| Nonlinearity Error | ±0.003% FSR[2] max |
| Differential Nonlinearity Error | ±0.003% FSR[2] max |
| STABILITY | |
| Differential Nonlinearity | ±2ppm/°C max |
| Gain (with internal reference) | ±12ppm/°C max |
| (without internal reference) | ±4ppm/°C max |
| Unipolar Offset | ±30μV/°C max |
| Bipolar Offset | ±7ppm/°C max |
| POWER SUPPLY SENSITIVITY | ±0.002% FSR/% $V_S$ |
| ANALOG INPUT | |
| Voltage Ranges | |
| Bipolar | ±5V, ±10V |
| Unipolar | 0 to +5V, 0 to +10V |
| Input Resistance | |
| 0 to +5V | 2.5kΩ |
| 0 to +10V, ±5V | 5.0kΩ |
| ±10V | 10.0kΩ |
| External Reference Input[3] | |
| Voltage Range | 0 to +12V |
| Input Resistance | 2.5kΩ |
| DIGITAL INPUT | |
| Convert Command | Positive Pulse, 100ns Width min<br>Negative Edge Triggered |
| Logic Loading | 1TTL Load |
| DIGITAL OUTPUT | |
| Parallel Output Data | |
| Unipolar | Binary (BIN) |
| Bipolar | Offset Binary (OBIN) Two's Complement |
| Output Drive | 1TTL Load |
| Status | Logic "1" During Conversion |
| Output Drive | 1TTL Load |
| INTERNAL REFERENCE VOLTAGE | +10V, ±0.3% |
| External Load Current | |
| (Rated Performance) | 2mA max |
| Temperature Stability | ±8.5ppm/°C max |
| POWER REQUIREMENTS[4] | |
| Voltage (Rated Performance) | ±15V ±3%, +5V ±3% |
| Voltage (Operating) | ±12V to ±17V, +4.75V to +5.25V |
| Supply Current Drain ±15V | ±25mA |
| +5V | 150mA |
| TEMPERATURE RANGE | |
| Specified | 0 to +70°C |
| Operating | -25°C to +85°C |
| Storage | -55°C to +85°C |
| SIZE | 2" X 2" X 0.4" (51 X 51 X 10.4mm) |
| Weight | 1.2 oz (33g) |

NOTES

[1] Offset and gain error are adjustable to zero by means of external potentiometers. See Figure 3 for proper connection.

[2] FSR means Full Scale Range.

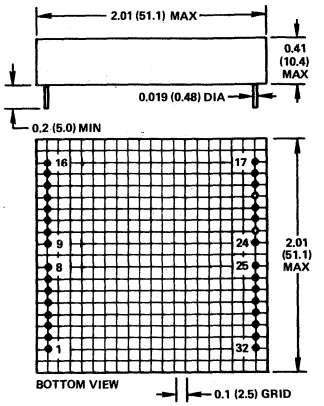
[3] Rated performance is specified with +10.0V reference.

[4] Recommended Power Supply: Analog Devices Model 923.

Specifications subject to change without notice.

## OUTLINE DIMENSIONS

Dimensions shown in inches and (mm).




TERMINAL PINS INSTALLED ONLY IN SHADED HOLE LOCATIONS.

## MATING CONNECTORS

AC1577 (2 REQUIRED)

## PIN DESIGNATIONS

| PIN | FUNCTION | PIN | FUNCTION |
|---|---|---|---|
| 1 | +5V | 32 | +15V |
| 2 | DIGITAL GROUND | 31 | -15V |
| 3 | MSB | 30 | ANALOG GROUND |
| 4 | MSB | 29 | ANALOG IN 1 |
| 5 | BIT 2 | 28 | ANALOG IN 2 |
| 6 | BIT 3 | 27 | ANALOG IN 3 |
| 7 | BIT 4 | 26 | +10V REF OUT |
| 8 | BIT 5 | 25 | REFERENCE IN |
| 9 | BIT 6 | 24 | OFFSET ADJUST |
| 10 | BIT 7 | 23 | NOT USED |
| 11 | BIT 8 | 22 | STATUS |
| 12 | BIT 9 | 21 | CONVERT COMMAND |
| 13 | BIT 10 | 20 | NOT USED |
| 14 | BIT 11 | 19 | LSB |
| 15 | BIT 12 | 18 | BIT 15 |
| 16 | BIT 13 | 17 | BIT 14 |

## OTHER HIGH RESOLUTION PRODUCTS FROM ANALOG DEVICES:

- 14-Bit/15-Bit Sampling A/D Converters; DAS1152/53
  - 25kHz (14-Bit)/20kHz (15-Bit) throughput rates
  - Second Source to A/D/A/M824 and A/D/A/M825 Modules
- 14-Bit/15-Bit Low Level Data Acquisition Systems: DAS1155/56
  - 25kHz (14-Bit)/20kHz (15-Bit) throughput rates
  - High Performance PGIA (1V/V–1000V/V), SHA and A/D Converter
- 14-Bit Sample-Hold Amplifier: SHA1144
  - Acquisition Time: 8μs max to ±0.003% (20V step)

## OPERATION

For operation, the only connections to the ADC1140 that are necessary are the power supplies, internal or external reference, input voltage pin programming, convert command and digital output. Refer to Table I for input pin programming and Figure 3 for offset and gain calibration.

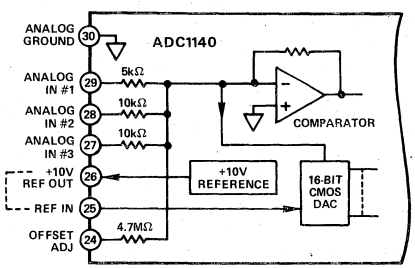



*Figure 2. Analog Input Block Diagram*

## ANALOG INPUT PROGRAMMING

The analog input section consists of three analog input terminals. Analog input range selection is accomplished by pin programming as shown in Table I.

In the unipolar mode, a 0 to +10V or a 0 to +5V input signal develops a 0 to +2mA current that is compared to the 0 to −2mA (shown in Figure 2) current output of the DAC.

In the bipolar mode, a +1mA offset current from the reference is applied to the comparator input via pin programming connections. The ADC1140 can then accept either ±5V or ±10V inputs. These inputs again will be converted to current and compared with the DAC's 0 to −2mA current output.

| Input Signal Range | Coding | Connect Input Signal To Pin(s) | Connect Pin 26 To Pin* | Connect Pin 30 To Pin(s) |
|---|---|---|---|---|
| ±10V | OBIN, Two's Comp | 28 | 27 | 29, 2 |
| ±5V | OBIN, Two's Comp | 29 | 27 | 28, 2 |
| 0 to +5V | BIN | 27, 28, 29 | Open | 2 |
| 0 to +10V | BIN | 27, 28 | Open | 29, 2 |

*If Internal Reference is used, Pins 25 and 26 must be connected together through a 50Ω potentiometer or 24.9Ω fixed resistor (see Figure 3 and the gain calibration section).

*Table I. Analog Input Voltage Pin Programming*

## OPTION OFFSET & GAIN CALIBRATION

Initial offset and gain errors can be adjusted to zero by potentiometers as shown in Figure 3. Proper offset and gain calibration requires great care and the use of an accurate and stable voltage reference. The voltage standard used as a signal source must be very stable. It should be capable of being set to within 1μV of the desired value at both ends of its range. The potentiometers selected should be of the good quality Cermet type. Multi-turn potentiometers having ten to fifteen turns and 100ppm/°C temperature coefficients will be adequate. The temperature coefficients contributed by these Cermet potentiometers will be less than 0.1ppm/°C.

By adjusting the offset first, gain and offset adjustments will remain independent of each other.

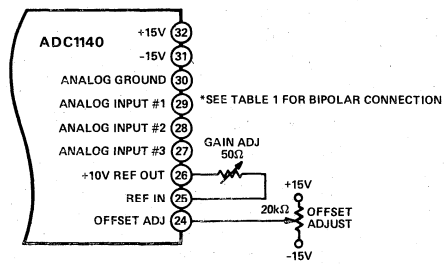



*Figure 3. Offset and Gain Calibration*

## OFFSET CALIBRATION

For 0 to +10V range, set the input voltage precisely to +76μV; for 0 to +5V range, set it at +38μV. Adjust the zero potentiometer until the binary coded converter is just on the verge of switching from 000 . . . 00 to 000 . . . 01.

For ±5V range, set the input voltage precisely to −4.999924V; for ±10V range, set it at −9.999847V. Adjust the zero potentiometer until the offset binary coded units are just on the verge of switching from 000 . . . 00 to 000 . . . 01 and the two's comp. coded units are just on the verge of switching from 100 . . . 0 to 100 . . . 1.

## GAIN CALIBRATION

Set the input voltage precisely at +9.99977V for 0 to +10V input range, +4.99977V for ±5V input range, +9.99954V for ±10V input range, or +4.99988V for 0 to +5V input range, adjust the gain potentiometer until binary and offset binary coded units are just on the verge of switching from 111 . . . 0 to 111 . . . 1 and two's comp. coded units are just on the verge of switching from 011 . . . 10 to 011 . . . 11. Note that these values are 1 1/2 LSBs less than nominal full scale.

## POWER SUPPLY AND GROUNDING CONNECTIONS

The analog power ground (pin 30) and digital ground (pin 2) are not connected internally. The connection must be made externally. The choice of an optimum "star" point is an important consideration in avoiding ground loops and to minimize coupling between the analog and digital sections. One suggested approach is shown in Figure 4.

Because the ADC1140 contains high quality tantalum capacitors on each of the power supply inputs to ground, external bypass capacitors are not required.

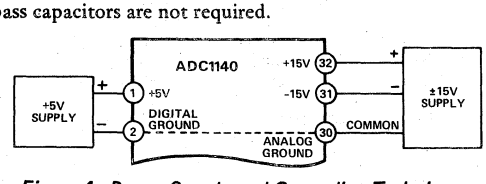



*Figure 4. Power Supply and Grounding Techniques*

## ADC1140 TIMING

Conversion is initiated with the negative going edge of the Convert Command pulse as shown in Figure 5. The Convert Command pulse width must be a minimum of 100ns. Once the conversion process is initiated, it cannot be retriggered until after the end of conversion.

With the negative edge of the Convert Command pulse, all internal logic is reset. The MSB is set low with the remaining digitial outputs set to logic high state, and the status line is set high and remains high thru the full conversion cycle.

During conversion each bit, starting with the MSB, is sequentially switched low at the rising edge of the internal clock. The DAC output is then compared to the analog input and the bit decision is made. Each comparison lasts one clock cycle with the complete 16-bit conversion taking 35μs maximum. At this time, the STATUS line goes low signifying that the low conversion is complete.

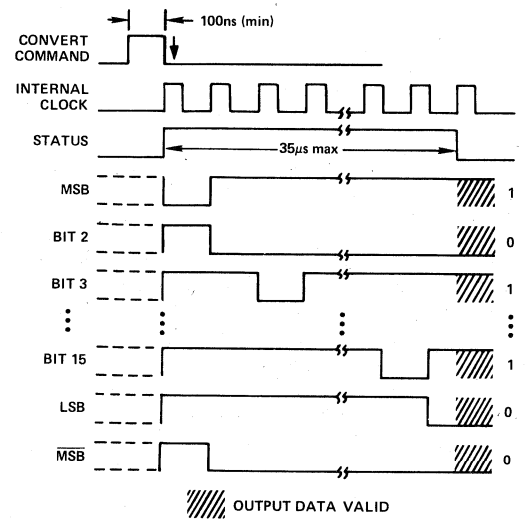



*Figure 5. ADC1140 Timing Diagram*

## ANALOG INPUT/OUTPUT RELATIONSHIPS

The ADC1140 produces a true binary coded output when configured as a unipolar device. Configured as a bipolar device, it can produce either offset binary or two's complement output codes. The most significant bit (MSB) is displayed on pin 4 for the binary and offset binary codes or on pin 3 for the two's complement code. Table II shows the unipolar analog input/digital output relationships. Table III shows the bipolar analog input/digital output relationships for offset binary code and two's complement codes.

| Analog Input 0 to +5V Range | Analog Input 0 to +10V Range | Digital Output Binary Code |
|---|---|---|
| +4.999924V | +9.99985V | 1111 1111 1111 1111 |
| +2.50000V | +5.00000V | 1000 0000 0000 0000 |
| +1.25000V | +2.50000V | 0100 0000 0000 0000 |
| +0.62500V | +1.25000V | 0010 0000 0000 0000 |
| +0.000076V | +0.000153V | 0000 0000 0000 0001 |
| +0.00000V | +0.00000V | 0000 0000 0000 0000 |

*Table II. Unipolar Input/Output Relationships*

| Analog Input ±5V Range | Analog Input ±10V Range | Digital Output Offset Binary Code | Digital Output 2's Complement Code |
|---|---|---|---|
| +4.99985V | +9.99970V | 1111 1111 1111 1111 | 0111 1111 1111 1111 |
| +2.50000V | +5.00000V | 1100 0000 0000 0000 | 0100 0000 0000 0000 |
| +0.000153V | +0.000305V | 1000 0000 0000 0001 | 0000 0000 0000 0001 |
| +0.00000V | +0.00000V | 1000 0000 0000 0000 | 0000 0000 0000 0000 |
| -5.00000V | -10.00000V | 0000 0000 0000 0000 | 1000 0000 0000 0000 |

*Table III. Bipolar Input/Output Relationships*

## HIGH RESOLUTION DATA ACQUISITION SYSTEM

Shown in Figure 6 is a high resolution data acquisition system. Here the SHA1144, a high resolution sample-hold amplifier, is used to drive the ADC1140. Conversion is initiated by the negative edge of the convert command pulse. At this time the STATUS pulse goes low causing the SHA1144 to go from the sample mode to the hold mode. When the conversion is complete, 35μs later, the STATUS pulse goes low, thus placing the SHA1144 in the sample mode.

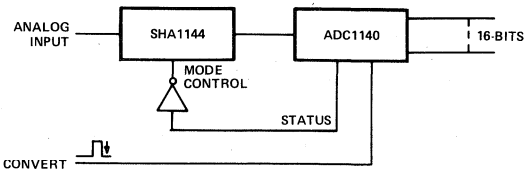



*Figure 6. High Resolution Data Acquisition System*

## EXTERNAL REFERENCE

The ADC1140 is capable of operating with an external +10.0V reference. Simply disconnect the gain trim potentiometer from pin 26 and connect it to the external reference as shown in Figure 7. The external reference output must appear as a low impedance and must remain very stable during conversion to insure that accuracy is maintained. Gain error is adjusted as previously discussed in the gain calibration section.

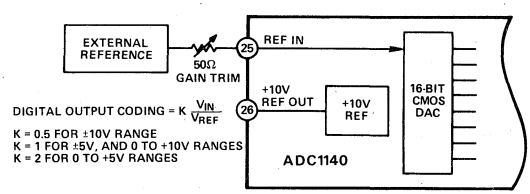



*Figure 7. External Reference*

The ADC1140 is factory tested and calibrated with the internal +10.0V reference voltage but nonstandard external voltages can be used with the digital output coding being determined by the formula shown in Figure 7.

## PIA INTERFACE

The ADC1140 can be used with a PIA to interface directly to a microprocessor. As shown in Figure 8 the 16-bit output of the ADC1140 is split into two 8-bit bytes. Part A of the PIA is programmed to read the eight most-significant-bits while Part B reads the eight least-significant-bits. Output CB2 is used to start the ADC1140 conversion process. CB1, of the PIA, is used to sense the STATUS of the ADC1140 so that the end of conversions can be determined. The control bus, address bus, and data bus are then connected directly to the microprocessor.

With the use of PIAs, control of one or more ADC1140s can be accomplished in many different configurations.

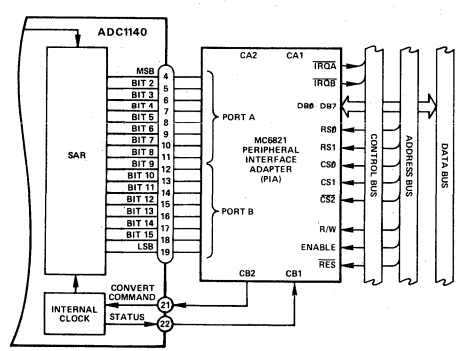



*Figure 8. ADC1140 Interface to PIA*

# Low Power/High Performance 16-Bit A/D Converter

# ADC1143

**FEATURES**

**Low Power Consumption:**
- **175mW max, $V_S$ = ±15V**
- **150mW max, $V_S$ = ±12V**

**Guaranteed Nonlinearity:**
- **±0.006% FSR max (ADC1143J)**
- **±0.003% FSR max (ADC1143K)**

**Guaranteed Differential Nonlinearity:**
- **±0.006% FSR max (ADC1143J)**
- **±0.003% FSR max (ADC1143K)**

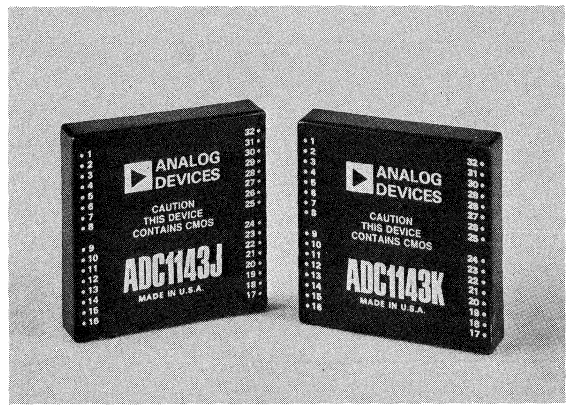
**Low Differential Nonlinearity T.C.:**
- **±2ppm/°C max (ADC1143J)**
- **±1ppm/°C max (ADC1143K)**

**Fast Conversion Time:**
- **70µs max (ADC1143J)**
- **100µs max (ADC1143K)**

**Wide Power Supply Operation:**
- **$V_S$ = ±11.4V to ±18.0V**
- **$V_D$ = +3.0V to +18.0V**

**APPLICATIONS**

**Seismic Data Acquisition**
**Oil Well Instrumentation**
**Portable Industrial Scales**
**Portable Test Equipment**
**Robotics**




The ADC1143 can operate with power supply voltages ranging from ±11.4V dc to ±18.0V dc for $V_S$ and +3V dc to +18V dc for the $V_D$ supply. An internal voltage reference is provided, but an external reference can be used. Five analog input voltage ranges are selectable via user pin programming: +5V, +10V, +20V, ±5V and ±10V. Digital output coding in unipolar operation is true binary; for bipolar operation, the coding is offset binary or two's complement. Digital outputs are provided in both parallel and serial formats.

11

## GENERAL DESCRIPTION

The ADC1143 is a low power 16-bit successive-approximation analog-to-digital converter with a maximum power consumption of 175mW at $V_S$ = ±15V, 150mW at $V_S$ = ±12V, and is contained in a 2″ × 2″ × 0.4″ module.

High performance like integral nonlinearity of ±0.006% FSR (ADC1143J)/±0.003% FSR (ADC1143K) and differential nonlinearity of ±0.006% FSR (ADC1143J)/±0.003% FSR (ADC1143K) are guaranteed. Additional guaranteed performance includes: differential nonlinearity T.C. of ±2ppm/°C (ADC1143J)/±1ppm/°C (ADC1143K), offset T.C. ±40µV/°C and gain T.C. ±12ppm/°C.

The ADC1143 makes extensive use of CMOS integrated circuits and thin-film components to obtain low power consumption, excellent performance and small size. The internal 16-bit CMOS DAC incorporates Analog Devices' proprietary thin-film resistor technology and proprietary current steering switches. CMOS successive-approximation registers, low power comparator and low noise reference are also used to optimize the performance of the ADC1143 (shown in Figure 1).

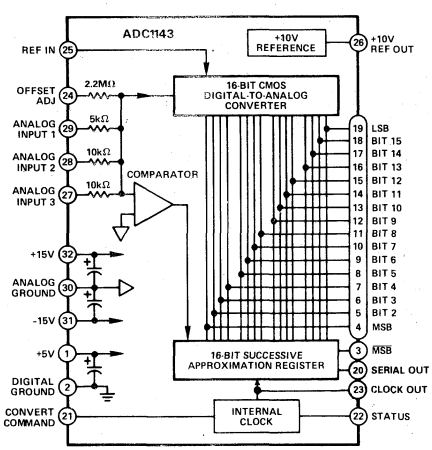



*Figure 1. ADC1143 Functional Block Diagram*

# SPECIFICATIONS (typical @ +25°C, $V_S = \pm 15V$, $V_D = +5V$, $V_{REF} = +10V$ unless otherwise specified)

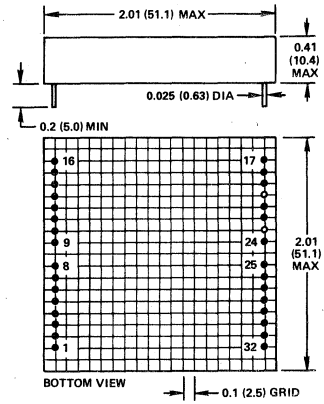
| MODEL | ADC1143J | ADC1143K |
|---|---|---|
| RESOLUTION | 16 Bits | * |
| CONVERSION TIME | 70μs (max) | 100μs (max) |
| ACCURACY | | |
| Integral Nonlinearity | ±0.006% FSR[1] (max) | ±0.003% FSR[1] (max) |
| Differential Nonlinearity | ±0.006% FSR[1] (max) | ±0.003% FSR[1] (max) |
| No Missing Codes (0 to +50°C) | | |
| 13 Bits | Guaranteed | |
| 14 Bits | | Guaranteed |
| STABILITY | | |
| Differential Nonlinearity | ±2ppm/°C (max) | ±1ppm/°C (max) |
| Offset | ±40μV/°C (max) | * |
| Bipolar Offset | ±9ppm/°C (max) | * |
| Gain | ±12ppm/°C (max) | * |
| ANALOG INPUT | | |
| Voltage Range | | |
| Unipolar | +5V, +10V, +20V | * |
| Bipolar | ±5V, ±10V | * |
| Input Resistance | | |
| +5V | 2.5kΩ | * |
| +10V, ±5V | 5.0kΩ | * |
| +20V, ±10V | 10.0kΩ | * |
| External Reference Input | | |
| Voltage Range[2] | 0 to +12V | * |
| Input Resistance | 10kΩ | * |
| DIGITAL INPUTS | | |
| Convert Command | Positive Pulse, 1μs width (min) negative edge triggered | * |
| Logic Loading | CMOS Compatible | * |
| DIGITAL OUTPUTS | | |
| Parallel Output Data | | |
| Unipolar | Binary (BIN) | * |
| Bipolar | Offset Binary (OBIN), Two's Comp | * |
| Output Drive | CMOS Comp, 2LSTTL Loads | * |
| Status | "0" During Conversion | * |
| Output Drive | CMOS Comp, 2LSTTL Loads | * |
| Serial Output | | |
| Output Drive | CMOS Comp, 1 LSTTL Load[3] | * |
| Clock Output | | |
| Output Drive | CMOS Comp, 1 LSTTL Load | * |
| INTERNAL REFERENCE ($V_{REF}$) | | |
| Voltage | +10V, ±0.3% | * |
| External Load Current | 2mA max | * |
| Temperature Stability | ±8.5ppm/°C max | * |
| POWER REQUIREMENTS | | |
| Voltage (rated performance) | ±15V(±5%), +5V(±5%) | * |
| Voltage (operating) | ±11.4V to ±18V, +3V to +18V | * |
| Supply Current Drain | | |
| $+V_S = +15V$ | 4mA | * |
| $-V_S = -15V$ | 5mA | * |
| $+V_D = +5V$ | 4mA | * |
| Total Power | | |
| $V_S = \pm 12V, V_D = +5V$ | 150mW max | * |
| $V_S = \pm 15V, V_D = +5V$ | 175mW max | * |
| POWER SUPPLY SENSITIVITY | | |
| Offset | ±0.001%FSR/% $\pm V_S$ | * |
| Gain | ±0.001%FSR/% $\pm V_S$ | * |
| TEMPERATURE RANGE | | |
| Rated Performance | 0 to +70°C | * |
| Operating | −25°C to +85°C | * |
| Storage | −25°C to +85°C | * |
| Relative Humidity | Meets MIL-STD 202E, Method 103B | * |
| SIZE | 2" × 2" × 0.4" (50.8 × 50.8 × 10.16mm) | * |
| Weight | 33g | * |

NOTES
[1]FSR Means Full Scale Range.
[2]Rated performance is specified with +10.0V reference.
[3]LSTTL drive requires 2.2kΩ pulldown resistor.

Offset and gain errors are adjustable to zero by means of external potentiometers.
See Figure 3 for proper connections.
Recommend Power Supply: Analog Devices Model 923
*Specifications same as ADC1143J
Specifications subject to change without notice.

## OUTLINE DIMENSIONS

Dimensions shown in inches and (mm).




TERMINAL PINS INSTALLED ONLY IN SHADED HOLE LOCATIONS.

## MATING CONNECTORS AC1584-3 (2 REQUIRED)

## PIN DESIGNATIONS

| PIN | FUNCTION | PIN | FUNCTION |
|---|---|---|---|
| 1 | +5V | 32 | +15V |
| 2 | DIGITAL GROUND | 31 | -15V |
| 3 | MSB | 30 | ANALOG GROUND |
| 4 | MSB | 29 | ANALOG IN 1 |
| 5 | BIT 2 | 28 | ANALOG IN 2 |
| 6 | BIT 3 | 27 | ANALOG IN 3 |
| 7 | BIT 4 | 26 | +10V REF OUT |
| 8 | BIT 5 | 25 | REFERENCE IN |
| 9 | BIT 6 | 24 | OFFSET ADJUST |
| 10 | BIT 7 | 23 | CLOCK OUT |
| 11 | BIT 8 | 22 | STATUS |
| 12 | BIT 9 | 21 | CONVERT COMMAND |
| 13 | BIT 10 | 20 | SERIAL OUT |
| 14 | BIT 11 | 19 | LSB |
| 15 | BIT 12 | 18 | BIT 15 |
| 16 | BIT 13 | 17 | BIT 14 |

## OPERATION

For operation, the only connections to the ADC1143 that are necessary are the power supplies, internal or external reference, input voltage pin programming, convert command and digital output. Refer to Table I for input pin programming and Figure 3 for offset and gain calibration.

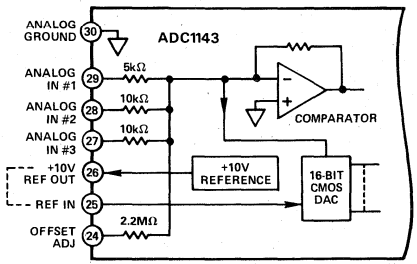



*Figure 2. Analog Input Block Diagram*

## ANALOG INPUT RANGE

The analog input voltage section of the ADC1143 consists of three analog input terminals (see Figure 2). Analog input voltage range selection is accomplished by pin programming as shown in Table I.

In the unipolar mode, a +5V, +10V or +20V input signal can be applied. These input voltages develop a 0 to +2mA current which is compared to the 0 to −2mA current output of the internal reference DAC in the ADC1143. In the bipolar mode, a ±5V or ±10V input signal can be applied. These input voltages develop a ±1mA current which is compared to a 0 to −2mA current of the internal reference DAC which is offset by +1mA, to produce a ±1mA current.

## OFFSET AND GAIN CALIBRATION

Initial offset and gain errors can be adjusted to zero by potentiometers as shown in Figure 3. Proper offset and gain calibration requires great care and the use of extremely sensitive and accurate reference instruments. The voltage reference used as a signal source must be very stable and have the capability of being set within ±1μV of the desired value. The potentiometers should be good quality cermet type. Multiturn potentiometers having ten to fifteen turns and ±100ppm/°C temperature coefficients will be adequate. The temperature coefficient contribution will be less than ±0.1ppm/°C.

By adjusting the offset first, gain and offset adjustment will remain independent of each other.

## OFFSET CALIBRATION

For +5V range, set the input voltage to precisely +38μV; for +10V range, set it to +76μV; for +20V range, set it to +153μV.

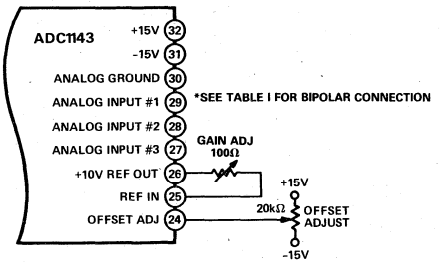



*Figure 3. Offset and Gain Calibration*

Adjust the offset potentiometer until the binary output code is on the verge of switching from 000 . . . 00 to 000 . . . 01.

For ±5V range, set the input voltage to precisely −4.999924V; for ±10V range, set it to −9.999847V. Adjust the offset potentiometer until the offset binary code is on the verge of switching between 000 . . . 00 and 000 . . . 01, and two's complement coded units are switching from 100 . . . 00 to 100 . . . 01.

## GAIN CALIBRATION

For +5V range, set the input voltage to precisely +4.99988V; for +10V range, set it to +9.99977V; for +20V range, set it to +19.9995V. Adjust the gain potentiometer until the binary output code is on the verge of switching from 111 . . . 10 to 111 . . . 11.

For ±5V range, set the input voltage to precisely +4.99977V; for ±10V range, set it to +9.99954V. Adjust the gain potentiometer until the offset binary code is on the verge of switching from 111 . . . 10 to 111 . . . 11, and the two's complement coded units are switching from 011 . . . 10 to 011 . . . 11.

## POWER SUPPLY AND GROUNDING CONNECTIONS

The analog power ground (pin 30) and digital ground (pin 2) are not connected internally in the ADC1143, thus the connection must be made externally. The choice of an optimum "star" point is an important consideration in avoiding ground loops and to minimize coupling between the analog and digital sections. One suggested approach is shown in Figure 4.

Because the ADC1143 contains high quality tantalum capacitors on each of the power supply inputs to ground, external bypass capacitors are not required.

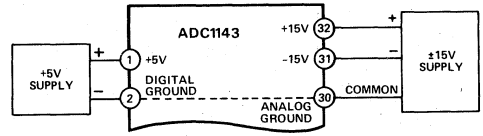



*Figure 4. Power Supply and Grounding Techniques*

| Input Voltage Range | Output Coding | Connect Input Signal To Pin(s) | Connect Pin* 26 to Pin # | Connect Pin 30 to Pin(s) |
|---|---|---|---|---|
| +5V | BIN | 27, 28, 29 | open | 2 |
| +10V | BIN | 27, 28 | open | 2, 29 |
| +20V | BIN | 27 | open | 2, 28, 29 |
| ±5V | OBIN, 2's Comp | 29 | 27 | 2, 28 |
| ±10V | OBIN, 2's Comp | 28 | 27 | 2, 29 |

*If internal reference is used, Pins 25 and 26 must be connected together through a 100Ω potentiometer or 49.9Ω fixed resistor (see Figure 3 and Gain Calibration Section).

*Table I. Analog Input Voltage Range Pin Programming*

## EXTERNAL REFERENCE

The ADC1143 is capable of operating with an external reference. Simply disconnect the gain trim potentiometer from Pin 26 and connect it to the external reference as shown in Figure 5. The ADC1143 is tested and specified with a +10.0V reference. An external reference with a voltage of 0 to +12V can be applied. The external reference must appear as a low impedance and must remain very stable during conversion to insure that accuracy is maintained.

When using an external reference, the digital output coding can be determined by the formula shown in Figure 5.

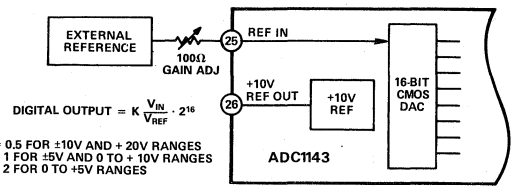



*Figure 5. External Reference*

## ADC1143 TIMING

Conversion is initiated with the negative going edge of the convert command pulse as shown in Figure 6. The convert command pulse width must be a minimum of 1μs. Once the conversion process is initiated, it cannot be retriggered until after the end of conversion.

With the negative edge of the convert command pulse, all internal logic is reset. The MSB is set high with the remaining bits set to logic low. The status line is set low and remains low through the full conversion cycle.

During conversion, each bit starting with the MSB is set high on the rising edge of the internal clock. The ADC's internal DAC output is then compared to the analog input and the bit decision is made. Each comparison lasts one clock cycle with the complete conversion of the ADC1143J and ADC1143K

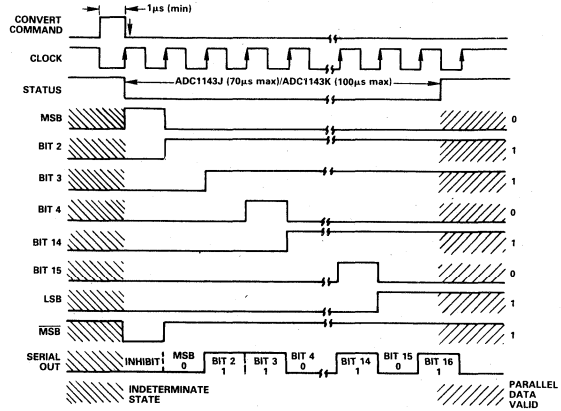



*Figure 6. ADC1143 Timing Diagram*

taking 70μs max and 100μs max respectively. The parallel output data is valid on the rising edge of the status line.

Serial output data is valid for each bit at the completion of clock cycle used to make the bit decision as shown in Figure 6.

## SEISMIC DATA ACQUISITION APPLICATION

The ADC1143's low power consumption and high performance make it ideally suited for portable seismic data acquisition systems like the one shown in Figure 7. In seismic data acquisition systems, geophones are used to receive reflected shock waves from subsurface strata, induced by controlled discharge of explosives. These reflected signals may travel several miles before reaching the geophones and are difficult to discern from noise or other interference like ground roll. The low level signals from the geophones are amplified and filtered appropriately to remove the undesired signals. The conditioned signal is amplified by the PGA then held by SHA and converted to digital form by the ADC1143. The digital data is stored on an on-site recorder for later data collection and processing.

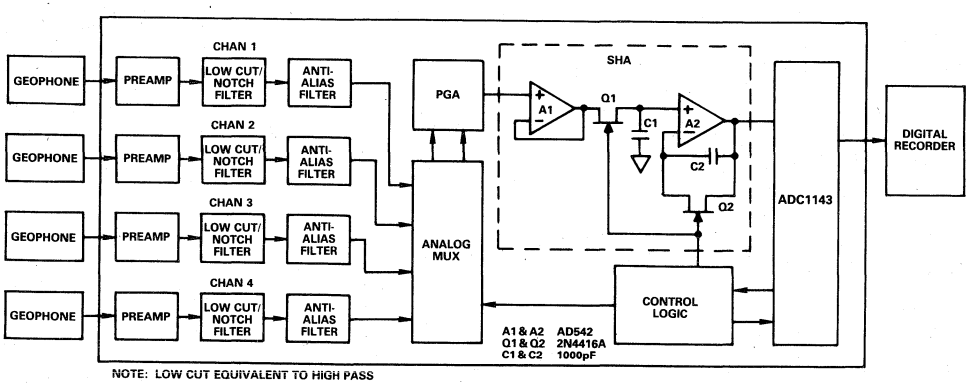



*Figure 7. Seismic Data Acquisition System Block Diagram*

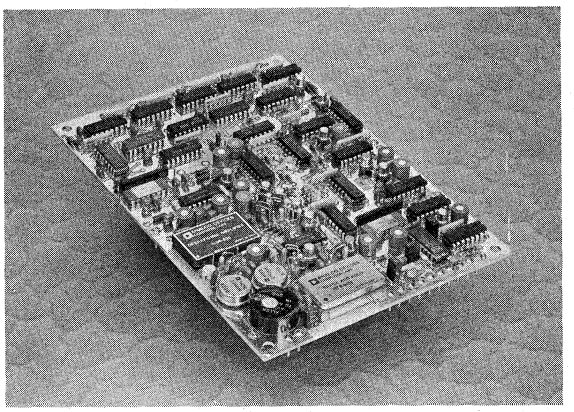
# ANALOG DEVICES

# 9-Bit Video Analog-to-Digital Converter

# CAV-0920

**FEATURES**
**9-Bit Resolution**
**20MHz Word Rate**
**Single 35-In$^2$ PC Board**
**ECL Compatible**
**No External Circuits Required**

**APPLICATIONS**
**Television Digitizing**
**Radar Digitizing**
**Medical Instrumentation**
**Digital Communications**
**Spectrum Analysis**



## GENERAL DESCRIPTION

The Analog Devices model CAV-0920 A/D converter combines performance, size, and economy to achieve a remarkable solution for high-speed digitizing problems.

The unit provides digital data with 9-bits of resolution at word rates from dc through 20MHz. It is a complete answer to the question of digitizing video, radar, and other high-frequency inputs; it includes a track-and-hold, along with encoding and timing circuits. The CAV-0920 is a "system solution" for the designer who wants to avoid the need to combine the plethora of components necessary to make IC encoders operate as functional A/D converters.

The unique digital correcting subranging (DCS) conversion technique used in the design virtually eliminates the errors normally associated with subranging A/D converters.

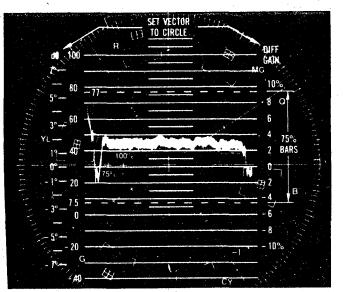
The CAV-0920 is constructed on a single PC board intended for mounting on a "mother" board in the user's system. Its small size makes it adaptable to a wide range of mother board sizes and allows room for including other (signal conditioning, processing, memory, etc.) circuits adjacent to the converter.

All inputs and outputs are ECL compatible. The A/D requires only an encode command and external power supplies for operation. Analog input impedance is 500 ohms/volt, making it easy to match lower impedances within the system.

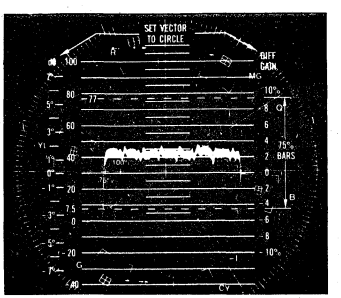
Gain and offset potentiometers on the PC card permit adjusting the input for optimum system operation.

With the exception of having two less pins (Bit 10 true and complement outputs), the CAV-0920 is pin-for-pin compatible with the MOD-1020.

Hybrid microcircuits, ICs, and discrete components are combined in the design, to obtain the maximum benefits of all technologies. The CAV-0920 is factory repairable and backed by Analog Devices' limited one-year warranty.




*Differential Phase – Model CAV-0920 A/D and Deglitched HDS-1015E D/A in Back-to-Back Arrangement; 15MHz Word Rate*




*Differential Gain – Model CAV-0920 A/D and Deglitched HDS-1015E D/A in Back-to-Back Arrangement; 15MHz Word Rate*

*The waveforms above were obtained using a Tektronix Model 149A N.T.S.C. Test Signal Generator with a 20-IRE TV test signal output. The display (output) was obtained using a Tektronix Model 520A Vectorscope.*

11

# SPECIFICATIONS (typical at +25°C with nominal power supplies unless otherwise noted)

| Model | Units | CAV-0920 |
|---|---|---|
| RESOLUTION (FS = Full Scale) | Bits (% FS) | 9 (0.2) |
| LSB WEIGHT | mV | 2 or 4 (Depending on Input) |
| ACCURACY | | |
| (Including Linearity) @ dc | % FS ± 1/2LSB | 0.1 |
| Monotonicity | | Guaranteed 0 to +70°C |
| Nonlinearity vs. Temperature | % of FS/°C | 0.001 |
| Gain vs. Temperature | % of FS/°C | 0.02 |
| DYNAMIC CHARACTERISTICS | | |
| AC Linearity (dc to 1MHz) | dB below FS[1] | 55 |
| (1MHz to 5MHz) | | 50 |
| (5MHz to 10MHz) | | 45 |
| Conversion Time[2] | ns (max) | 180 (±20) |
| Conversion Rate[3] | MHz | 20 |
| Aperture Uncertainty (Jitter) | ps, rms | ±25 |
| Aperture Time (Delay) | ns | 10 |
| Signal to Noise Ratio[4] | dB | 52 |
| Signal to Noise Ratio[5] | dB | 61 |
| Noise Power Ratio[6] | dB | 41 |
| Transient Response[7] | ns | 50 |
| Overvoltage Recovery[8] | ns | 50 |
| Input Bandwidth | | |
| Small Signal, 3dB[9] | MHz, min | 30 |
| Large Signal, 3dB[10] | MHz, min | 15 |
| Two Tone Linearity (@ Input Frequencies) | | |
| (60kHz; 62kHz) | dB below FS | 55 |
| (4.998MHz; 5.000MHz) | dB below FS | 50 |
| (9.996MHz; 9.998MHz) | dB below FS, min | 45 |
| Differential Gain[11,12] | % | 2 |
| Differential Phase[11,12] | Degree | 1 |
| ANALOG INPUT | | |
| Voltage Range | V | 1 p-p or 2 p-p, Depending on Jumper Option |
| | V, max | ±4 |
| Input Type | | Unipolar or Bipolar |
| Impedance | Ohms | 500 or 1000, Depending on Jumper Option |
| Offset | | Adjustable to Zero With On-Board Potentiometer |
| Offset vs. Temperature | % of FS/°C | 0.01 |
| ENCODE COMMAND INPUT | | |
| Logic Levels, ECL-Compatible | V | "0" = −1.7 |
| (Balanced Input) | | "1" = −0.9 |
| Impedance | Ohms, max | 100 Line-to-Line |
| Width[13] | | |
| Min | ns | 10 |
| Max | 70% Encode Command | Period |
| Frequency | MHz | 20 |
| (Calibration Frequency is Customer-Specified; See Ordering Information.) | | |
| DIGITAL OUTPUT | | |
| Format | Bits | 9 Parallel; NRZ |
| Logic Levels, ECL-Compatible | V | "0" = −1.7 |
| (Balanced Output) | | "1" = −0.9 |
| Drive | Ohms, min | 75, Line-To-Line |
| Time Skew | ns, max | 5 |
| Coding | | Binary (BIN); 2's Complement (2SC) |
| DATA READY OUTPUT | | |
| Logic Levels, ECL-Compatible | V | "0" = −1.7 |
| (Balanced Output) | | "1" = −0.9 |
| Drive | Ohms, min | 75, Line-to-Line |
| Rise and Fall Time | ns, max | 5 |
| Duration | ns (max) | 25 (±5) |
| POWER REQUREMENTS[14] | | |
| +15V ±5% | mA (max) | 198 (205) |
| −15V ±5% | mA (max) | 260 (265) |
| +5V ±5% | mA (max) | 86 (88) |
| −5.2V ±5% | A (max) | 1.8 (1.9) |
| Power Consumption | W (max) | 16.7 (17.4) |
| TEMPERATURE RANGE | | |
| Operating | °C | 0 to +70 |
| Storage | °C | −55 to +85 |
| Cooling Air Requirements | LFPM | 500 |
| (Linear Feet Per Minute) | | |
| MEAN TIME BETWEEN FAILURES[15] | | |
| (MTBF) | Hours | $7.5 \times 10^4$ |

NOTES

[1] AC Linearity expressed in terms of spurious in-band signals generated at 20MHz encode rate at analog input frequencies shown in ( ).

[2] Measured from leading edge Encode Command to trailing edge Data Ready; use trailing edge to strobe output data into external circuits.

[3] To be specified by customer. See Ordering Information

[4] Rms signal to rms noise ratio with 500kHz analog input.

[5] Peak-to-peak signal to rms noise ratio with 500kHz analog input.

[6] DC to 8.2MHz white noise bandwidth with slot frequency of 1.248MHz; and encode rate of 20MHz.

[7] For full-scale step input, 9-bit accuracy attained in specified time.

[8] Recovers to 9-bit accuracy in specified time after 2 × FS input overvoltage.

[9] With analog input 40dB below FS.

[10] With FS analog input; large-signal bandwidth flat within 0.2dB, dc to 10MHz.

[11] Applies to units optimized for video applications. See Ordering Information.

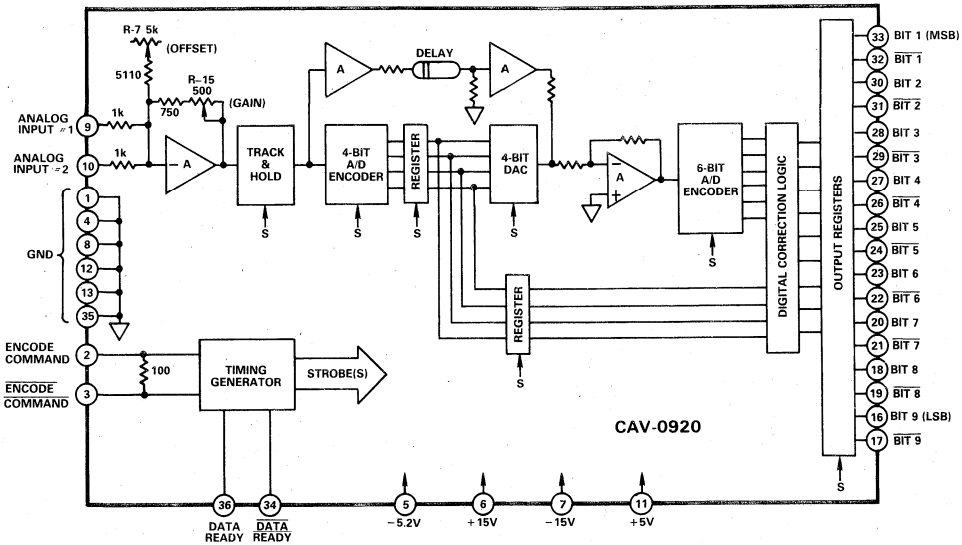
[12] Measured with 20-IRE Unit Reference, modulated ramp.

[13] Transition from digitial "0" to "1" initiates encoding.

[14] ±15V supplies need to be equal and opposite within 200mV and track over temperature.

[15] 25°Ambient.

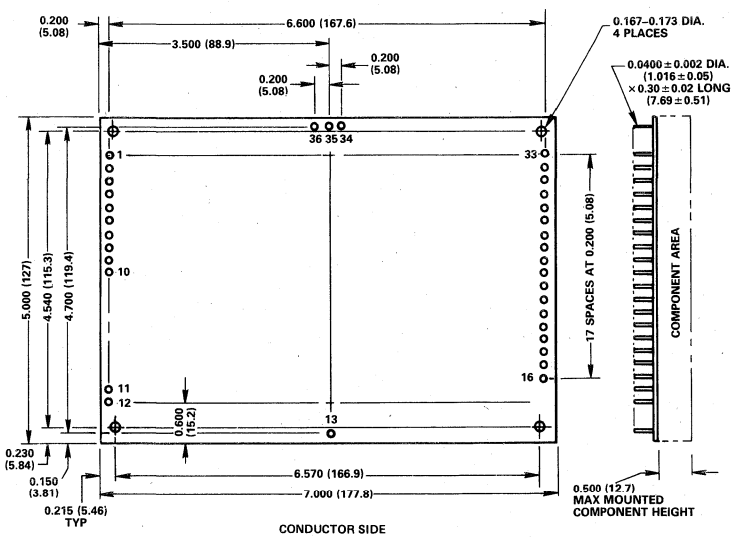
Specifications subject to change without notice.




*CAV-0920 Block Diagram*

## OUTLINE DIMENSIONS

Dimensions shown in inches and (mm).




## PIN DESIGNATIONS

| PIN | FUNCTION |
|---|---|
| 1 | GROUND |
| 2 | ENCODE COMMAND |
| 3 | $\overline{\text{ENCODE COMMAND}}$ |
| 4 | GROUND |
| 5 | −5.2V |
| 6 | +15V |
| 7 | −15V |
| 8 | GROUND |
| 9 | ANALOG INPUT #1 |
| 10 | ANALOG INPUT #2 |
| 11 | +5V |
| 12 | GROUND |
| 13 | GROUND |
| 16 | BIT 9 |
| 17 | $\overline{\text{BIT 9}}$ |
| 18 | BIT 8 |
| 19 | $\overline{\text{BIT 8}}$ |
| 20 | BIT 7 |
| 21 | $\overline{\text{BIT 7}}$ |
| 22 | $\overline{\text{BIT 6}}$ |
| 23 | BIT 6 |
| 24 | $\overline{\text{BIT 5}}$ |
| 25 | BIT 5 |
| 26 | $\overline{\text{BIT 4}}$ |
| 27 | BIT 4 |
| 28 | BIT 3 |
| 29 | $\overline{\text{BIT 3}}$ |
| 30 | BIT 2 |
| 31 | $\overline{\text{BIT 2}}$ |
| 32 | $\overline{\text{BIT 1}}$ |
| 33 | BIT 1 |
| 34 | $\overline{\text{DATA READY}}$ |
| 35 | GROUND |
| 36 | DATA READY |

ALL GROUNDS ARE CONNECTED TOGETHER INTERNALLY

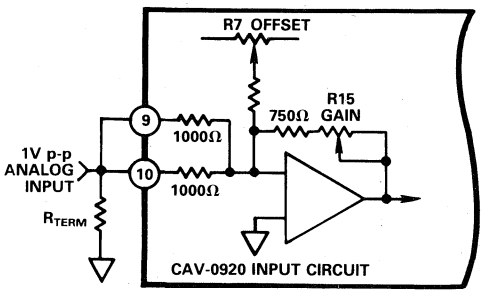
11

## CAV-0920 ANALOG INPUT RANGE OPTIONS

For 1V p-p input range, connect analog input to pin 10, and connect pins 9 and 10 together. Unterminated input impedance is 500 ohms. For 2V p-p input range, connect analog input to pin 10; pin 9 is left disconnected. Unterminated input impedance is 1,000 ohms.

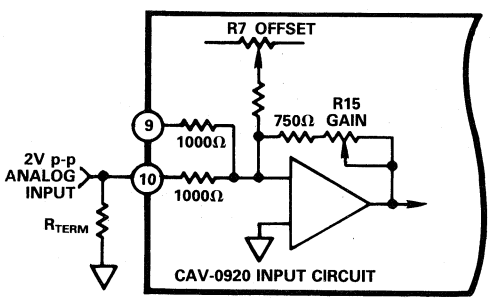
To obtain the desired terminated input impedance, connect the appropriate external terminating resistor between the analog input pin(s) and ground as shown in the examples. Input impedances greater than 1,000 ohms will result in loss of input bandwidth and should be avoided.

The OFFSET potentiometer (R7) has sufficient range to allow the user to operate the A/D in either the unipolar or bipolar mode.




*1V p-p Input Option*

| $Z_{IN}$ | $R_{TERM}$ (ohms) | ($R_{TERM}$ RESISTORS ARE 1%, 1/8W, MF) |
|---|---|---|
| 50 | 56.2 | |
| 75 | 88.7 | |
| 93 | 115.0 | |




*2V p-p Input Option*

| $Z_{IN}$ | $R_{TERM}$ (ohms) | ($R_{TERM}$ RESISTORS ARE 1%, 1/8W, MF) |
|---|---|---|
| 50 | 52.3 | |
| 75 | 80.6 | |
| 93 | 102.0 | |

## OFFSET AND GAIN ADJUSTMENT

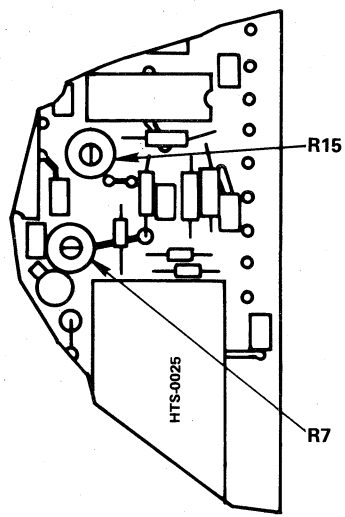
When adjusting the offset and gain of the A/D in the system, the OFFSET control (R7) is adjusted first. The CAV-0920 can be operated in either a unipolar or bipolar mode. For a standard binary output, adjustments for each mode are:

**Bipolar**

1. Apply 0V to analog input.
2. Adjust R7 OFFSET control while observing MSB (Bit 1). Adjust until digital output has MSB "toggling" between "0" and "1".
3. Apply desired maximum positive voltage to analog input.
4. Adjust R15 GAIN control while observing LSB (Bit 9). Adjust until digital output has Bits 1–8 solid "1" with LSB "toggling."

**Unipolar Positive**

1. Apply 0V to analog input.
2. Adjust R7 OFFSET control while observing LSB (Bit 9). Adjust until digital output has Bits 1–8 solid "0" with LSB "toggling".
3. Apply desired maximum positive voltage to analog input.
4. Adjust R15 GAIN control while observing LSB (Bit 9). Adjust until digital output has Bits 1–8 solid "1" with LSB "toggling".




*Part of CAV-0920*

## ORDERING INFORMATION

The encode (word) rate of the CAV-0920 A/D converter is specified by the customer, as outlined below.

Order by model number CAV-0920-XXX; in this model number, XXX is specified by the customer to indicate the desired word rate in MHz. The decimal place is assumed (but not shown) between the second and third places. CAV-0920-160, for example, indicates calibration at 16.0MHz.

The CAV-0920 will maintain 9-bit accuracy within ±12% of this specified word rate when the requested word rate is higher than 10MHz. In the example for a 16MHz word rate cited above, the CAV-0920 could be operated at 4 X burst frequency in either NTSC (3.58MHz) or PAL (4.43MHz) systems without readjustment.

For encode rates below 10MHz, the CAV-0920-100 maintains full accuracy through 10MHz.

If later applications of the converter require word rates outside the limits of the original calibration, the unit can be returned to the factory for calibration at the new frequency; there is a nominal charge for this service.

Mating sockets for the CAV-0920 are model number MSB-2 (thru hole) MSB-3 (closed end). These are individual solder-type pin sockets for mounting in PC boards; one is required for each of the 34 pins of the converter.

# 10-Bit Video Analog-to-Digital Converter

# CAV-1040

**PRELIMINARY TECHNICAL DATA**

**FEATURES**

- **10-Bit Resolution**
- **40MHz Word Rate**
- **Single 35-In$^2$ PC Board**
- **ECL Compatible**
- **No External Circuits Required**

**APPLICATIONS**

- **Radar Digitizing**
- **Medical Instrumentation**
- **Digital Communications**
- **Spectrum Analysis**

## GENERAL DESCRIPTION

The Analog Devices model CAV-1040 A/D converter is a "system solution" which combines 10-bit resolution, 40MHz word rates, and small size to solve high-speed digitizing problems. Its design is based on proven concepts introduced in the MOD-1020 and MOD-1205 A/D converters and takes advantage of recent technology to achieve exceptional cost/performance tradeoffs.

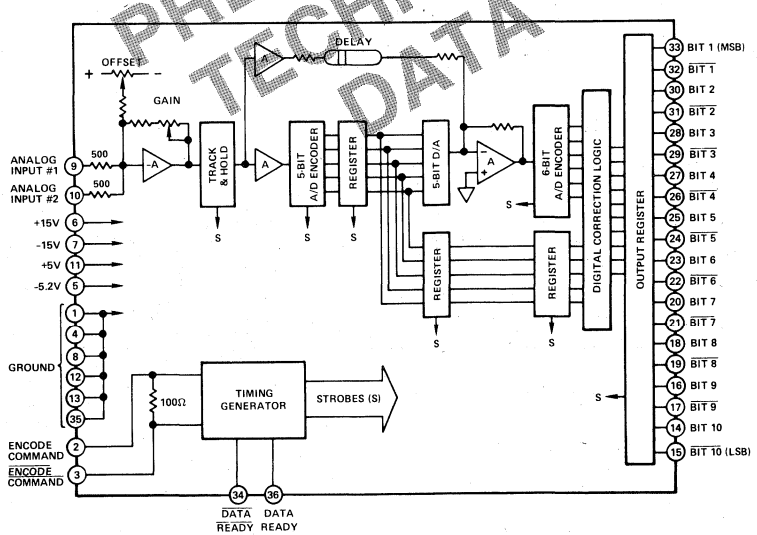
It is pin-for-pin compatible with the industry's first 10-bit, 20MHz A/D, the MOD-1020. But it *doubles* the word rate of its predecessor, making it possible for system designers to upgrade their systems without new layouts.

This remarkable converter is a complete answer to the question of digitizing radar, video, and/or other high-frequency inputs; it includes a track-and-hold, along with encoding and timing circuits. The CAV-1040 is an ideal choice for the designer who needs state-of-the-art performance in high-resolution, ultra-high-speed A/D conversion.

All inputs and outputs are ECL compatible. Analog input impedance is 500Ω on 1V range; 250Ω on 2V range. The A/D requires only an encode command and external power supplies for operation.

Hybrid microcircuits, IC's, and discrete components are combined to obtain the maximum benefits of all technologies. The CAV-1040 is factory repairable and backed by Analog Devices' limited one-year warranty.

PRELIMINARY TECHNICAL DATA



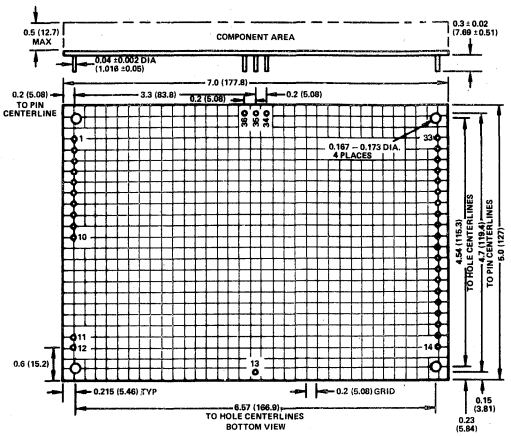

*CAV-1040 Block Diagram*

# SPECIFICATIONS (typical at +25°C with nominal power supplies unless otherwise noted)

| Model | Units | CAV-1040 |
|---|---|---|
| RESOLUTION (FS = Full Scale) | Bits | 10 |
| | %FS | 0.1 |
| LSB WEIGHT | | |
| 1V p-p FS | mV | 1 |
| 2V p-p FS | mV | 2 |
| ACCURACY | | |
| (Including Linearity) @ dc | % FS ± 1/2LSB | 0.05 |
| Monotonicity | | Guaranteed 0 to +70°C |
| DYNAMIC CHARACTERISTICS | | |
| In-Band Harmonics[1] | | |
| (dc to 1MHz) | dB below FS | 60 |
| (1MHz to 5MHz) | dB below FS | 55 |
| (5MHz to 20MHz) | dB below FS | 50 |
| Conversion Time[2] | ns | 90 + 1 clock period |
| Conversion Rate | MHz, max | 40 |
| Aperture Uncertainty (Jitter) | ps, max | ±25 |
| Signal to Noise Ratio (SNR)[3] | dB, min | 56 |
| Noise Power Ratio (NPR)[4] | dB (min) | 50 (48) |
| Input Bandwidth | | |
| Small Signal, 3dB[5] | MHz | 30 |
| Large Signal, 3dB[6] | MHz | 15 |
| ANALOG INPUT | | |
| Voltage Range | | |
| Input Pins 9 & 10 Connected | V, p-p FS | 1 |
| Input Pin 9 or 10 | V, p-p FS | 2 |
| | V, max | ±4 |
| Input Type | Either Unipolar or Bipolar | |
| Impedance | | |
| 1V Input Range | Ω | 250 |
| 2V Input Range | Ω | 500 |
| Offset | Adjustable to Zero with On-Card Potentiometer | |
| vs. Temperature | % of FS/°C | 0.025 |
| ENCODE COMMAND INPUT[7] | | |
| Logic Levels, ECL-Compatible | V | "0" = −1.7 |
| (Balanced Input) | V | "1" = −0.9 |
| Impedance (Line-to-Line) | Ω, max | 100 |
| Rise and Fall Times | ns, max | 5 |
| Width | | |
| Min | ns | 10 |
| Max | 70% of Encode Command Period | |
| Frequency | MHz | 40 |
| DIGITAL OUTPUT | | |
| Format | Bits | 10 Parallel; NRZ |
| Logic Levels, ECL-Compatible | V | "0" = −1.7 |
| (Balanced Output) | V | "1" = −0.9 |
| Drive (Line-to-Line) | Ω, min | 75 |
| Time Skew | ns, max | 5 |
| Coding | | Binary (BIN); 2's Complement (2SC) |
| DATA READY OUTPUT | | |
| Logic Levels, ECL-Compatible | V | "0" = −1.7 |
| (Balanced Output) | V | "1" = −0.9 |
| Drive (Line-to-Line) | Ω, min | 75 |
| Rise and Fall Time | ns, max | 5 |
| Duration | ns (max) | 20 (±5) |
| POWER REQUIREMENTS | | |
| +15V ±5% | mA (max) | 390 (425) |
| −15V ±5% | mA (max) | 175 (200) |
| +5V ±5% | mA (max) | 20 (25) |
| −5.2V ±5% | A (max) | 2.5 (2.8) |
| Power Consumption | W (max) | 21 (24) |
| TEMPERATURE RANGE | | |
| Operating | °C | 0 to +70 |
| Storage | °C | −55 to +85 |
| Cooling Air Requirements | LFPM (Linear Feet Per Minute) | 500 |
| CONSTRUCTION | | |
| Single Printed Circuit Card | Inches | 7.0 × 5.0 × 0.5 |

## OUTLINE DIMENSIONS

Dimensions shown in inches and (mm).




## PIN DESIGNATIONS

| PIN | FUNCTION | PIN | FUNCTION |
|---|---|---|---|
| 1 | GROUND | 19 | BIT 8 |
| 2 | ENCODE COMMAND | 20 | BIT 7 |
| 3 | ENCODE COMMAND | 21 | BIT 7 |
| 4 | GROUND | 22 | BIT 6 |
| 5 | -5.2V | 23 | BIT 6 |
| 6 | +15V | 24 | BIT 5 |
| 7 | -15V | 25 | BIT 5 |
| 8 | GROUND | 26 | BIT 4 |
| 9 | ANALOG INPUT #1 | 27 | BIT 4 |
| 10 | ANALOG INPUT #2 | 28 | BIT 3 |
| 11 | +5V | 29 | BIT 3 |
| 12 | GROUND | 30 | BIT 2 |
| 13 | GROUND | 31 | BIT 2 |
| 14 | BIT 10 | 32 | BIT 1 |
| 15 | BIT 10 | 33 | BIT 1 |
| 16 | BIT 9 | 34 | DATA READY |
| 17 | BIT 9 | 35 | GROUND |
| 18 | BIT 8 | 36 | DATA READY |

ALL GROUND PINS ARE CONNECTED TOGETHER WITHIN THE ADC.

NOTES

[1]In-Band Harmonics expressed in terms of spurious in-band signals generated at 40MHz encode rate at analog inputs shown in ( ).

[2]Measured from leading edge Encode Command to trailing edge Data Ready; use trailing edge to strobe output data into external circuits.

[3]RMS signal to rms noise ratio with 500kHz analog input.

[4]DC to 8.2MHz white noise bandwidth with slot frequency of 3.886MHz; and encode rate of 40MHz.

[5]With analog input 40dB below FS.

[6]With FS analog input. (Large-signal bandwidth flat within 0.2dB, dc to 8MHz).

[7]Transition from digital "0" to digital "1" initiates encoding.

Specifications subject to change without notice.

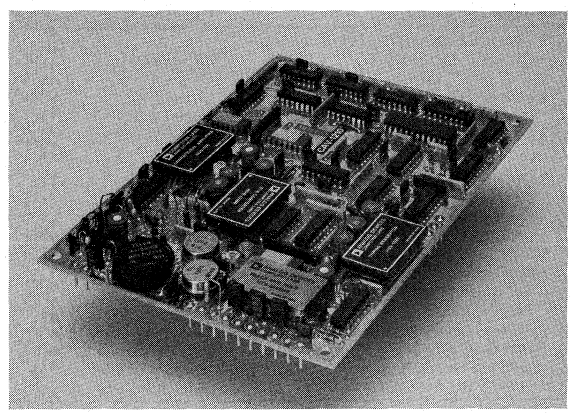
# ANALOG DEVICES

# 12-Bit Video Analog-to-Digital Converter

# CAV-1210

**FEATURES**
**12-Bit Resolution**
**10MHz Word Rate**
**Single 35-In$^2$ PC Board**
**ECL Compatible**
**No External Circuits Required**

**APPLICATIONS**
**Radar Digitizing**
**Medical Instrumentation**
**Digital Communications**
**Spectrum Analysis**



## GENERAL DESCRIPTION

The Analog Devices model CAV-1210 A/D converter combines performance, size, and economy to achieve a remarkable solution for high-speed digitizing problems.

The unit is capable of 12 bits of resolution at word rates through 10MHz. It is a complete answer to the question of digitizing radar, video, and/or other high-frequency inputs; it includes a track-and-hold, along with encoding and timing circuits. The CAV-1210 is a "system solution" for the designer who wants to avoid the need for combining the plethora of components necessary to make IC encoders operate as functional A/D converters.

The unit uses the unique digital correcting subranging (DCS) conversion technique, pioneered by Analog Devices, which virtually eliminates the errors normally associated with subranging A/D converters.

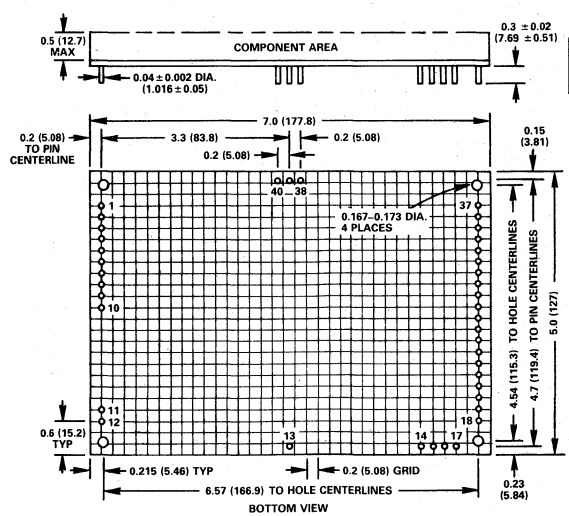
The CAV-1210 is constructed on a single PC board intended for mounting on a "mother" board in the user's system. Its small size makes it adaptable to a wide range of mother board sizes and allows room for including other (signal conditioning, processing, memory, etc.) circuits adjacent to the converter.

All inputs and outputs are ECL compatible; analog input impedance is 1000 ohms. The A/D requires only an encode command and external power supplies for operation.

Hybrid microcircuits, ICs and discrete components are combined in the design, to obtain the maximum benefits of all technologies. The CAV-1210 is repairable and backed by Analog Devices' limited one-year warranty.

## OUTLINE DIMENSIONS

Dimensions shown in inches and (mm).



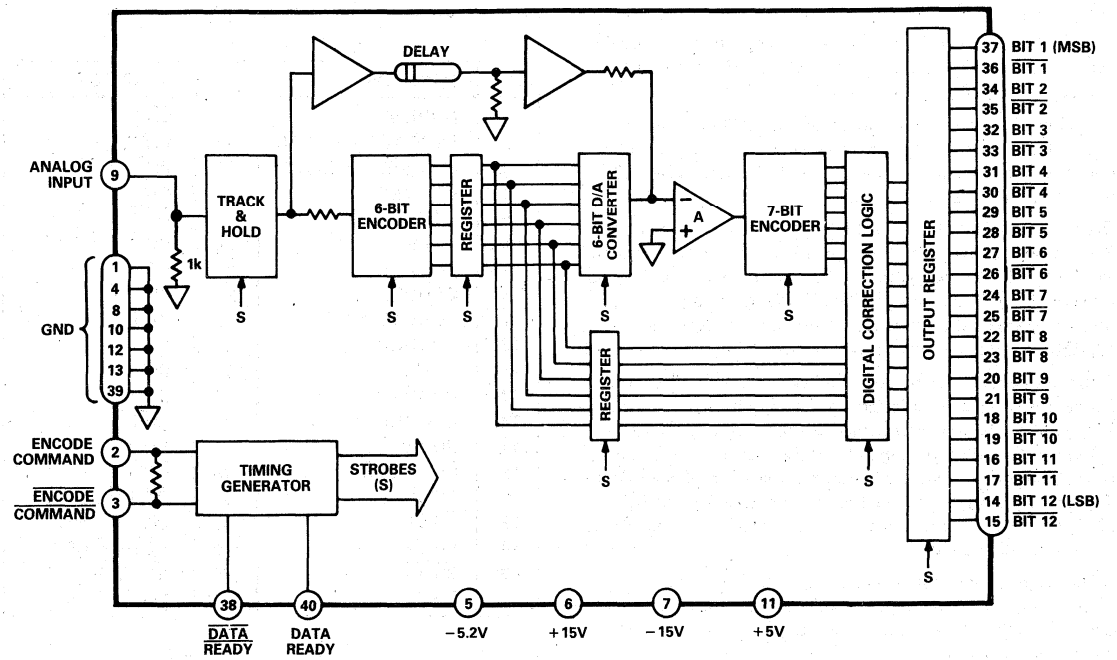

11

# SPECIFICATIONS (typical at +25°C with nominal power supplies unless otherwise noted)

| Model | Units | CAV-1210 |
|---|---|---|
| RESOLUTION (FS = Full Scale) | Bits (% FS) | 12 (0.024) |
| LSB WEIGHT | mV | 0.5 |
| ACCURACY | | |
| (Including Linearity) @ dc | % FS ± 1/2LSB | 0.0125 |
| Monotonicity | | Guaranteed 0 to +70°C |
| Nonlinearity vs. Temperature | % of FS/°C | 0.000125 |
| Gain vs. Temperature | % of FS/°C | 0.005 |
| DYNAMIC CHARACTERISTICS | | |
| AC Linearity[1] (dc to 1MHz) | dB below FS | 70 |
| (1MHz to 5MHz) | | 65 |
| Conversion Time[2] | ns (max) | 225 (± 20) |
| Conversion Rate[3] | MHz | 10 |
| Aperture Uncertainty (Jitter) | ps | ± 25 |
| Aperture Time (Delay) | ns | 6 |
| Signal to Noise Ratio (SNR)[4] | dB | 62 |
| Signal to Noise Ratio (SNR)[5] | dB | 71 |
| Noise Power Ratio (NPR)[6] | dB (min) | 53 (52) |
| Transient Response[7] | ns, max | 100 |
| Overvoltage Recovery[8] | ns, max | 200 |
| Input Bandwidth | | |
| Small Signal, 3dB[9] | MHz | 35 |
| Large Signal, 3dB[10] | MHz | 30 |
| Two-Tone Linearity (@ Input Frequencies) | | |
| (60kHz; 62kHz) | dB below FS, min | 70 |
| (2.498MHz; 2.500MHz) | dB below FS, min | 65 |
| (4.996MHz; 4.998MHz) | dB below FS, min | 60 |
| ANALOG INPUT | | |
| Voltage Range | V, FS | ± 1 |
| (+1V input = all "1s"; −1V input = all "0s") | V, max | ± 2 |
| Input Type | | Bipolar |
| Impedance | Ohms | 1000 |
| Offset | | |
| Initial (Set at Factory) | mV, max | ± 1 |
| vs. Temperature | % of FS/°C | 0.02 |
| ENCODE COMMAND INPUT[11] | | |
| Logic Levels, ECL-Compatible | V | "0" = −1.7 |
| (Balanced Input) | | "1" = −0.9 |
| Impedance | Ohms, max | 100 Line-to-Line |
| Width | | |
| Min | ns | 10 |
| Max | 70% of Encode Command Period | |
| Frequency | MHz | 10 |
| (Calibration Frequency is Customer-Specified; See Ordering Information.) | | |
| DIGITAL OUTPUT | | |
| Format | Bits | 12 Parallel; NRZ |
| Logic Levels, ECL-Compatible | V | "0" = −1.7 |
| (Balanced Output) | | "1" = −0.9 |
| Drive | Ohms, min | 75, Line-To-Line |
| Time Skew | ns, max | 5 |
| Coding | | Offset Binary (OBN); 2's Complement (2SC) |
| DATA READY OUTPUT | | |
| Logic Levels, ECL-Compatible | V | "0" = −1.7 |
| (Balanced Output) | | "1" = −0.9 |
| Drive | Ohms, min | 75, Line-to-Line |
| Rise and Fall Time | ns, max | 5 |
| Duration | ns (max) | 25 (± 5) |
| POWER REQUREMENTS[12] | | |
| +15V ± 5% | mA (max) | 185 (205) |
| −15V ± 5% | mA (max) | 240 (265) |
| +5V ± 5% | mA (max) | 120 (135) |
| −5.2V ± 5% | A (max) | 2.1 (2.3) |
| Power Consumption | W (max) | 18 (19.7) |
| TEMPERATURE RANGE | | |
| Operating[13] | °C | 0 to +70 |
| Storage | °C | −55 to +85 |
| Cooling Air Requirements | LFPM | 500 |
| (Linear Feet Per Minute) | | |
| MEAN TIME BETWEEN FAILURES[14] | | |
| (MTBF) | Hours | $1.06 \times 10^5$ |

NOTES
[1]AC Linearity expressed in terms of spurious in-band signals generated at 10MHz encode rate at analog input frequencies shown in ( ).
[2]Measured from leading edge Encode Command to trailing edge Data Ready; use trailing edge to strobe output data into external circuits.
[3]To be specified by customer. See Ordering Information.
[4]Rms signal to rms noise ratio with 500kHz analog input.
[5]Peak-to-peak signal to rms noise ratio with 500kHz analog input.
[6]DC to 4.1MHz white noise bandwidth with slot frequency of 3.886MHz; and encode rate of 10MHz.
[7]For full-scale step input, 12-bit accuracy attained in specified time.
[8]Recovers to 12-bit accuracy in specified time after 2 × FS input overvoltage.
[9]With analog input 40dB below FS.
[10]With FS analog input. (Large-signal bandwidth flat within 0.2dB, dc to 5MHz.
[11]Transition from digital "0" to digital "1" initiates encoding.
[12]±15V must be equal and opposite within 200mV and track over temperature.
[13]Some spec degradation may occur outside a "window" of 50° centered at +25°C.
[14]25°Ambient.

Specifications subject to change without notice.




*CAV-1210 Block Diagram*

11

## THEORY OF OPERATION

Refer to the block diagram of the CAV-1210.

The analog input signal to be digitized is applied first to a track-and-hold (T/H) amplifier, which is normally operated in the "track" mode, following all changes in analog input as they occur. The user of the CAV-1210 determines the point at which the analog signal is to be digitized by applying an Encode Command.

The leading edge of the encode command causes the track-and-hold circuit to switch momentarily to the "hold" mode of operation, "freezing" the analog input long enough to begin the digitizing process. The "held" value of the analog signal is applied to a 6-bit A/D encoder, and (through a buffer amplifier) to an analog delay circuit whose delay is equal to the time required for the first digitizing/reconstruction step of the encoding process.

The analog output of the T/H is now digitized and resolved to 6-bit accuracy and applied through registers to a 6-bit D/A converter, which has 12-bit accuracy. Via a second set of registers, the same 6-bit digitized signal is applied to the digital correction logic circuits. The value stored in the second bank of registers will ultimately represent Bits 1-6 of the final digital output of the CAV-1210.

The digitized signal applied to the fast-settling D/A converter is reconverted to an inverted analog signal and is applied with the delayed analog input to a wideband, fast-settling operational amplifier. The op amp output represents the residue signal which remains after a 6-bit representation of the analog input has been subtracted from that input.

This residue, or error, signal is digitized by a second encoder to a resolution of 7 bits and applied to the digital correction logic circuits along with Bits 1-6.

The correction circuits use a combination of the 6-bit and 7-bit signals to compensate for possible nonlinearities and other errors to assure the final 12-bit digital output will be 12-bit accurate.

Oversimplified, the digital correction circuits use the information contained in the 7-bit signal to determine whether or not Bits 1-6 need to be modified.

Basically, the correction circuits use the information contained in the MSB of the 7-bit byte to determine what action needs to be taken with regard to the first six bits. Depending upon its value, the circuits will pass the 6-bit information as it is, or add a value of binary "1" to it. Bits 2-7 of the 7-bit information become Bits 7-12 of the digital output of the CAV-1210.

This unique use of 13 bits to achieve an accurate 12 bits of resolution compensates for a multitude of potential errors which otherwise could be eliminated only by incorporating expensive, high precision parts into the design. Digitally corrected subranging (DCS) used in the CAV-1210 does not prevent such anomalies as gain error, track/hold droop error, linearity error, or offset error. But it obviates the effects of these problems and makes high-speed, high resolution digitizing an economic reality.

## ORDERING INFORMATION

The CAV-1210 A/D converter will meet all specifications shown in the Specifications table of the data sheet at encode (word) rates through 10MHz.

For standard CAV-1210 units intended to operate with specified performance over the full range through 10MHz, order model number CAV-1210-100.

If desired, the customer can order the unit calibrated at the factory for optimum performance at some specified rate within this range for those applications in which the unit will generally be operated at the same word rate.

Order by model number CAV-1210-XXX; in this model number, XXX is specified by the customer to indicate the desired optimized word rate. The decimal place is assumed (but not shown) between the second and third places. CAV-1210-050, for example, indicates final calibration and, consequently, optimum performance at 5.0MHz; but the unit will operate through 10MHz.

Optimum performance will be achieved within a ±12% band of frequencies around the selected word rate, but the user must keep in mind the upper performance specification of 10MHz. "Optimum" final calibration at 9.8MHz, for example, is not meant to imply optimum performance at word rates above 10MHz. The unit will operate beyond 10MHz, but accuracy, NPR, SNR, and/or other specifications may be outside the limits shown on Specifications page.

If later applications require word rates outside the limits of the original optimum frequency, the unit can be returned to the factory for calibration at a new optimum; there is a nominal charge for this service.

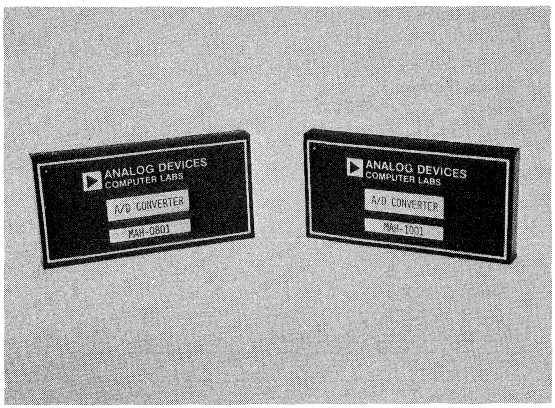
Mating sockets for the CAV-1210 are model number MSB-2 (thru hole) or MSB-3 (closed end). These are individual solder-type pin sockets for mounting in PC boards; one is required for each of the 40 pins of the converter.

| PIN | FUNCTION | PIN | FUNCTION |
|---|---|---|---|
| 1 | GROUND | 21 | $\overline{\text{BIT 9}}$ |
| 2 | ENCODE COMMAND | 22 | BIT 8 |
| 3 | $\overline{\text{ENCODE COMMAND}}$ | 23 | $\overline{\text{BIT 8}}$ |
| 4 | GROUND | 24 | BIT 7 |
| 5 | −5.2V | 25 | $\overline{\text{BIT 7}}$ |
| 6 | +15V | 26 | $\overline{\text{BIT 6}}$ |
| 7 | −15V | 27 | BIT 6 |
| 8 | GROUND | 28 | $\overline{\text{BIT 5}}$ |
| 9 | ANALOG INPUT | 29 | BIT 5 |
| 10 | GROUND | 30 | $\overline{\text{BIT 4}}$ |
| 11 | +5V | 31 | BIT 4 |
| 12 | GROUND | 32 | BIT 3 |
| 13 | GROUND | 33 | $\overline{\text{BIT 3}}$ |
| 14 | BIT 12 (LSB) | 34 | BIT 2 |
| 15 | $\overline{\text{BIT 12 (LSB)}}$ | 35 | $\overline{\text{BIT 2}}$ |
| 16 | BIT 11 | 36 | $\overline{\text{BIT 1 (MSB)}}$ |
| 17 | $\overline{\text{BIT 11}}$ | 37 | BIT 1 (MSB) |
| 18 | BIT 10 | 38 | $\overline{\text{DATA READY}}$ |
| 19 | $\overline{\text{BIT 10}}$ | 39 | GROUND |
| 20 | BIT 9 | 40 | DATA READY |

*CAV-1210 Pin Designations*

# Ultra High Speed 8- and 10-Bit A/D Converters

# MAH-0801, -1001




**FEATURES**

- **High Speed at Low Cost**
  - **8-Bits @ 750ns max**
  - **10-Bits @ 1μs max**
- **Monotonic Over Temperature**
- **Differential Nonlinearity ±1/4LSB typ**
- **Parallel and Serial Outputs**
- **Pin and Function Compatible with 4130, 4131**

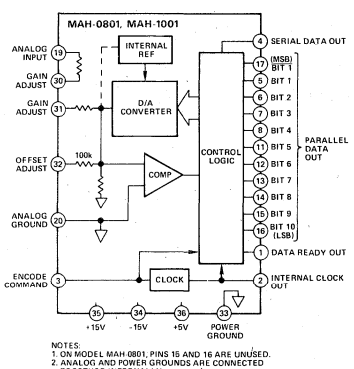
**APPLICATIONS**

- **High Speed Data Acquisition**
- **Real Time Waveform Analysis**
- **Radar Signal Processing**
- **Analytical Instruments**

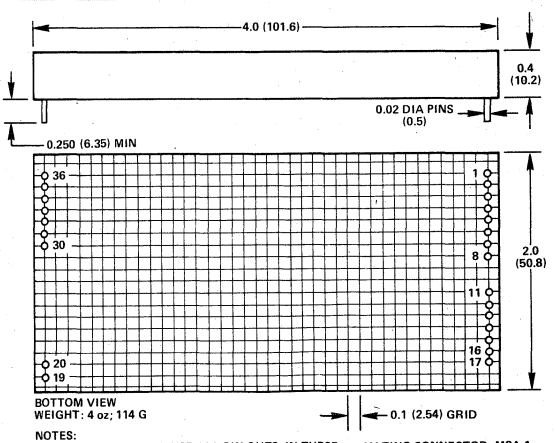
## GENERAL DESCRIPTION

The MAH series of high-speed analog-to-digital converters represent the latest "state-of-the-art" in high speed successive approximation technology. They are the fastest and most accurate complete converters of their type, featuring internal reference, clock, timing, encoding, and control logic functions. The MAH series A/Ds should be considered in applications where completeness of design function, ease of interface, and speed are required. These modules make maximum use of the latest monolithic and hybrid parts to minimize total parts complexity and increase reliability. They are designed to be form, fit, and function compatible with the T.P. 4130 and 4131, with advantages over the latter in overall accuracy without any sacrifice in speed.

In almost all applications, these A/Ds require the use of fast sample-and-hold. Depending upon the application, either the ADI THC or THS series of ultra-fast sample-and-holds are recommended.




*MAH-0801 and MAH-1001 Block Diagram*




NOTES:
SOME MODELS DO NOT USE ALL PIN OUTS. IN THESE CASES, UNUSED PINS ARE DELETED.
PINS ARE GOLD PLATED
DOT ON TOP INDICATES POSITION OF PIN 1

MATING CONNECTOR: MSA-1

11

# SPECIFICATIONS (typical @ +25°C unless otherwise noted)

| MODEL | UNITS | MAH-0801 | MAH-1001 |
|---|---|---|---|
| RESOLUTION FS @ Full Scale | Bits | 8 | 10 |
| ACCURACY (Relative to Full Scale) | ±% FS | 0.2 | 0.05 |
| Quantization Error | LSB | ±1/2 | * |
| Nonlinearity | LSB (max) | ±1/4 | ±1/2 |
| Differential Nonlinearity | LSB (max) | ±1/4 | ±1/2 |
| | LSB (typ) | ±1/8 | ±1/4 |
| Missing Codes | | No Missing Codes 0 to +70°C | |
| Monotonicity | | Monotonic 0 to +70°C | |
| TEMPERATURE COEFFICIENTS | | | |
| Differential Nonlinearity | ±ppm/°C | 3 | * |
| Gain | ±ppm/°C | 20 | * |
| Zero Offset (Unipolar) | ±μV/°C | 10 | * |
| Zero Offset (Bipolar) | ±ppm/°C | 15 | * |
| INPUT | | | |
| Ranges (Full Scale) | | | |
| MAH-XXXX-1 | V | 0 to -5 | * |
| MAH-XXXX-2 | V | 0 to -10 | * |
| MAH-XXXX-3 | V | ±5 | * |
| MAH-XXXX-4 | V | ±10 | * |
| MAH-XXXX-5 | V | ±1.024 | * |
| Impedance (Function of Option) | Ω/V | 100 | * |
| OVERVOLTAGE | V | To Twice Peak Input FS Without Damage. | |
| CONVERSION TIME[1] | ns max | 750 | 1000 |
| | ns typ | 700 | 950 |
| ENCODE COMMAND | | | |
| Logic Levels (1 Standard TTL Load) | V | "0" = 0 to +0.4, "1" = +2 to +5.5 | |
| Function | | Positive-going edge resets converter. Trailing edge starts conversion. | |
| Duration (Width) | ns min (max) | 50 (150) | * |
| Rise and Fall Times | ns max | 20 | * |
| Repetition Rate | kHz max | 1333 | 1000 |
| LOGIC OUTPUTS | | | |
| Levels TTL (Same as Encode Command) | | | |
| Drive Capability | | Data and Data Ready—10 Std TTL Loads, Clock—10 TTL Loads | |
| Parallel Data | | 8 or 10 lines of data held until start of next Encode Command | |
| Coding (Unipolar) | | CBN | * |
| (Bipolar) | | COB/C2SC | * |
| Serial Data | | MSB first, successive pulse output during conversion, NRZ. | |
| Coding | | Same as parallel output except 2SC not available. | |
| Clock | | Pulse train of 9 or 11 internal clock pulses, gated on during the conversion period. | |
| POWER REQUIREMENTS | | | |
| +14.5V to +15.5V | mA max | 50 | * |
| -14.5V to -15.5V | mA max | 30 | * |
| +5V ±5% | mA max | 250 | * |
| TEMPERATURE RANGE | | | |
| Operating | °C | 0 to +70 | * |
| Storage | °C | -55 to +85 | |
| PHYSICAL CHARACTERISTICS | | | |
| Case | | Diallyl Phthalate per MIL-M-14 Type SDG-F | |

NOTES

[1] Total conversion time from leading edge of encode command pulse to trailing edge of data ready pulse with 50ns wide encode command.

*Specifications same as MAH-0801.

Specifications subject to change without notice.

## OUTPUT CODING

The logic output coding is shown true relative to the analog input to the A/D. If an inverting track and hold—such as the Analog Devices THC series—or an inverting op amp is used ahead of the A/D, the true logic coding is inverted relative to the system input. This yields the systemic coding as follows:

| Scale | Input Voltage | Complementary Straight Binary |
|---|---|---|
| -FS -1LSB | -9.9900V | 1111 1111 11 |
| -3/4 FS | -7.5000V | 1100 0000 00 |
| -1/2 FS | -5.0000V | 1000 0000 00 |
| -1/4 FS | -2.5000V | 0100 0000 00 |
| -1LSB | -0.0010V | 0000 0000 01 |
| 0 | 0.0000V | 0000 0000 00 |

NOTE
(0 to -10V) for MAH-1001-2; LSB = 10mV for MAH-1001-1, apply input voltage factor of 1/2.

*Table I. MAH-0801 and MAH-1001 Unipolar Operation for Options 1 and 2*

Binary (BIN) in place of Complementary Binary (CBN) for options 1 and 2; Offset Binary (OBN) in place of Complementary Offset Binary (COB) for options 3, 4 and 5; Two's Complement (2SC) in place of Complementary Two's Complement (C2SC).

| Scale | Input Voltage | Complementary Offset Binary | Complementary Two's Complement |
|---|---|---|---|
| -FS -1LSB | -4.9900V | 1111 1111 11 | 0111 1111 11 |
| -3/4 FS | -3.7500V | 1110 0000 00 | 0110 0000 00 |
| -1/2 FS | -2.5000V | 1100 0000 00 | 0100 0000 00 |
| 0 | 0.0000V | 1000 0000 00 | 0000 0000 00 |
| +1/2 FS | +2.5000V | 0100 0000 00 | 1100 0000 00 |
| +3/4 FS | +3.7500V | 0010 0000 00 | 1010 0000 00 |
| +FS -1LSB | +4.9900V | 0000 0000 01 | 1000 0000 01 |
| +FS | +5.0000V | 0000 0000 00 | 1000 0000 00 |

NOTE
(-5V to +5V) for MAH-1001-3; LSB = 10mV for MAH-1001-4 apply input voltage factor of 2.

*Table II. MAH-0801 and MAH-1001 Bipolar Operation for Options 3 and 4*

| Scale | Input Voltage | Complementary Offset Binary | Complementary Two's Complement |
|---|---|---|---|
| -FS -1LSB | -1.022V | 1111 1111 11 | 0111 1111 11 |
| -1/2 FS | -0.512V | 1100 0000 00 | 0100 0000 00 |
| 0 | -0.000V | 1000 0000 00 | 0000 0000 00 |
| +1/2 FS | +0.512V | 0100 0000 00 | 1100 0000 00 |
| +FS | +1.024V | 0000 0000 00 | 1000 0000 00 |

NOTE
(-1.024V to +1.024V) for MAH-1001-5; LSB = 2mV.

*Table III. MAH-0801 and MAH-1001 Bipolar Operation for Option 5*

## CALIBRATION AND ADJUSTMENT

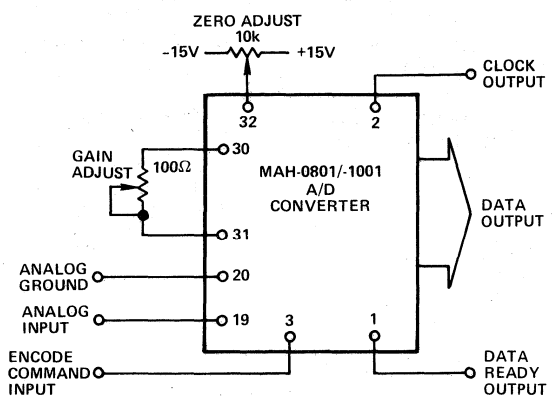



*Figure 1. MAH-0801 and MAH-1001 Hookup*

PROCEDURE:
1. APPLY ENCODE COMMAND PULSE TO THE ENCODE COMMAND INPUT (PIN 3).
2. CONNECT A PRECISION VOLTAGE SOURCE TO THE ANALOG INPUT (PIN 19) AND ANALOG GROUND (PIN 20). ADJUST THIS SOURCE FOR +1/2LSB. VARY THE ZERO ADJUST POTENTIOMETER FOR AN LSB FLUTTER (THIS WILL APPEAR AS AN EQUAL UNCERTAINTY AT THE OUTPUT BETWEEN THE CODES 0000 .... 0000 AND 0000 .... 0001).
3. WITH THE PRECISION VOLTAGE SOURCE ADJUSTED TO -FS +1/2LSB, ADJUST THE GAIN POTENTIOMETER FOR A FLUTTER BETWEEN CODES 1111 .... 1110 AND 1111 .... 1111.

*Unipolar Operation*

PROCEDURE:
1. APPLY AN ENCODE COMMAND TO THE ENCODE COMMAND INPUT (PIN 3).
2. CONNECT A PRECISION VOLTAGE SOURCE TO THE ANALOG INPUT (PIN 19) AND ANALOG GROUND (PIN 20). ADJUST THIS SOURCE TO +FS -1/2LSB. THE ZERO ADJUST POTENTIOMETER FOR A FLUTTER BETWEEN VARY CODES 0000 .... 0000 AND 0000 .... 0001.
3. ADJUST THE VOLTAGE SOURCE TO -FS +1/2LSB. ADJUST THE GAIN POTENTIOMETER FOR A FLUTTER BETWEEN THE CODES 1111 .... 1110 AND 1111 .... 1111.

*Bipolar Operation*

## TIMING DIAGRAM

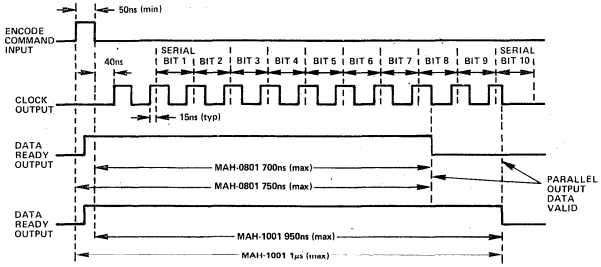



*Figure 2. MAH-0801 and MAH-1001 Timing Diagram*

## APPLICATIONS

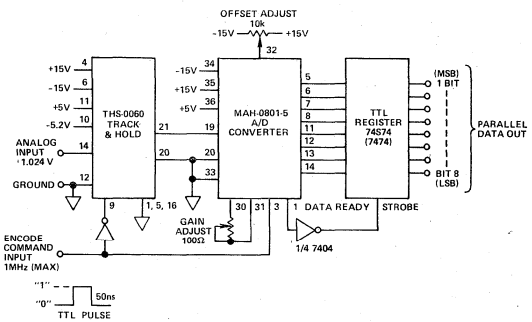



*Figure 3. Depicts a Complete 8-Bit, 1MHz Conversion System Using the THS-0060 Track-and-Hold and the MAH-0801-5 Low-Voltage Input A/D Converter*

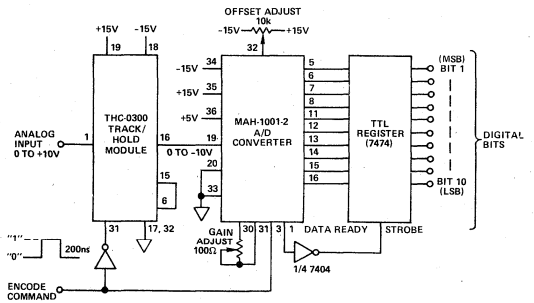



*Figure 4. Depicts the MAH-1001-2 A/D Converter Used with the THC-0300 Track-and-Hold*

### NOTES ON USAGE

The use of a large ground plane is highly recommended. Tie all grounds for both the ADC and T&H together. Make the distance from the ADC to the system ground as short as possible with as low an impedance as possible. Bypass each power supply run with a ceramic (0.1µF) and tantalum (3.3µF) capacitor. Keep the analog input as far away from the digital outputs as practical. Avoid the use of twisted pair cables for digital outputs wherever possible. The use of coax cable for analog inputs is recommended wherever practical to avoid digital feedback.

### PIN DESIGNATIONS
### MAH-0801, MAH-1001

| PIN | FUNCTION | PIN | FUNCTION |
|---|---|---|---|
| 1 | DATA READY OUT | 15 | BIT 9 OUT |
| 2 | INTERNAL CLOCK OUT | 16 | BIT 10 OUT (LSB) |
| 3 | ENCODE COMMAND IN | 17 | BIT 1 OUT (MSB) |
| 4 | SERIAL OUTPUT | 19 | ANALOG INPUT |
| 5 | BIT 1 OUT (MSB) | 20 | ANALOG GROUND |
| 6 | BIT 2 OUT | 30 | GAIN ADJUST |
| 7 | BIT 3 OUT | 31 | GAIN ADJUST |
| 8 | BIT 4 OUT | 32 | OFFSET ADJUST |
| 11 | BIT 5 OUT | 33 | POWER GROUND |
| 12 | BIT 6 OUT | 34 | -15V POWER IN |
| 13 | BIT 7 OUT | 35 | +15V POWER IN |
| 14 | BIT 8 OUT | 36 | +5V POWER IN |

NOTES
On Model MAH-0801, Pins 15 and 16 are deleted.
Power and Analog grounds are internally connected.

### ORDERING INFORMATION

The 8- and 10-bit versions of the MAH series may be ordered with various options according to the chart below.

**MAH-0801** **-1**

| RESOLUTION AND ACCURACY | ANALOG INPUT RANGE |
|---|---|
| MAH-0801 = 8 Bits | -1 0 to -5V FS |
| MAH-1001 = 10 Bits | -2 0 to -10V FS |
| | -3 ±5V FS |
| | -4 ±10V FS |
| | -5 ±1.024V FS |

# Ultra High Speed 8-, 10-, and 12-Bit A/D Converters

# MAS-0801, -1001, -1202

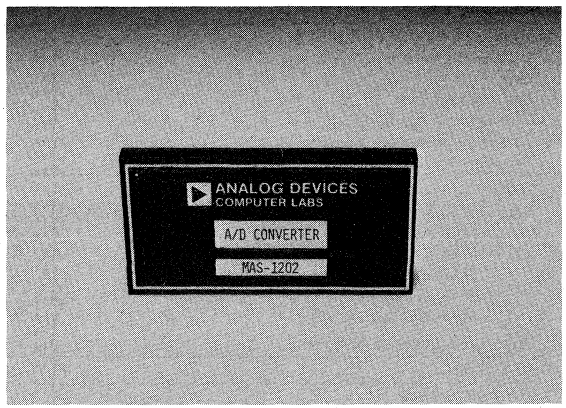
**FEATURES**

**High Speed at Low Cost**
- **8 Bits 1μs max**
- **10 Bits 1.5μs max**
- **12 Bits 2μs max**

**No Missing Codes Over Temperature**
**Low Power**
**Industry Standard Pin Out**
**Parallel and Serial Outputs**

**APPLICATIONS**

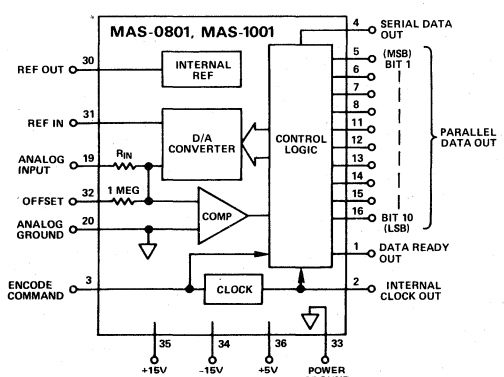
**High Speed Data Acquisition**
**Real Time Waveform Analysis**
**Radar Signal Processing**
**Analytical Instruments**



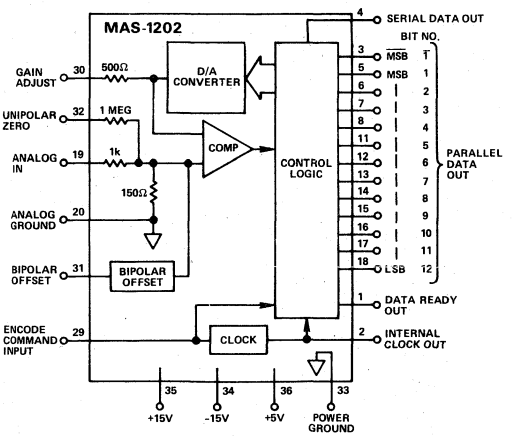

## GENERAL DESCRIPTION

The MAS series of high speed analog-to-digital converters represent the "state of the art" in application of the successive approximation conversion technique by providing highest speed at lowest cost. With monotonicity guaranteed over temperature these reliable modules are form, fit and function compatible with popular industry standards from Datel and Philbrick (for new designs consider the HAS series of hybrid converters).

In most applications these A/Ds should be used with a fast sample hold such as the THS/THC series.




*MAS-0801 and MAS-1001 Block Diagram*




*MAS-1202 Block Diagram*

11

# SPECIFICATIONS (typical @ +25°C unless otherwise noted)

| Model | Units | MAS-0801 | MAS-1001 | MAS-1202 |
|---|---|---|---|---|
| RESOLUTION FS = Full Scale | Bits | 8 | 10 | 12 |
| ACCURACY (Relative to Full Scale) | ±% FS | 0.2 | 0.05 | 0.012 |
| Quantization Error | LSB | ±1/2 | * | * |
| Nonlinearity | LSB (max) | ±1/2 | * | * |
| Differential Nonlinearity | LSB (max) | ±1/2 | * | * |
| Missing Codes | | No Missing Codes 0 to +70°C | | |
| TEMPERATURE COEFFICIENTS | | | | |
| Differential Nonlinearity | ±ppm/°C | 3 | * | * |
| Gain | ±ppm/°C | 20 | * | 30 |
| Gain (Option-P) | ±ppm/°C | 5 | * | NA |
| Zero Offset (Unipolar) | ±μV/°C | 10 | * | 100 |
| Zero Offset (Bipolar) | ±ppm/°C | 15 | * | * |
| Zero Offset (Option-P) | ±ppm/°C | 5 | * | NA |
| INPUT | | | | |
| Ranges (Full Scale) | | Options MAS-0801 and MAS-1001 ONLY | | STANDARD |
| MAS-XXXX-1 | V | 0 to -5 | * | 0 to +10/±5 |
| MAS-XXXX-2 | V | 0 to -10 | * | NA |
| MAS-XXXX-3 | V | ±5 | * | NA |
| MAS-XXXX-4 | V | ±10 | * | NA |
| MAS-XXXX-5 | V | ±1.024 | * | NA |
| Impedance (Function of Option) | Ω/V | 100 | * | 1150Ω |
| OVERVOLTAGE | V | To Twice Peak Input FS Without Damage. | | |
| CONVERSION TIME[1] | μs max | 1 | 1.5 | 2 |
| | μs typ | 0.8 | 1.3 | 1.8 |
| ENCODE COMMAND | | | | |
| Logic Levels (1 Standard TTL Load) | V | "0" = 0 to +0.4, "1" = +2 to +5.5 | | |
| Function | | Positive-going edge resets converter, Trailing edge starts conversion for 8- and 10-bit versions. | | |
| Duration (Width) | ns min | 50 | * | 100 |
| Rise and Fall Times | ns max | 20 | * | * |
| Repetition Rate | kHz max | 1000 | 666 | 500 |
| LOGIC OUTPUTS | | | | |
| Levels TTL (Same as Encode Command) | | | | |
| Drive Capability | | Data and Data Ready – 4 Std TTL Loads, Clock – 6TTL Loads | | |
| Parallel Data | | 8, 10 or 12 lines of data held until next Encode Command | | |
| Coding (Unipolar) | | CBN | * | BIN |
| (Bipolar) | | COB/2SC | * | OBN/2SC |
| Serial Data | | MSB first, successive pulse output during conversion, NRZ. | | |
| Coding | | Same as parallel output except 2SC not available. | | |
| Clock | | Pulse train of 9, 11 or 13 internal clock pulses, gated on during the conversion period. | | |
| POWER REQUIREMENTS | | | | |
| +14.5V to +15.5V | mA | 70 | * | 80 |
| -14.5V to -15.5V | mA | 30 | * | 20 |
| +5V ±5% | mA | 150 | * | * |
| TEMPERATURE RANGE | | | | |
| Operating | °C | 0 to +70 | * | * |
| Storage | °C | -55 to +85 | * | * |
| PHYSICAL CHARACTERISTICS | | | | |
| Case | | Diallyl Phthalate per MIL-M-14 Type SDC-F | | |

NOTES

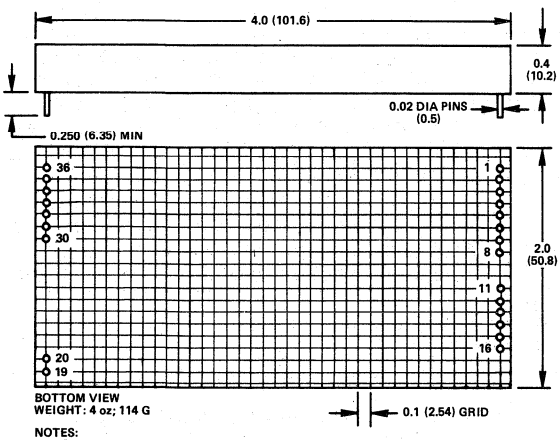
[1] Total conversion time from leading edge of encode command pulse to trailing edge of data ready pulse with 50ns wide encode command.

*Specifications same as MAS-0801.

Specifications subject to change without notice.

## OUTLINE DIMENSIONS

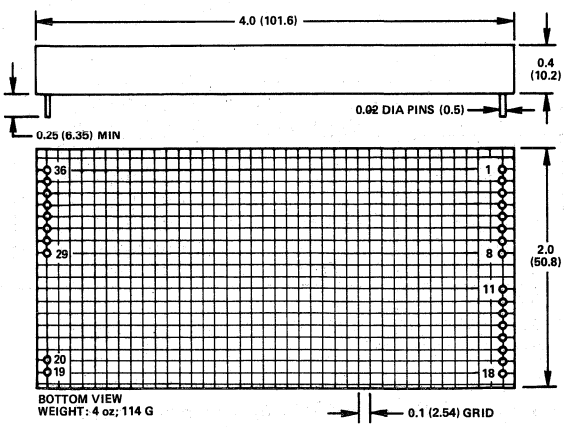
Dimensions shown in inches and (mm).




NOTES:
SOME MODELS DO NOT USE ALL PIN OUTS. IN THESE CASES, UNUSED PINS ARE DELETED.
PINS ARE GOLD PLATED
DOT ON TOP INDICATES POSITION OF PIN 1

## OUTLINE DIMENSIONS

Dimensions shown in inches and (mm).




NOTES:
PINS ARE GOLD PLATED
DOT ON TOP INDICATES POSITION OF PIN 1

## PIN DESIGNATIONS
## MAS-0801, MAS-1001

| PIN | FUNCTION | PIN | FUNCTION |
|---|---|---|---|
| 1 | DATA READY OUT | 15 | BIT 9 OUT |
| 2 | INTERNAL CLOCK OUT | 16 | BIT 10 OUT (LSB) |
| 3 | ENCODE COMMAND IN | 19 | ANALOG INPUT |
| 4 | SERIAL OUTPUT | 20 | ANALOG GROUND |
| 5 | BIT 1 OUT (MSB) | 30 | REFERENCE OUT |
| 6 | BIT 2 OUT | 31 | REFERENCE INPUT |
| 7 | BIT 3 OUT | 32 | OFFSET |
| 8 | BIT 4 OUT | 33 | POWER GROUND |
| 11 | BIT 5 OUT | 34 | -15V POWER IN |
| 12 | BIT 6 OUT | 35 | +15V POWER IN |
| 13 | BIT 7 OUT | 36 | +5V POWER IN |
| 14 | BIT 8 OUT | | |

## PIN DESIGNATIONS
## MAS-1202

| PIN | FUNCTION | PIN | FUNCTION |
|---|---|---|---|
| 1 | DATA READY | 16 | BIT 10 OUT |
| 2 | INTERNAL CLOCK OUT | 17 | BIT 11 OUT |
| 3 | BIT 1 OUT ($\overline{\text{MSB}}$) | 18 | BIT 12 OUT (LSB) |
| 4 | SERIAL DATA OUT | 19 | ANALOG INPUT |
| 5 | BIT 1 OUT (MSB) | 20 | ANALOG GROUND |
| 6 | BIT 2 OUT | 29 | ENCODE COMMAND IN |
| 7 | BIT 3 OUT | 30 | GAIN ADJUST |
| 8 | BIT 4 OUT | 31 | BIPOLAR OFFSET |
| 11 | BIT 5 OUT | 32 | UNIPOLAR ZERO |
| 12 | BIT 6 OUT | 33 | POWER GROUND |
| 13 | BIT 7 OUT | 34 | -15V POWER IN |
| 14 | BIT 8 OUT | 35 | +15V POWER IN |
| 15 | BIT 9 OUT | 36 | +5V POWER IN |

11

## ORDERING INFORMATION

The 8- and 10-bit versions of the MAS series may be ordered with various options according to the chart below.

| MAS-0801 | -1 | -CBN |
|---|---|---|
| RESOLUTION AND ACCURACY | ANALOG INPUT RANGE | LOGIC OUTPUT CODING (See Note 1) |
| MAS-0801 = 8 Bits<br>MAS-1001 = 10 Bits | -1 0 to -5V FS<br>-2 0 to -10V FS<br>-3 ±5V FS<br>-4 ±10V FS<br>-5 ±1.024V FS | CBN = Complementary Binary (Options 1 and 2)<br>COB = Complementary Offset Binary (Options 3, 4 and 5)<br>C2SC = Complementary Two's Complement (Options 3, 4 and 5) |

NOTES
1. For 12-bit performance order the MAS-1202 which has no options.
2. The mating connector for the MAS series is the MSA-1.

## OUTPUT CODING

The logic output coding is shown true relative to the analog input to the A/D. If an inverting track and hold—such as the Analog Devices THC series—or an inverting op amp is used ahead of the A/D, the true logic coding is inverted relative to the system input. This yields the systemic coding as follows:

Binary (BIN) in place of Complementary Binary (CBN) for options 1 and 2; Offset Binary (OBN) in place of Complementary Offset Binary (COB) for options 3, 4 and 5; Two's Complement (2SC) in place of Complementary Two's Complement (C2SC).

| Scale | Input Voltage | Complementary Straight Binary |
|---|---|---|
| -FS -1LSB | -9.9900V | 1111 1111 11 |
| -3/4 FS | -7.5000V | 1100 0000 00 |
| -1/2 FS | -5.0000V | 1000 0000 00 |
| -1/4 FS | -2.5000V | 0100 0000 00 |
| -1LSB | -0.0010V | 0000 0000 01 |
| 0 | 0.0000V | 0000 0000 00 |

NOTE
(0 to -10V) for MAS-1001-2; LSB = 10mV for MAS-1001-1, apply input voltage factor of 1/2.

*Table I. MAS-0801 and MAS-1001 Unipolar Operation for Options 1 and 2*

| Scale | Input Voltage | Complementary Offset Binary | Complementary Two's Complement |
|---|---|---|---|
| -FS -1LSB | -4.9900V | 1111 1111 11 | 0111 1111 11 |
| -3/4 FS | -3.7500V | 1110 0000 00 | 0110 0000 00 |
| -1/2 FS | -2.5000V | 1100 0000 00 | 0100 0000 00 |
| 0 | 0.0000V | 1000 0000 00 | 0000 0000 00 |
| +1/2 FS | +2.5000V | 0100 0000 00 | 1100 0000 00 |
| +3/4 FS | +3.7500V | 0010 0000 00 | 1010 0000 00 |
| +FS -1LSB | +4.9900V | 0000 0000 01 | 1000 0000 01 |
| +FS | +5.0000V | 0000 0000 00 | 1000 0000 00 |

NOTES:
(-5V to +5V) for MAS-1001-3; LSB = 10mV for MAS-1001-4 apply input voltage factor of 2.

In Table II, complementary 2SC is accomplished by factory option.

*Table II. MAS-0801 and MAS-1001 Bipolar Operation for Options 3 and 4*

| Scale | Input Voltage | Complementary Offset Binary | Complementary Two's Complement |
|---|---|---|---|
| -FS -1LSB | -1.022V | 1111 1111 11 | 0111 1111 11 |
| -1/2 FS | -0.512V | 1100 0000 00 | 0100 0000 00 |
| 0 | -0.000V | 1000 0000 00 | 0000 0000 00 |
| +1/2 FS | +0.512V | 0100 0000 00 | 1100 0000 00 |
| +FS | +1.024V | 0000 0000 00 | 1000 0000 00 |

NOTE
(-1.024V to +1.024V) for MAS-1001-5; LSB = 2mV.

*Table III. MAS-0801 and MAS-1001 Bipolar Operation for Option 5*

| Scale | Input Voltage | Straight Binary |
|---|---|---|
| +FS -1LSB | +9.9976V | 1111 1111 1111 |
| +7/8 FS | +8.7500V | 1110 0000 0000 |
| +3/4 FS | +7.5000V | 1100 0000 0000 |
| +1/2 FS | +5.0000V | 1000 0000 0000 |
| +1/4 FS | +2.5000V | 0100 0000 0000 |
| +1LSB | +0.0024V | 0000 0000 0001 |
| 0 | 0.0000V | 0000 0000 0000 |

NOTE
Unipolar Operation (0 to +10V)

*Table IV. MAS-1202 Unipolar Operation (0 to +10V)*

| Scale | Input Voltage | Straight Binary | Two's Complement |
|---|---|---|---|
| +FS -1LSB | +4.9976V | 1111 1111 1111 | 0111 1111 1111 |
| +3/4 FS | +3.7500V | 1110 0000 0000 | 0110 0000 0000 |
| +1/2 FS | +2.5000V | 1100 0000 0000 | 0100 0000 0000 |
| 0 | 0.0000V | 1000 0000 0000 | 0000 0000 0000 |
| -1/2 FS | -2.5000V | 0100 0000 0000 | 1100 0000 0000 |
| -3/4 FS | -3.7500V | 0010 0000 0000 | 1010 0000 0000 |
| -FS +1LSB | -4.9976V | 0000 0000 0001 | 1000 0000 0001 |
| -FS | -5.0000V | 0000 0000 0000 | 1000 0000 0000 |

NOTE
In Table V, TWO'S COMPLEMENT (2SC) is accomplished by using the $\overline{\text{MSB}}$ output for Bit 1.

*Table V. MAS-1202 Bipolar Operation (-5V to +5V)*

# ANALOG DEVICES

# 8-Bit Video Analog-to-Digital Converter

# MATV-0811, -0816, -0820

## FEATURES

**8-Bit Accuracy — Guaranteed Monotonic**
**Ultra-High Speed — dc to 20MHz Word Rates**
**Most Economical Video A/D**
**Smallest Available Complete A/D — 5.5″ X 4.38″ X 0.85″**
**Self Contained — Includes Input Buffer, Encoder, Reference, Timing, and Buffered Parallel Output**

## APPLICATIONS

**Digitize Color Television at Up to Three or Four Times NTSC or PAL Color Subcarrier Frequencies**
**Video Time Base Correction and Frame Synchronization**
**Radar Signal Processing**
**Real Time Transient and Continuous Spectrum Analysis**

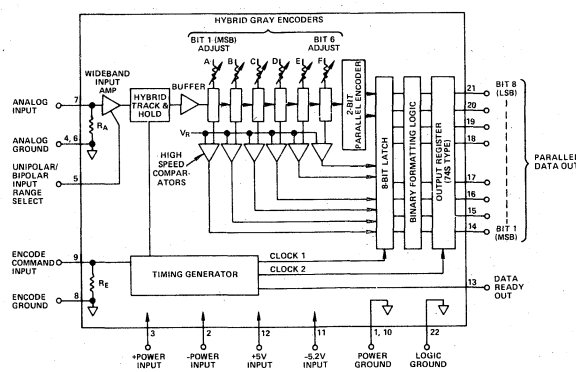



## GENERAL DESCRIPTION

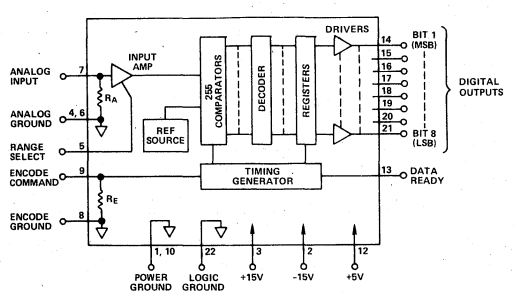
The Analog Devices' MATV series of A/D converters represent a major breakthrough in high-speed A/D technology. Providing conversion word rates from dc to 11MHz, 16MHz and 20MHz the MATV-0811, MATV-0816 and MATV-0820 are the lowest cost A/D converters in their performance class. As complete devices, they require only the addition of external power to accomplish precision video A/D conversion.

The use of internal hybrid microcircuit construction allows these modular A/D's to occupy a volume of only 21 cubic inches. They are housed in metal cases which not only shield the circuits from external RF interference, but aid in efficient heat dissipation. A choice of analog input voltages is available, including the industry standard 0 to +1V at 75Ω. The encode command input, data ready output, and the digital bit outputs are all TTL compatible. Designed to operate from either ±12V or ±15V analog and +5V digital supplies (MATV-0811 and MATV-0816 also require -5.2V), the MATV series dissipate less than 8 watts. Their weight is < 10 ounces due to enclosure rather than encapsulation. This technique facilitates rapid, inexpensive factory repair and aids in reliable printed circuit board mounting by the customer without extensive mechanical constraints or system engineering.

Relative dc accuracy is 0.2% of full scale ±1/2LSB when operating over the frequency range of dc to 20MHz. The MATV series is designed to digitize color television signals at rates up to 20MHz and is also ideally suited for other analog to digital conversion requirements, such as radar signal processing, laser pulse analysis, transient analysis, and medical electronics applications where real-time analysis and display of large quantities of information are required.




*MATV-0811, MATV-0816 Block Diagram*




$R_A$ AND $R_E$ ARE DETERMINED BY THE ANALOG INPUT IMPEDANCE AND ENCODE COMMAND INPUT IMPEDANCE, RESPECTIVELY.

*MATV-0820 Block Diagram*

11

# SPECIFICATIONS (typical @ +25°C and nominal power supply voltages unless otherwise noted)

| MODEL | UNITS | MATV-0811 | MATV-0816 | MATV-0820 |
|---|---|---|---|---|
| RESOLUTION (FS = Full Scale) | Bits/% FS | 8/0.4 | * | * |
| LSB Weight | % FS | 0.4 | * | * |
| ACCURACY (relative) at dc | typ | ±0.15% ±1/2LSB | *[1] | * |
| | max | ±0.2% ±1/2LSB | *[1] | * |
| Monotonicity | | GUARANTEED | * | * |
| Differential Nonlinearity vs Temperature | % FS/°C | 0.01 | * | 0.005 |
| Linearity and Gain vs Temperature | % FS/°C | 0.02 | * | 0.01 |
| DYNAMIC CHARACTERISTICS | | | | |
| AC Linearity @ Encode Rate[2] | MHz | 11 | 15 | 20 |
| Analog Input Frequency | | | | |
| DC to 3.6MHz | Spurious Signals are | | | |
| | > dB below FS | 50 | * | * |
| 3.6MHz to 5.5MHz | | 45 | * | * |
| Conversion Rate (Encode Word Rate) | MHz max | 11 | 16[1] | 20 |
| Conversion Time[3] | ns | 150±20 | 120±20 | 35±10 + 1/Encode Rate |
| Aperture Uncertainty (Jitter) | ps max | ±30 | * | * |
| Aperture Time | ns | 3 | * | 12 |
| Signal to Noise Ratio | | | | |
| (rms signal to rms noise) | dB min | 48 | * | * |
| (peak signal to rms noise) | dB min | 58 | * | * |
| Noise Power Ratio[4] | dB min | 37 | * | * |
| Transient Response[5] | ns | 50 | * | * |
| Overvoltage Recovery Time[6] | ns | 60 | * | * |
| Differential Gain[7] | % | 3 | * | * |
| Differential Phase | Degrees | 1 | * | * |
| Bandwidth | | | | |
| Small Signal 3dB | MHz | 20 | * | * |
| Large Signal 3dB | MHz | 15 | * | * |
| Flat ±0.1dB, dc through | MHz | 5.5 | * | * |
| INPUT[8] | | | | |
| Voltage Range | | | | |
| Unipolar (Pin 5 Grounded) | V | 0 to 1 | * | * |
| Bipolar (Pin 5 open) | V | ±0.5 | * | * |
| Impedance (Terminated to Ground) | Ω | 75 | * | * |
| ENCODE COMMAND INPUT[8] | | | | |
| Logic Levels, TTL Compatible | | "0" = 0 to +0.4V | * | * |
| | | "1" = +2.4V to +5V | * | * |
| Impedance (terminated to ground) | Ω | 75 ±5% | * | * |
| Rise and Fall Times (10% to 90%) max | ns | 10 | * | * |
| Duration/Width 50% points (see timing diagram) | ns min | 10 | * | 20 |
| | ns max | 50% duty cycle | 40 | * |
| Frequency (random or periodic) | dc to MHz | 11 | 16 | 20 |
| DIGITAL DATA OUTPUT[8] | | | | |
| Format | | Eight Parallel Bits NRZ | | |
| Logic Levels, TTL | | (Same as Encode Command) | | |
| Drive Capability (not short circuit protected) | TTL Loads | 10 Std | 10 Schottky | |
| Time Skew | ns max | 15 | 10 | 10 |
| Coding | | Straight Binary (BIN) | | |
| DATA READY OUTPUT | | | | |
| Format[9] | | RZ | * | * |
| Logic Levels, TTL | | (Same as Encode Command) | | |
| Drive Capability | | 10 Std | 10 Schottky | |
| Width | ns | 40±10 | 35±5 | 25±5 |
| POWER REQUIREMENTS[10] | | | | |
| MATV-0811, MATV-0816/MATV-0820 | | | | |
| +15V ±2%/+11.8V to +15.5V | mA max | 210 | * | 70 |
| −15V ±2%/−11.8V to −15.5V | mA max | 180 | * | 400 |
| +5V ±5%/+5V +5% | mA max | 450 | 540 | 200 |
| −5.2V ±5% | mA max | 280 | * | N/A |
| TEMPERATURE RANGE | | | | |
| Operating (case) | °C | 0 to +70 | * | * |
| Storage | °C | −55 to +85 | * | * |

*Same as MATV-0811.

NOTES

[1] Applies to a customer specified operating frequency, ±10%. Outside this range, accuracy may degrade to ±0.3% ±1/2LSB.

[2] AC linearity expressed in terms of spurious in-band signals generated at specified encode rates.

[3] Pipeline delay not related to encode rate.

[4] DC to 5MHz while noise BW with slot frequency at 500kHz.

[5] Time to achieve 8-bit (0.2%) accuracy after F.S. step input.

[6] For signals not exceeding 10% overvoltage, the A/D will recover to 8-bit accuracy within 60ns after the signal returns to the specified range. Overvoltage inputs greater than 150% of F.S. may damage input circuits and should be avoided.

[7] At maximum encode rate, 20 IRE unit subcarrier, not including quantization effects.

[8] Consult factory for other voltage, impedance and logic level options.

[9] The leading edge of the data ready pulse occurs approximately 10ns before output data changes. The trailing edge is recommended for strobing data into external circuits.

[9] For MATV-0811, the leading edge of the Data Ready pulse occurs approximately 15ns before output data changes. The trailing edge is recommended for strobing data into external circuits.

For MATV-0816, the leading edge of the Data Ready pulse occurs approximately 10ns before output data changes. The trailing edge is recommended for strobing data into external circuits.

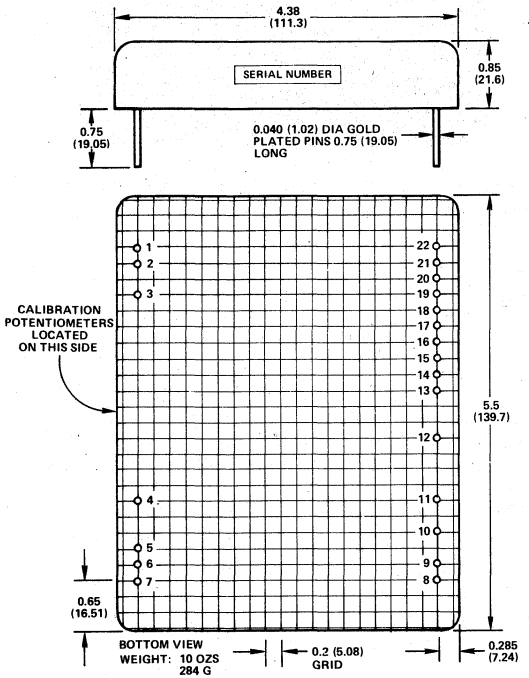
For MATV-0820, the leading edge of the Data Ready pulse occurs approximately simultaneously with output data changes. The trailing edge is recommended for strobing data into external circuits. This provides a minimum of 20ns set-up time for external registers.

[10] The A/D's are calibrated at the factory at either ±12V or ±15V as a no-cost option. Other operating voltages within this range may be specified by the user at slight additional cost. See application section for more information.

Specifications subject to change without notice.

## MECHANICAL OUTLINE AND DIMENSIONS

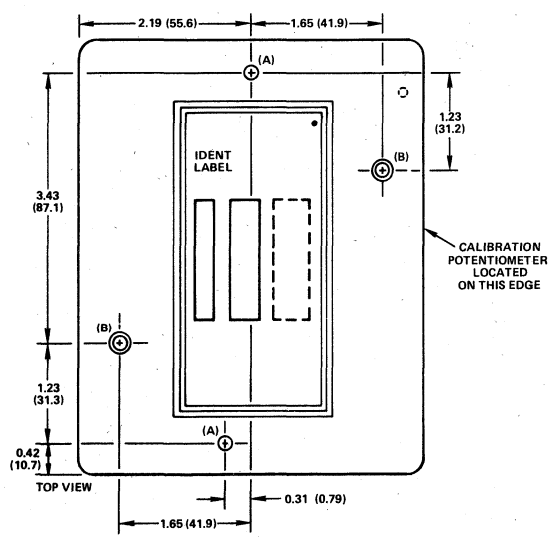
Dimensions shown in inches and (mm).




PINS ARE GOLD PLATED PER MIL-G-5204, TYPE II

NOTES:
DIMENSIONS AND LOCATION OF HOLD DOWN HOLES FOR MATV-0820 ARE SHOWN ON THE MECHANICAL OUTLINE FIGURE BELOW. NOT AVAILABLE ON MATV-0811 AND -0816.

DOT ON TOP INDICATES POSITION OF PIN 1.




(A) LOCATIONS ARE HOLES (0.16" TO 0.18" DIA.) THRU THE A/D SUITABLE FOR SECURING THE UNIT TO A MOTHER BOARD, ETC.
(B) LOCATIONS ARE EQUIPPED WITH #6X32 CLINCH NUTS (0.3" DEEP) SUITABLE FOR ATTACHING HEAT SINK, ETC.

DOT ON TOP INDICATES POSITION OF PIN 1.

## MATV SERIES
## PIN DESIGNATIONS

| PIN | FUNCTION | COMMENTS |
|---|---|---|
| 1 | POWER GROUND | * |
| 2 | - POWER INPUT | -11.8V (MIN); -16.5V (MAX) |
| 3 | + POWER INPUT | +11.8V (MIN); +16.5V (MAX) |
| 4 | ANALOG GROUND | * |
| 5 | RANGE SELECT | UNIPOLAR = GROUND<br>BIPOLAR = OPEN |
| 6 | ANALOG GROUND | * |
| 7 | ANALOG INPUT | OPTIONAL |
| 8 | ENCODE GROUND | * |
| 9 | ENCODE COMMAND | TTL, +5V (MAX) |
| 10 | POWER GROUND | * |
| 11 | NO CONNECTION 0820<br>-5.2V POWER INPUT<br>0811, 0816 | <br><br>-5V (MIN), -5.5V (MAX) |
| 12 | +5V POWER INPUT | +4.75V (MIN); +5.25V (MAX) |
| 13 | DATA READY OUTPUT | TTL LEVELS |
| 14 | BIT 1 OUTPUT (MSB) | TTL LEVELS |
| 15 | BIT 2 OUTPUT | TTL LEVELS |
| 16 | BIT 3 OUTPUT | TTL LEVELS |
| 17 | BIT 4 OUTPUT | TTL LEVELS |
| 18 | BIT 5 OUTPUT | TTL LEVELS |
| 19 | BIT 6 OUTPUT | TTL LEVELS |
| 20 | BIT 7 OUTPUT | TTL LEVELS |
| 21 | BIT 8 OUTPUT (LSB) | TTL LEVELS |
| 22 | DIGITAL LOGIC GND. | * |

*ALL GROUNDS ARE INTERNALLY CONNECTED

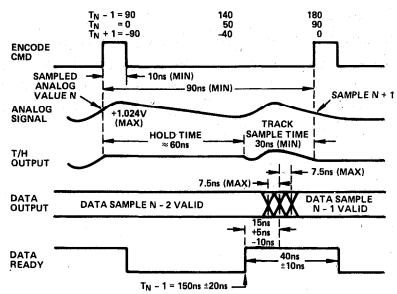



*Figure 1. MATV-0811 Timing Diagram at Maximum Sample Rate of 11MHz*

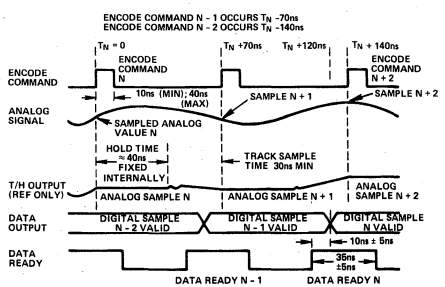
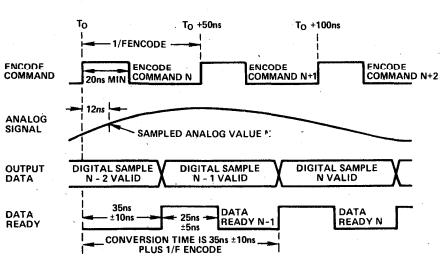



*Figure 2. MATV-0816 Timing Diagram at Sample Rate of 14.3MHz*




NOTE:
2 ENCODE COMMAND PULSES ARE REQUIRED TO OBTAIN FIRST "DATA READY".

*Figure 3. MATV-0820 Timing Diagram Shown at an Encode Frequency of 20MHz*

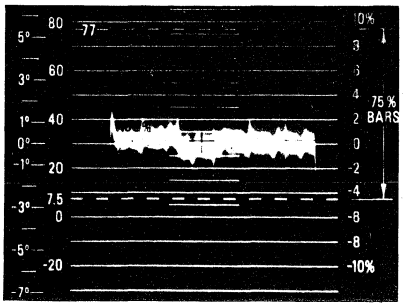



*Figure 4. Typical Differential Gain of MATV-0816 Operating at 15MHz Word Rates*

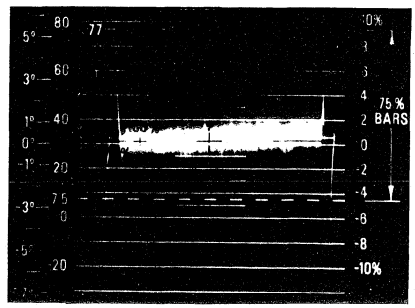



*Figure 5. Typical Differential Phase of MATV-0816 Operating at 15MHz Word Rates*

## ORDERING INFORMATION

Each MATV series A/D converter will be calibrated at ±15V as a standard. Order by model number either MATV-0811, MATV-0816 or MATV-0820.

### Optional Versions

The MATV series A/D's are available with a variety of options, including analog input range and impedance, encode command input impedance, encode word rate, power supply voltage calibration, etc. Any option other than what is shown on the data sheet will have longer delivery, since each non-standard device is built on a per order basis.

A complete listing of optional designators is available from either the factory or your local Analog Devices' sales office.

### Device Marking

The MATV series A/D that you order will be marked with a series of alphanumerics which specifically designate the options built into the device. For the standard devices, these will be as follows:

MATV-0811 will be marked MATV-0811-1-BIN-15 for older devices, or MATV-0811-AA150 for newer devices.

MATV-0816 will be marked MATV-0816-0175 BIN 75143150 for older devices, or MATV-0816 ABBA143150 for newer devices.

MATV-0820 will be marked MATV-0820-0175 BIN 75 for older devices, or MATV-0820 ABAA for newer devices.

This information is provided so that there will be no confusion as to why information other than the basic model number appears on the device identification label, which might cause problems at a customers' incoming inspection.

# 10-Bit Video Analog-to-Digital Converter

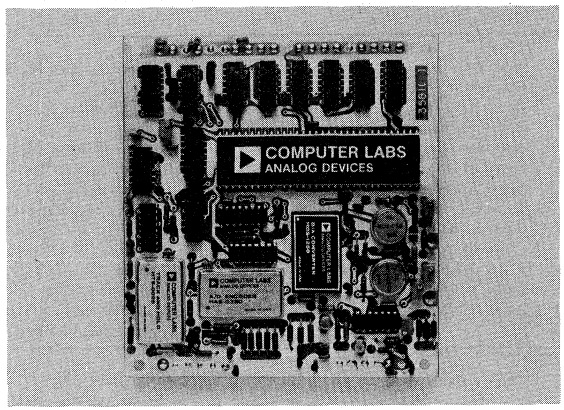
# MOD-1005

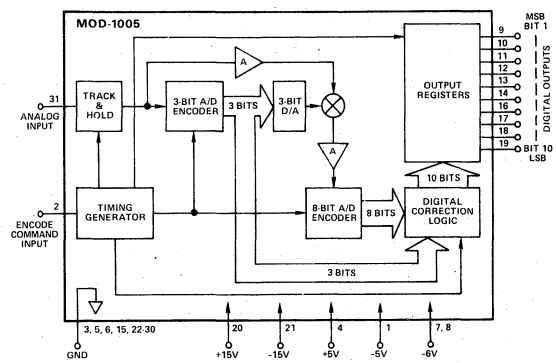
## FEATURES

- 10 Bits @ 5MHz Word Rate
- One-27 Sq. In. PC Board
- Built-In Track-and-Hold – 25ps Aperture Uncertainty
- 20MHz Analog Input Bandwidth
- TTL Compatible
- Low (10-Watt) Power Dissipation
- Signal-To-Noise Ratio Greater Than 58dB
- Noise Power Ratio Greater Than 49dB
- Completely Repairable

## APPLICATIONS

- Radar Digitizing
- Digital Communications
- Real Time Spectrum Analysis
- High Resolution TV




*Block Diagram*

## GENERAL DESCRIPTION

Analog Devices' model MOD-1005 is a very high-speed A/D converter capable of digitizing video input signals to 10-bit accuracy at random or periodic word rates of dc through 5MHz. The MOD-1005 is truly a breakthrough in high-speed A/D technology. It is the most cost effective A/D in this speed category, combining small size and low power dissipation with low cost.

The MOD-1005 is constructed on a single printed circuit card which is intended for mounting on a system mother-board, and occupies only 27 square inches. Within this A/D is the required sample/track and hold amplifier, encoder, timing circuits and output latches for a true simultaneous, all-parallel digital output.

The encode command input and digital outputs are TTL compatible. The A/D requires only an external encode command pulse and external power supplies for operation. NO external parts are required. Gain and offset potentiometers are provided on the card. The A/D is fully repairable either at the factory or in the field.

The MOD-1005 is ideally suited for systems requiring the ultimate in conversion speed and accuracy. Such applications include radar digitizing, digital communications, spectrum analysis, and many others. Each MOD-1005 is backed by Analog Devices' limited one year warranty.

# SPECIFICATIONS (typical @ +25°C with nominal power supplies unless otherwise noted)

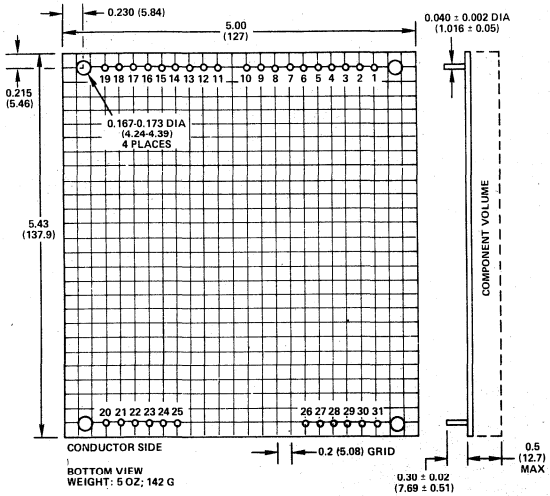
| MODEL | MOD-1005 |
|---|---|
| RESOLUTION (FS = FULL SCALE) | 10 Bits (0.1% FS) |
| LSB WEIGHT | 4mV |
| ACCURACY (INCLUDING LINEARITY) @ DC | ±0.05% Full Scale ±1/2LSB |
| Monotonicity | Guaranteed |
| Differential Nonlinearity vs. Temperature | 0.0005% of FS/°C |
| Gain vs. Temperature | 0.01% of FS/°C |
| DYNAMIC CHARACTERISTICS | |
| AC Linearity[1] | Spurious Signals >59dB below FS |
| Conversion Time | See Text |
| Conversion Rate (Word Rate) | dc to 5MHz |
| Aperture Uncertainty (Jitter) | ±25ps max |
| Aperture Time | 45ns (±10ns from unit to unit) |
| Signal to Noise Ratio (rms signal to rms noise) | 58dB min at 500kHz analog input |
| Noise Power Ratio[2] | 49dB min |
| Transient Response (Full Scale Step Input) | 10-Bit (0.05%) Accuracy within 50ns |
| Overvoltage Recovery Time | |
| Recovers to 10-bit accuracy after | |
| 2 X FS input overvoltage in | 200ns |
| Input Bandwidth (small signal, 3dB) | 20MHz min |
| Input Bandwidth (large signal, 3dB) | 15MHz min flat within ±0.1dB, dc through 5MHz |
| INPUT | |
| Voltage Range | ±2.048V FS |
| | ±4V Absolute max |
| Impedance | 50Ω |
| Offset Voltage | Adjust to 0 with On Board Potentiometer |
| Offset vs. Temperature | 0.01% Full Scale/°C |
| Bias Current | 1nA max |
| ENCODE COMMAND INPUT | |
| Logic Levels, TTL Compatible | "0" = 0 to +0.4V |
| | "1" = +2.4V to +5V |
| Logic Loading | 2 Standard TTL Gates |
| Rise and Fall Times | 10ns max |
| Duration Min/Max | 20ns/60% of Duty Cycle |
| Frequency (Random or Periodic) | dc to 5MHz |
| Sample Delay | 45ns (unit to unit tolerance is ±10ns) |
| DIGITAL DATA OUTPUT | |
| Format | 10 Parallel Bits, NRZ |
| Logic Levels, TTL Compatible | "0" = 0 to +0.4V |
| | "1" = +2.4V to +5V |
| Drive (Not Short Circuit Protected) | Up to 1 Schottky TTL or 2 Standard TTL Loads |
| Time Skew | 10ns max |
| Coding | 2's Complement (2SC) |
| Conversion Time | See Text on the Next Page |
| POWER REQUIREMENTS[3] | typ/max |
| +15V ±5% | 150/170mA |
| -15V ±5% | 150/170mA |
| -6V ±4% | 300/350mA |
| +5V ±5% | 350/400mA |
| -5V ±5% | 500/550mA |
| Power Consumption | 10 Watts |
| TEMPERATURE RANGE | |
| Operating | 0 to +70°C |
| Storage | -55°C to +85°C |
| Cooling Requirements | 100 Linear Feet Per Min (LFPM) |
| MTBF[4] | $7.62 \times 10^4$ Hours |
| PHYSICAL CHARACTERISTICS | |
| Construction | Single Printed Circuit Card |

NOTES
[1] AC linearity expressed in terms of spurious in-band signals generated as specified encode rates, with dc to 2.5MHz analog input.
[2] DC to 2.4MHz white noise BW with Slot frequency of 512kHz.
[3] ±15V supplies must be equal and opposite within 200mV and track over temperature.
[4] MTBF based on 30°C ambient; ground; benign.

Specifications subject to change without notice.

## OUTLINE DIMENSIONS

Dimensions shown in inches (mm).




## PIN DESIGNATIONS

| PIN | FUNCTION |
|---|---|
| 1 | -5V |
| 2 | ENCODE COMMAND |
| 3 | GND* |
| 4 | +5V |
| 5 | GND* |
| 6 | GND* |
| 7 | -6V |
| 8 | -6V |
| 9 | BIT 1 MSB |
| 10 | BIT 2 |
| 11 | BIT 3 |
| 12 | BIT 4 |
| 13 | BIT 5 |
| 14 | BIT 6 |
| 15 | GND* |

| PIN | FUNCTION |
|---|---|
| 16 | BIT 7 |
| 17 | BIT 8 |
| 18 | BIT 9 |
| 19 | BIT 10 LSB |
| 20 | +15V |
| 21 | -15V |
| 22 | GND* |
| 23 | GND* |
| 24 | GND* |
| 25 | GND* |
| 26 | GND* |
| 27 | GND* |
| 28 | GND* |
| 29 | GND* |
| 30 | GND* |
| 31 | ANALOG INPUT |

*ALL GROUND PINS ARE CONNECTED TOGETHER WITHIN THE MOD-1005

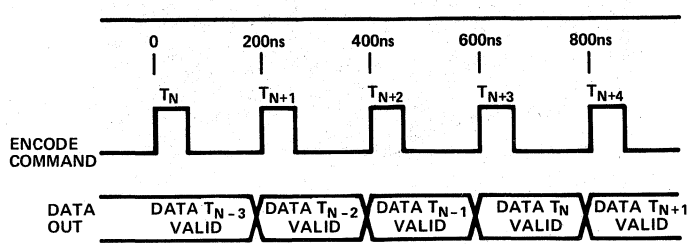
## ORDERING INFORMATION

Order model number MOD-1005 A/D converter. Mating pin sockets for the MOD-1005 are model number MSB-2 (31 required per A/D).

## CONVERSION TIME

Output data is valid two encode command clock periods plus 200ns after application of an initial encode command pulse. Due to the pipeline delay effect of the A/D, a total of three encode command pulses are required to shift the data to the output of the A/D. For example, with a 5MHz encode rate, data is valid 600ns after the application of the first encode command pulse – assuming that two pulses occur after the first.

Use of the trailing edge of the encode command is recommended for strobing output data into external register (see Figure 1).




DATA $T_N$ (THE RESULT OF ENCODE COMAND $T_N$) OCCURS TWO CONVERSION PERIODS PLUS 200ns AFTER ENCODE COMMAND $T_N$. FOR A 5MHz WORD RATE AS SHOWN, DATA IS VALID 200ns AFTER THE THIRD ENCODE COMMAND PULSE OR $T_N$ + 600ns. IN ALL CASES, THREE ENCODE COMMAND PULSES ARE REQUIRED FOR TRANSFER OF DATA TO THE OUTPUT, DUE TO THE PIPELINE DELAY EFFECT THROUGH THE A/D. NO DATA READY PULSE IS SUPPLIED.

*Figure 1. MOD-1005 Timing Diagram*

**GROUND CONNECTIONS**

It should be noted that the MOD-1005 PC board has 13 ground pins. These are all connected to the ground plane on the board. For best results it is recommended that ALL of these pins be connected to a massive system or "mother board" ground plane.

**CALIBRATION PROCEDURE (MOD-1005)**

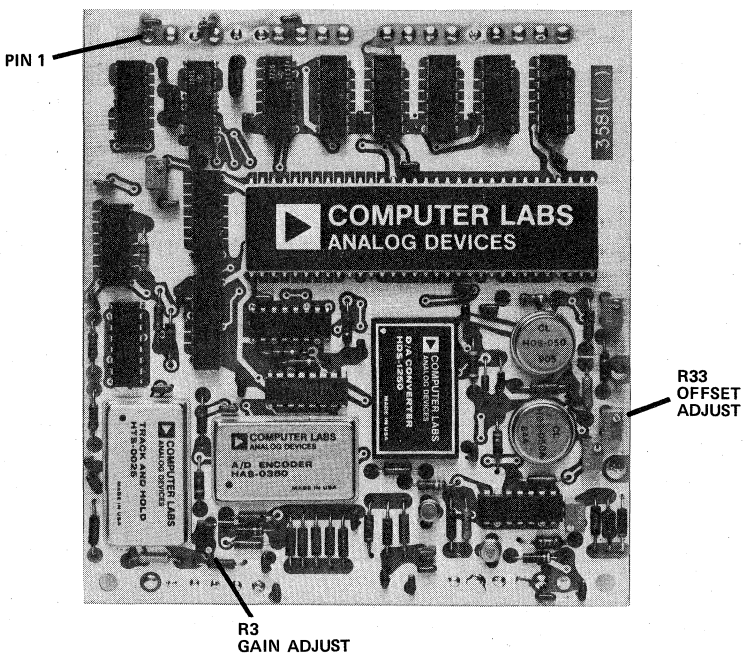
The MOD-1005 A/D is precisely calibrated at the factory before shipment, and should need no further calibration. However, if slight readjustments of the A/D are required in the system, the following procedure should be followed. It should be remembered that the output coding of this A/D is 2SC.

**Offset Adjustment**

The offset is adjusted by varying potentiometer R33 with 0 volts applied to the analog input. To obtain the proper output code, observe that the digital output is changing between 1 1 1 1 1 1 1 1 1 1 and 0 0 0 0 0 0 0 0 0 0 at this adjustment level. When properly adjusted a digital code of 0 0 0 0 0 0 0 0 0 0 will represent analog input 1LSB above zero volts, and a digital code of 1 1 1 1 1 1 1 1 1 1 will represent an analog input of 1LSB below zero volts.

**Gain Adjustment**

The gain is adjusted by varying potentiometer R3. This adjustment is made by applying +2.042V (FS -1 1/2LSB) to the analog input and while monitoring the digital output, adjust R3 for the output code varying between 0 1 1 1 1 1 1 1 1 0 and 0 1 1 1 1 1 1 1 1 1 (FS). If the user needs to offset the entire range of the A/D, this can be accomplished by readjusting R33 as required. However, in this procedure, the offset should always be adjusted first.




*A/D Converter Assembly*

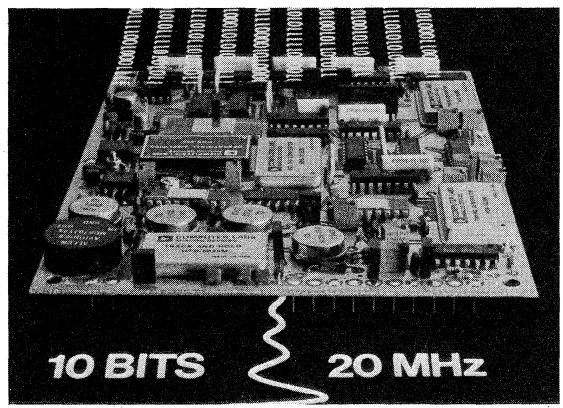
# ANALOG DEVICES

# 10-Bit Video Analog-to-Digital Converter

# MOD-1020

**FEATURES**
**10-Bits @ 20MHz Word Rates**
**One 35 Sq. In. PC Board**
**Built-In Track-and-Hold – 25ps Aperture**
**15MHz Large-Signal Input Bandwidth**
**ECL Compatible**
**Signal-to-Noise Ratio Greater Than 56dB**
**Noise Power Ratio Greater Than 45dB**

**APPLICATIONS**
**Television Digitizing**
**Radar Digitizing**
**Medical Instrumentation**
**Digital Communications**
**Spectrum Analysis**
**Sonar Digitizing**



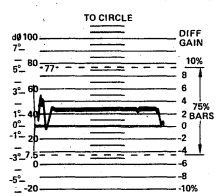

## GENERAL DESCRIPTION

The Analog Devices' model MOD-1020 is an ultra-high-speed A/D converter capable of digitizing video input signals to 10-bit accuracy at word rates through 20MHz. The MOD-1020 is another in the series of state-of-the-art A/D converters from Analog Devices that employs the unique digital correcting subranging (DCS) conversion technique to virtually eliminate errors normally associated with subranging type A/D converters. No other A/D converter commercially available offers the user the speed and accuracy attainable with the MOD-1020.

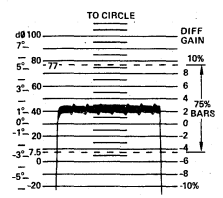
The MOD-1020 is constructed on a single printed circuit card which is intended for mounting on a system mother board and occupies only 35 square inches. The A/D is complete with internal track-and-hold, encoder, timing circuitry, references, and latched output. It produces a true all-parallel digital output.

The encode command input, digital outputs, and data ready output are balanced ECL compatible. The A/D requires only an external encode command input pulse and external power supplies for operation. The analog input impedance is at least 500Ω, so that the user can easily terminate the A/D with lower impedances in his system. Gain and offset potentiometers are provided on the card so that the A/D can be operated in either the unipolar or bipolar modes. The A/D is fully repairable.

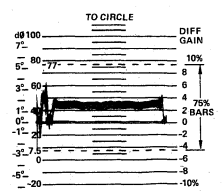
The MOD-1020 is ideally suited for systems requiring the ultimate in conversion speed and accuracy. Such applications include radar digitizing, digital communications (baseband digitizing), composite color television digitizing, spectrum analysis, medical instrumentation, and many others. Each MOD-1020 is backed by Analog Devices' limited one-year warranty.



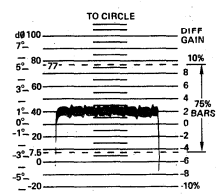

*Differential Phase – Generator and Vectorscope Back-to-Back No A/D Conversion*




*Differential Gain – Generator and Vectorscope Back-to-Back No A/D Conversion*




*Differential Phase – Model MOD-1020 ADC and Model 4120E DAC Back-to-Back 14.4MHz Conversion (Word) Rate*




*Differential Gain – Model MOD-1020 and Model 4120E DAC Back-to-Back 14.4MHz Conversion (Word) Rate*

The above waveforms were obtained utilizing a Tektronix Model 149A N.T.S.C. Test Signal Generator with a 20 IRE unit TV test signal output. The display (output) was obtained using a Tektronix Model 520A Vectorscope.

11

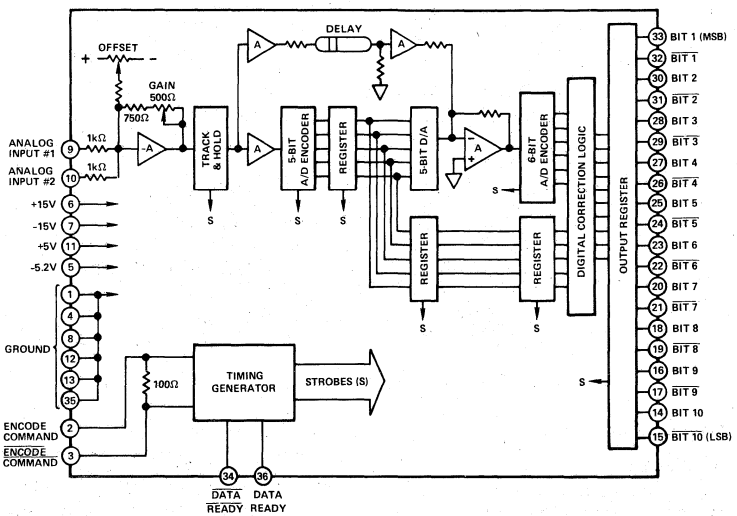
# SPECIFICATIONS (typical @ +25°C with nominal power supplies unless otherwise noted)

| MODEL | MOD-1020 |
|---|---|
| RESOLUTION (FS = FULL SCALE) | 10 Bits (0.1% FS) |
| LSB WEIGHT | 1mV or 2mV Depending on Analog Input Range |
| ACCURACY (INCLUDING LINEARITY) @ DC | ±0.05% Full Scale ±1/2LSB |
| Monotonicity | Guaranteed 0 to +70°C |
| Nonlinearity vs. Temperature | 0.0005% of FS/°C |
| Gain vs. Temperature | 0.015% of FS/°C |
| DYNAMIC CHARACTERISTICS | |
| AC Linearity[1] (dc to 1MHz) | Spurious Signals ≥60dB below FS |
| (1MHz to 5MHz) | Spurious Signals ≥55dB below FS |
| (5MHz to 10MHz) | Spurious Signals ≥50dB below FS |
| Conversion Time | See Text and Timing Diagram |
| Conversion Rate[2] | dc to 20MHz (See Note and Ordering Information) |
| Aperture Uncertainty (Jitter) | ±25ps max |
| Aperture Time (Delay) | 5ns (±2ns unit-to-unit tolerance) |
| Signal to Noise Ratio[3] | 56dB min |
| Signal to Noise Ratio[4] | 65dB min |
| Noise Power Ratio[5] | 45dB min, 47dB typ |
| Transient Response[6] | 50ns |
| Overvoltage Recovery[7] | 50ns |
| Input Bandwidth (small signal, 3dB)[8] | 30MHz |
| Input Bandwidth (large signal, 3dB)[9] | 15MHz; Flat within 0.2dB, dc to 10MHz |
| Two-Tone Linearity (@ Input Frequency); | |
| 60kHz; 62kHz | In-Band Spurious Signals ≥60dB below FS |
| 4.998MHz; 5.000MHz | In-Band Spurious Signals ≥55dB below FS |
| 9.996MHz; 9.998MHz | In-Band Spurious Signals ≥50dB below FS |
| Differential Gain[10] | 1% with 20 IRE Unit Reference |
| Differential Phase[10] | 0.5° with 20 IRE Unit Reference |
| ANALOG INPUT (See Notes on Input Range in Text) | |
| Voltage Range | 1V p-p or 2V p-p, Depending on Hook-Up<br>Either Unipolar or Bipolar<br>±4V Absolute max Input |
| Impedance | 1000Ω (2V Input Range)<br>500Ω (1V Input Range) |
| Offset | Adjustable to Zero with On-Card Potentiometer (R4) |
| Offset vs. Temperature | 0.01%/°C |
| ENCODE COMMAND INPUT | |
| Logic Levels, ECL Compatible | "0" = -1.7V |
| (Balanced Input) | "1" = -0.9V |
| Impedance | 100Ω Line-to-Line |
| Rise and Fall Times | 5ns max |
| Duration (min/max) | 10ns/70% of Duty Cycle |
| Frequency | Specified by Customer, to 20MHz (See Ordering Information) |
| DIGITAL OUTPUT DATA | |
| Format | 10 Parallel Bits, NRZ |
| Logic Levels, ECL Compatible | "0" = -1.7V |
| (Balanced Outputs) | "1" = -0.9V |
| Drive | 75Ω to 100Ω, Line-to-Line |
| Time Skew | 5ns max |
| Coding | Binary (BIN); 2's Complement (2SC) |
| DATA READY OUTPUT | |
| Logic Level, ECL Compatible | "0" = -1.7V |
| (Balanced Output) | "1" = -0.9V |
| Rise and Fall Times | 5ns max |
| Duration | 25ns ±3ns |
| Conversion Time | Output data valid 185 ±20ns after the leading edge of second Encode Command pulse—assuming that two pulses occur. Use of the trailing edge of the Data Ready pulses is required to shift the data to the output. For example, with a 20MHz encode rate, data is valid 285 ±20ns after the application of the first Encode Command pulse—assuming that two pulses occur. Use of the trailing edge of the Data Ready pulse is recommended for strobing output data into external registers. |
| POWER REQUIREMENTS | |
| +15V ±5% | 200mA |
| -15V ±5% | 200mA |
| +5V ±5% | 100mA |
| -5.2V ±5% | 2.7A |
| Power Consumption | 21 Watts |
| TEMPERATURE RANGE[11] | |
| Operating | 0 to +70°C |
| Storage | -55°C to +85°C |
| Cooling Requirements | 500 Linear Feet per Minute (LFPM) |
| PHYSICAL CHARACTERISTICS | |
| Construction | Single Printed Circuit Card |

NOTES

[1] AC linearity expressed in terms of spurious in-band signals generated at 20MHz encode rate at the analog frequencies ( ) shown.
[2] To be specified by the customer. See text and ordering information.
[3] RMS signal to rms noise ratio with 500kHz analog input.
[4] Peak-to-peak signal to rms noise ratio with 500kHz analog input.
[5] DC to 8.2MHz white noise bandwidth with slot frequency of 3.886MHz and an encode rate of 20MHz.
[6] Recovers to 10-bit accuracy after 2 X FS input overvoltage in time specified.
[7] For full-scale step input, attains 10-bit accuracy in time specified.
[8] With analog input signal 40dB below FS.
[9] With FS analog input.
[10] Applies to devices optimized for video applications. Differential gain and phase are measured and optimized for ADC's which have the following encode rate optional designators (see Ordering Information): "107" (3 X NTSC subcarrier); "133" (3 X PAL); "143" (4 X NTSC); "177" (4 X PAL).
[11] ±15V must be equal and opposite within 200mV and track over temperature.

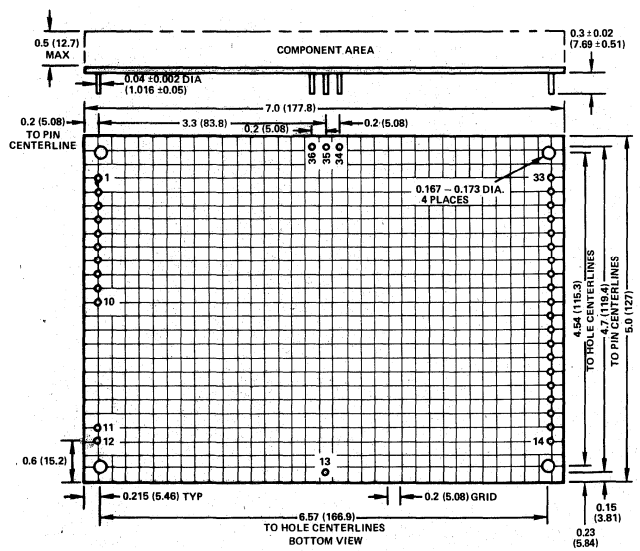
Specifications subject to change without notice.




*MOD-1020 Block Diagram*

## OUTLINE DIMENSIONS

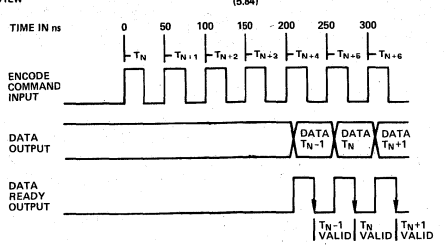
Dimensions shown in inches and (mm).




## PIN DESIGNATIONS

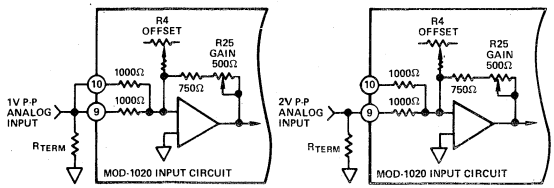
| PIN | FUNCTION | PIN | FUNCTION |
|---|---|---|---|
| 1 | GROUND | 19 | BIT 8 |
| 2 | ENCODE COMMAND | 20 | BIT 7 |
| 3 | ENCODE COMMAND | 21 | BIT 7 |
| 4 | GROUND | 22 | BIT 6 |
| 5 | -5.2V | 23 | BIT 6 |
| 6 | +15V | 24 | BIT 5 |
| 7 | -15V | 25 | BIT 5 |
| 8 | GROUND | 26 | BIT 4 |
| 9 | ANALOG INPUT #1 | 27 | BIT 4 |
| 10 | ANALOG INPUT #2 | 28 | BIT 3 |
| 11 | +5V | 29 | BIT 3 |
| 12 | GROUND | 30 | BIT 2 |
| 13 | GROUND | 31 | BIT 2 |
| 14 | BIT 10 | 32 | BIT 1 |
| 15 | BIT 10 | 33 | BIT 1 |
| 16 | BIT 9 | 34 | DATA READY |
| 17 | BIT 9 | 35 | GROUND |
| 18 | BIT 8 | 36 | DATA READY |

ALL GROUND PINS ARE CONNECTED TOGETHER WITHIN THE ADC.




OUTPUT DATA ARE VALID 185 ±20ns AFTER THE LEADING EDGE OF THE SECOND ENCODE COMMAND (TIME INCLUDES WIDTH OF DATA READY PULSE). TWO ENCODE COMMAND PULSES ARE REQUIRED TO SHIFT THE DATA TO THE OUTPUT.

*MOD-1020 Timing Diagram*




| $Z_{IN}$ | $R_{TERM}$ |
|---|---|
| 50Ω | 56.2Ω |
| 75Ω | 88.7Ω |
| 93Ω | 115.0Ω |

1V P-P INPUT OPTION

($R_{TERM}$ RESISTORS ARE 1%, 1/8W, MF)

| $Z_{IN}$ | $R_{TERM}$ |
|---|---|
| 50Ω | 52.3Ω |
| 75Ω | 80.6Ω |
| 93Ω | 102.0Ω |

2V P-P INPUT OPTION

FOR 1V P-P INPUT RANGE, CONNECT ANALOG INPUT TO PIN 9, AND CONNECT PINS 9 AND 10 TOGETHER. UNTERMINATED INPUT IMPEDANCE IS 500Ω. GAIN ADJUSTMENT RANGE (R25) IS ±20% MIN. FOR 2V P-P INPUT RANGE, CONNECT ANALOG INPUT TO PIN 9. PIN 10 IS LEFT DISCONNECTED. UNTERMINATED INPUT IMPEDANCE IS 1000Ω. GAIN ADJUSTMENT RANGE (R25) IS ±20%.

TO OBTAIN THE DESIRED TERMINATED INPUT IMPEDANCE, CONNECT THE APPROPRIATE EXTERNAL TERMINATING RESISTOR BETWEEN THE ANALOG INPUT PIN(S) AND GROUND, AS SHOWN IN THE ABOVE EXAMPLES. INPUT IMPEDANCES GREATER THAN 100Ω WILL RESULT IN LOSS OF INPUT BANDWIDTH AND SHOULD BE AVOIDED.

THE OFFSET POTENTIOMETER (R4) HAS SUFFICIENT RANGE TO ALLOW THE USER TO OPERATE THE ADC IN EITHER THE UNIPOLAR OR BIPOLAR MODE. THE ADC'S ARE CALIBRATED IN THE BIPOLAR CONFIGURATION AT THE FACTORY.

*MOD-1020 Analog Input Range Options*

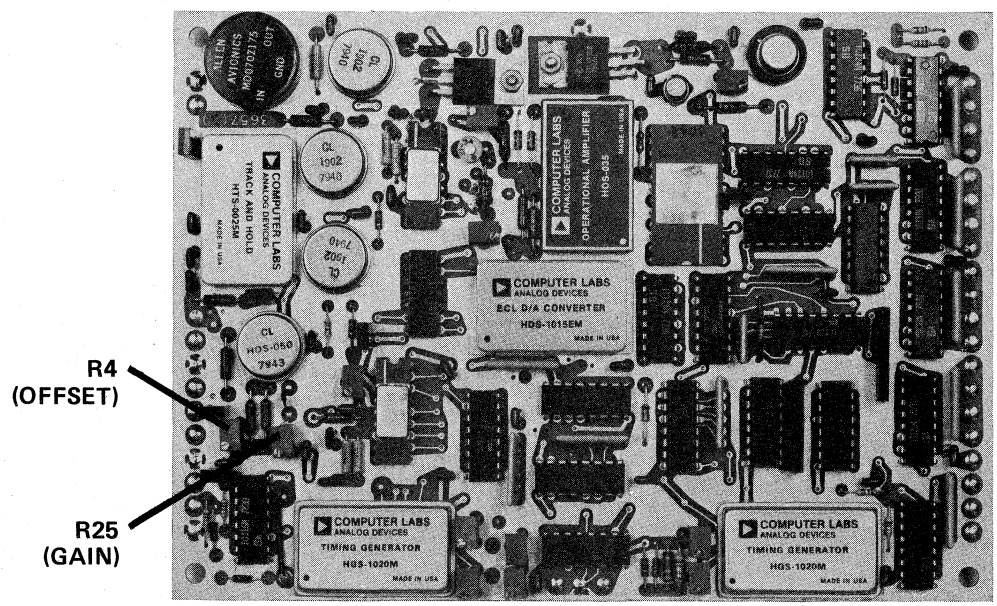
## OFFSET AND GAIN ADJUSTMENT

The offset of the ADC is adjusted by varying potentiometer R4. Apply an input voltage to the analog input corresponding to positive full scale. Adjust R4 such that the digital output is changing between 1111111111 and 1111111110.

The gain of the ADC is adjusted by varying potentiometer R25. Apply an input voltage to the analog input that corresponds to negative full scale. Adjust R25 such that the digital output is changing between 0000000000 and 0000000001.

In the foregoing, the ADC is calibrated to have a unipolar positive transfer function. If bipolar input range is required, adjust R4 to offset the entire input by one-half of the full scale input.

In setting the gain, always adjust R4 first to obtain the correct setting for full scale positive input.




*Location of Adjustment Potentiometers*

## ORDERING INFORMATION

IMPORTANT—THE ENCODE RATE OF THE MOD-1020 MUST BE SPECIFIED BY THE CUSTOMER AS SHOWN BELOW:

ORDER MODEL NUMBER: MOD-1020- "XXX", where "XXX" is to be specified by the customer. "XXX" represents the encode word rate in MHz with the decimal place assumed to be (but not shown) between the second and third places. Full 10-bit accuracy will be maintained within ±12% of this specified frequency, up to a maximum of 21MHz. For example, a device specified as MOD-1020-200 is for operation at 20.0MHz and will maintain accuracy from 17.6MHz to 21MHz.

For encode rates of 10MHz or less, the MOD-1020 will maintain fully accuracy to 10MHz. For encode frequencies of 10MHz or less, order MOD-1020-100.

Mating sockets for the MOD-1020 are model number MSB-2 (36 required per A/D).

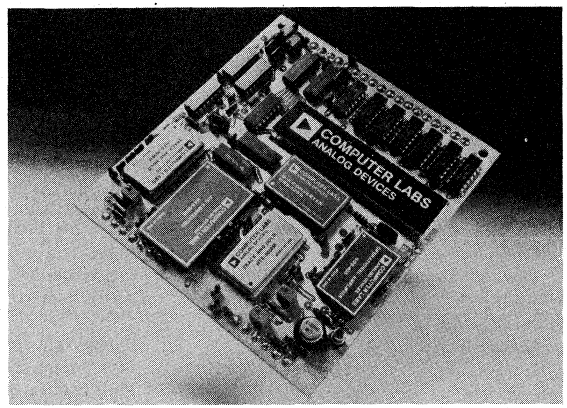
# ANALOG DEVICES

# 12-Bit Video Analog-to-Digital Converter

# MOD-1205

**FEATURES**
**12 Bits @ 5MHz Word Rate**
**One-27 Sq. In. PC Board**
**Built-In Track-and-Hold – 25ps Aperture Uncertainty**
**15MHz Analog Input Bandwidth**
**TTL Compatible**
**Low (13-Watt) Power Dissipation**
**Signal-to-Noise Ratio Greater Than 66dB**
**Noise Power Ratio Greater Than 56dB**
**Completely Repairable**

**APPLICATIONS**
**Radar Digitizing**
**Digital Communications**
**Real Time Spectrum Analysis**
**Signature Analysis**




## GENERAL DESCRIPTION

Analog Devices' model MOD-1205 is a very high-speed A/D converter capable of digitizing video input signals to 12-bit accuracy at random or periodic word rates of dc through 5MHz. The MOD-1205 is truly a breakthrough in high-speed A/D technology. It utilizes the latest state-of-the-art conversion technique called digital correcting subranging (DCS) to effectively eliminate errors normally associated with subranging type ADCs. It is the most cost effective A/D in this speed category, combining small size and low power dissipation with low cost.

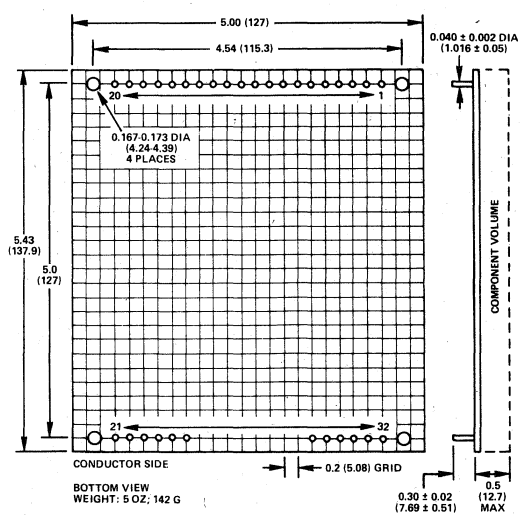
The MOD-1205 is constructed on a single printed circuit card which is intended for mounting on a system mother board and occupies only 27 square inches. Within this A/D is the required sample/track-and-hold amplifier, encoder, timing circuits and output latches for a true simultaneous, all-parallel digital output.

The encode command input and digital outputs are TTL compatible. The A/D requires only an external encode command pulse and external power supplies for operation. NO external parts are required. Gain and offset potentiometers are provided on the card. The A/D is fully repairable either at the factory or in the field.

The MOD-1205 is ideally suited for systems requiring the ultimate in conversion speed and accuracy. Such applications include radar digitizing, digital communications, spectrum analysis, and many others. Each MOD-1205 is backed by Analog Devices' limited one year warranty.

## OUTLINE DIMENSIONS

Dimensions shown in inches and (mm).




11

# SPECIFICATIONS (typical @ +25°C with nominal power supplies unless otherwise noted)

| MODEL | MOD-1205 |
|---|---|
| RESOLUTION (FS = FULL SCALE) | 12 Bits (0.024% FS) |
| LSB WEIGHT | 1mV |
| ACCURACY (INCLUDING LINEARITY) @ DC | ±0.0125% Full Scale ±1/2LSB |
| Monotonicity | Guaranteed (0 to +70°C) |
| Nonlinearity vs. Temperature | 0.005% of FS/°C, max |
| Gain vs. Temperature | 0.01% of FS/°C, type; 0.03% of FS/°C, max |
| DYNAMIC CHARACTERISTICS | |
| AC Linearity[1] (dc to 1MHz) | Spurious Signals >70dB below FS, max |
| (1MHz to 2.5MHz) | Spurious Signals >65dB below FS, max; >68dB, typ |
| Conversion Time | See Text and Timing Diagram |
| Conversion Rate (Word Rate) | 5MHz |
| Aperture Uncertainty (Jitter) | ±25ps max |
| Aperture Time | 30ns (±10ns from unit to unit) |
| Signal to Noise Ratio[2] | 66dB min; 68dB, typ |
| Noise Power Ratio[3] | 56dB min, 58dB typ |
| Transient Response[4] | 12-Bit (0.0125%) Accuracy within 200ns |
| Overvoltage Recovery Time[5] | 200ns |
| Input Bandwidth (small signal, 3dB) | 15MHz min |
| Input Bandwidth (large signal, 3dB) | 10MHz min; flat within ±0.1dB, dc through 5MHz |
| ANALOG INPUT | |
| Voltage Range | ±2.048V FS |
| | ±4V Absolute max |
| Impedance | 400Ω with pin 30 open, 50Ω with pin 30 grounded |
| Offset Voltage | Adjust to 0 with On Board Potentiometer |
| Offset vs. Temperature | 0.02% FS/°C, type; 0.05% of FS/°C, max |
| Bias Current | 1nA max |
| ENCODE COMMAND INPUT | |
| Logic Levels, TTL Compatible | "0" = 0 to +0.4V |
| | "1" = +2.4V to +5V |
| Logic Loading | 2 Standard TTL Gates |
| Rise and Fall Times | 10ns max |
| Duration min/max | 25ns/50% of Duty Cycle |
| Frequency (Random or Periodic) | 5MHz |
| DIGITAL DATA OUTPUT | |
| Format | 12 Parallel Bits, NRZ |
| Logic Levels, TTL Compatible | "0" = 0 to +0.4V |
| | "1" = +2.4V to +5V |
| Drive (Not Short Circuit Protected) | Up to 1 Schottky TTL or |
| | 2 Standard TTL Loads |
| Time Skew | 10ns max |
| Coding | Offset Binary (OBN) or 2's complement (2SC) |
| Conversion Time | See Text on the Next Page |
| POWER REQUIREMENTS[6] | |
| +15V ±5% | 200mA |
| -15V ±5% | 150mA |
| -6V ±4% | 700mA |
| +5V ±5% | 800mA |
| Power Consumption | 13 Watts |
| TEMPERATURE RANGE | |
| Operating | 0 to +70°C |
| Storage | -55°C to +85°C |
| Cooling Requirements | 500 Linear Feet Per Min (LFPM) @ +70°C |
| PHYSICAL CHARACTERISTICS | |
| Construction | Single Printed Circuit Card |

NOTES
[1] AC linearity expressed in terms of spurious in-band signals generated at specified encode rates at analog input frequencies ( ).
[2] rms signal to rms noise at 500kHz analog input.
[3] dc to 2.4MHz white noise bandwidth with slot frequency of 512kHz.
[4] For full-scale step input, attains 12-bit accuracy in time specified.
[5] Recovers to 12-bit accuracy after 2 × FS input overvoltage in time specified.
[6] ±15V supplies must be equal and opposite within 200mV and track over temperature.

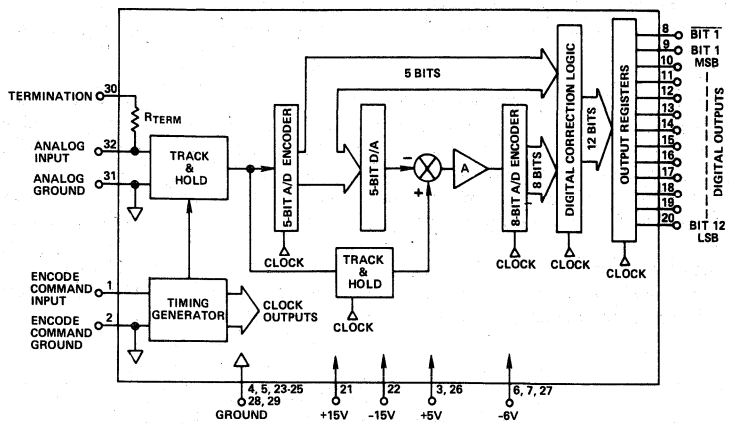
Specifications subject to change without notice.

| PIN | FUNCTION |
|---|---|
| 1 | ENCODE COMMAND |
| 2 | GND* |
| 3 | +5V |
| 4 | GND* |
| 5 | GND* |
| 6 | -6V |
| 7 | -6V |
| 8 | BIT 1 |
| 9 | BIT 1 (MSB) |
| 10 | BIT 2 |
| 11 | BIT 3 |
| 12 | BIT 4 |
| 13 | BIT 5 |
| 14 | BIT 6 |
| 15 | BIT 7 |
| 16 | BIT 8 |

| PIN | FUNCTION |
|---|---|
| 17 | BIT 9 |
| 18 | BIT 10 |
| 19 | BIT 11 |
| 20 | BIT 12 (LSB) |
| 21 | +15V |
| 22 | -15V |
| 23 | GND* |
| 24 | GND* |
| 25 | GND* |
| 26 | +5V |
| 27 | -6V |
| 28 | GND* |
| 29 | GND* |
| 30 | TERMINATION |
| 31 | GND* |
| 32 | ANALOG INPUT |

*ALL GROUND PINS ARE CONNECTED TOGETHER WITHIN THE MOD-1205

*Pin Designations*




NOTE: WITH PIN 30 OPEN, ANALOG INPUT IMPEDANCE IS 400Ω. WITH PIN 30 GROUNDED, ANALOG IMPEDANCE IS 50Ω.

*MOD-1205 Block Diagram*

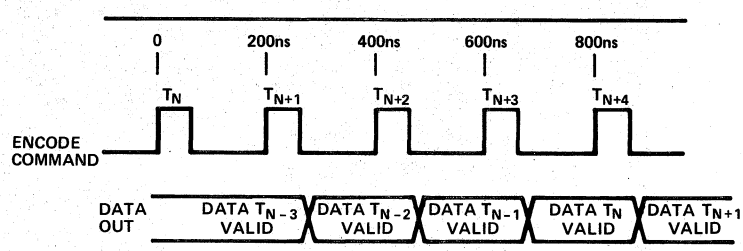
## ORDERING INFORMATION

Order model number MOD-1205 A/D converter. Mating pin sockets for the MOD-1205 are model number MSB-2 (32 required per A/D).

## CONVERSION TIME

Output data is valid two encode command clock periods plus 275ns ±25ns after application of an initial encode command pulse. Due to the pipeline delay effect of the A/D, a total of three encode command pulses are required to shift the data to the output of the A/D. For example, with a 5MHz encode rate, data is valid 675ns ±25ns after the application of the first encode command pulse—assuming that two pulses occur after the first.

Use of the trailing edge of the encode command is recommended for strobing output data into external register (see Figure 1).




DATA $T_N$ (THE RESULT OF ENCODE COMMAND $T_N$) OCCURS TWO CONVERSION PERIODS PLUS 275ns ±25ns AFTER ENCODE COMMAND $T_N$. FOR A 5MHz WORD RATE AS SHOWN, DATA IS VALID 275ns ±25ns AFTER THE THIRD ENCODE COMMAND PULSE OR $T_N$ + 675ns ±25ns. IN ALL CASES, THREE ENCODE COMMAND PULSES ARE REQUIRED FOR TRANSFER OF DATA TO THE OUTPUT, DUE TO THE PIPELINE DELAY EFFECT THROUGH THE A/D. NO DATA READY PULSE IS SUPPLIED.

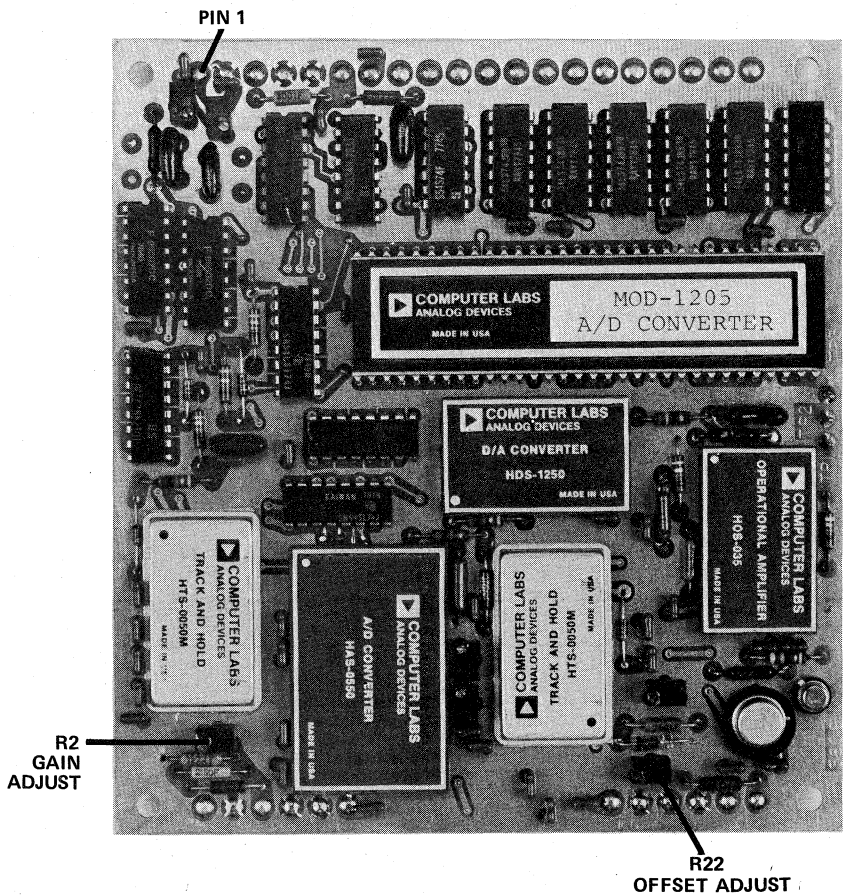
*Figure 1. MOD-1205 Timing Diagram*

**GROUND CONNECTIONS**
It should be noted that the MOD-1205 PC board has 9 ground pins. These are all connected to the ground plane on the board. For best results it is recommended that ALL of these pins be connected to a massive system or "mother board" ground plane.

**CALIBRATION PROCEDURE (MOD-1205)**
The MOD-1205 A/D is precisely calibrated at the factory before shipments and should need no further calibration. However, if slight readjustments of the A/D are required in the system, the following procedure should be followed. This procedure refers to a binary output.

**Offset Adjustment**
The offset is adjusted by varying potentiometer R22 with 0 volts applied to the analog input. To obtain the proper output code, observe that the digital output is changing between 1 0 0 0 0 0 0 0 0 0 0 0 and 0 1 1 1 1 1 1 1 1 1 1 1 at this adjustment level. When properly adjusted a digital code of 1 0 0 0 0 0 0 0 0 0 0 0 will represent analog input 1LSB above zero volts, and a digital code of 0 1 1 1 1 1 1 1 1 1 1 1 will represent an analog input of 1LSB below zero volts.

**Gain Adjustment**
The gain is adjusted by varying potentiometer R2. This adjustment is made by applying +2.0465V (FS -1 1/2LSB) to the analog input and while monitoring the digital output, adjust R2 for the output code varying between 1 1 1 1 1 1 1 1 1 1 1 0 and 1 1 1 1 1 1 1 1 1 1 1 1 (FS). If the user needs to offset the entire range of the A/D, this can be accomplished by a readjusting R22 as required. However, in this procedure, the offset should always be adjusted first.




*Location of Adjustment Potentiometers*

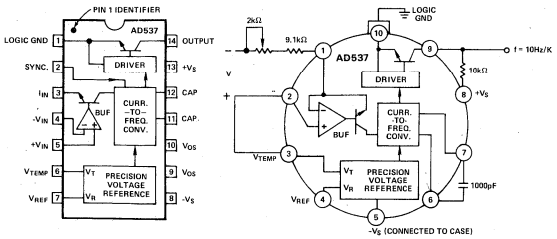
# Voltage-to-Frequency & Frequency-to-Voltage Converters

## Contents


| | Page |
|---|---|
| Selection Guides | |
| Voltage-to-Frequency Converters | 12–2 |
| Frequency-to-Voltage Converters | 12–4 |
| General Information | 12–5 |
| 451 100kHz to 20kHz Adjustable Frequency to Voltage Converter | 12–7 |
| 453 1kHz to 200kHz Adjustable Frequency to Voltage Converter | 12–7 |
| 458 100kHz Voltage to Frequency Converter | 12–13 |
| 460 1MHz Voltage to Frequency Converter | 12–13 |

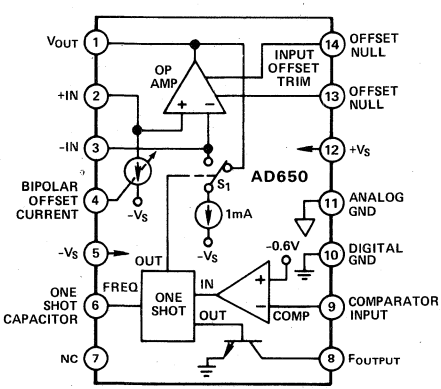

12

# Selection Guide
## Voltage-to-Frequency Converters



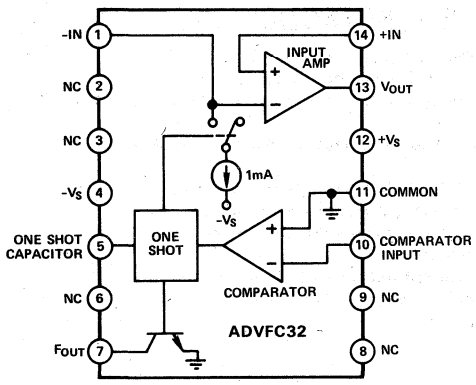

## AD537

| | Page |
|---|---|
| **Low Cost A/D Conversion** | Vol. I |
| **Versatile Input Amplifier** | 11-7 |
| **Positive or Negative Voltage Modes** | |
| **Negative Current Mode** | |
| **High Input Impedance, Low Drift** | |
| **Single Supply, 5 to 36 Volts** | |
| **Linearity: ±0.05% FS** | |
| **Low Power: 1.2mA Quiescent Current** | |
| **Full Scale Frequency up to 100kHz** | |
| **1.00 Volt Reference** | |
| **Thermometer Output (1mV/K)** | |
| **F/V Applications** | |




## AD650

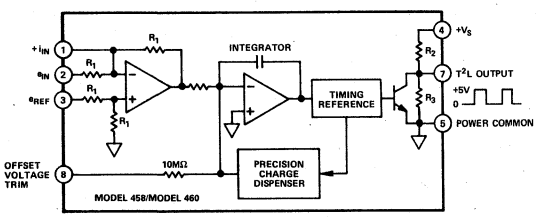
| | |
|---|---|
| **V/F Conversion to 1MHz** | Vol. I |
| **Reliable Monolithic Construction** | 11-15 |
| **Very High Linearity** | |
| **0.002% typ at 10kHz** | |
| **0.005% typ at 100kHz** | |
| **0.07% typ at 1MHz** | |
| **Input Offset Trimmable to Zero** | |
| **CMOS or TTL Compatible** | |
| **Unipolar, Bipolar, or Differential V/F** | |
| **V/F or F/V Conversion** | |




## ADVFC32

Page
Vol. I
11-27

**High Linearity**
**±0.01% max at 10kHz FS**
**±0.05% max at 100kHz FS**
**±0.2% max at 0.5MHz FS**
**Output DTL/TTL/CMOS Compatible**
**V/F or F/V Conversion**
**6 Decade Dynamic Range**
**Voltage or Current Input**
**Reliable Monolithic Construction**

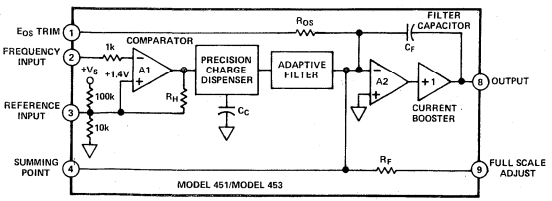



## MODEL 458/MODEL 460

Vol. II
12-13

**Model 458: Full Scale Output 100kHz**
**Model 460: Full Scale Output 1MHz**
**High Stability: 5ppm/°C max, Model 458L**
**15ppm/°C max, Model 460L**
**High Linearity: ±0.01% max at 100kHz, Model 458**
**±0.015% max at 1MHz, Model 460**
**Versatility: Differential Input Stage**
**Voltage and Current Inputs**
**Floating Inputs: ±10V CMV**
**Wide Dynamic Range: 6 Decades, Model 460**
**TTL/DTL Compatible Output**
**No External Components to Meet Rated Performance**

# Selection Guide
## Frequency-to-Voltage Converters




## MODEL 451/MODEL 453

Page
Vol. II
12-7

**Model 451: Full Scale Input 10kHz**
**Model 453: Full Scale Input 100kHz**
**Versatility: Adjustable Threshold, Gain & Output Offset**
**Guaranteed Low Nonlinearity: 80ppm max, 451L and 453L**
**Accepts TTL, CMOS, HNIL, Sinewave, Pulse, Squarewave and Triangle Wave Input Signals**
**No External Components to Meet Rated Performance**
**+20mA Output to Operate Relays and Meters**
**Low Profile Package, 0.4" Case Height**

# Orientation
# Voltage-to-Frequency & Frequency-to-Voltage Converters

## VOLTAGE-TO-FREQUENCY CONVERTERS

Voltage-to-frequency converters (VFC's) convert analog voltage or current levels to pulse trains or square waves in a logic-compatible form (usually TTL) at frequencies that are accurately proportional to the analog quantity. The output continuously tracks the input signal, responding directly to changes in the input signal; external-clock synchronization is not required. V/F converters find applications in analog-to-digital converters with high resolution, long-term high precision integrators, two-wire high-noise-immunity digital transmission, and digital voltmeters.

## FREQUENCY-TO-VOLTAGE CONVERTERS

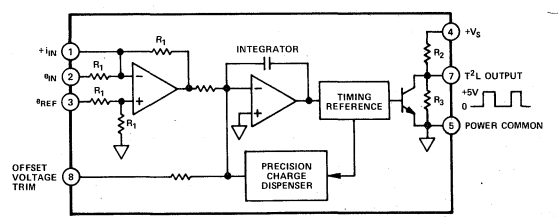
Frequency-to-voltage converters (FVC's) perform the inverse operation; they accept a wide variety of periodic waveforms and produce an analog output proportional to frequency. Combining adjustable threshold, gain, and output offset with low linearity-error, F/V converters offer economical solutions to a wide variety of applications where it is required to convert frequency to an analog voltage. Examples are motor-speed controllers, power-line frequency monitors, and VCO stabilization circuits. In analog-to-analog data transmission, they convert serially transmitted data in the form of pulse streams back to analog voltage.

Applications of both forms of conversion, as appropriate to specific device types, are illustrated with varying degrees of detail on the individual data sheets.

## FACTORS IN CHOOSING VFC's AND FVC's

*Voltage-to-frequency* converters are available from Analog Devices in both module- and monolithic-IC- form. The output of modular types, ranging from 10kHz to 1MHz F.S., is a train of pulses of constant height and width, with very low duty cycle for small analog inputs. The technical data in this volume embrace exceptionally high performance (low-drift and high-resolution) V/F converters, in the form of encapsulated modules. As the Selection Guide indicates, there is also technical data, to be found in Volume I, on a range of monolithic V/F converters, including ADI's unique AD537, which has symmetrical square-wave output, and both voltage and temperature references. Apart from performance specifications, the tradeoffs between module and IC are as follows: modular VFCs have the advantages of completely specified performance; they do not rely on the specifications of critical external components, because the complete self-contained functional package requires no external components; trims are optional. IC's, on the other hand, have the advantages of lower cost and smaller size, and—in the case of the AD537—versatility of output and input connections, lower offset drift, flexibility of frequency range, low power, single-supply operation, low external-component count, plus built-in voltage—and temperature—references. Modules offer better linearity, lower gain drift, and higher full-scale frequencies.

The most-popular VFC designs (Figure 1) contain an integrator, which charges at a rate proportional to the value of the input signal. Each time the integrator's charge has been increased by a precisely metered increment, the threshold crossing produces a pulse of accurately known area. The pulse serves both as the output (via a buffer) and as a subtractive charge

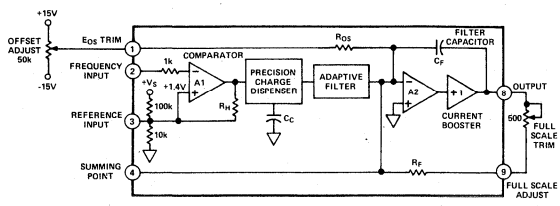



| MODEL | FULL SCALE OUTPUT | $R_1$ | $R_2$ | $R_3$ |
|---|---|---|---|---|
| 458 | 100kHz | 20kΩ | 10kΩ | 4.7kΩ |
| 460 | 1MHz | 10kΩ | 2kΩ | 910Ω |

*Figure 1. Block Diagram — Models 458, 460 VFC's*

increment to reduce the integrator's net charge. The next pulse is triggered when the net integral has again reached the threshold. The relationship between the pulse rate and the input level is linear.

12




| MODEL | $C_F$ | $R_{OS}$ | $R_H$ | $R_F$ |
|---|---|---|---|---|
| 451 | 0.015μF | 3.3MΩ | 2.2MΩ | 18kΩ |
| 453 | 0.001μF | 3.9MΩ | 1.0MΩ | 22kΩ |

*Figure 2. Block Diagram — Models 451 & 453 FVCs*

*Frequency-to-voltage*-converter modules (Figure 2) average a train of equal-area pulses that are generated internally by a precision charge dispenser, in response to each crossing of an input threshold. The analog output voltage is proportional to the sum of the pulse areas over a given period.

## SPECIFICATIONS

The salient specifications for VFC's are *(non)linearity*, as a percentage of full-scale frequency; *frequency range*, the greater the frequency range, the greater the resolution for a given counting period; *full-scale-calibration error; gain-temperature coefficient*, in ppm of signal per °C, where "gain" is the ratio of full-scale frequency to full-scale voltage, *input-offset temperature coefficient; overrange capability*, within rated specifications, and *step response*, the worst-case time interval required for the frequency to respond to a full-scale-step input change.

For FVC's, important specs, in addition to accuracy specs corresponding to the above, include *output ripple* (for specified input frequencies), *threshold* (for recognition that another cycle has been initiated, and for versatility in interfacing various types of sensors directly), *hysteresis*, to provide a degree of insensitivity to noise superimposed on a slowly-varying input waveform, and *dynamic response* (important in motor control).

Definitions of some critical specifications, and the conditions for adjusting or measuring them, are detailed on individual data sheets.

# Low-Cost, Versatile, 10/100kHz Frequency to Voltage Converters

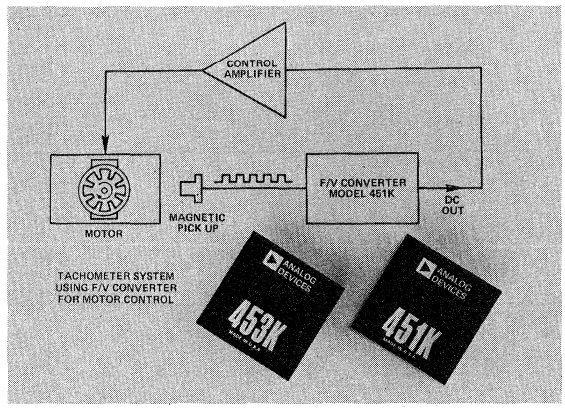
# MODELS 451, 453

**FEATURES**

- **Low Cost**
- **Versatility: Adjustable Threshold, Gain & Output Offset**
- **Guaranteed Low Nonlinearity: 80ppm Max, 451L and 453L**
- **Accepts TTL, CMOS, HNIL, Sinewave, Pulse, Squarewave and Triangle Wave Input Signals**
- **No External Components to Meet Rated Performance**
- **+20mA Output to Operate Relays and Meters**
- **Low Profile Package, 0.4" Case Height**
- **Meet MIL-STD-202E Environmental Testing**

**APPLICATIONS**

- **Motor Control and Speed Monitor**
- **Line Frequency Monitor and Alarm Indicator**
- **Fluid Flow Measurements and Control**
- **FM Demodulation and VCO Stabilization**
- **Frequency vs. Amplitude Response Measurements**




## GENERAL DESCRIPTION

Models 451 and 453 are low cost 10kHz and 100kHz frequency to voltage converters that feature excellent low nonlinearity to less than 80ppm, output current of +20mA and the capability of interfacing with TTL, HNIL, CMOS, sinewave, squarewave, pulse and triangular input signals. External components are not required to achieve rated performance, however, extreme versatility is maintained by allowing access to all critical points of the design. This versatility allows programmable input threshold, gain, and output offset voltage.

Both models 451 and 453 are available in three selections, each offering guaranteed maximum nonlinearity error as well as maximum gain drift error. Models 451J and 453J offer 0.03% max nonlinearity and 100ppm/°C max gain drift. Models 451K and 453K offer 0.015% max nonlinearity and 50ppm/°C max gain drift. Models 451L and 453L offer 0.008% max nonlinearity and 50ppm/°C max gain drift.

## WHERE TO USE FREQUENCY TO VOLTAGE CONVERTERS

Pin compatible with existing popular models, these versatile new designs offer economical solutions to a wide variety of applications where it is required to convert frequency to an analog voltage.

**Process Control Systems:** For motor speed controllers, power line frequency monitoring and fluid flow measurements where flow transducers, such as variable reluctance magnetic pickups, provide pulse train outputs as a linear function of flow rate.

**Audio and Accoustic Systems:** For wow and flutter measurements with tape recorders and turntables, FM demodulation and speaker response measurements.

**Test Instrumentation:** For VCO stabilization, analog readout frequency meter, vibrational analysis and frequency versus amplitude X-Y plots where the vertical axis presents the normal amplitude signal and the horizontal axis presents the output signal from the F/V converter.

**Data Acquisition Systems:** For converting serially transmitted data back to analog voltages.

## DESIGN FEATURES AND USER BENEFITS

The combination of low cost and high performance provided by models 451 and 453 offers exceptional quality and value to the OEM designer. These compact modules have been designed to provide maximum versatility, thereby increasing their utility in a broad scope of applications.

**Adjustable Input Threshold:** Threshold level is externally resistor programmable from 0 to ±12V, permitting simple, direct interface with low level signals, e.g. 10mV p-p, as well as with high level inputs such as CMOS and HNIL logic levels, e.g. 0 to +12V.

**Adjustable Gain:** Model 451 can be adjusted to provide full scale output voltage for any input frequency from 100Hz to 20kHz. Model 453 can be adjusted to provide full scale output voltage for any input frequency from 1kHz to 200kHz. This adjustable gain feature enables the user to easily match the maximum frequency output from a wide class of frequency transducers to the +10V full scale output from models 451 and 453. Increased signal conversion sensitivity with higher resolution results.

**Adjustable Output Offset Voltage:** The output offset is adjustable from -10V to +10V, enabling bipolar outputs or expanded scale measurements or setting the input frequency where zero output voltage occurs.

# SPECIFICATIONS (typical @ +25°C and $V_S$ = ±15V dc unless otherwise noted)

| MODEL | 10kHz FULL SCALE 451 J | 10kHz FULL SCALE 451 K | 10kHz FULL SCALE 451 L | 100kHz FULL SCALE 453 J | 100kHz FULL SCALE 453 K | 100kHz FULL SCALE 453 L |
|---|---|---|---|---|---|---|
| TRANSFER FUNCTION | $E_O = (10^{-3}\,V/Hz)(F_{IN})$ | | | $E_O = (10^{-4}\,V/Hz)(F_{IN})$ | | |
| FREQUENCY INPUT | | | | | | |
| Frequency Range | dc to 10kHz min | | | dc to 100kHz min | | |
| Overrange | 10% min | | | 10% min | | |
| Waveforms | Sine, Square, Triangle, Pulse Train | | | Sine, Square, Triangle, Pulse Train | | |
| Pulse Width (Pulse Train Input) | 20µs min | | | 2µs min | | |
| Threshold | +1.4V | | | +1.4V | | |
| With External Adjustment | 0V to ±12V | | | 0V to ±12V | | |
| Hysteresis | ±50mV | | | ±100mV | | |
| Levels (TTL Compatible) High | +1.45V to +12V | | | +1.5V to +12V | | |
| Low | -12V to +1.35V | | | -12V to +1.3V | | |
| Max Safe Input Voltage[1] | $\pm V_S$ | | | $\pm V_S$ | | |
| Impedance | 10MΩ‖10pF | | | 10MΩ‖10pF | | |
| ACCURACY | | | | | | |
| Warm-Up Time | one minute | | | one minute | | |
| Nonlinearity[2] | | | | | | |
| $F_{IN}$ = 1Hz to 11kHz | ±0.03% max | ±0.015% max | ±0.008% max | – | – | – |
| $F_{IN}$ = 1Hz to 110kHz | – | – | – | ±0.03% max | ±0.015% max | ±0.008% max |
| Gain vs. Temperature[3] (0 to +70°C) | ±100ppm/°C max | ±50ppm/°C max | ±50ppm/°C max | ±100ppm/°C max | ±50ppm/°C max | ±50ppm/°C max |
| vs. Supply Voltage | ±300ppm/% | | | ±350ppm/% | | |
| vs. Time | ±30ppm/month | | | ±30ppm/month | | |
| RESPONSE | | | | | | |
| Step Response to ±0.5% of Final Value | | | | | | |
| $F_{IN}$ = dc to Full Scale | 4ms | | | 0.8ms | | |
| $F_{IN}$ = Full Scale to dc | 30ms | | | 4ms | | |
| Internal Filter Time Constant | 200µs | | | 24µs | | |
| External Filter Time Constant | 20ms/µF | | | 20ms/µF | | |
| OUTPUT[4] | | | | | | |
| Voltage ($F_{IN}$ = Full Scale)[5] | +9.85V min; +9.95V max | | | +9.85V min; +9.95V max | | |
| Current ($E_O$ = +10V, -10V) | (+20, -2)mA min | | | (+20, -2)mA min | | |
| Offset Voltage[6] @ +25°C | ±7.5mV max | | | ±7.5mV max | | |
| vs. Temperature (0 to +70°C) | ±30µV/°C max | | | ±30µV/°C max | | |
| vs. Supply Voltage | ±100µV/% max | | | ±50µV/% max | | |
| vs. Time | ±100µV/month | | | ±100µV/month | | |
| Ripple | | | | | | |
| $F_{IN}$ = 1Hz | 3mV p-p | | | 55mV p-p | | |
| $F_{IN}$ = 10kHz | 80mV rms | | | 35mV rms | | |
| $F_{IN}$ = 100kHz | – | | | 35mV rms | | |
| Impedance | 0.1Ω | | | 0.1Ω | | |
| Offset Scale Factor[7] | -56µA/V | | | -45µA/V | | |
| POWER SUPPLY[8] | | | | | | |
| Voltage, Rated Performance | ±15V dc | | | ±15V dc | | |
| Voltage, Operating | ±(12 to 18)V dc | | | ±(12 to 18)V dc | | |
| Current, Quiescent | (+10, -8)mA | | | (+10, -8)mA | | |
| TEMPERATURE RANGE | | | | | | |
| Rated Performance | 0 to +70°C | | | 0 to +70°C | | |
| Operating | -25°C to +85°C | | | -25°C to +85°C | | |
| Storage | -55°C to +85°C | | | -55°C to +125°C | | |
| MECHANICAL | | | | | | |
| Case Size | 1.5" x 1.5" x 0.4" | | | 1.5" x 1.5" x 0.4" | | |
| Weight | 25 grams | | | 25 grams | | |

NOTES
[1] $F_{IN}$ and REF terminals can be shorted to $\pm V_S$ indefinitely without damage.
[2] Nonlinearity error is specified as a percentage of 10V full scale output level.
[3] Gain temperature drift is specified in ppm of output signal level.
[4] OUT terminal can be shorted indefinitely to $\pm V_S$ and ground without damage.
[5] Adjustable to +10.000V using FULL SCALE ADJUST trim pot.
[6] Adjustable to zero using 50kΩ OFFSET ADJUST trim pot.
[7] Current into the SUM PT terminal to offset the output voltage positive.
[8] Recommended power supply, ADI model 904, ±15V @ 50mA output.
Specifications subject to change without notice.

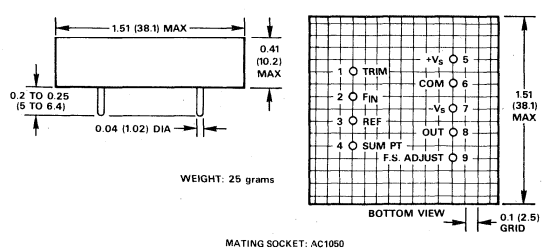
All Units Meet the Requirements of MIL-STD-202E as Outlined Below

| TEST | METHOD | CONDITION |
|---|---|---|
| High Temperature Storage | 108A | D (Non-Operating) |
| Moisture Resistance | 106D | (10 Days) |
| Solderability | 208C | |
| Thermal Shock | 107D | A (5 Cycles) |
| Terminal Strength | 211A | A (Pull Test; 10 lbs) |
| Temperature Cycling | 102A | D (-55°C/+85°C) |
| Vibration | 204C | B (15g Peak) |
| Barometric Pressure | 105C | B (50,000 Feet) |

*Table I. Environmental Specifications*

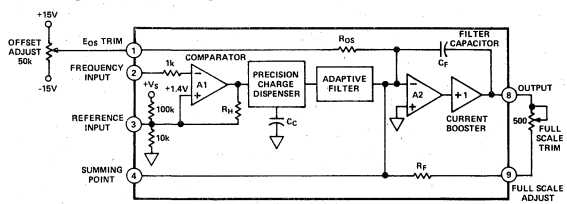
## OUTLINE DIMENSIONS

Dimensions shown in inches and (mm).



## FREQUENCY TO VOLTAGE OPERATION

Models 451 and 453 accept virtually any signal waveshape providing accurate conversion into an output voltage proportional to the input signal frequency. The only restriction is that the input signal must remain above the threshold level for 20μs when using model 451, and 2μs when using model 453. Linear, stable conversion over four decades of input range for model 451 and five decades of input range for model 453, is achieved using a precision charge-dispensing design approach. Figure 1 represents a functional block diagram for both models 451 and 453 frequency to voltage converters.




| MODEL | $C_F$ | $R_{OS}$ | $R_H$ | $R_F$ |
|---|---|---|---|---|
| 451 | 0.015μF | 3.3MΩ | 2.2MΩ | 18kΩ |
| 453 | 0.001μF | 3.9MΩ | 1.0MΩ | 22kΩ |

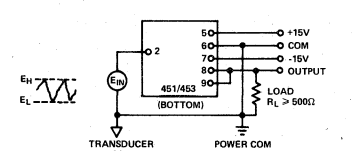
*Figure 1. Block Diagram — Models 451 & 453 F/V Converters*

## THEORY OF OPERATION

Input signals are applied directly to a comparator, A1, which is internally set to provide a +1.4V threshold with ±50mV hysteresis for model 451 and ±100mV hysteresis for model 453. This threshold level offers excellent noise immunity for TTL input levels. Following the input comparator is a precision charge dispensing circuit and output amplifier where the comparator signal is converted to a dc voltage. When the input comparator changes state, $C_C$ is alternately charged from a precision voltage reference and discharged through the summing point of an output amplifier, A2. A fixed amount of charge, Q, is controlled during each charge/discharge cycle. The higher the input frequency, the higher the average current into the summing point of A2. A current to voltage conversion is then accomplished by $R_F$. The current pulses from the charge dispensing circuit are integrated by $C_F$ to reduce ripple. Added filtering for low frequency input signals is provided by an adaptive filter at the output of the charge dispensing circuit.

## BASIC F/V HOOK-UP

Models 451 and 453 can be applied directly to achieve rated performance without external trim potentiometers or other components. Figure 2 illustrates the basic wiring connection for either F/V converter model. Using the basic hookup as shown, full scale output voltage accuracy is +10V, -½% to -1½%. The output offset voltage is 0V to ±7.5mV. The Full Scale and Output Offset errors can be eliminated by using the FINE TRIM PROCEDURE.




| MODEL | INPUT VOLTAGE RANGE | | INPUT FREQUENCY RANGE |
|---|---|---|---|
| | High ($E_H$) | Low ($E_L$) | ($F_{IN}$) |
| 451 | +1.45V to +12V | -12V to +1.35V | 0 to 11kHz |
| 453 | +1.5V to +12V | -12V to +1.3V | 0 to 110kHz |

*Figure 2. Basic Wiring Interconnection*

## FINE TRIM PROCEDURE

Connect the F/V converter as shown in Figure 3 and allow a five minute warm-up after initial power turn-on. Adjust the OFFSET ADJUST pot, $R_O$, for an output of 0.000V. The input terminal, $F_{IN}$, can be left open or tied to COM without affecting OFFSET ADJUST. Using a precision, stable frequency source connected to $F_{IN}$ terminal, set the input frequency to 10.000kHz for model 451 or 100.000kHz for model 453. Adjust the FULL SCALE ADJUST trim pot, $R_S$, for an output of +10.000V.

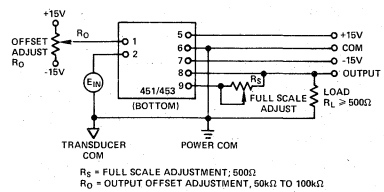



*Figure 3. Wiring Interconnection Showing Fine Adjustment Trims for Offset and Full Scale Frequency*

## ADDITIONAL TRIM CAPABILITY

**Adjusting Input Threshold:** The input comparator of models 451 and 453 shown in Figure 1, conditions the input signals providing protection against noisy environments as well as preventing double triggering with slow rise-time signals. Input levels up to the supply voltages, $\pm V_S$, will not cause damage to the input comparator.

Threshold voltage level, $V_T$, is internally set for both models 451 and 453 at +1.4V. Hysteresis, $V_H$, for model 451 is ±50mV, and ±100mV for model 453. Signals of virtually any waveshape which exceed the combined threshold and hysteresis levels, $V_T \pm V_H$, will trigger the F/V converter. The REF terminal permits the user to conveniently adjust the input threshold over the range from 0 to ±12V to achieve optimum noise rejection or increased triggering sensitivity.

**Increasing Threshold for Greater Noise Immunity:** Connecting an external resistor from the REF terminal to the positive supply voltage, $+V_S$, increases the input threshold level above +1.4V, offering increased input noise immunity. Optimum noise immunity is generally determined by adjusting the threshold level to a point mid-way between the high and low input signal levels. For example, for a 0 to +12V input swing — representative of CMOS and HNIL logic signals — a 17.6kΩ resistor from +15V to the REF terminal results in a +6V threshold.

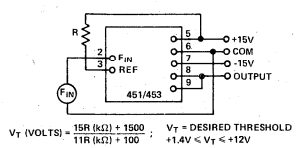


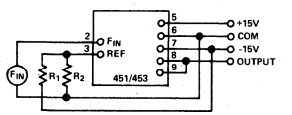

*Figure 4. Increasing Threshold Above +1.4V for Greater Noise Immunity*

Changes in impedance at the REF terminal result in changes to the hysteresis. Hysteresis levels can be calculated by assuming the comparator output is switching between ±12V. This ±12V signal is attenuated by a resistor-divider network formed by

$R_H$ (see Figure 1) and the parallel combination of all resistors attached at the comparator positive input. For example, with a 17.6kΩ resistor connected to the REF terminal, hysteresis becomes ±35mV for model 451 and ±75mV for model 453. The F/V converter will, therefore, trigger at +6V ±35mV for model 451 and +6V ±75mV for model 453.

**Decreasing Threshold for Signals Less Than +1.4V:** A resistor connected from the REF terminal to the negative power supply, $-V_S$, will increase the input triggering sensitivity for operation with signals below $+1.4V_{PK}$. As shown in Figure 5, a minimum threshold of zero volts is obtained with a 100kΩ resistor. The triggering level, $V_T \pm V_H$, will be established by the resulting hysteresis levels. With a 100kΩ to -15V, model 451 hysteresis will be ±50mV and model 453 hysteresis will be ±60mV.

To reduce the hysteresis for greater triggering sensitivity, a 1kΩ resistor can be connected from the REF terminal to COM. Signals exceeding ±5mV (10mV p-p) with model 451 and ±15mV (30mV p-p) for model 453, will operate the F/V converter. A 1kΩ resistor from REF to COM is the minimum value recommended to reduce hysteresis and achieve reliable operation.




| MODEL | $R_1$ | $R_2$ | THRESHOLD ($V_T$) | HYSTERESIS ($V_H$) | TRIGGER LEVELS ($V_T \pm V_H$) |
|---|---|---|---|---|---|
| 451 | ∞ | ∞ | +1.4V | ±50mV | +1.45V; +1.35V |
| | 100kΩ | ∞ | 0V | ±20mV | ±20mV (40mV p-p) |
| | 100kΩ | 1kΩ | 0V | ±5mV | ±5mV (10mV p-p) |
| 453 | ∞ | ∞ | +1.4V | ±100mV | +1.5V; +1.3V |
| | 100kΩ | ∞ | 0V | ±60mV | ±60mV (120mV p-p) |
| | 100kΩ | 1kΩ | 0V | ±15mV | ±15mV (30mV p-p) |

*Figure 5. Decreasing Threshold Below +1.4V to Increase Triggering Sensitivity for Low Level Input Signals*

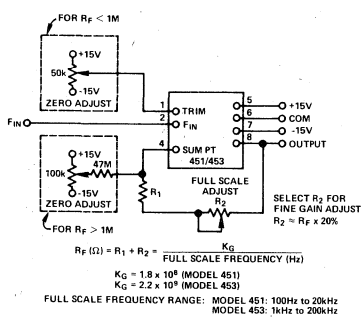



*Figure 6. Selecting External Gain Resistor $R_F$*

**Adjusting Gain:** Connect the FULL SCALE ADJUST terminal to the OUTPUT terminal to set the gain of model 451 at $10^{-3}$ V/Hz for a 10kHz full scale input frequency and the gain of model 453 at $10^{-4}$ V/Hz for a 100kHz full scale input frequency. Connecting an external resistor from the SUM PT terminal to the OUTPUT terminal and leaving the FULL SCALE ADJUST terminal open, facilitates gain adjustment. Model 451 can be adjusted over the range from $10^{-1}$ V/Hz to 5 x $10^{-4}$ V/Hz resulting in a full scale input frequency from 100Hz to 20kHz respectively. The gain of model 453 can be adjusted over the range from $10^{-2}$ V/Hz to 5 x $10^{-5}$ V/Hz resulting in a full scale input frequency from 1kHz to 200kHz respectively. The gain adjustment procedure is capable of increasing full scale frequency beyond the rated ranges for each model, however, nonlinearity will increase above 300ppm.

When using large values of $R_F$ to externally set gain of the F/V converter, the output amplifier gain increases resulting in an increase in sensitivity when using the OFFSET ADJUST trim pot. For improved resolution in high gain applications ($R_F >$ 1MΩ), an alternate method of trimming offset is shown in Figure 6.

**Offsetting the Output:** The output of models 451 and 453 can be offset over the range from -10V to +10V, enabling scale expansion for increased signal sensitivity as well as bipolar output swings up to 20V p-p.

Current introduced at the SUM PT terminal results in shifts of the output voltage directly proportional to the Offset Scale Factor, $K_S$. For model 451, $K_S$ = -56μA/V and for model 453, $K_S$ = -45μA/V. The offset current can be generated using an external resistor from a voltage reference to the SUM PT terminal. A stable, well regulated supply voltage, such as ADI's model 904 is recommended. To shift the output positive, 0 to +10V, connect the current resistor to the negative, $-V_S$ supply. To shift the output negative, 0 to -10V, connect the current resistor to the positive, $+V_S$, supply.

The example using model 451 illustrated in Figure 7 provides a 0 to +5V output change in response to a 5kHz to 10kHz input change. With this input, a bipolar output from -2.5V to +2.5V can be obtained by increasing the output voltage shift from -5V, ($R_C$ = 53.6kΩ) to -7.5V, ($R_C$ = 35.7kΩ).

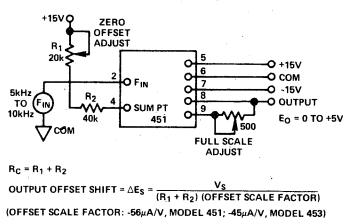



*Figure 7. Selecting External Output Offset Resistor, $R_C$*

## SCALE EXPANSION

By combining both gain and output offset voltage adjustments, signals which exhibit a center frequency with small frequency changes, can be converted with improved resolution. Representative signals benefiting from the Scale Expansion procedure outlined below, are tachometer and frequency modulated signals. In the case of tachometer outputs, the speed is often set at an idle point and changes in output frequency represent changes in motor loading conditions. In the case of FM signals, the F/V converter can be applied such that the carrier frequency produces zero output. The resulting output voltage from the F/V converter represents the modulating signal.

**Procedure for Scale Expansion:** The following procedure incorporates both gain and output offset adjustments to achieve scale expansion. An example is illustrated in Figure 8 for an FM signal with a 50kHz carrier frequency and ±5kHz modulating signal.

1) Determine the Gain: $G = \Delta E_O/\Delta F_{IN}$ where $\Delta E_O$ is the total output voltage change desired in volts, and $\Delta F_{IN}$ is the total input frequency change in Hz.

2) Calculate the external gain resistor, $R_F$;
$R_F(\Omega) = G(1.8 \times 10^7)$, model 451
$R_F(\Omega) = G(2.2 \times 10^8)$, model 453

3) Calculate the Output Offset Shift, $\Delta E_S$, required to achieve the desired maximum output voltage, $E_O$ (max) with the max input frequency, $F_{IN}$ (max), and the new gain;

$$\Delta E_S \text{ (volts)} = G\, F_{IN} \text{ (max)} - E_O \text{ (max)}$$

4) Calculate the offset current resistor, $R_C$;

$$R_C\ (\Omega) = \frac{V_S\, G}{(\Delta E_S)\,(k_s)}$$

$k_s = 56 \times 10^{-9}$, model 451
$k_s = 45 \times 10^{-10}$, model 453

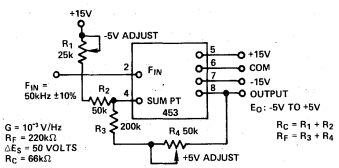



*Figure 8. Application of Model 453 in FM Demodulation*

**INTERFACING SIGNALS WITH DC OFFSETS > 10V**

Signals with dc levels up to ±10V can be directly connected to the input terminal of models 451 and 453. Capacitive coupling, as shown in Figures 9 and 10, is used for inputs with dc offsets greater than ±10V. The 1MΩ resistor illustrated in Figure 9 provides a dc return path to power common for the input comparator bias current. Threshold adjustments can be made following the capacitor, to set the F/V input sensitivity to match the ac signal peak-to-peak amplitude. Signals as low as 10mV p-p with model 451 and 30mV p-p model 453 are acceptable. Refer to Figures 4 and 5.

AC signals greater than $\pm V_S$ should be attenuated with a resistive divider network following the capacitor. When large input transients ($>\pm V_S$) are possible due to either a noisy environment or power turn-on surges, protection is provided with the addition of two diodes as shown in Figure 10.

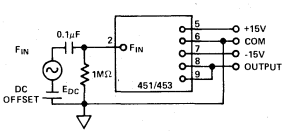



*Figure 9. Interfacing Signals With DC Offsets Greater Than ±10V*

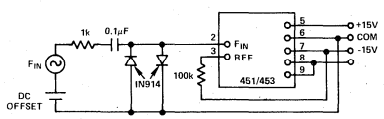



*Figure 10. Input Diode Protection for High Voltage Transients*

**PERFORMANCE SPECIFICATIONS**

**Nonlinearity:** Nonlinearity error is specified as a % of 10V full scale output voltage and is guaranteed for each model over the specified input range. Model 451 is rated over 1Hz to 11kHz range and model 453 is rated over 1Hz to 110kHz range. Typical nonlinearity performance is shown for all models in Figure 11.

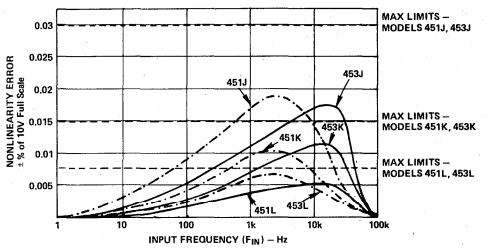



*Figure 11. Nonlinearity Error Versus Input Frequency*

**Gain Temperature Stability:** Gain Drift is specified in ppm of output signal and is guaranteed for each model over the 0 to +70°C temperature range. Models 451K, 451L, 453K and 453L offer ±50ppm/°C maximum gain drift. Models 451J and 453J offer ±100ppm/°C maximum gain drift. Gain drift is typically half the guaranteed limits.

**OUTPUT RIPPLE**

The output contains an ac ripple signal which increases in amplitude with input frequency. Adding external capacitance in parallel with the internal filter capacitor will reduce output ripple as shown in Figures 12 and 13.

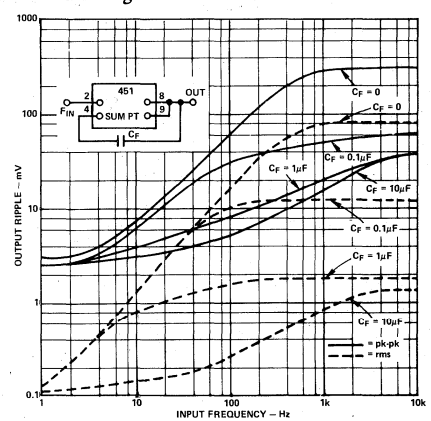



*Figure 12. Output Ripple Versus External Filter Capacitor ($C_F$) – Model 451*

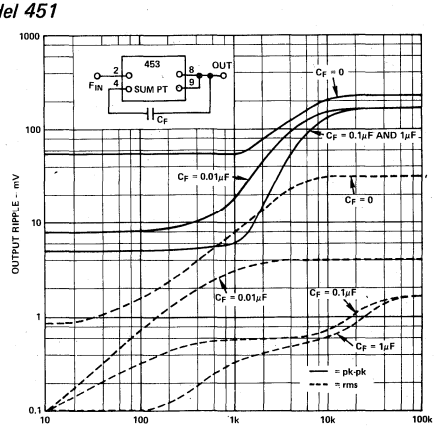



*Figure 13. Output Ripple Versus External Filter Capacitor ($C_F$) – Model 453*

### SETTLING TIME

Increasing the external filter capacitor to reduce output ripple will increase the settling time to step changes in frequency occurring at the input. Figure 14 shows curves of settling time to ±0.5% of final value for both increasing and decreasing full scale step changes. As $C_F$ increases in value, the total filter time constants for models 451 and 453 approach equal values, resulting in identical settling time.

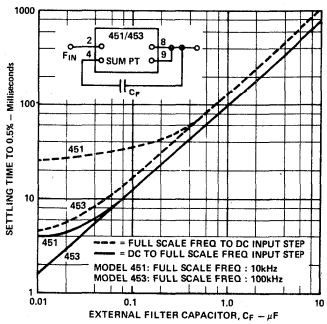



*Figure 14. Settling Time Versus External Filter Capacitor*

## APPLICATIONS IN PROCESS CONTROL SYSTEMS

### MOTOR CONTROLLER

In making rpm measurements, transducers are often encountered that have pulse-train outputs from variable-reluctance magnetic pickups (in which the output frequency is a function of rpm). These low level signals are generally in the range of 0 to 200mV peak. The adjustable input threshold feature of models 451 and 453 enables direct connection to low level transducers, offering simple, reliable interfacing.

The motor speed control and monitoring application shown in Figure 15 illustrates the F/V converter applied in a closed loop control system. R1 sets the threshold to +60mV with ±50mV hysteresis for model 451.

The +20mA output current capability of both models 451 and 453, enables direct interface to low impedance loads, up to 500Ω, such as analog meters or relays.

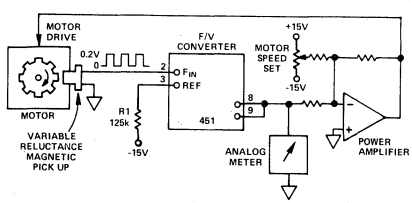



*Figure 15. Application of F/V Converter to Control and Monitor Motor Speed in Closed Loop System*

### SPEED SWITCH

With the addition of a low cost comparator and relay, the F/V converter provides a reliable approach to controlling heavy generator loads after the generator has reached a specified speed. As shown in Figure 16, the relay will remain open until the output from the F/V converter reaches a preset POWER ON trip level. The F/V output signal is linearly related to the speed of the motor, permitting precise control of the POWER ON set point.

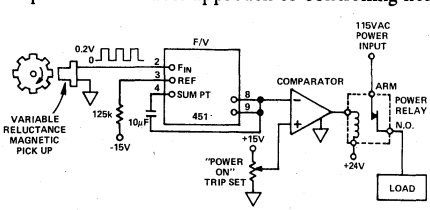



*Figure 16. Application of F/V Converter to Control Load Power*

## APPLICATION IN INSTRUMENTATION SYSTEMS

### FREQUENCY MONITORING

Small input frequency changes can be monitored more readily by using the programmable gain feature of models 451 and 453 to achieve greater signal sensitivity. In the application of model 451 illustrated in Figure 17, gain has been set to 0.1V/Hz, resulting in a 100Hz full scale frequency range. The output resolution for small changes occurring in the 60Hz line frequency has been improved. An additional advantage of this approach is the reduced accuracy and stability requirements placed on the relay trip levels, set by the voltage levels at the comparators. A precision voltage reference supply is not required.

Since both models 451 and 453 tolerate input signals up to the supply levels, $\pm V_S$, costly input protection is eliminated in most applications.

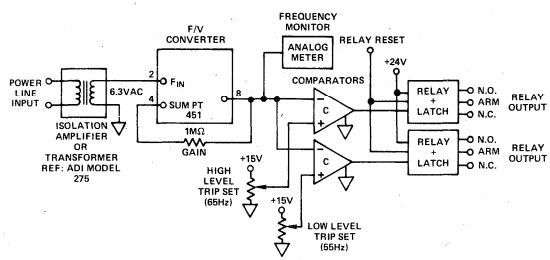



*Figure 17. Application of F/V Converter to Monitor 60Hz Line Frequency*

## APPLICATION IN DATA ACQUISITION SYSTEMS

### HIGH NOISE IMMUNITY TRANSMISSION

F/V converters are excellent companion products to V/F converters for use in low cost, two wire data transmission systems. As shown in Figure 18, this V/F/V approach utilizes the continuous self-clocking feature of the V/F converter thereby eliminating the need for costly additional twisted pair cable for external synchronization. Model 610 instrumentation amplifier amplifies the low level differential transducer signal to the 10V full scale of models 450 and 456 10kHz V/F converters. A differential line driver is used to drive a twisted pair cable through a noisy environment. A differential line receiver is used to drive model 451 10kHz F/V converter. The low cost of the V/F and F/V converters in addition to the simple twisted pair cabling approach make it economical to use a V/F/V converter pair for each channel in a data acquisition system.

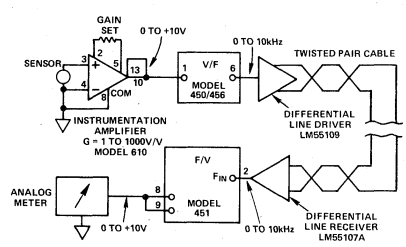



*Figure 18. Application of F/V Converter in a Low Cost, High Noise Rejection Two-Wire Data Transmission System*

# High Accuracy, 100kHz and 1MHz Voltage to Frequency Converters

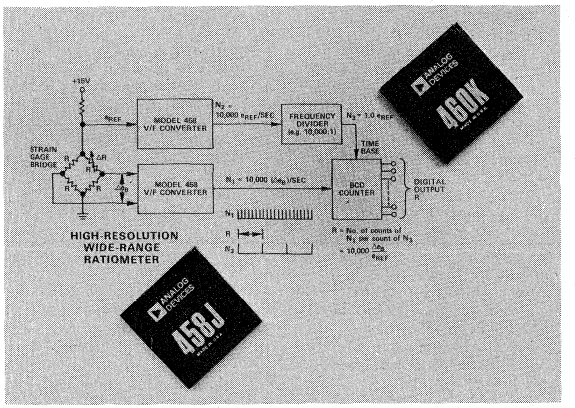
# MODELS 458 and 460

**FEATURES**

**High Stability:** 5ppm/°C max, Model 458L
15ppm/°C max, Model 460L
**High Linearity:** ±0.01% max at 100kHz, Model 458
±0.015% max at 1MHz, Model 460
**Versatility:** Differential Input Stage
Voltage and Current Inputs
Floating Inputs: ±10V CMV
**Wide Dynamic Range: 6 Decades, Model 460**
**TTL/DTL Compatible Output**

**APPLICATIONS**

**Fast Analog-to-Digital Converter**
**High Resolution Optical Data Link**
**Ratiometric Measurements**
**2-Wire High Noise Immunity Digital Transmission**
**Long Term Precision Integrator**




## GENERAL DESCRIPTION

Models 458 and 460 are high performance, differential input, voltage to frequency modular converters designed for analog to digital applications requiring accuracy and fast data conversion. Model 458 offers a 100kHz full scale frequency, guaranteed nonlinearity of ±0.01% maximum over five decades (1Hz to 100kHz) of operation and guaranteed low maximum gain drift in three model selections; model 458L: 5ppm/°C max; model 458K: 10ppm/°C max; and model 458J: 20ppm/°C max. Model 460 offers a 1MHz full scale frequency, guaranteed maximum nonlinearity of ±0.015% over six decades (1Hz to 1MHz) of operation and guaranteed low maximum gain drift in three selections; model 460L: 15ppm/°C max; model 460K: 25ppm/°C max; and model 460J: 50ppm/°C max. Model 460L is the industry's first 1MHz V/F converter to offer 15ppm/°C maximum gain drift.

The differential input stage of models 458 and 460 provide the versatility of either direct interface to off-ground 0 to +11V input signals with common mode voltages (CMV) to ±10V, as well as ground referenced positive, 0 to +11V or negative, 0 to -11V signals. Both models also accept positive current signals: 0 to +0.5mA, model 458; 0 to +1mA, model 460 for current to frequency (I/F) applications.

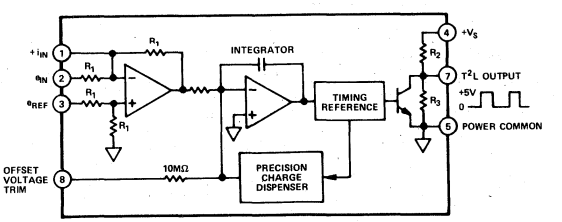
The rated performance of both models 458 and 460 is achieved without the need for external components or adjustments. Optional adjustments are available for trimming full scale frequency and the input offset voltage.

## WHERE TO USE MODELS 458 AND 460

The combination of low gain drift, low nonlinearity and the versatility of a differential input with both high speed (100kHz/1MHz) models, offer excellent solutions to a wide variety of demanding applications; in high speed remote data acquisition systems – two wire data transmission over long wires; in 5½ digit DVM's – featuring high resolution A/D conversion, monotonic performance, no missing codes and high noise rejection; in strain gage bridge weighing applications – accurate ratiometric measurements over wide dynamic range.

## DESIGN APPROACH - PRECISION CHARGE BALANCE

Models 458 and 460 incorporate a superior charge balance design that result in high linearity and temperature stability - see Figure 1. Both models accept unipolar, single-ended voltage or current input signals directly. By offsetting the input using the current terminal, models 458 and 460 will accept bipolar input voltages up to ±5V.




| MODEL | FULL SCALE OUTPUT | $R_1$ | $R_2$ | $R_3$ |
|---|---|---|---|---|
| 458 | 100kHz | 20kΩ | 10kΩ | 4.7kΩ |
| 460 | 1MHz | 10kΩ | 2kΩ | 910Ω |

*Figure 1. Block Diagram - Models 458, 460*

# SPECIFICATIONS (typical @ +25°C and $V_S$ = ±15V dc unless otherwise noted)

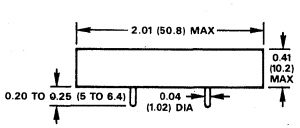
| MODEL | 100kHz Full Scale 458 J | K | L | 1MHz Full Scale 460 J | K | L |
|---|---|---|---|---|---|---|
| **TRANSFER FUNCTION** | | | | | | |
| Voltage Input | $f_{OUT} = (10^4 Hz/V)\ e_{IN}$ | | | $f_{OUT} = (10^5 Hz/V)\ e_{IN}$ | | |
| Current Input | $f_{OUT} = (2 \times 10^5 Hz/mA)\ i_{IN}$ | | | $f_{OUT} = (10^6 Hz/mA)\ i_{IN}$ | | |
| **ANALOG INPUT** | | | | | | |
| Configuration | Differential | | | Differential | | |
| Voltage Signal Range | | | | | | |
| $e_{IN}$ Terminal ($e_{REF}$ = 0) | 0 to +10V dc min | | | 0 to +10V dc min | | |
| $e_{REF}$ Terminal ($e_{IN}$ = 0) | 0 to -10V dc min | | | 0 to -10V dc min | | |
| Differential ($e_{IN} - e_{REF}$) | 0 to +10V dc min | | | 0 to +10V dc min | | |
| Overrange | +10% min | | | +10% min | | |
| Current Signal Range ($i_{IN}$) | 0 to +0.5mA min | | | 0 to +1mA min | | |
| Common Mode Voltage | ±10V | | | ±10V | | |
| Common Mode Rejection | 40dB | | | 40dB | | |
| Impedance, $e_{IN}$ Terminal | 20kΩ | | | 10kΩ | | |
| $e_{REF}$ Terminal | 40kΩ | | | 20kΩ | | |
| $i_{IN}$ Terminal | 0Ω | | | 0Ω | | |
| Max Safe Input | $\pm V_S$ | | | $\pm V_S$ | | |
| **ACCURACY** | | | | | | |
| Warm Up Time | 5 Seconds to 0.01% | | | 2 Minutes to 0.02% | | |
| Nonlinearity, $e_{IN}$ = +0.1mV to +11V | ±0.01% of Full Scale, max | | | ±0.015% of Full Scale, max | | |
| $e_{IN}$ = -0.1mV to -11V | ±0.01% of Full Scale | | | ±0.015% of Full Scale | | |
| Full Scale Error[1] | +0.1% to +2%, max | | | +0.1% to +2%, max | | |
| Gain vs. Temperature (0 to +70°C) | ±20ppm/°C max | ±10ppm/°C max | ±5ppm/°C max | ±50ppm/°C max | ±25ppm/°C max | ±15ppm/°C max |
| vs. Supply Voltage | ±15ppm/% | | | ±25ppm/% | | |
| vs. Time | ±5ppm/day, ±25ppm/month | | | ±10ppm/day | | |
| Input Offset Voltage[2] | ±10mV max | | | ±10mV max | | |
| vs. Temperature (0 to +70°C) | ±30μV/°C max | | | ±30μV/°C max | | |
| vs. Supply Voltage | ±10μV/% | | | ±10μV/% | | |
| vs. Time | ±2μV/day, ±20μV/month | | | ±10ppm/day | | |
| **RESPONSE** | | | | | | |
| Settling Time, ±0.01% +10V Step | 3 Output Pulses Plus 2μs | | | 2 Output Pulses Plus 2μs | | |
| Overload Recovery Time | 10ms | | | 1ms | | |
| **FREQUENCY OUTPUT[3]** | | | | | | |
| Waveform | TTL/DTL Compatible Pulses | | | TTL/DTL Compatible Pulses | | |
| Pulse Width | 5μs | | | 500ns | | |
| Rise and Fall Time | 300ns/50ns | | | 60ns/50ns | | |
| Pulse Polarity | Positive | | | Positive | | |
| Logic "1" (High) Level | +2.4V min | | | +2.4V min | | |
| Logic "0" (Low) Level | +0.4V max | | | +0.4V max | | |
| Capacitive Loading | 500pF max | | | 200pF max | | |
| Fan Out Loading | 10 TTL Loads min | | | 10 TTL Loads min | | |
| Impedance | 3kΩ (High State) | | | 670Ω (High State) | | |
| **POWER SUPPLY[4]** | | | | | | |
| Voltage, Rated Performance | ±15V dc | | | ±15V dc | | |
| Voltage, Operating | ±(13 to 18)V dc | | | ±(13 to 18)V dc | | |
| Current, Quiescent | (+25, -8)mA | | | (+25, -8)mA | | |
| **TEMPERATURE RANGE** | | | | | | |
| Rated Performance | 0 to +70°C | | | 0 to +70°C | | |
| Operating | -25°C to +85°C | | | -25°C to +85°C | | |
| Storage | -55°C to +125°C | | | -55°C to +125°C | | |
| **MECHANICAL** | | | | | | |
| Case Size | 2" x 2" x 0.4" | | | 2" x 2" x 0.4" | | |
| Weight | 45 Grams | | | 45 Grams | | |
| Mating Socket | AC1016 | | | AC1016 | | |

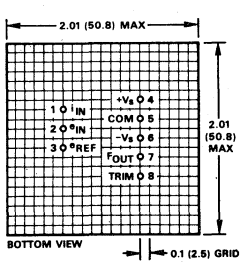
NOTES
[1] Adjustable to zero using 500Ω potentiometer.
[2] Adjustable to zero using 50kΩ potentiometer.
[3] Protected for continuous short-circuits to ground and momentary (less than 1 sec) shorts to the $+V_S$ supply. Output is not protected for shorts to the $-V_S$ supply.
[4] Recommended power supply, ADI model 904, ±15V @ 50mA output.

Specifications subject to change without notice.

## OUTLINE DIMENSIONS

Dimensions shown in inches and (mm).




**MATING SOCKET: AC1016**

## VOLTAGE TO FREQUENCY OPERATION

Models 458 and 460 provide accurate conversion of analog signals into a train of constant width and constant amplitude pulses at a rate directly proportional to the analog signal amplitude. The output continuously tracks the input signal, responding directly to changes in the input signal; external clock synchronization is not required. The output pulse train is TTL/DTL compatible, permitting direct interface to digital processing circuits.

## BASIC V/F HOOK-UP AND OPTIONAL TRIMS

Models 458 and 460 can be applied directly to achieve rated performance without external trim potentiometers or other components. Figures 2, 3 and 4 below illustrate the basic wiring connections for either V/F converter model. Using the basic hookup without trims, full scale ($e_{IN}$ = 10V) accuracy is +0.1% to +2% and the input offset voltage is ±10mV max. The full scale and input offset voltage errors can be eliminated by using the FINE TRIM PROCEDURE.

## FINE TRIM PROCEDURE

Connect the optional trims as shown in Figure 2, 3 or 4 and allow a five minute warm-up after initial power turn-on. Using a precision, stable voltage source, set the input voltage, $e_S$, to 10mV. Adjust the OFFSET trim, $R_O$, for an output pulse interval of 0.01 sec (model 458) or 0.001 sec (model 460).

### V/F INTERCONNECTIONS

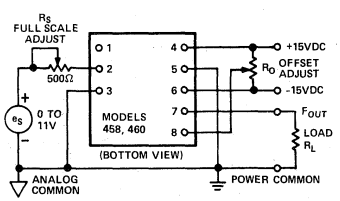



*Figure 2. Positive Input Signal*

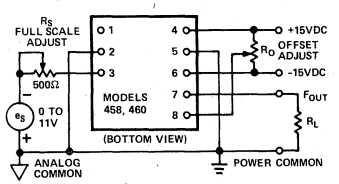



*Figure 3. Negative Input Signal*

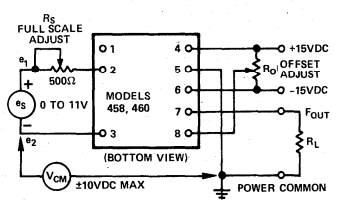



*Figure 4. Floating Input Signal*

EXTERNAL CONNECTIONS FOR VOLTAGE TO FREQUENCY OPERATION, WITH OPTIONAL INPUT OFFSET VOLTAGE AND FULL SCALE FREQUENCY ADJUSTMENTS

$R_S$ = FULL SCALE ADJUSTMENT; (Use low T.C. Cermet, <50ppm/°C or equivalent)
$R_O$ = INPUT OFFSET ADJUSTMENT; 50kΩ (Use low T.C. Cermet, <50ppm/°C or equivalent)

CAUTION: DO NOT SHORT OUTPUT TERMINAL TO -15V

Set the input voltage to +10.000V and adjust the FULL SCALE trim for an output pulse frequency of 100kHz (model 458), or 1MHz (model 460). The V/F converter may now be used without further adjustment.

## DIFFERENTIAL INPUT

The $e_{IN}$ and $e_{REF}$ input terminals represent a true differential input capable of accepting a signal from a strain gage bridge, a balanced line, or a signal source sitting at a common mode voltage. The differential input eliminates the need for a differential amplifier to handle these signals.

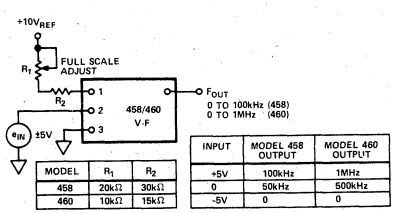
To apply the 458 or 460 voltage inputs differentially, the $e_{IN}$ pin must always be positive with respect to the $e_{REF}$ pin as shown in Figure 4. The differential signal source may be completely floating with common mode voltages up to ±10V max. For differential inputs the output frequency is:

$$F_{OUT} = \left[ \underbrace{(e_1 - e_2)}_{\text{INPUT SIGNAL}} + \underbrace{\left(\frac{e_1 + e_2}{2}\right) \times \left(\frac{1}{CMR}\right)}_{\text{CMR ERROR}} \right] K_g$$

$K_g$ = $10^4$ Hz/V; model 458
$10^5$ Hz/V; model 460

## OFFSETTING INPUT FOR BIPOLAR INPUTS

The input summing terminal, $+i_{IN}$, may be used to improve dynamic response as well as scale the output frequency to directly convert bipolar input voltages. An offset current is fed through an external resistor from a stable voltage reference. As shown in Figure 5, input voltages of ±5V min can be converted directly.

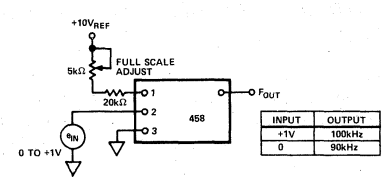



| MODEL | $R_1$ | $R_2$ |
|---|---|---|
| 458 | 20kΩ | 30kΩ |
| 460 | 10kΩ | 15kΩ |

| INPUT | MODEL 458 OUTPUT | MODEL 460 OUTPUT |
|---|---|---|
| +5V | 100kHz | 1MHz |
| 0 | 50kHz | 500kHz |
| -5V | 0 | 0 |

*Figure 5. Offsetting Input to Accept ±5V Bipolar Inputs*

The output may also be scaled up so that low amplitude signals, such as 1V will give full scale output frequency; 100kHz model 458 or 1MHz model 460. By scaling the output frequency for low level signals, the step response will significantly improve. As shown in Figure 6 for model 458, the step response for a 1 volt input decreases from 200μs before input scaling, to 20μs with scaling.




| INPUT | OUTPUT |
|---|---|
| +1V | 100kHz |
| 0 | 90kHz |

*Figure 6. Offsetting Input to Achieve Improved Dynamic Response for Small Signal Inputs*

12

## PERFORMANCE SPECIFICATIONS

**Nonlinearity:** Nonlinearity error is specified as a % of 10V full scale input and is guaranteed over the 0.1mV to 11V operating signal range; ±0.01% max, models 458J/K/L, ±0.015% max, models 460J/K/L. Typical nonlinearity performance is illustrated in Figure 7.

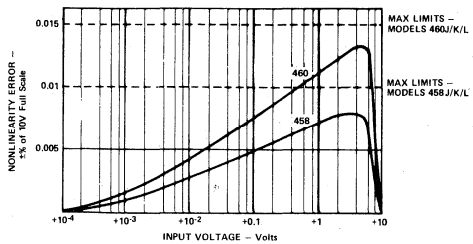



*Figure 7. Nonlinearity Error Versus Input Voltage*

**Gain Temperature Stability:** Gain drift is specified in ppm of output signal and is guaranteed for each model over the 0 to +70°C temperature range; 5ppm/°C (458L), 10ppm/°C (458K), 20ppm/°C (458J), 15ppm/°C (460L), 25ppm/°C (460K) and 50ppm/°C (460J) max.

## LONG TERM PRECISION INTEGRATOR

In critical measurement applications, such as pollution monitoring where it is required to integrate for periods greater than 1 hour with overall accuracy of 0.05%, the V/F converter offers a superior low cost approach when compared to the traditional operational integrator circuit. As shown in Figure 8, the analog signal is applied to a precision input amplifier, model 52K and then to the V/F input. The V/F output is connected to a large capacity counter and display, operating as a totalizer. The total pulse count is equal to the time integral of the analog input signal. Since the output displayed is an accumulated pulse count, there is no integrator drift error. A feature of this approach is the infinite hold capability without errors due to time drift, since the counter may be held at any time without affecting the output reading.

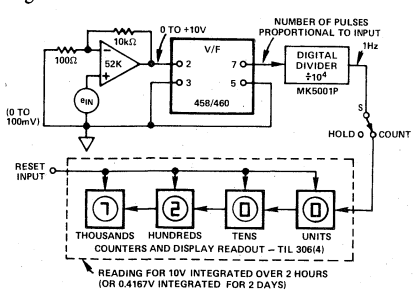



*Figure 8. Models 458/460 as Long Term Integrator with Arbitrary Display Calibration. Frequency Division Ratio can Otherwise be Chosen to Provide Direct Readout in any Desired Units.*

## CMOS/HNIL COMPATIBLE OUTPUT

The circuit shown in Figure 9 may be used to shift the output of the 458/460 from 0 to +5V to 0 to +12V, to provide a 4V noise immunity for driving high noise immunity logic (HNIL) and CMOS logic.

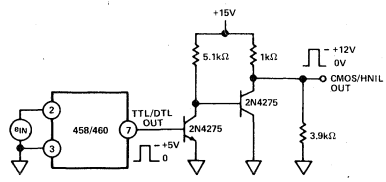



*Figure 9. Circuit for Shifting the Output of the 458/460 to Drive CMOS/HNIL Logic*

## PRECISION HIGH CMV ANALOG ISOLATOR

By combining the V/F converter with a floating power supply and optical isolator as shown in Figure 10, accurate low level measurements in the presence of high common mode voltages may be achieved. Only the CMV rating of the optical isolator and the breakdown rating of the power supply limit the CMV rating. Using this approach for isolating transducers, ground loop problems are eliminated. Cost and complexity are minimized since only a single optical isolator is required to couple the serial pulse output from the V/F to the digital readout.

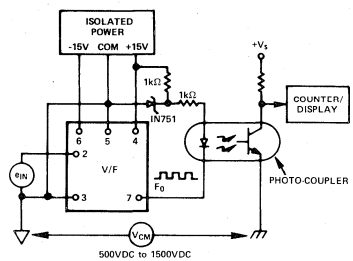



*Figure 10. Optical Isolation Using LED Photo Isolator to Provide Up to 1500V dc CMV Isolation*

## APPLICATION IN DATA ACQUISITION SYSTEMS

**High Noise Immunity Data Transmission:** A method of accurately transmitting analog data through high noise environments is illustrated in Figure 11. This approach utilizes the self clocking output of models 458 and 460 and eliminates the need for costly additional twisted pair for external synchronization. Model 610 amplifies the low level differential transducer signal up to the 10V full scale V/F input level. A differential line driver is used to drive a twisted pair cable. The differential line driver and receiver offer high noise immunity to common mode noise signals.

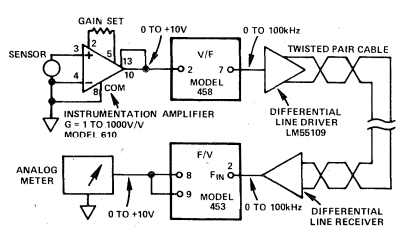



*Figure 11. Application of Model 458 V/F Converter in a High Performance, High Noise Rejection Two-Wire Data Transmission System*

# Synchro & Resolver Converters

## Contents


| | Page |
|---|---|
| Selection Guide | 13–2 |
| General Information | 13–4 |
| API1620/1718 Synchro/Resolver Angle Position Indicators and Digital Converter | 13–5 |
| DSC1705/1706 Digital-to-Synchro Converters (14/12 Bits) | 13–9 |
| DTM1716/1717 Digital Vector Generators | 13–13 |
| •IPA1751, OSC1754 Inductosyn™ Preamp and Power Oscillator | 13–17 |
| IRDC1730/1733 12-Bit, Tracking Inductosyn™/Resolver-to-Digital Converter | 13–21 |
| IRDC1731 4000 Count, Tracking Inductosyn™/Resolver-to-Digital Converter | 13–27 |
| •MCI1794 MULTIBUS™ Compatible Multi-Channel Interface | 13–31 |
| RTM/STM1686/1696/1736/1687/1697/1737 5VA Output Transformers | 13–33 |
| SAC1763 Synchro/Resolver-to-Linear dc Converter | 13–37 |
| SBCD1752/1753/1756/1757 BCD Output Synchro-to-Digital Converters (Low Profile, 12/10/14 Bits) | 13–41 |
| SCDX/RCDX1623 Solid State Control Differential Transmitter | 13–45 |
| SDC1700/1702/1704 Synchro-to-Digital Converters (Low Profile, 12/10/14 Bits) | 13–49 |
| SDC/RDC1721 16-Bit, High Accuracy, Three-State Latched Output S/D Converter | 13–55 |
| SDC1725/1726 Synchro-to-Digital Converters with 3-State-Latched Outputs | 13–59 |
| SPA1695 Synchro/Resolver Power Amplifier | 13–63 |
| SSCT/RSCT1621 Solid State Control Transformer | 13–65 |
| TSL1612 Processors for 2-Speed Synchro-to-Digital Conversion | 13–69 |


•New product since publication of *1982–1983 Databook Update.*


Inductosyn is a registered trademark of Farrand Industries, Inc.
MULTIBUS is a registered trademark of Intel Corporation.


13

# Selection Guide
## Synchro & Resolver Converters

The products in this section are generally concerned with angular measurements. They include the following classes of device:

Digital Angle to Trigonometric (sine-cosine) Analog Voltage
Digital-to-Resolver Converters
Digital-to-Synchro Converters
Inductosyn™-to-Digital Converters
Resolver-to-Analog Voltage Converters
Resolver-to-Digital Converters
Resolver-to-Digital Display (Angular-Position Indicators)
Synchro-to-Analog Voltage Converters
Synchro-to-Digital Converters
Synchro-to-Digital Display (Angular-Position Indicators)

Complete descriptions, specifications, and applications information on the products in this section can be found in the data sheets. Brief general information can be found overleaf.

The Selection Guide is provided to ease the job of finding the right unit to do your job. Devices are listed in the Selection Guide vertically, by model number, in alphabetic, then numeric order, as well as by function and type of input. Salient characteristics are listed horizontally. A bullet is placed at each intersection that is appropriate for each device.

| | | | ANALOG I/O | | | | | DIGITAL I/O | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | BCD | | | | RESOLUTION (BITS) | | | |
| | | | SYNCHRO | RESOLVER | INDUCTOSYN™ | LINEAR | BINARY | 0 to ±180° | 0 to 360° | PULSE TRAIN | 16 | 14 | 12 | 10 | |
| SYNCHRO RESOLVER INPUT | Angle Position Indicator | API1620 | • | • | | | • | • | | • | | | | | |
| | | API1718 | • | • | | | • | • | | • | | | | | |
| DIGITAL INPUT | Digital to Synchro Resolver | DSC1705 | • | • | | | • | | | | • | | | | |
| | | DSC1706 | • | • | | | • | | | | | • | | | |
| | | DRC1745 | • | • | | | • | | | | • | | | | |
| | | DRC1746 | • | • | | | • | | | • | | | | | |
| | Digital to Trig. (Analog) | DRC1765 | | • | | • | • | | | | • | | | | |
| | | DRC1766 | | • | | • | • | | | • | | | | | |
| | | DTM1716 | | • | | • | | | | | • | | | | |
| | | DTM1717 | | • | | • | | | | | | • | | | |
| INDUCTOSYN INPUT | Inductosyn/ Resolver to Digital | IRDC1730 | | • | • | | • | | | | | • | | | |
| | | IRDC1731 | | • | • | | | | • | | | • | | | |
| | | IRDC1732 | | • | • | | • | | | | | • | | | |
| | | IRDC1733 | | • | • | | • | | | | | • | | | |
| | | 1S20 | | • | • | | • | | | | | • | | | |
| | | 1S40 | | • | • | | • | | | | • | | | | |
| | | 1S60 | | • | • | | • | | | | • | | | | |
| | | 1S61 | | • | • | | • | | | | • | | | | |
| RESOLVER INPUT | Resolver to Digital Converters | RDC1740 | | • | | | • | | | | | • | | | |
| | | RDC1741 | | • | | | • | | | | | | • | | |
| | | RDC1742 | | • | | | • | | | | | | • | | |
| | Sync/Resolver Analog | SAC1763 | • | • | | • | | | | | | | | | |
| | Synchro or Resolver to BCD Converters | SBCD1752[1] | • | • | | | | • | | | | •[1] | | | |
| | | SBCD1753[2] | • | • | | | | | • | | | •[2] | | | |
| | | SBCD1756[1] | • | • | | | | • | | | | •[1] | | | |
| | | SBCD1757[2] | • | • | | | | | • | | | •[2] | | | |
| | Synchro or Resolver to Binary | SDC1700 | • | • | | | • | | | | | | • | | |
| | | SDC1702 | • | • | | | • | | | | | | | • | |
| | | SDC1704 | • | • | | | • | | | | | • | | | |
| | | SDC1721 | • | • | | | • | | | | • | | | | |
| | | SDC1725 | • | • | | | • | | | | | | • | | |
| | | SDC1726 | • | • | | | • | | | | | | | • | |
| SYNCHRO INPUT | Synchro to Digital | SDC1740 | • | | | | • | | | | | • | | | |
| | | SDC1741 | • | | | | • | | | | | | • | | |
| | | SDC1742 | • | | | | • | | | | | | • | | |

NOTES
[1] 13-Bit BCD plus sign.
[2] 14-Bits BCD.
Industosyn is a registered trademark of Farrand Industries Inc.
Shading indicates new products since publication of *1982–1983 Databook Update.*

Here's an example of its use: if you were looking for a 14-bit digital-to-resolver converter with the highest accuracy in the smallest package, you might start at the 14-bit column; you would see that there are two resolver families that have 14-bit resolution and error less than 5 arc-minutes: DRC1745 and DRC1705; the DRC1745 is a hybrid, and the DRC1705 is in a >0.4″ module. Thus, you would be quickly led to look at the DRC1745 data sheet and be guided to its location by the page number at the right.

In addition to the devices listed in the chart, data sheets for the following accessory products are also to be found in this section:


Resolver and Synchro 5VA Output Transformers, models RTM/STM1686/1696/1736/1687/1697/1737 — Volume II, Page 13-33

Synchro/Resolver 5VA-Output Power Amplifier, model SPA1695 — Volume II, Page 13-63

Two-Speed Processor for Coarse/Fine Synchro/Resolver Systems, model TSL1612 — Volume II, Page 13-69


| ACCURACY (arc-min) | | | | | ASSEMBLY/PACKAGE TECHNOLOGY | | | | PAGE | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | MODULE | | | | | |
| <1 | <5 | <10 | <20 | >20 | HYBRID | <0.4″H | 0.4″H | >0.4″H | INSTRUMENT | VOLUME I | VOLUME II | |
| | • | | | | | | | • | | 13-5 | | API1620 |
| | • | | | | | | | • | | 13-5 | | API1718 |
| | • | | | | | | • | | | 13-9 | | DSC1705 |
| | • | • | | | | | • | | | 13-9 | | DSC1706 |
| | • | | | | • | | | | 13-5 | | | DRC1745 |
| | • | | | | • | | | | 13-5 | | | DRC1746 |
| | • | | | | • | | | | 13-13 | | | DRC1765 |
| | • | | | | • | | | | 13-13 | | | DRC1766 |
| | • | | | | | • | | | | 13-13 | | DTM1716 |
| | • | | | | | • | | | | 13-13 | | DTM1717 |
| | | • | | | | • | | | | 13-21 | | IRDC1730 |
| | | • | | | | • | | | | 13-27 | | IRDC1731 |
| | | • | | • | • | | | | 13-17 | | | IRDC1732 |
| | | • | | | | • | | | | 13-21 | | IRDC1733 |
| | | • | | | • | | | | 13-29 | | | 1S20 |
| | | • | | | • | | | | 13-29 | | | 1S40 |
| | • | • | | | • | | | | 13-29 | | | 1S60 |
| | | • | • | | • | | | | 13-29 | | | 1S61 |
| | | • | | | • | | | | 13-23 | | | RDC1740 |
| | | • | • | | • | | | | 13-23 | | | RDC1741 |
| | | • | | | • | | | | 13-23 | | | RDC1742 |
| | | | • | | | | | • | | 13-37 | | SAC1763 |
| | | | • | | | | | • | | 13-41 | | SBCD1752[1] |
| | | | • | | | | | • | | 13-41 | | SBCD1753[2] |
| | | | • | | | | | • | | 13-41 | | SBCD1756[1] |
| | | | • | | | | | • | | 13-41 | | SBCD1757[2] |
| | | • | | | | | • | | | 13-49 | | SDC1700 |
| | • | | | • | | | • | | | 13-49 | | SDC1702 |
| | | • | | | | | • | | | 13-49 | | SDC1704 |
| • | | • | | | | | | • | | 13-55 | | SDC1721 |
| | | | | | | • | | | | 13-59 | | SDC1725 |
| | | | • | | | • | | | | 13-59 | | SDC1726 |
| | | • | | | • | | | | 13-23 | | | SDC1740 |
| | | • | • | | • | | | | 13-23 | | | SDC1741 |
| | | • | | | • | | | | 13-23 | | | SDC1742 |

13

# Orientation
## Synchro & Resolver Converters

These products constitute a complete line of devices for the digital measurement and control of angular and linear displacements by means of synchros, resolvers, and Inductosyns. In addition to modules and hybrid circuits that perform the appropriate conversions, the line also includes modules that perform purely algebraic or logical functions; in some cases, solid-state circuitry emulates the functions of electromechanical devices.

The range of synchro processing modules now available covers a wide area of application. They are widely used in military and radar applications, but there are additional fields in which they could be used to advantage because of the proven ruggedness and high precision of the electromechanical hardware, their standardized specifications, and their low cost. They have a number of advantages over potentiometers and optical systems.

In this introductory section, there will be provided a brief set of device definitions. Detailed data and applications information is given in the data sheets. For a complete introduction to synchro/digital conversion, Analog Devices has available a 208-page book, *Synchro and Resolver Conversion*, edited by G. Boyes (1980), $11.50.

In this section, and in much of the text, the word "Synchro" appears frequently. In many cases, the word "Resolver" could be used in its place. The modules make use of angular data in resolver form; if the input data is in three-wire synchro form, transformers in "Scott T" configuration convert it to resolver form; analog outputs are available in both forms. There are a number of voltage and frequency options.

### REPRESENTATION OF ANGLES IN DIGITAL FORM

**Binary**

The most commonly used method of representing angles in digital form is simple natural binary weighting, where the most-significant bit (MSB) represents 180°, the next represents 90°, etc. The table shows the bit weights in degrees, degrees-and-minutes, and radians for this coding method.

**BCD**

When angular measures have to be displayed in visual form, BCD coding is used, through the use of binary-to-BCD converters, such as the BDM1615, which provides the necessary scaling and conversion, e.g., from 10100000000000 (180° + 45°) to 10 0010 0101.0000 000 (or 225.00°).

### TYPICAL S/D/S DEVICES

**Binary-to-Binary-Coded-Digital Converter (BDM1615/16/17)**

A device that accepts angular data in binary form and converts it to BCD form, with fractional degrees in decimal fractions of 1° (1615, 1617) or minutes and seconds (1616). The BCD output is modulo 360°.

| Bit No. | Degrees | Degrees, minutes | | Radians |
|---|---|---|---|---|
| 1 | 180 | 180 | 0 | 3.141593 |
| 2 | 90 | 90 | 0 | 1.570796 |
| 3 | 45 | 45 | 0 | 0.785398 |
| 4 | 22.5 | 22 | 30 | 0.392699 |
| 5 | 11.25 | 11 | 15 | 0.196349 |
| 6 | 5.625 | 5 | 37.5 | 0.098175 |
| 7 | 2.8125 | 2 | 48.75 | 0.049087 |
| 8 | 1.40625 | 1 | 24.38 | 0.024544 |
| 9 | 0.70312 | 0 | 42.19 | 0.012272 |
| 10 | 0.35156 | 0 | 21.09 | 0.006136 |
| 11 | 0.17578 | 0 | 10.55 | 0.003068 |
| 12 | 0.08789 | 0 | 5.27 | 0.001534 |
| 13 | 0.04395 | 0 | 2.64 | 0.000767 |
| 14 | 0.02197 | 0 | 1.32 | 0.000383 |
| 15 | 0.01099 | 0 | 0.66 | 0.000192 |
| 16 | 0.00549 | 0 | 0.33 | 0.000096 |

**Digital-to-Synchro Converters (DSC1705/06)**

Devices that accept parallel binary digital inputs (14 or 12 bits) and an ac reference signal, and provide outputs in 3-wire synchro form.

**Inductosyn/Resolver-to-Digital Converter (IRDC1730)**

A device that produces a digital output capable of resolving (to 12 bits) intermediate distances within a single track-pitch of a Farrand linear-Inductosyn stator in displacement- and angle-measuring Inductosyn systems. The moving element is used as though it were a resolver input; hence the device will also convert resolver information to digital.

**Synchro-to-Digital Converter**

A device that accepts either 3-wire synchro- or 4-wire resolver inputs, together with a 2-wire ac reference, and outputs angular binary data in a continuously tracking mode, employing a Type 2 servo loop. The inputs may be from either remote synchros or from electrically simulated synchros (e.g., DSC's).

**Digital Converter and Processor for Two-Speed Synchros (TSL1612)**

A two-speed processor takes as inputs two sets of digital information, representing the angles from coarse and fine synchros, and combines them to produce a single 19-bit word representing the actual angle of the "coarse" shaft. The TSL consists of the processing logic alone—it can be used with a pair of SDC's, which provide the two sets of digital information.

# ANALOG DEVICES

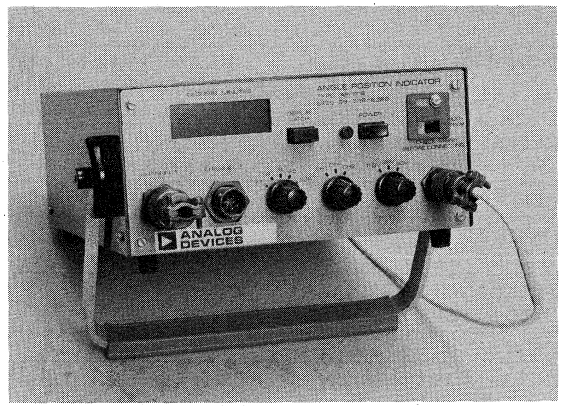
# Synchro/Resolver Angle Position Indicators and Digital Converter

# API1620 and API1718

**FEATURES**
**Five Digit Display**
**Accuracy 0.02° (API1620) or 2 arc-minutes (API1718)**
**Two Channel Input**
**Accepts High or Low Level Synchros, Resolvers or Magslips**
**47Hz to 600Hz Carrier Frequency**
**16-Bit BCD or Natural Binary Output**
**Storage Compartment for Leads/Connectors**

**API1620 FEATURES**
**Degrees and Decimal Parts of a Degree Display**
**Display Test Facility**
**Full Scale 359.99°**

**API1718 FEATURES**
**Nato Codified**
**Degrees and Minutes Display**
**Display Latch Facility**
**Full Scale 359° 59′**




## DESCRIPTION

The Angle Position Indicators API1620 and API1718 are instruments for displaying in visual digital form the angle represented by synchro, magslip or resolver signals. In addition to displaying the angle in visual form the APIs also convert the input angular signals into natural binary or BCD angular data at TTL levels for use externally. Facility is provided for the connection of two sets of input signals which may be alternately switched into the converter. The APIs have been designed to accommodate input signals from all the usually encountered angular data transmission systems i.e., Synchros, Magslips and Resolvers at both high and low voltage levels and at frequencies from 47Hz to 600Hz. The two sets of inputs to the APIs can be different e.g., a 60Hz synchro on one input together with a 400Hz resolver on the other. The facility of switching from one set of inputs to the other enables the angular position of separate devices to be directly compared. The meters have been designed to work with any reference voltage from 6V rms to 115V rms.

## STORAGE COMPARTMENT

A storage compartment for storing the input leads and connectors is provided on the underside of the instrument, access to this is by an easily operated slotted screw fastener. The API is delivered with part of the Application Kit stored in this compartment.

## SELF TESTING

Both Angle Position Indicators have a self checking facility. This is provided by internally simulated input angles of 45° and 225° selected by the front panel mode switch. The simulated angles have an accuracy an order of magnitude greater than the Instrument.

## NATO CODE NUMBER

The API1718 BCD option has been issued with a Nato Stock Number, 6625-99-539-8389, which eases acceptance of the Angle Position Indicator in military applications.

## MODELS AVAILABLE

The two Angle Position Indicators described in this data sheet differ primarily in the format of the display and the presence of a Display Check or Display Latch facility.

Model API1620 has a display format of degrees and decimal parts of a degree with a full scale range of 359.99° and an accuracy of 0.02°. It has a display check facility on the front panel and is available in two options, viz.

BINARY option has 16-bit representation at TTL levels of the input angular signal in natural binary form on the rear connector.

BCD option has a 5 decade BCD representation at TTL levels of the input angular signal on the rear connector.

Model API1718 has a display format of degrees and minutes with a full scale range of 359° 59 minutes and an accuracy of 2 arc minutes. It has a display latch facility on the front panel and is available in two options, viz.

BINARY option has a 16-bit representation at TTL levels of the input angular signal in natural binary form on the rear connector.

BCD option has a 5 decade BCD representation at TTL levels of the input angular signal on the rear connector.

13

# SPECIFICATIONS (typical @ +25°C unless otherwise noted)

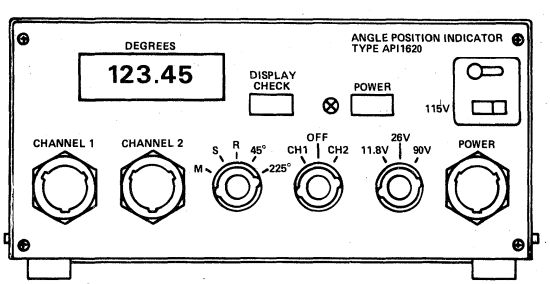
| Models | API1620 | API1718 |
|---|---|---|
| ACCURACY[1] | ±0.02° at 400Hz<br>±0.03° at 60Hz | 2 arc minutes at 400Hz<br>3 arc minutes at 60Hz |
| ANGULAR RANGE | 000.00° to 359.99°<br>continuous rotation | 000.00° to 359° 59 minutes<br>continuous rotation |
| TEMPERATURE RANGE | Operational 0 to +50°C<br>Storage −5°C to +55°C | * |
| INPUT SIGNAL VOLTAGE | 11.8V rms 200Hz to 600Hz<br>26.0V rms 200Hz to 600Hz<br>90.0V rms 47Hz to 600Hz | * |
| REFERENCE VOLTAGE | 6V rms to 115V rms with no adjustments required | * |
| REFERENCE FREQUENCY | 47Hz to 600Hz | * |
| INPUT IMPEDANCE | Signal 2MΩ<br>Reference 200kΩ | * |
| TOLERANCE ON SIGNAL TO REFERENCE PHASE | ±20° | * |
| DISPLAY | 5 digit, dot matrix LED | * |
| DATA OUTPUT (TTL) ON REAR CONNECTOR (BCD 2TTL Loads, Binary 3TTL Loads) | Either 5 decade BCD or 16-bit natural binary. Degrees and decimal parts of a degree format. | * |
| INHIBIT INPUT (TTL) (1TTL LOAD) | Logic "0" = Hold<br>Logic "1" = Track | * |
| BUSY OUTPUT (TTL) (10TTL LOADS) | Logic "0" = Data Stable<br>Logic "1" = Busy | * |
| POWER SUPPLY | 23VA (typ), 28VA (max) at either 115V rms or 220V rms ±15% 47Hz to 400Hz | * |
| WEIGHT | 10 lbs 4.53Kgm | * |
| SIZE (EXCLUDING HANDLE) | 11.75" X 8" X 4"<br>(300mm X 204mm X 102mm) | * |
| NATO STOCK NO. | – | 6625–99–539–8389<br>(BCD version only) |

NOTES

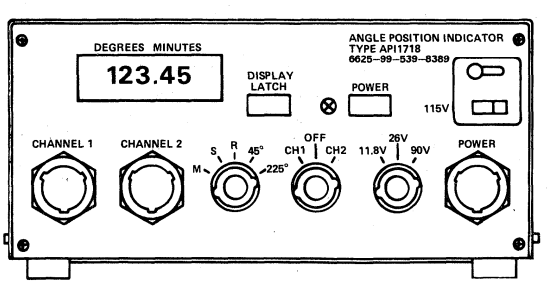
*Specifications same as API1620.

[1] Full accuracy is maintained if signal voltages within ±10% of the nominal values are applied (all lines varying together). The input amplifier limits are set at +15% of the nominal voltage levels, no damage will occur if 90 volts is applied on the 11.8 volts or 26.0 volt settings and up to 150 volts can be applied on the 90 volts setting without damage. For voltages considerably lower than the normal voltages the API will continue to function at a reduced accuracy; the inaccuracy will manifest itself mainly as an hysteresis error.

Specifications subject to change without notice.




*Front Panel of the API1620*




*Front Panel of the API1718*

## DATA READOUT

The digital angle readout is displayed on a five digit display by Light Emitting Diode (LED) dot matrix indicators on the front panel.

The API1620 model displays this angle as degrees and hundredths of a degree.

The API1718 model displays this angle as degrees and minutes.

The displayed angle is also available at TTL levels in either Binary or BCD format on the rear connector. *In both APIs this angle is produced in degrees and hundredths of a degree.*

## DISPLAY CHECK (API1620)

The API1620 has a display check press button on the front panel which when pressed causes all the dots in all LED matrices to be illuminated.

## POWER CONNECTIONS

The Angle Position Indicators can be powered from 115V ac or 220V ac ±15%, the changeover switch being on the front panel. The supply frequency can be 47Hz to 400Hz.

## DISPLAY LATCH (API1718)

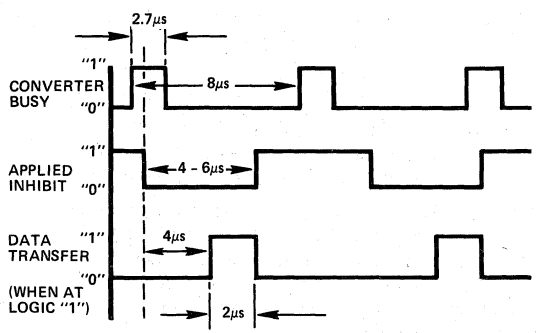
The API1718 has a Display Latch button on the front panel which when pressed will hold the display at its existing reading –but does not effect the digital output data.

Both APIs have a latch facility available on Pin 36 on the rear connector. This "$\overline{\text{INHIBIT}}$" input will "Freeze" both the display and the digital output data if a Logic "0" is applied.

## OUTPUTTING VALID DATA

A "Converter Busy" pulse is available on Pin 37 of the rear connector, which indicates the state of the converter. When this line is at Logic 1 the converter is busy and the data is changing. A Logic 0 indicates that the data is valid.

Data can be transmitted without error under the following timing sequence.




*Data Transfer Waveforms*

## DATA OUTPUT CONNECTIONS AND BIT WEIGHTS

The APIs are available in two forms one giving the output in BCD form and the other giving the output in natural binary form. In both cases the resolution corresponds to 16-bits binary. The pin connections for the 37 way DCM 37S Souriau rear connector are given in the following table.

## OPERATING NOTES

The line voltage selector switch must be set in the correct position before the power is applied. To the left of the voltage selector switch is the instrument "on/off" press button and to the left of that is the power indicator neon.

| PIN NUMBER | NATURAL BINARY VERSION BIT NO. | BIT WEIGHT | BCD VERSION CODING |
|---|---|---|---|
| 1 | GROUND | | GROUND |
| 2 | 16 | 0·0055 | 0·01° |
| 3 | 15 | 0·0110 | 0·02° |
| 4 | 14 | 0·0220 | 0·04° |
| 5 | 13 | 0·0439 | 0·08° |
| 6 | 12 | 0·0879 | 0·10° |
| 7 | 11 | 0·1758 | 0·20° |
| 8 | 10 | 0·3516 | 0·40° |
| 9 | 9 | 0·7031 | 0·80° |
| 10 | N/C | | 1·0° |
| 11 | N/C | | 2·0° |
| 12 | 8 | 1·4063 | 4·0° |
| 13 | 7 | 2·8125 | 8·0° |
| 14 | 6 | 5·6250 | 10·0° |
| 15 | 5 | 11·2500 | 20·0° |
| 16 | 4 | 22·5000 | 40·0° |
| 17 | 3 | 45·0000 | 80·0° |
| 18 | 2 | 90·0000 | 100·0° |
| 19 | 1 | 180·0000 | 200·0° |
| 20 | N/C | | N/C |
| TO↓ | •• | | TO↓ |
| 35 | N/C | | N/C |
| 36 | $\overline{\text{INHIBIT}}$ | | $\overline{\text{INHIBIT}}$ |
| 37 | BUSY | | BUSY |

*Connections on Output Connector at rear of API*

## SIGNAL VOLTAGE SELECTOR SWITCH

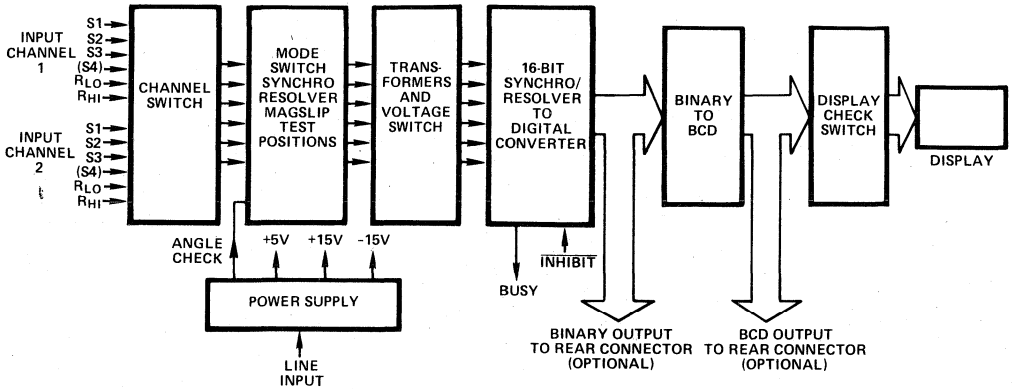
The three position selector switch alters the transformers to suit the synchro or resolver voltages being applied to the API. THIS SWITCH SHOULD BE SET IN THE 90 VOLT POSITION DURING 45° OR 225° CHECKING, no damage will be done if this or any of the switches are in wrong positions but errors in checking could occur.

## MODE SELECTOR SWITCH

This mode selector switch marked M, S, R, 45°, 225° meaning Magslip, Synchro, Resolver, 45° check and 225° check is for making appropriate changes according to whether a magslip synchro or resolver is being used. If two differing systems are being applied to the inputs e.g. Channel 1 resolver at 26V and Channel 2 synchro 90V, then the mode switch will have to be changed from R to S and the voltage switch from 26V to 90V when changing from Channel 1 to Channel 2. No damage will be done to the API by any order of switching but some change of loading on the inputs may occur. To avoid this problem the channel switch marked CH1, OFF, CH2 should be set in the OFF position when changing the mode and voltage switches.

## DIRECTION OF DATA ROTATION

The convention of zero angle on Magslips differs from Synchros by 150°. Correction for this has been made inside the APIs, so that zero degrees will be indicated on the API for both Synchro and Magslips set to zero. The direction of rotation convention is different for Synchros and Magslips this has not been changed so that a clockwise rotation (from zero) of the synchro will give the same reading as an anticlockwise rotation (from zero) of a Magslip.




*Schematic Arrangement of the API1620 and API1718*

**REFERENCE INPUT**

Both the Angle Position Indicators require a reference voltage to be supplied via the input connectors. This must be the same reference as supplied to the devices under test and can be any voltage from 6V rms 115V rms.

**POWER AND SIGNAL INPUT CONNECTIONS**

The power and input connectors have lettered pins (see table on previous page). Connections are:

**Power**

Fixed Connector: Amphenol 62GB-57A-8-3.3P
Free Connector: Amphenol 62GB-16F-8-3.3S

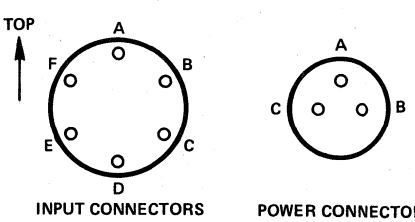
| | | |
|---|---|---|
| 3 Way: | Pin A | Ground |
| | Pin B | Live |
| | Pin C | Neutral |

**Inputs**

Fixed Connector: Amphenol 62GB-57A-10-6P
Free Connector: Amphenol 62GB-16F-10-6S

| | | |
|---|---|---|
| 6 Way: | Pin A to S1 | Pin D to S4 |
| | Pin B to S3 | Pin E to Ref High |
| | Pin C to S2 | Pin F to Ref Low |

For resolver inputs the sine voltage is applied to S1 and S3 and the cosine to S2 and S4. The phase of the resolver connections should be such that if S3 and S4 and Ref Low are regarded as common then in the first angular quadrant 0 to 90° the voltages on S2 and Ref High will be in time phase, i.e., positive together and negative together and the voltages on S1 and Ref High will be 180° out of time phase. For synchro or magslip operation the connections should be made to S1, S2 and S3 in rotation.




*Pin Connections as Viewed Looking at the Front of the API1620 and API1718*

**APPLICATIONS OF THE ANGLE POSITION INDICATOR**

The API finds many applications in both civil and military systems where it is common place to use synchro or resolver angular data transmission.

In many areas of mechanical engineering where angular settings have to be made to high accuracies, the APIs can be used with a precision synchro to display the shaft angle—or by using both inputs to compare shaft angle settings.

Other examples of the API's applications are checking constant velocity, coupling (universal joints) and measuring nonuniformity in the gearing velocity of gear boxes. By converting the digital output data to printers, permanent records can be obtained.

**FUSES**

The API1620 is protected by a 300mA anti-surge fuse in the fuse holder in the rear panel. The API1718 has two 160mA anti-surge fuses located on the rear panel for 240V operation. When used at 115V the 300mA fuses supplied should be fitted.

**ORDERING INFORMATION**

The APIs should be ordered according to the following:

| | |
|---|---|
| API1620/BCD | degrees and hundredths display. BCD digital data output on rear connector. |
| API1620/BIN | degrees and hundredths display. Binary digital data output on rear connector. |
| API1718/BCD | degrees and minutes display. BCD digital data output on rear connector. Nato Code: 6625—99—539—8389. |
| API1718/BIN | degrees and minutes display. Binary digital data output on rear connector. |

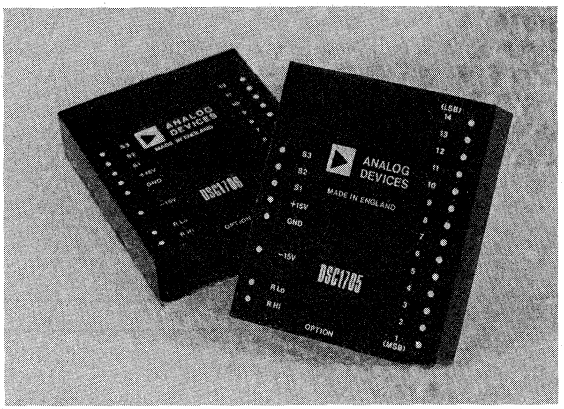
The API1620 is supplied with the following applications kit: 2 input connectors Amphenol sockets type 62GB—16F10—6S, 1 mains lead with Amphenol socket type 62GB—16F8—3.3S attached, one 37 way DCM37S Souriau connector with cover and spring clip. 1 Users Handbook. Calibration Result Sheet.

The API1718 is supplied with the following applications kit: 2 input leads with Amphenol socket type 62GB—16F10—6S attached. (Nato stock number 6625—99—541—3454). 1 mains lead with Amphenol socket type 62GB—16F8—3.3S attached. (Nato stock number 6625—99—541—3453). One 37 way connector DCM37S/Souriau connector with cover and spring clip. 1 Users Handbook. 3 Spare fuses (one 160mA anti-surge, two 300mA anti-surge). Calibration result sheet.

# DSC1705/1706

**FEATURES**
- Very Low Radius Vector Variation (Transformation Ratio) (±0.1%)
- High Accuracy (±2 arc-mins at +25°C)
- 12- or 14-Bit Resolution
- No 5 Volt Power Supply Required
- MIL Spec/Hi Rel Versions Available
- Internal 1.3VA Amplifiers
- Internal Transformers (400Hz Option)
- No Trims or Adjustments Necessary

**APPLICATIONS**
- Driving Control Transformers
- Driving Torque Receivers (with External Amplifiers)
- Servo Mechanisms
- Retransmission Systems
- Positional Control




## GENERAL DESCRIPTION

The DSC1705 and DSC1706 are Digital-to-Synchro and Digital-to-Resolver converters capable of driving electromechanical loads of up to 1.3VA.

They accept a 14- or 12-bit digital input representing angle and a reference voltage of either 60Hz or 400Hz, and produce a 3 wire or 4 wire output suitable for driving Synchros or Resolvers.

The 400Hz converters contain internal 1.3VA amplifiers as well as output and reference transformers.

The 60Hz versions contain internal 1.3VA amplifiers but require external output and reference transformers.

If it is necessary to drive a load requiring more than 1.3VA, options for both the 400Hz and 60Hz converters are available allowing the use of external amplifiers and transformers.

## RADIUS VECTOR

One of the outstanding features of these converters is the almost negligible Radius Vector variation (Transformation Ratio).

On many Digital-to-Synchro converters presently available, the individual sine and cosine outputs produced do not follow the exact sine and cosine laws, and depending upon angle can vary up to ±7%. This is not always important as the ratio of the sine to the cosine, i.e., the tangent, is always correct to the specified accuracy of the converter. There are cases however, when driving torque receivers and certain servo control loops when this variation is unacceptable.

*The design of the DSC1705 and DSC1706 has reduced this variation to less than ±0.1%. This means that when the converters are used in closed loop servo systems, the gain of the closed loop is independent of the digital input angle, thus making reference correction unnecessary.*

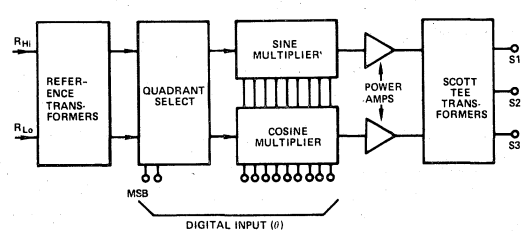
## MODELS AVAILABLE

The two Digital to Synchro/Resolver converters described in this data sheet differ primarily in the areas of resolution and accuracy as follows:

Model DSC1705XYZ is a 14-bit converter with an overall accuracy of ±4 arc-minutes.

Model DSC1706XYZ is a 12-bit converter with an overall accuracy of ±8 arc-minutes.

The XYZ option code defines the option thus: (X) signifies the operating temperature range, (Y) signifies the reference frequency, (Z) signifies the output and the reference voltages, whether the output is in Synchro or Resolver format and whether external transformers are required.




*Principle of Operation*

## FUNCTIONAL DIAGRAM, DSC1705 and DSC1706

The principle of operation of the converters described in this data sheet is shown in the diagram above.

13

# SPECIFICATIONS (typical @ +25°C unless otherwise noted)

| Model | DSC1705 | DSC1706 |
|---|---|---|
| ACCURACY[1] | ±4 arc-minutes | ±8 arc-minutes |
| RESOLUTION | 14 Bits (1LSB = 1.3 arc-minutes) | 12 Bits (1LSB = 5.3 arc-minutes) |
| INPUT CODE | 14-Bits Natural Parallel Binary with MSB = 180° | 12-Bits Natural Parallel Binary with MSB = 180° |
| REFERENCE VOLTAGE INPUT | | |
| With Internal Transformers | | |
| Low Level | 26V rms | * |
| High Level | 115V rms | * |
| External Transformer Options[2] | 4V rms | * |
| REFERENCE FREQUENCY | 60Hz or 400Hz | * |
| REFERENCE INPUT IMPEDANCE | | |
| With Internal Transformers | | |
| Low Level | 20kΩ | * |
| High Level | 200kΩ | * |
| External Transformer Options[2] | 10kΩ | * |
| DIGITAL INPUT (TTL COMPATIBLE) | 1TTL Load | * |
| OUTPUT VOLTAGE AND FORMAT | | |
| With Internal Transformers | | |
| Low Level | 11.8V rms Line-to-Line Synchro or Resolver | * |
| High Level | 90V rms Line-to-Line Synchro or Resolver | * |
| External Transformer Options[3] | 7V rms Sine and Cosine | * |
| LOAD CAPABILITY | 1.3VA | * |
| SHORT CIRCUIT PROTECTION | Continuous for 5 minutes | * |
| OUTPUT SETTLING TIME[4] | 50μs for 180° Step | * |
| RADIUS VECTOR VARIATION (Transformation Ratio) | ±0.1% max Sine and Cosine | * |
| INTERNAL TRANSFORMER ISOLATION | 500V dc | * |
| POWER SUPPLIES | | |
| Voltage | ±15V dc ±5% | * |
| Current | | |
| (a) No Load | 95mA per Line | * |
| (b) Full Load Mean | 225mA per Line | * |
| WARM-UP TIME | 1sec to Full Accuracy | * |
| OPERATING TEMPERATURE RANGE | 0 to +70°C Standard | * |
| | -55°C to +105°C Extended | * |
| STORAGE TEMPERATURE RANGE | -55°C to +125°C | * |
| SIZE | 3.125" x 2.625" x 0.8" | * |
| | (79.4mm x 66.7mm x 20.3mm) | * |
| WEIGHT | 8 ounces (224 grams) max | * |
| MEAN TIME BETWEEN FAILURES (MTBF) CALCULATED | 150,000 Hours | * |

NOTES

*Specifications same as DSC1705.

[1] Accuracy applies over the full operating temperature range of the option and for:
(a) ±10% reference frequency and amplitude variation.
(b) 10% harmonic distortion on the reference.
(c) ±5% power supply variation.
(d) Any balanced load from no load to full load.

[2] Refers to input to converter and not to external transformers.

[3] Refers to output from internal converter amplifiers and not from external transformers.

[4] Dependent upon option and load conditions.

Specifications subject to change without notice.

## CONNECTING THE CONVERTER

400Hz options. All these converters contain internal output and reference transformers.

The digital input should be connected to pins "1" through "12" on the DSC1706 and pins "1" through "14" on the DSC1705, noting that pin "1" is the Most Significant Bit (MSB).

"S1", "S2" and "S3" should be connected to the appropriate inputs on the synchro being driven. ("S4" is used also when connection is made to a resolver).

The reference should be connected to "$R_{Hi}$" and "$R_{Lo}$" ensuring that the phase is correct.

"GND" is the common for both power supplies and digital inputs.

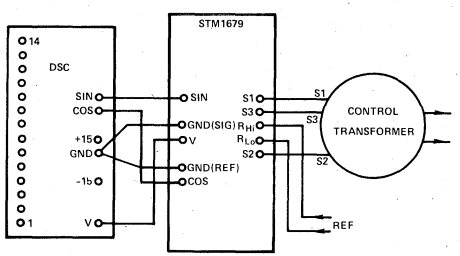
60Hz Options. For 60Hz operation, an external transformer, STM1679 is required.

The power supplies and digital input should be connected as for the 400Hz version.

The STM1679 transformer should have its pins "SIN", "COS" and "V" connected to the equivalent pins on the converter. The "GND(SIG)" and "GND(REF)" should both be connected to "GND" on the converter.

The outputs to the load should be taken from "S1", "S2" and "S3" on the STM1679 transformer ("S4" also in the case of a resolver).

The reference input should be made to "$R_{Hi}$" and "$R_{Lo}$" on the STM1679.




*60Hz Connection to a Control Transformer (Diagram Shows Bottom View of Modules)*

## OPERATION WITH EXTERNAL AMPLIFIERS OR TRANSFORMER OTHER THAN STM1679

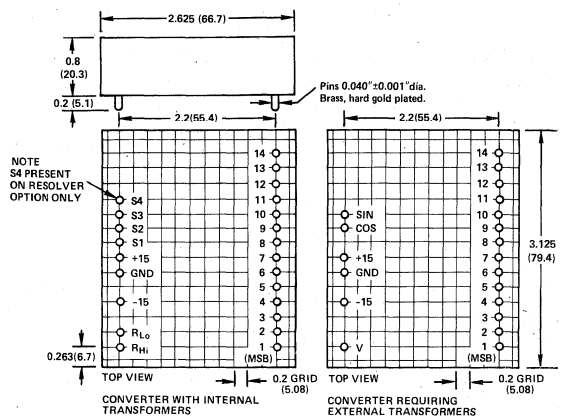
For certain applications, the power output required by the load will be greater than the 1.3VA supplied by the internal amplifiers. Thus external amplifiers and transformers will be needed. Products offered to fulfull this requirement are:

SPA1695 – Dual 5VA Amplifier
STM1696 – 5VA output and reference transformers (400Hz)
STM1697 – 5VA output and reference transformers (60Hz)

If you have a requirement for such products please request the data sheet.

## CONVERTER OUTLINE DIMENSIONS AND PIN CONNECTION DIAGRAM

Dimensions shown in inches and (mm).

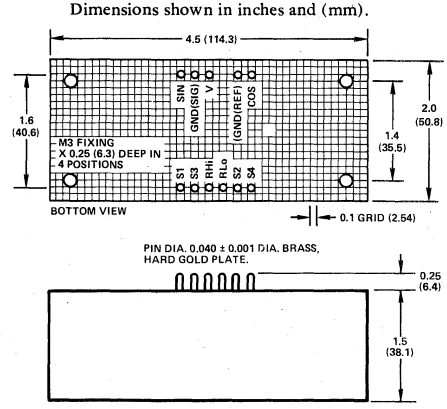



NOTE
DIAGRAMS ABOVE SHOW DSC1705.
DSC1706 DOES NOT HAVE PINS "13" AND "14".

**MATING SOCKET: CAMBION 450-3388-01-03**

## TRANSFORMER (STM1679) OUTLINE DIMENSIONS AND PIN CONNECTION DIAGRAM

Dimensions shown in inches and (mm).




## BIT WEIGHT TABLE

| Bit Number | Weight in Degrees |
|---|---|
| 1 (MSB) | 180.0000 |
| 2 | 90.0000 |
| 3 | 45.0000 |
| 4 | 22.5000 |
| 5 | 11.2500 |
| 6 | 5.6250 |
| 7 | 2.8125 |
| 8 | 1.4063 |
| 9 | 0.7031 |
| 10 | 0.3516 |
| 11 | 0.1758 |
| 12 (LSB for DSC1706) | 0.0879 |
| 13 | 0.0439 |
| 14 (LSB for DSC1705) | 0.0220 |

## LOADING THE DSC's WITH CONTROL TRANSFORMERS (CT's)

The most common device to be driven by Digital to Synchro converters is the control transformer (CT)

The minimum power required to drive a CT can be expressed as:

$$(VA) = \frac{V^2}{|Z_{so}|} \cdot \frac{3}{4}$$

where V is the line to line voltage and $Z_{so}$ is the impedance between one input terminal and the other two shorted together with the rotor open circuit. ($Z_{so} = R_{so} + j\,X_{so}$)

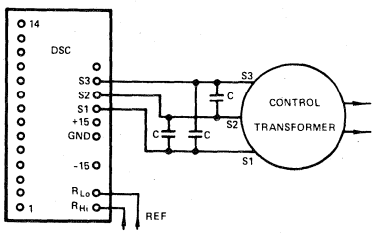
For example, if a CT has a $Z_{so}$ of 700 + j 4900 and a line to line voltage of 90 volts, then:

$$|Z_{so}| = \sqrt{700^2 + 4900^2} = 4950 \text{ Ohms}$$

$$\text{and } (VA) = \frac{90^2}{4950} \cdot \frac{3}{4} = 1.23VA$$

## TUNING CT LOADS

The load can be reduced by tuning the output with 3 capacitors as shown below.




*Capacitor Connection for Tuning CT's*

C should be equal to:

$$\frac{X_{so}}{2\omega\,(R_{so}^2 + X_{so}^2)}$$

The power required after tuning will be:

$$(VA) \text{ untuned} \quad x \frac{R_{so}}{Z_{so}}$$

Therefore in the above example the capacitor value should be:

$$\frac{4900}{2 \times 2\pi \times 400\,(245 \times 10^5)} = 40nF$$

and the power required after tuning will be:

$$1.23 \times \frac{700}{4950} = 0.17VA$$

Note allowance should always be made for tolerances in the CT windings, capacitors and frequency.

## PRACTICAL CONSIDERATIONS OF TUNING CT LOADS

1. The capacitors used need not be of high tolerance, 20% is sufficient.
2. Three capacitors must be used, one across S1 and S2, one across S1 and S3 and one across S2 and S3.
3. Voltage working and type of capacitors should be as follows:

   **11.8V Line-to-Line options:**
   15 Volt ac working or greater, non-polarized tantalum type.

   **90V Line-to-Line options:**
   100 Volt ac working or greater, for example, low K ceramic types.
4. For tuning Resolver loads, two capacitors only are required, one connected between S1 and S3 and the other connected between S2 and S4.

## CONTROL DIFFERENTIAL TRANSMITTERS (CDX's)

The loading on a DSC of these devices can be considered in a similar way to that of CT's. However becasue a CT normally follows a CDX, the effective Z will need to be calculated. This value will normally be between 66% and 80% of the $Z_{so}$ quoted for the CDX.

## TORQUE RECEIVERS (TR's)

Torque receivers are more difficult devices to drive than CT's and CDX's, and in general external amplifiers and transformers will be necessary. However, because of the lack of radius vector variation, the DSC1705 and DSC1706 are far more suited to driving TR's than converters with a variation of ±7%.

For a deviation of an angle $\theta$, the drive current required will be:

$$\frac{2 \cdot V \cdot \sin\frac{\theta}{2}}{|Z_{ss}|}$$

Points to be observed are:

(a) The TR should not be allowed to lock up.
(b) A phase lead equal to that specified for the TR should be introduced into the reference input to the DSC.
(c) The reference should always be present on the TR and the converter.
(d) The DSC output voltage should be matched exactly to the voltage requirements of the TR.

## CAUTIONS

(a) Do not connect a 115V reference to a 26V converter.
(b) Do not reverse the power supplies.
(c) Do not connect the reference to any other pins except "$R_{Hi}$" and "$R_{Lo}$".

## ORDERING INFORMATION

When ordering, the converter part numbers should be suffixed by an option code in order to fully define the item. All standard options and their appropriate option codes are listed below.

| Part Number[1] | Resolution | Operating Temp. Range | Line-to-Line Output Voltage and Format | Reference Voltage | Reference Frequency |
|---|---|---|---|---|---|
| DSC1705511 | 14 Bits | 0 to +70°C | 11.8V Synchro | 26V | 400Hz |
| DSC1705512 | 14 Bits | 0 to +70°C | 90.0V Synchro | 115V | 400Hz |
| DSC1705611 | 14 Bits | -55°C to +105°C | 11.8V Synchro | 26V | 400Hz |
| DSC1705612 | 14 Bits | -55°C to +105°C | 90.0V Synchro | 115V | 400Hz |
| DRC1705518 | 14 Bits | 0 to +70°C | 11.8V Resolver | 26V | 400Hz |
| DRC1705618 | 14 Bits | -55°C to +105°C | 11.8V Resolver | 26V | 400Hz |
| DSC1705507 and STM1679522 | 14 Bits | 0 to +70°C | 90.0V Synchro | 115V | 60Hz |
| DSC1705607 and STM1679622 | 14 Bits | -55°C to +105°C | 90.0V Synchro | 115V | 60Hz |

Note: 1. For 12-bit resolution, substitute DSC1706 in place of DSC1705 in the above.
2. For options not shown above, consult the factory.

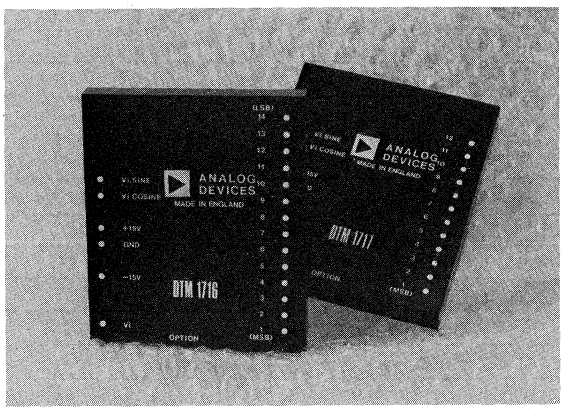
# ANALOG DEVICES

# Digital Vector Generator

# DTM1716/1717 SERIES

**FEATURES**
**Accurate Sine, Cosine Multiplication**
**14-Bit Resolution**
**3 Arc-Minutes Accuracy**
**0.1% Radius Accuracy**
**Low Profile (0.4")**
**Maximum Frequency to Full Accuracy 2.5kHz**
**Low Feedthrough**

**APPLICATIONS**
**Digital to Synchro Conversion**
**Displays**
**Axis Rotation**
**Simulators**
**Numerical Control**
**Prediction**
**Vector Resolution**
**Spectrum Analysis**
**Ultra Low Frequency Oscillators**




## GENERAL DESCRIPTION

The DTM1716 and DTM1717 are computing converters which have a digital angle input in natural binary form and a bipolar analog input $V_i(t)$. There are two analog outputs $V_{01}(t)$ and $V_{02}(t)$, the outputs are related to the inputs by;

$$V_{01}(t) = V_i(t) \sin \phi(t) \qquad V_{02}(t) = V_i(t) \cos \phi(t)$$

where $\phi$ is the digital angular input. $\phi$ ranges from 0 to 360°. The analog input has a range of ±10V; the analog output has a range of ±10V.

The digital input has a resolution of 14 bits for the DTM1716 and 12 bits for the DTM1717. The modules are powered from ±15V supply lines.

If the output voltages are regarded as the components of a vector, the radius accuracy is better than 0.1% and the angular inaccuracy is less than 3 arc minutes for the DTM1716.

A block diagram of the DTM1716 is shown in Figure 1.

Particular attention has been paid in the design to achieve high accuracy in the sine and cosine generation so that they may be used separately as accurate functions.

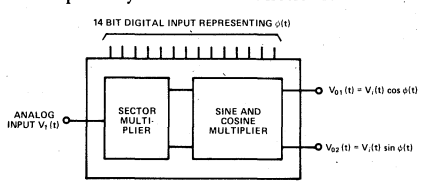



*Figure 1. Diagram of DTM1716*

Two models are available each with two options as shown below.

DTM1716500 has 14-bit digital input resolution and a 0 to +70°C operating temperature range.

DTM1716600 has 14-bit digital input resolution and a -55°C to +105°C operating temperature range.

DTM1717500 has a 12-bit digital input resolution and a 0 to +70°C operating temperature range.

DTM1717600 has a 12-bit digital input resolution and -55°C to +105°C operating temperature range.

13

## OPERATION

The operation of the DTM1716 is straightforward, being powered from ±15V lines relative to the common pin. No damage is caused by either the +15V or -15V being disconnected but they must not be reversed. The analog input is protected against a short circuit to either power line. The output is short circuit proof and can be connected to either power line without damage. The digital inputs are standard TTL levels. The module dimensions and pin out are shown in Figure 2.

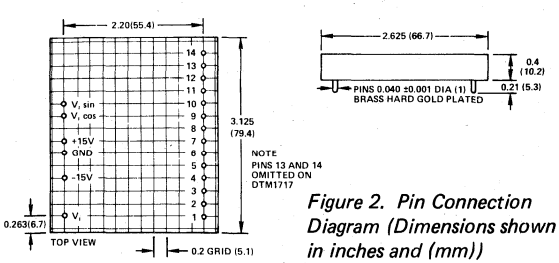



*Figure 2. Pin Connection Diagram (Dimensions shown in inches and (mm))*

**MATING SOCKET: CAMBION 450-3388-01-03**

# SPECIFICATIONS (typical @ +25°C unless otherwise noted)

| MODELS | DTM1716 | DTM1717 |
|---|---|---|
| DIGITAL ANGULAR RESOLUTION | 14 bits (1 LSB = 1.3 arc-mins) | 12 bits (1 LSB = 5.3 arc-mins) |
| FULL SCALE OUTPUT | ±10V | * |
| SCALING ACCURACY | 0.1% FSR | * |
| FULL SCALE INPUT | ±10V | * |
| SCALE TEMPCO | 25ppm/°C of FSR | * |
| ZERO OFFSET | 5.0mV max | * |
| OFFSET DRIFT | 50μV/°C | * |
| AC ACCURACY<br>Analog Step Response<br>(10V Step) | <br>40μs<br>(to 0.1%) | <br>* |
| MAX SLEW RATE | 0.5V/μs | * |
| FULL POWER OUTPUT | 8kHz | * |
| FEEDTHROUGH | <1mV at 400Hz | * |
| ANALOG INPUT IMPEDANCE | 20kΩ | * |
| ANALOG OUTPUT IMPEDANCE | 100mΩ | * |
| OUTPUT LOAD | 2kΩ | * |
| OUTPUT PROTECTION | Short circuit proof | * |
| DIGITAL INPUT | 14-bit natural parallel binary,<br>1TTL Load | 12-bit natural parallel binary,<br>1TTL Load |
| RESPONSE TO DIGITAL STEP (90°) (FS Analog Input) | 40μs to 0.1% of final value | * |
| VECTOR ACCURACY[1]<br>Radius Error<br>Angular Error | <br>0.1% FSR<br>±3 arc-mins | <br>*<br>* |
| POWER SUPPLY REJECTION | 80dB | * |
| POWER SUPPLIES | +15V @ 60mA max<br>-15V @ 50mA max | *<br>* |
| TEMPERATURE RANGE<br>Operating<br>Storage | 0 to +70°C Standard<br>or -55°C to +105°C extended<br>-55°C to +125°C | *<br>*<br>* |
| DIMENSIONS | 3.125 x 2.625 x 0.4"<br>79.4 x 66.7 x 10.2mm | * |
| WEIGHT | 3 oz (85 grams) | * |

NOTES

*Specification same as DTM1716.

[1] See Figure 4.

Specifications subject to change without notice.

**ABSOLUTE MAXIMUM INPUTS**

$V_i$ to GND . . . . . ±V Supply
+15V Supply Pin . . . . . +17V
-15V Supply Pin . . . . . -17V
Logic Inputs . . . . . -0.4V to +5.5V

## APPLICATIONS OF THE DTM1716

Figure 3 shows how the DTM1716 can be used in radars and radar simulators for modulating display sawtooth generators using signals derived from a synchro transmitter on the antenna and a Synchro to Digital converter. The synchro signal representing the antenna angle is converted to a 14-bit natural binary representation by the Synchro to Digital converter SDC1704. The digital angle is applied to the digital input of the DTM1716. A dc voltage is applied to the DTM1716 analog input which controls the radius of the displayed raster. The output voltages are used to provide the X and Y time base currents. The switches across the capacitors are opened on the leading edge of the transmission pulse and closed after a time interval determined by the range.

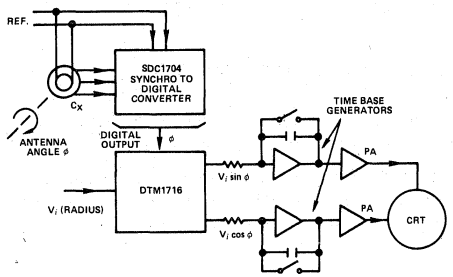



*Figure 3. PPI Waveform Generation Using the DTM1716*

## AXIS ROTATION

Figure 4 shows how two DTM1716's may be used to compute the new two dimensional coordinates of a point relative to a rotated set of axes. The input voltage $X_1$ and $Y_1$ are proportional to the coordinates of a point in the XY plane. If a digital angle $\phi$ is applied to the DTM1716's, the output voltages $X_2$ and $Y_2$ correspond to the X and Y coordinates of the point relative to a set of axes rotated through the angle $\phi$. The systems can be extended to three dimensions.

The arrangement as shown in Figure 4 may also be used to obtain the new coordinates of a point which is rotated through the angle in the same coordinate set. This scheme provides a low cost, accurate and compact solution to transformation problems.

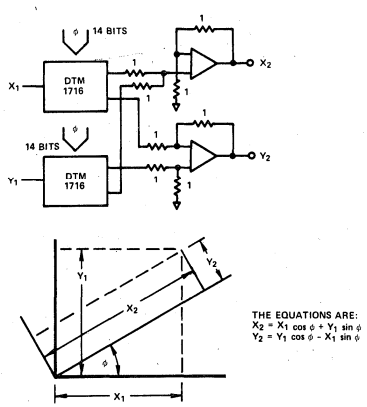



*Figure 4. Axis Rotation in Two Dimensions Using the DTM1716*

## SYNCHRO TO INVARIANT SINE/COSINE

In many engineering applications it is required to obtain voltages proportional to the sine and cosine of an angular movement and to be able to scale the voltages electrically. Figure 5 shows how a Synchro to Digital converter and the DTM1716 may be used for this purpose. The advantage of this scheme is that the coefficients of sine and cosine are electrically scalable by means of the bipolar voltage $V_i$, saving memory space, multipliers, power and space.

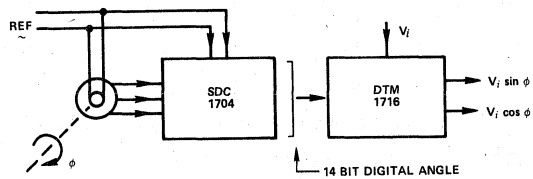



*Figure 5. Synchro to Invariant Sine/Cosine Using the SDC1704 and DTM1716*

## POWER SPECTRUM ANALYSIS

Figure 6 shows a less usual application of the DTM1716 in the spectrum analysis of low frequency signals. This has the advantage of providing almost infinite resolution at extremely low relative cost.

A simple method of obtaining the power in the frequency interval $f \pm \Delta f$ is shown in Figure 6.

The input waveform from which the power spectrum is required is g(t). Multiplication of this waveform by Sin $2\pi ft$ causes the energy in the waveform between $f - \Delta f$ and $f + \Delta f$ to be shifted to lie between $-\Delta f$ and $f + \Delta f$. The low pass filter passes this voltage waveform to the square law devices to produce an output proportional to the power. Two channels, sine and cosine, are used for the case where g(t) may contain a periodic component. If for example there is a line in the power spectrum, without the use of the two channels the output at that frequency would depend upon its phase. The use of both sine and cosine multiplication avoids this problem.

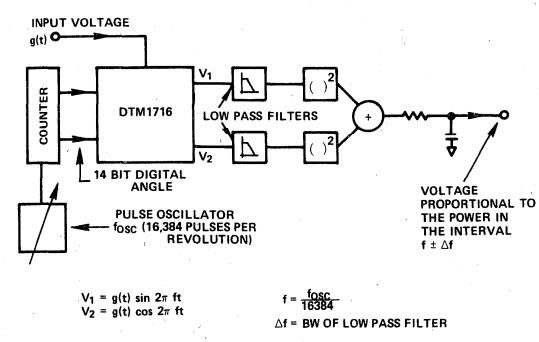



*Figure 6. The Use of the DTM1716 to Obtain the Power Frequency Spectrum of g(t)*

13

## PHASE MODULATION

The DTM1717 can be used for low frequency phase modulation of subcarriers. Figure 7 shows the method which uses two DTM1717's and an ADC. Frequency modulation can be obtained if the amplitude of the signal is made to be inversely proportional to its frequency. This can be accomplished by inserting an integrator in series with the modulation input. Similar techniques can be used for very low frequency synthesis.

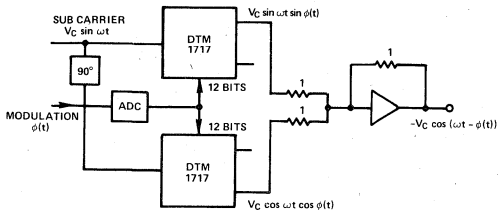



*Figure 7. Phase Modulation Using 2 DTM1717's*

## ORDERING INFORMATION

There are only two options for each of the DTM1716 and DTM1717. They are the commercial or extended temperature ranges. The appropriate designations are as follows:

DTM1716500 (14 bits) 0 to +70°C
DTM1716600 (14 bits) -55°C to +105°C
DTM1717500 (12 bits) 0 to +70°C
DTM1717600 (12 bits) -55°C to +105°C

## OTHER PRODUCTS

Many modular and hybrid devices concerned with the conversion of synchro data are manufactured by us, some of these are listed below.

## DIGITAL VECTOR GENERATORS

The DRC1765 and 1766 are hybrid digital-to-resolver converters that perform a similar function to the DTM1716 but operate over the extended temperature range of -55°C to +125°C.

## SYNCHRO-TO-DIGITAL CONVERTERS

SDC1700 series of low profile modular converters with 10-, 12- and 14-bit natural binary output. These all have internal transformers for all frequency options.

SDC1740 series of hybrid converters with 10-, 12- and 14-bit natural binary output. These hybrid converters offer transformer isolation of both the signal and reference inputs. The operating temperature range is the extended range of -55°C to +125°C.

## DIGITAL-TO-SYNCHRO CONVERTERS

DSC1705 and 1706 are modular 14- and 12-bit digital-to-synchro converters with a 1.3VA output and internal transformers for signal and reference isolation.

DRC1745 and 1746 are hybrid 14- and 16-bit signal to resolver converters with a 2VA output working over the extended temperature range of -55°C to +125°C.

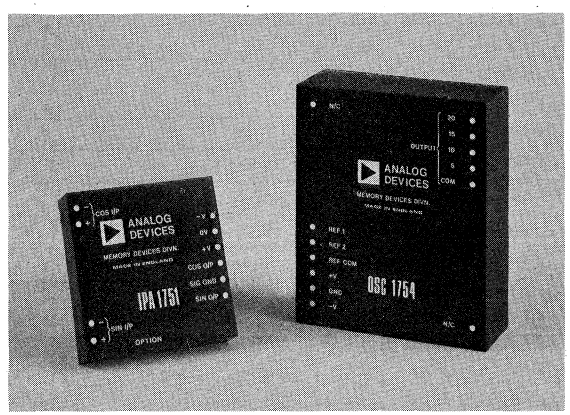
# Inductosyn™ Preamplifier and Power Oscillator

# IPA1751, OSC1754

**FEATURES**
**IPA1751**
**Encapsulated for Protection**
**Phase Shift <5°**
**Phase Match >1°**
**Load Capacity 10,000pF**

**OSC1754**
**Isolated Output**
**Multi-Tapped**
**Quadrature Reference Output**

**APPLICATIONS**
**The IPA1751 and OSC1754 when used with one of the IRDC1730 series Inductosyn/resolver-to-digital converters offers the user all the electronic modules necessary for the Inductosyn to controller interface.**




## GENERAL DESCRIPTION

### IPA1751

The output signals from an Inductosyn slider are at a low level of the order millivolts and requires amplification and buffering before transmission to an Inductosyn to digital converter. The IPA1751 provides the necessary gain and output impedance for this purpose.

Any gain mismatch in the two channels amplifying the sine and cosine outputs of the Inductosyn slider contributes to the system error. The IPA1751 with a 0.15% gain match over the temperature range only contributes an error of 0.23 micron using a 2mm pitch Inductosyn. By carefully controlling phase mismatch to less than 1° the error contribution is only 0.2 micron in a 2mm pitch Inductosyn.

The IPA1751 with an output resistance of less than 3 ohms and a capability of driving a cable capacity of 10,000pF is totally suited to machine tool application where the Inductosyn to digital converter is remote from the measuring Inductosyn.

### OSC1754

The OSC1754 provides the drive for energization of the Inductosyn track. Transformer isolated outputs are available at four voltages that allows a wide range of track resistance to be accommodated. In addition to the power output, a two low power outputs are provided one in phase and one 90° in advance of the power output. The necessity for a quadrature output is for the reference input of the IRDC, since Inductosyn track impedance is predominantly resistive, the slider sine and cosine output voltages are in phase quadrature with the voltage.

The demands on the absolute accuracy of the phase, frequency and amplitude are not exacting owing to the method of conversion used in the IRDC that is tolerant to all these parameters (see IRDC1730/31/33 Data Sheets).

13

## MODELS AVAILABLE

Model IPA1751/560 is a two channel preamplifier 1kHz to 10kHz operating 0 to +70°C.

Model OSC1754/500 is a power oscillator at 10kHz operating 0 to +70°C.

Inductosyn is a registered trademark of Farrand Industries, Inc.

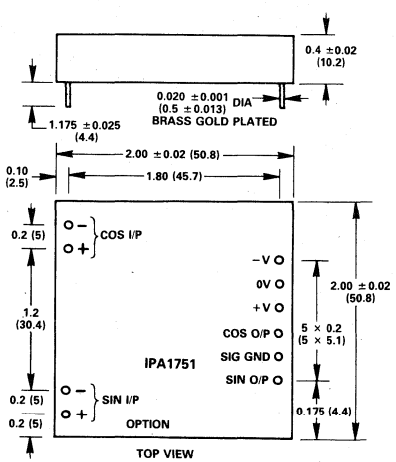
# SPECIFICATIONS (typical @ +25°C over full range of power supply inputs unless otherwise noted)

| Model | IPA1751/560 |
|---|---|
| GAIN | 1300 ± 10% |
| GAIN MISMATCH | |
| Channel to Channel | |
| Over Temperature Range | ±0.15% (equivalent to 2.5 arc mins) |
| PHASE SHIFT | <5° |
| PHASE MISMATCH | |
| Channel to Channel | <1° |
| CROSSTALK | <0.1% |
| OPERATING FREQUENCY | 10kHz |
| INPUT RESISTANCE | 5kΩ ± 10% |
| OUTPUT RESISTANCE | <5Ω |
| MAX LOAD CAPACITY | 10,000pF |
| MAXIMUM SIGNAL | |
| OUTPUT LEVEL | 3V rms |
| POWER SUPPLIES | |
| Voltage | ±12V to ±15V |
| Current | 30mA max |
| TEMPERATURE RANGE | |
| Operating | 0 to +70°C |
| Storage | −55°C to +125°C |
| SIZE | 2.0″ × 2.0″ × 0.4″ (50.8mm × 50.8mm × 10.2mm) |

NOTE
Specifications subject to change without notice.

## OUTLINE DIMENSIONS

Dimensions shown in inches and (mm).




## HYBRID INDUCTOSYN PREAMPLIFIER AND POWER OSCILLATOR

The IPA1764 and OSC1758 are extended temperature devices (−55°C to +125°C) with performance similar to the IPA1751 and OSC1754 described in this data sheet. U.S. MIL-STD-883B processing is available on these products.

These products are housed in a hermetically sealed 18-pin double DIP metal case – 0.775″ (19.7mm) × 0.975″ (24.8mm) × 0.2″ (5.1mm).

## OTHER PRODUCTS

We manufacture a range of Inductosyn/resolver-to-digital converters specifically designed for the numerical controlled machine tool and robot applications.

**IRDC1730** – 12-bit parallel binary output with analog velocity output, direction and ripple carry logic outputs. Tracking rate up to 170 revolutions per second.

**IRDC1731** – A serial output converter with 4,000 counts per revolution, direction and ripple carry output. Tracking rate up to 100 revolutions/pitches per second.

**IRDC1732** – A low cost hybrid. Twelve-bit parallel tri-state latched binary output.

**IRDC1733** – With the features of the IRDC1730 without analog velocity and at a reduced cost.

In addition to this above range, we manufacture a complete range of modular and hybrid synchro/resolver-to-digital and digital-to-synchro/resolver converters.

## ABSOLUTE MAXIMUM VALUES

Sin & Cos I/P . . . . . ±V
+V Pin . . . . . +17V
−V Pin . . . . . −17V
Sin & Cos O/P 1k Load . . . . . ±10V
Indefinite Short Circuit Proof

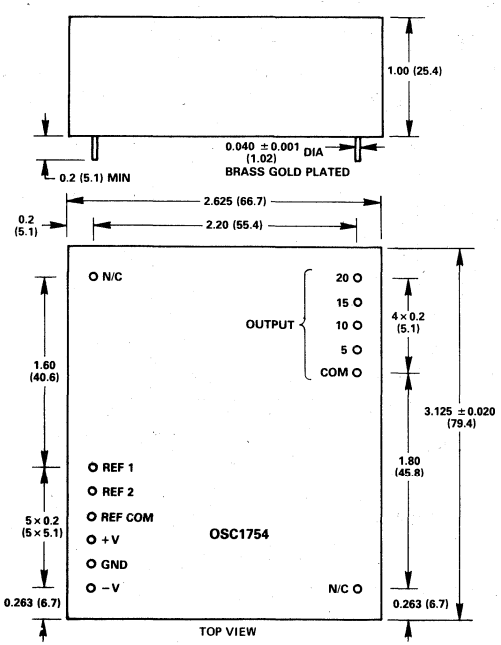
# SPECIFICATIONS (typical @ +25°C with ±15V supplies unless otherwise noted)

| Model | OSC1754/500 | Comments and Conditions |
|---|---|---|
| FREQUENCY | 10kHz ±5% | Over Temperature Range |
| OUTPUTS | 20V rms | With +V = ±15V |
| ISOLATED | 15V rms 5 Watts | All Output Meet ±5% |
| POWER O/P | 10V rms Maximum | Tolerance Over Temperature |
| | 5V rms | Range Fully Loaded. |
| REFERENCE 1 | 2.5V rms @ 4mA max in | Additional 7% max Change No |
| | Phase with Power Outputs | Load to Full Load. |
| REFERENCE 2 | 2.5V rms @ 4mA max 90° | N.B. All Outputs Vary Proportional to |
| | Phase Advanced WRT Power Outputs | +V Supply |
| POWER SUPPLY | +12V to +15V | |
| | 100mA max | No Load |
| | 500mA max | Full Load |
| −V | −12 to −15 | |
| | 20mA max | Independent of Load |
| TEMPERATURE RANGE | | |
| Operating | 0 to +70°C | |
| Storage | −55°C to +125°C | |
| SIZE | 3.125" × 2.625" × 1" | |
| | (79.4mm × 66.7mm × 25.4mm) | |
| WEIGHT | 8 oz | |
| | 224g | |

NOTE
Specifications subject to change without notice.

## OUTLINE DIMENSIONS

Dimensions shown in inches and (mm).




## ABSOLUTE MAXIMUM VALUES

+V Pin . . . . . +18V
−V Pin . . . . . −18V

13

## APPLICATION OF OSC1754 AND IPA1751

The diagram below shows a "hookup" with the preamplifier power oscillator and an IRDC1733 with an Inductosyn. Precise application information is not possible as the Inductosyn in its application has many variables.

### Current Set Resistor

This resistor is used to match the voltage output of the oscillator to the Inductosyn track resistance and provide the manufacturer's recommended current. By variation of the voltage outputs and current resistance, track by this up to approximately 30 feet (9.1 meters) can be accommodated.

### Decoupling

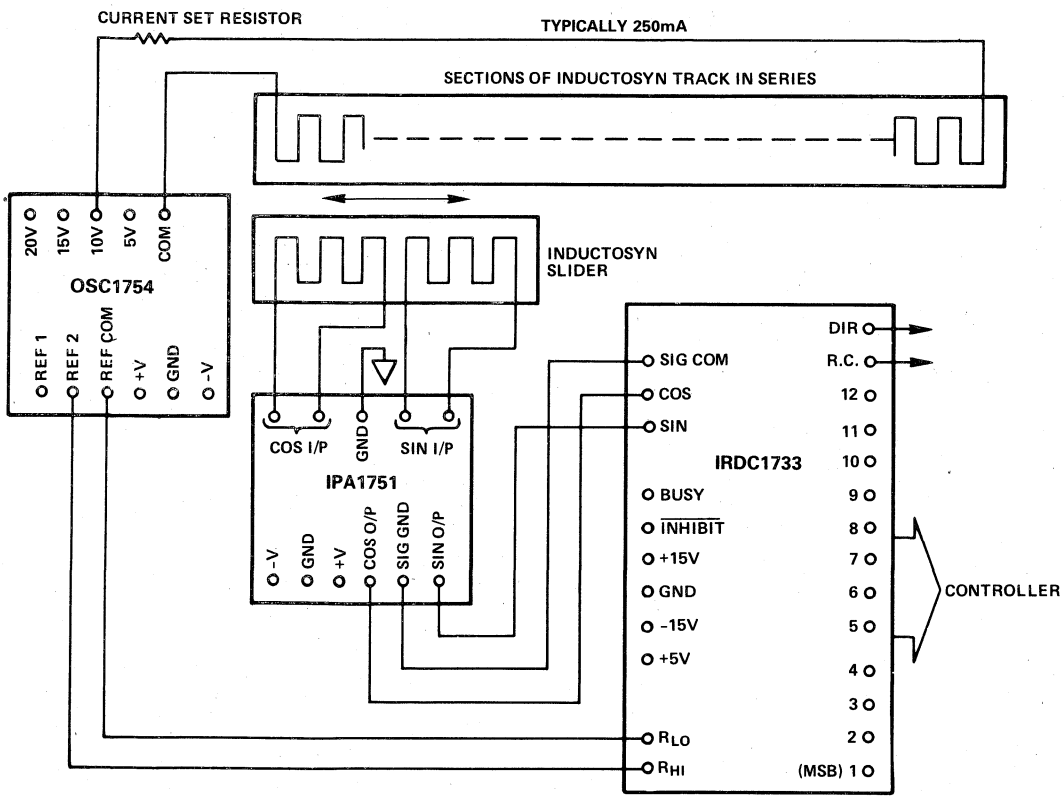
The preamplifier and oscillator have internal high frequency decoupling capacitors on the supply lines, however, it is recommended that electrolytic decoupling capacitors are connected close to the module pins.

### Channel Gains

There are several ways to achieve a signal value of 2.5V rms at the converter input. When setting gains it is important that the 2.5V rms signal is the maximum in either channel.

Within the limits set by noise, slider exactation can be varied. A useful feature of the tracking converter is its ability to reject incoherent and common mode noise.

As the input impedance of the IRDC is resistive, the gain can be scaled by the addition of series resistors. The required value is 2.22kΩ per excess volt, the mismatch being more important than the absolute value. A mismatch of 0.1% in the values gives rise to an error of 0.0000787 of the Inductosyn pitch.




*Use of IRDC1733 with Inductosyn Preamplifier IPA1751 and Power Oscillator OSC1754*

### ORDERING INFORMATION

IPA1751/560 Preamplifier 0 to +70°C
OSC1754/500 Oscillator 10kHz, 0 to +70°C

# ANALOG DEVICES

# 12-Bit, Tracking Inductosyn™/ Resolver-to-Digital Converters

# IRDC1730/1733

## FEATURES

- Uses Ratiometric Amplitude Measurement Principle
- Can Be Used with Inductosyns or Resolvers
- 12-Bit Parallel Word Representing Resolver Shaft Angle or Distance Moved Through Inductosyn Pitch
- Tracking Rates at Up to 170 revs/sec (10,200 rpm) or 170 Pitches Per Second
- Transformer Isolated Inputs
- Resistive Scaling Facility Accommodates Most Resolver Signal Levels
- Direction Output
- Ripple Clock Output (Revolution or Pitch Count)
- DC Velocity Output Representing Input Rate
- No External Trims or Adjustments
- Four Frequency Options (400Hz, 2.6kHz, 5kHz or 10kHz)
- Low Profile Module (0.4", 10.2mm)
- Designed to Meet Intrinsic Safety Requirements

## APPLICATIONS

- Industrial Control
- Machine Tool and Robot Control

## GENERAL DESCRIPTION

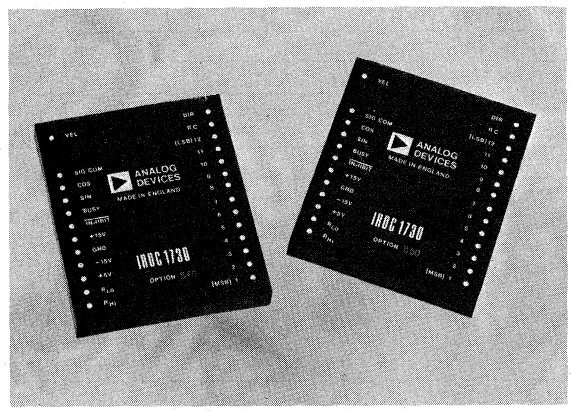
The IRDC1730/33 convert resolver format (sine and cosine) signals into a 12-bit parallel word. The units accept inputs from either a resolver, in which case the 12-bit word represents the angle of the resolver shaft or from an Inductosyn slider via external pre-amps in which case the 12-bit word represents the distance moved through an Inductosyn pitch.

The converters are of the continuous tracking type working on a type 2 servo loop principle and operate for input rates of up to 170 revs per second (in the case of the 5kHz and 10kHz versions). In the case of an Inductosyn input used at these frequencies, they will track at a maximum rate of 170 pitches per second.

The converters are available in 4 different frequency options, 400Hz, 2.6kHz, 5kHz and 10kHz; and the signal and reference inputs, which are transformer isolated, are accepted as 2.5 volts rms max. *An outstanding feature of the converters is that even though the signal and reference inputs are transformer isolated, they can still be externally resistively scaled to accommodate the user's particular voltage levels.*

*A further advantage of the IRDC1730/33 is that they work on a ratiometric, amplitude comparison principle and therefore any voltage drop between the resolver or the Inductosyn and the converter does not substantially affect the accuracy. The amplitude measurement technique also ensures a high degree of noise immunity which might exist on the signal input lines.*

Inductosyn is a registered trademark of Farrand Industries, Inc.




In addition to the digital output, the IRDC1730 also provides a dc velocity signal which is proportional to the rate at which the input is changing.

A direction signal is also provided as well as a ripple clock output which gives a pulse every time the resolver input passes through the zero position or the Inductosyn slider moves to an adjacent pitch (see timing diagram).

The IRDC1730/33 are housed in a 0.4" (10.2mm) low profile module and weighs only 3.5 ozs (100G).

## MODELS AVAILABLE

The IRDC1730/33 are available in two operating temperature versions, each one of which is available in four frequency options. For details of how to specify an exact part number see "Ordering Information".

## OPERATION OF THE CONVERTER

The IRDC1730/33 are tracking converters. This means that the output always automatically follows the input for speeds up to the maximum specified tracking rate of the particular option. There is no requirement for "Convert Command" signals. One full revolution of the resolver or the movement of the slider through a distance equivalent to one pitch of the Inductosyn will cause the output of the converter to change from an output of all "zeroes" through to an output of all "ones" or vice versa. As the output of the converter passes through electrical zero of the resolver or the Inductosyn, a pulse will be output on the Ripple Clock (RC) pin. The direction of rotation is indicated by the DIR signal.

# SPECIFICATIONS (typical @ +25°C unless otherwise stated)

| Model | IRDC1730 | IRDC1733 |
|---|---|---|
| ACCURACY[1] | ±8 arc-minutes Static Input (see tracking rate specification) | * |
| RESOLUTION | 12 Bits (LSB = 5.27 arc-minutes or 1/4096 of a pitch) | * |
| DIGITAL OUTPUT | Parallel, 2TTL Loads, MSB = 180° or half pitch posn. | * |
| SIGNAL AND REFERENCE FREQUENCY[1] | 400Hz, 2.6kHz, 5kHz or 10kHz | * |
| SIGNAL VOLTAGE[1] | 2.5 volts max (Sine and Cosine) rms | * |
| SIGNAL IMPEDANCE | 5.6kΩ | * |
| REFERENCE VOLTAGE[1] | 2.5 volts rms | * |
| REFERENCE IMPEDANCE | 5.6kΩ | * |
| ALLOWABLE PHASE SHIFT[2] (Signal to reference) | ±20° will give no additional error with a static input | * |
| TRANSFORMER ISOLATION | 500 volts dc | * |
| TRACKING RATE (min, i.e., at least) | For ±14 arc-minutes Accuracy: | * |
| | 68 rps (400Hz) | * |
| | 87 rps (2.6kHz) | * |
| | 170 rps (5kHz, 10kHz) | * |
| | For ±10.5 arc-minutes Accuracy: | * |
| | 34 rps (400Hz) | * |
| | 43 rps (2.6kHz) | * |
| | 85 rps (5kHz, 10kHz) | * |
| SETTLING TIME (For 179° Step) | | |
| 400Hz Options | 38ms | * |
| 2.6kHz Options | 33ms | * |
| 5/10kHz Options | 12ms | * |
| ACCELERATION CONSTANT ($K_A$) | | |
| 400Hz Options | 88,435/sec$^2$ | * |
| 2.6kHz Options | 469,000/sec$^2$ | * |
| 5/10kHz Options | 1,015,000/sec$^2$ | * |
| "BUSY" OUTPUT | Logic "HI" when busy. 350ns max width. 1TTL load. | * |
| DIRECTION OUTPUT (DIR) | Logic "LO" when counting up. Logic "HI" when counting down. 2 STTL load (Mil) 4STTL loads (comm). Valid for min of 300ns before and min of 75ns after positive going edge of BUSY. | * |
| RIPPLE CLOCK OUTPUT (RC) | Low going pulse indicating when internal counters will change from all "1s" to all "0s" or vice versa. Duration equals BUSY period, between contiguous positive going edges. | * |
| INHIBIT INPUT | Logic "LO" to inhibit. 1LS TTL Load. | * |
| VELOCITY OUTPUT CHARACTERISTICS: | | |
| Scaling | ±5V ±5% dc for max stated tracking rate of option | NA |
| Polarity | Positive going voltage for increasing angle | |
| Zero Offset | 5mV max at +25°C max | |
| | 10mV max at max specified operating temperature | |
| Gain Temperature Coefficient | 0.07%/°C typical, 0.2%/°C max | |
| Linearity | 2% over one fifth max tracking rate | |
| Output Noise | Less than 5mV in 0 to 20Hz bandwidth | |
| POWER SUPPLIES | ±15 volts @ 25mA | * |
| | +5 volts @ 185mA | * |
| POWER DISSIPATION | 1.33 Watts | * |
| TEMPERATURE RANGE | 0 to +70°C Standard | * |
| | -55°C to +105°C Extended | * |
| DIMENSIONS | 2.625" X 3.125" X 0.4" (66.6mm X 79.3mm X 10.2mm) | * |
| WEIGHT | 3.5 ozs. | * |

NOTES

[1] Accuracy applies over the operating temperature range and over: (a) ±10% signal and reference voltage and frequency variation (b) ±10% signal and reference harmonic distortion (c) ±5% power supply variation.

[2] See "Dynamic Accuracy vs. Resolver Phase Shift" on next page.

*Specifications same as IRDC1730.

Specifications subject to change without notice.

## CONNECTING THE CONVERTER AND RESISTIVELY SCALING THE INPUTS

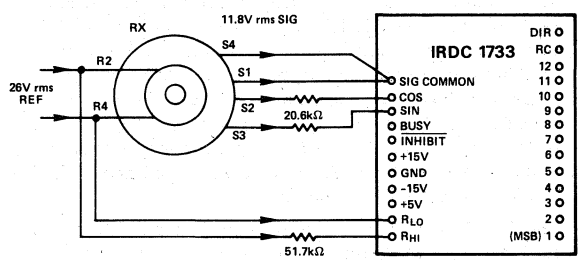
The sine and cosine signal inputs from the resolver or the Inductosyn slider are required to be 2.5V rms at the converter pins (see note 1, on previous page).

The resistive voltage scaling facility enables higher voltages to be interfaced by the simple addition of external scaling series resistors.

In the case of the signal voltages, the resistor value should be 2.22kΩ per extra volt required. The matching of the resistors is more important than the absolute calculated value. A matching of 0.1% between the two resistors will give rise to an additional error of 1.7 arc-minutes or 0.0000787 times the Inductosyn pitch.

The reference input can also be scaled using a resistance of 2.2kΩ per extra volt in the $R_{HI}$ line. The absolute value of this resistor is not critical as long as the voltage appearing on the converter pins is within ±10% of 2.5 volts rms.

An example of resistive scaling is shown below where a resolver with a signal voltage of 11.8 volts rms and a reference voltage of 26 volts rms is being used with the IRDC1730.




*Resistive Scaling of a Resolver to the IRDC1733*

The electrical connections to the converter are straightforward. The power lines, which must not be reversed, are ±15V and +5V. They must be connected to the "±15V" and "+5V" pins with the common connection to GND. It is suggested that 0.1μF and 6.8μF capacitors be placed in parallel from +15V to GND, from -15V to GND and from +5V to GND.

## DYNAMIC ACCURACY VS RESOLVER PHASE SHIFT

Most resolvers, particularly those of the brushless variety, exhibit a phase shift between the signal and the reference. This phase shift will give rise under dynamic conditions to an additional error defined by:

$$\frac{\text{Shaft speed (RPS) X Phase Shift (Degs)}}{\text{Reference Frequency}}$$

For example, for a phase shift of 20°, a shaft rotation of 22 RPS and a reference frequency of 5kHz, the IRDC1730/33 will exhibit an additional error of:

$$\frac{20 \times 22}{5000} = 0.088^\circ$$

This effect can be eliminated by putting a phase lead in the reference to the converter equivalent to the phase shift in the resolver.

## THEORY OF OPERATION

The sine and cosine signals are applied to the signal transformers to produce on the secondary windings the following voltages:

$$V_1 = K\,E_O \sin \omega t \sin \theta$$
$$V_2 = K\,E_O \sin \omega t \cos \theta$$

Where $\theta$ is the angle of the resolver shaft or the distance moved through a particular pitch of the Inductosyn.

To understand the conversion process, then assume that the current word state of the up-down counter is $\phi$.

The $V_1$ is multiplied by Cos $\phi$ and $V_2$ is multiplied by Sin $\phi$ to give:

$$K\,E_O \sin \omega t \sin \theta \cos \phi$$
and $$K\,E_O \sin \omega t \cos \theta \sin \phi$$

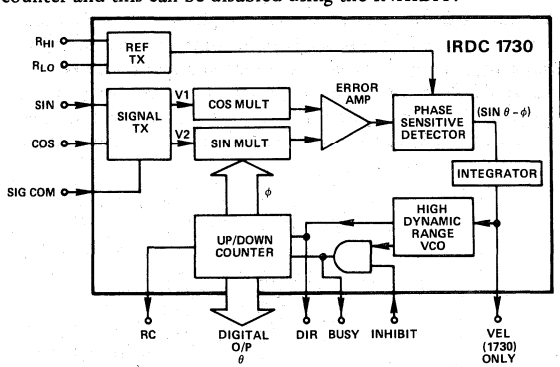
These signals are subtracted by the error amplifier to give:

$$K\,E_O \sin \omega t (\sin \theta \cos \phi - \cos \theta \sin \phi)$$
or $$K\,E_O \sin \omega t \sin (\theta - \phi)$$

A phase sensitive detector, integrator and Voltage Controlled Oscillator (VCO) form a closed loop system which seeks to null Sin $(\theta - \phi)$.

When this is accomplished, the word state of the up-down counter ($\phi$), equals within the rated accuracy of the converter, the resolver shaft angle $\theta$.

The Ripple Clock output (RC) is provided from the most significant end of the counter while the direction output (DIR) is taken from the steering logic input to the counter. The BUSY output is derived from the clock used to drive the counter and this can be disabled using the INHIBIT.

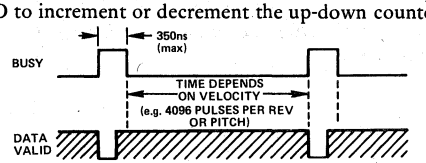



*Schematic Diagram of the IRDC1730/33*

## DATA TRANSFER

The readiness of the converter for data transfer is indicated by the state of the BUSY pin, (see diagram).

The voltage appearing on the BUSY pin consists of a train of pulses, at TTL levels, when the input to the converter is changing. The converter is busy when the BUSY pin is at a TTL "Hi" level. These pulses correspond to those delivered by the VCO to increment or decrement the up-down counter (see




*Data Transfer Diagram (See Also Timing Diagram)*

schematic diagram). Thus the pulses will occur for increasing and decreasing counts.

The most suitable time for transferring data is at or following the negative going transition of BUSY.

Taking the $\overline{\text{INHIBIT}}$ to a logic "Lo" state prevents the VCO (BUSY) pulses from updating the up-down counter. However, if applied during a BUSY pulse, the $\overline{\text{INHIBIT}}$ will not become effective until the end of the BUSY pulse.

An alternative method of transferring the data is by applying the $\overline{\text{INHIBIT}}$ (taking it to a logic "Lo" state), waiting for at least the width of a BUSY pulse, transferring the data and releasing the $\overline{\text{INHIBIT}}$.

Note that sustained application of the $\overline{\text{INHIBIT}}$ opens the internal control loop and the converter may take an appreciable time to recover to full accuracy when the loop is restored.

**USE OF THE IRDC1730 IN A RESOLVER MACHINE TOOL APPLICATION**

In many machine tool applications, a resolver is fitted to the axis lead screw in order to provide a method of measuring linear displacement. The IRDC being a tracking converter with no drift or stale data problems and having a very high maximum tracking rate (over 10,000 rpm in the case of the 5 and 10kHz versions) forms an ideal method of converting the output of the resolver into digital format for use by the controller. The diagram below shows how the resolver may be used in this type of application as well as a method of using external counters to count the number of revolutions of the lead screw and so give an absolute digital representation of the machine axis position.

Note that unlike the phase measuring resolver to digital conversion techniques which require the resolver to be supplied with a very accurate sine and cosine waveform, this method requires that the resolver rotor is energized and the sine and cosine outputs from the stator taken to the converter. *The advantage of this method is that the converter's ratiometric operation does not require a particularly stable voltage or frequency reference to be applied to the resolver rotor.* In addition, any small drops in voltage between the resolver and the converter or any noise induced in the signal lead, will not substantially affect the accuracy.

The "Set Datum" microswitch shown on the end of the lead screw and the associated circuitry is used to zero the counters when the axis movement is at the end of the lead screw. As long as the microswitch operates within a pitch, the datum can then be set electronically.

**USE OF THE IRDC1730 WITH AN INDUCTOSYN FOR MEASURING LINEAR OR ROTARY DISPLACEMENT**

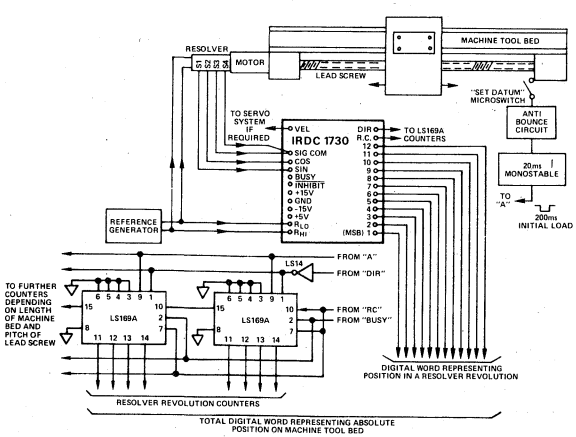
The IRDC1730 can be used very effectively with an Inductosyn to provide a very accurate linear or rotary measurement system. Inductosyns are normally of 2mm pitch and therefore the resolution obtainable will be in excess 0.5 microns. The use of the IRDC1730 in, for example, a machine axis control system is shown in the diagram below.

The Inductosyn gives signals similar to a resolver but with two important differences. The output signals from the slider are very small and need preamplification before being applied to the converter.

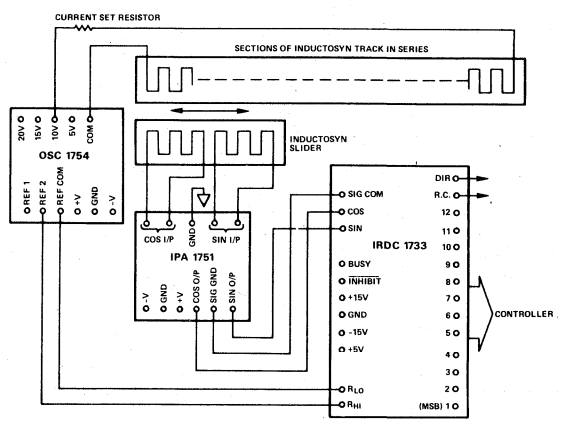
These signals are also advanced in electrical phase by 90° with respect to the current flowing in the Inductosyn track. The simplest way of correcting this is to drive a reference input to the converter which is also shifted in phase by 90°. This is performed internally in the OSC 1754 drive oscillator.

The amplifiers which are necessary between slider and converter need to have equal gains in order to amplify the signals to the 2.5 volts rms required by the converter. (A gain ratio of 1.002 will give rise to an inaccuracy of 1/6000 of a pitch). A typical voltage which might be available at the input to the amplifier is 2mV. The amplifiers should be connected as close to the slider as possible with the longer connecting leads being at the high voltage level. The low output impedance of the amplifiers will then drive the cable.

The "Set Datum" circuitry shown in the diagram is identical to that used for the resolver application, the only provision being that the microswitch always operates within the same pitch of the Inductosyn.



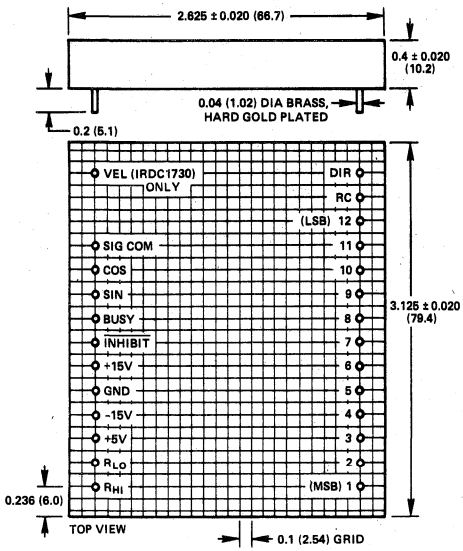

*Using the IRDC1730 with a Resolver on a Machine Tool Axis*




*Use of IRDC1733 with Inductosyn Pre-Amplifier IPA1751 and Power Oscillator OSC1754*

## CONVERTER OUTLINE DIMENSIONS AND PIN CONNECTION DIAGRAM

Dimensions shown in inches and (mm).



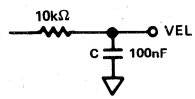

Individual Mating Sockets: Cambion 450-3388-03-01

## BIT WEIGHT TABLE

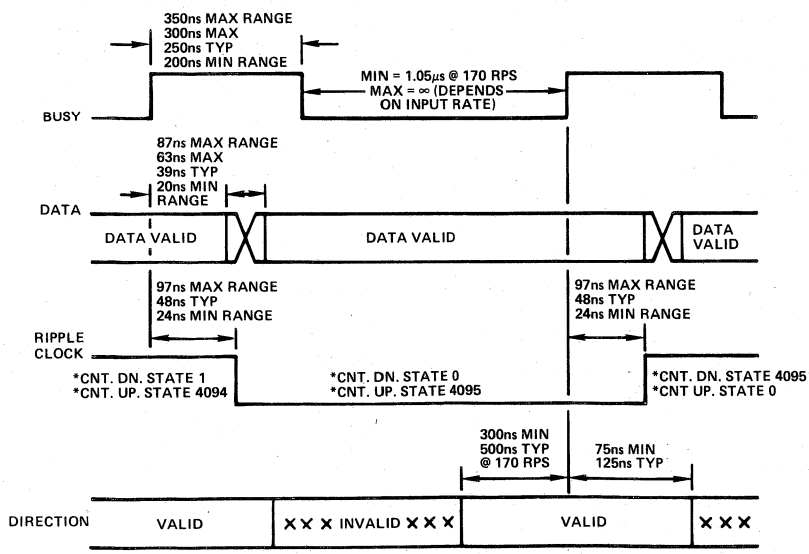
| Bit Number | Weight in Degrees |
|---|---|
| 1 (MSB) | 180.0000 |
| 2 | 90.0000 |
| 3 | 45.0000 |
| 4 | 22.5000 |
| 5 | 11.2500 |
| 6 | 5.6250 |
| 7 | 2.8125 |
| 8 | 1.4063 |
| 9 | 0.7031 |
| 10 | 0.3516 |
| 11 | 0.1758 |
| 12 (LSB) | 0.0879 |

## VELOCITY OUTPUT FILTER

The velocity output of the IRDC1730 is internally filtered as shown below.




## TIMING DIAGRAM

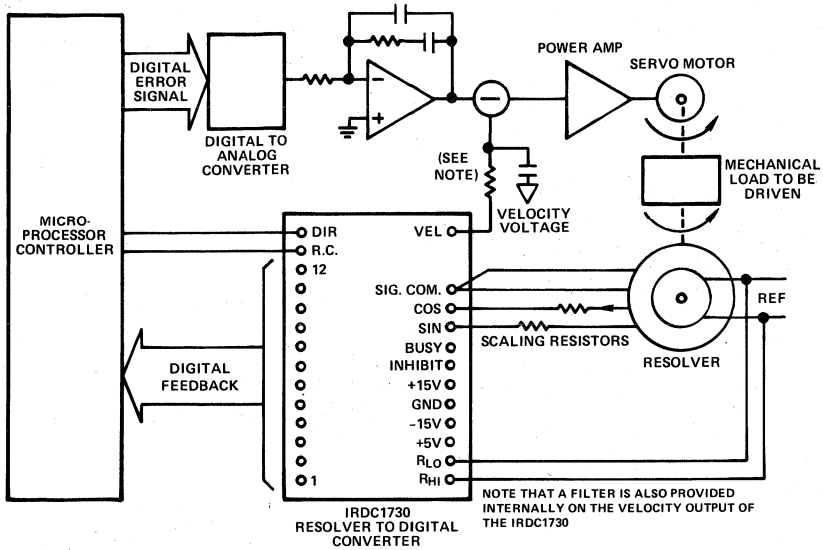



*CNT DN. SHOWS STATE OF DATA OUTPUT WHEN COUNTING DOWN.
*CNT. UP. SHOWS STATE OF DATA OUTPUT WHEN COUNTING UP.

13

## USE OF THE IRDC1730 VELOCITY OUTPUT VOLTAGE

The diagram below shows the use of the velocity output voltage of the IRDC1730 in a servo system.




*Practical control using the IRDC1730 as a virtual tachometer*

## TRANSFER FUNCTIONS

The transfer functions of the various options of the IRDC1730 is as shown below.

**400Hz Options**

$$\frac{\theta_0}{\theta_1} = \frac{4.815 \times 10^5 s + 9.331 \times 10^7}{s^3 + 1.055 \times 10^3 s^2 + 4.815 \times 10^5 s + 9.331 \times 10^7}$$

**2.6kHz Options**

$$\frac{\theta_0}{\theta_1} = \frac{2.745 \times 10^6 s + 1.935 \times 10^9}{s^3 + 4.125 \times 10^3 s^2 + 2.745 \times 10^6 s + 1.935 \times 10^9}$$

**5kHz and 10kHz Options**

$$\frac{\theta_0}{\theta_1} = \frac{5.909 \times 10^6 s + 3.908 \times 10^9}{s^3 + 3.85 \times 10^3 s^2 + 5.909 \times 10^6 s + 3.908 \times 10^9}$$

## OTHER PRODUCTS

In addition to the IRDC1730/33, we also manufacture a very comprehensive range of products which are concerned with the conversion of synchro and resolver information into digital format.

Of particular note is the IRDC1731 which accepts similar inputs to the IRDC1730 but provides a 4000 count serial output. Also we manufacture:

IPA1751 Inductosyn pre-amplifier
OSC1754 Inductosyn/resolver power oscillator
SDC1740/41/42 14- and 12-bit hybrid synchro/resolver-to-digital converters with *internal transformers.*
SDC1702, 1700 and 1704 10-, 12- and 14-bit synchro/resolver-to-digital converters.
SDC1725 and 1726 12- and 10-bit synchro/resolver-to-digital converters with latched three-state outputs.
SDC1721 16-bit synchro/resolver-to-digital converter.
DTM1716 and 1717 digital vector generators.
DSC1705 and 1706 14- and 12-bit digital-to-synchro/resolver converters with low radius vector variation.
API1620 angle position indicator.

## ORDERING INFORMATION

The IRDC1730 part number is suffixed with an X and a Y code to denote operating temperature range and reference frequency as follows. (Note that the Z code used in our other products to denote voltage is left as a zero in this product).

IRDC1730/XY0
IRDC1733/XY0

Y = 1 400Hz
Y = 4 2.6kHz
Y = 5 5kHz
Y = 6 10kHz

X = 5 0°C to +70°C
X = 6 −55°C to +105°C

## ABSOLUTE MAXIMUM INPUTS

| | |
|---|---|
| $R_{HI}$ to $R_{LO}$ | ±5V rms |
| Sin/Cos to Signal Common | ±5V rms |
| +15V Pin | +17V |
| −15V Pin | −17V |
| +5V Pin | −0.4V to 7V |
| Any Logic Inputs | −0.4V to +5.5V |

All dc voltages are with respect to GND pin.

Note:
No damage will result by allowing the signal and reference voltages to be applied without the dc power supplies present.

# 4000 Count, Tracking Inductosyn™/ Resolver-to-Digital Converter

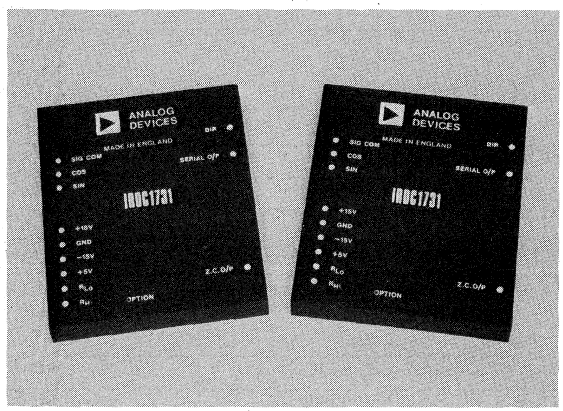
# IRDC1731

**FEATURES**

- Works on Amplitude Measurement Technique
- Can Be Used with Inductosyns or Resolvers
- 4000 Count Serial Output per Revolution or Pitch
- Transformer Isolated Inputs
- 100 revs/sec (pitches/sec) Tracking Rate
- Resistive Scaling Facility Accommodates Most Signal Levels
- Direction Output
- Zero Crossing Output (Pitch or Revolution Counter)
- No External Trims or Adjustments
- Low Profile 0.4″ (10.2mm)

**APPLICATIONS**

- Digital Display of Inductosyn or Resolver Information in Robotics or Machine Tool Axis Measurement




## GENERAL DESCRIPTION

The IRDC1731 converts resolver format (sine and cosine) signals into a 4000 count serial output. The unit accepts inputs from either a resolver, in which case the 4000 counts represent 1 revolution of the shaft or from an Inductosyn slider via external pre-amps in which case the 4000 counts represent a distance corresponding to 1 pitch of the Inductosyn track.

The converter is of the continuous tracking type working on a type 2 servo loop principle and operates for input rates of up to 100 revolutions per second in the case of the resolver and 100 pitches per second in the case of the Inductosyn. *The continuous tracking principle gives the advantages of zero drift and instantly available, nonstale data.*

The converter operates on a 5kHz reference frequency and the inputs, which are transformer isolated, are accepted as 2.5 volts rms max.

*An outstanding feature of the converter is that even though the signal and reference inputs are transformer isolated, they can be externally resistively scaled to accommodate the user's particular voltage levels.*

A further advantage of the IRDC1731 is that it works on a ratiometric, amplitude comparison principle and therefore any voltage drops between the resolver or the Inductosyn and the converter does not substantially affect the accuracy. The amplitude measurement technique also ensures a high degree of immunity to noise which may exist on the signal input lines.

In addition to the serial output, a direction signal is provided as well as a Zero Crossing signal which gives a pulse every time the resolver input passes through the zero position or the Inductosyn slider moves to an adjacent pitch.

The IRDC1731 is housed in a 0.4″ (10.2mm) low profile module and weights only 3.5 ozs. (100 G).

## MODELS AVAILABLE

Two models of the IRDC1731 are available, viz:

Model IRDC1731550 which operates over a 0 to +70°C temperature range. (Commercial temperature option).

Model IRDC1731650 which operates over a -55°C to +105°C temperature range. (Extended temperature option).

13

Inductosyn is a registered trademark of Farrand Industries, Inc.

# SPECIFICATIONS (typical @ +25°C unless otherwise stated)

| Model | IRDC1731 |
|---|---|
| ACCURACY[1] | ±2 counts (static input)<br>±3 counts (50 pitches or revs/sec input)<br>±4 counts (100 pitches or revs/sec input) |
| RESOLUTION | 4000 counts equals one revolution of resolver or one pitch of the Inductosyn |
| DIGITAL OUTPUT | Serial, negative going pulses, width 1.0 ±0.5μs<br>4 TTL loads – commercial temperature options<br>2 TTL loads – extended temperature options |
| SIGNAL AND REFERENCE FREQUENCY | 5kHz |
| SIGNAL INPUT VOLTAGE[1] | 2.5 volts rms |
| SIGNAL INPUT IMPEDANCE | 5.6kΩ |
| REFERENCE INPUT VOLTAGE[1] | 2.5 volts rms |
| REFERENCE INPUT IMPEDANCE | 5.6kΩ |
| PHASE SHIFT (Signal to Reference) (See 'Dynamic Accuracy vs. Resolver Phase Shift') | ±20° will give no additional error with a static input |
| TRANSFORMER ISOLATION | 500 volts dc |
| TRACKING RATE (Minimum) | 100revs/sec (Resolver input)<br>100 pitches/sec (Inductosyn input) |
| STEP RESPONSE (179° Step) | 80ms max for ±1 count additional error |
| ACCELERATION<br>Constant $K_a$ | <br>650,000/sec[2] |
| DIRECTION OUTPUT (DIR) | Logic "Lo" when counting up. Logic "Hi" when counting down. Direction output level changes at least 0.25μs before serial output pulse.<br>4 TTL loads – commercial temperature options<br>2 TTL loads – extended temperature options |
| ZERO CROSSING OUTPUT (Z.C. O/P) | Positive going pulse, 1.0 ±0.5μs in width produced when resolver input passes through zero position or Inductosyn slider moves to adjacent pitch.<br>4 TTL loads – commercial temperature options<br>2 TTL loads – extended temperature options |
| POWER SUPPLIES[1] | +15V dc @ 35mA max<br>-15V dc @ 35mA max<br>+5V dc @ 170mA max |
| POWER DISSIPATION | 1.90 watts max |
| OPERATING TEMPERATURE RANGE<br>Commercial<br>Extended | <br>0 to +70°C<br>-55°C to +105°C |
| STORAGE TEMPERATURE RANGE | -55°C to +125°C |
| DIMENSIONS | 2.625" X 3.125" X 0.4"<br>(66.7mm X 79.4mm X 10.2mm) |
| WEIGHT | 3.5 ozs. (100 G) |

NOTES

[1] Accuracy applies over the appropriate operating temperature range and:
(a) ±10% signal and reference voltage amplitude variation.
(b) ±10% signal and reference harmonic distortion.
(c) ±10% variation in reference frequency.
(d) ±5% power supply variation.

Specifications subject to change without notice.

## OPERATION OF THE CONVERTER

The IRDC1731 is a tracking converter meaning that the output automatically follows the input up to a rate of 100 revs. or pitches per second without the need for any convert command signal. 4000 negative going pulses are output for each full revolution or pitch and a TTL direction output (DIR) indicates the direction of motion.

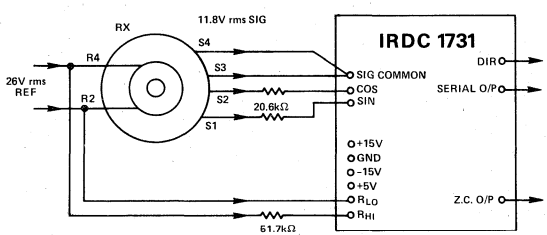
## CONNECTING THE CONVERTER AND RESISTIVELY SCALING THE INPUTS

The sine and cosine signal inputs from the resolver or Inductosyn and the reference input are required to be 2.5 volts rms. The voltage scaling facility enables higher voltages to be interfaced by the simple addition of external series scaling resistors.

In the case of the signal voltages, the resistors should be 2.22kΩ per extra volt required. The matching of the resistors is more important than the absolute calculated value. A matching of 0.1% between the two resistors will give rise to an additional error of ±0.31 counts.

The reference input can be scaled resistively also using a resistance of 2.2kΩ per extra volt in the $R_{HI}$ line. The absolute accuracy of this resistor value is not critical as long as the voltage appearing on the converter pins is within the tolerance specified for the 2.5 volt rms reference input.

An example of resistive scaling is shown below where a resolver with a signal voltage of 11.8 volts rms and a reference voltage of 26 volts rms is being used with the IRDC1731.




The electrical connections to the converter are straightforward. The power lines, which must not be reversed, are ±15V and +5V. They must be connected to the "±15V" and "+5V" pins with the common connection to the ground pin GND.

It is suggested that 0.1μF and 6.8μF capacitors be placed in parallel from +15V to GND, from -15V to GND and from +5V to GND.

## USE OF THE IRDC1731 IN A RESOLVER MACHINE TOOL APPLICATION

In many machine tool applications, a resolver is fitted to the axis lead screw in order to provide a method of measuring linear displacement. The IRDC1731, being a tracking converter and having no drift or stale data problems, forms an ideal method of converting the output of the resolver into digital format, either for use by a processor or for a visual digital readout of axis position. The diagram shows how a resolver may be used in this type of application with the

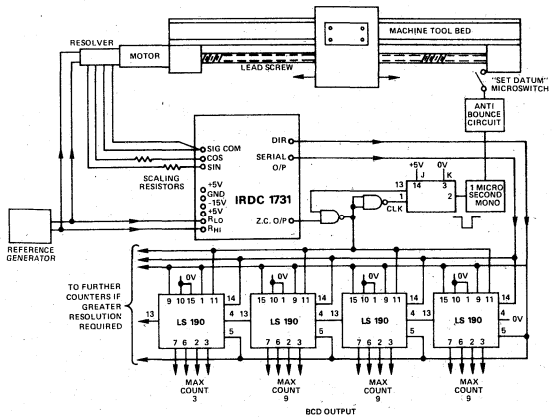



*Figure 1. Diagram Showing IRDC1731 Used with a Resolver in a Machine Tool Axis Measurement System*

IRDC1731 and external counters to provide a BCD (Binary Coded Decimal) indication of axis position.

In the diagram shown, the number of counters will be sufficient to register the 4000 counts produced by one revolution of the resolver. This means that the counter output will represent a distance equivalent to one pitch of the lead screw (normally 2, 5 or 10 millimeters). In order to provide a readout of the absolute position on the lead screw, more counters can be added as indicated in the diagram.

The "Set Datum" microswitch shown on the end of the lead screw and the associated circuitry is used to zero the counters when the axis movement is at the end of the lead screw. Once the microswitch has been activated, the counters will be reset to zero by the next zero crossing pulse (Z.C. O/P) and the counting will commence. This method gives the advantage that the lead screw zero datum can be accurately set to within one count while the microswitch is only required to operate within one revolution of the lead screw.

## DYNAMIC ACCURACY VS. RESOLVER PHASE SHIFT

Most resolvers, particularly those of the brushless variety, exhibit a phase shift between the signal and the reference. This phase shift will give rise under dynamic conditions to an additional error defined by:

$$\frac{\text{Shaft Speed (R.P.S.)} \times \text{Phase Shift (Deg)}}{\text{Reference Frequency}}$$

For example, for a phase shift of 20°, a shaft rotation of 22 revs. per second and a reference frequency of 5kHz, the IRDC1731 will exhibit an additional error of:

$$\frac{20 \times 22}{5000} = 0.088^\circ = 0.98 \text{ counts}$$

This effect can be eliminated by putting a phase lead in the reference to the converter equivalent to the phase shift in the resolver.

13

## USE OF THE IRDC1731 WITH AN INDUCTOSYN FOR MEASURING LINEAR DISPLACEMENT

The IRDC1731 can be used very effectively with an Inductosyn to provide a very accurate linear displacement measurement system. Inductosyns are normally of 2mm pitch and, therefore, the resolution obtainable will be 0.0005mm or 0.5 microns.

The diagram indicates the method of converting the Inductosyn output into digital format.

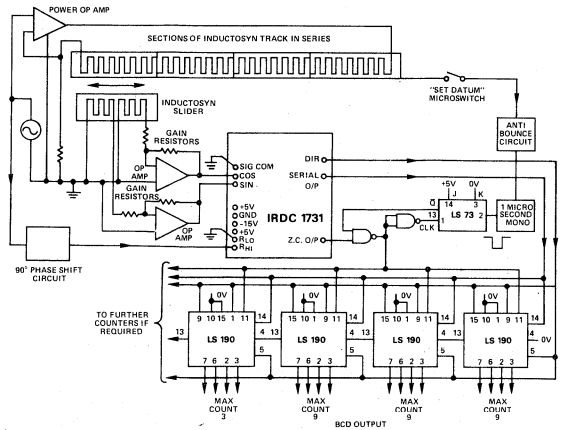



*Figure 2. An Inductosyn Used with the IRDC1731 and External Counters*

The Inductosyn in this case is made to behave like a resolver. The fixed track is driven from an ac current generator at a frequency of 5kHz, and the resolver format sine and cosine signals are available from the slider. The reason for using a current source is that the track is mainly resistive and it is better to determine the phase by deliberately driving the track from a current source and inserting a 90 degree phase advance into the reference rather than having a less accurately defined phase shift due to the track's X to R ratio.

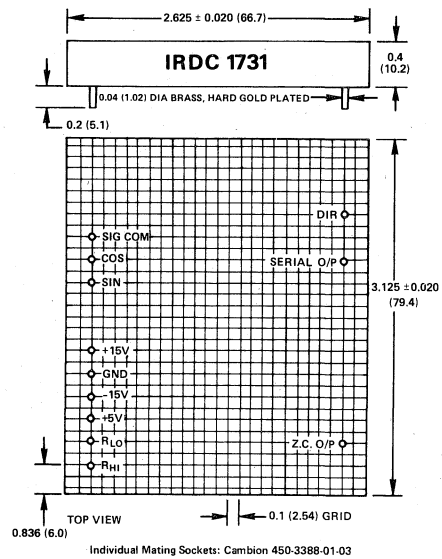
The amplifiers which are necessary between slider and converter need to have equal gains in order to amplify the signals to the 2.5 volts rms required by the converter. (A gain ratio of 1.002 will give rise to an inaccuracy of 1/6000 of a pitch.) A typical voltage which might be available at the input to the input to the amplifiers is 3mV. The amplifiers should be connected as close to the slider as possible with the longer connecting leads being at the high voltage level. The low output impedance of the amplifiers will then drive the cable.

Further information on interfacing the IRDC1731 to Inductosyns is available from the factory.

The "Set Datum" circuitry shown in the diagram is identical to that used for the resolver application, the only provision being that the microswitch always operates within the same pitch of the Inductosyn.

## OUTLINE DIMENSIONS

Dimensions shown in inches and (mm).




Individual Mating Sockets: Cambion 450-3388-01-03

## ORDERING INFORMATION

Order IRDC1731550 for operation over temperature range of 0 to +70°C. (Commercial)

Order IRDC1731650 for operation over temperature range of −55°C to +105°C. (Extended)

## OTHER PRODUCTS

In addition to the IRDC1731, we also manufacture a very comprehensive range of products which are concerned with the conversion of synchro and resolver information into digital format.

Of particular note is the IRDC1730 which accepts similar inputs to the IRDC1731 but provides a parallel 12-bit digital representation of the input as well as a direction and Zero crossing output. In addition a dc voltage is provided which represents input velocity.

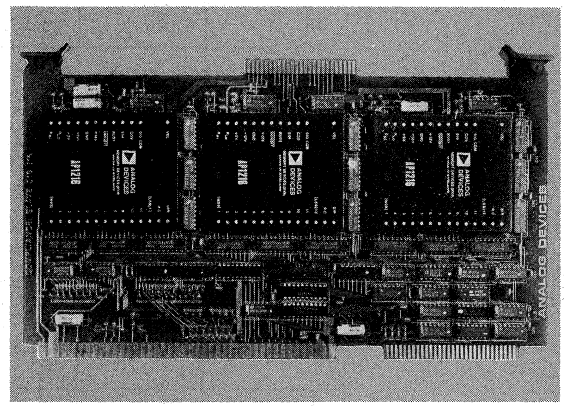
# ANALOG DEVICES

# MULTIBUS™ Compatible Multi-Channel Interface

# MCI 1794

**FEATURES**

- **Complete Three-Channel Tracking Inductosyn™/ Resolver-to-Digital Converter**
- **12-Bit Angular Resolution**
- **12-Bit Pitch Counter**
- **I/O or Memory Mapped**
- **Compatible with Both 8- and 16-Bit MULTIBUS Processors**
- **Three Independent Channels**
- **Tracking Rates up to 170rpm (10,200rpm)**
- **Powered from the Standard MULTIBUS Supplies**



## GENERAL DESCRIPTION

The MCI1794 is a complete three–channel tracking Inductosyn or resolver-to-digital converter. Each channel converts an input angle into a 12-bit binary data and also contains an independent 12-bit pitch counter for multiturn applications.

The MCI1794 compliance is: Slave D16, I16.

The MCI1794 greatly simplifies the task of interfacing Inductosyns or resolvers with Intel 8080/85/86 based microprocessors and is particularly useful in numerically and computer controlled machines.

The MCI1794 is provided with wire-wrap links which preset the port address (Table I).

The user can change the links to suit both the required addresses and the master data bus requirements.

## 8- AND 16-BIT MULTIBUS COMPATIBILITY

The resolver board is capable of operating on both 8-bit and 16-bit buses. Read and write operations to and from the resolver board are accomplished through seven on-board I/O ports. Ports 0 to 5 are concerned with reading the shaft angle and pitch. Port 6 is used to reset the read signal logic.

The shaft angle and its pitch are represented by two 12-bit words. Each of the 3 axis resolvers has one 16-bit and one 8-bit port. The word structure of each of the six resolver ports is given in Table I. The shaft pitch is obained from a 12-bit counter which is clocked each time the shaft rotates through 360°. The pitch counters of each axis can be cleared independently by performing an I/O write to either of the two port addresses for the axis concerned.

**Inductosyn is a registered trademark of Farrand Industries, Inc.**
**MULTIBUS is a registered trademark of Intel Corporation.**

## DATA ACQUISITION

To allow maximum flexibility the resolver board has been designed to work in both 8-bit and 16-bit bus systems.

Each resolver has a unique I/O board address which is set by connecting the BOARD SELECT pin (T57) to one of the outputs of the board select decoders, BSO-BS15 (Table II). A total of 16 boards can be connected to the same computer bus. The position of the board select address in the I/O address field is set by connecting 104 (LSB), 105, 106 and 107 (MSB) to the appropriate address pins Z58-Z44 (ADRI-ADRF). A further three address lines are decoded to select which on-board port is to be accessed. The position of the on-board port select lines in the I/O field is determined by connecting 100, 101 and 102 to the appropriate address pins. It is usual to have the on-board port address below the board select address.

The board is normally fitted with three IRDC1730/33 converters. For complete information regarding these parts ask for the separate data sheet.

13

The remaining address line, i.e., those which have not been decoded, should be connected to connector pins T16 through T26, with any spare connector pins between T16 and T26 being connected to T6 (Logical 1).

## ANALOG INPUT SIGNALS

The analog inputs are connected via a 50-pin connector, J. The pin designation of this connector is given in Table III and should be read in conjunction with the IRDC1730 data sheet.

| Port Address (Hex) | Channel No. | Data M.S. 4 Bits | Data L.S. 4 Bits | Port No. |
|---|---|---|---|---|
| 48 | Channel 1 | Pitch M.S. 8 Bits | | 0 |
| 4B | Channel 1 | Pitch L.S.P. | Angle M.S.P. | 1 |
| 4A | Channel 1 | Angle L.S. 8 Bits | | 1 |
| 44 | Channel 2 | Pitch M.S. 8 Bits | | 2 |
| 47 | Channel 2 | Pitch L.S.P. | Angle M.S.P. | 3 |
| 46 | Channel 2 | Angle L.S. 8 Bits | | 3 |
| 40 | Channel 3 | Pitch M.S. 8 Bits | | 4 |
| 43 | Channel 3 | Pitch L.S.P. | Angle M.S.P. | 5 |
| 42 | Channel 3 | Angle M.S. 8 Bits | | 5 |
| 4C | Clear | Not Applicable | | 6 |

*Table I. MCI1794 Port Designation (as Supplied): 8-Bit Data Bus*

| MSB Port Address (Hex) | BS No. Connected to T57 |
|---|---|
| 0 | 0 |
| 1 | 4 |
| 2 | 2 |
| 3 | 6 |
| 4* | 1* |
| 5 | 5 |
| 6 | 3 |
| 7 | 7 |
| 8 | 8 |
| 9 | 9 |
| A | 10 |
| B | 11 |
| C | 12 |
| D | 13 |
| E | 14 |
| F | 15 |

*N.B. This address is pre-wired.

*Table II. Post Address Significance When T57 (Board Select) is Connected to a BS Terminal*

| J2–J50 | | All GND |
|---|---|---|
| J1 | Channel 1 | Velocity Output |
| J3 | Channel 1 | Signal Common |
| J5 | Channel 1 | Cosine Input |
| J7 | Channel 1 | Sine Input |
| J9 | Channel 1 | GND |
| J13 | Channel 1 | $R_{LO}$ Input |
| J15 | Channel 1 | $R_{HI}$ Input |
| J17 | Channel 2 | Velocity Output |
| J19 | Channel 2 | Signal Common |
| J21 | Channel 2 | Cosine Input |
| J23 | Channel 2 | Sine Input |
| J29 | Channel 2 | $R_{LO}$ Input |
| J31 | Channel 2 | $R_{HI}$ Input |
| J33 | Channel 3 | Velocity Output |
| J35 | Channel 3 | Signal Common |
| J37 | Channel 3 | Cosine Input |
| J39 | Channel 3 | Sine Input |
| J45 | Channel 3 | $R_{LO}$ Input |
| J47 | Channel 3 | $R_{HI}$ Input |

*Table III. J Connector Pin Designation*

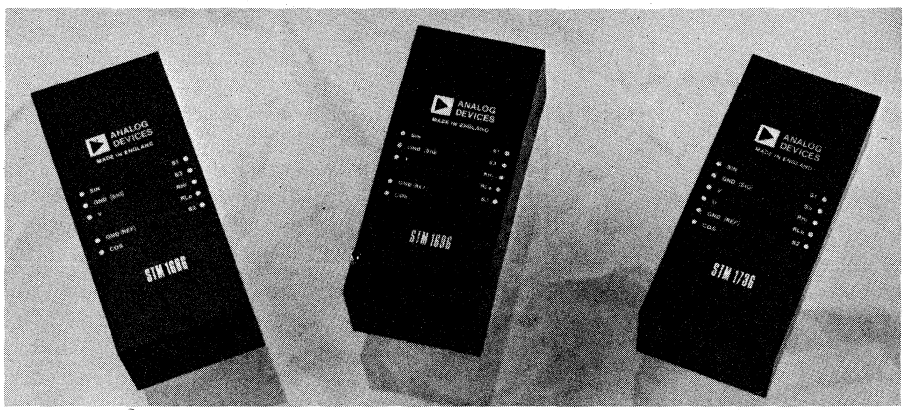
## ORDERING INFORMATION

The Y of the suffix specifies the frequency option of the IRDC1730 converters.

MCI1794/5Y0

- Y = 1 400Hz
- Y = 4 2.6kHz
- Y = 5 5kHz
- Y = 6 10kHz

# RTM/STM 1686/1696/1736/1687/1697/1737




## RTM/STM 1686

**SPECIFICATIONS** (typical @ +25°C unless otherwise noted)

| | |
|---|---|
| ACCURACY[1] (after balancing) | ±2.4 arc minutes |
| OPERATING FREQUENCY | 400Hz |
| LOAD CAPABILITY | 5VA |
| OPERATING TEMPERATURE | -55°C to +105°C |
| STORAGE TEMPERATURE | -55°C to +125°C |
| VOLTAGE ISOLATION | 500V dc |
| WEIGHT | 21 ounces (580G) |

NOTES

[1] Accuracy applies over the full operating temperature range of the option and for:

(a) ±10% reference frequency and amplitude variation.
(b) 10% harmonic distortion on the reference.
(c) Any balanced load from no load to full load.

Specifications subject to change without notice.

### APPLICATION OF THE RTM/STM1686

The RTM/STM1686 should be used in conjunction with the DTM1716 or the DTM1717 Digital Vector Generator and the SPA1695 Power Amplifier.

### ORDERING INFORMATION

| Part Number | Operating Temp. Range | Line-to-Line Output Voltage and Format | Reference Voltage | Reference Frequency |
|---|---|---|---|---|
| STM1686611 | -55°C to +105°C | 11.8V Synchro | 26V | 400Hz |
| STM1686612 | -55°C to +105°C | 90.0V Synchro | 115V | 400Hz |
| RTM1686618 | -55°C to +105°C | 11.8V Resolver | 26V | 400Hz |

Note: For options not shown above, consult the factory.

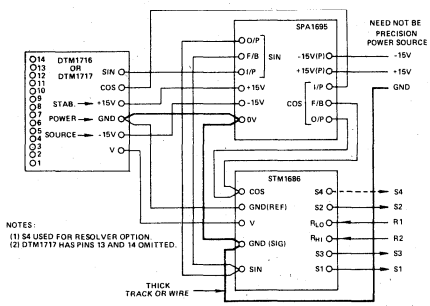
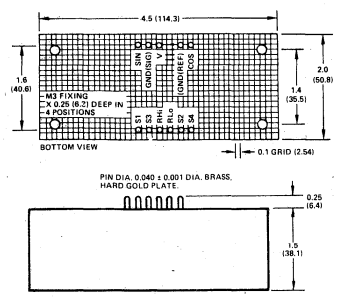



*Figure 1. Diagram Showing Connection of the STM1686 to a DTM1716 or DTM1717 and SPA1695 (See Notes)*

### RTM/STM1686 OUTLINE DIMENSIONS AND PIN CONNECTION DIAGRAM

Dimensions shown in inches and (mm).




13

# RTM/STM 1696

**SPECIFICATIONS** (typical @ +25°C unless otherwise noted)

| | |
|---|---|
| ACCURACY[1] (after balancing) | ±2.4 arc minutes |
| OPERATING FREQUENCY | 400Hz |
| LOAD CAPABILITY | 5VA |
| OPERATING TEMPERATURE | -55°C to +105°C |
| STORAGE TEMPERATURE | -55°C to +125°C |
| VOLTAGE ISOLATION | 500V dc |
| WEIGHT | 22 ounces (620G) |

NOTE:
[1] See STM1686 note 1.
Specifications subject to change without notice.

### APPLICATION OF THE RTM/STM1696

The RTM/STM1696 should be used in conjunction with the DSC1705 or DSC1706 Digital-to-Synchro (or Resolver) Converter and the SPA1695 Power Amplifier.

### ORDERING INFORMATION

| Part Number | Operating Temp. Range | Line-to-Line Output Voltage and Format | Reference Voltage | Reference Frequency |
|---|---|---|---|---|
| STM1696611 | -55°C to +105°C | 11.8V Synchro | 26V | 400Hz |
| STM1696612 | -55°C to +105°C | 90.0V Synchro | 115V | 400Hz |
| RTM1696618 | -55°C to +105°C | 11.8V Resolver | 26V | 400Hz |

Note: For options not shown above, consult the factory.

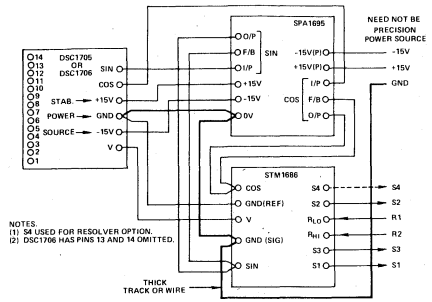
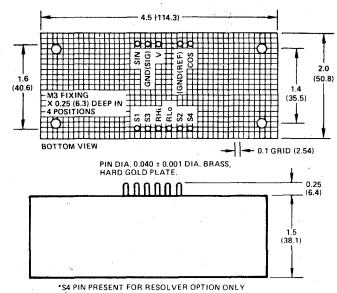



*Figure 2. Diagram Showing Connection of the STM1696 to a DSC1705 or DSC1706 and SPA1695 (See Notes)*

### RTM/STM1686 OUTLINE DIMENSIONS AND PIN CONNECTION DIAGRAM

Dimensions shown in inches and (mm).




# RTM/STM 1736

**SPECIFICATIONS** (typical @ +25°C unless otherwise noted)

| | |
|---|---|
| ACCURACY[1] (after balancing) | ±2.4 arc minutes |
| OPERATING FREQUENCY | 400Hz |
| LOAD CAPABILITY | 5VA |
| OPERATING TEMPERATURE | -55°C to +105°C |
| STORAGE TEMPERATURE | -55°C to +125°C |
| VOLTAGE ISOLATION | 500V dc |
| WEIGHT | 19 ounces (540G) |

Note:
[1] See STM1686 note 1.
Specifications subject to change without notice.

### APPLICATIONS OF THE RTM/STM1736

The RTM/STM1736 should be used in conjunction with the DSC1605 or the DSC1606 Digital-to-Synchro Converter and the SPA1695 Power Amplifier.

### ORDERING INFORMATION

| Part Number | Operating Temp. Range | Line-to-Line Output Voltage and Format | Reference Voltage | Reference Frequency |
|---|---|---|---|---|
| STM1736611 | -55°C to +105°C | 11.8V Synchro | 26V | 400Hz |
| STM1736612 | -55°C to +105°C | 90.0V Synchro | 115V | 400Hz |
| RTM1736613 | -55°C to +105°C | 11.8V Resolver | 11.8V | 400Hz |
| RTM1736614 | -55°C to +105°C | 26V Resolver | 26V | 400Hz |
| RTM1736618 | -55°C to +105°C | 11.8V Resolver | 26V | 400Hz |

Note: For options not shown above, consult the factory.

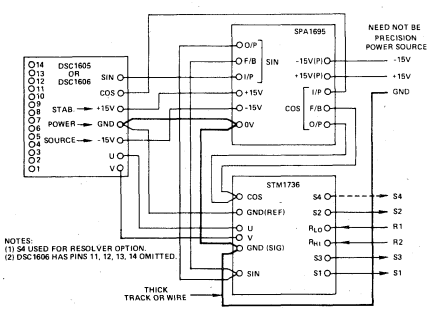
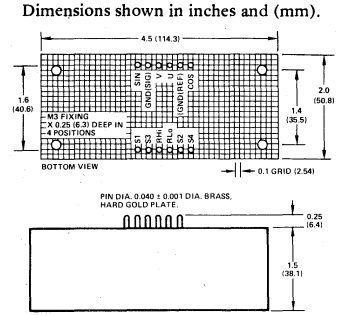



*Figure 3. Diagram Showing Connection of the STM1736 to a DSC1605 or DSC1606 and SPA1695 (See Notes)*

### RTM/STM1736 OUTLINE DIMENSIONS AND PIN CONNECTION DIAGRAM

Dimensions shown in inches and (mm).




### NOTES FOR FIGURES 1, 2, AND 3:

1. The "Sin F/B" and the "Cos F/B" pins of the SPA1695 should be connected directly of the "Sin" and "Cos" terminals on the output transformer *at the transformer.* This is to compensate for any drop in voltage along the connections between the "Sin O/P" and "Cos O/P" pins of the amplifier and the transformer.

2. The "+15V" and "–15V" pins of the SPA1695 should be connected to a regulated power supply in order to drive the internal operational amplifiers. The "+15V(P)" and "–15V(P)" are used for the output stage and these supplies need not be a precision source, the range of voltage when considering all tolerances including ripple, should be between 14.75 and 20 volts.
3. The part of the 0 volt system local to the amplifier and converter should be tapped from the "GND(SIG)" pin on the transformer and should not interconnect with any other part of the 0 volt system by any other method (see above diagram).

# STM 1687

**SPECIFICATIONS** (typical @ +25°C unless otherwise noted)

| | |
|---|---|
| ACCURACY[1] (after balancing) | ±2.4 arc minutes |
| OPERATING FREQUENCY | 60Hz |
| LOAD CAPABILITY | 5VA |
| OPERATING TEMPERATURE | -55°C to +105°C |
| STORAGE TEMPERATURE | -55°C to +125°C |
| VOLTAGE ISOLATION | 500V dc |
| WEIGHT | 3 lbs (1.34kg) |

Note:
[1] See STM1686 note 1.
Specifications subject to change without notice.

**APPLICATION OF THE STM1687**
The STM1687 should be used in conjunction with the DTM1716 or the DTM1717 Digital Vector Generator and the SPA1695 Power Amplifier.

**DIMENSIONS AND CONNECTIONS**
The STM1687 consists of a kit of two D3953 transformers and one A10163 transformer. These should be connected as shown in Figure 4.

The dimensions are given in Figures 7 and 8.

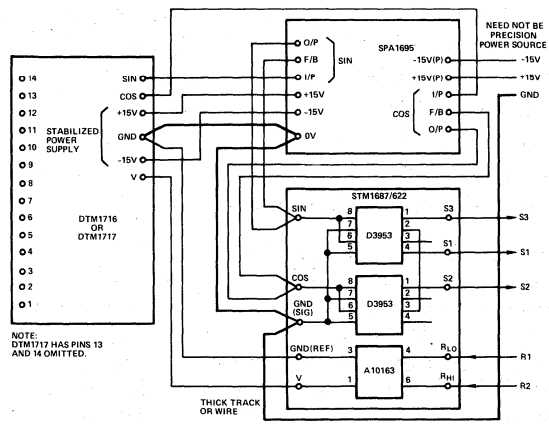



*Figure 4. Diagram Showing the Connection of a STM1687 to a DTM1716 or DTM1717 and a SPA1695*

**ORDERING INFORMATION**
The transformer should be ordered as:

| | |
|---|---|
| STM1687622 | 50/60Hz, Synchro output, 90 volt signal, 115 volt reference. |

Note: For options not shown above, consult the factory.

# STM 1697

**SPECIFICATIONS** (typical @ +25°C unless otherwise noted)

| | |
|---|---|
| ACCURACY[1] (after balancing) | ±2.4 arc minutes |
| OPERATING FREQUENCY | 60Hz |
| LOAD CAPABILITY | 5VA |
| OPERATING TEMPERATURE | -55°C to +105°C |
| STORAGE TEMPERATURE | -55°C to +125°C |
| VOLTAGE ISOLATION | 500V dc |
| WEIGHT | 3 lbs (1.34kg) |

Note:
[1] See STM1686 note 1.
Specifications subject to change without notice.

**APPLICATION OF THE STM1697**
The STM1697 should be used in conjunction with the DSC1705 or the DSC1706 Digital to Synchro Converter and the SPA1695 Power Amplifier.

**DIMENSIONS AND CONNECTIONS**
The STM1697 consists of a kit of two D3953 transformers and one A10033 transformer. These should be connected as shown in Figure 5.

The dimensions are given in Figures 7 and 8.

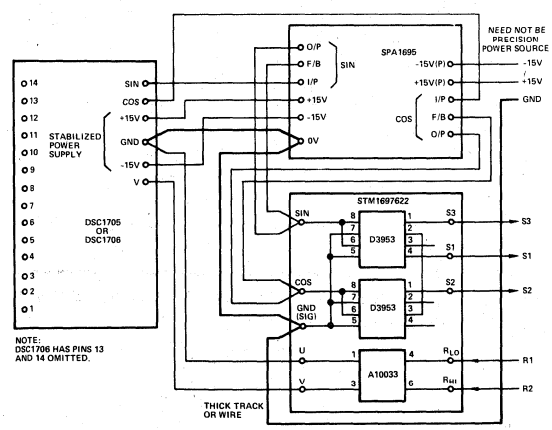



*Figure 5. Diagram Showing the Connection of a STM1697 to a DSC1706 or DSC1705 and a SPA1695*

**ORDERING INFORMATION**
This transformer should be ordered as:

| | |
|---|---|
| STM1697622 | 50/60Hz, Synchro output, 90 volt signal, 115 volt reference. |

Note: For options not shown above, consult the factory.

# STM 1737

**SPECIFICATIONS** (typical @ +25°C unless otherwise noted)

| | |
|---|---|
| ACCURACY[1] (after balancing) | ±2.4 arc minutes |
| OPERATING FREQUENCY | 60Hz |
| LOAD CAPABILITY | 5VA |
| OPERATING TEMPERATURE | -55°C to +105°C |
| STORAGE TEMPERATURE | -55°C to +125°C |
| VOLTAGE ISOLATION | 500V dc |
| WEIGHT | 3 lbs (1.34kg) |

Note:
[1] See STM1686 note 1.

Specifications subject to change without notice.

### APPLICATION OF THE STM1737

The STM1737 should be used in conjunction with the DSC1605 or the DSC1606 Digital-to-Synchro Converter and the SPA1695 Power Amplifier.

### DIMENSIONS AND CONNECTIONS

The STM1737 consists of a kit of two D3953 transformers and one A10033 transformer. These should be connected as shown in Figure 6.

The dimensions are given in Figures 7 and 8.

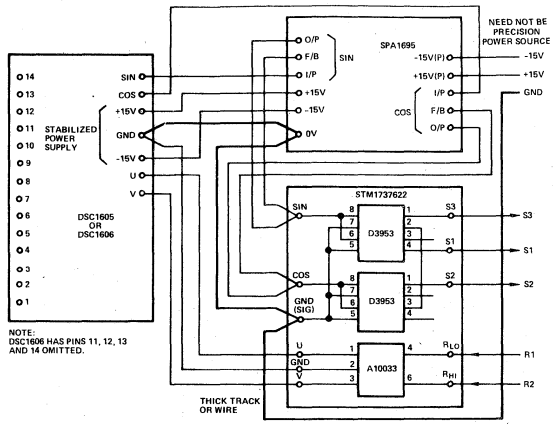



*Figure 6. Diagram Showing the Connection of a STM1737 to a DSC1606 or DSC1605 and a SPA1695*

### ORDERING INFORMATION

This transformer should be ordered as:

| | |
|---|---|
| STM1737622 | 50/60Hz, Synchro output, 90 volt signal, 115 volt reference. |

Note: For options not shown above, consult the factory.

### OUTLINE DIMENSIONS

Dimensions shown in inches and (mm).

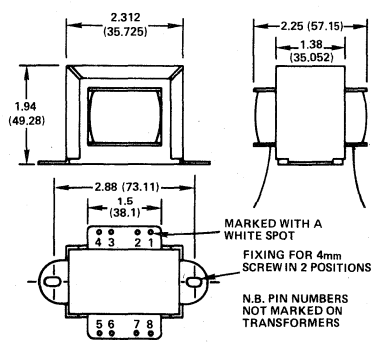



*Figure 7. Outline Drawing and Dimensions of the D3953 Transformer*

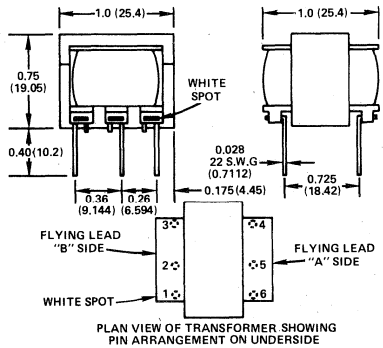



*Figure 8. Outline Drawing and Dimensions of the A10163 and A10033 Transformers*

### BALANCING SCOTT-T TRANSFORMERS (APPLIES ONLY TO TRANSFORMERS IN KIT FORM).

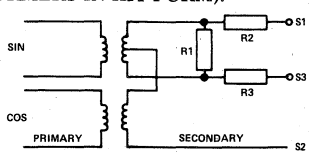



*Figure 9. Diagram Showing Balancing Circuit*

The Scott T transformers (two D3953 transformers) can be balanced by the following method:

Connect the primary windings of the transformers to give a known angle input of 45°. This can be done by connecting the two coils in parallel to a 7V rms supply, thus giving an equal sine and cosine contribution.

The 3 wire output signal is then monitored on an Angle Position Indicator (e.g. API1620 or API1718) with no load attached. A resistor R1 should be connected across S1 and S3 until the API reads 45.00°.

A balanced load is then connected across S1, S2 and S3 the change in angle is monitored by the API and minimized by adding resistors (R2 and R3) in series with S1 and S3. R2 and R3 will have equal values. Increasing R2 and R3 will decrease the angle monitored by the API.

Suggested initial values for R1 is 27kΩ and for R2 and R3 is 30Ω.

The transformer modules STM1686, 1696 and 1736 are balanced before leaving the factory.

# Synchro/Resolver-to-Linear DC Converter

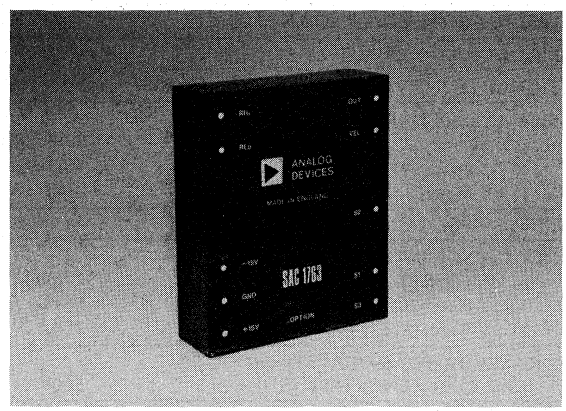
# SAC1763

## FEATURES

- High Dynamic Performance (27,000°/sec)
- High Accuracy (±11 Arc-Minutes)
- Internal Converter Tracking Loop Provides High Noise Immunity
- Low Output Ripple (Less than 5mV p-p)
- DC Output Proportional to Input Rate
- 50Hz to 2.6kHz Reference Frequency Operation
- Self Contained—No External Transformers or Adjustments Needed

## APPLICATIONS

- Measurement and Recording of Synchro or Resolver Information on Chart Recorders, X-Y Plotters, FM Recorders, Etc.
- Servo Control and Positioning




## GENERAL DESCRIPTION

The SAC1763 is a Synchro/Resolver-to-Linear dc Converter. It takes input angular information in synchro or resolver form voltages and gives an output voltage which is linearly proportional to the input angle. The output voltage of ±10V at ±5mA represents an input angular change of ±180 degrees of the synchro or resolver format signals applied to the converter input.

Options are available for all the standard line to line voltages and frequencies for either synchro or resolver inputs. Theses options together with commercial or extended temperature ranges are determined by a code following the type number (see ordering information).

An important feature of the SAC1763 series converters is that no external transformer modules are required. The transformer isolation is carried out by micro transformers which are inside the converter module *even for the 60Hz versions.*

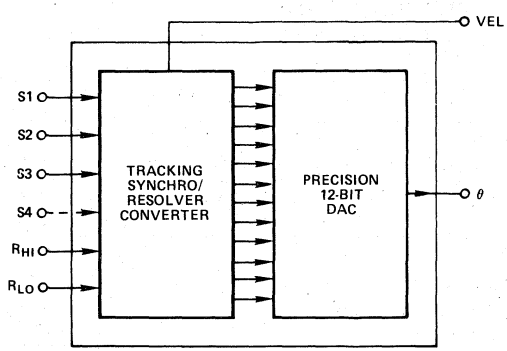
When converters are used in control loops, it is often useful to have a voltage which is proportional to angular velocity. This voltage is available and has been brought out on all SAC1763 converters. The availability of the velocity voltage eliminates the need for a tachometer for stabilization.

## MODELS AVAILABLE

Options of the SAC1763 are available to cover all the standard synchro and resolver voltages and frequencies. In addition, options exist for standard operating temperature (0 to +70°C) and extended operating temperature (-55°C to +105°C) (see ordering information).

## THEORY OF OPERATION

The SAC1763 is based upon the well proven 12-bit tracking Synchro/Resolver Converter type SDC1700. This is followed by a 12-bit precision DAC (Digital-to-Analog Converter).




13

# SPECIFICATIONS (max at 25°C unless otherwise stated)[1]

| Model | SAC1763 |
|---|---|
| ACCURACY[2] | ±11 arc-minutes |
| RESOLUTION | 1 part in 4096 |
| ANALOG OUTPUT | ±10V Representing ±180° 5mA is Available |
| OUTPUT DRIFT | 0.175 arc-minutes per °C |
| OUTPUT RIPPLE AND NOISE | <5mV p-p |
| SIGNAL AND REFERENCE FREQUENCY[1] | 60Hz, 400Hz and 2.6kHz |
| SIGNAL INPUT VOLTAGE (LINE TO LINE) | 90V, 26V or 11.8V rms |
| SIGNAL IMPEDANCE | |
| 90V Signal | 200kΩ Resistive |
| 26V Signal | 58kΩ Resistive |
| 11.8V Signal | 27kΩ Resistive |
| REFERENCE VOLTAGE | 115V, 26V or 11.8V rms |
| REFERENCE IMPEDANCE | |
| 115V Reference | 270kΩ |
| 26V Reference | 56kΩ |
| 11.8V Reference | 27kΩ |
| TRANSFORMER ISOLATION ON SIGNAL AND REFERENCE INPUTS | 500V dc |
| MAX INPUT RATES FOR FULL ACCURACY | |
| 60Hz Options | 5revs/sec |
| 400Hz Options | 36revs/sec |
| 2.6kHz Options | 75revs/sec |
| MAX ACCELERATION ON INPUT FOR ADDITIONAL ERROR LESS THAN 6 ARC-MINUTES | |
| 60Hz Options | 166°/sec² |
| 400Hz Options | 9668°/sec² |
| 2.6kHz Options | 45,528°/sec² |
| STEP RESPONSE (179° Step) (For less than 6 arc-minutes error) | |
| 60Hz | 1.5sec |
| 400Hz | 125ms |
| 2.6kHz | 50ms |
| VELOCITY VOLTAGE OUTPUT (See also Specifications on the next page) | ±10V nominal for ∓max input rate of the option |
| POWER SUPPLY REQUIREMENTS | +15V at 150mA<br>-15V at 45mA |
| POWER DISSIPATION | 2.93 watts |
| OPERATING TEMPERATURE RANGE | |
| Standard | 0 to +70°C |
| Extended | -55°C to +105°C |
| STORAGE TEMPERATURE | -55°C to +125°C |
| DIMENSIONS | 3.12" X 2.625" X 0.8"<br>(79.4mm X 66.7mm X 20.3mm) |
| WEIGHT | 7 ozs. (200 grams) |

NOTES

[1] The converters can be used over the following reference frequency ranges with no loss of accuracy. They will, however, retain the dynamic characteristics (input rate and acceleration) quoted for the particular option.

60Hz options can be used over 50Hz to 800Hz
400Hz options can be used over 400Hz to 2000Hz
2.6kHz options can be used over 2kHz to 3.5kHz

[2] Accuracy is specfied for the following conditions:

(a) ±10% signal and reference amplitude variation.
(b) ±10% signal and reference harmonic distortion.
(c) ±5% power supply variation.

Specifications subject to change without notice.

## CONNECTING THE CONVERTER

The electrical connections to the converter are straighforward. The power lines, which must not be reversed, are ±15V. They must be connected to the "+15V" and "-15V" pins with the common connection to the ground pin "GND".

It is suggested that 0.1μF and 6.8μF capacitors be placed in parallel from +15V to GND, from -15V to GND.

In the case of a Synchro, the signals are connected to "S1", "S2" and "S3" according to the following convention:

$$E_{S1} - S3 = E_{RLO} - RHI \text{ Sin } \omega t \text{ Sin } \theta$$
$$E_{S3} - S2 = E_{RLO} - RHI \text{ Sin } \omega t \text{ Sin } (\theta + 120^\circ)$$
$$E_{S2} - S1 = E_{RLO} - RHI \text{ Sin } \omega t \text{ Sin } (\theta + 240^\circ)$$

For a resolver, the signals are connected to "S1", "S2", "S3" and "S4" according to the following convention:

$$E_{S1} - S3 = E_{RLO} - RHI \text{ Sin } \omega t \text{ Sin } \theta$$
$$E_{S2} - S4 = E_{RHI} - RLO \text{ Sin } \omega t \text{ Cos } \theta$$

The system reference voltage is connected to pins "$R_{HI}$" and "$R_{LO}$" in accordance with the above convention.

The analog output voltage representing the digital angle is between the pin "OUT" and "GND", ±10V corresponding to ±180 degrees. Up to 5mA may be taken from the "OUT" pin. The relationship between the output voltage and the input angle is shown in the diagram below.

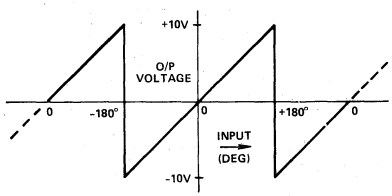



*Diagram Showing Relationship Between Input and Output*

Sometimes, it is required that the input/output relationship of the converter is the other way round. This can be achieved in the case of synchro options by interchanging connections "S1" and "S3". This is shown in the diagram below.

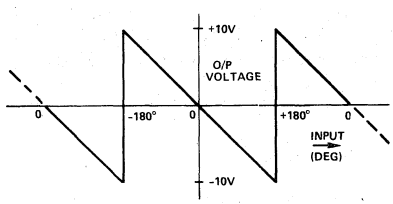



*Diagram Showing Relationship Between Input and Output When "S1" and "S3" are Interchanged*

## VELOCITY PIN

The analog voltage proportional to the rate of change of angle is provided between the pins VEL and GND. The variation is ±10.0V nominal for the maximum velocity of the option.

This pin provides a dc voltage output which is proportional to the angular velocity of the input. The voltage goes negative for an increasing digital angle and goes positive for a decreasing digital angle.

The characteristics of the velocity pin output are given in the following table.

| | |
|---|---|
| Scaling of Output Voltage for One Fifth max Velocity | 2 Volts (Nominal) |
| Output Voltage Temp. Coeff. | 0.05%/°C of Output |
| Output Voltage Drift (All Models) | 0 to +70°C ±50μV/°C<br>-55°C to +105°C ±100μV/°C |
| Linearity | 0 to 100°/sec 60Hz Options 1.5%<br>0 to 800°/sec 400Hz Options 2%<br>0 to 1600°/sec 2.6kHz Options 2% |
| Noise (0 to 20Hz) | 60Hz Options: 0 to 200°/sec 2mV rms<br>400Hz Options: 0 to 1600°/sec 2mV rms<br>2.6kHz Options: 0 to 3300°/sec 2mV rms |
| Impedance (Output) | 1Ω |
| max Current Available | 1mA |

The velocity voltage can be used in closed loop servo systems for stabilization instead of a tachometer.

The SAC1763 velocity outputs do not have the disadvantages of being inefficient at low speeds and do not need gearing required by tachometers. In addition, the output is available at no extra cost.

For other velocity output scaling and linearity consult the factory.

## RESISTIVE SCALING OF INPUTS

A feature of this converter is that the signal and reference inputs can be resistively scaled to accommodate any range of input signal and reference voltages.

This means that a standard converter can be used with a personality card in systems where a wide range of input and reference voltages are encountered.

To calculate the values of the external scaling resistors in the case of a Synchro Converter, add 1.11kΩ per extra volt of signal in series with "S1", "S2" and "S3", and 2.2kΩ per extra volt of reference in series with "$R_{HI}$".

In the case of a Resolver-to-Digital Converter, add 2.22kΩ in series with "S1" and "S2" per extra volt of signal and 2.2kΩ per extra volt of reference in series with "$R_{HI}$".

For example, assume that we have an 11.8V line to line, 26V reference Synchro Converter, and we wish to use it with a 60V line to line signal with a 115V reference.

In each signal input line, the extra voltage capability required is:

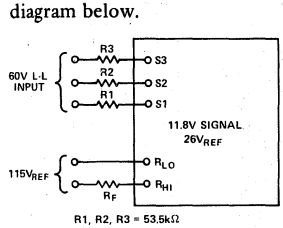
$$60 - 11.8 = 48.2V$$

Therefore each one of the three resistors needs to have a value of:

$$48.2 \times 1.11 = 53.5k\Omega$$

Similarly the single resistor needed in series with "$R_{HI}$" can be calculated as being 195.8kΩ.

The inputs of the converter can therefore be scaled as in the diagram below.




NOTE
IN THE CASE OF THE SIGNAL RESISTORS THE RATIO ERRORS BETWEEN THE RESISTANCES IS MORE IMPORTANT THAN THE ABSOLUTE RESISTANCE VALUES.

IN GENERAL A 1% RATIO ERROR WILL GIVE RISE TO AN EXTRA INACCURACY OF 17 ARC-MINUTES WHILE A RATIO ERROR OF 0.1% WILL GIVE RISE TO AN EXTRA INACCURACY OF 1.7 ARC-MINUTES.

THE ABSOLUTE VALUE OF $R_F$ IS NOT CRITICAL.

13

## USING THE CONVERTERS WITH OTHER THAN THE SPECIFIED REFERENCE FREQUENCY

The converters can be used with different reference frequencies, other than those for which they are basically specified, with no resulting loss of accuracy (see below). However, they will retain the dynamic characteristics given in the specification.

| Basic Option | Frequency Range for no Loss in Accuracy |
|---|---|
| 60Hz | 50Hz → 800Hz |
| 400Hz | 400Hz → 2000Hz |
| 2.6kHz | 2kHz → 3.5kHz |

## TRANSFER FUNCTION

The transfer functions for the three reference frequency options of the converters are shown below.

**60Hz Options**

$$\frac{\theta_0}{\theta_1} = \frac{1.9 \times 10^5 \, (1 + 5.6 \times 10^{-2} s)}{s^3 + 1.03 \times 10^2 s^2 + 1.08 \times 10^4 s + 1.9 \times 10^5}$$

**400Hz Options**

$$\frac{\theta_0}{\theta_1} = \frac{8.8 \times 10^7 \, (1 + 6.8 \times 10^{-3} s)}{s^3 + 8.04 \times 10^2 s^2 + 6.1 \times 10^5 s + 8.8 \times 10^7}$$

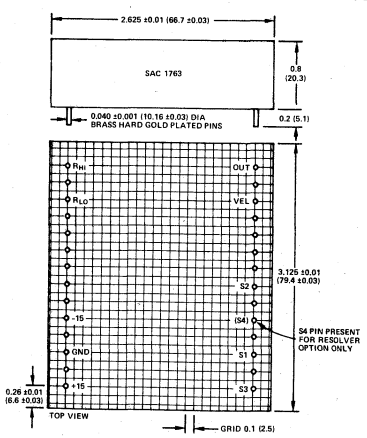
**2.6kHz Options**

$$\frac{\theta_0}{\theta_1} = \frac{10^9 \, (1 + 3.3 \times 10^{-3} s)}{s^3 + 1.7 \times 10^3 s^2 + 3.303 \times 10^6 s + 10^9}$$

## OUTLINE DIMENSIONS AND PIN CONNECTION DIAGRAM

Dimensions shown in inches and (mm).

**MATING SOCKET: CAMBION 450-3388-01-03**




## APPLICATIONS OF THE SAC1763

The SAC1763 may be used to record synchro or resolver information, from for example gyrocompasses or other navigational aids, on to equipment such as X-Y recorders, chart recorders or FM tape recorders, see below.

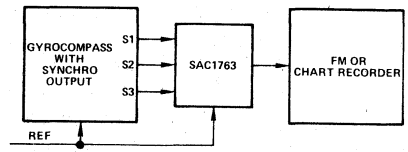



*Diagram Showing Gyrocompass Information Being Recorded Using SAC1763*

The applications of the SAC1763 are not only in measurement of synchro or resolver information but also in controlling angular movement. The diagram below shows the SAC1763 being used inside an angular control loop where the input is a dc voltage. The availability of the velocity voltage eliminates the need for an electromechanical tachometer for stabilization purposes.

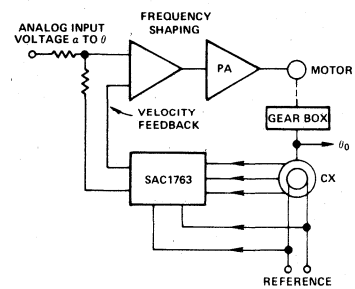



*Diagram Showing the SAC1763 Used in a Servo System Where the Input is a dc Voltage*

## ORDERING INFORMATION

The full part number for all the standard converter options defining reference and signal voltage and frequency, operating temperature range and whether Synchro or Resolver format is given below. It should also be remembered that the signal and reference inputs can be resistively scaled (see section "Resistive Scaling of Inputs") and that in certain cases reference frequencies other than those specified can be used. (See section "Using the Converters with other than the Specified Reference Frequency".)

| Part Number | Operating Temp. Range | L to L Voltage/Format | Ref. Voltage | Ref. Freq. |
|---|---|---|---|---|
| SAC1763511 | 0 to +70°C | 11.8V Synchro | 26 Volts | 400Hz |
| SAC1763611 | -55°C to +105°C | 11.8V Synchro | 26 Volts | 400Hz |
| SAC1763512 | 0 to +70°C | 90.0V Synchro | 115 Volts | 400Hz |
| SAC1763612 | -55°C to +105°C | 90.0V Synchro | 115 Volts | 400Hz |
| SAC1763522 | 0 to +70°C | 90.0V Synchro | 115 Volts | 60Hz |
| SAC1763622 | -55°C to +105°C | 90.0V Synchro | 115 Volts | 60Hz |
| SAC1763513 | 0 to +70°C | 11.8V Resolver | 11.8 Volts | 400Hz |
| SAC1763613 | -55°C to +105°C | 11.8V Resolver | 11.8 Volts | 400Hz |
| SAC1763514 | 0 to +70°C | 26.0V Resolver | 26 Volts | 400Hz |
| SAC1763614 | -55°C to +105°C | 26.0V Resolver | 26 Volts | 400Hz |
| SAC1763518 | 0 to +70°C | 11.8V Resolver | 26 Volts | 400Hz |
| SAC1763618 | -55°C to +105°C | 11.8V Resolver | 26 Volts | 400Hz |
| SAC1763543 | 0 to +70°C | 11.8V Resolver | 11.8 Volts | 2.6kHz |
| SAC1763643 | -55°C to +105°C | 11.8V Resolver | 11.8 Volts | 2.6kHz |
| SAC1763544 | 0 to +70°C | 26.0V Resolver | 26 Volts | 2.6kHz |
| SAC1763644 | -55°C to +105°C | 26.0V Resolver | 26 Volts | 2.6kHz |
| SAC1763548 | 0 to +70°C | 11.8V Resolver | 26 Volts | 2.6kHz |
| SAC1763648 | -55°C to +105°C | 11.8V Resolver | 26 Volts | 2.6kHz |

# ANALOG DEVICES

# BCD Output Synchro-to-Digital Converters

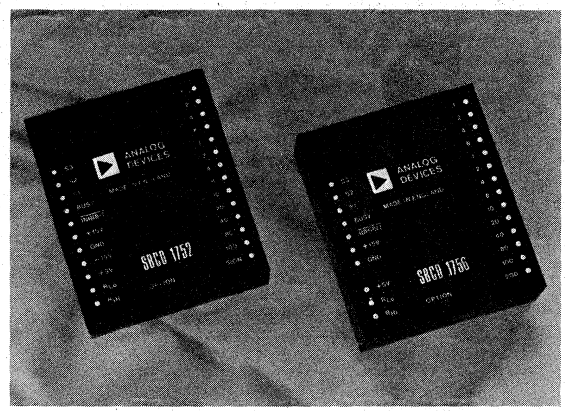
# SBCD1752/1753/1756/1757

**FEATURES**

- **BCD (Binary Coded Decimal) Output Representing 0 to 359.9° or 0 to ±179.9°**
- **-15V Power Supply Requirement Optional**
- **High Tracking Rate (75 revs/sec)**
- **Internal Microtransformers for 60Hz, 400Hz and 2.6kHz Options**
- **Voltage Scaling with External Resistors (Unique Feature)**
- **Transformer Isolated Outputs**
- **Low Cost**
- **MIL Spec/Hi Rel Options Available**

**APPLICATIONS**

- **Visual Display of Angular Information**
- **Valve Position Indication**
- **Antenna Monitoring**
- **Industrial Controls**




## GENERAL DESCRIPTION

The SBCD1752, SBCD1753, SBCD1756 and the SBCD1757 are modular, continuous tracking Synchro/Resolver-to-Digital converters which employ a type 2 servo loop.

They are intended for use in both Industrial and Military applications either for displaying angular data directly, or for inputting BCD information directly into a data processing system.

The input signals can be either 3 wire synchro plus reference or 4 wire resolver plus reference, depending on the option. The outputs will be presented in parallel Binary Coded Decimal (BCD).

Particular attention has been paid in the design, to achieving the highest tracking rates and accelerations possible, compatible with the resolution and carrier frequency used, while at the same time obtaining a high overall accuracy.

One of the outstanding features of these converters is the use made of precision Scott T and reference microtransformers. *This has made it possible to include the transformers within the module, even for the 60Hz version as well as providing facilities for external voltage scaling.*

## MODELS AVAILABLE

The four Synchro-to-Digital converters described in this data sheet, differ primarily in the areas of output format and power supply requirements.

Model SBCD1752XYZ is a 13-bit plus sign, BCD output converter, giving -180.0° to -0.1° and +0.0 to +179.9° requiring ±15V and +5V power supplies, and having an overall accuracy of ±0.2 Degrees.

Model SBCD1753XYZ is a 14-bit, BCD output converter, giving 0 to 359.9°, requiring ±15V and +5V power supplies, and having an overall accuracy of ±0.2 Degrees.

Model SBCD1756XYZ is a 13-bit plus sign, BCD output converter, giving -180.0° to -0.1° and +0.0 to +179.9° requiring +15V and +5V power supplies, and having an overall accuracy of ±0.2 Degrees.

Model SBCD1757XYZ is a 14-bit, BCD output converter, giving 0 to 359.9°, requiring +15V and +5V power supplies, and having an overall accuracy of ±0.2 Degrees.

The XYZ code defines the option thus:

X signifies the operating temperature range.
Y signifies the reference frequency.
Z signifies the input voltage and range and whether it will accept Synchro or Resolver information.

More information about the option code is given under the heading "Ordering Information".

## DATA TRANSFER (ALL MODELS)

The readiness of the converters for data transfer is indicated by the state of the BUSY pin. The voltage appearing on the BUSY pin consists of a train of pulses, at TTL levels, of length according to the option (see Specifications table). The converter is busy when the BUSY pin is at TTL "High" level. The pulses occur for increasing and decreasing counts.

The most suitable time for transferring data is 400ns after the trailing edge of the BUSY pulse, and the times allowable for data transfer are shown in the specification. Even at the maximum speed of the option, these times will be sufficient to transfer data before the next BUSY pulse occurs.

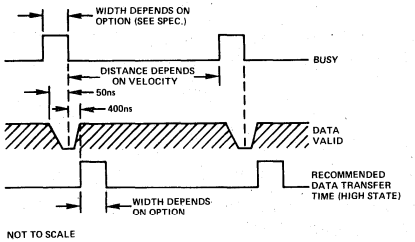
# SPECIFICATIONS (typical at 25°C unless otherwise stated)

| MODELS | SBCD1752 | SBCD1753 | SBCD1756 | SBCD1757 |
|---|---|---|---|---|
| ACCURACY[1] (max Error) | | | | |
| All Frequency Options | ±0.2 Degrees | * | * | * |
| OUTPUT | Parallel BCD, 8TTL Loads | * | * | * |
| RESOLUTION | 13-Bit + Sign Representing −180.0° to −0.1° and +0.0° to +179.9° | 14 Bit Representing 0 to 359.9° | * | ** |
| SIGNAL AND REFERENCE FREQUENCY | 60Hz, 400Hz and 2.6kHz | * | * | * |
| SIGNAL VOLTAGE (Line to Line) | | | | |
| Low Level | 11.8V rms | * | * | * |
| High Level | 90.0V rms | * | * | * |
| SIGNAL IMPEDANCES | | | | |
| Low Level | 26kΩ (Resistive) | * | * | * |
| High Level | 200kΩ (Resistive) | * | * | * |
| REFERENCE VOLTAGE | | | | |
| Low Level | 26V (11.8V Signal) | * | * | * |
| High Level | 115V (90V Signal) | * | * | * |
| REFERENCE IMPEDANCE | | | | |
| Low Level | 56kΩ (Resistive) | * | * | * |
| High Level | 270kΩ (Resistive) | * | * | * |
| TRANSFORMER ISOLATION | 500V dc | * | * | * |
| TRACKING RATE (min) | | | | |
| 60Hz | 5 Revolutions Per Second | * | * | * |
| 400Hz | 36 Revolutions Per Second | * | * | * |
| 2.6kHz | 75 Revolutions Per Second | * | * | * |
| Accel.[1] Constant $K_a$ | | | | |
| 60Hz | 2000/sec$^2$ | * | * | * |
| 400Hz | 120,000/sec$^2$ | * | * | * |
| 2.6kHz | 600,000/sec$^2$ | * | * | * |
| STEP RESPONSE (179° Step) (For 0.1° Error) | | | | |
| 60Hz | 1.5sec | * | * | * |
| 400Hz | 125ms | * | * | * |
| 2.6kHz | 50ms | * | * | * |
| POWER LINES | +15V @ 25mA | * | +15V @ 80mA | *** |
| | −15V @ 25mA | * | +5V @ 500mA | *** |
| | +5V @ 500mA | * | | |
| POWER DISSIPATION | 3.25 Watts | * | 3.7 Watts | *** |
| BUSY LOGIC OUTPUT, POSITIVE PULSE (1 TTL Load) | | | | |
| 60Hz | 3.5 to 4.5μs | * | * | * |
| 400Hz | 0.5 to 1.25μs | * | * | * |
| 2.6kHz | 0.5 to 1.25μs | * | * | * |
| MAX DATA TRANSFER TIME (From 400ns After Trailing Edge of BUSY at max Velocity) | | | | |
| 60Hz | 40μs | * | * | * |
| 400Hz | 5.0μs | * | * | * |
| 2.6kHz | 1.8μs | * | * | * |
| $\overline{\text{INHIBIT}}$ INPUT (To Inhibit) | Logic "0" 1TTL Load | * | * | * |
| TEMPERATURE RANGE | | | | |
| Operating | 0 to +70°C Standard | * | * | * |
| | −55°C to +105°C Extended | * | * | * |
| Storage | −55°C to +125°C | * | * | * |
| DIMENSIONS | 3.125" x 2.625" x 0.8" (79.4 x 66.7 x 20.4mm) | * * | * * | * * |
| WEIGHT | 6.4 ozs. (180 grams) | * | 6.5 ozs. (185 grams) | *** |

NOTES
[1] Specified over the appropriate operating temperature range and for
(a) ±10% signal and reference amplitude variation
(b) 10% signal and reference harmonic distortion
(c) ±5% power supply variation
(d) ±10% variation in reference frequency.

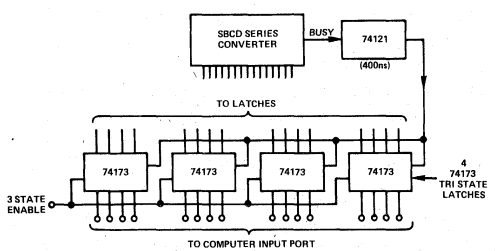
*Specifications same as SBCD1752
**Specifications same as SBCD1753
***Specifications same as SBCD1756

Specifications subject to change without notice.




*Data Transfer Diagram*

The function of the $\overline{\text{INHIBIT}}$ pin is to enable the user to inhibit the update of the converter's output counter. This is achieved by taking the $\overline{\text{INHIBIT}}$ pin to a TTL Logic zero. If used, the $\overline{\text{INHIBIT}}$ should be applied 400ns after the trailing edge of the BUSY pulse. This will ensure that the data on the output pins is valid. The data should then be transferred and the $\overline{\text{INHIBIT}}$ released before the next BUSY pulse occurs. The worst case times allowable for data transfer in this case are shown in the Specifications under the heading of "MAX DATA TRANSFER TIME (from 400ns After Trailing Edge of BUSY at Max Velocity)". It should be noted that the application of the $\overline{\text{INHIBIT}}$ will not prevent the BUSY pulses appearing on the BUSY pin, and thus if the $\overline{\text{INHIBIT}}$ is not released by the time that the next BUSY pulse occurs, the BUSY pulse will still appear, although the internal converter loop will have been opened. Under this condition, a worst case recovery time, equivalent to that of a step of 179 degrees may be encountered (see Spec.). To avoid this and to ensure valid data transfer, the system shown in the diagram is recommended.




*Suggested External Interface Circuitry*

In cases where the converter is connected to a data bus or used as a peripheral, the method outlined in the above diagram is recommended. The $\overline{\text{INHIBIT}}$ is not necessary in this case, and the external "Enable" has control of the converter output.

The AC1755 mounting card described later in this data sheet contains the external components shown in the diagram.

## CONNECTING THE CONVERTER

The power lines, which should not be reversed, should be connected to "+15V", "-15V" and "+5V" in the case of the SBCD1752 and SBCD1753, and to "+15V" and "+5V" in the case of the SBCD1756 and SBCD1757, with the common connection to "GND" in all cases.

It is suggested that 0.1$\mu$F and 6.8$\mu$F capacitors be placed in parallel from +15V to GND, from -15V to GND and from +5V to GND.

The digital output connections in the case of the SBCD1753 and SBCD1757 should be taken from the pins marked "0.1" through to "200"; these values being represented in degrees.

In the case of the SBCD1752 and SBCD1756, the data should be taken from the pins marked "0.1" through to "100", these values also being represented in degrees. In the case of these latter units the "SIGN" pin will indicate the polarity of the output, Logic "0" representing positive angles and Logic "1" representing negative angles.

In the case of a synchro, the signals are connected to $S_1$, $S_2$ and $S_3$ according to the following convention:

**Synchro connection**

$E_{S1-S3} = E_{RLO-RHI} \sin \omega t \sin \theta$
$E_{S3-S2} = E_{RLO-RHI} \sin \omega t \sin (\theta + 120^\circ)$
$E_{S2-S1} = E_{RLO-RHI} \sin \omega t \sin (\theta + 240^\circ)$

For a resolver, the signals are connected to "S1", "S2", "S3" and "S4" according to the following convention:

**Resolver Connection**

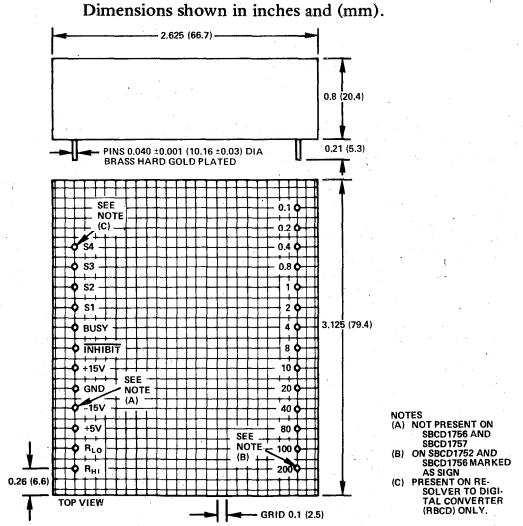
$E_{S1-S3} = E_{RLO-RHI} \sin \omega t \sin \theta$
$E_{S2-S4} = E_{RHI-RLO} \sin \omega t \cos \theta$

The BUSY and $\overline{\text{INHIBIT}}$ pin (if used), should be connected as described under the heading "DATA TRANSFER".

The reference connections are made to pins $R_{HI}$ and $R_{LO}$.

**PIN CONNECTION DIAGRAM**

Dimensions shown in inches and (mm).



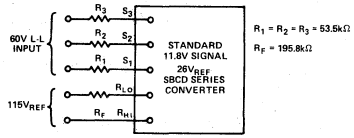

**MATING SOCKET: CAMBION 450-3388-01-03**

## RESISTIVE SCALING OF INPUTS

A unique feature of the SBCD1752/1753/1756/1757 converters is that the inputs can be resistively scaled to accommodate any value of input signal and reference voltage.

In order to calculate the values of the external scaling resistors necessary, add 1.11k$\Omega$ in series with the input per extra volt in the case of the signal, and 2.2k$\Omega$ per extra volt in the case of the reference.

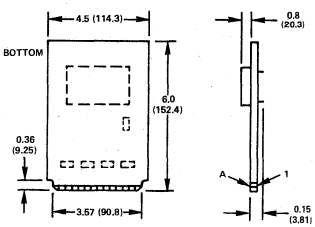
For example, assume that it is required to use a standard 11.8V line to line signal, 26V reference converter with 60V line to line signal and a 115V reference. The resistors should be arranged as in the diagram.




**Note:** In the case of $R_1$, $R_2$, and $R_3$, the ratio error between the resistances is more critical than the absolute value. In general a 1% ratio error will give rise to an extra inaccuracy of 0.28 Degrees, while a ratio accuracy of 0.1% will give rise to an extra inaccuracy of 0.028 Degrees. The absolute value of $R_F$ is not critical.

## CARD MOUNTING

All the converters can be mounted on an AC1755 mounting card. This card contains the latches and monostable, described under the "DATA TRANSFER" heading, which are necessary to transfer the data on to a computer bus system, as well as sockets for the converter. The latches have a tri-state output to facilitate ease of use. The AC1755 also contains facilities for the inclusion of input signal scaling and reference resistors as described under the heading "RESISTIVE SCALING OF INPUTS". The card uses a 22/22 0.156" pitch edge connector. The pin-out is shown below. If it is not required to use the external latches, they can be jumpered on the board.




*AC1755 Mounting Card (First Angle Projection). Dimensions Shown in Inches and (mm).*

| Edge Pin Number | Function | Edge-Pin Letter | Function |
|---|---|---|---|
| 1 | R (Lo) | A | Tri-State Enable |
| 2 | R (Hi) | F | +15 Volts |
| 3 | $S_3$ | H | +15 Volts |
| 4 | $S_2$ | J | -15 Volts (3) |
| 5 | $S_1$ | K | -15 Volts (3) |
| 6 | $S_4$ | L | GND |
| | | M | GND |
| 13 | BUSY | N | +5 Volts |
| 15 | INHIBIT | P | +5 Volts |
| 16 | 0.1 | T | 8 |
| 17 | 0.2 | U | 10 |
| 18 | 0.4 | V | 20 |
| 19 | 0.8 | W | 40 |
| 20 | 1 | X | 80 |
| 21 | 2 | Y | 100 |
| 22 | 4 | Z | 200 (1) SIGN (2) |

NOTES
(1) SBCD1753 and SBCD1757 only
(2) SBCD1752 and SBCD1756 only
(3) SBCD1752 and SBCD1753 only

*AC1755 Mounting Card Edge Connections*

## ORDERING INFORMATION

Converters should be ordered by the appropriate part number (i.e., SBCD1752, SBCD1753, SBCD1756 or SBCD1757) followed by the appropriate option code.

If the unit is to be a Resolver-to-Digital converter, the SBCD should be replaced by RBCD in the part number.

The XYZ options are as follows:

X signifies the operating temperature range thus;
X = 5 0 to +70°C (Commercial Temp.)
X = 6 -55°C to +105°C (Extended Temp.)

Y signifies the reference frequency thus;
Y = 1 signifies 400Hz
Y = 2 signifies 60Hz*
Y = 4 signifies 2.6kHz

Z signifies the input signal and reference voltages and whether the converter is a Synchro-to-Digital or a Resolver-to-Digital converter. The options for Z are:

| | |
|---|---|
| Z = 1 signifies Synchro, | signal 11.8 Volts reference 26 Volts |
| Z = 2 signifies Synchro, | signal 90 Volts reference 115 Volts |
| Z = 8 signifies Resolver, | signal 11.8 Volts reference 26 Volts |

Thus an SBCD1753 with a commercial (0 to +70°C) operating range, using a 400Hz, 26 volt reference with an 11.8 volt signal would be ordered as an SBCD1753511.

*For 50Hz operation, a 60Hz converter can be used with no reduction in accuracy.

In addition a 400Hz unit will work with a 2.6kHz reference and a 60Hz unit will work with a 400Hz reference; however they will have the velocity and acceleration characteristics of the lower frequency rated unit.

## OTHER PRODUCTS

The SBCD series of Synchro-to-Digital converters are just a few of the modules and instruments concerned with Synchro conversion manufactured by us. Some of our other products are listed below and technical data is available. If you have any questions about our products or require advice about the use of them for a particular application, please contact our Applications Engineering Department.

## SYNCHRO-TO-DIGITAL CONVERTERS

The SDC1700 is a low profile (0.4") converter with a 12-bit natural binary output. Its overall accuracy is ±8.5 arc-minutes, and the module contains internal transformers for all reference frequency options including 60Hz. The SDC1702 is similar to the SDC1700 but has a 10-bit natural binary output and an overall accuracy of ±22 arc-minutes.

The SDC1704 is similar to the above two converters, but has a 14-bit natural binary output and an overall accuracy of ±2.0 arc-minutes ±1LSB.

## TWO SPEED PROCESSORS

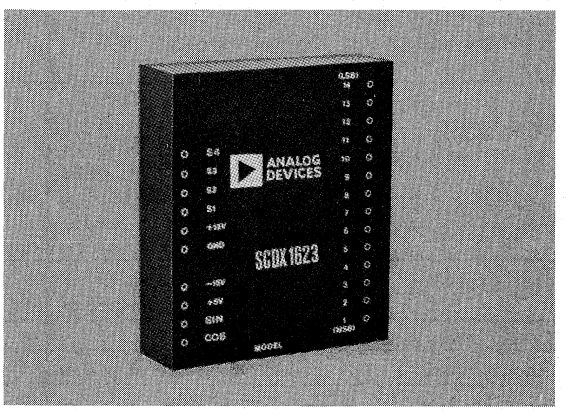
The TSL1612 and the TSL1729 both produce one digital output word up to 20 bits in length from the outputs of 2 Synchro-to-Digital converters in a coarse/fine system. The TSL1612 is used for ratios of 9:1, 18:1 and 36:1, while the TSL1729 is programmable for all ratios from 1:1 to 63:1.

# ANALOG DEVICES

# Solid State Control Differential Transmitter

## SCDX/RCDX1623

**FEATURES**
**Accuracy is ±4 Arc Minutes**
**14 Bit Resolution**
**Small Size – 3.125" x 2.6" x 0.8"**
**Low Power Dissipation – 1.5 Watts**
**Mil. Spec. Versions Available**




**DESCRIPTION**

The SCDX/RCDX Series are solid state control differential transmitters. Their function is analogous to an electro-mechanical CDX except that the mechanical input of the CDX has been replaced by a binary input angle. The solid state differential transmitter accepts a digital angle input together with either a 3 wire synchro (SCDX) (or 4 wire resolver; RCDX) angle input and gives as output synchro or resolver signals representing the difference between the two input angles. Thus the outputs can be described by A sin $\omega$t sin $(\theta - \phi)$ and A sin $\omega$t cos $(\theta - \phi)$ where $\theta$ represents the synchro or resolver input angle, $\phi$ represents the binary input angle (14 bits) and $\omega$ is the synchro excitation frequency.

The outputs from the SCDX resemble in their function the outputs from a conventional resolver but they are not transformer isolated. The outputs are from a pair of operational amplifiers (5.0 volts rms at maximum) which can be fed into a power amplifier and Scott transformer to provide either 3 wire synchro or 4 wire resolver outputs at appropriate voltage levels.

Both 60Hz and 400Hz versions of the SCDX series are available. The 400Hz modules have the input transformers contained inside the module for either synchro or resolver inputs. The SCDX modules for use on 60Hz do not contain the input transformers; suitable external transformers are available for either synchro or resolver inputs.

These transformers are designated STM 1671/XYZ or RTM 1671/XYZ where the X, Y and Z signify the temperature and voltage conditions.

13

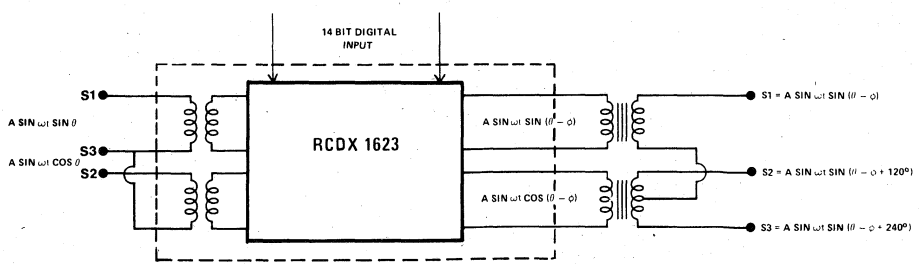



*Figure 1.*

# SPECIFICATIONS (typical @ +25°C and ±15V unless otherwise noted)

| | |
|---|---|
| Accuracy* | ±4 arc minutes |
| Resolution | 14 bits (1 LSB = 1.3 arc minutes) |
| Digital Inputs | 14 bits natural binary |
| Digital Input Levels | TTL, DTL |
| Digital Input Loading | 3 TTL loads |
| Response Time to 180° digital or synchro input step | 300 micro seconds |
| Signal Inputs | Resolver 5.0 volts 400Hz<br>Synchro 11.8 volts rms 400Hz<br>Resolver 11.8 volts rms 400Hz<br>Resolver 26.0 volts rms 400Hz<br>Synchro 90 volts rms 60Hz or 400Hz<br>Resolver 90 volts rms 60Hz or 400Hz<br>Resolver 115 volts rms 60Hz or 400Hz |
| Signal Impedance | Low level 20K ohms L-L<br>High level 200K ohms L-L |
| Transformer Isolation | 500 volts DC |
| Output Voltage | 5 volts rms into 2K ohms (min) |
| Carrier Phase Shift | Less than 1 degree |
| Power Supplies | +15 volts at 45mA<br>-15 volts at 45mA<br>+5 volts at 20mA |
| Operating Temperature Range | -55°C to +105°C or<br>0°C to +70°C |
| Storage Temperature Range | -55°C to +125°C |
| Warm up | Full accuracy upon switch on |
| Dimensions | 3.125" x 2.625" x 0.8"<br>79.4mm x 66.6mm x 20.5mm |
| Weight | 7 oz. (200 grams) |

***Note: Accuracy applies over operating temperature range and for –**

**a) ±10% signal amplitude variations**
**b) 10% signal harmonic distortion**
**c) ±10% signal frequency variation**
**d) ±5% power supply variation**

**Specifications subject to change without notice.**

## PRINTED CIRCUIT CARDS FOR SCDX/RCDX 400Hz AND 60Hz MODULES

Printed circuit cards are available for both the 400Hz and the 60Hz SCDX or RCDX modules. In the case of the 400Hz versions of the SCDX or RCDX the input transformers are contained inside the modules which are mounted on the smaller printed circuit card. For 60Hz use the input transformer module is mounted on the printed circuit card. The edge connections are shown in table 1 the connections are 22/22 way – 0.156" pitch. (Pin 3, i.e. $S_4$ is only used on AC 1656 in which case it is connected to W.)

The card type numbers are AC 1637 for mounting the 400Hz module and AC 1656 for mounting the 60Hz module and its transformer unit.

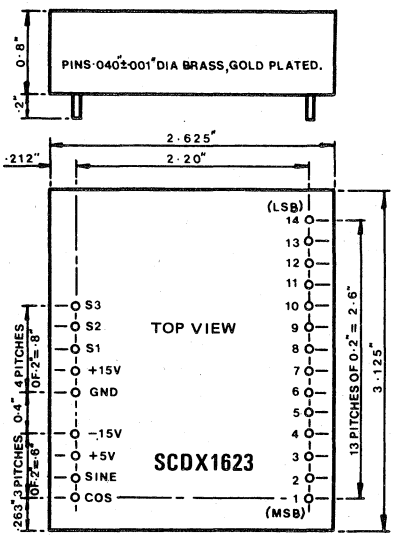
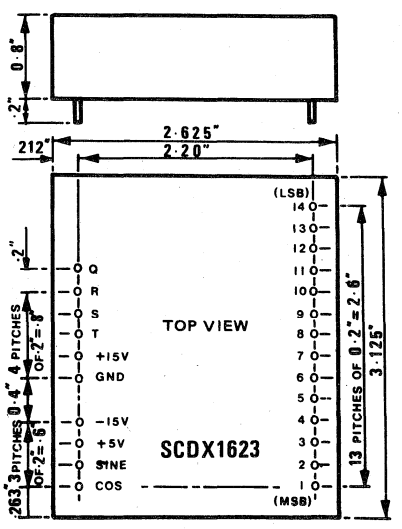



*Figure 2. 400Hz SCDX Module*



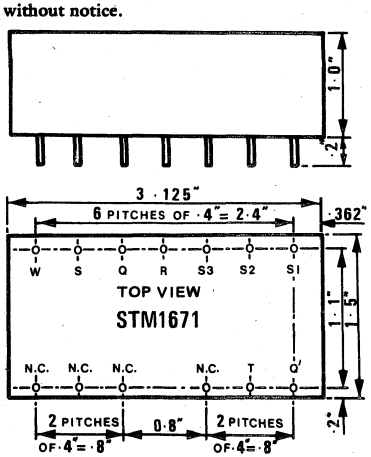




*Figure 3. STM 1671 and 60Hz SCDX Modules*

## USE OF THE SCDX AND RCDX

The inputs to the SCDX are two angles one as either resolver or synchro wires and the other in digital form. The output from the SCDX or RCDX is from operational amplifiers giving 5 volts RMS capable of driving into loads of 2K ohms or more and it is in resolver form. The output can in some cases be used directly or via a directly connected Scott transformer to convert to synchro three wire data. The output magnitudes represent the sine and cosine of the difference between the input angle and the digital angle.

## CONNECTIONS

The SCDX modules can be used for either synchro or resolver use and in each case they can be used at 400Hz or 60Hz.

**400Hz operation.** In the case of 400Hz operation the input transformers are contained inside the SCDX module or RCDX module. The internal connections are different for the resolver and synchro use but in both cases the input pins marked $S_1$, $S_2$ and $S_3$ are used for the signal voltages. For resolver use $S_1$ is the sin input, $S_2$ is the cosine input and $S_3$ is the common connection. For synchro use the signals are applied to the pins $S_1$, $S_2$ and $S_3$ in rotation. The distinction between the modules is in the marking RCDX or SCDX. Different signal voltage levels are accommodated by different transformer windings and are determined by the number representing Z in the ordering code; see the back page for details. A diagram showing the pin arrangement for the 400Hz version of the SCDX and RCDX is shown in Fig. 2.

**60Hz operation.** In this case the signal input uses four pins to the SCDX or RCDX modules which will be marked QRST, these pins take in resolver format signals (2 volts rms max.) Pin T is common, S is plus cosine, R is plus sine, and Q is minus cosine. The pins QRST on the RCDX or SCDX module must be connected to the pins QRST on the transformer module, i.e. Q→Q etc. In the case of 60Hz synchro use the inputs must be applied to the pins marked $S_1$, $S_2$ and $S_3$ on the transformer module. In the case of 60Hz resolver use the sine input must be applied between $S_1$ and $S_3$ and the cosine input between $S_2$ and W. (The sense of the connections is such that if W and $S_3$ are regarded as common then $S_1$ and $S_2$ will be in time phase with each other in the first quadrant.)
No reference input is used in this module. A diagram showing the SCDX module and the STM 1671 transformer module pin arrangement and marking is shown in Fig. 3.

**Warning** *In no circumstances should the synchro or resolver voltages be connected directly to the pins marked QRST.*

The outputs are directly available from the module on the pins marked sine and cos.

Pins 1 to 14 are the TTL digital angle input pins, pin 1 is the MSB (180°).

The power supplies and ground are as shown in Fig. 2.
*The power supply lines should not be reversed.*

| PIN No | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| FUNCTION | Sin | Cos | S4 | S3 | S2 | NC | NC | NC | NC | NC | NC | NC | $S_1$ | NC | +15 | Bit 14 | Bit 13 | Bit 12 | Bit 11 | Bit 10 | Bit 9 | Bit 8 |
| PIN LETTER | A | B | C | D | E | F | H | J | K | L | M | N | P | R | S | T | U | V | W | X | Y | Z |
| FUNCTION | NC | NC | NC | NC | NC | GD | GD | -15 | -15 | NC | NC | +5 | +5 | NC | NC | Bit 7 | Bit 6 | Bit 5 | Bit 4 | Bit 3 | Bit 2 | Bit 1 |

***TABLE 1. Edge Connections for Cards AC1637 and AC1656 When Used to Hold SCDX or RCDX Modules***

BIT WEIGHT TABLE

| Bit Number | Weight in Degrees |
|---|---|
| 1 (MSB) | 180.0000 |
| 2 | 90.0000 |
| 3 | 45.0000 |
| 4 | 22.5000 |
| 5 | 11.2500 |
| 6 | 5.6250 |
| 7 | 2.8125 |
| 8 | 1.4063 |
| 9 | 0.7031 |
| 10 | 0.3516 |
| 11 | 0.1758 |
| 12 | 0.0879 |
| 13 | 0.0439 |
| 14 | 0.0220 |

## APPLICATIONS

The SCDX so far described has an input angle $\theta$ from Synchro lines and a digital input angle $\phi$, the output is either resolver or synchro signals representing the angle $(\theta - \phi)$. Alternative types of SCDX are available in which the output due to the input angles $\theta$ and $\phi$ is synchro or resolver signals representing $(\theta + \phi)$. With the availability of SCDX units which can either add or subtract the input angles a greater flexibility of application is available. A common and obvious application for the SCDX is to add computer provided angular information to synchro wires. The example of application shown here has been chosen to show how apart from coupling in and out of computer systems, the advent of angle to digital conversion and visa versa has generated applications which do not have simple electromechanical equivalents.

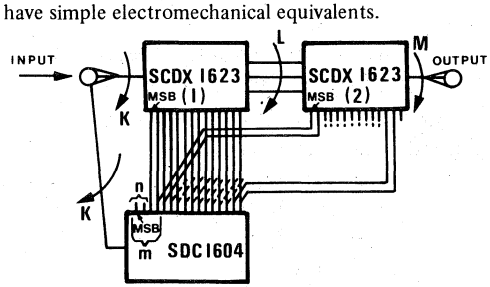



***Figure 4. "Gear-Box" Using SCDX Modules***

Fig. 4 Shows three interconnected modules i.e. two SCDX's and one synchro to digital converter. The inputs and outputs are either three wire synchro or four wire resolver signals. Modules interconnected in this way are used to give the electrical equivalent of gear changing. K represents the angular rotation of the input signals, L represents the angular rotation of the signals coupling the output of SCDX (1) to the input of SCDX (2) and M represents the angular rotation of the output signals. The coupling between the 16 bit synchro to digital converter and the SCDX (1) has been offset by "n" bits from the M.S.B. As a result of this the rotation L will be given by:–

$$L = K \pm 2^n K \text{-----(1)}$$

In (1) the plus or minus sign will depend upon whether the SCDX (1) is of the type that gives out $\theta + \phi$ or $\theta - \phi$.

The interconnections between the synchro to digital converter and the SCDX (2) have also been staggered by m digits from

the M.S.B. and this means that M will be given by:–

$$M = L \pm 2^m K \text{-----(2)}$$

again the plus or minus sign will depend upon whether the SCDX (2) adds or subtracts.

Combining (1) and (2) gives,

$$M = K(1 \pm 2^n \pm 2^m)$$

For n and m up to 3 all the odd ratios from 3 – 1 to 17 – 1 are possible. For n = O (i.e. direct connection) using an "adding" SCDX (1) and the non-binary even ratios 6 and 10 are obtained for m = 2 and m = 3. Higher ratios can be obtained at the expense of angular resolution by taking n and m greater than 3.

If in Fig. 4 the staggering of the interconnections is reversed i.e. the M.S.B. on the synchro to digital converter is connected to the second M.S.B. on SCDX (1) reduction ratios can be obtained but there will be severe limitations on the total output excursion in angle due to the saw toothed behaviour of the input information to the SCDX's. This difficulty can be overcome by using the system of Fig. 4 in a feed-back loop. Showing the unit of Fig. 4 as a step up ratio box N in Fig. 5 an alternative method of speed reduction is obtained.

With such a system however instability may occur unless the frequency response characteristic of the synchro to digital converter in Fig. 5 is shaped for the particular ratio.

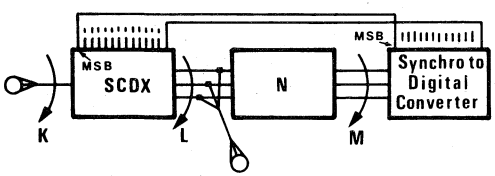



***Figure 5. Reduction Gearing Using Step Up in the Feedback Path***

In Fig. 5 K is the input angle L is the output angle, N is the step up ratio, and the following hold:–

$$M = LN$$
$$L = K - M$$
$$= K - LN$$
$$L = \frac{K}{1+N}$$

giving a ratio of 1 + N. The problem of shaping the frequency response of the synchro to digital converter or putting some dominant lag around the loop should not be overlooked.

An interesting application of the SCDX occurs in providing a local method of deviating or biasing a controlled system, for example a radar antenna. Fig. 6 shows a system for controlling an output rotation from a digital input. The unit marked SSCT is a solid state control transformer which is another module produced by Analog Devices. This module, the SSCT, is the equivalent of its electromechanical counterpart. It has as inputs an angle in synchro format $\theta$ and a control angle $\phi$ in digital form. It gives out a carrier voltage with an amplitude proportional to sin $(\theta - \phi)$. By using a phase sensitive detector shown as A and a D.C. motor system the control loop is formed. The output shaft will take up an angle demanded by the digital input angle $\phi$.

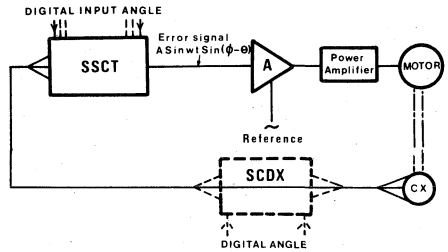



***Figure 6. The Use of an SCDX to Produce an Offset Angle Inside a Control Loop***

If an SCDX is inserted in the loop as shown by the dotted lines, the setting of the output angle will be determined by both the input digital angle $\phi$ and the digital angle $\alpha$, being either the sum or difference according to how the SCDX is connected. The input angle $\alpha$ applies a shift in angle equivalent to altering the mechanical connection between the antenna and the electromechanical control transmitter or adding an angle to the input demand. Such a scheme could be very useful in the initial stages of on site commissioning of equipment.

## ORDERING INFORMATION

The module numbers RCDX 1623 and SCDX 1623 must be followed by a code XYZ defining the requirements in more detail. X signifies temperature range, Y signifies the frequency of operation and Z determines the signal and reference voltage levels. XY and Z **must** be replaced by numbers following the number 1623 where:–

X = 5 signifies temperature range 0 to 70°C
X = 6 signifies temperature range –55°C to + 105°C

Y = 1 signifies reference frequency of 400Hz
Y = 2 signifies reference frequency of 60Hz

Z = 1 signifies synchro signal voltage 11.8 volts, reference 26.0 volts (Y must equal 1)
Z = 2 signifies synchro signal voltage 90.0 volts, reference 115.0 volts (Y may equal 1 or 2)
Z = 3 signifies resolver signal voltage 11.8 volts, reference 11.8 volts (Y must equal 1)
Z = 4 signifies resolver signal voltage 26.0 volts, reference 26.0 volts (Y must equal 1)
Z = 5 signifies resolver signal voltage 90.0 volts, reference 90.0 volts (Y may equal 1 or 2)
Z = 6 signifies resolver signal voltage 115.0 volts, reference 115.0 volts (Y may equal 1 or 2)
Z = 8 signifies resolver signal voltage 11.8 volts, reference 26 volts (Y must equal 1)
Z = 9 signifies resolver signal voltage 5.0 volts (SCDX only) (Y must equal 1)

EXAMPLE: RCDX 1623/514 is for a solid state control transmitter with resolver inputs, suitable for operation over the temperature range 0 to 70°C working at 400Hz with 26.0 volts signal and 26.0 volts reference.

**Transformer module.** For 60Hz operation the transformer module STM 1671/XYZ is required where the XYZ are as above.

**Mounting Cards.** For plug-in mounting cards order:
AC 1656 – for 60Hz units, AC 1637 – for 400Hz units

# ANALOG DEVICES

# Low Profile Synchro/Resolver-to-Digital Converter

# SDC1700/1702/1704 SERIES

## FEATURES

- Internal Microtransformers for 60Hz, 400Hz and 2.6kHz References
- Low Profile (0.4")
- 10-, 12- or 14-Bit Resolution for 360°
- High Tracking Rates (75 revs/sec)
- Voltage Scaling with External Resistors (Unique Feature)
- DC Voltage Output Proportional to Angular Velocity
- Low Cost
- Lightweight 3oz. (85 grams)
- MIL Spec/Hi Rel Options Available

## APPLICATIONS

- Servo Mechanisms
- Retransmission Systems
- Coordinate Conversion
- Antenna Monitoring
- Simulation
- Industrial Controls
- Fire Control Systems
- Machine Tool Control Systems

## GENERAL DESCRIPTION

The SDC1700, SDC1702 and SDC1704 are modular, continuous tracking Synchro/Resolver-to-Digital Converters which employ a type 2 servo loop.

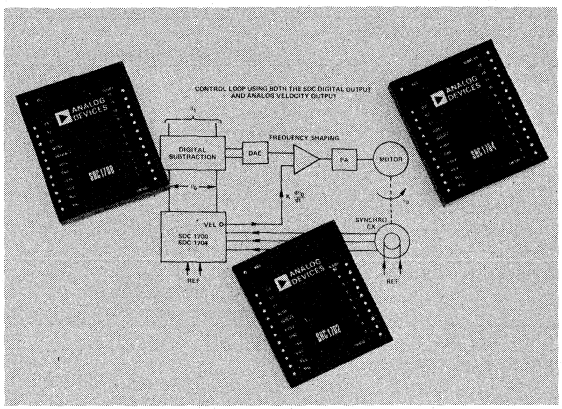
They are intended for use in both Industrial and Military applications.

The input signals can be either 3 wire synchro plus reference or 4 wire resolver plus reference, depending on the option. The outputs will be presented in TTL compatible, parallel natural binary.

One of the outstanding features of the converters is the use of precision Scott T and reference microtransformers. *This has made it possible to include the transformers within the module, even on the 60Hz option, and yet still maintain the profile height of 0.4".*

Particular attention has been paid in the design, to achieving the highest tracking rates and accelerations possible, compatible with the resolution and carrier frequency used, while at the same time obtaining a high overall accuracy.

When SDC's are used in control loops, it is often useful to have a voltage which is proportional to angular velocity. This voltage is available and has been brought out on all the SDC1700 converters.




Extended temperature range versions of all the converters are available.

## MODELS AVAILABLE

The three Synchro-to-Digital Converters described in this data sheet differ primarily in the areas of resolution, accuracy and dynamic performance as follows:

Model SDC1702XYZ is a 10-bit converter which has an overall accuracy of ±22 arc-minutes and a resolution of 21 arc-minutes.

Model SDC1700XYZ is a 12-bit converter with an overall accuracy of ±8.5 arc-minutes and a resolution of 5.3 arc-minutes.

Model SDC1704XYZ is a 14-bit converter with an overall accuracy of ±2.2 arc-minutes ±1LSB and a resolution of 1.3 arc-minutes.

The XYZ code defines the option thus: (X) signifies the operating temperature range, (Y) signifies the reference frequency, (Z) signifies the input voltage and range, and whether it will accept synchro or resolver format.

More information about the option code is given under the heading of "Ordering Information".

NOTE
**For all the standard options, no external transformers are needed with these converters.**

13

# SPECIFICATIONS (typical @ +25°C unless otherwise noted)

| MODELS | SDC1702 | SDC1700 | SDC1704 |
|---|---|---|---|
| ACCURACY[1] (max error) | | | |
| 60Hz | ±22 arc-minutes | ±8.5 arc-minutes | ±2.9 arc-minutes ±1LSB |
| 400Hz | ±22 arc-minutes | ±8.5 arc-minutes | ±2.2 arc-minutes ±1LSB |
| 2.6kHz | ±22 arc-minutes | ±8.5 arc-minutes | ±2.9 arc-minutes ±1LSB |
| RESOLUTION | 10 Bits (1LSB = 21 arc-mins) | 12 Bits (1LSB = 5.3 arc-mins) | 14 Bits (1LSB = 1.3 arc-mins) |
| OUTPUT (In Parallel) | 10 Bits (Natural Binary) | 12 Bits (Natural Binary) | 14 Bits (Natural Binary) |
| SIGNAL AND REFERENCE FREQUENCY | 60Hz, 400Hz, 2.6kHz | * | * |
| SIGNAL VOLTAGE (Line-to-Line) | | | |
| Low Level | 11.8V rms | * | * |
| High Level | 90V rms | * | * |
| SIGNAL IMPEDANCES | | | |
| Low Level | 26kΩ (Resistive) | * | * |
| High Level | 200kΩ (Resistive) | * | * |
| REFERENCE VOLTAGE | | | |
| Low Level | 26V (11.8V Signal) | * | * |
| High Level | 115V (90V Signal) | * | * |
| REFERENCE IMPEDANCE | 270kΩ (115V Signal) | * | * |
| | 56kΩ (26V Reference) | * | * |
| | (Impedance is Resistive) | * | * |
| TRANSFORMER ISOLATION | 500V dc | * | * |
| TRACKING RATE (min) | | | |
| 60Hz | 5 Revolutions Per Second | * | 500°/sec |
| 400Hz | 36 Revolutions Per Second | * | 12 Revolutions Per Second |
| 2.6kHz | 75 Revolutions Per Second | * | 25 Revolutions Per Second |
| Accel.[1] Constant $K_a$ | | | |
| 60Hz | 1880/sec² | * | 520/sec² |
| 400Hz | 110,000/sec² | * | 36,000/sec² |
| 2.6kHz | 518,000/sec² | * | 170,000/sec² |
| STEP RESPONSE (179° Step) (For 1LSB Error) | | | |
| 60Hz | 1.5sec | * | * |
| 400Hz | 125ms | * | * |
| 2.6kHz | 50ms | * | * |
| POWER LINES | ±15V @ 25mA, +5V @ 70mA (±5%) | * | ±15V @ 30mA, +5V @ 85mA (±5%) |
| POWER DISSIPATION | 1.1 Watts | * | 1.3 Watts |
| DATA LOGIC OUTPUT[2] (TTL Compatible) | 2TTL Loads SDC17026YZ<br>4TTL Loads SDC17025YZ | 2TTL Loads SDC17006YZ<br>4TTL Loads SDC17005YZ | 2TTL Loads on All Options |
| BUSY LOGIC OUTPUT, POSITIVE PULSE (1 TTL Load) | | | |
| 60Hz | 9.0μs (±30%) | * | 9.0μs (±30%) |
| 400Hz | 2.0μs (±30%) | * | 2.0μs (±30%) |
| 2.6kHz | 2.0μs (±30%) | * | 1.3μs (±30%) |
| MAX DATA TRANSFER TIME | | | |
| 60Hz | 40μs | * | 35μs |
| 400Hz | 5.0μs | * | 3.0μs |
| 2.6kHz | 1.8μs | * | 0.8μs |
| INHIBIT INPUT (To Inhibit) | Logic "0" 1 TTL Load | * | Logic "0" 2 TTL Loads |
| WARM UP TIME | 1 sec to Rated Accuracy | * | * |
| TEMPERATURE RANGE | | | |
| Operating | 0 to +70°C Standard | * | * |
| | -55°C to +105°C Extended | * | * |
| Storage | -55°C to +125°C | * | * |
| DIMENSIONS | 3.125" x 2.625" x 0.4" (79.4 x 66.7 x 10.2mm) | * | * |
| WEIGHT | 3 ozs. (85 grams) | * | * |

NOTES
*Specifications same as SDC1702.
[1] Specified over the appropriate operating temperature range of the option and for: (a) ± 10% signal and reference amplitude variation (b) 10% signal and reference Harmonic Distortion (c) ±5% power supply variation (d) ±10% variation in reference frequency.
[2] It is recommended that buffers should be used if the above converters are required to drive over a distance greater than 6".

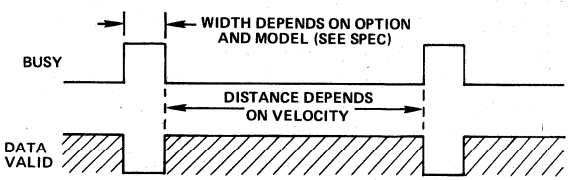
Specifications subject to change without notice.

## DATA TRANSFER (All Models)

The readiness of the converters for data transfer is indicated by the state of the BUSY pin.

The voltage appearing on the BUSY pin consists of a train of pulses, at TTL levels, of length according to the model and option (see specification table). The converter is busy when the BUSY pin is at a TTL "High" level. These pulses correspond to those delivered by the VCO to increment or decrement the up-down counter (see schematic diagram). Thus the pulses will occur for increasing and decreasing counts.

The most suitable time for transferring data is when the BUSY is at a logic "Lo" state, and the times allowable for data transfer are shown in the specification. Even at the maximum speed of the option, these times will be sufficient to transfer data before the next BUSY pulse occurs.




*Data Transfer Diagram*

## DATA TRANSFER DIAGRAM

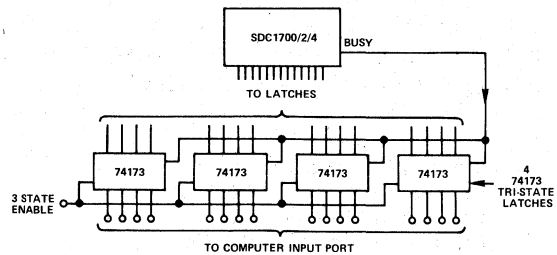
Taking the INHIBIT to a logic "Lo" state prevents the VCO (BUSY) pulses from updating the up-down counter. However, if applied during a BUSY pulse, the INHIBIT will not become effective until the end of the BUSY pulse.

The best method of transferring the data is by applying the INHIBIT (taking it to a logic "Lo" state), waiting for at least the width of a BUSY pulse, transferring the data and releasing the INHIBIT.

Note that sustained application of the INHIBIT opens the internal control loop and the converter may take on appreciable time to recover to full accuracy when the loop is restored.

## INTERFACING WITH A COMPUTER

It is recommended that external latches are used to enable data to be transferred onto a computer data bus. One method is shown in the diagram. Using this method will mean that the latches are constantly updated by the BUSY signal, while at the same time enabling inputs to be made to the computer by means of normal data transfer procedures. The AC1755 mounting card contains these external components.




*Suggested External Computer Interface Circuitry*

## THEORY OF OPERATION

If the unit is a Synchro-to-Digital Converter, then the 3 wire synchro output will be connected to S1, S2 and S3 on the module and the Scott T transformer pair will convert these signals into resolver format.

i.e., $V_1 = K E_O \sin \omega t \sin \theta$

$V_2 = K E_O \sin \omega t \cos \theta$

Where $\theta$ is the angle of the Synchro Shaft.

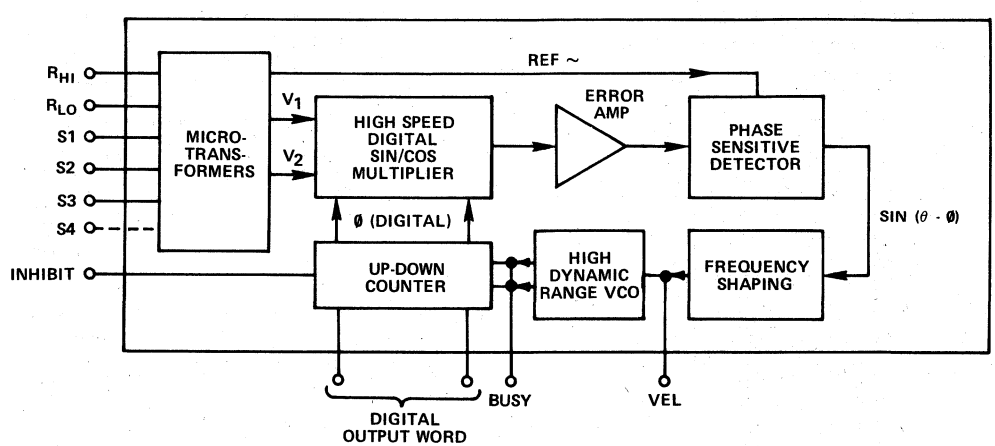
If the unit is a Resolver-to-Digital Converter, then the 4 wire resolver output will be connected to S1, S2, S3 and S4 on the module and the microtransformer will act purely as an isolator.

To understand the conversion process, then assume that the current word state of the up-down counter is $\phi$.

The $V_1$ is multiplied by Cos $\phi$ and $V_2$ is multiplied by Sin $\phi$ to give

$K E_O \sin \omega t \sin \theta \cos \phi$

and $K E_O \sin \omega t \cos \theta \sin \phi$




*Functional Diagram of the SDC1700/2/4 Converters*

These signals are subtracted by the error amplifier to give:

$$K E_O \text{ Sin } \omega t \text{ (Sin } \theta \text{ Cos } \phi - \text{Cos } \theta \text{ Sin } \phi)$$

or $$K E_O \text{ Sin } \omega t \text{ Sin } (\theta - \phi)$$

A phase sensitive detector, integrator and Voltage Controlled Oscillator (VCO) form a closed loop system which seeks to null Sin $(\theta - \phi)$.

When this is accomplished, the word state of the up-down counter $(\phi)$, equals within the rated accuracy of the converter, the synchro shaft angle $\theta$.

## CONNECTING THE CONVERTER

The electrical connections to the converter are straightforward. The power lines, which must not be reversed, are ±15V and 5V. They must be connected to the "±15V" and "5V" pins with the common connection to the ground pin GND.

It is suggested that 0.1μF and 6.8μF capacitors be placed in parallel from +15V to GND, from -15V to GND and from +5V to GND.

The digital output is taken from pins:

1 through to 10 for the SDC1702
1 through to 12 for the SDC1700
1 through to 14 for the SDC1704

Pin 1 represents the MSB in each case. The reference connections are made to pins "$R_{HI}$" and "$R_{LO}$".

In the case of a Synchro, the signals are connected to "S1", "S2" and "S3" according to the following convention:

$$E_{S1-S3} = E_{RLO-RHI} \text{ Sin } \omega t \text{ Sin } \theta$$
$$E_{S3-S2} = E_{RLO-RHI} \text{ Sin } \omega t \text{ Sin } (\theta + 120^\circ)$$
$$E_{S2-S1} = E_{RLO-RHI} \text{ Sin } \omega t \text{ Sin } (\theta + 240^\circ)$$

For a resolver, the signals are connected to "S1", "S2", "S3" and "S4" according to the following convention:

$$E_{S1-S3} = E_{RLO-RHI} \text{ Sin } \omega t \text{ Sin } \theta$$
$$E_{S2-S4} = E_{RHI-RLO} \text{ Sin } \omega t \text{ Cos } \theta$$

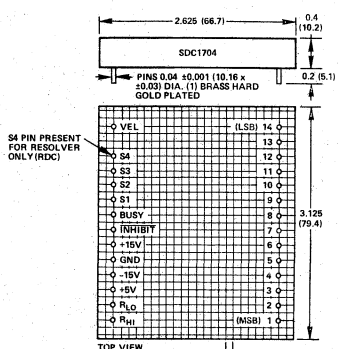
The analog voltage representing velocity is available between "VEL" and "GND".

The "BUSY" and "INHIBIT" pin (if used), should be connected as described under the heading "Data Transfer".

NOTE: If the INHIBIT pin is used (i.e., driven to 0 volts), the control loop will be opened and a finite time will be required (see spec) for the converter to recover.

### OUTLINE DIMENSIONS AND PIN CONNECTION DIAGRAM

**Dimensions are shown in inches and (mm).**




NOTE
ABOVE DIAGRAM ILLUSTRATES CONNECTIONS FOR SDC1704.
FOR SDC1700, PINS 13 AND 14 ARE OMITTED. PIN 12 IS LSB.
FOR SDC1702, PINS 11, 12, 13, 14 ARE OMITTED. PIN 10 IS LSB.

**MATING SOCKET: CAMBION 450-3388-01-03**

## RESISTIVE SCALING OF INPUTS

A unique feature of the SDC1700 series of converters is that the inputs can be resistively scaled to accommodate any range of input signal and reference voltages.

This means that a standard converter can be used with a personality card in systems where a wide range of input and reference voltages are encountered. In addition it should be noted that a 400Hz unit will operate from a 2.6kHz reference. It will however have the velocity and acceleration characteristics as specified for the 400Hz converter. A 60Hz converter will operate from a 400Hz reference and will have the velocity and acceleration characteristics as specified for the 60Hz converter.

To calculate the values of the external scaling resistors for a synchro converter, add 1.11kΩ in series with S1, S2 and S3 per extra volt in the case of the signal, and 2.2kΩ in the case of the reference. In the case of a resolver converter add 2.22kΩ per extra volt in series with S1 and S2 for the signal and 2.2kΩ per extra volt in series with $R_{HI}$ for the reference.

For example, assume that we have an 11.8 volt line to line signal/26.0 volt reference converter, and we wish to use a 60 volt line to line signal with a 115 volt reference.

Thus in each signal input line, the extra voltage capability required is:

60 - 11.8 = 48.2 volts

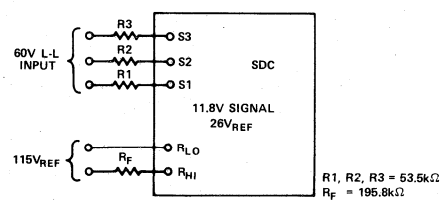
Therefore each resistor needs to have a value of 48.2 x 1.11 = 53.5kΩ. In the case of the reference, the extra voltage capability required is:

115 - 26.0 = 89 volts

Therefore the resistor needs to have a value of:

89.0 x 2.2 = 195.8kΩ

Thus the inputs can be scaled as in the diagram below.




NOTE
IN THE CASE OF R1, R2 AND R3, THE RATIO ERRORS BETWEEN THE RESISTANCES IS MORE IMPORTANT THAN THE ABSOLUTE RESISTANCE VALUES.

IN GENERAL A 1% RATIO ERROR WILL GIVE RISE TO AN EXTRA INACCURACY OF 17 ARC-MINUTES WHILE A RATIO ERROR OF 0.1% WILL GIVE RISE TO AN EXTRA INACCURACY OF 1.7 ARC-MINUTES.

THE ABSOLUTE VALUE OF $R_F$ IS NOT CRITICAL.

### BIT WEIGHT TABLE

| Bit Number | Weight in Degrees |
|---|---|
| 1 (MSB) | 180.0000 |
| 2 | 90.0000 |
| 3 | 45.0000 |
| 4 | 22.5000 |
| 5 | 11.2500 |
| 6 | 5.6250 |
| 7 | 2.8125 |
| 8 | 1.4063 |
| 9 | 0.7031 |
| 10 (LSB for SDC1702) | 0.3516 |
| 11 | 0.1758 |
| 12 (LSB for SDC1700) | 0.0879 |
| 13 | 0.0439 |
| 14 (LSB for SDC1704) | 0.0220 |

## VELOCITY PIN

This pin provides a voltage output which is proportional to the angular velocity of the input. The voltage goes negative for an increasing digital angle and goes positive for a decreasing digital angle.

The characteristics of the velocity pin output are given in the table below.

| | |
|---|---|
| Scaling of Output Voltage for One Fifth max Velocity | 2Volts (Nominal) |
| Output Voltage Temp. Coeff. | 0.05%/°C of Output |
| Output Voltage Drift (All Models) | 0 to +70°C ±50μV/°C<br>-55°C to +105°C ±100μV/°C |
| Linearity: | 0°/sec to 800°/sec SDC1704 400Hz 1%<br>0°/sec to 100°/sec SDC1704 60Hz 1%<br>0°/sec to 800°/sec SDC1700/2 400Hz 2%<br>0°/sec to 100°/sec SDC1700/2 60Hz 1.5% |
| Noise: (0 to 20Hz) | @1600°/sec SDC1700/2/4 400Hz 2mV rms<br>@200°/sec SDC1700/2/4 60Hz 2mV rms |
| Impedance (Output) | 1Ω |
| max Current Available | 1mA |

The velocity voltage can be used in closed loop servo systems for stabilization instead of a tachometer.

The SDC1700/2/4 velocity outputs do not have the disadvantages of being inefficient at low speeds and do not need gearing required by tachometers. In addition, the output is available at no extra cost.

*For other velocity output scaling and linearity consult the factory.*

Two examples of the use of the velocity pin are shown in the diagram below.

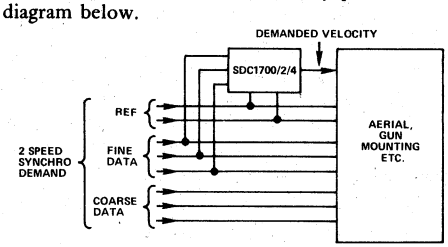



*Diagram showing a velocity feed forward application. The SDC is used to produce the demanded velocity from Synchro form inputs.*

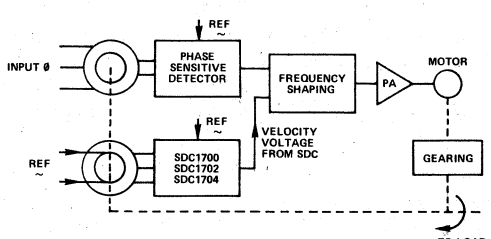
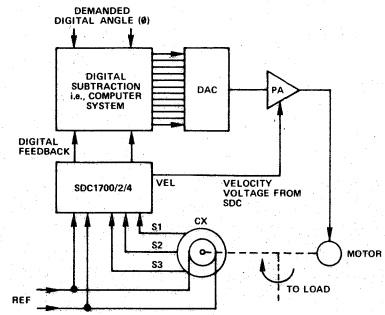



*Diagram showing the velocity voltage being used to stabilize an electro-mechanical control loop*

## APPLICATIONS OF SYNCHRO-TO-DIGITAL CONVERTERS

SDCs can be used in a variety of ways in control loops as well as for the conversion of angular data into a form which is readily acceptable to digital displays or computers.

The diagram below shows an SDC being used in a digitally controlled feedback loop.




*An SDC Being Used in a Digitally Controlled Feedback Loop*

Such loops as shown in the diagram above require the high dynamic performance of the SDC1700 series converters. It should be noted that in this application, the SDC1700 series will replace conventional tachometers and phase sensitive detectors while at the same time provide digital position feedback.

Many synchro systems employ a two speed, geared arrangement utilizing one synchro for the fine shaft and one for the coarse. An example of this type is shown below.

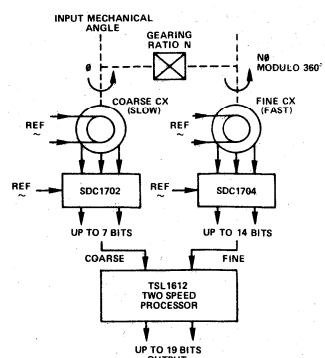



*Diagram Showing Coarse/Fine Synchro Processor System*

In the above example, two tracking SDC's are being used to provide data for coarse/fine (two speed) data transmission systems.

The TSL1612 is a processor which combines the outputs of two SDC's to provide one output word of up to 19 bits in length.

The TSL1612 is available for any ratio between 2:1 and 36:1 and provides automatic compensation for misalignment of the coarse synchro relative to its shaft. It also corrects for any overlap between the digits of the coarse and fine shafts.

## MEAN TIME BETWEEN FAILURES (M.T.B.F.)

The estimated mean time between failures is given as follows:

| | |
|---|---|
| SDC1700/2 | 174,000 Hours |
| SDC1704 | 167,000 Hours |

Further information relating to M.T.B.F. and to the quality control and test procedures employed by us can be obtained from the factory on request.

## TRANSFER FUNCTION

The transfer function of the SDC1700/2 and SDC1704, 400Hz versions, is given below.

For the transfer functions of the other models or for a detailed analysis of those given here, please contact us.

SDC1700/2 400Hz

$$\frac{\theta_0}{\theta_1} = \frac{8.8 \times 10^7 \,(1 + 6.8 \times 10^{-3} s)}{s^3 + 8.04 \times 10^2 s^2 + 6.1 \times 10^5 s + 8.8 \times 10^7}$$

SDC1704 400Hz

$$\frac{\theta_0}{\theta_1} = \frac{2.95 \times 10^7 \,(1 + 8.2 \times 10^{-3} s)}{s^3 + 8.05 \times 10^2 s^2 + 1.95 \times 10^5 s + 2.95 \times 10^7}$$

## CARD MOUNTING

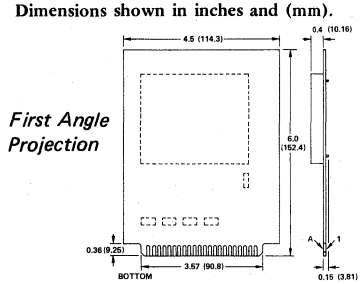
All the converters can be mounted on an AC1755 mounting card. This card contains the latches described under the "Data Transfer" heading, which are necessary to transfer the data on to a computer bus system, and sockets for the converter.

The latches have a tri-state output to facilitate ease of use.

The AC1755 also contains facilities for the inclusion of input signal and reference scaling resistors as described under the heading "Resistive Scaling of Inputs".

The card uses a 22/22 0.156" pitch edge connector. The pin out is shown below. If it is not required to use the external latches, they can be jumpered on the board.

**AC1755 MOUNTING CARD**
**Dimensions shown in inches and (mm).**




**EDGE CONNECTIONS AC1755**

| Edge Pin Number | Function | Edge Pin Letter | Function |
|---|---|---|---|
| 1 | R (Lo) | A | Tri-State Enable |
| 2 | R (Hi) | F | +15V |
| 3 | S3 | H | +15V |
| 4 | S2 | J | -15V |
| 5 | S1 | K | -15V |
| 6 | S4 | L | GND |
| 8 | VEL | M | GND |
| 13 | BUSY | N | +5V |
| 15 | INHIBIT | P | +5V |
| 16 | BIT 14 | T | BIT 7 |
| 17 | BIT 13 | U | BIT 6 |
| 18 | BIT 12 | V | BIT 5 |
| 19 | BIT 11 | W | BIT 4 |
| 20 | BIT 10 | X | BIT 3 |
| 21 | BIT 9 | Y | BIT 2 |
| 22 | BIT 8 | Z | BIT 1 |

NOTE: SDC1702 does not use pins 16, 17, 18 or 19. SDC1700 does not use pins 16 and 17.

## ORDERING INFORMATION

Parts should be ordered by the appropriate part number (i.e., SDC1700, SDC1702, SDC1704) followed by the appropriate XYZ option code.

If the unit is to be a Resolver-to-Digital Converter, the SDC should be replaced by RDC in the part number.

The XYZ options are as follows:
X signifies the operating temperature range and the options are:

X = 5 signifies 0 to +70°C (commercial) temperature.
X = 6 signifies -55°C to +105°C (extended) temperature.

Y signifies the reference frequency and the options are:

Y = 1 signifies 400Hz
Y = 2 signifies 60Hz *
Y = 4 signifies 2.6kHz

Z signifies the input signal and reference voltages and whether the converter is an SDC or an RDC. The options are:

Z = 1 signifies synchro, signal 11.8V rms, reference 26V rms
Z = 2 signifies synchro, signal 90V rms, reference 115V rms
Z = 3 signifies resolver, signal 11.8V rms, reference 11.8V rms
Z = 4 signifies resolver, signal 26V rms, reference 26V rms
Z = 8 signifies resolver, signal 11.8V rms, reference 26V rms

Thus, for example, an SDC1704 with a commercial (0 to +70°C) operating range, using a 400Hz, 26V reference with an 11.8V signal would be ordered as an SDC1704511.

For other than these options, consult the factory.

## CAUTIONS

Do not reverse the power supplies.
Do not connect signal and/or reference inputs to other than S1, S2, S3, S4, $R_{HI}$ or $R_{LO}$.

Do not connect signals and/or references to a lower voltage rated converter. (Such as a 115V Synchro into a 26V Converter).

Misconnections as per the above will damage the units and void the warranty.

## OTHER PRODUCTS

The SDC1700/2/4 converters are just a few of the modules and instruments concerned with Synchro and Resolver conversion manufactured by us.

Other products are listed below and technical data is available. If you have any questions about our products, or require advice about the use of them for a particular application, please contact our Applications Engineering Department.

## TWO SPEED PROCESSORS

Which utilize the digital outputs of two SDCs in a 2 speed coarse/fine system to produce one combined digital word of up to 19 bits in length. The TSL1612 in particular is available for any ratio between 2:1 and 36:1.

## DIGITAL-TO-SYNCHRO CONVERTERS

Resolutions of between 10 and 14 bits are available.

## BCD OUTPUT SYNCHRO-TO-DIGITAL CONVERTERS

The SBCD1752 and SBCD1753 are converters with a BCD instead of a binary output based upon the SDC1700. They have outputs of ±180.0 degrees and 0 to 360.0 degrees respectively.

*50Hz Operation

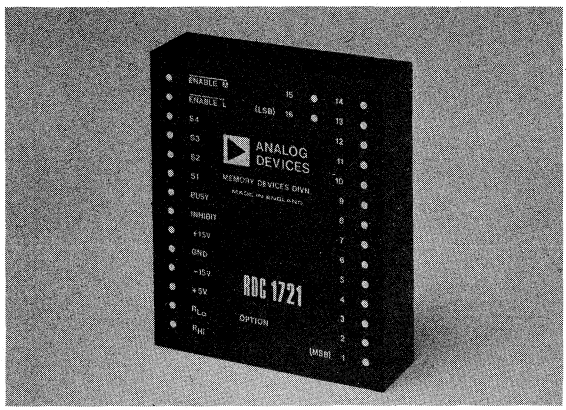
For 50Hz operation, a 60Hz converter can be used with no reduction in accuracy.

# 16-Bit, High Accuracy Three-State Latched Output Synchro-to-Digital Converters

## SDC/RDC1721

**FEATURES**
- High Accuracy ±40 arc-sec
- 16-Bits Resolution
- Three State Latched Output
- Simple Data Transfer
- Internal Transformers
- Continuous Tracking—Even During Data Transfer
- Extended Temp Range Options Available

**APPLICATIONS**
- Replacing Two Speed Systems
- Test Equipment
- Servo Mechanisms
- Antenna Monitoring
- Simulation
- Artillery Fire Control Systems




### GENERAL DESCRIPTION

The SDC1721 is a 16-bit output, high accuracy, continuous tracking Synchro- or Resolver-to-Digital Converter with three state latched outputs. The converter employs a type 2 Servo Loop and is accurate to ±40 arc-secs.

The input signals can be either 3 wire synchro plus reference or 4 wire resolver plus reference depending on the option. The outputs will be present in TTL compatible parallel natural binary, buffered by three-state latches.

The three-state output facility not only simplifies multiplexing of more than one device onto a single data bus but also enables the "$\overline{\text{INHIBIT}}$" to be used without opening the internal converter loop.

The SDC1721 is available in a 400Hz to 2.6kHz option as standard and contains internal transformers which provide isolation on the signal and reference inputs.

The converter requires no external trims or adjustment components.

### MODELS AVAILABLE

Options of the SDC1721 are available to cover the standard Synchro and Resolver voltages as well as standard and extended temperature ranges.

More information about the options available and their ordering code is given under the heading of "Ordering Information".

### THEORY OF OPERATION

If the unit is a Synchro-to-Digital Converter the 3 wire synchro output will be connected to S1, S2 and S3 on the module and the Scott T transformer pair will convert these signals into resolver format.

i.e., $V_1 = K E_O \sin \omega t \sin \theta$

$V_2 = K E_O \sin \omega t \cos \theta$

Where $\theta$ is the angle of the synchro shaft.

If the unit is a Resolver-to-Digital Converter, the 4 wire resolver output will be connected to S1, S2, S3 and S4 on the module and the microtransformers will act purely as isolators.

13

To understand the conversion process, assume that the current word state of the up-down counter is $\phi$.

Then $V_1$ is multiplied by $\cos \phi$ and $V_2$ is multiplied by $\sin \phi$ to give:

$$K E_O \sin \omega t \sin \theta \cos \phi$$

and

$$K E_O \sin \omega t \cos \theta \sin \phi$$

These signals are subtracted by the error amplifier to give:

$$K E_O \sin \omega t (\sin \theta \cos \phi - \cos \theta \sin \phi)$$

or

$$K E_O \sin \omega t \sin (\theta - \phi)$$

A phase sensitive detector, integrator and voltage controlled oscillator (VCO) form a closed loop system which seeks to null $\sin (\theta - \phi)$.

# SPECIFICATIONS (typical @ +25°C unless otherwise noted)

| Model | SDC/RDC1721 |
|---|---|
| ACCURACY[1] | ±40 arc-seconds |
| RESOLUTION | 16 Bits (1LSB = 19.8 arc-seconds) |
| OUTPUT | 16-Bits Parallel Natural Binary |
| SIGNAL AND REFERENCE FREQUENCY | 360Hz–2.9kHz |
| SIGNAL VOLTAGE (Line to Line) | 11.8V rms<br>26V rms<br>90V rms |
| SIGNAL IMPEDANCES<br>11.8V Signal<br>26V Signal<br>90V Signal | <br>200kΩ min<br>500kΩ min<br>1MΩ min |
| REFERENCE VOLTAGE | 11.8V rms<br>26V rms<br>115V rms |
| REFERENCE IMPEDANCE (Resistive)<br>11.8V Reference<br>26V Reference<br>115V Reference | <br>27kΩ<br>56kΩ<br>270kΩ |
| TRANSFORMER ISOLATION | 500V dc |
| ALLOWABLE PHASE SHIFT BETWEEN SIGNAL AND REFERENCE | ±20 deg |
| TRACKING RATE (Minimum) | 3 Revolutions Per Second |
| ACCELERATION<br>Constant $K_a$ | <br>55,000/sec$^2$ |
| STEP RESPONSE (179° Step)<br>(For 1LSB Error) | <br>250ms |
| POWER LINES | +15V @ 45mA typ (80mA max)<br>−15V @ 45mA typ (80mA max)<br>+5V @ 110mA typ (250mA max) |
| POWER DISSIPATION | 1.9 Watts typ (3.65 Watts max) |
| DATA LOGIC OUTPUTS[2]<br>(TTL Compatible) | <br>6TTL Loads all Options |
| BUSY LOGIC OUTPUT LOADING[2] | 2TTL Loads |
| BUSY LOGIC OUTPUT WIDTH[2] | 330ns max |
| $\overline{\text{INHIBIT}}$ INPUT (TO INHIBIT) | Logic "0" 1TTL Load |
| $\overline{\text{ENABLE}}$ INPUTS (TO ENABLE)[3] | Logic "0" 1TTL Load |
| WARM-UP TIME | 5sec to Rated Accuracy |
| TEMPERATURE RANGE<br>Operating<br><br>Storage | <br>0 to +70°C Standard<br>−55°C to +70°C Extended<br>−55°C to +125°C |
| DIMENSIONS | 3.125" X 2.625" X 0.8"<br>(79.4 X 66.7 X 20.3mm) |
| WEIGHT | 3.3 ozs (93 G) |

NOTES

[1] Specified for: (a) ±10% signal and reference amplitude variation; (b) 10% signal and reference harmonic distortion; (c) ±5% power supply variation; and (d) ±10% variation in reference frequency.

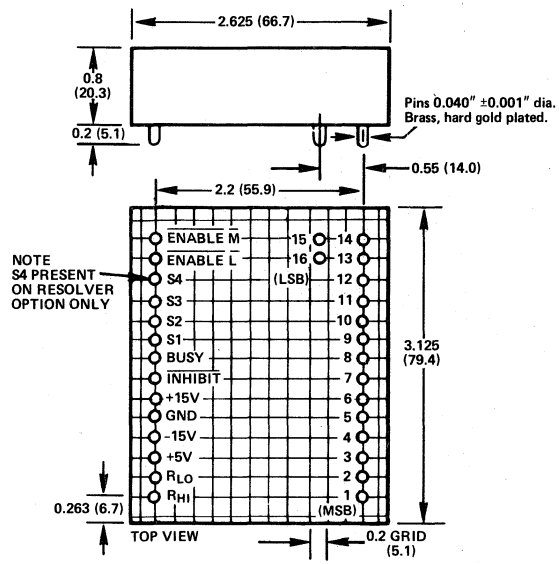
[2] Schottky logic loading rules apply.

[3] $\overline{\text{ENABLE}}$ M enable most significant 8 bits. $\overline{\text{ENABLE}}$ L enable least significant 8 bits.

Specifications subject to change without notice.

## CONVERTER OUTLINE DIMENSIONS AND PIN CONNECTION DIAGRAM

Dimensions shown in inches and (mm).




## ABSOLUTE MAXIMUM VOLTAGES

$R_{HI}$ to $R_{LO}$ . . . . . ±50% V* rms
Signal Inputs . . . . . ±50% V* rms
(Line to Line)
+15V Pin . . . . . +17V
−15V Pin . . . . . −17V
+5V Pin . . . . . −0.4V to 7V
Any Logic Inputs . . . . . −0.4V to +5.5V

*where V is voltage option

When this is accomplished, the word state of the up-down counter ($\phi$) equals, within the rated accuracy of the converter, the synchro shaft angle $\theta$.

Assuming that the "INHIBIT" is at a logic high state, then the digital word $\phi$ will be strobed into the latches 150ns after the up-down counter has been updated. If the three state ENABLE $\overline{M}$ and $\overline{L}$ are at a logic low, then the digital output word will be presented to the output pins of the module.

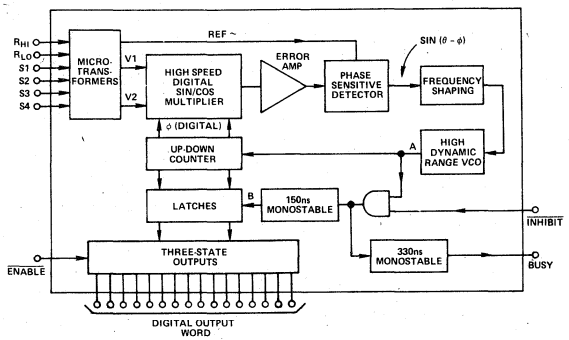



*Figure 1. Functional Diagram RDC1721*

| Bit Number | Weight in Degrees |
|---|---|
| 1 (MSB) | 180.00000 |
| 2 | 90.00000 |
| 3 | 45.00000 |
| 4 | 22.50000 |
| 5 | 11.25000 |
| 6 | 5.62500 |
| 7 | 2.81250 |
| 8 | 1.40625 |
| 9 | 0.70313 |
| 10 | 0.35156 |
| 11 | 0.17578 |
| 12 | 0.08789 |
| 13 | 0.04395 |
| 14 | 0.02197 |
| 15 | 0.01099 |
| 16 | 0.00549 |

*Bit Weight Table*

## DATA TRANSFER

Data transfer from the SDC1721 is very straightforward.

Consider the timing sequence shown in the timing diagram, Figure 2 which assumes that the input to the converter is changing.

From this diagram, it can be seen that there are two ways to transfer data.

One method is to detect the state of the BUSY signal, which is high for 330ns while the up-down counters and latches are settling, and transfer data when it is in a low state.

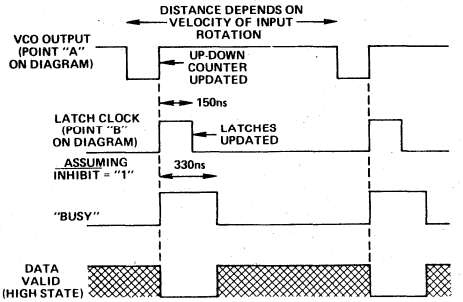



*Figure 2. Timing Diagram*

However, a much more satisfactory method is to use the "INHIBIT" inputs. As can be seen from the functional diagram application of the "INHIBIT" prevents the two monostables being triggered and consequently the latches being updated. Therefore, it follows that data will always be valid from 330ns after the INHIBIT has been taken to a logic low state, see Figure 3. It can also be seen that this method of data transfer is valid regardless of when the INHIBIT is applied.

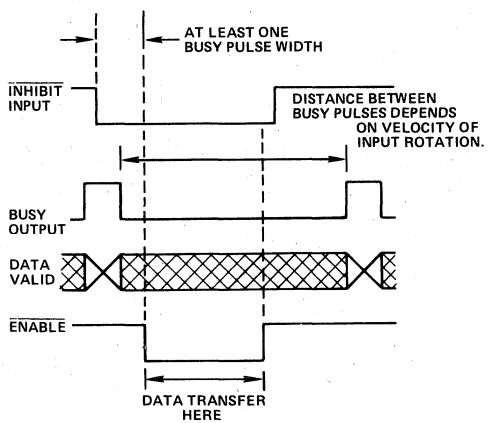



*Figure 3. Diagram Showing Data Transfer Using the "INHIBIT" Input*

The three-state ENABLE can be used at any time in order to present the data in the latches to the output pins. ENABLE $\overline{M}$ enables the most significant 8 bits while ENABLE $\overline{L}$ enables the least significant 8 bits.

Note that the operation of the internal converter loop cannot be affected in anyway by the logic state present on the INHIBIT and ENABLE pins.

13

## CONNECTING THE CONVERTER

The electrical connections to the converter are straightforward. The power lines, which must not be reversed, should be connected to the "+15V", "–15V" and "+5V" pins with the common connection to the ground pin "GND". It is suggested that a parallel combination of a 0.1$\mu$F and a 6.8$\mu$F capacitor is placed in each of the three positions from "+15V" to "GND", from "–15V" to "GND" and from "+5V" to "GND".

The digital output is taken from pins:

"1" through to "16" for the SDC1721

Pin "1" represents the MSB.

The reference connections are made to "$R_{HI}$" and "$R_{LO}$".

In the case of a Synchro the signals are connected to "S1", "S2" and "S3" according to the following convention:

$$E_{S1-S3} = E_{RLO-RHI} \sin \omega t \sin \theta$$
$$E_{S3-S2} = E_{RLO-RHI} \sin \omega t \sin (\theta + 120^\circ)$$
$$E_{S2-S1} = E_{RLO-RHI} \sin \omega t \sin (\theta + 240^\circ)$$

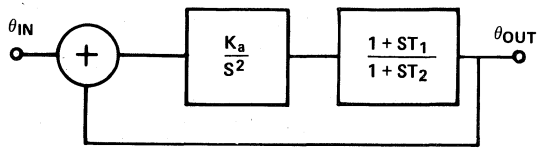
For a resolver, the signals are connected to "S1", "S2", "S3" and "S4" according to the following convention:

$$E_{S1-S3} = E_{RLO-RHI} \sin \omega t \sin \theta$$
$$E_{S2-S4} = E_{RHI-RLO} \sin \omega t \cos \theta$$

The "BUSY", "$\overline{\text{INHIBIT}}$" and "$\overline{\text{ENABLE}}$" pins should be connected as described under the heading "Data Transfer".

## DYNAMIC PERFORMANCE

The transfer function of the converter is given below.




Open loop gain:

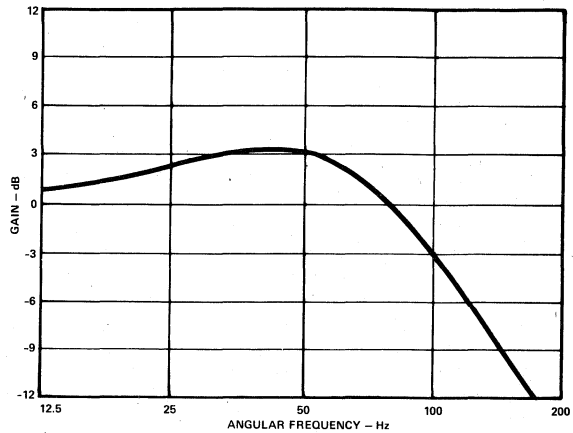
$$\frac{\theta_{OUT}}{\theta_{IN}} = \frac{K_a}{S^2} \cdot \frac{1 + ST_1}{1 + ST_2}$$

Closed loop gain:

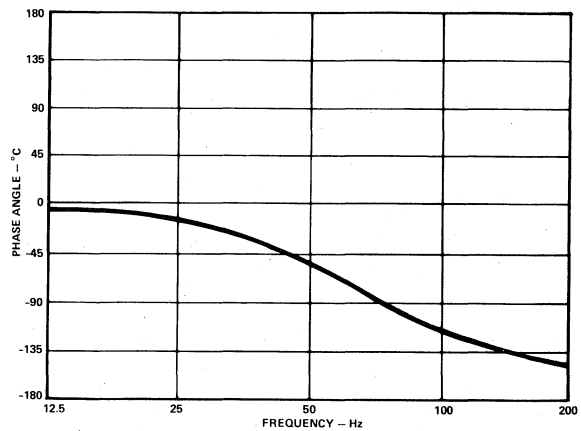
$$\frac{\theta_{OUT}}{\theta_{IN}} = \frac{1 + ST_1}{1 + ST_1 + \frac{S^2}{K_a} + \frac{S^3 T_2}{K_a}}$$

Where:

$K_a$ = 55,000
$T_1$ = 6.8 milliseconds
$T_2$ = 1.22 milliseconds




*Magnitude of Gain vs. Frequency*




*Output Angular Phase vs. Frequency*

## OTHER PRODUCTS

The SDC/RDC1721 is just one of the modules and instruments concerned with Synchro and Resolver conversion manufactured by us. Full technical data and applications literature is available for all products. If you have any questions about our products or require advice about the use of them for a particular application, please contact our Applications Engineering Department.

## ORDERING INFORMATION

When ordering please use the XYZ option code as defined below to fully specify the part number.

**SDC1721XYZ**

SDC = Synchro-to-Digital Converter
RDC = Resolver-to-Digital Converter

| | | | | | |
|---|---|---|---|---|---|
| Z = 1 Signal | 11.8V | Reference | 26V | Synchro |
| Z = 2 Signal | 90V | Reference | 115V | Synchro |
| Z = 3 Signal | 11.8V | Reference | 11.8V | Resolver |
| Z = 4 Signal | 26V | Reference | 26V | Resolver |
| Z = 8 Signal | 11.8V | Reference | 26V | Resolver |

Y = 1 400 Hz Reference Frequency
X = 5 0 to 70°C Operating Temperature Range
X = 6 –55°C to +105°C Operating Temperature Range

# Ultra-Low Profile (0.35″) Three-State Latched Output S-to-D Converters

## SDC1725/1726

### FEATURES
- Three-State Latched Output
- Continuous Tracking Even During Data Transfer
- Simple Data Transfer Facility
- Low Profile 0.35″ (8.9mm)
- Internal Transformers for 60Hz, 400Hz and 2.6kHz References
- Signal and Reference Voltage Scaling with External Resistors
- High Tracking Rates (50 revs/sec)
- Lightweight 3.3 oz. (93 gms)
- MIL Spec/Hi Rel Options Available

### APPLICATIONS
- Servo Mechanisms
- Retransmission Systems
- Coordinate Conversion
- Antenna Monitoring
- Simulators
- Industrial Controls
- Artillery Fire Control Systems
- Machine Tool Control Systems

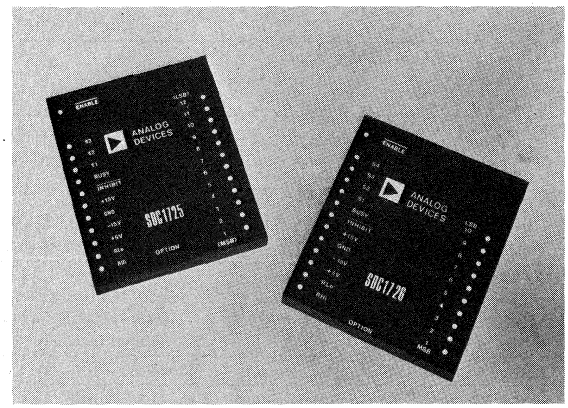
### GENERAL DESCRIPTION
The SDC1725 and SDC1726 are modular, continuous tracking Synchro/Resolver-to-Digital Converters which employ a type 2 servo loop and contain three-state latches on the digital outputs.

The input signals can be either 3 wire synchro plus reference or 4 wire resolver plus reference depending on the option. The outputs will be presented in TTL compatible parallel natural binary, buffered by three-state latches.

*The three-state output facility not only simplifies multiplexing of more than one device onto a single data bus but also enables the "INHIBIT" to be used without opening the internal converter loop.*

Another outstanding feature of these converters is the use of precision Scott T and reference microtransformers. This has made it possible to include internal transformers, even on the 60Hz options, and yet obtain a profile height lower than any other modular Synchro/Resolver to Digital Converter currently available.

NOTE
No external transformers are required with these converters.




### MODELS AVAILABLE
The two Synchro/Resolver-to-Digital Converters described in this data sheet differ primarily in the areas of resolution and accuracy as follows:

Model SDC1725XYZ is a 12-bit converter with an overall accuracy of ±3.2 arc-minutes ±1LSB and a resolution of 5.3 arc-minutes.

Model SDC1726XYZ is a 10-bit converter with an overall accuracy of ±22 arc-minutes and a resolution of 21 arc-minutes.

The XYZ code defines the option as follows: (X) signifies the operating temperature range, (Y) signifies the reference frequency, (Z) signifies the signal and reference voltage and whether it will accept synchro or resolver format.

More information about the option code is given under the heading of "Ordering Information".

13

# SPECIFICATIONS (typical at +25°C unless otherwise stated)

| Models | SDC1725 | SDC1726 |
|---|---|---|
| ACCURACY[1] (max Error all Options) | ±3.2 arc-minutes ±1LSB | ±22 arc-minutes |
| RESOLUTION | 12 Bits | 10 Bits |
| OUTPUT | 12-Bits Parallel Natural Binary | 10-Bits Parallel Natural Binary |
| SIGNAL AND REFERENCE FREQUENCY | 60Hz, 400Hz, 2.6kHz | * |
| SIGNAL VOLTAGE (Line to Line) | | |
| Low Level | 11.8V rms | * |
| High Level | 90.0V rms | * |
| SIGNAL IMPEDANCES | | |
| Low Level | 26kΩ Resistive | * |
| High Level | 200kΩ Resistive | * |
| REFERENCE VOLTAGE | | |
| Low Level | 26V rms (11.8V Signal) | * |
| High Level | 115V rms (90.0V Signal) | * |
| REFERENCE IMPEDANCE | | |
| Low Level | 56kΩ (26V Reference) | * |
| High Level | 270kΩ (115V Reference) | * |
| | (Impedance is Resistive) | * |
| TRANSFORMER ISOLATION | 500V dc | * |
| TRACKING RATE (Minimum) | | |
| 60Hz Options | 5 Revolutions Per Second | * |
| 400Hz Options | 36 Revolutions Per Second | * |
| 2.6kHz Options | 50 Revolutions Per Second | * |
| ACCELERATION | | |
| Constant $K_a$ | | |
| 60Hz Options | 2000/sec$^2$ | * |
| 400Hz Options | 120,000/sec$^2$ | * |
| 2.6kHz Options | 600,000/sec$^2$ | * |
| STEP RESPONSE (179° Step) (For 1LSB Error) | | |
| 60Hz Options | 1.5sec | * |
| 400Hz Options | 125ms | * |
| 2.6kHz Options | 50ms | * |
| POWER LINES | +15V @ 25mA | * |
| | −15V @ 25mA | * |
| | +5V @ 120mA | * |
| POWER DISSIPATION | 1.35 Watts | * |
| DATA LOGIC OUTPUTS[2] (TTL Compatible) | 6TTL Loads All Options | * |
| BUSY LOGIC OUTPUT LOADING[2] | 2TTL Loads | * |
| BUSY LOGIC OUTPUT WIDTH[2] | 330ns max, 200ns min | * |
| INHIBIT INPUT (TO INHIBIT) | Logic "0" 1 TTL Load | * |
| ENABLE INPUT (TO ENABLE) | Logic "0" 1 TTL Load | * |
| WARM UP TIME | 1sec to Rated Accuracy | * |
| TEMPERATURE RANGE | | |
| Operating | 0 to +70°C Standard | * |
| | −55°C to +105°C Extended | * |
| Storage | −55°C to +125°C | * |
| DIMENSIONS | 3.125" X 2.625" X 0.35" | * |
| | (79.4 X 66.7 X 8.9mm) | * |
| WEIGHT | 3.3 ozs (93 gms) | * |

NOTES

[1] Specified over the appropriate operating temperature range and for: (a) ±10% signal and reference amplitude variation; (b) 10% signal and reference harmonic distortion; (c) ±5% power supply variation; and (d) ±10% variation in reference frequency.

[2] Schottky logic loading rules apply.

*Specifications the same as for SDC1725.

Specifications subject to change without notice.

## THEORY OF OPERATION

If the unit is a Synchro-to-Digital Converter the 3 wire synchro output will be connected to S1, S2 and S3 on the module and the Scott T transformer pair will convert these signals into resolver format.

i.e., $V_1 = K E_O \text{ Sin } \omega t \text{ Sin } \theta$

$V_2 = K E_O \text{ Sin } \omega t \text{ Cos } \theta$

Where $\theta$ is the angle of the synchro shaft.

If the unit is a Resolver-to-Digital Converter, the 4 wire resolver output will be connected to S1, S2, S3 and S4 on the module and the microtransformers will act purely as isolators.

To understand the conversion process, assume that the current word state of the up-down counter is $\phi$.

Then $V_1$ is multiplied by Cos $\phi$ and $V_2$ is multiplied by Sin $\phi$ to give:

$K E_O \text{ Sin } \omega t \text{ Sin } \theta \text{ Cos } \phi$

and

$K E_O \text{ Sin } \omega t \text{ Cos } \theta \text{ Sin } \phi$

These signals are subtracted by the error amplifier to give:

$K E_O \text{ Sin } \omega t \text{ (Sin } \theta \text{ Cos } \phi - \text{Cos } \theta \text{ Sin } \phi)$

or

$K E_O \text{ Sin } \omega t \text{ Sin } (\theta - \phi)$

A phase sensitive detector, integrator and voltage controlled oscillator (VCO) form a closed loop system which seeks to null Sin $(\theta - \phi)$.

When this is accomplished, the word state of the up-down counter ($\phi$) equals, within the rated accuracy of the converter, the synchro shaft angle $\theta$.

Assuming that the "INHIBIT" is at a logic high state, then the digital word $\phi$ will be strobed into the latches 150ns after the up-down counter has been updated. If the three state "ENABLE" is at a logic low, then the digital output word will be presented to the output pins of the module.

## DATA TRANSFER

Data transfer from the SDC1725 and SDC1726 is very straightforward.

Consider the timing sequence shown in the timing diagram which assumes that the input to the converter is changing.

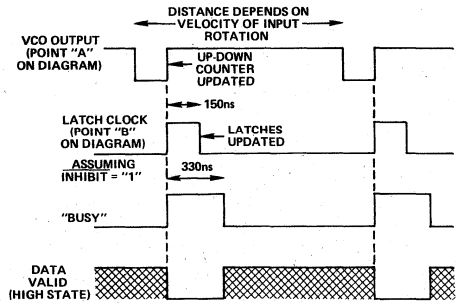
From this diagram, it can be seen that there are two ways to transfer data.

One method is to detect the state of the BUSY signal, which is high for 330ns while the up-down counters and latches are settling, and transfer data when it is in a low state.

However, a much more satisfactory method is to use the "INHIBIT" input. As can be seen from the functional diagram application of the "INHIBIT" prevents the two monostables being triggered and consequently the latches being updated. Therefore, it follows that data will always be valid from 330ns after the INHIBIT has been taken to a logic low state. It can also be seen that this method of data transfer is valid regardless of when the INHIBIT is applied.

The three-state ENABLE can be used at any time in order to present the data in the latches to the output pins. A logic low on this pin will cause the data to be presented to the outputs.

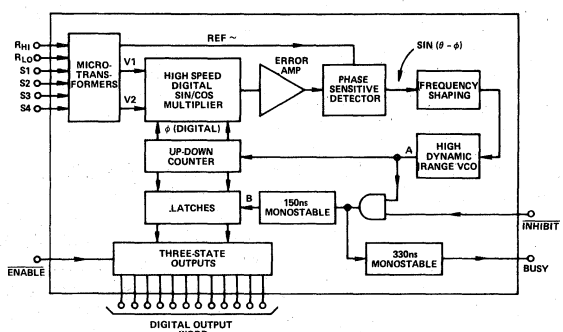
Note that the operation of the internal converter loop cannot be affected in any way by the logic state present on the INHIBIT and ENABLE pins.




*Timing Diagram*

| Bit Number | Weight in Degrees |
|---|---|
| 1 | 180.0000 |
| 2 | 90.0000 |
| 3 | 45.0000 |
| 4 | 22.5000 |
| 5 | 11.2500 |
| 6 | 5.6250 |
| 7 | 2.8125 |
| 8 | 1.4063 |
| 9 | 0.7031 |
| 10 (LSB - SDC1726) | 0.3516 |
| 11 | 0.1758 |
| 12 (LSB - SDC1725) | 0.0879 |

*Bit Weight Table*




*Functional Diagram SDC1725*

## CONNECTING THE CONVERTER

The electrical connections to the converter are straightforward. The power lines, which must not be reversed, should be connected to the "+15V", "-15V" and "+5V" pins with the common connection to the ground pin "GND". It is suggested that a parallel combination of a 0.1$\mu$F and a 6.8$\mu$F capacitor is placed in each of the three positions from "+15V" to "GND", from "-15V" to "GND" and from "+5V" to "GND".

The digital output is taken from pins:

"1" through to "10" for the SDC1726

"1" through to "12" for the SDC1725

Pin "1" represents the MSB in each case.

The reference connections are made to "$R_{HI}$" and "$R_{LO}$".

In the case of a Synchro the signals are connected to "S1", "S2" and "S3" according to the following convention:

$$E_{S1-S3} = E_{RLO-RHI} \sin \omega t \sin \theta$$
$$E_{S3-S2} = E_{RLO-RHI} \sin \omega t \sin (\theta + 120^\circ)$$
$$E_{S2-S1} = E_{RLO-RHI} \sin \omega t \sin (\theta + 240^\circ)$$

For a resolver, the signals are connected to "S1", "S2", "S3" and "S4" according to the following convention:

$$E_{S1-S3} = E_{RLO-RHI} \sin \omega t \sin \theta$$
$$E_{S2-S4} = E_{RHI-RLO} \sin \omega t \cos \theta$$

The "BUSY", "$\overline{\text{INHIBIT}}$" and "$\overline{\text{ENABLE}}$" pins should be connected as described under the heading "Data Transfer".

## RESISTIVE SCALING OF INPUTS

A feature of this range of converters is that the signal and reference inputs can be resistively scaled to accommodate any range of input signal and reference voltages.

This means that a standard converter can be used with a personality card in systems where a wide range of input and reference voltages are encountered.

To calculate the values of the external scaling resistors in the case of a Synchro Converter, add 1.11kΩ per extra volt of signal in series with "S1", "S2" and "S3", and 2.2kΩ per extra volt of reference in series with "$R_{HI}$".

In the case of a Resolver-to-Digital Converter, add 2.22kΩ in series with "S1" and "S2" per extra volt of signal and 2.2kΩ per extra volt of reference in series with "$R_{HI}$".

For example, assume that we have an 11.8V line to line, 26V reference Synchro Converter, and we wish to use it with a 60V line to line signal with a 115V reference.

In each signal input line, the extra voltage capability required is:

$$60 - 11.8 = 48.2V$$

Therefore each one of the three resistors needs to have a value of:

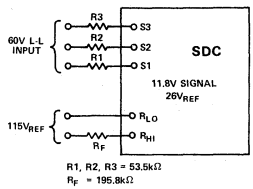
$$48.2 \times 1.11 = 53.5k\Omega$$

Similarly the single resistor needed in series with "$R_{HI}$" can be calculated as being 195.8kΩ.

The inputs of the converter can therefore be scaled as in the diagram below.

## USING THE CONVERTERS WITH OTHER THAN THE SPECIFIED REFERENCE FREQUENCY

A 60Hz converter can be used from 50Hz to 400Hz, and a 400Hz converter can be used from 400Hz up to 2.6kHz, but they will have the dynamic characteristics specified for the unit concerned.




R1, R2, R3 = 53.6kΩ
$R_F$ = 195.8kΩ

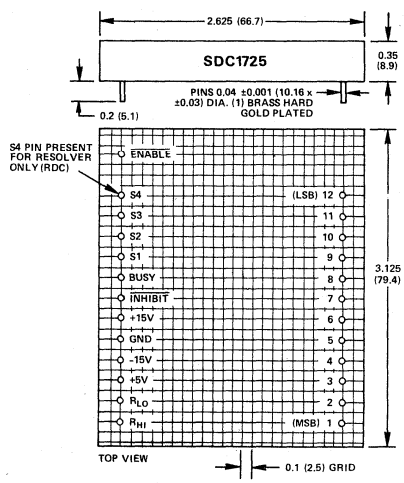
NOTE
IN THE CASE OF THE SIGNAL RESISTORS THE RATIO ERRORS BETWEEN THE RESISTANCES IS MORE IMPORTANT THAN THE ABSOLUTE RESISTANCE VALUES.

IN GENERAL A 1% RATIO ERROR WILL GIVE RISE TO AN EXTRA INACCURACY OF 17 ARC-MINUTES WHILE A RATIO ERROR OF 0.1% WILL GIVE RISE TO AN EXTRA INACCURACY OF 1.7 ARC-MINUTES.

THE ABSOLUTE VALUE OF $R_F$ IS NOT CRITICAL.

## OUTLINE DIMENSIONS AND PIN CONNECTION DIAGRAM

Dimensions shown in inches and (mm).




NOTE
THE ABOVE DIAGRAM SHOWS THE CONNECTIONS FOR THE SDC1725. ON THE SDC1726, PINS 11 AND 12 ARE OMITTED AND PIN 10 IS THE LSB.

**MATING SOCKET: CAMBION 450-3388-01-03**

## ORDERING INFORMATION

When ordering, the converter part numbers should be suffixed by an option code in order to fully define them. All the standard options and their option codes are shown below. For options not shown, please consult the factory.

| Part Number | Resolution | Operating Temp. Range | L to L Voltage/Format | Ref. Voltage | Ref. Freq. |
|---|---|---|---|---|---|
| SDC1725511 | 12 Bits | 0 to +70°C | 11.8V Synchro | 26 Volts | 400Hz |
| SDC1725611 | 12 Bits | -55°C to +105°C | 11.8V Synchro | 26 Volts | 400Hz |
| SDC1725512 | 12 Bits | 0 to +70°C | 90.0V Synchro | 115 Volts | 400Hz |
| SDC1725612 | 12 Bits | -55°C to +105°C | 90.0V Synchro | 115 Volts | 400Hz |
| RDC1725518 | 12 Bits | 0 to +70°C | 11.8V Resolver | 26 Volts | 400Hz |
| RDC1725618 | 12 Bits | -55°C to +105°C | 11.8V Resolver | 26 Volts | 400Hz |
| SDC1725522 | 12 Bits | 0 to +70°C | 90.0V Synchro | 115 Volts | 60Hz |
| SDC1725622 | 12 Bits | -55°C to +105°C | 90.0V Synchro | 115 Volts | 60Hz |
| SDC1725541 | 12 Bits | 0 to +70°C | 11.8V Synchro | 26 Volts | 2.6kHz |
| SDC1725641 | 12 Bits | -55°C to +105°C | 11.8V Synchro | 26 Volts | 2.6kHz |
| RDC1725548 | 12 Bits | 0 to +70°C | 11.8V Resolver | 26 Volts | 2.6kHz |
| RDC1725648 | 12 Bits | -55°C to +105°C | 11.8V Resolver | 26 Volts | 2.6kHz |

NOTE
For 10-bit resolution, substitute 1726 in place of 1725 in the part number above.

# Synchro/Resolver Power Amplifier

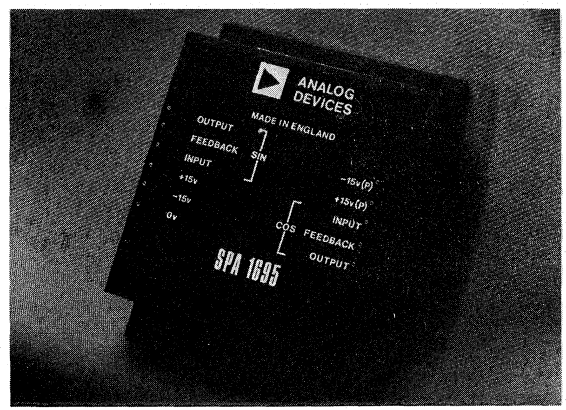
# SPA1695

## FEATURES

**5VA Output – Capable of Driving 4 Size 11 CT's**
**Indefinite Short Circuit Protection**
**Metal Case Acts as Heatsink**
**Easily Mounted**
**Voltage Sensing Facility**
**Operation with No Derating Up to +105°C**
**Suitable for 50 to 400Hz Operation**

## APPLICATIONS

**Can Be Used With the Digital Vector Generators (DTM1716 and DTM1717) to Drive Control Transformers (CT's)**




## GENERAL DESCRIPTION

The SPA1695 is a two channel amplifier intended for use in conjunction with the DTM1716 and DTM1717 Digital Vector Generators for driving Control Transformers (CT's).

The unit is capable of supplying 5VA to the load and therefore can be used in cases where the internal amplifiers of a Digital-to-Synchro Converter are not sufficient (i.e., in general when the load exceeds 1.3VA).

The SPA1695 is contained in an aluminium case which has pre-drilled flanges for mounting purposes and excellent heatsinking properties.

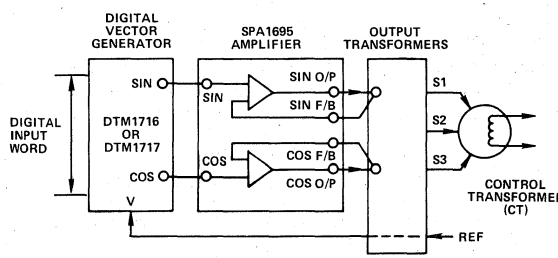
The amplifier has no derating up to +105°C and is indefinitely short circuit protected at 25°C ambient.

The unit accepts resolver format inputs (Sine and Cosine) at 7 volts rms max. The output of the amplifier is in resolver format at 7 volts rms max and should be fed into suitable transformers (see ordering information).

Voltage sensing pins are provided to compensate for any voltage drop which may occur between the output of the amplifier and the output transformer.

## MODELS AVAILABLE

The SPA1695 does not require any option numbers in order to fully specify it. The standard unit operates over the frequency range 50 to 400Hz and over the temperature range of –55°C to +105°C.




*Implementation of the SPA1695 Amplifier*

## SCHEMATIC DIAGRAM OF AN SPA1695 AMPLIFIER BEING USED TO DRIVE A CONTROL TRANSFORMER (CT)

The above diagram shows a Digital Vector Generator being used in conjunction with the SPA1695 amplifier and external transformers to drive a Control Transformer.

The diagram illustrates the use of the Sine and Cosine feedback pins ("Sin F/B" and "Cos F/B").

13

## SPECIFICATIONS (typical at 25°C unless otherwise noted)

| | |
|---|---|
| POWER OUTPUT[1] | 5VA |
| ACCURACY[2] (between channels) | 2 arc-minutes |
| GAIN ACCURACY[2] (matching) | 0.1% |
| INPUT VOLTAGE (per channel) | 7V rms |
| OPERATING FREQUENCY | 50 to 400Hz |
| INPUT IMPEDANCE | Greater than 50kΩ |
| INPUT BIAS CURRENT | Less than 1μA |
| GAIN (per channel) | Unity |
| INPUT DRIFT | 50μV/°C |
| INITIAL OUTPUT OFFSET | 3mV max at 25°C |
| CROSS OVER DISTORTION | 0.01% max |
| DERATING OF AMPLIFIER | None up to +105°C |
| POWER SUPPLY REQUIREMENTS: | |
| ±15V(P) No Load | 115mA Unregulated |
| ±15V(P) Average Full Load | 630mA Unregulated |
| ±15V | 15mA Regulated |
| WEIGHT | 275 Grams (9.7 ozs) |
| SIZE | 3.46" x 2.68" x 0.98" (88mm x 68mm x 25mm) |
| OPERATING TEMERATURE RANGE | -55°C to +105°C |
| STORAGE TEMPERATURE RANGE | -55°C to +125°C |

NOTES
1. Power output is sufficient to drive four 400Hz 90 volts line to line control transformers.
2. Valid over full temperature range of -55°C to +105°C.

Specifications subject to change without notice.

## CONNECTING THE SPA1695

The diagram shows the connection of the SPA1695 to the DTM1716 or DTM1717 Digital Vector Generator, and STM1686 output and reference transformers.

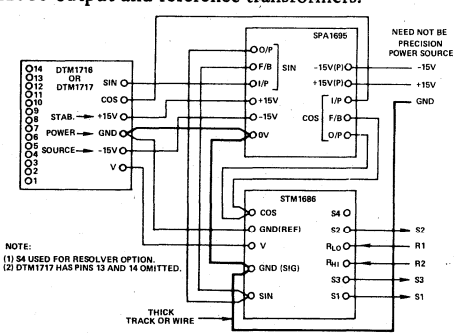



*Diagram Showing Connection of the SPA1695 to a DTM1716 or DTM1717 and STM1686*

**NOTES:**

1. The "Sin F/B" and the "Cos F/B" pins of the SPA1695 should be connected directly the the "Sin" and "Cos" terminals on the output transformer at the transformer. This is to compensate for any drop in voltage along the connections between the "Sin O/P" and "Cos O/P" pins of the amplifier and the transformer.
2. The "+15V" and "-15V" pins of the SPA1695 should be connected to a regulated power supply in order to drive the internal operational amplifiers. The "+15V(P)" and "-15V(P)" are used for the output stage and these supplies need not be a precision source. The minimum voltage when considering all tolerances including ripple, should be between 14.75 and 20 volts.
3. The part of the 0 volt system local to the amplifier and converter should be tapped from the "GND(SIG)" pin on the transformer and should not interconnect with any other part of the 0 volt system by any other method (see above diagram).
4. In the above diagram, connection is also shown between the reference transformers, contained in the STM1686 and the Digital Vector Generator.

## USING TWO SPA1695 AMPLIFIERS IN PUSH-PULL CONFIGURATION

Twice the output power may be achieved by connecting the outputs from two SPA1695 amplifiers in push-pull configuration, the two devices being fed with out of phase signals.

For more information consult the factory.

## ADDITIONAL HEATSINKING

Although the SPA1695 case will provide the necessary heatsink properties to allow the amplifier to provide the 5VA power output over the full temperature range, it is recommended that additional heatsinking be provided where possible.

## ORDERING INFORMATION AND TRANSFORMER TYPE

Part number SPA1695 is sufficient to specify the amplifier – no option codes are needed.

The transformers should be ordered according to the following:

| | |
|---|---|
| STM1686611 | 400Hz, Synchro output, 11.8 volt signal, 26 volt reference. |
| STM1686612 | 400Hz, Synchro output, 90 volt signal, 115 volt reference. |
| RTM1686618 | 400Hz, Resolver output, 11.8 volt signal, 26 volt reference. |
| STM1687622 | 50/60Hz, Synchro output, 90 volt signal, 115 volt reference. |

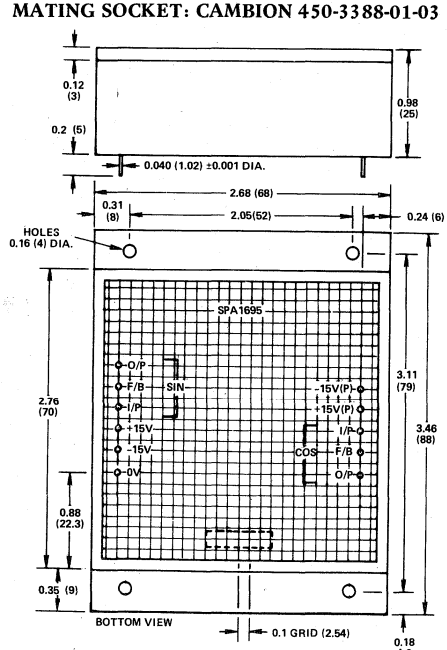
**NOTES:**

1. Above transformers are suitable for use over the temperature range -55°C to +105°C.
2. If it is required to use the SPA1695 with Digital to Resolver converters, then use:
   a. STM1736 for 400HZ and STM1737 for 50/60Hz systems in the case of the DRC1605 and DRC1606 converters.
   b. STM1696 for 400Hz and STM1697 for 50/60Hz systems in the case of the DRC1705 and DRC1706 converters.

## AMPLIFIER OUTLINE DIMENSIONS AND PIN CONNECTION DIAGRAM

Dimensions shown in inches and (mm).

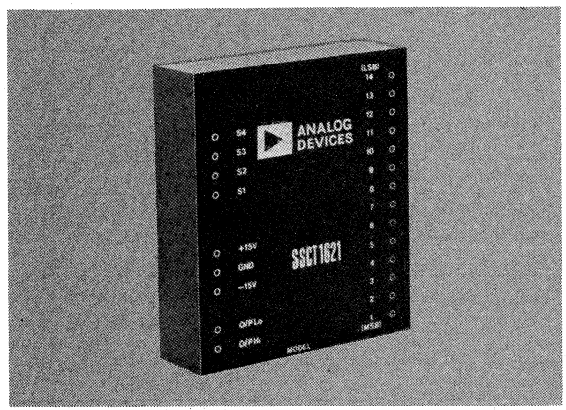
**MATING SOCKET: CAMBION 450-3388-01-03**



# Solid State Control Transformer

## SSCT/RSCT1621

**FEATURES**
**Accuracy ±4 Minutes of Arc**
**Low Power Dissipation**
**Accommodates ±12.5° Error Angle About Null**
**Synchro Input Isolation**
**Transformer Output Isolation**
**No 5 Volt Line Required**




### DESCRIPTION

The SSCT 1621 and RSCT 1621 are solid state control transformers which perform identical functions to electro-mechanical control transformers except that the mechanical inputs have been replaced by digital inputs. The SSCT is for three wire synchro inputs the RSCT is for four wire resolver inputs. In other respects they are idential. The solid state control transformer accepts three or four wire input information together with a 14 bit digital angle input and gives out a voltage at the carrier frequency with a magnitude proportional to the sine of the difference between the two angles. The output can be described by A sin $2\pi ft$ $\sin(\theta-\phi)$ where "$\phi$" represents the 14 bit parallel binary input angle, "$\theta$" represents the input angle from the three wire synchro or four wire resolver, and f is the excitation frequency.

The scaling of the output is 0.4 volts/degree and the nominal ouput voltage range is ± 5 volts rms. This implies a span of ± 12.5° for full scale ouput (These voltages are for the ouput side of the output transformer which has a step down ratio of 7 to 5).

The solid state control transformer 1621 is intended for use as an error generator in follow up servo systems and for this reason the span of the output is more than adequate for all such systems. Since the output is by transformer coupling various output voltage scalings can be obtained on special order.

The solid state control transformer 1621 provides an attractive alternative to digital-to-synchro converters in follow up servo applications, the elimination of the balanced output transformers removes constraints associated with Digital to Synchro converters.



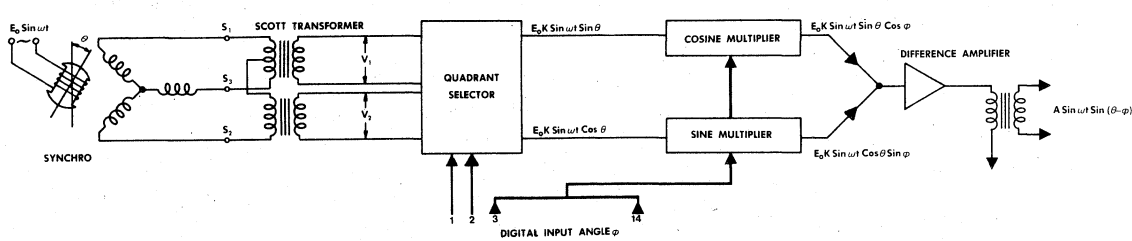



*Figure 1. SSCT Schematic Diagram*

# SPECIFICATIONS (typical @ +25°C and ±15V unless otherwise noted)

| | |
|---|---|
| Accuracy* | ± 4 minutes of arc. |
| Resolution | 14 bits (1 LSB = 1.3 arc minutes) |
| Digital input | 14 bits natural parallel binary |
| Logic levels | DTL/TTL |
| Digital input loading | "1" 0.4 mA, "0" 1.6 mA |
| Scaling | 0.4 volts/degree |
| Output signal | 400 Hz: 5 volts rms (max) into 500 ohms<br>60 Hz: 7 volts (max) into 1K ohms |
| Output angle range | ± 12.5 degrees |
| Output impedance | 10 ohms |
| Step response time, synchro or digital input | Less than 1 milli-second |
| Synchro/Resolver input | All standard 60Hz or 400Hz synchro or resolver levels (see ordering code overleaf) |
| Power supplies | ± 15 volts at 40 mA/line |
| Size | 3·125" x 2·625" x 0·8"<br>79·4 mm x 66·6 mm x 20·5 mm |
| Operating Temperature | 0 to +70 degrees C.<br>–50 to +105 degrees C. |
| Storage Temperature | –50 to +125 degrees C. |

*Accuracy applies over the operating temperature range for:-

(a) ± 10% signal variation
(b) 10% signal harmonic distortion
(c) ± 5% power supply variation

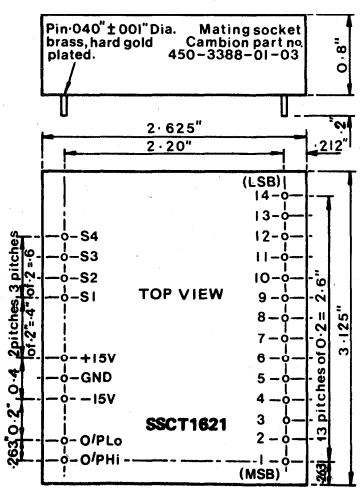



*Figure 2. Pin Arrangement of the SSCT1621 (400Hz)*

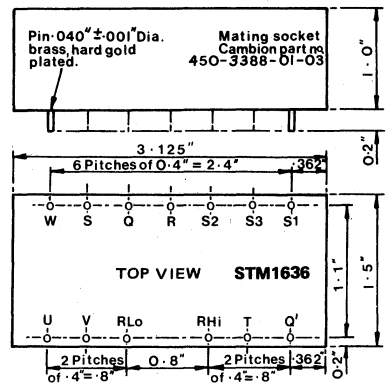



*Figure 3. Pin Arrangement of the STM1636*

## ELECTRICAL CONNECTIONS

**400 Hz operation.** The physical form and dimensions of the 1621 for 400 Hz use are shown in Fig. 2. For operation on 400 Hz both the signal input transformers and an output transformer are encapsulated within the module. The signal connections are made via the pins marked $S_1$, $S_2$, $S_3$ and $S_4$. For synchro use only the pins $S_1$, $S_2$ and $S_3$ are used ($S_4$ is not used). For resolver use, the sine input is applied between pins $S_1$ and $S_3$ and the cosine input between $S_2$ and $S_4$ and the polarities are such that if $S_1$ is connected to $S_2$ and both to common, then the voltages on $S_3$ and $S_4$ will be in time phase in the first quadrant.

The output which is provided on the pins marked O/P Hi and O/P Lo has a maximum voltage of 5 volts rms and is suitable for driving loads of 500 ohms or greater. This output is coupled from the output operational amplifier by means of a 7:5 step down transformer which is contained inside the SSCT module.

**60 Hz operation.** When used on 60 Hz the SSCT has an external transformer module for the signal input transformers (see Fig. 3). No output transformer is used on 60Hz, *the output being taken directly from the pins V and U (output Hi and Lo respectively) on the SSCT module.* The output voltage is 7 volts rms directly from the output of an operational amplifier (it is short-circuit proof) and is suitable for driving into loads of 1K ohms or more. The signal inputs to the module are in resolver form and connect via the pins marked Q.R.S.T. The pins Q.R.S.T. on the SSCT module must be connected to the pins marked Q.R.S.T. on the transformer module Q ⟶ Q etc. (see Fig. 4). The input signal connections are made to the transformer module pins marked $S_1$ $S_2$ $S_3$ and W. For synchro use the signals are connected to $S_1$ $S_2$ and $S_3$, no use being made of pin W. For resolver use the sine input is applied between pins $S_1$ and $S_3$ and the cosine input between $S_2$ and W. The polarity should be such that if $S_1$ and $S_2$ are connected together and regarded as common, the voltages on $S_3$ and W will be in time phase in the first quadrant.

*The remaining pins on the transformer module i.e. U, V, RLo, RHi and Q' should not be used in this application.*

The SSCT module makes use of only ±15 volts which should be connected to the pins marked +15, -15 and GND on the module.

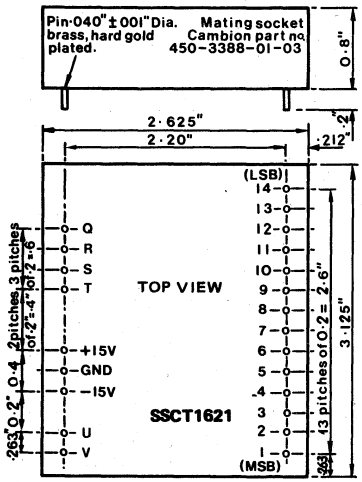



*Figure 4. Pin Arrangement of the SSCT1621 (60Hz)*

Table 1 shows the bit weights for the digital inputs which connect to pins 1 through to 14. The levels required are TTL with loading of 0.4 mA for the "1" state and 1.6 mA for the "0" state.

**BIT WEIGHT TABLE**

| Bit Number | Weight in Degrees |
|---|---|
| 1 (MSB) | 180.0000 |
| 2 | 90.0000 |
| 3 | 45.0000 |
| 4 | 22.5000 |
| 5 | 11.2500 |
| 6 | 5.6250 |
| 7 | 2.8125 |
| 8 | 1.4063 |
| 9 | 0.7031 |
| 10 | 0.3516 |
| 11 | 0.1758 |
| 12 | 0.0879 |
| 13 | 0.0439 |
| 14 (LSB) | 0.0220 |

*TABLE 1.*

## DIGITALLY CONTROLLED SERVO LOOP USING THE SSCT 1621

Fig. 5 shows how the SSCT would be used in a servo loop where the input angle is defined digitally as a 14 bit word into the SSCT. If the servo power drive is a D.C. motor the SSCT signal is fed into a phase sensitive detector together with the reference signal which is followed by a suitable power amplifier to drive the motor. The mechanically coupled synchro transmitter energised by the reference signal provides the angular feedback signal to the SSCT. In low power systems a bi-phase motor might be used in which case the phase sensitive detector would be omitted and the reference signal fed to the motor as well as to the synchro transmitter.

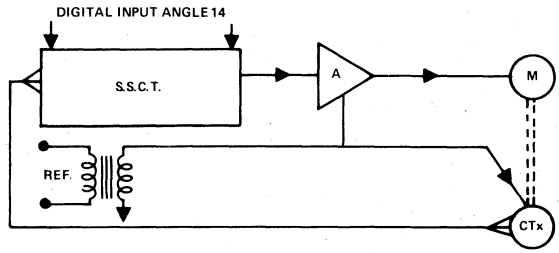



*Figure 5. Servo Using S.S.C.T.*

The system using the SSCT provides an alternative to the use of a digital to synchro converter followed by an electromechanical control transformer; the SSCT control loop is simpler than the DSC system and is capable of providing higher accuracy.

In addition to its use in the simple servo control loop as shown, the SSCT has application in electronic speed changing systems where it is used in conjunction with synchro to digital converters (SDC's) and solid state control transformers (SCDX's) which are also available in encapsulated modules.

The output of the 400 Hz SSCT is from a transformer contained inside the module the standard ratio of which is 7:5, but other ratios can be provided to meet special needs.

## ORDERING INFORMATION

The model Number SSCT/1621 for Synchro use or RSCT/1621 for resolver use, must be followed by a 3 digit number XYZ which defines the operating conditions and signal levels. X defines the operating temperature range, Y determines the frequency and Z determines the signal voltage level and synchro or resolver use as follows:–

| | | | |
|---|---|---|---|
| X | = | 5 | signifies temperature range 0 - 70°C |
| X | = | 6 | signifies temperature range – 55°C to +105°C |
| Y | = | 1 | signifies carrier frequency of 400 Hz |
| Y | = | 2 | signifies reference frequency of 60Hz |
| Z | = | 1 | signifies synchro signal voltage 11.8 volts (Y must = 1) |
| Z | = | 2 | signifies synchro signal voltage 90 volts (Y = 1 or 2) |
| Z | = | 3 | signifies resolver signal voltage 11.8 volts (Y must = 1) |
| Z | = | 4 | signifies resolver signal voltage 26.0 volts (Y must = 1) |
| Z | = | 5 | signifies resolver signal voltage 90.0 volts (Y = 1 or 2) |
| Z | = | 6 | signifies resolver signal voltage 115.0 volts (Y = 1 or 2) |
| Z | = | 8 | signifies resolver signal voltage 11.8 volts (Y must = 1) |

The external signal transformer module for 60 Hz use is **designated STM 1636/XYZ or RTM 1636/XYZ for either synchro or resolver use.**

**CARD MOUNTING** A printed circuit card for holding the 400 Hz version of the 1621 is available, it is the P.C. card type AC 1637.

# ANALOG DEVICES

# Two Speed Processor (for Coarse/Fine Synchro/Resolver Systems)

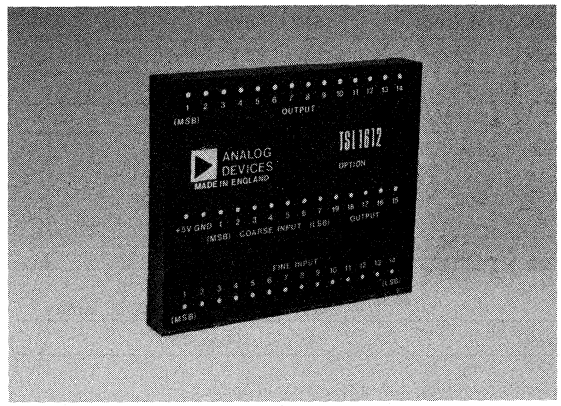
# TSL1612

**FEATURES**

**36:1, 18:1 or 9:1 Ratios with Same Module**
**No False Output Readings**
**Fast (500ns) Parallel Operation**
**Easy to Use**
**Up to 19-Bits Resolution**
**Automatic Correction for Misalignment Between Synchros or Resolvers**
**Low Profile – 0.4″ (10.2mm)**

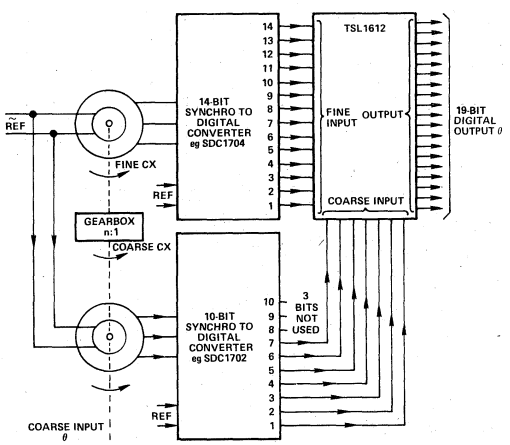
**APPLICATIONS**

**Combining the Digital Outputs of Synchro-or-Resolver-to-Digital Converters in Coarse/Fine Systems**




## GENERAL DESCRIPTION

The TSL1612 is used for combining the digital outputs of two Synchro- or Resolver-to Digital Converters in a mechanically or electrically geared coarse/fine system in order to produce a single unambiguous digital word representing the coarse shaft angle (see diagram).




DIGITIZING THE OUTPUT OF THE COARSE AND FINE SYNCHRO TRANSMITTERS (CX'S) IN A TWO SPEED SYSTEM

The unit described in this data sheet provides for ratios of 9:1, 18:1 and 36:1 in a single module. However, other ratios are sometimes encountered in coarse/fine Synchro or Resolver Systems, and details of special versions of the TSL1612 for use with ratios of 2:1 thru 35:1 are available on request.

The digital inputs to the TSL1612 are up to 14 bits from the fine converter and up to 7 bits from the coarse converter according to the gear ratio required. The output is up to 19-bits parallel binary angle data. The module may be used with any Synchro or Resolver Converters which produce parallel binary output.

## MODELS AVAILABLE

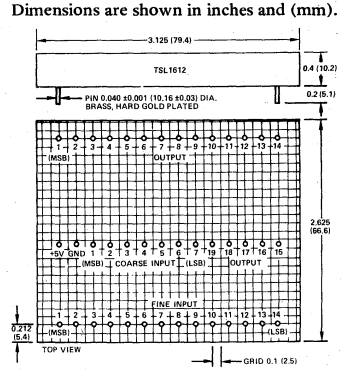
The standard TSL1612 which provides for ratios of 36:1, 18:1 and 9:1 has two options. They are as follows:

| | |
|---|---|
| TSL1612500 | 0 to +70°C Operating Temperature |
| TSL1612600 | -55°C to +105°C Operating Temperature |

13

## OUTLINE DIMENSIONS AND PIN CONNECTION DIAGRAM

Dimensions are shown in inches and (mm).




**MATING SOCKET: CAMBION 450-3388-01-03**

# SPECIFICATIONS (typical @ +25°C unless otherwise noted)

| | |
|---|---|
| Ratios: | 36:1, 18:1, 9:1 |
| Fine Synchro Input | Up to 14-Bits Parallel Binary Angle |
| Coarse Synchro Input | Up to 7-Bits Parallel Binary Angle |
| Logic Levels | DTL/TTL Compatible |
| Input Loading | 2TTL Loads |
| Output Fan Out | 5TTL Loads |
| Digital Output | Up to 19-Bits Parallel Binary Angle |
| Accuracy | ±1LSB |
| Conversion Time | 500ns |
| Temperature Range | |
| Storage | −55°C to +125°C |
| Operating | 0 to +70°C Standard |
| | −55°C to +105°C Extended |
| Power Supplies | +5V ±5% @ 600mA |
| Size | 3.125" X 2.625" X 0.4" |
| | 79.4mm X 66.6mm X 10.2mm |
| Weight | 3.5ozs. 100 grams |

Specifications subject to change without notice.

### CONNECTING THE TSL1612

For all ratios the fine SDC outputs connect directly to the fine TSL1612 inputs i.e. bit (1) out to bit (1) in through to bit 14 out to bit 14 in. If a Synchro- or Resolver-to-Digital Converter with a resolution of less than 14 bits is used to provide the fine input, then the unused inputs to the TSL1612 should be grounded and the output accuracy will be reduced accordingly by the same number of bits.

The connections of the coarse inputs and the TSL1612 outputs change according to the ratio to be obtained ie:-

### 36:1 RATIOS

Bits 1 to 7 from the coarse Synchro- or Resolver-to-Digital Converter should be connected to bits 1 to 7 on the coarse input of the TSL1612. The output is taken from bits 1 to 19.

### 18:1 RATIOS

Bits 1 to 6 from the coarse Synchro- or Resolver-to-Digital Converter should be connected to bits 2 to 7 on the coarse input of the TSL1612. The output is taken from bits 2 to 19 (bit 2 is the MSB of the output word).

### 9:1 RATIOS

Bits 1 to 5 from the coarse Synchro- or Resolver-to-Digital Converter should be connected to bits 3 to 7 on the coarse input of the TSL1612. The output is taken from bits 3 to 19 (bit 3 is the MSB of the output word).

### CORRECTION FOR MISALIGNMENT OF THE COARSE AND FINE SYNCHROS OR RESOLVERS

In the two speed digital converters which receive inputs from both the coarse and fine synchros, circumstances will occur when the coarse angle determined by the most significant digits of fine synchro will conflict with the overlapping least significant digits of the coarse synchro. (This is due to the backlash in the gearing or misalignment in the synchros causing different readings at the major transition points.) Digital logic circuits for resolving this conflict are included in the TSL1612. The digital reading from the fine synchro is made to dominate in the overlapping region, and a correction is made bringing the coarse reading into line to provide an unambiguous digital representation of the angle of the coarse shaft. The TSL1612 will correct for a misalignment of (90 divided by the ratio) degrees.

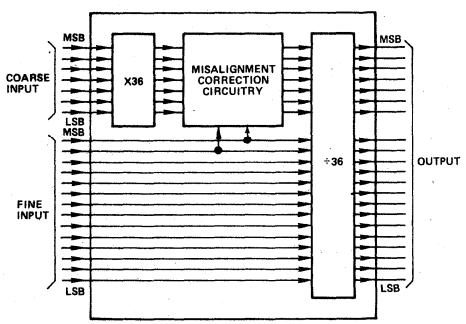
### DATA TRANSFER FROM THE TSL1612

Data transfer can be made in a number of ways in which two are listed below.

1. The BUSY outputs of the fine and coarse Synchro/Resolver-to-Digital Converter can be "OR"ed together to give an indication of when neither converter is being updated (see appropriate converter data sheet). The data can then be taken from the TSL1612. (The conversion time of the TSL1612 is usually insignificant.)
2. The INHIBIT can be applied to both the Synchro/Resolver-to-Digital Converters simultaneously in order to freeze their outputs (see appropriate data sheet). When the inputs to the TSL1612 are frozen the output data can be taken. In cases where 12 bits is sufficient for the fine input, the three-state input SDC1725 Synchro/Resolver-to-Digital Converter should be used in conjunction with the SDC1726 on the coarse input. These converters allow the INHIBIT to be used without any risk of opening the internal converter tracking loop (see data sheet).

### THEORY OF OPERATION

The theory of operation of the TSL1612 is shown in the diagram below.




FUNCTIONAL DIAGRAM OF TSL1612

### ORDERING INFORMATION

Order:—

TSL1612500 for 0 to +70°C Operating Temperature Range.

TSL1612600 for −55°C to +105°C Operating Temperature Range.

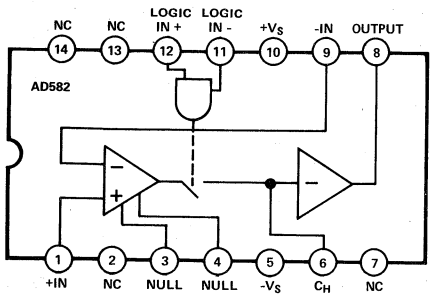
# Sample/Track-Hold Amplifiers

## Contents


| | Page |
|---|---|
| Selection Guide | 14–2 |
| General Information | 14–8 |
| Definitions | 14–9 |
| ADSHM-5 Ultra-Fast 0.01% Track/Sample-Hold Amplifiers | 14–11 |
| SHA1144 Module, High-Resolution Sample-Hold Amplifier | 14–15 |
| THS/THC Modules, Ultra-High Speed Track-Hold Amplifier Series | 14–19 |

# Selection Guide
## Sample/Track-Hold Amplifiers

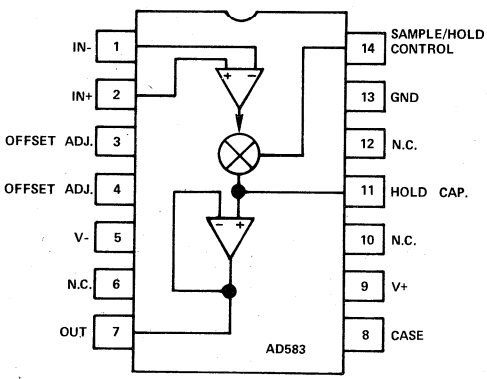
## General Purpose




### AD582

Page
Vol. I
14–23

**Suitable for 12-Bit Applications**
**High Sample/Hold Current Ratio: $10^7$**
**Low Acquisition Time: 6μs to 0.1%**
**Low Charge Transfer: <2pC**
**High Input Impedance in Sample and Hold Modes**
**Connect in Any Op Amp Configuration**
**Differential Logic Inputs**

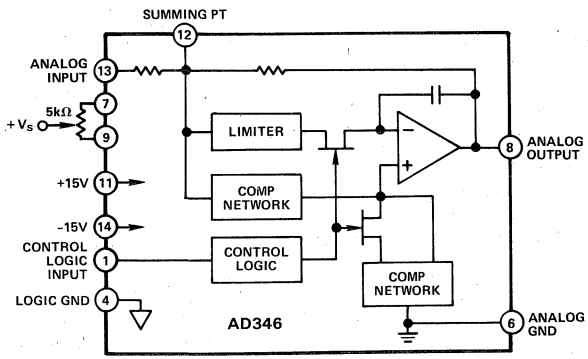



### AD583

Vol. I
14–27

**High Sample-to-Hold Current Ratio: $10^6$**
**High Slew Rate: 5Vμs**
**High Bandwidth: 2MHz**
**Low Aperture Time: 50ns**
**Low Charge Transfer: 10pC**
**DTL/TTL Compatible**
**May Be Used as Gated Op Amp**

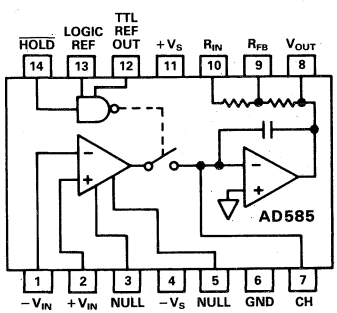
# High Speed




## AD346

Page
Vol. I
14–11

**Fast 2.0μs Acquisition Time to ±0.01%**
**Low Droop Rate: 0.5mV/ms**
**Low Offset**
**Low Glitch: <40mV**
**Aperture Jitter: 400ps**
**Extended Temperature Range: −55°C to +125°C**
**Internal Hold Capacitor**



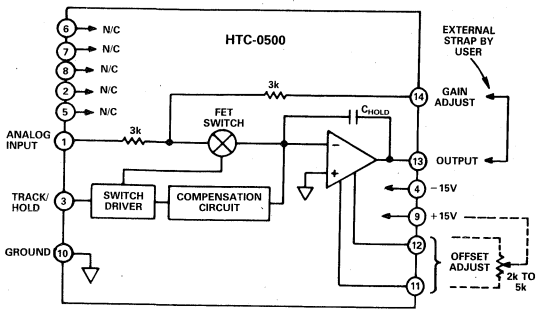

## AD585

Vol. I
14–31

**Fast 2.5μs Acquisition Time to ±0.01%**
**Low Droop Rate: 0.5mV/ms**
**Low Offset: 1mV**
**Sample/Hold Offset Step: 1mV**
**Aperture Jitter: 0.5ns**
**Extended Temperature Range: −55°C to +125°C**
**Internal Hold Capacitor**

**APPLICATIONS**
**Data Acquisition Systems**
**Data Distribution Systems**
**Analog Delay & Storage**
**Peak Amplitude Measurements**

# Selection Guide
## Sample/Track-Hold Amplifiers
### High Speed

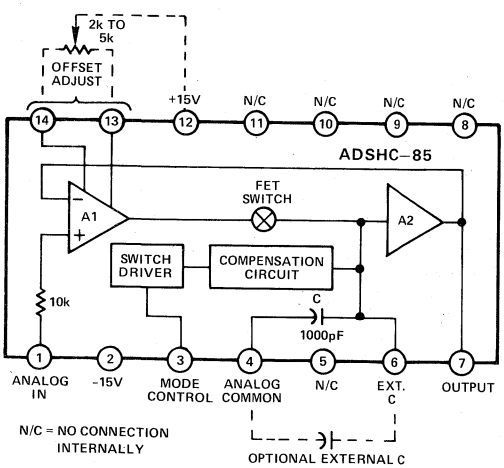



## HTC-0500

**700ns Acquisition Time**
**<750mW Power Dissipation**
**14-Pin DIP**
**0.01% Linearity**

**APPLICATIONS**
**Data Acquisition Systems**
**Data Distribution Systems**
**Analog Delay and Storage**
**Peak Amplitude Measurements**

Page
Vol. I
14–45

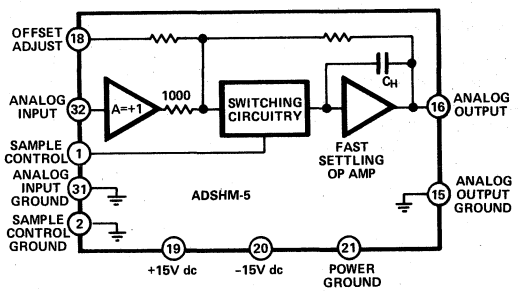



## ADSHC-85

**Improved SHC-85 Replacement**
**500ns Sample-to-Hold Transient**
**50μV rms Noise**
**Low Droop Rate of 0.2mV/ms**

Vol. I
14–37

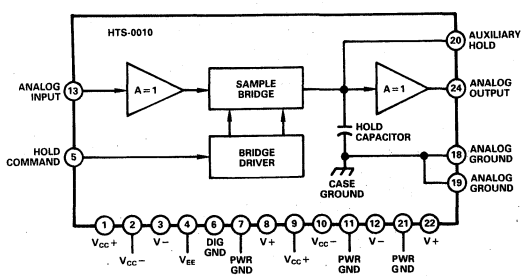
# Very High Speed




## ADSHM-5

Page

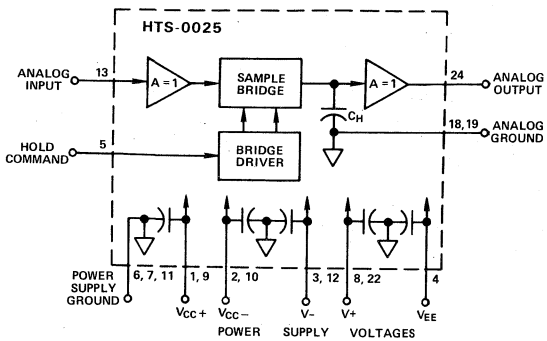
- **2nd Source–Replaces All SHM-5 Series** Vol. II 14–11
- **Fast 350ns Acquisition Time to ±0.01%**
- **Aperture Uncertainty 250ps**
- **ADSHM-5K**
- **Ultra Fast 250ns Acquisition Time to ±0.01%**
  **100ns Acquisition Time to ±0.1%**
- **Wide 12MHz Bandwidth**
- **300V/µs Slew Rate**
- **Super Low 2nA Input Bias Current**




## HTS-0010

- **Aperture Jitter of 5ps** Vol. I 14–49
- **Acquisition Time 10ns**
- **Output Current ±40mA**
- **Slew Rate 300V/µs**

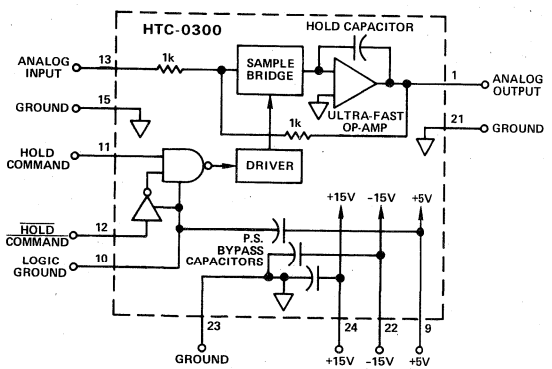
# Selection Guide
## Sample/Track-Hold Amplifiers
## Very High Speed




### HTS-0025

**Aperture Time to 20ps**
**Acquisition Time to 20ns**
**Linearity 0.01%**
**$10^{10}\Omega$ Input Z (HTS-0025)**
**±50mA Output Current**

Page
Vol. I
14–55

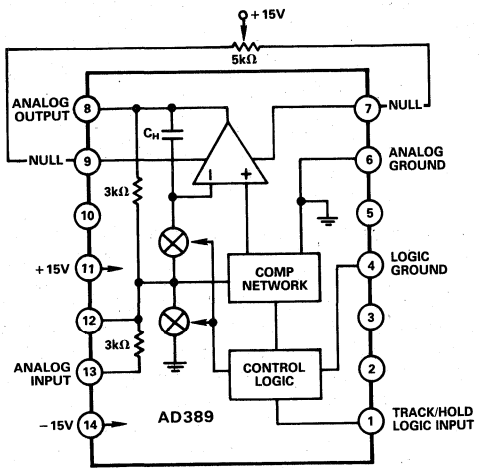



### HTC-0300

**Aperture Jitter of 100ps**
**Input Range ±10V**
**Output Current ±50mA**
**Max Droop Rate 5μV/μs**

Vol. I
14–41

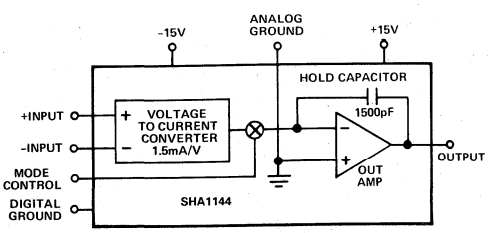
# High Resolution




## AD389

Page
Vol. I
14–17

**Companion to High Resolution A/D Converters**
**Fast Acquisition Time: 2.5μs to ±0.003%**
**Low Droop Rate: 0.1μV/μs**
**Aperture Jitter: 400ps**
**Internal Hold Capacitor**
**Unity Gain Inverter**
**Low Power Dissipation: 300mW**




## SHA1144

Vol. II
14–15

**High Resolution 14-Bit Sample-and-Hold Amplifier**
**±10V Range**
**50ns Aperture Delay**
**0.5ns Aperture Jitter**
**Acquisition Time: 6μs to ±0.003%**
**6μs Settling Time**
**0.001% Max Gain Linearity Error**
**Complete with Input Buffer: No External Components Required to Meet Rated Performance**

# Orientation
## Sample/Track-Hold Amplifiers

The technical data in this volume embrace high-performance (high-resolution and high-speed) sample/track-holds, in the form of encapsulated modules. As the Selection Guide indicates, data on a variety of monolithic and hybrid sample/track-holds can be found in Volume I.

Besides the products in this section (stand-alone devices for performing the sample/track-hold function) similar functions can be found integrated into a variety of component and subsystem products. Component examples: a number of video A/D converters have on-board track-holds (MOD-1205); some high-speed D/A converters have on-board sample-holds for deglitching (MDD); and high-resolution D/A converters have deglitcher options (Deglitcher IV for the DAC1138). Besides these, sample-hold functions are inherent in Data-Acquisition Subsystems, Microcomputer Analog I/O Boards, Intelligent Measurement-and-Control Subsystems, and MACSYM.

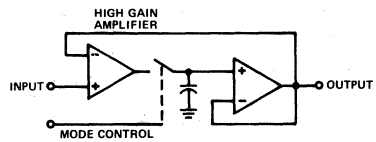
The principal application for sample/track-hold amplifiers is to maintain an analog-to-digital converter's input constant during conversion, at a value representing the analog input as of a certain precisely known time. The characteristics of the SHA are crucial to system accuracy and the reliability of the digital data, especially in 12-bit and/or high-throughput-rate applications.

A sample/track-hold amplifier (s/h or SHA), as its name indicates, has two modes of operation, programmed by a digital control-input. In the *track*– or *sample*–mode, the output follows the input, usually with a gain of +1. When the mode-input switches to *hold*, the output of the SHA ideally retains the last value it had when the command to hold was given, and it retains that value until the logic input dictates *track (sample)*, at which time the output ideally jumps to the input value and follows the input until the next *hold* command is given.

Analog Devices *track-holds* and *sample-holds* are functionally identical; they are designed to acquire input signals for either immediate hold or for a possibly extended period of tracking. They should not be confused with ac devices termed "sample-hold" that can *only* obtain quick samples and cannot track the input continuously.

### SHA CIRCUITRY AND HARDWARE

A sample-hold amplifier usually consists of a storage capacitor, input- and output buffer-amplifiers, and a switch and its drive-circuitry. During *sample*, the circuit is connected to promote rapid charging of the capacitor. During *hold,* the capacitor is disconnected from its charging source and–ideally– retains its charge. The figure below shows a typical feedback configuration: the input buffer is a high-gain differential amplifier with a current output that charges the capacitor through the logic-controlled switch. The capacitor is unloaded by a unity-gain buffer-follower. The output is fed back to the negative input (as in an op-amp follower configuration), and thus, in *sample*, the charge on the capacitor is compelled to follow the input. In *hold*, the input amplifier no longer drives the capacitor; it retains its charge, unloaded by the output follower. In another popular configuration, the capacitor is used as the feedback element of an inside-the-loop integrator (SHA1144). The highest-speed devices usually run open-loop.

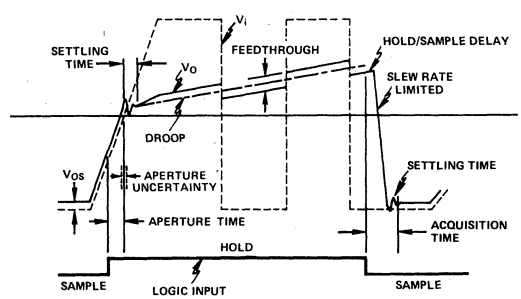



Since drive current is finite, and leakage current in *hold* is not zero, the capacitance–if large–limits the slewing rate in *sample* and–if small–converts leakage current to "droop" in *hold*. In s/h *modules*, the capacitance is usually fixed, and the properties of the complete device are optimized for one condition– and so specified. In s/h *monolithic ICs*, the capacitor is omitted, and furnished by the user (both for flexibility and because good capacitors for this purpose are hard to integrate). The optimum capacitance can be selected for the specific application. In some types, (e.g., SHA1144), the gain connections are external, like those of an op amp, permitting gains other than +1.

### PERFORMANCE

In the *sample* mode, it is useful to consider that a SHA's performance can be characterized by specifications similar to those of a closed-loop operational amplifier (offset, drift, nonlinearity, gain error, bias current, etc.), but with somewhat slower response (gain-bandwidth, slewing rate, settling time) because of the need to charge the storage capacitor.

However, during the *sample-to-hold, hold,* and *hold-to-sample* states, the dynamic nature of the mode-switching introduces a number of specifications that are peculiar to SHAs. The most-important of these are defined below and illustrated in the adjoining figure. They include the *aperture time* and its *uncertainty*, the *sample-to-hold step, feedthrough* and *droop* (in hold), and *acquisition time.*



**DEFINITIONS**

*Acquisition Time* is the time required by the output of the device to reach its final value, within a specified error band, after the *sample* command has been given. Included are switch-delay time, the slewing interval, and settling time for a specified output-voltage change.

*Aperture (Delay) Time* is the time required after the *hold* command for the switch to open fully. The sample is, in effect, delayed by this interval, and the *hold* command would have to be advanced by this amount for precise timing.

*Aperture Uncertainty*—or *Aperture (Delay) Jitter*—is the range of variation in the *aperture time*. If the *aperture time* is "tuned out" by advancing the *hold* command a suitable amount, this spec establishes the ultimate timing error, hence, the maximum sampling frequency to a given resolution. For example, the ADSHM-5K specs are 20ns and 100ps.

*Charge Transfer* (or *offset step*), the principal component of *sample-to-hold* offset (or *pedestal*), is the charge transferred to the storage capacitor via stray capacitance when switching to the *hold* mode. It can sometimes be reduced by lightly coupling an appropriate-polarity version of the *hold* signal to the capacitor for cancellation. The associated voltage error ($\Delta Q/C$) can be reduced by using greater capacitance for storage; but this increases response time.

*Droop* is the change of the output voltage during *hold* as a result of leakage or bias currents flowing through the storage capacitor. Its polarity depends on the sources of leakage current within a given device. In ICs, it is specified as a *(droop* or *drift)* current, in modules, a dV/dt. (Note: $I = CdV/dt$.)

*Feedthrough* is the fraction of the input signal variation or ac input waveform that appears at the output in *hold*. It is caused by stray capacitive coupling from the input to the storage capacitor, principally across the open switch.

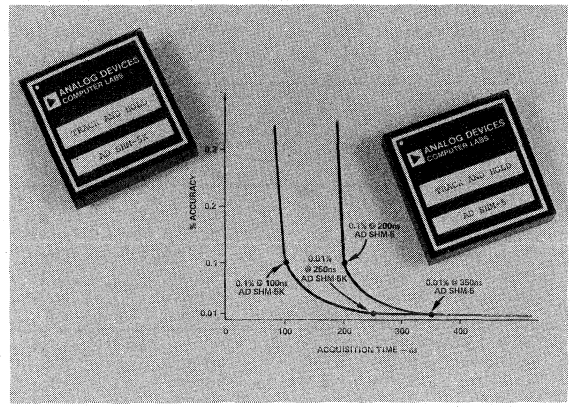
*Sample-to-Hold Offset*, a shift in level between the last value in *sample* and the value settled-to in *hold*, is the residual step error after the *charge transfer* is accounted for and/or cancelled. Since it is unpredictable in magnitude and may be a function of the signal, it is also known as *offset nonlinearity*.

# Ultra Fast 0.01% Track/Sample - Hold Amplifiers

# ADSHM-5/ADSHM-5K

**FEATURES**
**ADSHM-5**
**2nd Source—Replaces all SHM-5 Series**
**Fast 350ns Acquisition Time to ±0.01%**
**Aperture Uncertainty 250ps**
**ADSHM-5K**
**Ultra Fast 250ns Acquisition Time to ±0.01%**
**100ns Acquisition Time to ±0.1%**
**Wide 12MHz Bandwidth**
**300V/μs Slew Rate**
**Super Low 2nA Input Bias Current**

**APPLICATIONS**
**Fast Data Acquisition**
**Data Distribution Systems**
**Peak Measurement**
**Simultaneous Sample & Hold**
**Analog Delay & Storage**




## GENERAL DESCRIPTION

The ADSHM-5 is a new ultra-fast (350ns to 0.01%) sample-hold amplifier designed for use with high-speed 10- and 12-bit analog-to-digital converters, such as Analog Devices' MAH, MAS, and HAS Series, as well as other manufacturers' types.

Designed specifically to second source other SHM-5's, the ADSHM-5 is a fit, form and function equivalent for these modules.

When used in a 12-bit data acquisition system, the ADSHM-5 acquires to within 12 bits (±0.01%) in 350ns for a 10V step change. For systems requiring 10-bit performance, the ADSHM-5 acquires to within ±0.1% in just 200ns max.

Other salient features of the ADSHM-5 include 0.005% max Tracking Nonlinearity and a Small Signal Bandwidth of 5MHz.

To upgrade system performance one need only to look at the new ADSHM-5K. While sharing the same pinout and package of the ADSHM-5, this all new module utilizes the latest "state-of-the-art" hybrid techniques to offer the user the optimum in specifications. The ADSHM-5K features a maximum 12-bit acquisition time of only 250ns and 10-bit acquisition time of an astonishing 100ns max. Another improvement is in acquisition time where the input buffer must also respond to a 10V step change, such as in multiplexed applications. The total acquisition time in this application is only 350ns max. Further, the Small Signal Bandwidth has been improved from 5MHz to 12MHz.

Both units are packaged in a 2"X2"X0.4" case. The operating temperature range is 0 to +70°C, and the power requirements are ±15V dc @ 75mA max.

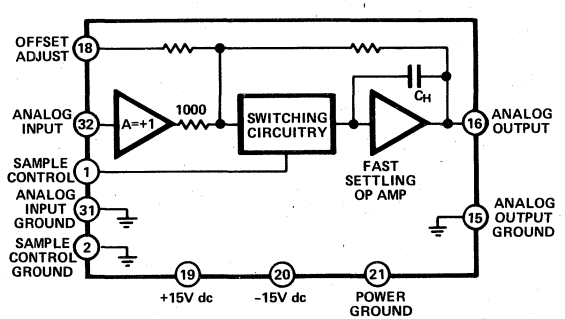



*Figure 1. ADSHM-5; ADSHM-5K Block Diagram*

## TRACK-AND-HOLD (T/H) MODE

When a unit is operated in the T/H mode, it is allowed to "track" the input signal for a period of time prior to initiating a "Hold Command." During the track period, the output follows the input, and the device functions like a unity gain amplifier.

When a Logic "0" is applied to the "Sample Control" input of the T/H, its output is frozen. This output level is held until the track mode is reestablished by a Logic "1" at the "Sample Control" input. This operation is shown graphically in Figure 4. The held output level is the voltage value at the input at the instant the hold command is applied, plus the aperture time.

14

# SPECIFICATIONS (typical @ +25°C and ±15V dc power supplies unless otherwise noted)

| MODEL | UNITS | ADSHM-5 | ADSHM-5K |
|---|---|---|---|
| ANALOG INPUT | | | |
| Input Voltage Range | V min | ±10 | * |
| Input Overvoltage, No Damage | V max | ±15 | * |
| Input Impedance | Ω | 100M | $10^{10}$ |
| Input Bias Current | nA max | 250 | 2 |
| Offset Adjustment Range | mV | ±300 | * |
| SAMPLE CONTROL INPUT | | | |
| Sample Mode: Logic "1", TTL[1] | V | +2.0 to +5.5 | * |
| Hold Mode: Logic "0", TTL | V | 0 to +0.8 | * |
| Loading | mA | +1 | * |
| ANALOG OUTPUT | | | |
| Output Voltage Range | V min | ±10 | * |
| Output Current | mA | ±40 | ±50 |
| Output Impedance | Ω max | 0.1 | * |
| Noise (dc to 2.5MHz) | μV | 100 | * |
| ACCURACY/STABILITY DC | | | |
| Gain[2] | V/V | −1.000 ±0.1% | * |
| Gain vs. Temperature | ppm/°C | ±10 | * |
| Output Offset vs. Temperature | μV/°C max | ±30 | * |
| Output Offset vs. Supply | mV/V | 1 | * |
| Tracking Nonlinearity | % max | ±0.005 | * |
| Output Offset Voltage, Sample Mode | mV max | ±50 | * |
| DYNAMIC RESPONSE[3] | | | |
| Acquisition Time[4], 10V to 0.1% | ns max | 200 | 100 |
| Acquisition Time[4], 10V to 0.01% | ns max | 350 | 250 |
| Acquisition Time[5], 10V to 0.01% | ns typ | 1,000 | 300 |
| Bandwidth, Tracking, −3dB | MHz | 5 | 12 |
| Slew Rate, Tracking | V/μs | 25 | 300 |
| Aperture Delay Time[6] | ns | 20 | * |
| Aperture Uncertainty Time | ps | 250 | 100 |
| Hold Mode Droop | μV/μs max | 20 | 12 |
| Hold Mode Feedthrough, dc to 500kHz | dB | 70 | * |
| Sample to Hold Offset Error | mV max | ±5 | * |
| POWER REQUIREMENT | | | |
| Power Supply Voltage | V dc | ±15 ±0.5 | * |
| Quiescent Current | mA max | 75 | * |
| PHYSICAL–ENVIRONMENTAL | | | |
| Operating | °C | 0 to +70 | * |
| Storage | °C | −55 to +125 | * |
| Relative Humidity | % | Up to 100%, noncondensing | * |
| Case Size | " | 2.0 X 2.0 X 0.4 | * |
| Case Material | N/A | Diallyl Phthalate per MIL-M-14 Type SDG-f | |
| Pins | N/A | 0.020" round, gold plated; 0.25" long min | |

NOTES
[1] TTL compatible. Schottky Pull Up (74S132 or equivalent) recommended to supply the 1mA required.
[2] The Gain Error of ±0.1% can be adjusted out most easily by using the Gain Adjust of the companion A/D converter.
[3] When switched into Hold, about 50ns is required for switching transients to settle. This time should be allowed before initiating the first conversion.
[4] From Tracking Mode.
[5] From Input Buffer.
[6] The Analog Signal Delay from the input to the Sampling Switch is approximately 32ns. Aperture Delay time is 20ns.

*Specifications same as ADSHM-5.

Specifications and prices subject to change without notice.

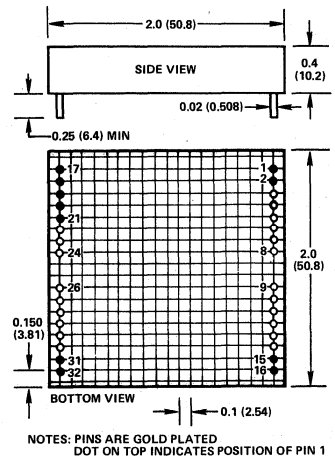



*Figure 2. Mechanical Dimensions Dimensions shown in inches and (mm).*

| PIN | FUNCTION |
|---|---|
| 1 | SAMPLE CONTROL |
| 2 | SAMPLE CONTROL GND |
| 15 | ANALOG OUTPUT GND |
| 16 | ANALOG OUTPUT |
| 17 | NC |
| 18 | OFFSET ADJUST |
| 19 | +15V POWER |
| 20 | -15V POWER |
| 21 | POWER GROUND |
| 31 | ANALOG INPUT GND |
| 32 | ANALOG INPUT |

*Figure 3. Pin Designations*

Variations in the instants of sampling are called Aperture Uncertainty. It appears as jitter in the sampling point and can cause significant errors when very high dV/dt inputs are sampled.

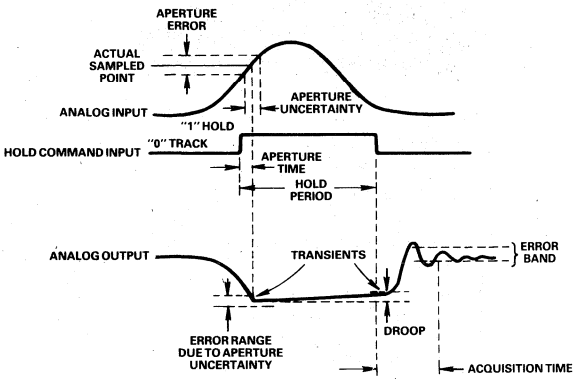



*Figure 4. Track/Hold Waveforms*

During the hold period, feedthrough and droop rate can introduce errors at the output. It is important that a track-and-hold have high feedthrough rejection to prevent input to output leakage during the hold period. The droop rate is the amount the output changes during the hold period, as a result of loading on the internal hold capacitor.

When the sample control input returns to the track condition, the amount of time required for the T/H output to reestablish accurate tracking of the input signal is called the acquisition time. Figure 5 shows settling accuracy versus acquisition time for the ADSHM-5 and ADSHM5-K.

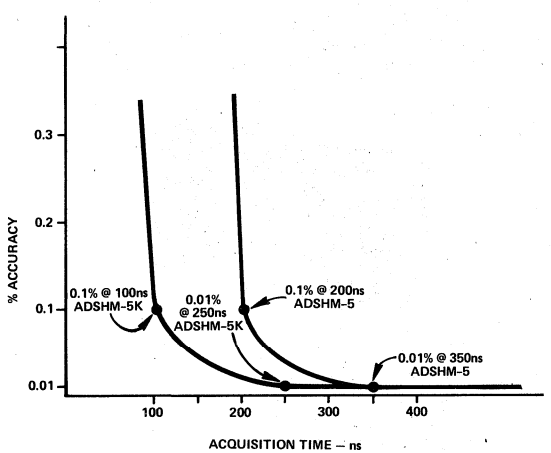



*Figure 5. Acquisition Time vs. Settling Accuracy*

**SAMPLE-AND-HOLD (S/H) MODE**

In the S/H mode of operation, devices are normally left in the hold condition. A very short sample pulse is applied to the sample control input when a new sample needs to be obtained at the output. The sample pulse width is dictated by the acquisition time.

**OPERATION WITH A/D CONVERTER**

The most common use for a track-and-hold is to place it ahead of an A/D converter to allow the digitizing of signals with bandwidths higher than the digitizer alone can handle. The use of the ADSHM series track-and-holds can allow a reduction of system aperture to 100ps. These track-and-holds may also be used for peak holding functions, simultaneous sampling A/Ds (with appropriate analog multiplexing), and other high-speed analog signal processing applications. The ADSHM series is designed to operate in either the track-and-hold or sample-and-hold modes. They perform well with the MAH series A/D converters as well as several other manufacturers' types, such as the Datel ADCEH series.

By using the circuit shown in Figure 6 using a 12-bit, 2μs A/D converter, throughput rates of up to 450kHz can be achieved for ultra-high-speed data acquisition applications.

The maximum value of input signal frequency that can be acquired and digitized (by the A/D converter) to within ±1/2LSB can be determined by the following:

$$fs = \frac{2^{-N}}{2\pi T_A} = \frac{1}{2\pi \cdot 4096 \cdot 1 \times 10^{-10}} = 388.7\text{kHz}$$

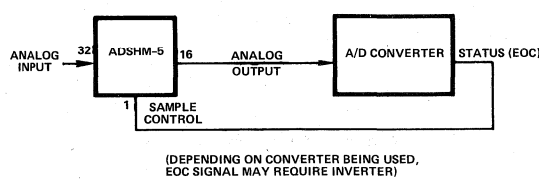



*Figure 6. Typical Circuit for Operation with A/D Converter*

**PEAK DETECTOR**

Figure 7 shows a slope-sensitive circuit which is capable of finding the peaks of positive excursions of an input waveform and digitizing the result. The circuit may be implemented without the A/D converter, in which case the output is an analog level held by the T/H module that may be observed or measured in some other manner.

The comparator triggers the T/H module when the positive slope of the input signal drops below a threshold slope equal to 15V/R2C1. A minimum positive slope of 15V/R1C1 is required to arm the detector. Resistors R1 and R2 are used to provide a guard band to prevent noise from triggering the circuit. The guard-band voltage is equal to 15V X R1/R2 and is generally set to approximately 5mV to 20mV.

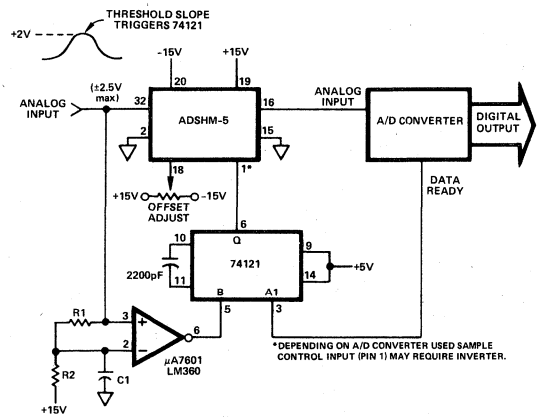



*Figure 7. Peak Detector Circuit*

**OFFSET ADJUSTMENT**

The maximum sample-to-hold offset error of 5mV is constant with signal level. The circuit of Figure 8 can be used to adjust this error out while in the hold mode. Please note that the ADSHM-5 or ADSHM-5K can be adjusted for zero output offset in either the tracking (sample) mode or the hold mode, but not in both at the same time.

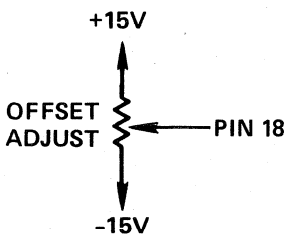



*Figure 8. Offset Adjustment*

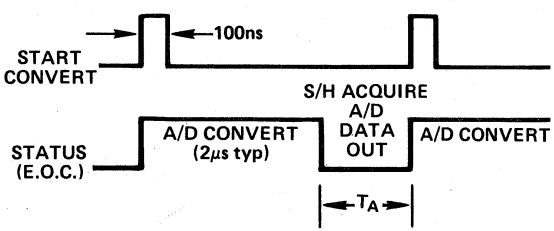
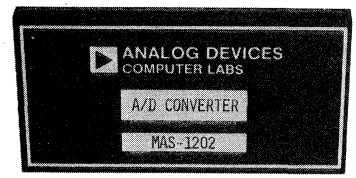



*Figure 9. Timing Diagram Acquisition Time*
*$T_A$ = ADSHM-5 = 350ns; $T_A$ = ADSHM-5K = 250ns*

## RECOMMENDED FOR USE WITH THESE POPULAR A/D CONVERTERS

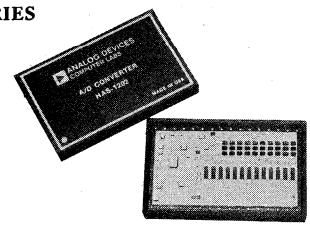
**MAS SERIES**




FEATURES
High Speed at Low Cost
- 8 Bits 1μs max
- 10 Bits 1.5μs max
- 12 Bits 2μs max

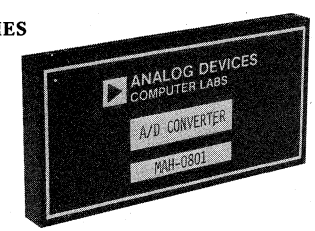
No Missing Codes Over Temperature
Low Power
Industry Standard Pin Out
Parallel and Serial Outputs
Pin and Function Compatible with ADCEH Series

**HAS SERIES**



FEATURES
Reliable Hybrid Construction
Conversion Times as Low as 1.2μs
Resolution: 8, 10 and 12 Bits
Exceptional Accuracy, 0.012% of FS
Low Power
Contained in Glass or Metal 32-Pin DIP
Adjustment-Free Operation

**MAH SERIES**




FEATURES
High Speed at Low Cost
- 8 Bits @ 750ns max
- 10 Bits @ 1μs max

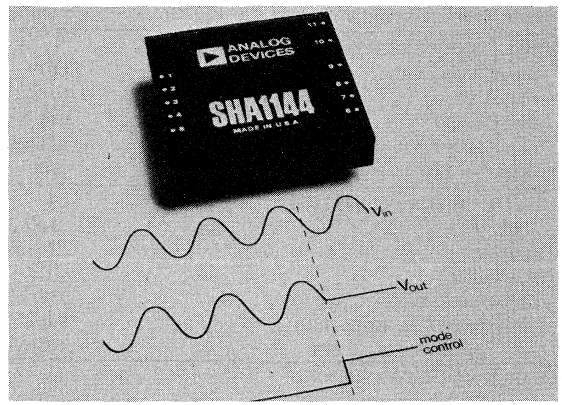
Monotonic Over Temperature
Differential Nonlinearity ±1/4LSB typ
Parallel and Serial Outputs
Pin and Function Compatible with 4130, 4131

# High Resolution 14-Bit Sample and Hold Amplifier

# SHA1144

**FEATURES**
- ±10V min Input/Output Range
- 50ns Aperture Delay
- 0.5ns Aperture Jitter
- 6μs Settling Time
- ±0.001% Max Gain Linearity Error
- Complete with Input Buffer

**APPLICATIONS**
- Track and Hold
- Peak Measurement Systems
- Data Acquisition Systems
- Simultaneous Sample-and-Hold




## GENERAL DESCRIPTION

The SHA1144 is a fast sample-hold amplifier module with accuracy and dynamic performance appropriate for applications with fast 14-bit A/D converters. In the "sample" mode, it acts as a fast amplifier, tracking the input signal. When switched to the "hold" mode, the output is held at a level corresponding to the input signal voltage at the instant of switching. The droop rate in "hold" is appropriate to allow accurate conversion by 14-bit A/D converters having conversion times of up to 150μs.

## DYNAMIC PERFORMANCE

The SHA1144 was designed to be compatible with fast 14-bit A/D converters such as the Analog Devices' ADC1130 and ADC1131 series, which convert 14 bits in 25μs and 12μs, respectively. Maximum acquisition time of 8μs for the SHA1144 permits high sampling rates for 14-bit conversions. The SHA1144 is guaranteed to have a maximum gain nonlinearity of ±0.001% of full scale to insure 1/2LSB accuracy in 14-bit systems. When in the "hold" mode, the droop rate is 1μV/μs, so the SHA1144 will hold an input signal to ±0.003% of full scale (20V p-p) for over 600μs.

## PRINCIPLE OF OPERATION

The SHA1144 consists basically of two high speed operational amplifiers, a storage capacitor, and a digitally controlled switch. It differs from typical sample-and-hold modules in one important respect; application versatility. The user completes the SHA1144 feedback circuit external to the module. Therefore, the module may be used in inverting or noninverting configurations and can easily be arranged to provide circuit gain of more than unity to simplify signal conditioning in a subsystem.

## FEEDBACK CONNECTIONS

A block diagram of the SHA1144 is shown in Figure 1. The input section acts as a voltage-to-current converter, providing the current needed to charge the "hold" capacitor. The output amplifier isolates the "hold" capacitor and provides low output impedance for driving the load. Since feedback is not hardwired in the module, both inverting and noninverting input terminals are available, and the SHA1144 can be connected as a follower with unity gain or potentiometric gain, as well as inverter or even a differential amplifier. Since the unity gain follower mode will be the most frequent application, performance data listed in the Specifications table is based on this operating mode.

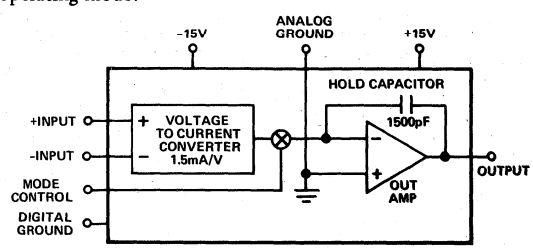



*Figure 1. Block Diagram – SHA1144*

# SPECIFICATIONS (typical @ +25°C, gain = +1V/V and nominal supply voltages unless otherwise noted)

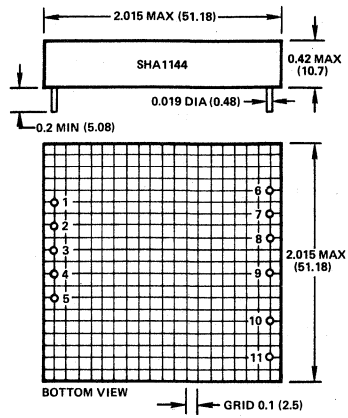
| MODEL | | SHA1144 |
|---|---|---|
| ACCURACY | | |
| Gain | | +1V/V |
| Gain Error | | ±0.005% |
| Gain Nonlinearity | | ±0.0005% (±0.001% max) |
| Gain Temperature Coefficient (0 to +70°C) | | ±1ppm/°C (±2ppm/°C max) |
| INPUT CHARACTERISTICS | | |
| Input Voltage Range | | ±10V |
| Impedance | | $10^{11}\ \Omega \parallel 10pF$ |
| Bias Current | | 0.5nA max |
| Initial Offset Voltage | | Adjustable to Zero |
| Offset vs. Temperature (0 to +70°C) | | ±30μV/°C max |
| OUTPUT CHARACTERISTICS | | |
| Voltage | | ±10V min |
| Current | | ±20mA min |
| Resistance | | <1Ω |
| Capacitive load | | 350pF |
| Noise @ 100kHz Bandwidth | | 70μV p-p |
| @ 1MHz Bandwidth | | 175μV p-p |
| SAMPLE MODE DYNAMICS | | |
| Frequency Response | | |
| Small Signal (-3dB) | | 1MHz |
| Full Power | | 50kHz |
| Slew Rate | | 3V/μs |
| SAMPLE-TO-HOLD SWITCHING | | |
| Aperture Delay Time | | 50ns |
| Aperture Uncertainty | | 0.5ns |
| Offset Step | | 1mV |
| Offset Nonlinearity | | 160μV |
| Switching Transient | | |
| Amplitude | | 50mV |
| Settling Time to ±0.003% | | 1μs |
| HOLD MODE DYNAMICS | | |
| Droop Rate | | 1μV/μs (2μV/μs max) |
| Variation with Temperature | | double every +10°C |
| Feedthrough (for 20V p-p Input @ 1kHz) | | -80dB |
| HOLD-TO-SAMPLE SWITCHING | | |
| Acquisition Time to ±0.003% | (20V Step) | 6μs (8μs max) |
| | (10V Step) | 5μs |
| ±0.01% | (20V Step) | 5μs |
| | (10V Step) | 4μs |
| DIGITAL INPUT | | |
| Sample Mode (Logic "1") | | +2V<Logic "1"<+5.5V @ 15nA max |
| Hold Mode (Logic "0") | | 0V<Logic "0"<+0.8V @ 5μA (20μA max) |
| POWER REQUIRED[1] | | +15V ±3% @ 60mA |
| | | -15V ±3% @ 45mA |
| TEMPERATURE RANGE | | |
| Operating | | 0 to +70°C |
| Storage | | -55°C to +85°C |

NOTES
[1] Recommended Power Supply ADI Model 902-2, ±15V @ ±100mA output.

Specifications subject to change without notice.

## OUTLINE DIMENSIONS

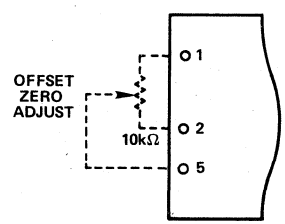
Dimensions shown in inches and (mm).




## PIN DESIGNATIONS

1. TRIM
2. TRIM
3. +INPUT
4. -INPUT
5. TRIM
6. +15V
7. ANALOG GROUND
8. -15V
9. ANALOG OUTPUT
10. MODE CONTROL
11. DIGITAL GROUND

## OFFSET ZERO ADJUST (OPTIONAL)



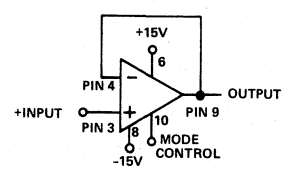




*Figure 2. Unity Gain Follower*

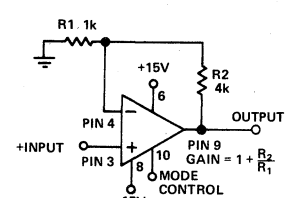



*Figure 3. Noninverting Operation*

## OUTLINE DIMENSIONS

Dimensions shown in inches and (mm).

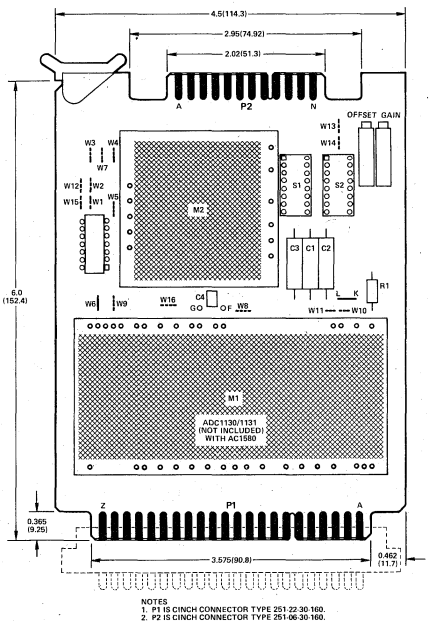



*Figure 4. AC1580 Mounting Board*

### OPTIONAL AC1580 EVALUATION BOARD

The optional AC1580, shown in Figure 4, is available for benchtop-evaluation of the SHA1144.

S1, S2: Harris HI508A multiplexers (optional, not included).

### DATA ACQUISITION APPLICATION

Successive-approximation A/D converters can generate substantial linearity errors if the analog input varies during the period of conversion; even the fast 14-bit models available cannot tolerate input signal frequencies of greater than a few Hz. For this reason, sample-and-hold amplifiers like the SHA1144 are connected between the A/D and its signal source to hold the analog input constant during conversion.

When the SHA1144 is connected to an A/D, its aperture time uncertainty, rather than the A/D's conversion time, is the factor which limits the allowable input signal frequency. The SHA1144, with a typical aperture delay time of 50ns and an uncertainty of 0.5ns, will change from the sample mode to the hold mode 50 to 50.5ns after the "1" to "0" transition of the mode control input. If the system timing is so arranged as to initiate the mode control signal 50ns early, then switching will actually occur within 0.5ns of the desired time as shown below.

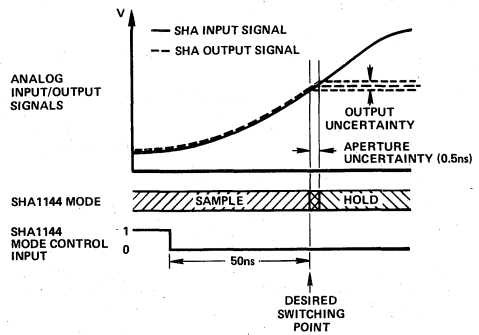



*Figure 5. Aperture Uncertainty*

The maximum allowable slew rate will thus equal the quotient of the maximum allowable voltage uncertainty and the 0.5ns aperture uncertainty. For sinewave inputs, the corresponding maximum frequency is expressed by:

$$f_{max} = \left(\frac{\Delta E}{E_{FS}}\right)\left(\frac{1}{2\pi\Delta t}\right) \cong 3.18 \times 10^8 \left(\frac{\Delta E}{E_{FS}}\right)$$

where: $\Delta E$ = the allowable voltage uncertainty

$E_{FS}$ = the sinewave magnitude

For a system containing a SHA1144 and a 14-bit A/D with ±10V input signals and an allowable input uncertainty of ±1/2LSB (±620μV), the maximum allowable signal frequency will be 19.7kHz.

### POWER SUPPLY AND GROUNDING CONNECTIONS

The proper power supply and grounding connections are shown below in Figure 6.

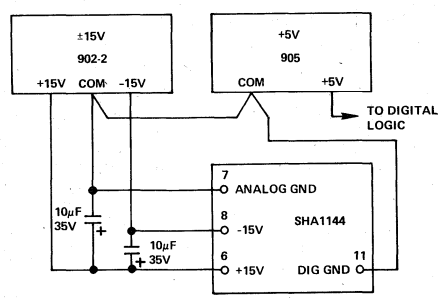



*Figure 6. Power Supply and Grounding Connections*

The ±15V power supplies must be externally bypassed as shown. The capacitors should be tantalum types and should be installed as close to the module pins as possible. The analog and digital ground lines should be run separately to their respective power supply commons to prevent coupling of digital switching noise to the sensitive analog circuit section.

14

## OPERATION WITH AN A/D CONVERTER

Figure 7 below shows the appropriate connections between the SHA1144 and a successive approximation A/D converter in block diagram form.

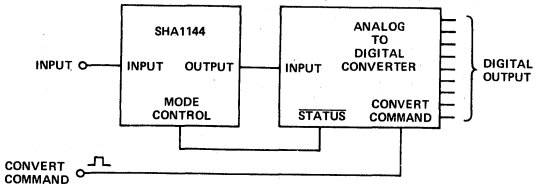



*Figure 7. SHA1144 and A/D Connections*

The resulting timing sequence at the start of conversion is illustrated in Figure 8.

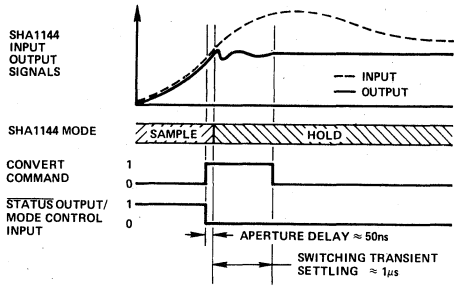



*Figure 8. A/D and SHA Timing at Start of Conversion*

Note that the leading edge of the convert command pulse causes the converter's STATUS output to go to Logic "0" which in turn switches the SHA1144 from sample to hold. As discussed previously, the typical SHA1144 actually changes modes 50 to 50.5ns after the "1" to "0" transition of the mode control input. This mode switching causes a transient on the output terminal which decays to within 0.003% of the final value in approximately 1μs. Once the transient has settled, the convert command input is returned to Logic "0" and the conversion proceeds. As shown in Figure 9, the STATUS signal returns to Logic "1" and the SHA1144 returns to the sample mode at the end of conversion. Within 6μs, it will have acquired the input signal to 0.003% accuracy and a new conversion cycle may be started.

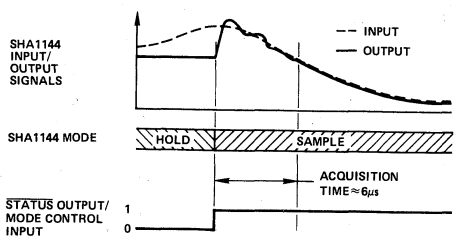



*Figure 9. A/D and SHA Timing at End of Conversion*

## OPERATION WITH AN A/D AND MULTIPLEXER

The subsystem of Figure 10 may also be connected to a multiplexer like the Harris HI508A as shown below.

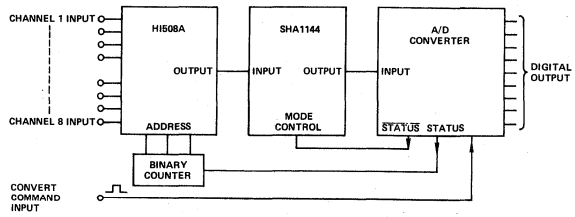



*Figure 10. A/D, SHA, and MPX Connections*

The leading edge of the convert command pulse sets the STATUS output to Logic "0" thereby switching the SHA1144 to "hold"; the corresponding change to Logic "1" of the STATUS output increments the binary counter and changes the multiplexer address. Since the SHA1144's aperture time is small with respect to the multiplexer switching time, it will have switched to the hold mode before the multiplexer actually changes channels. The multiplexer switching transients will settle out long before the SHA returns to "sample" at the end of conversion. The timing sequence described above is illustrated in Figure 11.

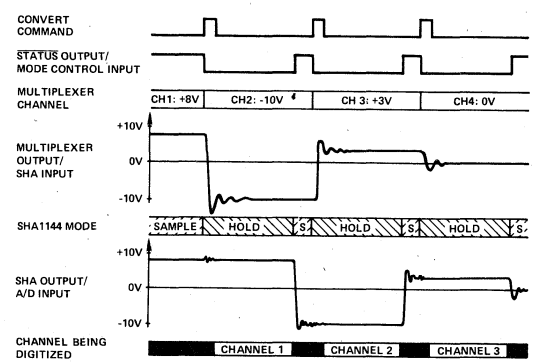



*Figure 11. A/D, SHA, and MPX Timing*

This method of sequencing the multiplexer may be altered to permit random addressing or addressing in a preset pattern. The timing of the multiplexer address changes may also be altered but consideration should be given to the effects of feedthrough in the SHA1144. Feedthrough is the coupling of analog input signals to the output terminal while the SHA is in "hold". Large multiplexer switching transients occuring during A/D conversion may introduce an error.

# ANALOG DEVICES

# Ultra High Speed Sample/Track-and-Hold Amplifiers

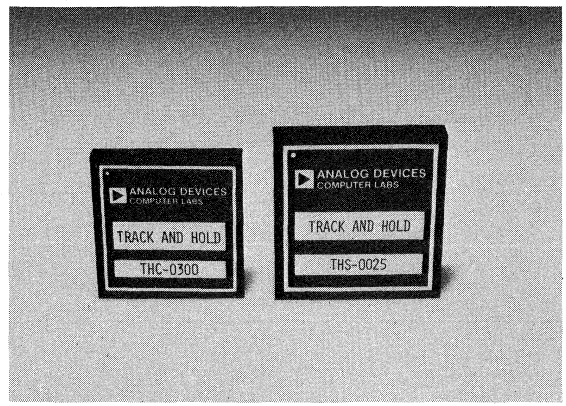
## THS, THC SERIES

**FEATURES**

**20ps Aperture Uncertainty (THS)**
**25 or 100ns Acquisition Times**
**0.01% Linearity**
**DC Coupled High Input Z Buffer**

**APPLICATIONS**

**Data Acquisition Systems**
**Peak Measurement Systems**
**Simultaneous Sample & Hold**
**Analog Delay & Storage**




### GENERAL DESCRIPTION

The THC-0300 and THS-0025 Sample/Track-and-Hold Amplifiers offer designers a choice of modules which can best meet the needs for various kinds of applications.

The THS-0025 has an acquisition time of 25ns and is capable of sample rates of 30MHz or higher for use in systems requiring this type of performance. The THC-0300 is not as fast as its companion T/H, but offers low droop rates, high output drive, and low feedthrough for situations which need those parameters. The combination of the two devices allows the system designer to make economical tradeoffs in choosing the precise characteristics needed for his design.

Both units feature high input impedance buffer amplifiers. The HTS-0025 is an "open-loop" T/H and achieves its speed with a dc-coupled Schottky diode sampling bridge; the "closed loop" HTC-0300 uses MOS FET switches.

### APPLICATIONS

The most common use for a track and hold is to place it ahead of an A/D converter to allow the digitizing of signals with bandwidths higher than the digitizer alone can handle. The use of the THS-0025 can allow a reduction of system aperture to 20ps while THC-0300 units provide 100ps. These track and holds may also be used for peak holding functions, simultaneous sampling A/D's (with appropriate analog multiplexing), and other high speed analog signal processing applications. These modules have been used to construct 13-bit A/D converters with word rates as high as 10MHz. The THS/THC series is designed to operate in either the track-and-hold or sample-and-hold modes. They perform well with the MAS series' A/D converters.

### TRACK-AND-HOLD (T/H) MODE

When a THS/THC unit is operated in the T/H mode, it is allowed to "track" the input signal for a period of time prior to initiating a "hold command". During the track period, the output follows the input, and the device functions as an amplifier. In the THC-0300, a resistor-gain-programmable op amp provides this function.

When a Logic "1" is input to the "hold command" input of the T/H, its output is frozen. This output level is held until the track mode is reestablished by a Logic "0" at the "hold command" input. This operation is shown graphically in Figure 1. The held output level is the voltage value at the input at the instant the hold command is applied, plus the aperture time.

Variations in the instants of sampling are called aperture uncertainty. It appears as jitter in the sampling point and can cause significant errors when very high dV/dt inputs are sampled.

During the hold period, feedthrough and droop rate can introduce errors at the output. It is important that a track and hold have high feedthrough rejection to prevent input to output leakage during the hold period. The droop rate is the amount the output changes during the hold period, as a result of loading on the internal hold capacitor.

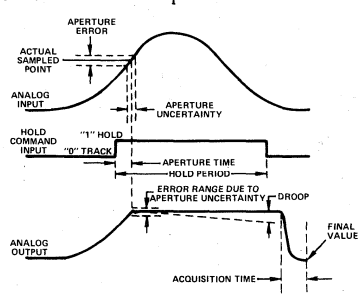



*Figure 1. Track-and-Hold Operation*

14

# SPECIFICATIONS (typical at 25°C and nominal supply voltages)

| MODEL | UNITS | FAST THC-0300 | ULTRA FAST THS-0025 |
|---|---|---|---|
| DYNAMIC CHARACTERISTICS | | | |
| Acquisition Time (to 0.1%) | ns | 100 | 25 |
| Sample Rate (max)[1] | MHz | 5 | 30 |
| Aperture Time TTL | ns | 18 | 10 |
| ECL | ns | 8 | 6 |
| Settling Time THC to 0.1%, THS to 1% (See Figure 2) | ns | 80 | 15 |
| Bandwidth (Small Signal 3dB) | MHz | 12 | 60 |
| Slew Rate | V/μs | 300 | 300 |
| Aperture Uncertainty | ps max | 100 | 20 |
| Harmonic Distortion, 500kHz THC, 5MHz THS | dB | 68 | * |
| Feedthrough Rejection (dc to max Sample Rate/2) (dc to 5MHz THS) | dB | 63 | 65 |
| Droop Rate | μV/μs | 12 | 5000 |
| ACCURACY/STABILITY DC | | | |
| Gain | V/V | −1 ±2% (Pin 6 to Pin 15) | 0.975 |
| Gain vs. Temperature | ppm/°C | 10 | 5 |
| Zero Offset Voltage | | Adjustable to Zero | * |
| Offset vs. Temperature | ppm/°C | 10 | 30 |
| Linearity | % | ±0.01 | * |
| INPUT | | | |
| Voltage | V max | ±10 | ±2 |
| Impedance | Ω | $10^{10}$ | 1M |
| Bias Current | nA | 0.05 | * |
| OUTPUT | | | |
| Voltage | V max | ±10 | ±2 (No Load) |
| Current | mA | ±50 | * |
| Impedance | | Less than 0.01Ω @ dc | 5Ω (Output 1, Pin 21)<br>75Ω (Output 2, Pin 22) |
| Noise (dc to 15MHz THS) (dc to 2.5MHz THC) | μV rms | 100 | 200 |
| HOLD COMMAND (DIGITAL INPUTS) | | | (TTL or ECL Offered as no cost Options) |
| TTL Single Line Input (2 Std. TTL Loads) | | | |
| "0" = Sample/Track | | 0 to +0.4V | * |
| "1" = Hold | | +2.4 to +5V | * |
| ECL | | Single Line Input[2] | Two Line Complementary[3] |
| "0" = Sample/Track | V | −1.7 | * |
| "1" = Hold | V | −0.8 | * |
| POWER REQUIREMENTS | | | |
| +15V ±5% (THC) +12V to +15V (THS) | mA max | 90 | 100 |
| −15V ±5% (THC) −12V to −15V (THS) | mA max | 80 | 100 |
| +5V ±5% (THS) TTL Option | mA max | N/A | 20 |
| −5.2V ±5% (THS) | mA max | N/A | 80 |
| −5.2V ±5% (THS) ECL Option | mA max | N/A | 24 |
| Power Supply Rejection Ratio ±15V | mV/V max | 10 | 20 |
| TEMPERATURE RANGE | | | |
| Operating | °C | 0 to +70 | * |
| Storage | °C | −55 to +125 | * |
| PHYSICAL CHARACTERISTICS | | | |
| Case | | diallyl phthalate per MIL-M-14 type SDG-F | * |

NOTES

[1] Sample rates shown are a guide only and are based on system acquisition times—not logic speed. These rates can be exceeded with acquisition time trade-offs.

[2] These inputs are unterminated. An external pull down resistor should be used when driven by ECL 10k logic source.

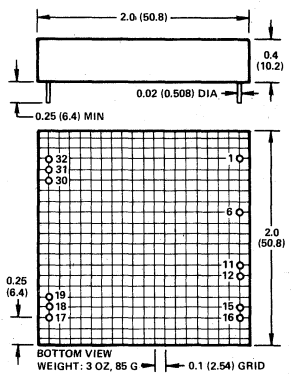
[3] These inputs are each terminated with a 330Ω pull down resistor to −5.2V.

*Specifications same as THC-0300.

Specifications subject to change without notice.

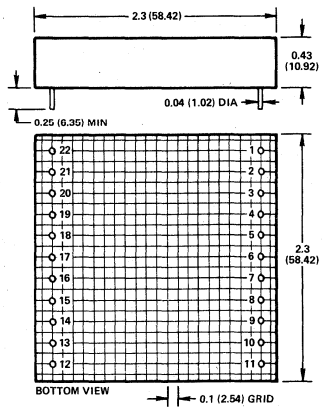
## OUTLINE DIMENSIONS

Dimensions shown in inches and (mm).




NOTES: PINS ARE GOLD PLATED.
DOT ON TOP INDICATES POSITION OF PIN 1.

*THC-0300*




NOTES: PINS ARE GOLD PLATED.
DOT ON TOP INDICATES POSITION OF PIN 1.

*THS-0025*

## PIN DESIGNATIONS

| PIN | THC-0300 FUNCTION | THS-0025 FUNCTION |
|---|---|---|
| 1 | ANALOG INPUT | GROUND |
| 4 | N/A | +15V |
| 5 | N/A | GROUND |
| 6 | FEEDBACK | -15V |
| 7 | N/A | HOLD COMMAND (ECL) |
| 8 | N/A | HOLD COMMAND (ECL) |
| 9 | N/A | HOLD COMMAND (TTL) |
| 10 | N/A | -5.2V |
| 11 | OFFSET ADJUST | +5V |
| 12 | OFFSET ADJUST | GROUND |
| 13 | N/A | OFFSET ADJUST |
| 14 | N/A | ANALOG INPUT 1 |
| 15 | UNITY GAIN | N/A |
| 16 | ANALOG OUTPUT | GROUND |
| 17 | GROUND | N/A |
| 18 | -15V | N/A |
| 19 | +15V | N/A |
| 20 | N/A | GROUND |
| 21 | N/A | ANALOG OUTPUT 1 |
| 22 | N/A | ANALOG OUTPUT 2 |
| 30 | HOLD COMMAND (ECL) | N/A |
| 31 | HOLD COMMAND (TTL) | N/A |
| 32 | GROUND | N/A |

When the hold command input returns to the track condition, the amount of time required for the T/H output to reestablish accurate tracking of the input signal is called the acquisition time. Figure 2 shows settling accuracy versus acquisition time. Figure 3 shows superimposed photographs of the input and output waveforms of a THS-0025 operated as a track-and-hold amplifier. Note that the output re-acquires the input just 12ns after the end of the hold time.

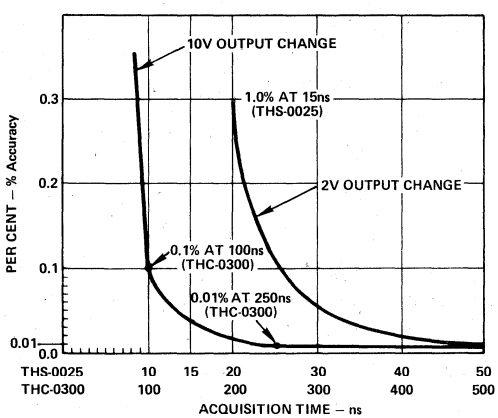



*Figure 2. Acquisition Time vs. Settling Accuracy*

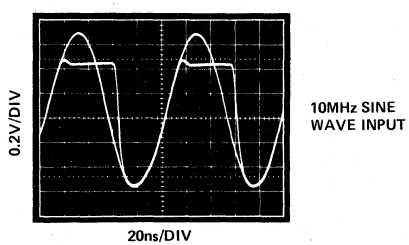



*Figure 3. Track-and-Hold Operation (THS-0025)*

### SAMPLE AND HOLD (S/H) MODE

In the S/H mode of operation, devices are normally left in the hold condition. A very short sample pulse is applied to the hold command input when a new sample needs to be obtained at the output. The sample pulse width is dictated by the acquisition time. For small sample-to-sample variations, a pulse width as narrow as 12ns may be used for THS-0025 units and 80ns for THC-0300 units. For greater accuracy, sample pulses should be wider (see Figure 2).

In general, however, the pulse width to the THS-0025 should be 15ns to 50ns, depending on required accuracy. Figure 4 shows the input and output waveforms of a THS-0025 used in the S/H mode.

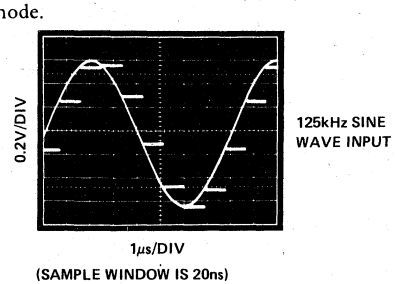



*Figure 4. Sample-and-Hold Operation (THS-0025)*

14

## APPLICATION NOTES

Figure 5 shows a slope sensitive circuit which is capable of finding the peaks of positive excursions of an input waveform and digitizing the result. The circuit may be implemented without the A/D converter, in which case the output is an analog level held by the T/H module that may be observed or measured in some other manner.

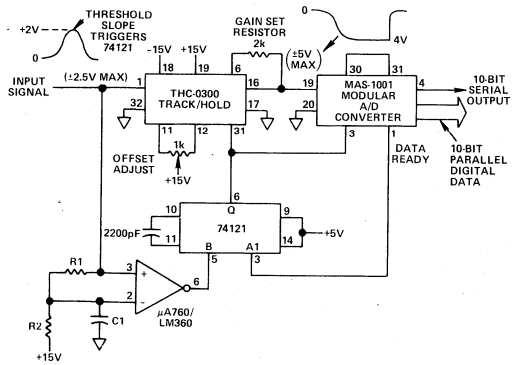



*Figure 5. Peak Detector (THC-0300)*

The comparator triggers the T/H module when the positive slope of the input signal drops below a threshold slope equal to 15V/R2C1. A minimum positive slope of 15V/R1C1 is required to arm the detector. Resistors R1 and R2 are used to provide a guard band to prevent noise from triggering the circuit. The guardband voltage is equal to 15V X R1/R2 and is generally set to approximately 5 to 20mV.

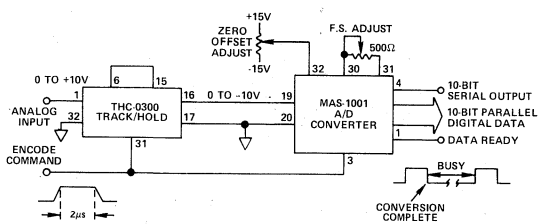



*Figure 6. A/D Conversion System (THC)*

| | |
|---|---|
| Throughput Rate | Greater than 400kHz |
| Overall Accuracy | 0.05% |
| Resolution | One Part in 1024 (10 Bit) |
| Aperture Uncertainty | 100ps |

| Analog Input | Digital Output |
|---|---|
| 0V | 0000000000 |
| +5.000V | 1000000000 |
| +9.990V | 1111111111 |

*Table I. Capsule Performance for the A/D System*

Analog Devices' THC series track-and-holds are designed to interface directly with the MAS series A/D converters as well as other commercially available modular A/Ds. In the above application, the THC module is used to acquire the analog signal to be converted and hold the sampled output over a much longer time period to permit the A/D module to accurately encode the analog data sample. In this way, the system aperture time is reduced to less than 100ps, and analog bandwidths up to the Nyquist limit may be accurately digitized.

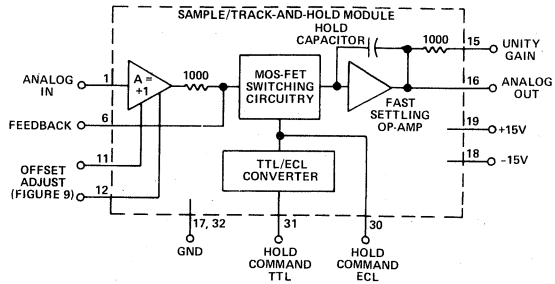



*Figure 7. Sample/Track-and-Hold THC-0300 Block Diagram*

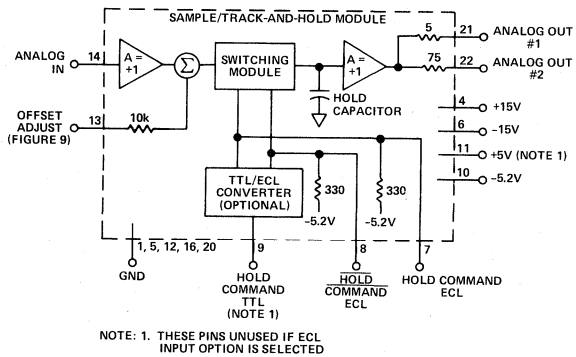



*Figure 8. Sample/Track-and-Hold THS-0025 Block Diagram*

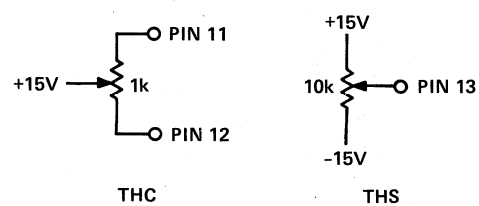



*Figure 9. Optional Offset Adjustments*

## ORDERING INFORMATION

Order THS-0025 TTL, THS-0060 TTL, or THS-0225 TTL for TTL Hold Command Option.

Order THS-0025 ECL, THS-0060 ECL, or THS-0225 ECL for Balanced ECL Hold Command Input.

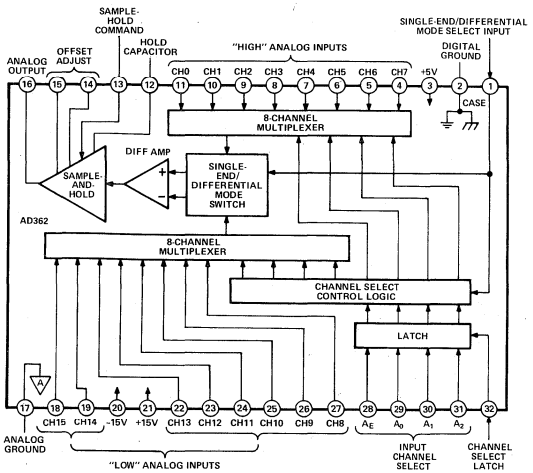
Order THC-0300, THC-0750, THC-1500 as required. All have available TTL and ECL Logic Inputs.

# Data Acquisition Subsystems

## Contents


| | Page |
|---|---|
| Selection Guide | 15–2 |
| DAS1128 16/8-Channel 12-Bit Data Acquisition Module | 15–5 |
| DAS1152/1153 14-Bit and 15-Bit Sampling Analog-to-Digital Converters | 15–13 |
| DAS1155/1156 14-Bit and 15-Bit Low Level Data Acquisition Systems | 15–17 |

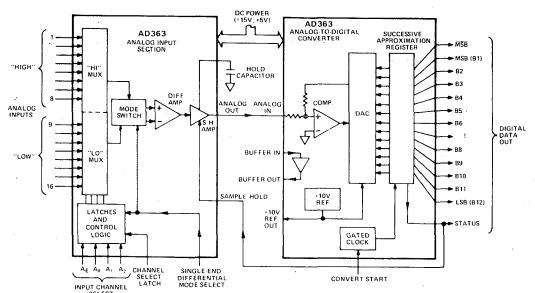
# Selection Guide
## Data Acquisition Subsystems




## AD362

Page Vol. I 15-5

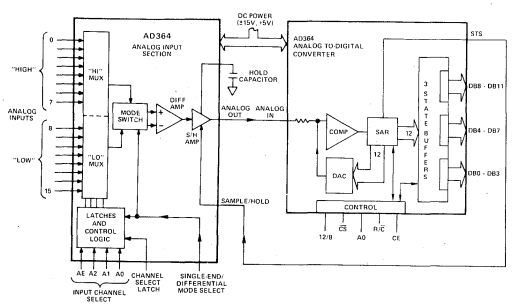
- 16 Single-Ended or 8 Differential Channels with Switchable Mode Control
- True 12-Bit Precision: Nonlinearity $\leq \pm 0.005\%$
- High Speed: 10μs Acquisition Time to 0.01%
- Complete and Calibrated: No Additional Parts Required
- Small, Reliable: 32-Pin Hermetic Metal DIP
- Versatile: Simple Interface to Popular Analog-to-Digital Converters
- High Differential Input Impedance ($10^{10}\Omega$) and Common-Mode Rejection (80dB)
- Fully Protected Multiplexer Inputs




## AD363

Vol. I 15-13

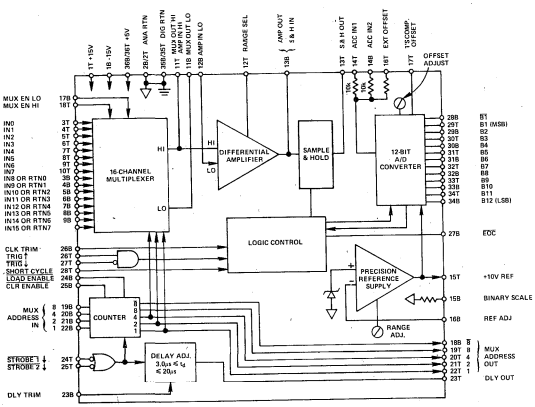
- Complete System in Reliable IC Form
- Small Size
- 16 Single-Ended or 8 Differential Channels with Switchable Mode Control
- Versatile Input/Output/Control Format
- Short-Cycle Capability
- True 12-Bit Operation: Nonlinearity $\leq \pm 0.012\%$
- Guaranteed No Missing Codes Over Temperature Range
- High Throughput Rate: 30kHz
- Low Power: 1.7W




## AD364

Vol. I 15-17

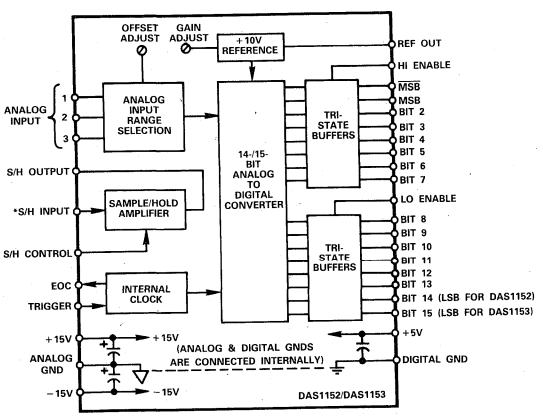
- Complete Data Acquisition System in 2-Package IC Form
- Full 8- or 16-Bit Microprocessor Bus Interface
- 16 Single-Ended or 8 Differential Channels with Switchable Mode Control
- True 12-Bit Operation: Nonlinearity $\leq \pm 0.012\%$
- Guaranteed No Missing Codes Over Specified Temperature Range
- High Throughput Rate: 20kHz
- Fast Successive Approximation Conversion: 25μs
- Buried Zener Reference for Long-Term Stablility and Low Gain TC
- Small Size: Requires Only 2.8 Square Inches
- Short Cycle Capability
- Low Power: 1.4W




## DAS1128

Page Vol. II 15-5

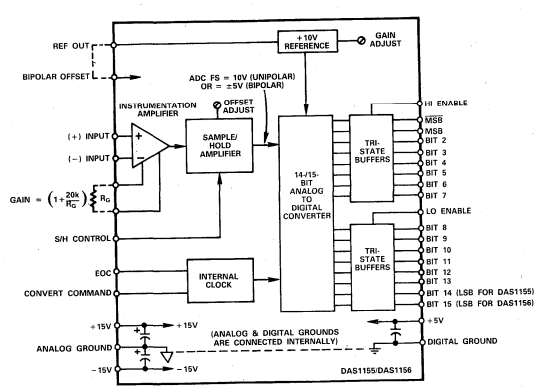
- Complete Data Acquisition System
- 12-Bit Digital Output
- 16 Single or 8 Differential Analog Inputs
- High Throughput Rate
- Selectable Analog Input Ranges
- Versatile Input/Output/Control Format
- Low 3 Watt Power Dissipation
- Small 3″ × 4.6″ × 0.375″ Module




## DAS1152/DAS1153

Vol. II 15-13

- 14-Bit & 15-Bit Sampling A/D Converter
- Complete with High Accuracy Sample/Hold and A/D Converter
- Differential Nonlinearity: ±0.002% FSR max (DAS1153)
- Nonlinearity: DAS1152: ±0.005% FSR max
  DAS1153: ±0.003% FSR max
- Low Differential Nonlinearity T.C.: ±2ppm/°C max
- High Throughput Rate: 25kHz min (DAS1152)
- High Feedthrough Rejection: −96dB
- Byte-Selectable Tri-State Buffered Outputs
- Internal Gain & Offset Potentiometers
- Improved Second Source to A/D/A/M 824 and A/D/A/M 825 Modules




## DAS1155/DAS1156

Vol. II 15-17

- 14-Bit & 15-Bit Low Level Data Acquisition System
- Functionally Complete:
  Includes Instrumentation Amplifier, Sample/Hold Amplifier, and Analog-to-Digital Converter
- Differential Nonlinearity: ±0.002% FSR max (DAS1156)
- Guaranteed Nonlinearity: ±0.005% FSR (DAS1155)
  ±0.003% FSR (DAS1156)
- High Common-Mode Rejection: −80dB (up to 500Hz)
- High Feedthrough Rejection: −96dB
- Resistor Programmable Gain: 1V/V to 1000V/V
- Byte Selectable Tri-State Buffer Outputs
- Internal Gain and Offset Potentiometers

15

# ANALOG DEVICES

# Low-Cost, High Speed Data Acquisition Module

# DAS1128

**FEATURES**

- **Complete Data Acquisition System**
- **12-Bit Digital Output**
- **16 Single or 8 Differential Analog Inputs**
- **High Throughput Rate**
- **Selectable Analog Input Ranges**
- **Versatile Input/Output Control Format**
- **Low 3 Watt Power Dissipation**
- **Small 3″ x 4.6″ x 0.375″ Module**




## GENERAL DESCRIPTION

The DAS1128 is a complete self-contained miniature high speed data acquisition system. The compact 3″ x 4.6″ x 0.375″ module provides the designer with an easily implemented solution to the data acquisition problem. It contains an analog input signal multiplexer, a sample-and-hold amplifier, a 12-bit A/D converter, and all of the programming, timing and control circuitry needed to perform the complete data acquisition function.

The DAS1128 is a high performance device which can digitize an analog signal to an accuracy of ±½LSB out of 12 bits, relative to full scale. It has ±8ppm/°C gain temperature coefficient, and the maximum throughput rate can be varied from 50,000 conversions/second for a 12 bit conversion from different analog input channels, to 200,000 conversions/second for a successive 4-bit conversion made on a single channel.

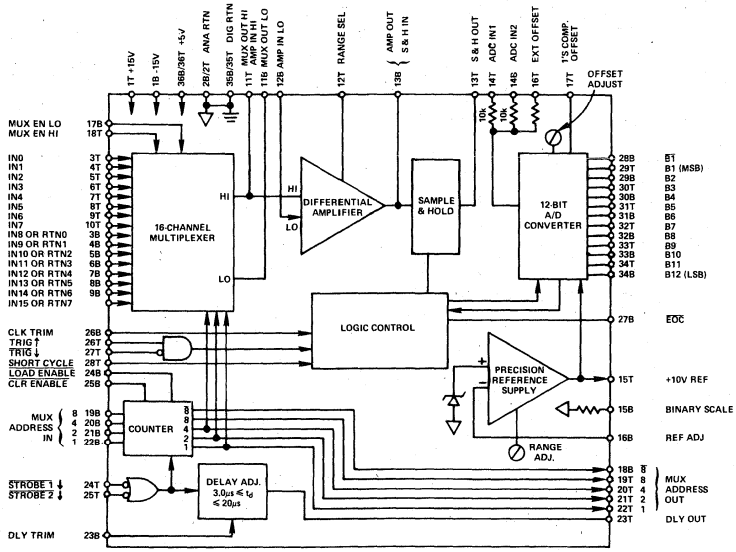



*Figure 1. Functional Block Diagram*

# SPECIFICATIONS (typical @ +25°C and ±15V unless otherwise noted)

**ANALOG INPUTS**

| | |
|---|---|
| Number of Inputs to Multiplexer | 16 Single Ended, 8 True-Differential, 16 Pseudo-Differential |
| Input Voltage (Full Scale Range) | -10V to +10V, 0V to +10V, -5V to +5V, 0V to +5V, -10.24V to +10.24V, 0V to +10.24V, -5.12V to +5.12V, or 0V to +5.12V. |
| Maximum Input Voltage | ±15V |
| Input Current (per channel) | 5nA max |
| Input Impedance | $>10^{10}$ ohms |
| Input Capacitance | 10pF for "OFF" channel<br>100pF for "ON" channel |
| Input Fault Current (power off or MUX failure) | Internally limited to 20mA |
| Direct ADC Input Impedance | 10kΩ for each input line |

**ACCURACY**[1]

| | |
|---|---|
| Resolution | 12 Bits |
| Error Relative to F.S. | ±½LSB |
| Quantization Error | ±½LSB |
| Differential Nonlinearity Error | |
| @ 33kHz throughput rate | ±½LSB, 1LSB max |
| @ 50kHz throughput rate | ±1LSB |
| Noise Error | ±¼LSB |
| -FS to +FS Error Between Successive Channel Transitions | ±1LSB |

**TEMP. COEFFICIENTS**

| | |
|---|---|
| Gain | 8ppm/°C, 20ppm/°C max |
| Offset | 5ppm/°C, 15ppm/°C max |
| Differential Nonlinearity | 2.5ppm/°C, 6ppm/°C max |

**SIGNAL DYNAMICS**

| | |
|---|---|
| Throughput Rate (12 Bits) | 50kHz (max)<br>(includes 5μs for MUX and SHA settling time plus 15μs for ADC) |
| MUX Crosstalk ("OFF" channels to "ON" channel) | >80dB down @ 1kHz |
| Differential Amplifier CMRR | 70dB to 1kHz |
| SHA Acquisition Time to 0.01% | 4.5μs max |
| SHA Aperture Uncertainty | 10ns |
| SHA Feedthrough | 70dB down @ 1kHz |

**DIGITAL INPUT SIGNALS**

| | |
|---|---|
| Compatibility | Standard DTL/TTL logic levels, 1 unit load/line |
| MUX Address Inputs (8, 4, 2, 1; Pins 19B through 22B) | Positive true natural binary coding selects channel for random addressing mode. Must be stable for 100ns after $\overline{\text{STROBE}}$. |
| MUX ENABLE HI (Pin 18T) | High (Logic "1") input enables MUX "HI" output (for inputs 0 through 7) |
| MUX ENABLE LO (Pin 17B) | High (Logic "1") input enables MUX "LO" output (for inputs 8 through 15) |
| $\overline{\text{STROBE}}$ (Pin 24T or 25T) | Negative going transition (Logic "1" to Logic "0") updates MUX address register. $\overline{\text{STROBE}}$ 1 must be a Logic "1" to enable $\overline{\text{STROBE}}$ 2. $\overline{\text{STROBE}}$ 2 must be at Logic "1" to enable $\overline{\text{STROBE}}$ 1. |
| $\overline{\text{LOAD ENABLE}}$ (Pin 24B) | High (Logic "1") input allows next $\overline{\text{STROBE}}$ command to sequentially advance MUX address register.<br>Low (Logic "0") input allows next $\overline{\text{STROBE}}$ command to update MUX address register according to external address inputs. |
| $\overline{\text{CLEAR ENABLE}}$ (Pin 25B) | Low (Logic "0") input allows next $\overline{\text{STROBE}}$ command to reset MUX address to channel "0" overriding $\overline{\text{LOAD ENABLE}}$. |
| TRIGGER (Pin 26T) | Positive going transition (Logic "0" to Logic "1") initiates A/D conversion (even during conversion); $\overline{\text{TRIGGER}}$ (Pin 27T) must be at Logic "0" to allow TRIGGER function. |
| $\overline{\text{TRIGGER}}$ (Pin 27T) | Negative going transition (Logic "1" to Logic "0") initiates A/D conversion; Pin 26T (TRIGGER) must be at Logic "1" to allow $\overline{\text{TRIGGER}}$ function. |

**DIGITAL OUTPUT SIGNALS**

| | |
|---|---|
| Compatibility | Standard DTL/TTL logic levels; 5 unit loads/line. |
| Parallel Outputs | $\overline{\text{B1}}$, B1 through B12 |
| Coding | Natural binary, two's complement, offset binary, or one's complement. Pin selectable. |
| MUX Address Outputs ($\overline{8}$, 8, 4, 2, 1; pins 18B, 19T through 22T) | Positive true natural binary coding indicates channel selected. |
| DELAY OUT (Pin 23T) | Negative going transition (Logic "1" to Logic "0") occurring normally 5μs (adjustable from 3.0μs to 20μs) after $\overline{\text{STROBE}}$ command initiates A/D conversion automatically when connected to the $\overline{\text{TRIGGER}}$. |
| $\overline{\text{EOC}}$ (Pin 27B) | High (Logic "1") output during A/D conversion. |

**ADJUSTMENTS & TRIMS**

| | |
|---|---|
| Offset Adjust | |
| Internal Adjustment (Externally Accessible) | ±10LSBs (min) |
| Remote External Adjustment (Pin 16T) | ±10LSBs (min) |
| Range Adjust | |
| Internal Adjustment (Externally Accessible) | ±10LSBs (min) |
| Remote External Adjustment (Pin 16B) | ±10LSBs (min) |
| Clock Trim (Pin 26B) | |
| Factory Setting (Pin 26B "OPEN") | 1.25μs/Bit |
| External Adjustment Range | 1.25μs/Bit to 2.08μs/Bit |
| Delay Trim (Pin 23B) | |
| Factory Setting (Pin 23B "OPEN") | 3.0μs |
| External Adjustment Range | 3.0μs to 20μs |

**CONTROLS**

| | |
|---|---|
| SHORT CYCLE (Pin 28T) | Connect to ground for full 12 bit resolution. Connect to $B_n$ output for resolution to $B_{n-1}$ bits. |
| Channel Selection Mode (MUX Address Loading Mode) | Random, sequential continuous, and sequential triggered. Pin selectable. |
| A-D Conversion/Channel-Select Sequences | Normal (input channel remains selected during its A/D conversion) and overlap (next channel selected during A/D conversion). Pin selectable. |
| Range Select (Pin 12T) | Differential Amplifier gain control: connect to ANA RTN (Pin 2T) for X1 gain; connect to AMP OUT (Pin 13B) for X2 gain. This control is used in FSR selection procedure. |
| BINARY SCALE (Pin 15B) | Connect to REF ADJ (Pin 16B) to set reference to 10.24V. This control is used in FSR selection procedure, see Table II. |
| OUTPUT CODING (Pin 17T) | Ground for 1's complement output code; connect to -15V dc for other available codes. |

**POWER REQUIREMENTS**

| | |
|---|---|
| +15V ±3% | 40mA, 50mA max |
| -15V ±3% | 70mA, 100mA max |
| +5V ±5% | 250mA, 500mA max |
| Power Supply Sensitivity[2]: | |
| Gain | ±2.0mV/V |
| Offset | ±4.0mV/V |
| Ref | ±0.5mV/V |

**ENVIRONMENT & PHYSICAL**

| | |
|---|---|
| Operating Temperature | 0 to +70°C |
| Storage Temperature | -25°C to +85°C |
| Relative Humidity | Up to 95% noncondensing |
| Electrical Shielding | RFI & EMI 6 sides (except connector area) |
| Packaging | Insulated steel cased module 3.00" x 4.60" x 0.375" |

NOTES

[1] Warm-Up time to rated accuracy is 5 minutes.

[2] Specification applies only when tracking +15V and -15V supplies are used, and for slowly occuring variations in power supply voltages.

Specifications subject to change without notice.

## THEORY OF OPERATION

A block diagram of the DAS1128 is shown in Figure 1. Analog input signals are applied to the various inputs of the 16 channel CMOS multiplexer. This multiplexer in conjunction with the differential amplifier that follows it, can be configured by the user to accept 16 single ended analog inputs, or 8 fully differential analog inputs. It can also be connected as a 16 channel "pseudo-differential" input device, which permits some of the benefits of differential operation while maintaining a 16 channel input capability.

The differential buffer amplifier is gain programmable by the user via jumpers at the module pins. This feature, along with the selectable reference voltages, permits the user to set up the DAS1128 to operate on any of 8 input voltage ranges. The differential amplifier drives a sample-and-hold amplifier, whose function it is to hold the selected analog input signal at a constant level while the A/D converter is making a conversion.

The A/D converter is a high speed 12-bit successive approximation device that has been designed using the Analog Devices' AD562, 12-bit integrated circuit D/A. The reference voltage for the conversion is supplied by an adjustable precision reference circuit that has a temperature coefficient of 5ppm/°C.

In addition to these basic functional blocks, the DAS1128 also contains all of the clock circuitry necessary to perform the complete data acquisition function. The internal clock can be externally adjusted to provide various throughput rates at different accuracies. Input channel addressing logic is provided, as is the capability to short cycle the A/D converter (i.e. perform conversions of less than 12-bits resolution). It is also possible for the user to adjust the time interval between input channel selection and the commencement of a conversion. The user can thus trade off speed vs. accuracy in the settling time of the multiplexer and sample-and-hold amplifier, as well as speed versus accuracy of the A/D converter.

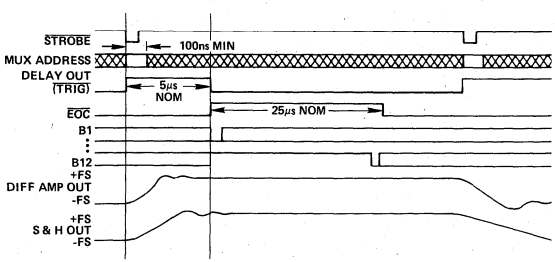



*Figure 2. Simplified Timing Diagram, Showing Time-Interval Assignments and Constants*

## INPUT CONNECTIONS

As shown in Figure 3, three input configurations can be used. 16 single-ended inputs (3a) can be connected to the multiplexer, all referenced to analog gnd. In the second configuration (3b), the inputs are connected individually as 8 true differential pairs. In this case the differential amplifier is connected "Differentially" with the output of the MUX. Finally, a "Pseudo-Differential" connection (3c) can be realized under favorable ground path conditions. In this configuration the differential amplifier Lo terminal is used as the ground return for all sensors. In each of these input schemes, it should be noted that the input multiplexer has been designed to protect itself and signal sources from both overvoltage failure and from fault currents due to power-off loading or MUX failure.

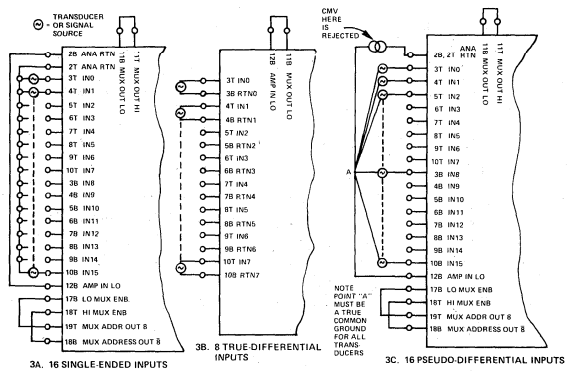



*Figure 3. Signal Input Connections for Three Different Configurations*

Full scale range of the DAS1128 may be set by appropriate jumper connections for 8 different ranges: 0 to +10V; 0 to +5V; 0 to +10.24V; 0 to +5.12V; -10 to +10V; -5 to +5V; -10.24 to +10.24V; -5.12 to +5.12V.

Note that 10.24 and 5.12 ranges are commonly used since conversion increments become 5mV/bit, 2.5mV/bit, and 1.25mV/bit.

## MUX AND S/H DYNAMICS – OVERLAP MODE

The overlap mode is defined as the ability of MUX to accept a new channel address thereby selecting the next channel to be sampled while the previously acquired sample is being held by the S/H for conversion. The dynamic characteristics of the S/H circuit are shown in Figure 4. Maximum throughput rates are obtainable when a single channel is held at a single address and the channel is sampled repeatedly. In a dynamic condition, data-throughput rates obtainable are shown in Figure 5.

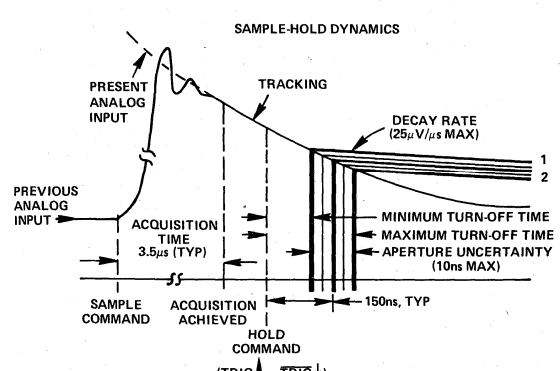



*Figure 4. Sample-Hold Parameters Defined and Specified*

## SHORT CYCLE

It is possible to short cycle the DAS1128, i.e. stop the conversion after less than 12 bits. This can be done by connecting an external jumper between short cycle terminal and one of the output terminals. With shorter cycles the attainable throughput rate increases, see Figure 5. In short cycle operation the $\overline{EOC}$ will decrease proportionately to the number of bits selected. Note the short cycle terminal *must* be grounded for full 12-bit operation.

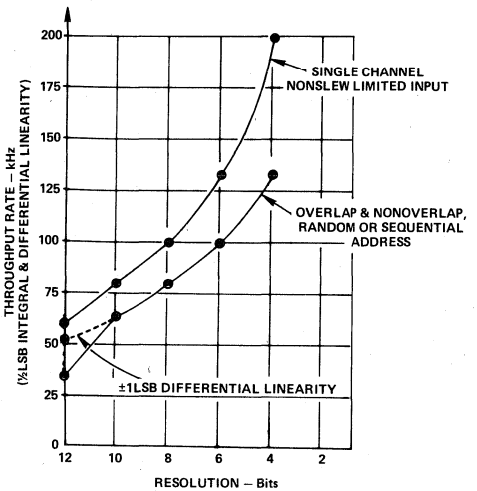
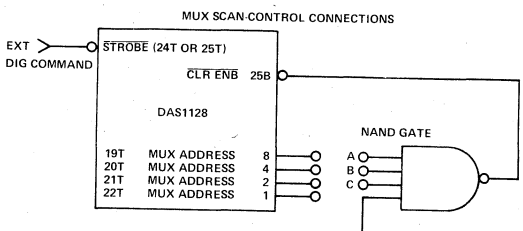



*Figure 5. DAS1128 Throughput Rates*

## MUX ADDRESSING

External terminals have been provided for the address counter. Thus the address counter can be configured to produce the following modes: Continuous sequential scanning (free running), sequential scanning with external step command, abbreviated scan continuously, random channel selection. See Figure 6 and set up procedure for details.




| LAST CHANNEL | MUX ADDRESS 8 | 4 | 2 | 1 | DIG. GROUND |
|---|---|---|---|---|---|
| 1 | X | X | X | A | X |
| 2 | X | X | B | X | X |
| 3 | X | X | B | A | X |
| 4 | X | C | X | X | X |
| 5 | X | C | X | A | X |
| 6 | X | C | B | X | X |
| 7 | X | C | B | A | X |
| 8 | C | X | X | X | X |
| 9 | C | X | X | A | X |
| 10 | C | X | B | X | X |
| 11 | C | X | B | A | X |
| 12 | B | C | X | X | X |
| 13 | B | C | X | A | X |
| 14 | A | C | B | X | X |
| 15 | X | X | X | X | A |

X = NO CONNECTION

IF $\overline{LOAD\ ENB}$ IS ALSO USED, CONNECT THIS INPUT TO IT (TO 24B). THIS GIVES LOADING PREFERENCE OVER CLEARING.

NOTE: FOR INITIAL CHANNEL = M, CONNECT GATE OUTPUT TO $\overline{LOAD\ ENB}$ (24B) AND CODE CHANNEL IN 8, 4, 2, 1 TO ADDRESS M. HOWEVER, THIS PRECLUDES RANDOM ADDRESSING.

*Figure 6. To shorten scanning sequence of multiplexer channels, make the appropriate connections, (as shown in the chart) between an external NAND gate and MUX ADDRESS terminals 19T to 21T*

## GROUNDING CONSIDERATIONS

Attention should be given to the methods of connection for electrical returns and voltage reference points. Analog return (ANA RTN) and digital return (DIG RTN) are provided. The following rules should be applied when integrating the DAS1128 into the system.

1. If the ±15V power supply is floating (for optimum analog accuracy), connect its return to ANA RTN (Pin 2B or 2T). If the ±15V power supply is *not* floating, connect its return to DIG RTN (Pin 35T or 35B).
2. Connect the +5V supply return to DIG RTN (Pin 35T or 35B). If this supply also powers additional equipment, run separate, parallel returns to the equipment ground and to DIG RTN (Pin 35T or 35B).
3. To minimize signal grounding problems, single-ended input signals should only be returned to ANA RTN (Pin 2B or 2T). If this is not possible, then connect the input signals in either the "true differential" or "pseudo-differential" configurations (see Figure 3).
4. Connect computer ground to DIG RTN (Pin 35T or 35B). Use heavy wire or ground planes.
5. The computer chassis should be connected to the computer and power supply grounds at only one point.
6. Connect the third-wire ground from main ac power input to the computer power supply return.

## GAIN AND OFFSET ADJUSTMENTS

The DAS1128 is calibrated with external gain and offset adjustment potentiometers connected as shown in Figure 7 and 8. The offset adjustment potentiometer has an adjustment range of at least ±10LSBs, and the gain range adjustment potentiometer has an adjustment range of at least ±10LSBs.

Offset calibration is not affected by changes in gain calibration, and should therefore be performed prior to gain calibration. Proper gain and offset calibration requires great care and the use of extremely sensitive and accurate reference instruments. The voltage standard used as a signal source must be very stable. It should be capable of being set to within ±1/10LSB of the desired value at any point within its range.

These adjustments are not made with zero and full scale input signals, and it may be helpful to understand why. An A/D converter will produce a given digital word output for a small range of input signals, the nominal width of the range being one LSB. If the input test signal is set to a value which should cause the converter to be on the verge of switching between two adjacent digital outputs, the unit can be calibrated so that it does switch at just that point. With a high speed convert command rate and a visual display, these adjustments can be performed in a very accurate and sensitive way. Analog Devices *Analog-Digital Conversion Notes* gives more detailed information on testing and calibrating A/D converters.

## OFFSET CALIBRATION

For unipolar +10V operation set the input voltage precisely to +0.0012V and adjust the offset potentiometer until the converter is just on the verge of switching from 000000000000 to 000000000001.

For ±5V bipolar operation set the input voltage precisely to -4.9988V; for ±10V units set it to -9.9976V. Adjust the offset

potentiometer, Figure 7, until Offset Binary coded units are just on the verge of switching from 000000000000 to 000000000001 and Two's Complement coded units are just on the verge of switching 100000000000 to 100000000001.

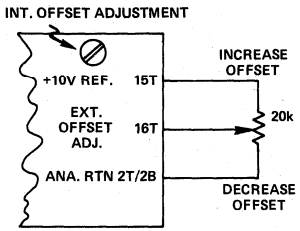



*Figure 7. Ext. Offset Adjustment*

## GAIN CALIBRATION

Set the input voltage precisely to +9.9963V for unipolar operation, +4.9963V for inputs of ±5V or +9.9926V for inputs of ±10V. Note that these values are 1½LSBs less than nominal full scale. Adjust the 20k variable gain resistor, Figure 8, until Binary and Offset Binary coded units are just on the verge of switching from 111111111110 to 111111111111 and Two's Complement coded units are just on the verge of switching from 011111111110 to 011111111111.

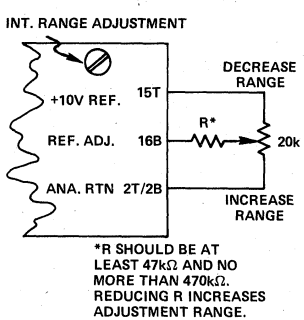



*Figure 8. Ext. Ref. Adjustment*

## CLOCK RATE ADJUSTMENT

The clock rate may be adjusted for best conversion time/accuracy trade-off. The conversion time is varied by means of the external circuitry shown in Figure 9. An open CLK TRIM terminal (Pin 26B) results in 1.25μs/bit nominal conversion time. A grounded CLK TRIM terminal (for highest accuracy) results in 2.08μs/bit conversion.

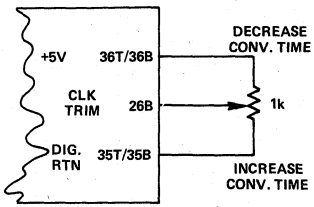



*Figure 9. Clock Trim*

## DELAY TIME ADJUSTMENT

The DLY OUT signal may be adjusted to vary the A/D converter triggering time by means of the external circuitry shown in Figure 10. An open DLY TRIM terminal (Pin 23B) results in a nominal delay time of 3.0μs. A grounded DLY TRIM terminal (for highest-accuracy) results in 20μs delay time nominal.

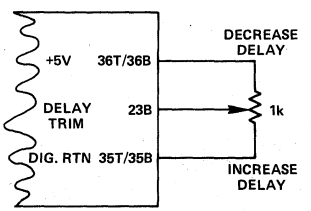



*Figure 10. Delay Trim*

15

**TABLE I**

| INPUT CONFIGURATION | ANALOG INPUT CONNECTIONS | ANALOG INPUT RETURN | JUMPER CONNECTIONS |
|---|---|---|---|
| 16 Single-Ended Inputs (Figure 3a) | 3T thru 10T and 3B thru 10B | All input returns to 2B or 2T | 11B to 11T<br>12B to 2B or 2T<br>17B to 19T<br>18T to 18B |
| 8 Differential Inputs (Figure 3b) | 3T thru 10T | 3B thru 10B | 11B to 12B<br>17B to 18T to "1" |
| 16 Pseudo-Differential Inputs (Figure 3c) | 3T thru 10T and 3B thru 10B | Common Input return to 12B | 11B to 11T<br>17B to 19T<br>18T to 18B |

**RECOMMENDED SET-UP PROCEDURE**

1. Select input configuration, see Table I.
2. Select MUX address mode.
   The method of addressing the multiplexer can be selected by connecting the unit as follows:

   RANDOM. Set Pin 24B ($\overline{\text{LOAD ENB}}$) to Logic "0". The next falling edge of $\overline{\text{STROBE}}$ will load the address presented to Pins 19B through 22B (8, 4, 2, 1). The code on these lines must be stable during the falling edge of $\overline{\text{STROBE}}$ plus 100ns.

   SEQUENTIAL FREE RUNNING. Set to Logic "1", Pin 24B ($\overline{\text{LOAD ENB}}$) and 25B ($\overline{\text{CLR ENB}}$). Connect Pin 27B ($\overline{\text{EOC}}$) to Pin 24T ($\overline{\text{STROBE 1}}$). Connect Pin 23T (DLY OUT) to Pin 27T ($\overline{\text{TRIG}}$). Use Pin 26T ($\overline{\text{TRIG}}$) as a run/stop control (i.e., A/D conversion will continue while TRIG is high and will stop while TRIG is low).

   SEQUENTIAL TRIGGERED. Set to Logic "1", Pins 24B ($\overline{\text{LOAD ENB}}$) and 25B ($\overline{\text{CLR ENB}}$). Connect Pin 24T ($\overline{\text{STROBE}}$) to external triggering source. The multiplexer address register will automatically advance by one channel whenever a $\overline{\text{STROBE}}$ command is received. The initial channel can be selected by setting Pin 24B ($\overline{\text{LOAD ENB}}$) to Logic "0" during only one $\overline{\text{STROBE}}$ command. The multiplexer address will then be determined by the logic levels on Pins 19B through 22B (the external MUX address lines). Channel "0" can be selected as the initial channel by setting Pin 25B ($\overline{\text{CLR ENB}}$) to Logic "0" during only one $\overline{\text{STROBE}}$ command. The final channel can be selected by following the procedure presented in Figure 6.
3. Select A-D conversion/channel select sequence (see Figure 5).
   (1) NORMAL (input channel remains selected during its A/D conversion). Connect Pin 23T (DLY OUT) to Pin 27T ($\overline{\text{TRIG}}$).
   (2) OVERLAP (next channel is selected during A/D conversion). Connect Pin 27B ($\overline{\text{EOC}}$) to TTL compatible inverter input. Connect inverter output to Pin 24T ($\overline{\text{STROBE}}$). Connect Pin 23T (DLY OUT) to Pin 27T ($\overline{\text{TRIG}}$). Adjust the delay to at least 4$\mu$s greater than $\overline{\text{EOC}}$, 20$\mu$s max (see Figure 10). The signal on Pin 26T (TRIG) serves as RUN/STOP control.
   (3) REPETITIVE SINGLE CHANNEL. After selecting the input channel to be repetitively sampled (see MUX ADDRESS MODE, above), set Pin 27T ($\overline{\text{TRIG}}$) to Logic "0". Connect Pin 26T (TRIG) to a triggering source. Conversion process is initiated by positive edge of TRIG command.
4. Select output resolution.
   a. Full 12-bit resolution: connect Pin 28T (SHORT CYCLE) to Pin 35B (DIG RTN).
   b. Bn (Bn $<$ 12) bit resolution: connect Pin 28T to the output pin for Bn + 1.
5. Select optimum throughput rate.
   The system clock frequency and the STROBE to TRIG delay (if used) can be trimmed to optimize the accuracy/throughput rate trade-off. See Figures 9 and 10.
6. Select input voltage full scale range. See Table II.
7. Select output digital coding. See Table III.

**TABLE II**

| FOR FULL SCALE RANGE OF: | MAKE THE FOLLOWING CONNECTIONS |
|---|---|
| 0 to +10V | 12T to 2T; 14T to 14B to ADC Source*. |
| 0 to +10.24V | same as 0 to +10V, *plus* 15B to 16B. |
| 0 to +5V | 12T to 13B; 14T and 14B to ADC Source*. |
| 0 to +5.12V | same as 0 to +5V, *plus* 15B to 16B. |
| -10V to +10V | 12T to 2T; 14T to 15T; and 14B to ADC Source*. |
| -10.24V to +10.24V | same as -10V to +10V, *plus* 15B to 16B. |
| -5V to +5V | 12T to 13B; 14T to 15T and 14B to ADC Source*. |
| -5.12V to +5.12V | same as -5V to +5V, *plus* 15B to 16B. |

*ADC Source is usually Sample and Hold Output (13T), but may be any signal source including Diff. Amp. Output (13B) if Sample and Hold is not desired.

**TABLE III**

| OUTPUT CODE | CONNECTIONS |
|---|---|
| Unipolar Binary | Connect 17T to -15V<br>Use 29T (B1) for MSB |
| 2's Complement | Connect 17T to -15V<br>Use 28B ($\overline{\text{B1}}$) for MSB |
| Offset Binary | Connect 17T to -15V<br>Use 29T (B1) for MSB |
| 1's Complement | Connect 17T to 2B<br>Use 28B ($\overline{\text{B1}}$) for MSB |

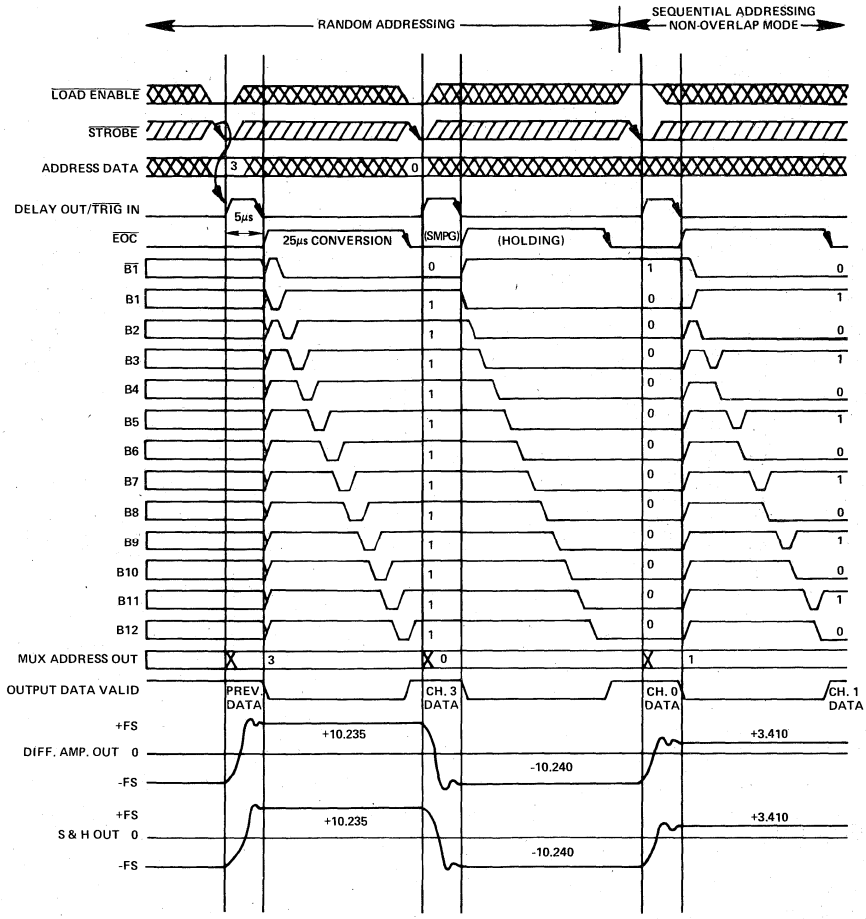



*Figure 11. Timing for Non-Overlap Operation in Both Random and Sequential Addressing Modes. For Status Keys and Signal Condition Data, Refer to Box Below.*

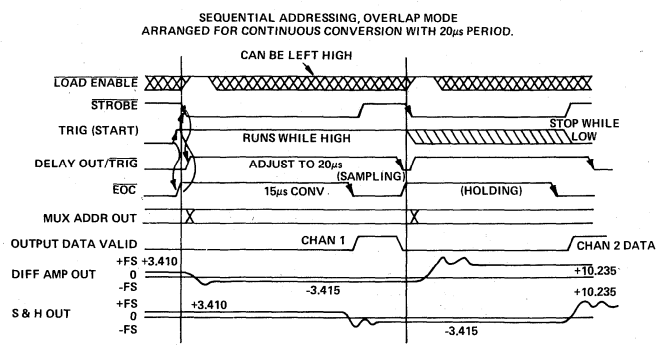



*Figure 12. Timing Diagram for Overlap Operation in the Sequential Addressing Mode. For Status Keys and Signal Condition Data, See Box at Right.*

**SIGNAL CONDITIONS AND STATUS KEYS FOR FIGURES 11 AND 12.**

CH. 2 = -3.415V CODE 010 101 010 101
CH. 3 = +10.235V CODE 111 111 111 111
CH. 0 = -10.240V CODE 000 000 000 000
CH. 1 = +3.410V CODE 101 010 101 010

ADC SET UP FOR ±10.24V. INPUT, OFFSET BINARY. (FOR TWO'S COMPLEMENT, USE $\overline{B1}$ FOR MSB.)

| KEY | INPUTS | OUTPUTS |
|---|---|---|
| XXX | May change | Don't know |
| ZZZ | May change 0 to 1 | Changes 0 to 1 |
| SSS | May change 1 to 0 | Changes 1 to 0 |
| OR | Must be stable | Will be stable |

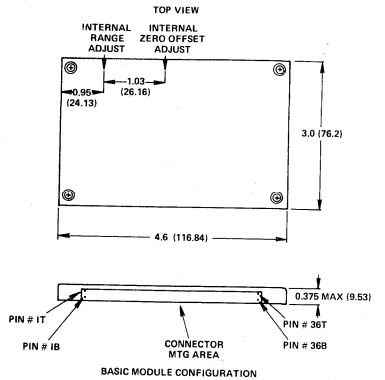
# Outline Drawings and Pin Designations

### DAS1128 CONNECTOR PIN DIAGRAM

| | | | | |
|---|---|---|---|---|
| +15V | 1T | 1B | -15V | |
| ANA RTN | 2T | 2B | ANA RTN | |
| CH 0 IN | 3T | 3B | CH 8 IN | (CH 0 RTN) |
| CH 1 IN | 4T | 4B | CH 9 IN | (CH 1 RTN) |
| CH 2 IN | 5T | 5B | CH 10 IN | (CH 2 RTN) |
| CH 3 IN | 6T | 6B | CH 11 IN | (CH 3 RTN) |
| CH 4 IN | 7T | 7B | CH 12 IN | (CH 4 RTN) |
| CH 5 IN | 8T | 8B | CH 13 IN | (CH 5 RTN) |
| CH 6 IN | 9T | 9B | CH 14 IN | (CH 6 RTN) |
| CH 7 IN | 10T | 10B | CH 15 IN | (CH 7 RTN) |
| MUX HI OUT | 11T | 11B | MUX LO OUT | |
| RANGE SEL | 12T | 12B | AMP IN LO | |
| S & H OUT | 13T | 13B | AMP OUT | |
| ADC IN 1 | 14T | 14B | ADC IN 2 | |
| +10V REF | 15T | 15B | BINARY SCALE | |
| EXT OFFSET | 16T | 16B | REF ADJ | |
| OUTPUT CODING | 17T | 17B | ENABLE LO | |
| ENABLE HI | 18T | 18B | 8 OUT | |
| 8 OUT / 4 OUT / 2 OUT / 1 OUT — MUX ADDRESS LINES | 19T–22T | 19B–22B | 8 IN / 4 IN / 2 IN / 1 IN — MUX ADDRESS LINES | |
| DLY OUT | 23T | 23B | DLY TRIM | |
| $\overline{\text{STROBE 1}}$ | 24T | 24B | $\overline{\text{LOAD ENB}}$ | |
| $\overline{\text{STROBE 2}}$ | 25T | 25B | CLR ENB | |
| TRIG | 26T | 26B | CLK TRIM | |
| $\overline{\text{TRIG}}$ | 27T | 27B | $\overline{\text{EOC}}$ | |
| SHORT CYCLE | 28T | 28B | $\overline{\text{B1}}$ OUT | |
| B1 OUT | 29T | 29B | B2 OUT | |
| B3 OUT | 30T | 30B | B4 OUT | |
| B5 OUT | 31T | 31B | B6 OUT | |
| B7 OUT | 32T | 32B | B8 OUT | |
| B9 OUT | 33T | 33B | B10 OUT | |
| B11 OUT | 34T | 34B | B12 LSB OUT | |
| DIG RTN | 35T | 35B | DIG RTN | |
| +5V | 36T | 36B | +5V | |

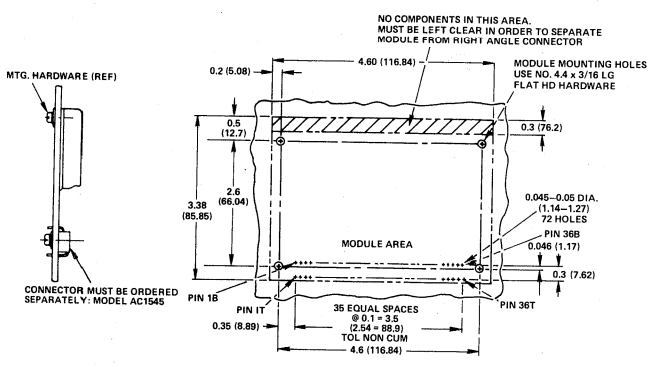
### OUTLINE DIMENSIONS

Dimensions shown in inches and (mm).




BASIC MODULE CONFIGURATION

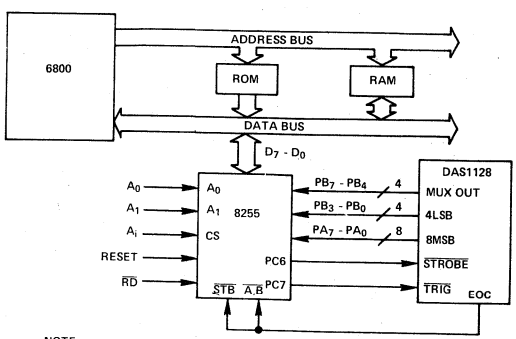
### P. C. BOARD LAYOUT




P.C. BOARD LAYOUT

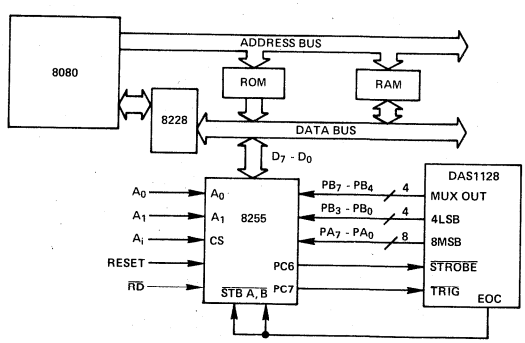
# Typical Applications

### DAS1128 WITH MOTOROLA 6800




NOTE:
1. 8255 USED IN MODE 1 (STROBED I/O)
2. PC6 INDEXES MUX TO DESIRED CHANNEL
3. CS TO $A_i$ (WHERE, $A_i$ IS AN ADDRESS BIT OTHER THAN $A_0$ OR $A_1$)
4. PC7 INITIATES CONVERSION
5. EOC STROBES IN DATA AND MUX INFO
6. 8255 SHOWN, HOWEVER 6820 CAN ALSO BE USED

### DAS1128 WITH INTEL 8080




NOTE:
1. 8255 USED IN MODE 1 (STROBED I/O)
2. CS TO $A_i$ (WHERE, $A_i$ IS AN ADDRESS BIT OTHER THAN $A_0$ OR $A_1$)
3. PC6 INDEXES MUX TO DESIRED CHANNEL
4. PC7 INITIATES CONVERSION
5. EOC STROBES IN DATA AND MUX INFO

# ANALOG DEVICES

# 14-Bit & 15-Bit Sampling Analog-to-Digital Converter

# DAS1152/DAS1153

**FEATURES**

- **Complete with High Accuracy Sample/Hold and A/D Converter**
- **Differential Nonlinearity: ±0.002% FSR max (DAS1153)**
- **Nonlinearity: DAS1152: ±0.005% FSR max**
  **DAS1153: ±0.003% FSR max**
- **Low Differential Nonlinearity T.C.: ±2ppm/°C max**
- **High Throughput Rate: 25kHz min (DAS1152)**
- **High Feedthrough Rejection: −96dB**
- **Byte-Selectable Tri-State Buffered Outputs**
- **Internal Gain & Offset Potentiometers**
- **Improved Second Source to A/D/A/M 824 and A/D/A/M 825 Modules**

**APPLICATIONS**

- **Process Control Data Acquisition**
- **Automated Test Equipment**
- **Seismic Data Acquisition**
- **Nuclear Instrumentation**
- **Medical Instrumentation**
- **Robotics**




## GENERAL DESCRIPTION

The DAS1152/DAS1153 are 14-/15-bit sampling analog-to-digital converters having a maximum throughput rate of 25kHz/20kHz. They provide high accuracy, high stability, and functional completeness all in a 2″ × 4″ × 0.44″ metal case.

Guaranteed high accuracy system performance such as nonlinearity of ±0.005% FSR (DAS1152)/±0.003% FSR (DAS1153) and differential nonlinearity of ±0.003% FSR (DAS1152)/±0.002% FSR (DAS1153) are provided. Guaranteed stability such as differential nonlinearity T.C. of ±2ppm/°C (DAS1153) maximum, zero T.C. of ±80μV/°C maximum, gain T. C. of ±8ppm/°C maximum and power supply sensitivity of ±0.001% FSR/% $V_S$ are also provided by the DAS1152/DAS1153.

The DAS1152/DAS1153 make extensive use of both integrated circuit and thin film components to obtain their excellent performance, small size, and low cost. The devices contain a precision sample/hold amplifier, high accuracy 14-/15-bit analog-to-digital converter, tri-state output buffers, internal gain and offset trim potentiometers, and power supply bypass capacitors (as shown in Figure 1).

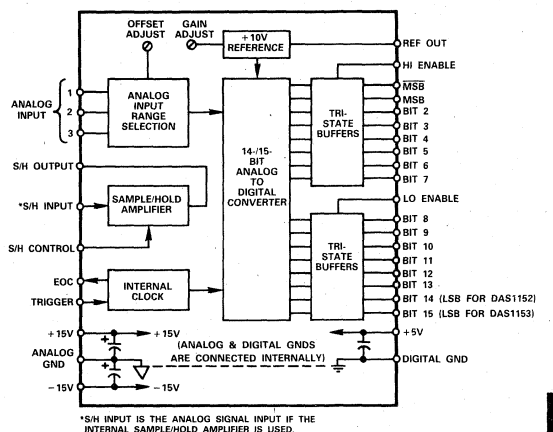



*Figure 1. DAS1152/DAS1153 Block Diagram*

Four analog input voltage ranges are selectable via user pin programming: 0 to +5V, 0 to +10V, ±5V, and ±10V. Unipolar coding is provided in true binary format with bipolar coding displayed in offset binary and two's complement. Tri-state buffers provide easy interface to bus structured applications.

15

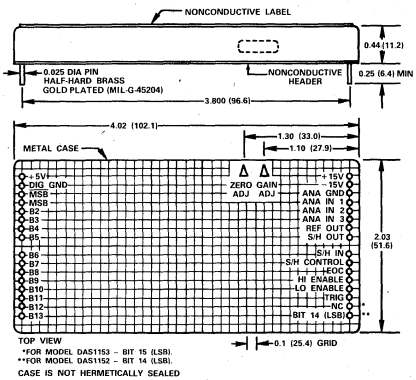
# SPECIFICATIONS (typical @ +25°C unless otherwise specified)

| MODEL | DAS1152 | DAS1153 |
|---|---|---|
| RESOLUTION | 14 Bits | 15 Bits |
| DYNAMIC PERFORMANCE | | |
| Throughput Rate | 25kHz min | 20kHz min |
| Conversion Time | 35μs max | 44μs max |
| S/H Acquisition Time | 4μs max | 5μs max |
| S/H Aperture Delay | 50ns | * |
| S/H Aperture Uncertainty | 1ns | * |
| Feedthrough Rejection[1] | −96dB | * |
| Droop Rate | 0.05μV/μs (0.1μV/μs max) | * |
| Dielectric Absorption Error | ±0.005% of Input Voltage Change | * |
| ACCURACY | | |
| Integral Nonlinearity[2] | ±0.005% FSR[3] max | ±0.003% FSR[3] max |
| Differential Nonlinearity | ±0.003% FSR[3] max | ±0.002% FSR[3] max |
| No Missing Codes | Guaranteed | * |
| ±3σ Noise (S/H plus A/D) | 75μV rms | * |
| ±3σ Noise (A/D) | 50μV rms | * |
| STABILITY | | |
| Differential Nonlinearity T.C. | ±2ppm/°C max | * |
| Gain T.C. | ±8ppm/°C max | * |
| Zero T.C. | ±30μV/°C typ, ±80μV/°C max | * |
| Power Supply Sensitivity | ±0.001% FSR[3]/% $V_s$ | * |
| ANALOG INPUT | | |
| Voltage Range | | |
| Bipolar | ±5V, ±10V | * |
| Unipolar | 0 to +5V, 0 to +10V | * |
| ADC Input Impedance 0 to +5V | 2.5kΩ | * |
| 0 to +10V, ±5V | 5kΩ | * |
| ±10V | 10.0kΩ | * |
| S/H Input Impedance | 100MΩ‖5pF | * |
| DIGITAL INPUTS | | |
| Convert Command[4] | 1TTL Load, Positive Pulse | * |
| | Negative Edge Triggered | * |
| S/H Control | HOLD = Logic 0 | * |
| | SAMPLE = Logic 1 | * |
| Low Enable, High Enable | ENABLE = Logic 0 | * |
| DIGITAL OUTPUTS | | |
| Parallel Data Outputs | | |
| Unipolar | Binary | * |
| Bipolar | Offset Binary, 2's Complement | * |
| Output Drive | 2TTL Loads | * |
| Status | Logic "1" During Conversion | * |
| Output Drive | 2TTL Loads | * |
| INTERNAL REFERENCE VOLTAGE | +10V, ±0.3% | * |
| External Load Current (Rated Performance) | 2mA max | * |
| Temperature Stability | ±5ppm/°C max | * |
| POWER REQUIREMENTS | | |
| Rated Voltages | ±15V (±3%), +5V (±5%) | * |
| Operating Voltages[5] | ±12V to +17V, +4.75V to +5.25V | * |
| Supply Current Drain ±15V | ±37mA | * |
| +5V | 80mA | * |
| TEMPERATURE RANGE | | |
| Specified | 0 to +70°C | * |
| Operating | −25°C to +85°C | * |
| Storage | −25°C to +85°C | * |
| Relative Humidity | Meets MIL-STD-202E, Method 103B | * |
| Shielding | Electrostatic (RFI) 6 Sides, | * |
| | Electromagnetic (EMI) 5 Sides | * |
| SIZE | 2" × 4" × 0.44" Metal Package | * |

NOTES
*Specifications same as DAS1152
[1]Measured in hold mode, input 20V pk-pk @ 10kHz.
[2]Worst-case summation of S/H and A/D nonlinearity errors.
[3]FSR means Full Scale Range.
[4]When connecting the Convert Command and the S/H control terminals together, the pulse width must be long enough for the S/H amplifier to acquire the input signal to the required accuracy 4μs (max, DAS1152)/5μs (max, DAS1153). If the A/D converter is only used, the Convert Command pulse width should be 100ns min (see Figure 2).
[5]If only the ADC portion is used, the operating power supply voltage can be maintained at ±12V to ±17V. But if the S/H section is required, the operating voltage must be maintained at ±15V (±3%) or the S/H input voltage must be limited to −7V to +10V for a ±12V supply voltage.
[6]Recommended Power Supply: Analog Devices Model 923.
Specifications subject to change without notice.

## OUTLINE DIMENSIONS

Dimensions shown in inches and (mm).



*FOR MODEL DAS1153 – BIT 15 (LSB).
**FOR MODEL DAS1152 – BIT 14 (LSB).
CASE IS NOT HERMETICALLY SEALED

## OPERATION

The DAS1152/DAS1153 are functionally complete data acquisition subsystems being fully characterized as such. All the necessary data acquisition and microprocessor interface elements are provided internal to these devices. Accuracy and performance criteria are tested and specified for the entire system. Thus, design time and associated high accuracy problems are minimized because layout and component optimization have already been performed.

For operation, the only connections necessary to the DAS1152/DAS1153 are the ±15V and +5V power supplies, analog input signal, trigger pulse, and the HI-ENABLE/LO-ENABLE tri-state controls. Analog input and digital output programming are user selectable via external jumper connections.

## ANALOG INPUT SECTION

The analog input can be applied to just the A/D converter or to the internal sample/hold amplifier ahead of the A/D converter. When using just the A/D converter, apply the analog input per the voltage range pin programming shown in Table I. When using the sample/hold amplifier in conjunction with A/D converter, apply the analog input to the S/H INPUT terminal and connect the S/H OUTPUT terminal to the appropriate A/D converter analog input.

| Analog Voltage Input Range | Connect $V_{IN}$ or S/H Out To | Connect Analog Common To | Connect Ref Out To |
|---|---|---|---|
| 0 to +5V | ANA IN 1, ANA IN 2, ANA IN 3 | Ground | NC* |
| 0 to +10V | ANA IN 2 ANA IN 3 | Ground ANA IN 1 | NC* |
| ±5V | ANA IN 1 | Ground, ANA IN 3 | ANA IN 2 |
| ±10V | ANA IN 3 | Ground, ANA IN 1 | ANA IN 2 |

*No Connection

*Table I. Analog Input Pin Programming*

Errors due to source loading are eliminated since the sample/hold amplifier is a high-impedance unity-gain amplifier. High feedthrough rejection is provided for either single-channel or multichannel applications. Feedthrough rejection can be optimized, in multichannel applications, by changing channels at the rising or falling edge of the S/H control pulse.

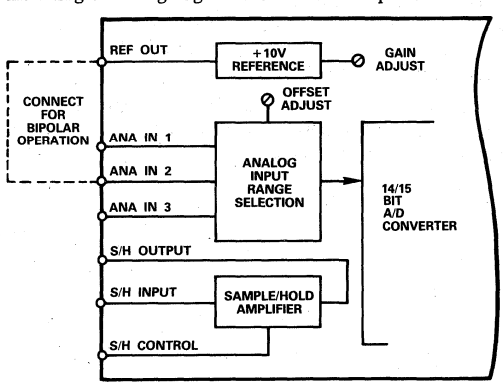



*Figure 2. Analog Input Block Diagram*

## TIMING DIAGRAM

The timing diagram for the DAS1152/DAS1153 is illustrated in Figure 3. This figure also includes the sample/hold amplifier acquisition time.

If the sample/hold amplifier is required, the TRIGGER input and S/H CONTROL terminal can be tied together providing only one conversion control signal. When the trigger pulse goes high, it places the sample/hold amplifier in the sample mode allowing it to acquire the present input signal. The trigger pulse must remain high for a minimum of 4μs (DAS1152)/5μs (DAS1153) to insure accuracy is attained. If the sample/hold amplifier is not used, the trigger pulse needs to be only 100ns (min) in length to satisfy the A/D converter trigger requirements. At the falling edge of the trigger pulse, the sample/hold amplifier is placed in the hold mode, the A/D conversion begins, and all internal logic is reset. Once the conversion process is initiated, it cannot be retriggered until after the end of conversion.

With this negative edge of the trigger pulse the MSB is set low with the remaining digital outputs set to logic high state, and the status line is set high and remains high through the full conversion cycle. During conversion each bit, starting with the MSB, is sequentially switched low at the rising edge of the internal clock. The DAC output is then compared to the analog input and the bit decision is made. Each comparison lasts one clock cycle with the complete 14-/15-bit conversion taking 35μs/44μs maximum for the DAS1152/DAS1153 respectively. At this time, the STATUS line goes low signifying that the conversion is complete. For microprocessor bus applications, the digital output can now be applied to the data bus by enabling the tri-state buffers. For maximum data throughput, the digital output data should be read while the sample/hold amplifier is acquiring the new analog input signal.

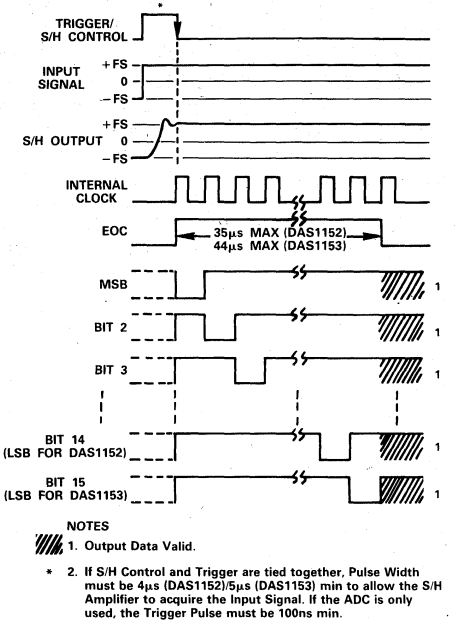



*Figure 3. DAS1152/DAS1153 Timing Diagram*

## GAIN AND OFFSET ADJUSTMENT

The DAS1152/DAS1153 contain internal gain and offset adjustment potentiometers. Each potentiometer has ample adjustment range so that gain and offset errors can be trimmed to zero.

Since offset calibration is not affected by changes in gain calibration, it should be performed prior to gain calibration. Proper gain and offset calibration requires great care and the use of extremely sensitive and accurate reference instruments. The voltage standard used as a signal source must be very stable and be capable of being set to within ±1/10LSB of the desired value at any point within its range.

## OFFSET CALIBRATION

For a 0 to +10V unipolar range set the input voltage precisely to +305μV for the DAS1152 and +153μV for the DAS1153. For a 0 to +5V unipolar range set the input to +153μV for the DAS1152 and +76μV for the DAS1153. Then adjust the zero potentiometer until the converter is just on the verge of switching from 000.....000 to 000.....001.

For the ±5V bipolar range set the input voltage precisely to +305μV for the DAS1152 and +153μV for the DAS1153. For a ±10V bipolar range set the input voltage precisely to +610μV for the DAS1152 and +305μV for the DAS1153. Adjust the zero potentiometer until the offset binary coded units are just on the verge of switching from 000.....000 to 000.....001 and the two's complement coded units are just on the verge of switching from 100.....000 to 100.....001.

## GAIN CALIBRATION

Set the input voltage precisely to +9.99909V (DAS1152)/ +9.99954V (DAS1153) for the 0 to +10V units, +4.99954V (DAS1152)/+4.99977V (DAS1153) for 0 to +5V units, +9.99817V (DAS1152)/+9.99909V (DAS1153) for ±10V units, or +4.99909V (DAS1152)/+4.99954V (DAS1153) for ±5V units. Note that these values are 1 1/2LSBs less than nominal full scale. Adjust the gain potentiometer until binary and offset binary coded units are just on the verge of switching from 11.....10 to 11.....11 and two's complement coded units are just on the verge of switching from 011.....10 to 011.....11.

## DAS1152/DAS1153 INPUT/OUTPUT RELATIONSHIPS

The DAS1152/DAS1153 produces a true binary coded output when configured as a unipolar device. Configured as a bipolar device, it can produce either offset binary or two's complement output codes. The most significant bit (MSB) is used to obtain the binary and offset binary codes while ($\overline{\text{MSB}}$) is used to obtain two's complement coding. Table II shows the DAS1152/DAS1153 unipolar analog input/digital output relationships. Tables III and IV show the DAS1152/DAS1153 bipolar analog input/digital output relationships.

## NOMINAL BIPOLAR INPUT-OUTPUT RELATIONSHIPS

| ANALOG INPUT | | | |
|---|---|---|---|
| 0 to +5V Range | | 0 to +10V Range | |
| DAS1152 | DAS1153 | DAS1152 | DAS1153 |
| +4.99969V | +4.99984V | +9.99939V | +9.99969V |
| +2.50000V | +2.50000V | +5.0000V | +5.00000V |
| +0.62500V | +0.62500V | +1.25000V | +1.25000V |
| +0.0003V | +0.00015V | +0.0006V | +0.0003V |
| +0.0000V | +0.0000V | +0.0000V | +0.0000V |

| DIGITAL OUTPUT | |
|---|---|
| Binary Code | |
| DAS1152 | DAS1153 |
| 11 111 111 111 111 | 111 111 111 111 111 |
| 10 000 000 000 000 | 100 000 000 000 000 |
| 00 100 000 000 000 | 001 000 000 000 000 |
| 00 000 000 000 001 | 000 000 000 000 001 |
| 00 000 000 000 000 | 000 000 000 000 000 |

*Table II. Unipolar Input/Output Relationships*

| Analog Input | | Digital Output | |
|---|---|---|---|
| ±5V Range | ±10V Range | Offset Binary Code | Two's Complement Code |
| +4.99939V | +9.99878V | 11 111 111 111 111 | 01 111 111 111 111 |
| +2.50000V | +5.0000V | 11 000 000 000 000 | 01 000 000 000 000 |
| +0.00061V | +0.00122V | 10 000 000 000 001 | 00 000 000 000 001 |
| +0.00000V | +0.00000V | 10 000 000 000 000 | 00 000 000 000 000 |
| −5.00000V | −10.00000V | 00 000 000 000 000 | 10 000 000 000 000 |

*Table III. DAS1152 Bipolar Input/Output Relationships*

| Analog Input | | Digital Output | |
|---|---|---|---|
| ±5V Range | ±10V Range | Offset Binary Code | Two's Complement Code |
| +4.99969V | +9.99939V | 111 111 111 111 111 | 011 111 111 111 111 |
| +2.50000V | +5.0000V | 110 000 000 000 000 | 010 000 000 000 000 |
| +0.0003V | +0.00061V | 100 000 000 000 001 | 000 000 000 000 001 |
| +0.00000V | +0.00000V | 100 000 000 000 000 | 000 000 000 000 000 |
| −5.00000V | −10.00000V | 000 000 000 000 000 | 100 000 000 000 000 |

*Table IV. DAS1153 Bipolar Input/Output Relationships*

## TRI-STATE DIGITAL OUTPUT

The ADC digital outputs are provided in parallel format to the output tri-state buffers. The output information can be applied to a data bus in either a one-byte or a two-byte format by using the HIGH BYTE ENABLE and LOW BYTE ENABLE terminals. If the tri-state feature is not required, normal digital outputs can be obtained by connecting the enable pins to ground.

## POWER SUPPLY AND GROUNDING CONNECTIONS

Although the analog power ground and the digital ground are connected in the DAS1152/DAS1153, care must still be taken to provide proper grounding due to the high accuracy nature of these devices. Though only general guidelines can be given, grounding should be arranged in such a manner as to avoid ground loops and to minimize the coupling of voltage drops (on the high current carrying logic supply ground) to the sensitive analog circuit sections. Analog and digital grounds should remain separated on the PC board and terminated at the respective DAS1152/DAS1153 terminals.

No power supply decoupling is required since, the DAS1152/ DAS1153, contain high quality tantalum capacitors on each of the power supply inputs to ground.

# 14-Bit & 15-Bit Low Level Data Acquisition Systems

# DAS1155/DAS1156




**FEATURES**

- **Functionally Complete:**
  - **Includes Instrumentation Amplifier, Sample/Hold Amplifier, and Analog to Digital Converter**
- **Differential Nonlinearity: ±0.002% FSR max (DAS1156)**
- **Guaranteed Nonlinearity: ±0.005% FSR (DAS1155)**
  **±0.003% FSR (DAS1156)**
- **High Common Mode Rejection: −80dB (up to 500Hz)**
- **High Feedthrough Rejection: −96dB**
- **Resistor Programmable Gain: 1V/V to 1000V/V**
- **Byte Selectable Tri-State Buffer Outputs**
- **Internal Gain and Offset Potentiometers**

**APPLICATIONS**

- **Low Level High Accuracy Data Acquisition Systems**
- **Process Control**
- **Nuclear Instrumentation**
- **Automated Test Equipment**
- **Medical Instrumentation**

## GENERAL DESCRIPTION

The DAS1155/DAS1156 are 14-/15-bit low level data acquisition systems having a minimum throughput rate of 25kHz/20kHz. These data acquisition systems provide high accuracy, high stability, and functional completeness all in a 2″ × 4″ × 0.44″ metal case.

Guaranteed high accuracy system performance such as nonlinearity of ±0.005% FSR (DAS1155)/±0.003% FSR (DAS1156) and differential nonlinearity of ±0.003% FSR (DAS1155)/±0.002% FSR (DAS1156) are provided. Guaranteed stability such as differential nonlinearity T.C. of ±2ppm/°C maximum, offset T.C. of ±(1 + 50/G) μV/°C (RTI) and gain T.C. (RTI) of ±16ppm/°C are also provided by the DAS1155/DAS1156.

Each DAS1155/DAS1156 makes extensive use of both integrated circuit and thin-film components to obtain its excellent performance and small size. Incorporated in these devices are a gain programmable instrumentation amplifier, precision sample/hold amplifier, high accuracy 14-/15-bit analog to digital converter, tri-state output buffers, gain and offset trim potentiometers, and power supply bypass capacitors (as shown in Figure 1).

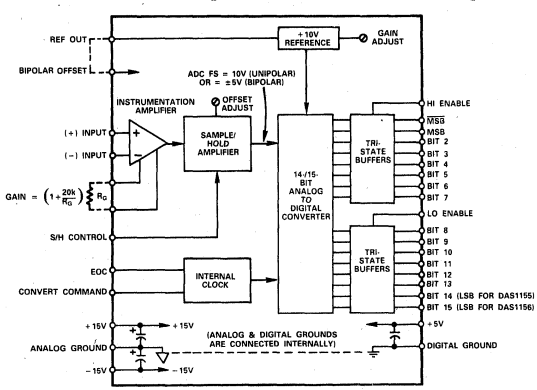



*Figure 1. DAS1155/DAS1156 Block Diagram*

Unipolar coding is provided for true binary format with bipolar coding displayed in offset binary or two's complement. Tri-state buffers are available for easy interface to bus structured applications.

## OPERATION

The DAS1155/DAS1156 are designed, built, and tested to meet system data acquisition requirements. These units can significantly reduce design and debug time by providing, in one package, all of the circuitry necessary for low level data acquisition and microprocessor bus interface.

For operation, the only connections necessary to the DAS1155/DAS1156 are the ±15V and +5V power supplies, analog input signal, trigger pulse, and the HI-ENABLE/LO-ENABLE tri-state controls. Digital output programming is user selectable via external jumper connections.

15

## ANALOG INPUT SECTION

The analog input section consists of a true differential instrumentation amplifier used to obtain high accuracy measurements in the presence of noise (as shown in Figure 2). It also provides input impedance of (100MΩ) and high common mode rejection of (−80dB). User selectable gain of 1V/V to 1000V/V via an external resistor enables either low level or high level full scale ranges to be applied to the input (+10mV to +10V unipolar, ±5mV to ±5V bipolar) with gain determined by the following formula:

$$\text{GAIN} = 1 + \left(\frac{20k}{R_G}\right)$$

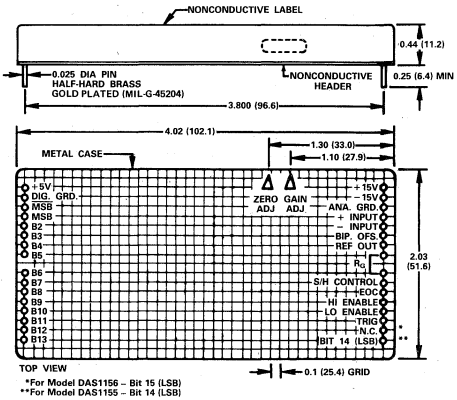
# SPECIFICATIONS (typical @ +25°C and rated supplies unless otherwise noted)

| MODEL | DAS1155 | DAS1156 |
|---|---|---|
| RESOLUTION | 14 Bits | 15 Bits |
| **DYNAMIC CHARACTERISTICS** | | |
| ADC Conversion Time | 35μs max | 44μs max |
| IA Settling Time, (10V Output Swing) | | |
| to 0.003% FSR @ G = 1 | 15μs max | * |
| to 0.003% FSR @ G = 10 | 15μs max | * |
| to 0.01% FSR @ G = 1000 | 50μs | * |
| Throughput Rate @ G = 1, 10 | 25kHz min | 20kHz min |
| **SAMPLE HOLD** | | |
| Acquisition Time | 4μs max | 5μs max |
| Aperature Delay Time | 50ns | * |
| Aperture Uncertainty Time | 1ns | * |
| Feedthrough Rejection [1] | −96dB | * |
| Droop Rate | 0.05μV/μs | * |
| **ACCURACY** | | |
| Differential Nonlinearity (FSR)[2] | ±0.003% max | ±0.002% max |
| Integral Nonlinearity (FSR)[3] | ±0.005% max | ±0.003% max |
| No Missing Codes | Guaranteed | * |
| Offset Error | Adjustable to Zero | * |
| Gain Error | Adjustable to Zero | * |
| **STABILITY** | | |
| Offset (RTI) T.C. | $\pm\left(1+\frac{50}{G}\right)$ μV/°C | * |
| Gain (RTI) T.C. | ±16ppm/°C | * |
| Differential Nonlinearity T.C. | ±2ppm/°C max | * |
| Power Supply Sensitivity | ±0.0015% FSR/% $V_S$ | * |
| **ANALOG INPUTS** | | |
| Voltage Input Range $\left(\frac{\text{ADC FSR}}{\text{Gain}}\right)$ | +10mV to +10V (Unipolar) | * |
| | ±5mV to ±5V (Bipolar) | * |
| Instrumentation Amplifier | | |
| Gain | Resistor Programmable | * |
| Gain Range | 1 to 1000 | * |
| Gain Equation | $G=1+\left(\frac{20k\Omega}{R_G}\right)$ | * |
| Input Impedance | $10^8\Omega$ | * |
| Bias Current | 50nA | * |
| Offset Current | 2nA | * |
| CMR (up to 500Hz) | −80dB | * |
| CMV | ±10V | * |
| **DIGITAL INPUTS** | | |
| ADC Convert Command[4] | 1TTL Load, Positive Pulse | |
| | Negative Edge Triggered | |
| SHA Control | HOLD = Logic 0 | |
| | SAMPLE = Logic 1 | |
| Low Enable, High Enable | ENABLE = Logic 0 | |
| **DIGITAL OUTPUTS** | | |
| Parallel Data Outputs | Tri-State | |
| Unipolar | Binary | |
| Bipolar | Offset Binary, 2's Complement | |
| Output Drive | 2TTL Loads | |
| Status | Logic "1" During Conversion | |
| Output Drive | 2TTL Loads | |
| **INTERNAL REFERENCE VOLTAGE** | +10V, ±0.3% | |
| External Load Current (Rated Performance) | 2mA (max) | |
| Temperature Stability | ±8.5ppm/°C (max) | |
| **POWER REQUIREMENTS** | | |
| Rated Voltages | ±15V ±5%, +5V ±5% | |
| Operating Voltages[5] | ±12V to ±17V, +4.75V to +5.25V | |
| Supply Current Drain ±15V | ±40mA | |
| +5V | 80mA | |
| **TEMPERATURE RANGE** | | |
| Specified | 0 to +70°C | |
| Operating | −25°C to +85°C | |
| Storage | −25°C to +85°C | |
| Relative Humidity | (Meets MIL-STD-202E, Method 103B) | |
| **SHIELDING** | Electrostatic (RFI) 6 sides, Electromagnet (EMI) 5 sides | |
| **SIZE** | 2" × 4" × 0.44" metal package | |

NOTES
[1]Measured in hold mode, input 20V pk-pk @ 10kHz.
[2]FSR means Full Scale Range.
[3]Worst-case summation of IA, S/H and A/D nonlinearity errors.
[4]When connecting the Convert Command the S/H control terminals together, the pulse width must be long enough for the S/H amplifier to acquire the input signal to the required accuracy 4μs (min, DAS1155) 5μs (min, DAS1156).
[5]If a ±12V operating power supply is used, the analog input must be limited to ±7V.
[6]Recommended Power Supply: Analog Devices Model 923.
*Same specifications as for DAS1155.
Specifications subject to change without notice.

## OUTLINE DIMENSIONS

Dimensions shown in inches and (mm).




## INTERCONNECTION AND SHIELDING TECHNIQUES

To preserve the high CMR characteristics of the DAS1155/DAS1156, care must be taken to minimize noise wherever possible. For best performance use twisted shielded cable, for the sensitive input signal, to reduce inductive and capacitive pickup. The cable should be connected as close as possible to the input common mode signal source. Place the gain setting resistor as close as possible to its respective terminal connections to avoid pickup.

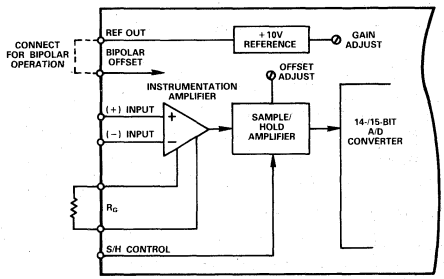



*Figure 2. Analog Input Block Diagram*

The gain T.C., of the DAS1155/DAS1156, will be directly affected by the resistor used for $R_G$. Using a high quality metal film resistor is recommended. Bipolar operation is obtained by connecting the REF OUT and the BIPOLAR OFFSET terminals together.

The output of the instrumentation amplifier drives the sample/hold amplifier which has a gain of 1V/V. The sample/hold amplifier holds the input signal at a constant level during the A/D conversion. Acquisition times of 4μs and 5μs maximum are provided respectively by the DAS1155 and DAS1156. Full scale A/D converter input range is programmed for + 10V (unipolar) or ± 5V (bipolar). Therefore, the instrumentation amplifier gain must be set accordingly to obtain maximum usable resolution.

## COMMON MODE REJECTION

CMR is dependent on source impedance imbalance, signal frequency, and amplifier gain. CMR is specified having a ± 10V CMV and 1kΩ source imbalance over a frequency range of dc to 500Hz. Figure 3 illustrates the typical CMR vs. source impedance imbalance for the DAS1155/DAS1156. Increasing the input gain of the instrumentation amplifier increases the CMR. At Gain = 1V/V, CMR is maintained greater than 80dB for source impedance imbalance up to 10kΩ. Figure 4 illustrates the CMR vs. gain and frequency.

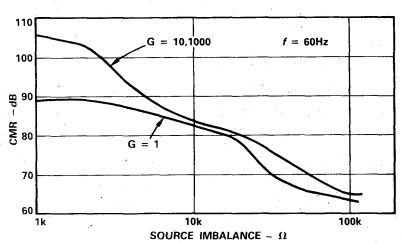



*Figure 3. CMR vs Gain and Source Imbalance DAS1155/DAS1156*

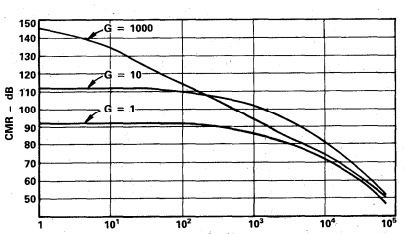



*Figure 4. CMR vs Frequency DAS1155/DAS1156*

## SETTLING TIME VS. GAIN

Illustrated in Figure 5 is the typical settling time vs. gain of the instrumentation amplifier in the DAS1155/DAS1156. Settling times are specified to 0.003% FSR for gains 1 and 10, and to 0.01% FSR for gain to 1000 having an output step voltage of 10 volts. Settling time to 0.003% FSR for gains greater than 10 are not shown because of the effects of voltage noise at the higher gains.

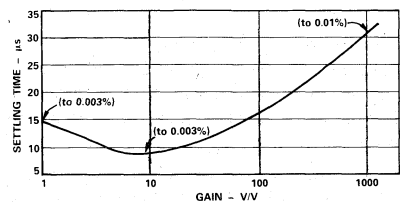
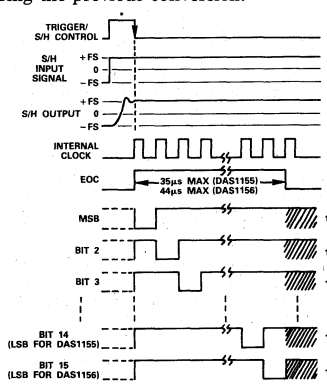



*Figure 5. Typical Settling Time vs Gain*

## TIMING DIAGRAM

The timing diagram for the DAS1155/DAS1156 is illustrated in Figure 6. This figure includes the sample/hold amplifier characteristics and assumes that the instrumentation amplifier is allowed to settle during the previous conversion.




**NOTES**

1. Output Data Valid.
2. This Diagram assumes that the Instrumentation Amplifier is allowed sufficient time to settle before the Sample/Hold Amplifier is placed in the Sample Mode. Instrumentation Amplifier settling can take place during the A/D Conversion process for the next conversion (see throughput rate).
3. The S/H Control and Trigger are tied together, Pulse Width must be 4μs (min)/5μs (min) to allow the S/H Amplifier to acquire the Input Signal.

*Figure 6. DAS1155/DAS1156 Timing Diagram*

The TRIGGER input and S/H CONTROL terminal can be tied together requiring only one conversion control signal. When the trigger pulse goes high, it places the sample/hold amplifier in the sample mode allowing it to acquire the present input signal. The trigger pulse must remain high for a minimum of 4μs/5μs, for the DAS1155/DAS1156 respectively, to insure accuracy is attained. At the falling edge of the TRIGGER pulse, the sample/hold amplifier is placed in the hold mode, the A/D conversion

begins, and all internal logic is reset. Once the conversion process is initiated, it cannot be retriggered until after the end of conversion.

With this negative edge of the trigger pulse the MSB is set low with the remaining digital outputs set to logic high state, and the status line is set high and remains high thru the full conversion cycle. During conversion each bit, starting with the MSB, is sequentially switched low at the rising edge of the internal clock. The internal DAC output is then compared to the analog input and the bit decision is made. Each comparison lasts one clock cycle with the complete 14-/15-bit conversion taking 35μs/ 44μs maximum respectively for the DAS1155/DAS1156.

At this time, the STATUS line goes low signifying that the conversion is complete. For bus applications, the digital output can now be applied to the selected data bus by enabling the tri-state buffers with the HI-ENABLE and LO-ENABLE terminals.

## GAIN AND OFFSET ADJUSTMENTS

The DAS1155/DAS1156 each are provided with internal gain and offset adjustment potentiometers. Each potentiometer has ample adjustment range so that gain and offset errors can be trimmed to zero.

Since offset calibration is not affected by changes in gain calibration, it should be performed first. Proper gain and offset calibration require great care and the use of extremely sensitive and accurate reference instruments. The voltage standard used as a signal source must be very stable and be capable of being set to within ±1/10LSB of the desired value at any point within its range.

The analog input values given in Tables I, II, III and in the following Offset & Gain Calibration Section, are values that should be present at the input to the internal ADC. The value of the analog input will be affected by the gain of the input instrumentation amplifier.(Example: For a full scale input of 0 to +5V, divide the 0 to +10V range input values by 2 and set input gain to 2.)

| Analog Input 0 to +10V Range | | Digital Output Binary Code | |
|---|---|---|---|
| DAS1155 | DAS1156 | DAS1155 | DAS1156 |
| +9.99939V | +9.99969V | 11 111 111 111 111 | 111 111 111 111 111 |
| +5.00000V | +5.00000V | 10 000 000 000 000 | 100 000 000 000 000 |
| +1.25000V | +1.25000V | 00 100 000 000 000 | 001 000 000 000 000 |
| +0.0006V | +0.0003V | 00 000 000 000 001 | 000 000 000 000 001 |
| +0.0000V | +0.0000V | 00 000 000 000 000 | 000 000 000 000 000 |

*Table I. Nominal Unipolar/Output Relationships*

| Analog Input ±5V Range | Digital Output Offset Binary Code | Two's Complement Code |
|---|---|---|
| +4.99939V | 11 111 111 111 111 | 01 111 111 111 111 |
| +2.50000V | 11 000 000 000 000 | 01 000 000 000 000 |
| +0.00061V | 10 000 000 000 001 | 00 000 000 000 001 |
| +0.00000V | 10 000 000 000 000 | 00 000 000 000 000 |
| −5.00000V | 00 000 000 000 000 | 10 000 000 000 000 |

*Table II. DAS1155 Bipolar Input/Output Relationships*

| Analog Input ±5V Range | Digital Output Offset Binary Code | Two's Complement Code |
|---|---|---|
| +4.99969V | 111 111 111 111 111 | 011 111 111 111 111 |
| +2.50000V | 110 000 000 000 000 | 010 000 000 000 000 |
| +0.00030V | 100 000 000 000 001 | 000 000 000 000 001 |
| +0.00000V | 100 000 000 000 000 | 000 000 000 000 000 |
| −5.00000V | 000 000 000 000 000 | 100 000 000 000 000 |

*Table III. DAS1156 Bipolar Input/Output Relationships*

## OFFSET CALIBRATION

For 0 to +10V unipolar range set the input voltage precisely to +305μV for the DAS1155 and +153μV for the DAS1156. Then adjust the zero potentiometer until the converter is just on the verge of switching from 00-----00 to 00-----01.

For the ±5V bipolar range set the input voltage precisely to +305μV for the DAS1155 and +153μV for the DAS1156. Adjust the zero potentiometer until the offset binary coded units are just on the verge of switching from 00-----00 to 00-----01 and the two's complement coded units are just on the verge of switching from 10-----00 to 10-----01.

## GAIN CALIBRATION

Set the input voltage precisely to +9.99909 (DAS1155)/ +9.99954V (DAS1156) for the 0 to +10V units, or +4.99909V (DAS1155)/+4.99954V (DAS1156) for ±5V units. Note that these values are 1 1/2LSB less than nominal full scale. Adjust the gain potentiometer until binary and offset binary coded units are just on the verge of switching from 11-----10 to 11-----11 and two's complement coded units are just on the verge of switching from 011-----10 to 011-----11.

## THROUGHPUT RATE

Throughput rates for the DAS1155/DAS1156 can be increased by the use of the OVERLAP MODE, i.e. updating the input while the ADC is making a conversion.

The guaranteed throughput rates are 25kHz @ G = 1, 20kHz @ G = 1000 for the DAS1155 and 20kHz @ G = 1 and 1000 for the DAS1156. When the IA settling time is less than or equal to the sum of SHA acquisition time and ADC conversion time, 39μs, the DAS throughput rate equals 1/39μs or 25.6kHz. When IA settling time is greater than 39μs (see Figure 5), the DAS throughput rate becomes dependent upon the IA settling time and equals its reciprocal.

## DAS1155/DAS1156 INPUT/OUTPUT RELATIONSHIPS

The DAS1155/DAS1156 produces a true binary coded output when configured as a unipolar device. Configured as a bipolar device, it can produce either offset binary or two's complement output codes. The most significant bit (MSB) is used to obtain the binary and offset binary code while the ($\overline{\text{MSB}}$) is used to obtain the two's complement code. Table I shows the unipolar analog input/digital output DAS1155/DAS1156 relationships. Tables II and III show the DAS1155/DAS1156 bipolar analog input/digital output relationships respectively.

## TRI-STATE DIGITAL OUTPUT

The digital outputs are provided in parallel format to the output tri-state buffers. The output information can be applied to a data buss in either a one-byte or a two-byte format by using the HI-ENABLE and LO-ENABLE terminals. If the tri-state feature is not required, normal digital outputs can be obtained by connecting the enable pins to ground.

## POWER SUPPLY AND GROUNDING CONNECTIONS

Although the analog power ground and the digital ground are connected in the DAS1155/DAS1156, care must still be taken to provide proper grounding due to the high accuracy nature of the devices. Though only general guidelines can be given, grounding should be arranged in such a manner as to avoid ground loops and to minimize the coupling of voltage drops (on the high current carrying logic supply ground) to the sensitive analog circuit sections. Analog and digital grounds should remain separated on the PC board and terminated at the respective DAS1155/ DAS1156 terminals.

No power supply decoupling is required since, both the DAS1155 and DAS1156, contain high quality tantalum capacitors on each of the power supply inputs to ground.

# Digital Panel Instruments

## Contents


| | Page |
|---|---|
| Selection Guides | |
| Logic (+5V) Powered Digital Panel Meters | 16-2 |
| AC-Powered Digital Panel Meters | 16-3 |
| Digital Temperature Meters | 16-4 |
| General Information | 16-5 |
| Definitions – Terms & Specifications | 16-6 |
| **DIGITAL PANEL METERS** | |
| AD2004 High Performance 4 1/2 Digit DPM for System Applications | 16-9 |
| AD2006 AC Powered 3 1/2 Digit DPM with Sperry Display | 16-11 |
| AD2010 Low Cost 3 1/2 Digit DPM for OEM Applications | 16-15 |
| AD2016 Low Cost 3 1/2 Digit Line Powered DPM with LED Display | 16-19 |
| AD2021 Low Cost 3 1/2 Digit Logic Powered DPM with LED Displays | 16-23 |
| AD2024/AD2027 Low Cost 4 1/2 Digit DPMs with LED Displays | 16-25 |
| AD2025/AD2028 Low Cost 4 3/4 Digit DPMs with LED Displays | 16-29 |
| AD2026 Low Cost 3 Digit Analog Panel Meter Replacement | 16-33 |
| **TEMPERATURE MEASUREMENT AND SIGNAL CONDITIONING COMPONENTS** | |
| AD2036 6 Channel Scanning Digital Thermometer | 16-35 |
| AD2037/AD2038 6 Channel Scanning Digital Voltmeter/Thermometer | 16-37 |
| AD2040 Low Cost Temperature Indicator | 16-39 |
| AD2050/AD2051 Microprocessor-Based Thermocouple Meters | 16-43 |
| •AD2060/AD2061 Microprocessor-Based RTD/Thermistor Meters | 16-45 |


•New product since publication of *1982–1983 Databook Update.*

16

# Selection Guide
## Digital Panel Instruments

For the purpose of selection, the instruments in this section are divided into three classes, each having its own Selection Guide:

1. 3- to 4 3/4-digit panel meters for general applications, powered by dc voltage furnished by the user's instrumentation-system +5V logic supply
2. 3- to 4 3/4-digit panel meters for general applications, powered by ac line voltage, and including multi-channel scanning and true-rms types
3. Single- and scanning multi-channel digital temperature meters for measurements with thermocouples, RTDs, thermistors, and AD590 semiconductor temperature sensors

The Selection Guides permit all the devices in each class to be compared in terms of their salient features, to narrow the field of choice to one or two devices, for which page locations are given. The data sheets in this Volume have technical

| | | LOGIC (+5V) POWERED DIGITAL PANEL METERS | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | AD2026-1 | AD2006D | AD2010 | AD2021 | AD2004 | AD2027 | AD2028 |
| Digits; F.S. Range | 3; -99 to +999mV | • | | | | | | |
| | 3½; ±199.9mV<br>±1.999V<br>±19.99V | | • | • | •<br>•<br>• | | | |
| | 4½; ±1.9999V<br>±19.999V | | | | | • | •<br>• | |
| | 4¾; ±3.9999V<br>±39.999V | | | | | | | •<br>• |
| Input Type | Ltd. Differential<br>Differential | • | • | • | • | | • | • |
| | Floating | | | | | • | | |
| Data Outputs | Character Serial<br>Parallel BCD<br>Parallel BCD Latched | | • | •<br>• | • | •<br>• | •<br>• | •<br>• |
| Display Type | LED<br>Gas Discharge | • | • | • | • | • | • | • |
| Display Size in/mm | | 0.5/13 | 0.55/14 | 0.27/7 | 0.5/13 | 0.27/7 | 0.43/11 | 0.43/11 |
| Max Case Depth[1] in/mm | | 0.65/17 | 4.8/122 | 1.4/36 | 1.9/48 | 3.3/84 | 4.8/122 | 4.8/122 |
| Volume II Page | | 16-33 | 16-11 | 16-15 | 16-23 | 16-9 | 16-25 | 16-29 |

NOTE

[1] Case depth includes mating connector. All logic powered DPMs use industry standard case with 3.175" X 1.810" (80.65 X 45.97mm) cutout. All ac-powered DPMs except AD2006 use industry standard case with 3.930" X 1.682" (99.82 X 42.72mm) cutout. AD2006 uses same case as logic powered DPMs.

descriptions, specifications, and in many cases, applications information. Complete data sheets for most of these instruments, with further information on application and use of the products, are available upon request. General information on digital panel instruments can be found in the pages that follow the Selection Guides.

For temperature instrumentation, there are a number of other products dedicated to temperature measurement, included in this Databook, that may be of interest. They are to be found in these sections: Transducers & Signal Conditioners, μMAC-4000 Intelligent Measurement-and-Control Subsystems, and MACSYM. Power supplies for excitation of system-powered panel instruments may be found in the Power Supply section.

Finally, in the Synchro & Resolver Conversion section, there are the benchtop API1620 and API1718 Angle Position Indicators, which accept synchro or resolver input, convert to digital, and provide a 5-digit numerical LED display of the angle, and a 5-decade BCD or 16-bit binary data output.

| | | AC-POWERED DIGITAL PANEL METERS | | | | | |
|---|---|---|---|---|---|---|---|
| | | AD2026-2 | AD2006 | AD2016 | AD2024 | AD2025 | AD2037 |
| 6-Channel Scanning | | | | | | | ● |
| Digits; F.S. Range | 3; -99 to +999mV | ● | | | | | |
| | 3½; ±199.9mV<br>±1.999V<br>±19.99V<br>199.9V<br>600V | | ● | ●<br>●<br>● | | | ●<br>● |
| | 4½; ±1.9999V<br>±19.999V | | | | ●<br>● | | |
| | 4¾; ±3.9999V<br>±39.999V | | | | | ●<br>● | |
| Input Type | Single Ended<br>Ltd. Differential<br>Differential | | ● | ● | ● | ● | ● |
| | Floating<br>True RMS | ● | | | | | ● |
| Data Outputs | Character Serial<br>Parallel BCD<br>Parallel BCD Latched | | ● | ●<br>●<br>● | ●<br>● | ●<br>● | ● |
| Display Type | LED<br>Gas Discharge | ● | ● | ● | ● | ● | ● |
| Display Size in/mm | | 0.5/13 | 0.55/14 | 0.5/13 | 0.43/11 | 0.43/11 | 0.5/13 |
| Max Case Depth[2] in/mm | | 2.44/63 | 4.95/126 | 4.77/121 | 5.3/135 | 5.3/135 | 6.03/153 |
| Volume II Page | | 16-33 | 16-11 | 16-19 | 16-25 | 16-29 | 16-37 |

NOTES

[1] Full scale inputs when reading out in dB are 500mV, 5V, 50V, 500V and 625V rms.

[2] Case depth includes mating connector. All logic powered DPMs use industry standard case with 3.175" X 1.810" (80.65 X 45.97mm) cutout. All ac-powered DPMs except AD2006 use industry standard case with 3.930" X 1.682" (99.82 X 42.72mm) cutout. AD2006 uses same case as logic powered DPMs.

16

# Selection Guide
## Digital Panel Instruments

| | | | DIGITAL TEMPERATURE/ TRANSDUCER METERS | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | AD2036 | AD2037 | AD2038 | AD2040 | AD2050 | AD2051 | AD2060 | AD2061 |
| Input | Number of Channels | 1 | • | • | • | • | • | • | • | • |
| | | 6 | | | | | | | | |
| Sensor (Determines Temperature Range) | Thermocouple Type | Switch Selected | • | | | | • | • | • | • |
| | | User Specified | • | | | | • | • | | |
| | | J, K, T | | | | | • | • | | |
| | | E, R, S | | | | | • | • | | |
| | AD590 (−55°C to +150°C) | | | | • | • | | | | |
| | RTD | | | • | | | | | • | • |
| | Thermistor | | | • | | | | | • | • |
| Features | Self-Calibration | | | | | | • | • | • | • |
| | Cold-Junction Compensation | | • | | | | • | • | | |
| | Linearization | | • | | | | • | • | • | • |
| | Isolation | | • | • | • | | •[1] | •[1] | •[1] | •[1] |
| Readout | Digits | 3+, 2− | | | | • | | | | |
| | | 3½ | • | • | • | | • | • | • | • |
| | LED Display Height | 0.5″, 13mm | • | • | • | • | | | | |
| | | 0.56″, 14.3mm | | | | | • | • | • | • |
| Digital Data Output | Isolated Parallel BCD, Latched | | • | • | • | | | | | |
| | 7-Bit Character-Serial ASCII | | | | | | • | • | • | • |
| | Isolated, 20mA current loop | | | | | | • | • | | |
| Analog Output | Voltage | | • | • | • | | • | • | • | • |
| Power Supply | AC Line | | • | • | • | • | • | • | • | • |
| | DC +7.5V to +28V | | | | | | • | • | • | • |
| | +5V | | • | | | • | | | | |
| | +12V | | • | | | | | | | |
| Volume II Page | | | 16-35 | 16-37 | 16-37 | 16-39 | 16-43 | 16-43 | 16-45 | 16-45 |

NOTE

[1] AC line-operated versions.

Shading indicates new product since publication of *1982–1983 Databook Update.*

# Orientation
# Digital Panel Instruments

## UNDERSTANDING DPMS

### Introduction

A DPM is basically an analog to digital converter with a visual readout. The DPM samples the input voltage periodically, converts that voltage to digital outputs, and displays the corresponding reading visually. A digital panel meter, then, consists of four basic functional sections: the input section, including signal conditioning and analog to digital conversion circuitry; the display; the data outputs; and the power supply.

### Processing The Input Signal

The primary function of the input section is to convert an analog voltage input into a digital signal for display. Besides this basic function, the input section also buffers the input to provide a high input impedance, prevent circuit damage in overvoltage conditions, reject both normal mode and common mode noise on the input signal, compensate for large variations in operating temperature, and sometimes even measure the ratio of two separate input voltages.

The analog to digital conversion scheme used on most DPMs is the dual-slope type, due to its inherent stability and normal mode noise rejection. The dual slope converter can also be used to measure the ratio of two input voltages, in some DPM designs. Lower-resolution DPMs sometimes use staircase or single slope converters, which require RC filtering of the input signal for normal mode noise rejection.

The input of the DPM may be single-ended, differential or floating. Single-ended inputs measure the input voltage with respect to input common and may require some care in application to avoid ground loop problems. To prevent ground loops, some of Analog Devices' DPMs use a "limited differential input", where a resistor separates analog and digital grounds, allowing up to 200mV of common mode voltage and providing up to 60dB of common-mode rejection.

True differential input DPMs accommodate common mode voltages of up to ±5V, adequate for most bridge transducer type applications. For very high common mode voltages, the opto-isolation technique, used in several Analog Devices' DPMs, allows common mode voltages of up to ±300V and provides 100 to 120dB of common mode rejection, even when BCD data outputs are being used. Any ac powered DPM can be floated on the power supply transformer to provide isolation and CMR, similarly to the opto-isolated DPM, if no BCD outputs or control signals are being used (i.e., in readout-only operation). Further information on DPM input configurations can be found in the section, "DPM Input Types and Their Applications."

### Displaying the Data

Once the input signal is digitized, it is decoded and displayed on a digital readout. Numerous types of displays are available today, but Analog Devices' DPMs use large LED (light emitting diode) displays on all of the latest models. Seven-segment LED displays as large as 0.56 (14.3mm) offer the ultimate in ruggedness, reliability and aesthetic appeal, and challenge Beckman gas discharge displays for size.

Beckman displays and smaller 0.27″ (6mm) solid state LEDs are also used by Analog Devices. The large shaped characters of the Beckman display easily read at up to 30 feet (9 meters) away. The neon orange digits can be filtered to provide either an amber or a red display. The smaller LEDs, packaged with counting and decoding logic circuitry, permit the extremely small packaging of the AD2010 and the AD2004.

### Producing Digital Outputs

Since the visual display of a DPM must be in a decimal format, the counters used in DPM conversion circuitry are always binary-coded decimal (BCD) counters. The data-output format depends on the circuit design of the meter: most designs using TTL integrated circuits have parallel BCD data outputs, with all BCD bits available simultaneously. Parallel data is easiest to interface to, since most data peripherals, such as printers and comparators, require parallel data. Parallel data can be latched, and therefore valid, except for the period of several microseconds after each conversion, when it is updated, or unlatched, where the data is valid only between conversions. In either case, a STATUS or DATA READY signal is available to indicate when the data outputs are valid.

DPMs using MOS-LSI (metal-oxide semiconductor, large scale integrated circuits) usually have character serial outputs, where each BCD digit is gated onto a single set of parallel output lines in sequence. This technique is used to reduce the number of pins used on the LSI chip and to simplify data interfacing to the display. Although some data peripherals, such as microprocessors, require character-serial data inputs, for many applications it is necessary to use latches or shift registers to convert the data into a parallel format for interfacing. Most DPMs using LSI have an extra cost option available that provides parallel data outputs.

Digital data outputs from DPMs are generally compatible with DTL or TTL logic systems, but some of the newer DPMs using LSI are only compatible with CMOS logic. The parallel output option with these LSI DPM designs, however, is generally TTL compatible for ease in interfacing.

**Understanding Performance Specifications**

*Resolution, Accuracy, and Stability*—these three specs are very important in the selection of a DPM. Although more digits may mean more resolution, the digits themselves are useless unless the accuracy is sufficient for the digits to have real meaning. Therefore, accuracy and resolution should be comparable.

Besides temperature variations, there are three components of DPM inaccuracy: *zero offset error, gain error,* and *quantization error.* In any device using a counter and clock to determine a digital output, there is always a potential ±1 count error in the output. This is caused by the timing of the input gate of the counter; when the gate closes asynchronously with the clock, a clock pulse that occurs just as the gate closes may or may not be counted, hence the fixed ±1 digit inaccuracy.

Zero level offsets in the analog circuitry cause errors specified as a percentage of full scale reading. These errors can be corrected by a zero calibration potentiometer requiring periodic resetting, or by internal calibration circuits that set the zero level automatically between each reading, assuring no zero level contribution to the error.

Gain variations occur as a function of signal level in the analog circuitry and produce errors which are specified as a percentage of the reading. These are the hardest errors to design out of a DPM circuit, but they can be minimized by component specification and selection. A range potentiometer is used for periodic adjustment of the gain. Gain errors may also be calibrated out in "smart" instruments having an automatic internal calibration facility (e.g. AD2050).

Since all the electronic components used in the design of a DPM have some temperature dependence, one can expect the accuracy of the DPM to be affected by changes in operating temperature. If automatic zero correction circuitry is not used, the zero level may drift with temperature. Variations in the reference voltage circuitry and its associated switches will cause changes in the gain of the DPM, but careful selection and matching of components can minimize this error.

To illustrate these specifications, consider a 3½ digit DPM (1999 counts full scale). The resolution of the unit is the value of one digit, 1 part in 2000 or 0.05% of full scale. If the accuracy is comparable to the resolution (exclusive of digital indecision), the DPM should have a maximum error of ±0.05% ±1 digit.

Temperature coefficient specifications for a DPM should be very good to maintain the accuracy. A tempco of only 50ppm/°C (0.005%/°C) will produce an additional error of ±0.05% over a range of only ±10°C.

Since each manufacturer tends to use a different method of specifying accuracy and temperature coefficients, specifications must be expressed in common terms to be comparable. For example, one may find specifications for 3½ digit DPMs in the formats shown below ("R" = "of reading"):

Unit 1: max error: ±0.05% R ±1 digit, tempco: ±50ppm(R)/°C

Unit 2: max error: ±0.02% R ±0.03% F.S. ±1 digit, tempco: ±0.004%R ±0.001% F.S./°C

Unit 3: max error: ±0.05% R ±0.05% F.S. ±1 digit, for temperature +15°C to +35°C

To compare the three units, one must establish a common ground: full scale reading, temp range +15°C to +35°C (±10°C). The specification then becomes:

Unit 1: ±0.05% F.S. ±1 digit ±(50ppm(F.S.)/°C x ±10°C)
= ±0.05% F.S. ±1 digit ±0.05% F.S.
= 0.1% F.S. ±1 digit

Unit 2: ±(0.02% F.S. ±0.03% F.S.) ±1 digit (0.004% F.S. ±0.001% F.S.)/°C x ±10°C
= 0.05% F.S. ±1 digit ±0.05% F.S.
= 0.1% F.S. ±1 digit

Unit 3: ±0.05% F.S. ±0.05% F.S. ±1 digit
= 0.1% F.S. ±1 digit

Even though all units are specified differently, they have equivalent performance.

**DEFINITIONS – TERMS & SPECIFICATIONS**

Accuracy (absolute): DPMs are calibrated with respect to a reference voltage which is in turn calibrated to a recognized voltage standard. The absolute accuracy error of the DPM is the tolerance of the full-scale set point referred to the absolute voltage standard.

Accuracy (relative): Relative accuracy error is the difference between the nominal and actual ratios to full scale of the digital output corresponding to a given analog input. See also: linearity.

Automatic Zero: To achieve zero stability, a time interval during each conversion is provided to allow the circuitry to compensate for drift errors, thereby, providing virtually no zero drift error.

Bias Current: The current required from the source at zero signal input by the input circuit of the DPM. Bias current is normally specified at typical and maximum values. Analog Devices' DPMs using transistor input circuitry are bias current sinks.

Binary Coded Decimal (BCD): Data coding where each decimal digit is represented by a group of 4 binary coded digits (called "quads"). Each quad has bits corresponding to 8, 4, 2 and 1 and 10 permissible levels with weights 0-9. BCD is normally used where a decimal display is needed.

Bipolar: A bipolar DPM measures inputs which may be of either positive or negative polarity and automatically displays the polarity as well as the magnitude of the input voltage on the readout.

Character Serial BCD: Multiplexed BCD data outputs, where each digit is gated sequentially onto four common output lines.

Common-Mode Rejection: A differential-input DPM will reject any input signals present at both input terminals simultaneously if they are within the common mode voltage range.

Common mode rejection is expressed as a ratio and usually given in dB. (CMR = 20 log CMRR). 120dB of common-mode rejection (CMRR = $10^6$) means that a 10V common-mode voltage is processed as though it were an additive-differential input signal of 10$\mu$V magnitude.

Common Mode Voltage: A voltage that appears in common at both input terminals of a device, with respect to its ground.

Conversion Rate: The frequency at which readings may be processed by the DPM. Specifications are typically given for internally clocked rates and maximum permissible externally-triggered rates.

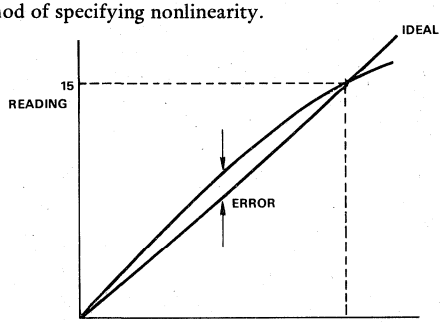
Conversion Time: The maximum time required for a DPM to complete a reading cycle, specified for the full scale reading.

Dual-Slope Conversion: An integrating A/D conversion technique in which the unknown signal is converted to a proportional time interval, which is then measured digitally. This is done by integrating the unknown for a predetermined time.

Then a reference input is switched to the integrator, and integrates "down" from the level determined by the unknown, until a "zero" level is reached. The time for the second integration process is proportional to the average of the unknown signal level over the predetermined integrating period.

Input Impedance: The complex ratio of signal voltage to signal current at the input terminals. For dc measuring DPMs, the input is measured at dc. For ac measuring DPMs, it is expressed as a dc resistance shunted by a specified capacitance.

Linearity: The conventional definition for nonlinearity of a DPM is the deviation from a "best" straight line which has been fitted to a calibration curve. Analog Devices defines nonlinearity as the deviation from a straight line drawn between the zero and full scale end points. Not only is this an easier method for customer calibration, it is also a more conservative method of specifying nonlinearity.



*Linearity*

Normal Mode Rejection: Filtering or integrating the input signal improves noise rejection of undesired signals present at the analog *high* input. Normal mode rejection is expressed as the ratio of the actual value of the undesired signal to its measured value over a specified frequency range. (NMR (dB) = 20 log NMRR, e.g. NMR = 40dB means an attenuation of 100:1).

Overload: An input voltage exceeding the full scale range of the DPM produces an overload condition. An overload condition is usually indicated by conspicuous manipulation of the display such as all dashes, flashing zeros, etc. On a 3½ digit DPM with a range of 199.9mV, a ⩾200mV signal will produce an overload condition.

Overrange: An input signal that exceeds all nines on a DPM, but is less than an overload. On a 3½ digit DPM with a full scale range of 199.9mV, the all-nines range is 0–99.9mV, and signals from 100–199.9mV are said to fall in the 100% overrange region. Some DPMs have higher overrange capability. A 3¾ digit DPM has a full scale range of 3.999 or 300% overrange.

Overvoltage Protection: The input section of the DPM must provide protection from large overloads. Specifications are given for sustained dc voltages that can be tolerated.

Parallel BCD: A data output format where all digital outputs are present simultaneously.

Range (Temperature Operating): The range of temperatures over which the DPM will meet or exceed its performance specifications.

Range (Full Scale): The range of input signals that can be measured by a DPM before reaching an overload condition. A 3½ digit DPM's full-scale range consists of three digits (all-nines range) and 100 percent overrange capability.

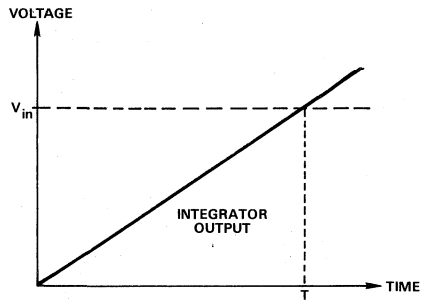
Ratiometric: Dual Slope DPMs compare voltage inputs to a stable internal reference voltage. In some systems, the voltage being measured is a function of another voltage, and accurate measurements should be made as the ratio of the two voltages. Some DPMs provide inputs for external reference voltages for ratiometric measurements.

Resolution: The smallest voltage increment that can be measured by a DPM. It is a function of the full scale range and number of digits of a DPM. For example, if a 3½ digit DPM has a resolution of 1 part in 2000 (0.05%) over a full scale range of 199.9mV, the DPM can resolve 0.1mV.



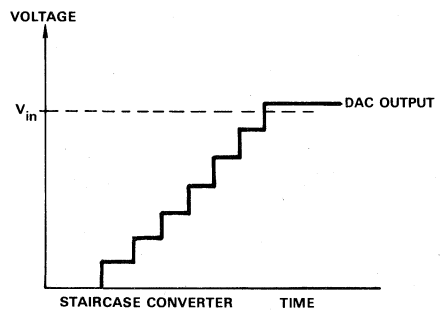
| Digits | Counts (F.S.) | Resolution (% F.S.) |
|---|---|---|
| 2½ | 199 | 0.5% |
| 3 | 999 | 0.1% |
| 3½ | 1999 | 0.05% |
| 3¾ | 3999 | 0.025% |
| 4 | 9999 | 0.01% |
| 4½ | 19999 | 0.005% |
| 4¾ | 39999 | 0.0025% |

Single Slope Conversion: In the single slope converter, a reference voltage is integrated until the output of the integrator is equal to the input voltage. The time period required for the integrator to go from zero to the level of the input is proportional to the magnitude of the input voltage and is measured by an internal clock.




*Single Slope Converter*

Staircase Conversion: A simple analog-to-digital conversion technique in which a clock and counter drives a digital-to-analog converter which produces an output voltage waveform resembling a staircase. A comparator stops the counter when the voltage exceeds the input voltage; the count achieved by the counter is the digitized output.




*Staircase Converter*

Temperature Coefficient: The additive error term (ppm/°C or % Reading/°C) caused by effects of variations in operating temperature on the electronic characteristics of the DPM.

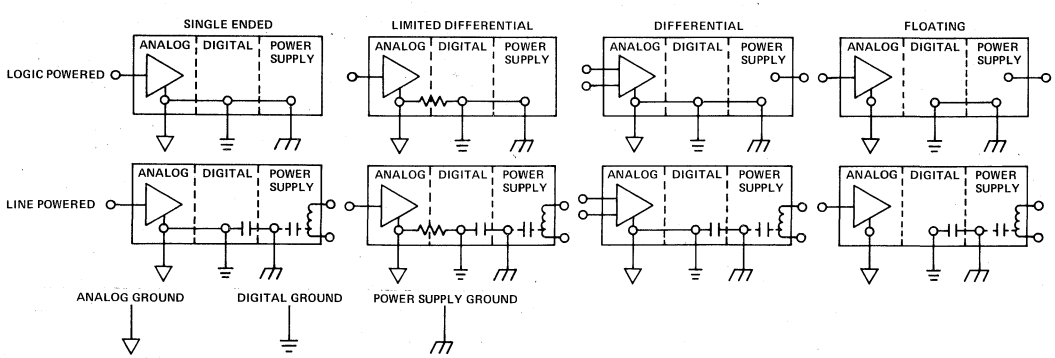
Unipolar Input DPM: A DPM designed to measure input voltages of only one polarity.

**DPM Input Types And Their Applications**

The four different input configurations used on DPMs (single-ended, limited differential, differential, and floating) are made available to solve various applications problems. In OEM applications where the DPM is a dedicated readout for an instrument or system, a single-ended DPM is usually desired for its low cost. But single-ended DPMs require care in application to prevent ground loops from interfering with measurements. The "limited differential" input pioneered by Analog Devices, however, uses a single resistor to isolate analog and digital (and, in logic powered DPMs, the power supply) grounds to effectively eliminate ground loops. This limited differential input allows up to approximately 200 millivolts of common mode voltage and 60dB of common mode rejection without imposing the cost penalties of a true differential or floating input. Thus the majority of DPM applications require only a single-ended or limited differential input DPM.

But if the DPM is measuring the output of a bridge transducer, higher common mode voltages must be accommodated, and differential input DPMs which allow a CMV up to ±5V are usually necessary. Where extremely high common mode voltages are required, such as current measurements, a floating (usually opto-isolated) input DPM can provide for up to ±300V CMV. Either the differential or floating input DPM will also provide greater common mode noise rejection, if necessary.

If digital control signals and BCD data outputs are not needed, any ac line powered DPM can be floated on the power supply transformer to provide high CMV and CMR. But care must be exercised when applied in this fashion at high CMV, since all connections may be floating at dangerously high voltages. All line powered DPMs have a connection for "earth ground" which may be connected to a transformer shield or guard track on the printed circuit board, but this earth ground is usually capacitively coupled to the digital ground for noise rejection. Always insure that the earth ground is not directly connected to digital ground when "floating" a line powered DPM in this manner.




*Grounding Configurations of DPMs*

# High Performance 4½ Digit DPM For System Applications

# AD2004

**FEATURES**
**Floating Optically Isolated Analog Section**
**Excellent Common Mode Rejection: 120dB at ±300V**
**High Normal Mode Rejection: 60dB**
**5V dc Powered**
**Automatic Zero with Maximum Error: 0.01% ±1 Digit**
**LED Display with Latched Digital Outputs**
**Small Size: 1.8"H x 3"W x 2.5"D**

**APPLICATIONS**
**Industrial Weighing Systems**
**Process Control Monitoring**
**Precision Differential Measurement**
**Ground Loop Elimination**
**Off Ground Signal Measurements**
**Analytical and Scientific Instrumentation**




## GENERAL DESCRIPTION

Analog Devices' model AD2004 is a 4½ Digit, 5V dc powered digital panel meter offering 0.01% ±1 digit accuracy, resolution of 0.1mV, common mode voltage (CMV) of ±300V with a common mode rejection ratio (CMRR) of 120dB.

Using optically coupled isolation techniques for the signal channel, this new design is capable of performing precision measurements of floating differential voltages in noisy environments or under widely varying common mode voltage levels of up to ±300V. The optically isolated design assures ground loop elimination and permits critical measurement of off ground signals such as those found in the nuclear and process control industries.

The AD2004 features a 4½ digit light-emitting-diode (LED) display with a full scale range of 0 to ±1.9999 volts and latched digital data outputs and control interface signals. Automatic-zero correction circuitry measures and compensates for offset and offset drift errors thereby providing virtually no zero error.

The conversion rate of the AD2004 is normally 4 readings per second. However, an external trigger may be applied to vary the sampling rates from a maximum of 8 readings per second down to an indefinite hold rate. During conversion, the previous reading is held by the latched logic. The numeric readout is available as BCD data. Application of the metering system in a computer or data logging system is made easy with the availability of the "overrange," "polarity," "overload," and "status" signals.

The AD2004 can operate from the users 5V dc system supply, thereby, eliminating the shielding and decoupling needed for line powered units when the ac line must be routed near signal leads.

## TYPICAL APPLICATIONS INCLUDE:

- Ground loop elimination between input transducer and output circuit functions.
- High resolution monitoring of small signals impressed on high off-ground voltages of up to ±300V.
- Electronic indicating weighing systems for industrial applications. Numerical output may be interfaced with a digital computer or data logging system.
- Digitally controlled industrial process where analog and digital signal isolation is required.
- Balanced strain gage bridge output measurement for industrial requirements.
- Digital indicating micrometer using a linear variable differential transformer (LVDT). Due to the high normal mode rejection ratio of the AD2004, the ac excitation of the LVDT does not induce errors into the system.
- Analytic and Scientific Instrument displays with isolated numeric readout.

## FLOATING DIFFERENTIAL INPUT OFFERS HIGH CMV AND CMR

Figure 1 illustrates the isolation technique used to achieve high CMV and CMR.

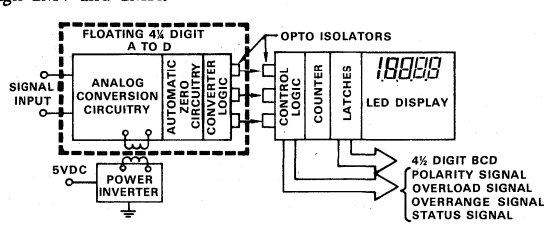



*Figure 1. Simplified Block Diagram*

16

**For detailed information, contact factory.**

# SPECIFICATIONS (typical @ +25°C and +5V dc unless otherwise noted)

DISPLAY OUTPUT
- Display consists of five LEDs for data digits plus 100% overrange.
- Overload – Four data digits display zeros and flashes when reading exceeds the input range (>1.9999 volts).
- Decimal Points – Selectable at input connector.

INPUT
- Full Scale Range – 0 to ±1.9999 volts
- Automatic Zero
- Automatic Polarity
- Floating
- Bias Current – <1nA max
- Impedance – >100MΩ
- Overvoltage Protection – ±50V sustained without damage.
- Decimal Points (4) – Selectable by Logic "1" or by leaving open. Grounding the input turns decimal points off.

ACCURACY (30 Minute Warm-Up)
- 0.01% of Reading ±1 Digit
- Resolution – 0.1mV
- Temperature Range – 0 to +50°C operating
- Temperature Coefficient – ±15ppm/°C max

NORMAL MODE REJECTION
- 60dB without filter @ 50-60Hz minimum

COMMON MODE REJECTION
- 120dB typical dc-1kHz with 1kΩ unbalance

COMMON MODE VOLTAGE (with digital interface signals connected)
- ±300V dc (600V peak to peak)

DATA PROCESSING SIGNALS

| | IN | OUT |
|---|---|---|
| • DTL/TTL Compatible Logic "0" | <0.8V | <0.4V |
| Logic "1" | >2.0V | >2.4V |

- Inputs

  External Trigger – Operation in the External Trigger mode requires the External Hold input be held at Logic "0" or grounded. A negative going external trigger pulse (Logic "1" or Logic "0" and return) is required to start each conversion. The DPM is reset on the negative transition and a new conversion is triggered on the positive transition. The pulse width must be greater than 100ns. The STATUS signal is set at the negative transition and the actual conversion begins 0–3.3μs (maximum of 1 clock pulse) after the positive transition to allow synchronizing conversion with the internal clock.

  External Hold – When this input is grounded or held at 0.8V max, the last conversion is held and displayed. For a new conversion under internal control, this input must be open or at Logic "1".

- Output

  4BCD Digits (8421 Positive True) - Latched - 3TTL loads

  Overrange – Logic "1" indicates an overrange – Latched – 9TTL loads

  Overload – Logic "1" indicates the input has exceeded the input range – Latched – 9TTL loads

  Status Signal – Logic "0" indicates conversion is complete – 9TTL loads

  Polarity – Logic "1" with positive polarity input – Latched – 7TTL loads

CONVERSION TIME
- 125ms for *Full Scale* Input (145ms for AD2004/E)

SPEED
- External Trigger – 8 conversions per second (6 conversions per second for AD2004/E)
- Internal Conversion – 4 conversions per second
- Hold and Read on Command

SIZE AND WEIGHT
- 3"W x 1.8"H x 2.5"D (7.62 x 4.57 x 6.35cm) (overall depth for case and connector is 3.3" (8.38cm)). Weight, 8 oz. (227 gm).

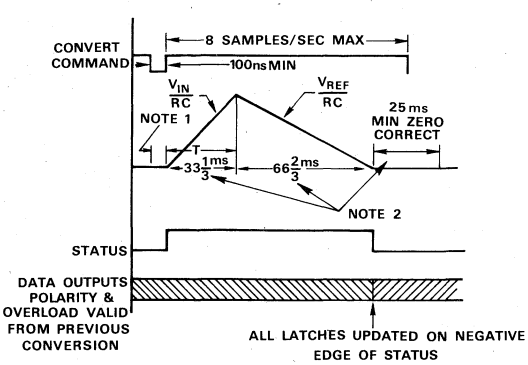
POWER
- 5V dc ±5% @ 800mA typ, 900mA max

ORDERING GUIDE
- AD2004 – Standard AD2004 as described above – tuned for peak normal mode rejection at 60Hz and its harmonics.
- AD2004/E – Standard AD2004 as described above – tuned for peak normal mode rejection at 50Hz and its harmonics.

CONNECTOR
- AC1600 6 feet of decade coded wire mated with "3M" Connector (Part No. 3414)

  AC1601 "3M" mating connector (Part No. 3414) only

NOTE
Specifications subject to change without notice.




NOTE:
1. Maximum Delay of One Clock Pulse 3.3μs to Synchronize with Clock.
2. AD2004E (50Hz Model) Timing.
   Ramp up 40ms
   Ramp down 80ms
   Zero correct 25ms

   Maximum Trigger Rate 6ms

*Figure 2. AD2004 Timing Diagram*

# AC Powered 3½ Digit DPM with Sperry Display

# AD2006

**FEATURES**
**AC Line Powered (+5V dc Powered Optional)**
**0.55" Sperry Display**
**Differential Input**
**Maximum Error: ±0.05%±1 Digit**
**AC Terminal Strip for Safety**
**Ratiometric Operation**
**Power Outputs for External Circuitry**

**APPLICATIONS**
**Analytical, Medical and Scientific Instrumentation**
**Industrial Test Equipment**
**Process Control Instrumentation**




## GENERAL DESCRIPTION

Analog Devices' model AD2006 is an ac line-powered, 3½ digit panel meter with Sperry displays for high visibility. The design of the AD2006 includes ratiometric operation and external power outputs to increase its application versatility.

The AD2006 provides high accuracy measurements of bipolar, differential input signals over a full scale range of ±1.999V, with a maximum error of ±0.05% (reading) ±1 digit. For most applications, the differential input section provides greater than 70dB of common mode rejection (CMRR) at common mode voltages (CMV) up to ±5V. In addition, the AD2006 can be floated on the ac power supply in the single-ended mode, allowing common mode voltages up to ±300V to be accommodated with common mode rejection exceeding 100dB. To insure the safety of operational personnel and interconnected equipment, especially at high CMV, a terminal strip is provided for connection of ac power.

For best visual readout, the AD2006 is internally programmed to make 5 readings per second. For data acquisition applications, up to 90 conversions per second can be externally triggered. DTL/TTL compatible parallel BCD data outputs and control signals are provided for interfacing to other digital data systems. To extend its versatility, external power outputs suitable for powering op amps and IC circuits are available to facilitate scaling or buffering inputs and driving external logic. Standard ratiometric operation allows normalizing inputs to an external reference voltage for making compensated measurements with bridge and potentiometric transducers.

In addition to ac line powered versions, the AD2006/D is available for operation from +5V dc power supplies commonly used for digital logic circuitry. The AD2006/D has identical performance specifications to all other AD2006 versions, except that it cannot be floated on the power supply for measurements at high common mode voltages and, of course, the +5V dc output is not available.

## LARGE CLEAR DISPLAY ENHANCES READABILITY

The AD2006 uses large (0.55") Sperry, seven-segment, planar gas-discharge displays which appear as continuous solid digits. The display size, brightness and contrast ratio makes the AD2006 readable at distances up to 40 feet or more and in any ambient lighting condition including bright sunlight. The display is filtered to provide bright red digits and is readable without distortion over a 130° viewing angle. Overload conditions are indicated by displaying all dashes with the polarity sign remaining valid. The polarity sign can be blanked for display in engineering units where polarity indication is unnecessary.



**For detailed information, contact factory.**

# SPECIFICATIONS (typical @ +25°C unless otherwise noted)

DISPLAY OUTPUT
- Sperry Gas Discharge displays (seven segment, 0.55" (1.4cm)H), for 3 data digits, 100% overrange and polarity indication.
- Overload: Center segment dashes, polarity remains valid.
- Decimal Points: Selectable at input connector (contact closure).
- Polarity Sign may be blanked for display in engineering units.

INPUT
- Full Scale Range: 0 – ±1.999V
- Automatic Polarity
- Differential
- Bias Current: High Input – 3nA typ. (7nA maximum)
  Low Input – 200nA typ. (500nA maximum)
- Impedance: >100MΩ
- Overvoltage Protection: Analog Hi = ±50V sustained
  Analog Low = ±30V sustained

EXTERNAL REFERENCE INPUT
- Range: +5.8 to +6.8 Volts
- Input Impedance: >0.5MΩ
- Not protected against overvoltage
- Absolute Value Measurements: Internal +6.4V reference must be externally connected to the reference input.

ACCURACY
- Maximum Error: 0.05% of reading ±1 digit
- Resolution: 1mV
- Temperature Range: 0 to +50°C operating, -55°C to +85°C storage.
- Temperature Coefficient: Gain: <50ppm/°C
  Zero: <±50μV/°C

COMMON MODE REJECTION
- Differential Mode: 70dB, dc to 1kHz, with 1kΩ unbalance
- Floated on power supply transformer: >100dB[1]

COMMON MODE VOLTAGE
- Differential Mode: ±5V
- Floating Mode: ±300V dc (600V p-p ac)[1]

SPEED
- External Trigger: Up to 90 conversions per second (without display)
- Internal Trigger: 5 conversions per second
- Hold and Read on Command

CONVERSION TIME
- Normal Conversion: 9ms maximum
- Overload Conversion: 11ms maximum

INTERFACE SIGNALS
- DTL/TTL Compatible

| | IN | OUT |
|---|---|---|
| logic "0" | <0.8V | <0.4V |
| logic "1" | >2.0V | >2.4V |

- Inputs
  Polarity Sign Blanking: Logic "0" or grounding blanks the polarity sign being displayed.
  External Hold: Logic "0" or grounding this input disables the internal trigger, and the last conversion is held and displayed. External triggering can only be done when the AD2006 is in "HOLD".
  External Trigger: A negative trigger pulse applied to the external trigger input will initiate conversion.
- Outputs
  Status: All digital outputs are valid when status is low (logic "0"), logic "1" indicates conversion is in process.
  3BCD Digits (8421 positive true), unlatched, 6TTL loads.
  Overrange: Logic "1", unlatched, 6TTL loads, indicates overrange (>1.000V).
  Overload: Logic "1" unlatched, 6TTL loads, indicates overload (>1.999V), logic "0" indicates data is valid.
  Polarity: Logic "1", latched, 6TTL loads, indicates positive polarity.
  $\overline{\text{Polarity}}$: Logic "1", latched, 6TTL loads indicates negative polarity.[2]

POWER
- AC line power (see option table), 7 Watts at nominal line voltage.
- AD2006/D: +5V dc @ 850mA

WARMUP
- 20 minutes to specified accuracy.

ADJUSTMENTS
(recommended calibration period: 6 months)
- Gain
- Zero Offset

EXTERNALLY AVAILABLE POWER OUTPUTS
- +5V ±5% @ 50mA (continuous short circuit protection)[1]
- ±15V ±10% @ 10mA (No short circuit protection; may require filtering for power supply-sensitive components)

SIZE
- 3"W x 1.8"H x 4"D (7.62 x 4.57 x 10.16cm) (4.95" (12.57cm) max to rear of mating connector, 4.80(12.19cm) max on AD2006/C)

WEIGHT
- 19 oz. (540gm) with ac power
- 10½ oz. (300gm) on AD2006/D

OPTIONAL FEATURES & ORDERING GUIDE
(All options on any AD2006 are listed on the label affixed to the bottom of the unit.)
- Power Supply Inputs (only one may be specified)

| | | |
|---|---|---|
| AD2006 | 115V ac ±10% | (50 – 60Hz) |
| AD2006/E | 220V ac ±10% | (50 – 60Hz) |
| AD2006/H | 240V ac ±10% | (50 – 60Hz) |
| AD2006/F | 100V ac ±10% | (50 – 60Hz) |
| AD2006/D | +5V dc ±5% | |

- Card Edge Connector: AD2006/C
- Any combination of the above options -- excluding power inputs -- can be specified. When ordering, specify power supply option first, then the other option desired. For example, an AD2006/E/C operates on 220V ac, and has the connector card edge.
- Display Lenses (only one may be specified):
  Lens-5 will be supplied if none is specified)
  Lens-5 Red w/ADI Logo
  Lens-6 Red no ADI Logo
  Lens-9 Amber w/ADI Logo
  Lens-10 Amber no ADI Logo

CONNECTOR
- 3M connector #3414, (optional) AC1600–34 pin connector and 6 ft. (1.83m) of color-coded, 34 way, 28 AWG flat woven cable.
- AC1601-connector only.
- AD2006/C requires 30 pin, 0.156 spacing, Viking No. 2VK 15D/1-2 or Cinch type 251 No. 5030A30.
- AD2006/C optional – Order AC1501.
- AC Power Line Cords are not supplied by ADI.

NOTES
[1] Not applicable to AD2006/D.
[2] Not applicable to AD2006/C.
Specifications subject to change without notice.

## RATIOMETRIC OPERATION EXTENDS APPLICATIONS

The AD2006 has provision for making measurements normalized to an external reference voltage. This feature allows compensation for transducer outputs sensitive to excitation voltage variations, by making all measurements with reference to the excitation voltage. Figure 1 shows the AD2006 used with a bridge transducer which may be measuring temperature, pressure or any other physical parameter. The excitation voltage of the transducer is used as the reference input of the DPM. When used in the ratiometric mode, reference inputs in the range of +5.8 to 6.8 volts must be presented to the REFERENCE INPUT. The reference input must be relatively stable since the

DPM measures $\frac{\int_t E_{in}dt}{\int_t E_{ref}dt}$ not $\int_t \frac{E_{in}}{E_{ref}}dt$, and any variations

in the reference voltage during conversion may produce erroneous readings.

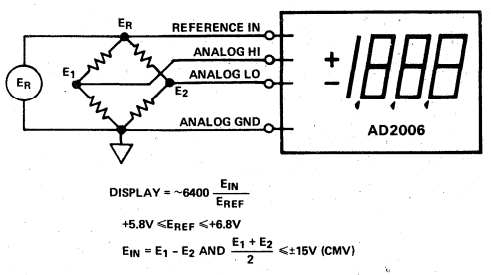



*Figure 1. Bridge Transducer Measurements Using the AD2006's Ratiometric Input*

The REFERENCE OUTPUT can be used for driving transducers if it is properly buffered using an external op amp. Figure 2 shows a thermistor temperature measuring circuit using the AD2006 to power the entire measurement system. The REFERENCE INPUT is a high impedence input which will not load any reference source, but this input is not protected from overload damage. If normal operation of a AD2006 is required, connection of the Reference Output to the Reference Input will allow operation using the internal +6.4V reference source.

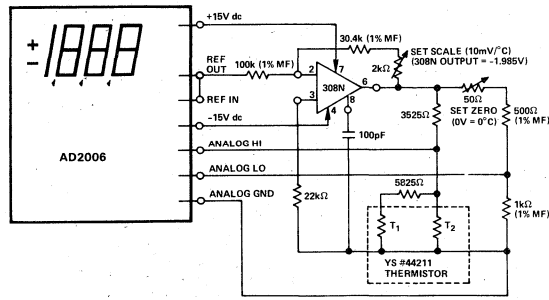



*Figure 2. AD2006 Thermistor Temperature Measurement System*

## DC OUTPUTS CAN POWER EXTERNAL CIRCUITRY

Since the circuitry of the AD2006 requires ±15V and +5V to be generated internally, these voltages are made available to allow operation of external circuitry used in conjunction with the DPM. Sufficient power is available to drive op amps to scale inputs or even buffer the reference output to drive transducers such as in the thermistor application shown in Figure 2. The +5V output (not available on AD2006/D models) can be used for external logic. In many measurement systems, these power outputs will be sufficient to power all the circuitry external to the DPM. Although the regulation and ripple are adequate for the sensitive analog and digital circuitry of the AD2006, further filtering may be necessary for components that are extremely power supply sensitive.

## AD2006 THEORY OF OPERATION

Figures 3 and 4 are the block diagram and timing diagram for the AD2006. The AD2006 uses a standard dual slope conversion technique with an absolute value voltage to current converter on the input. The absolute value of the analog input voltage produces a proportional current. When the convert command pulse initiates conversion, this current is integrated "up" for a fixed time period (1000 clock periods). The con-

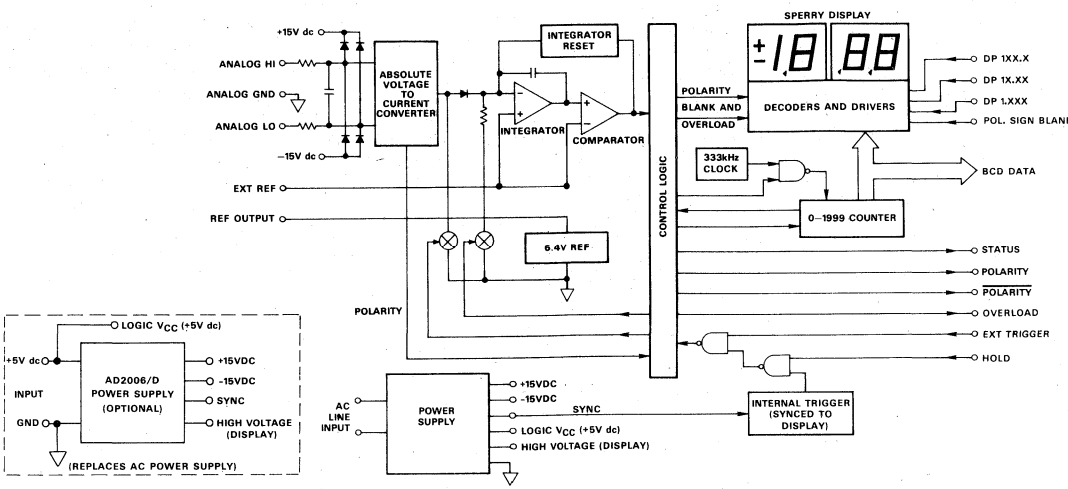



*Figure 3. AD2006 Block Diagram*

verter then integrates "down" using a reference current of opposite polarity until the comparator senses that the integrator output voltage has returned to the original baseline. During the ramp-down period, the counters count clock pulses, and the number stored at the end of ramp-down is proportional to the analog input voltage.

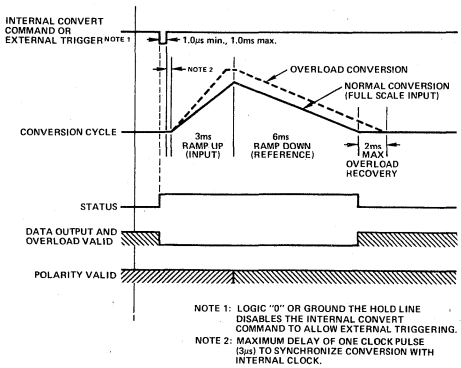



*Figure 4. AD2006 Timing Diagram*

## INTERFACING THE AD2006

AC POWER CONNECTIONS: Connect ac power lines to the terminal strip on the rear of the AD2006. The ground line is internally connected to the case of the DPM. To assure safe operation, always use three-wire ac only, and cover the terminal strip with the protective cover provided. AD2006/D versions use the +5V dc Output and the Digital Ground as power supply INPUTS.

INPUT CONNECTIONS: Differential input signals should be connected between the ANALOG HI and the ANALOG LOW. The ANALOG GROUND must be connected to the system ground. For single-ended operation, connect the ANALOG LOW to the ANALOG GROUND. To allow operation at high common mode voltage, the AD2006 may be floated on the ac power supply transformer in the single-ended mode, without the digital interface signals connected. (See note on decimal points. AD2006/D versions can only be operated in the differential mode.) For absolute value measurements, the REFERENCE OUTPUT must be connected to the REFERENCE INPUT.

DECIMAL POINTS: Grounding the appropriate pin will illuminate the desired decimal point. (Note: Decimal points can be used in the "floating" mode if and only if the appropriate pin is grounded only to the AD2006 digital ground.

DIGITAL DATA OUTPUTS: The digital data outputs are unlatched, positive true, parallel BCD, at DTL/TTL logic levels. All data outputs are valid when the STATUS line is low (logic "0"). Erroneous data will be present when the conversion is in process and the STATUS line is high.

EXTERNAL CONTROL SIGNALS:

*EXTERNAL HOLD:* Logic "0" or grounding the HOLD input disables the internal trigger, and the last conversion is held and displayed. If a HOLD input is applied during conversion, the conversion will be completed and displayed. No further conversions will be made unless the HOLD input is removed or an EXTERNAL TRIGGER pulse is applied.

*EXTERNAL TRIGGER:* Operating in the EXTERNAL TRIGGER mode requires that the HOLD line be held at logic "0" or grounded. A negative going trigger pulse (logic "1" to logic "0" and return) of 1µs minimum and 1ms maximum width applied to the trigger input will initiate a conversion. The external trigger input must be a pulse since the STATUS is set on the negative-going edge of the pulse and the conversion is initiated on the positive-going edge of the pulse. Triggering at high rates asynchronously with line frequency may cause modulation of the display brightness, since the display is blanked both during conversion and during the negative half of the line cycle. *Care should be taken to insure that triggering does not occur during conversion, as this will cause an erroneous conversion.*

*POLARITY SIGN:* A logic "0" or ground blanks the polarity sign being displayed.

## CALIBRATION PROCEDURES

*WARNING: For the safety of personnel and interconnected equipment, all calibration should be done using a PLASTIC TRIMMING TOOL ONLY.*

The accuracy of the AD2006 should be checked approximately every six months. A precision voltage reference or a calibrated DVM or DMM and a stable voltage source are required. The location of the adjustment potentiometers are shown on the mechanical layout drawings. Under most circumstances, only the gain will need adjustment. Should zero adjustment be necessary, adjust the zero before adjusting the gain.

ZERO OFFSET: Apply an input of 0V or short the analog inputs. If the meter does not read zero, adjust the zero offset pot until the meter reads zero and the polarity sign periodically changes. (Turning the pot clockwise, viewed from the back, makes the reading more negative.)

GAIN: Set the input of the panel meter to 1.900V. The input can be from a precision reference source, or from a stable voltage source set using a calibrated DVM or DMM. If the meter does not read 1900, adjust the gain pot to set the proper reading. (Turning the pot clockwise will increase the reading.) This is a bipolar adjustment, when correctly adjusted, the meter will read correctly for both polarities.

# Low Cost 3½ Digit DPM For OEM Applications

# AD2010

**FEATURES**
**LED Display with Latched Digital Outputs**
**Small Size, Lightweight**
**Automatic Zero Correction; Max Error: 0.05% ±1 Digit**
**High Normal Mode Rejection: 40dB @ 50 or 60Hz**
**Optional Ratiometric Operation**
**Leading "0" Display Blanking**
**5V dc Powered**

**APPLICATIONS**
**Medical/Scientific/Analytic Instruments**
**Data Acquisition Systems**
**Industrial Weighing Systems**
**Readouts in Engineering Units**
**Digital Thermometers**




## GENERAL DESCRIPTION

Analog Devices' model AD2010 represents an advance in price/performance capabilities of 3½ digit digital panel meters. The AD2010 offers 0.05% ±1 digit maximum error with bipolar, single ended input, resolution of 100μV, and a common mode rejection ratio of 60dB (CMRR) at ±200mV (CMV).

The AD2010 features a light-emitting-diode (LED) display with a full scale range of 0 to ±199.9 millivolts, latched digital data outputs and control interface signals, and leading zero display blanking. Automatic-zero correction circuitry measures and compensates for offset and offset drift errors, thereby providing virtually no error. Another useful feature of the AD2010 is its 5V dc operation. The AD2010 can operate from the users' 5V dc system supply, thereby eliminating the shielding and decoupling needed for line powered units when the ac line must be routed near signal leads.

To satisfy most application requirements, the conversion rate of the AD2010 is normally 4 readings per second. However, an external trigger may be applied to vary the sampling rates from a maximum of 24 readings per second down to an indefinite hold time. The AD2010 can also be connected for automatic conversion at its maximum conversion rate. During conversion, the previous reading is held by the latched logic. The numeric readout is available as BCD data. Application of the metering system in a computer or data logging system is made easy with the availability of the "overrange," "polarity," "overload," and "status" signals.

The AD2010/R option for ratiometric operation allows readings to be made of the ratio of two input voltages as well as the absolute value of the input. AD2010/R operation is described in a later section.

A simplified block diagram of the AD2010, illustrating the features described above is shown in Figure 1.

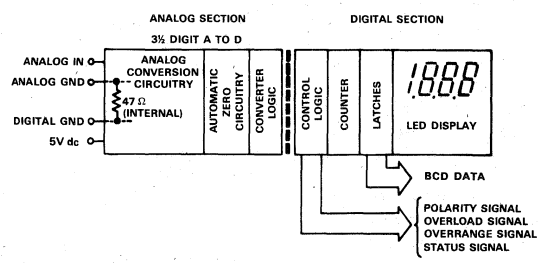



*Figure 1. Simplified Block Diagram*

## IMPROVED NOISE IMMUNITY, ACCURACY AND ZERO STABILITY

Dual-slope integration, as used in the AD2010 and as described in the theory of operation section, offers several design benefits.

- Conversion accuracy, for example, is independent of both the timing capacitor value and the clock frequency, since they affect both the up ramp and down ramp integration in the same ratio.
- Normal mode noise at line frequencies or its harmonics is rejected since the average value of this noise is zero over the integration period.
- To achieve zero stability, a time interval during each conversion is provided to allow the automatic-zero correction circuitry to measure and compensate for offset and offset drift errors, thereby, providing virtually no zero error.

16

**For detailed information, contact factory.**

# SPECIFICATIONS (typical @ +25°C and +5VDC unless otherwise noted)

DISPLAY OUTPUT
- Display consists of four LED's (7 segment – 0.27" (6.9mm) high). for data digits plus 100% overrange and polarity indication.
- Overload – three data digits display zeros and flashes.
- Decimal Points – selectable at input connector.
- Leading "0" Display Blanking – controlled externally.

INPUT
- Full Scale Range – 0 to ±199.9 millivolts
- Automatic Zero
- Automatic Polarity
- Bias Current – 3nA
- DC Impedance – 100MΩ
- Overvoltage Protection – 20V sustained, 50V momentary without damage.
- Decimal Points (3) – illuminate with logic "1", extinguish with logic "0".

ACCURACY
- Maximum Error – 0.05% of reading ±1 digit
- Resolution – 0.1 millivolt
- Temperature Range – 0 to +50°C operating
  -30°C to +85°C storage
- Temperature Coefficient – ±50ppm/°C

NORMAL MODE REJECTION
- 40dB @ 60Hz (50Hz on AD2010/E)

COMMON MODE REJECTION
- 60dB @ ±200mV

CONVERSION RATE
- External Trigger – up to 24 conversions per second
- Internal Trigger – 4 conversions per second
- Automatic – A new conversion is initiated automatically upon completion of conversion in process; conversion rate will vary from 24/sec to 40/sec depending on input magnitude.
- Hold and Read upon command.

CONVERSION TIME
- Normal Conversion – 42ms max (full scale input)
  50ms max Model AD2010/E
- Overload Conversion – 62ms max

INTERFACE SIGNALS
- DTL/TTL Compatible

| | IN | OUT |
|---|---|---|
| logic "0" | <0.8V | <0.4V |
| logic "1" | >2.0V | >2.4V |

- Inputs

External Trigger – Operation in the "External Trigger" mode requires that the "External Hold" input be a logic "0" or ground.

Negative Trigger Pulses – Applying a logical "low" to the "HOLD" input disables the internal trigger. A negative trigger pulse (logic "1" to logic "0") of 1.0μs minimum applied to the "EXT TRIGGER" input will initiate conversion in the same manner as the internal oscillator. The external trigger should not be repeated, however, until the "status" indicates completion of the conversion in process.

Positive Trigger Pulses – The "HOLD" input can be used to trigger the AD2010 from a "normally low" signal with the "EXT TRIGGER" input open or logic "1". Following a "hold" a new reading will be initiated on the leading edge of the "hold" signal. Thus, a momentary positive pulse on the "HOLD" input can be used to trigger the AD2010. The drift correct interval, however, begins on the trailing edge of the positive pulse, so if the pulse width exceeds 1ms, the conversion will actually be initiated by the internal trigger.

Maximum Conversion Rate - Automatic – The AD2010 can also be connected for automatic conversion at its maximum conversion rate by connecting the "status" output back into the "hold" input. In this manner the status signal going high at the end of one conversion immediately initiates a new conversion. The pulses appearing on the status line can be used to step a multiplexer directly, since the built-in drift-correct delay of 8.33ms will allow settling of the input prior to conversion. A logic "0" applied to the "EXT TRIGGER" will inhibit the automatic trigger mode.

External Hold – Logic "0" or ground applied to this input disables the internal trigger and the last conversion is held and displayed. For a new conversion under internal control the input must be opened or at logic "1". For a new conversion under external control, a positive pulse of less than 1.0ms can be applied (as previously explained).

OUTPUTS
- 3 BCD Digits (8421 Positive True) - latched - 3TTL loads
- Overrange - logic "1" - latched - 6TTL loads, indicates overrange.
- Overload - logic "0" indicates overload (>199.9mV) logic "1" - latched - 6TTL loads, indicates data valid.
- Polarity - logic "1" - latched - 6TTL loads, indicates positive polarity input.
- Status - logic "0" - conversion in process logic "1" - latched - 6TTL loads, indicates conversion complete.

POWER
- +5V dc ±5%, 500mA

WARM UP
- Essentially none to specified accuracy

ADJUSTMENTS
- Range potentiometer for full scale calibration. Calibration recommended every six months.
- Normal Mode Rejection potentiometer (AD2010R only)

SIZE
- 3"W x 1.8"H x 0.84"D (76.2 x 45.7 x 21.3mm) (overall depth for case and printed circuit board extension is 1.40" (35.6mm)).

ORDERING GUIDE
- AD2010 - Standard AD2010 as described above - tuned for peak normal mode rejection at 60Hz and its harmonics.
- AD2010/E - Standard AD2010 as described above - tuned for peak normal mode rejection at 50Hz and its harmonics.
- AD2010/R - Standard AD2010 as described above - with Ratiometric option.
- AD2010/E/R - Standard AD2010/E as described above with Ratiometric option.

WEIGHT
- 4 oz. (113.5gm)

CONNECTOR RECOMMENDATION
- 30 Pin 0.156 spacing, Viking No. 2Vk 15D/1-2 or Cinch type 251 No. 5030A30.
- Optional - Order AC1501.

Specifications subject to change without notice.

**5V dc OPERATION PROVIDES REDUCED NOISE PICKUP, IMPROVES RELIABILITY**

A DPM designed for 5V dc operation offers the user many advantages over ac line powered devices. These benefits include:

- REDUCED NOISE PICKUP AND SUSCEPTIBILITY. Since line voltages are not required for operation, signal leads and internal circuitry need not be exposed to this source of noise, thereby, reducing power-frequency interference. A separate 5V dc power supply also provides additional isolation from line transients. Shielding and decoupling of the DPM circuits can also be eliminated. The DPM may be used as a component without danger of shock hazards to operational personnel or nearby circuitry.
- IMPROVED RELIABILITY. DPMs without power supplies generally require less space and generate less heat. The result is improved reliability while achieving lower cost. The smaller package size provides greater packaging flexibility and requires less ventilation behind the panel.

**LEDs GIVE LONG LIFE, SHARP DISPLAY**

The numeric outputs are displayed using 0.27" high, 7 segment, red LEDs. The LEDs provide the physical ruggedness typical of ICs, with a life expectancy in excess of 100,000 hours. The displayed numerals are sharp and easily readable at distances of up to 8 feet. The clean uncluttered look of the lens and case design further enhance the visual attractiveness of the display.

Optical features of the display include: a minimum photometric brightness of 200 foot-lamberts, and a 6300 angstrom, wavelength at peak emission (red). Other display features include programmable decimal points, automatic zero, 4 readings per second display rate, external trigger-and-hold rate of up to 24 readings per second, flashing-zeros overload indication, and leading "zero" display blanking.

**COMPACT DESIGN FEATURES EASY SNAP-IN INSTALLATION**

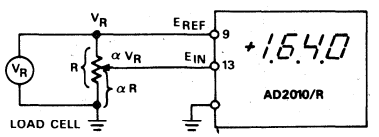
The AD2010 is housed in an aluminum case providing light weight, structural strength, optimum heat dissipation and shielding against external noise. With overall dimensions as shown in Figure 6, minimum space is required both on the panel and behind it. No tools are required for installation. You simply snap in the case, then snap on the filter and lens. Its light weight makes AD2010 ideal for applications in hinged panel equipment.

**THEORY OF OPERATION**

The AD2010 (Timing Diagram Figure 7) uses a dual-slope integrating A/D conversion scheme. When an input signal is applied to the DPM, it is applied to an integrator at the same time a counter is activated, initiating the count of clock pulses. After a predetermined number of counts (a fixed interval of time, T), the polarity of the input signal is strobed and a reference voltage having opposite polarity is applied to the integrator. At this instant, the accumulated charge on the integrating capacitor, C, is proportional to the average value of the input over the interval T. The integral of the reference is an opposite-going ramp having the fixed slop $V_{REF}/RC$. At the same time, the counter is again counting from zero. When the integrator output reaches zero, the count is stopped, and the analog circuitry is reset. Since the charge gained is proportional to $V_{IN}T$, and the equal amount of charge lost is proportional to $V_{REF}/\Delta t$, then the number of counts relative to the full count is proportional to $\Delta t/T$, or $V_{IN}/V_{REF}$. The output of the counter is a BCD number, which is decoded and displayed as the digital representation of the input.

**AD2010/R OPTION EXPANDS APPLICATION**

RATIOMETRIC OPERATION WITH EXTERNAL REFERENCE: The ratiometric option (AD2010/R) allows readings to be normalized to an external reference. This option can be useful where the analog voltage to be measured is accurate relative to an external reference which in itself is not accurate. A ratiometric application is illustrated in Figure 2. In this example, a position readout potentiometer operates with an external excitation supply which itself may not be very accurate. However, the potentiometer output relative to the reference supply, will be accurate due to the potentiometric configuration.




$$\text{DISPLAY} = 2000\left(\frac{E_{IN}}{E_{REF}}\right) = 2000\alpha$$

WHERE: $E_{IN} = \alpha V_R$, $E_{REF} = V_R$, $E_{IN} \leq E_{REF}$

LIMITS: $+100\text{mV} \leq E_{REF} \leq +300\text{mV}$ and $\pm 100\text{mV} \leq E_{IN}$ MAX $\leq \pm 200\text{mV}$

*Figure 2. Ratiometric Operation*

In the AD2010 the normal reference voltage is 200mV and is internally connected. The AD2010/R, however, has a "Reference Input" where an external reference voltage in the range of 100-300mV can be applied. The displayed output is given by:

$$\text{Display} = 2000\left(\frac{E_{IN}}{E_{REF}}\right)$$

The AD2010 also has a "Reference Output" where the normal 200mV reference is available. Absolute measurements using the AD2010/R can be made by externally connecting "Reference Output" to "Reference Input." The "Reference Output" is provided for this purpose only. It should be noted that the ratiometric option is intended only for normalization, and that the external reference must be a steady dc voltage.

**INTERFACING THE DPM**

The AD2010 can also be connected for automatic conversion at its maximum conversion rate by connecting the "status" output (Pin K) back into the "hold" input (Pin D). The 70ns pulses appearing on the status output line may be used to step a multiplexer. The status pulse width may be increased (if desired) as shown in Figure 3.

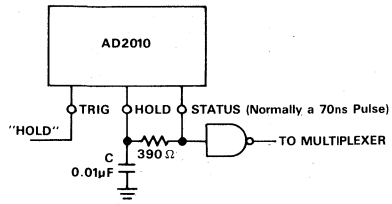



*Figure 3. Increasing Pulse Width for Multiplexer Control in the Automatic Mode*

To maximize the common mode rejection, an external 100μF @ 3V capacitor, C, is recommended as illustrated in Figure 4. The capacitor will reduce ground noise and ripple where the interconnection wires are 12 inches or longer. The polarization of C will depend on actual configuration.

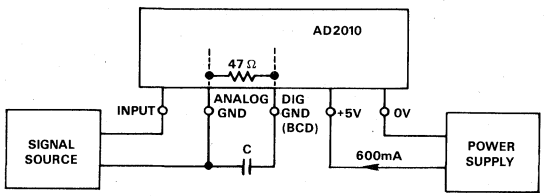



*Figure 4. Insuring Maximum Common Mode Voltage Rejection*

The latched digital data outputs and control interface signals are available at the rear of the AD2010. The signals may be interfaced with the system using a Cinch or Viking PC edge connector with 0.156" spacing or the AC1501 connector option. Signal and pin designations are shown in Figure 5.

| PIN REF | PIN FUNCTION |
|---|---|
| 1 | EXTERNAL TRIGGER |
| 2 | 800's DIGIT |
| = KEY | |
| 3 | 400's DIGIT |
| 4 | DP 1XX.X |
| 5 | OVERLOAD |
| 6 | 40's DIGIT |
| 7 | 20's DIGIT |
| 8 | DIGITAL GRD |
| 9* | REF IN (2010/R ONLY) |
| 10 | REF OUT |
| 11 | CLOCK OUT |
| 12 | 4's DIGIT |
| 13 | ANALOG IN |
| 14 | ANALOG GRD |
| 15 | DP 1X.XX |

| PIN REF | PIN FUNCTION |
|---|---|
| A | 1000's DIGIT (OVERRANGE) |
| B | 100's DIGIT |
| C | 200's DIGIT |
| D | HOLD |
| E | POLARITY |
| F | 80's DIGIT |
| H | 10's DIGIT |
| J | POWER SUPPLY GND |
| K | STATUS |
| L | 8's DIGIT |
| M | 1's DIGIT |
| N | +5V POWER INPUT |
| P | 2's DIGIT |
| R | LEADING ZERO SUPPRESSION |
| S | DP 1.XXX |

*WHEN IT IS DESIRED TO USE THE AD2010/R INTERNAL 200mV REFERENCE, EXTERNALLY CONNECT PIN "9" TO PIN "10". "REF IN" NOT PROTECTED AGAINST OVERLOAD.

*Figure 5. AD2010 Connector Pin Designations*

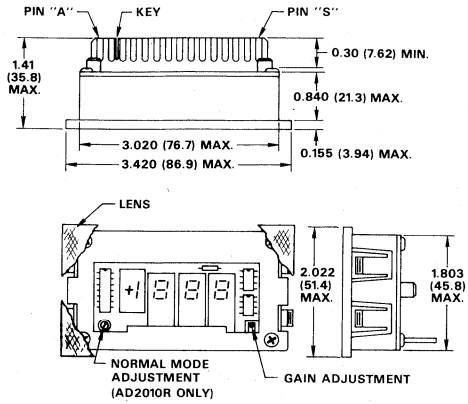
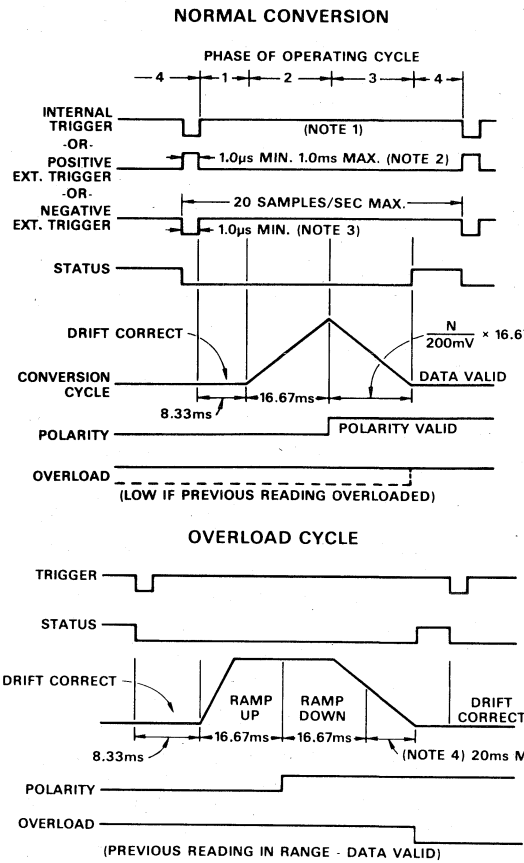



*Figure 6. Overall Dimensions*
All dimensions are given in inches and (mm).




NOTES:
1. The internal trigger rate is 4 conversions/sec.
2. A logic "0" applied to the "HOLD" input (pin D) disables the internal trigger. A positive pulse of 1ms max will initiate conversion. The "status" output may be used in this way for automatic triggering.
3. With the internal trigger disabled a negative pulse applied to the "external trigger" (pin 1) will initiate conversion.
4. Total ramp down time dependent on extent of overload (additional 20ms max).

*Figure 7. AD2010 Timing Diagram*

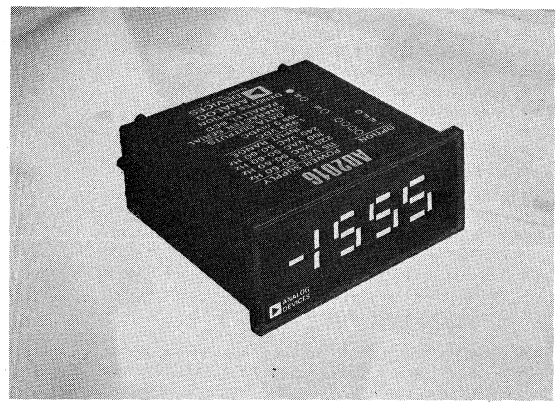
# ANALOG DEVICES

# Low Cost, 3½ Digit, Line Powered DPM With LED Display

# AD2016

**FEATURES**
**"Second Generation" MOS/LSI Design**
**Large 0.5" (13mm) LED Displays**
**AC Line Powered, Universal Transformer**
**±199.9mV dc, ±1.999V dc or ±19.99V dc Full Scale Ranges**
**Auto-Zero Correction**
**Limited Differential Input**
**Character Serial Data Output Standard, Parallel Data Optional**
**Industry Standard Case Design — Second Sources Available**

**APPLICATIONS**
**General Purpose ac Line Powered DPM Requirements**



## GENERAL DESCRIPTION

The AD2016 is a low cost, 3½ digit, line powered Digital Panel Meter with large LED displays, designed for general purpose DPM applications. The AD2016 measures bipolar input voltages over full scale ranges of ±199.9mV dc, ±1.999V dc or ±19.99V dc with an accuracy of ±0.05% reading ±0.025% full scale, ±1 digit. By using the "limited differential" input first used on Analog Devices' AD2010, the AD2016 input prevents ground loop problems and provides common mode noise rejection at common mode voltages up to ±200mV. Normal mode rejection is 40–45dB at 50 to 60Hz.

AD2016 models are available for operation at any line voltage and frequency required throughout the world. But, since the AD2016 uses a "universal" transformer, simple internal changes by bridging solder pads allow easy changing of the input power voltage for specific requirements. Thus, the OEM need not stock a variety of models for export requirements, but can easily change the voltage as required.

## THE BENEFITS OF SECOND GENERATION DESIGN

The AD2016 is designed around MOS/LSI (Metal Oxide Semiconductor, Large Scale Integration) integrated circuits to reduce the number of components and power consumption, which greatly enhances reliability. However, these ICs provide the performance and features of earlier DPM design. The large 0.5 inch (13mm) LED displays provide the visual appeal of the gas discharge displays with the reliability of all solid state devices.

## VERSATILE DATA INTERFACING

Since the AD2016 is designed around MOS/LSI circuits, the BCD output data is presented in a bit parallel, character serial format compatible to CMOS logic systems. Although some applications, such as interfacing with microprocessors are simplified with this data format, many applications involving line printers or comparators require parallel data outputs. For these applications, the AD2016/B provides parallel BCD data, TTL compatible. The conversion from a serial to a parallel format is done using shift registers, so the output data is fully latched. The AD2016/B also has two "Hold" inputs, one which stops DPM conversions and one which prevents data updating. Thus, the data outputs can be held for data transfer while the DPM continues to convert and update the display.

## STANDARD PACKAGING/SECOND SOURCES

The AD2016 is packaged in Analog Devices' ac line powered DPM case, which requires the same panel cutout as cases used by most other manufacturers of ac line powered DPMs. In addition, the pin connections are the same as several other DPMs, including the Analog Devices' AD2009. (Even the BCD outputs of the AD2016/B are the same as the AD2009). With this commonality between DPMs, the user is assured of having second sources available or can update instrument or system designs to utilize the newer technology of the AD2016 without expensive mechanical or electrical changes to current products.

16

## DESIGNED AND BUILT FOR RELIABILITY

Even beyond the reliability advantages of the LSI IC design and LED displays, the AD2016 has had extreme care taken in its design and manufacture to insure reliability. Manufacturing processes are monitored by continual quality assurance inspections to insure proper workmanship and testing. Automatic test equipment is used to test each DPM at board level and final assembly to assure thorough testing without error. And, each AD2016 gets one full week of failure-free burn-in at 50°C and with cycled power before shipment.

# SPECIFICATIONS (typical at +25°C and nominal power supply voltage)

DISPLAY OUTPUT
- Light-emitting diode (LED), planar seven segment display readouts, 0.5" (13mm) high for 3 data digits, 100% overrange and negative polarity indication. Overload indicated by flashing display, polarity remains valid.
- Decimal points (3) selectable at input connector.
- Display Blanking

ANALOG INPUT
- Configuration: bipolar, limited differential
- Full Scale Ranges: ±1.999V dc (standard), ±199mV dc ("S" option) or ±19.99V dc ("V" option)
- Automatic Polarity
- Auto Zero
- Input Impedance: 100MΩ (1MΩ – "V" option)
- Bias Current: 50pA
- Overvoltage Protection: ±200V dc sustained

ACCURACY
- ±0.05% reading ±0.025% full scale ±1 digit[1]
- Resolution: 1mV (standard), 100μV ("S" option), 10mV ("V" option)
- Temperature Range[2]: 0 to +50°C operating, -25°C to +85°C storage
- Temperature Coefficient: Gain: 50ppm/°C
  Zero: Auto Zero
- Warm Up Time to Rated Accuracy: less than one minute
- Settling Time to Rated Accuracy: 0.5 seconds (-full scale to +full scale)

NORMAL MODE REJECTION
- 45dB at 50–60Hz (40dB, "V" option)

COMMON MODE REJECTION

| Input Range | Limited Differential (dc-10kHz, no imbalance) | Floating[3] (dc-100Hz, 1kΩ imbalance) |
|---|---|---|
| ±199.9mV | 50dB | 120dB |
| ±1.999V | 35dB | 120dB |
| ±19.99V | 15dB | 100dB |

COMMON MODE VOLTAGE
- Limited Differential Mode: ±200mV
- Floated On Power Supply Transformer When No BCD Outputs or Control Signals are Used: ±300V dc or 600V ac p-p

CONVERSION RATE
- 5 conversions per second
- Hold and read on command

CONTROL INPUTS[3]

Display Blanking (TTL/DTL Compatible, 3 TTL Loads)
Logic "0" or grounding blanks the entire display except for the decimal points at the tens and hundreds digits. Logic "1" or open circuit for normal operation. Display blanking has no effect on the output data and the display is valid immediately upon removal of a blanking input.

Converter Hold (CMOS, TTL/DTL Compatible, 1 LPTTL Load)
Logic "0" or grounding causes the DPM to cease conversions and display the data from the last conversion. Logic "1" or open circuit for normal operation. After a "Converter Hold" is removed, one or two conversions are needed before the reading or BCD data is valid.

Decimal Points (Not TTL Compatible)
Grounding or Logic "0" will illuminate the desired decimal point. External drive circuitry must sink 50mA at a 25% duty cycle when a decimal point is illuminated.

Data Hold (AD2016/B Only) (TTL/DTL Compatible, 1 TTL Load)
Logic "0" or grounding inhibits updating of the latched parallel output data of the AD2016/B. Logic "1" or open circuit allows the data to be updated after each DPM conversion. This input has no effect on the normal conversion of the DPM.

DATA OUTPUTS[3] (See applications section for details on the data outputs)

Bit Parallel, Character Serial BCD Data Outputs Standard. 4 BCD data bits, positive true logic (CMOS, LPTTL or LP Schottky compatible, 1 LP Schottky load); 4 digit strobes (CMOS, TTL compatible, 1 TTL load); Polarity (CMOS, TTL compatible, 1 TTL load), logic "1" indicates positive polarity; Clock Output (CMOS, LPTTL or LP Schottky compatible, 1 LP Schottky load); Status Output (CMOS or LPTTL, 1 LPTTL load) are available.

Parallel BCD (AD2016/B) Optional. 3 BCD digits, Overrange, Overload and Data Ready Outputs (TTL compatible, 4 TTL loads). BCD data outputs are latched, positive true logic. The Overload Output is at Logic "0" for inputs greater than full scale range, Logic "1" when other data outputs are valid. Polarity Output (TTL compatible, 4 TTL loads latched) indicates positive polarity when high (Logic "1").

POWER INPUT

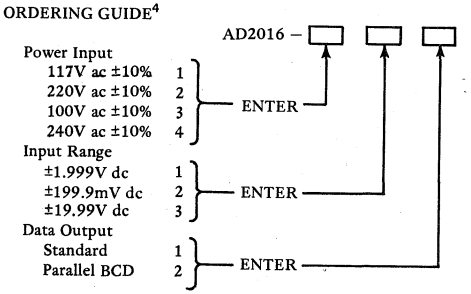
AC line, 50–60Hz. Power Consumption: 3.3 watts at 60Hz; 3.8 watts at 50Hz (Parallel BCD: 3.9 watts at 60Hz; 4.4 watts at 50Hz).

CALIBRATION ADJUSTMENTS (See application section for calibration instructions)
- Gain
- Zero (capability for system zero adjustment, meter is auto zero)
- Recommended recalibration interval: six months

SIZE
- 4.22"W x 1.97"H x 4.15"L (107 x 50 x 105mm)
- 4.77" (121mm) to rear of card edge connector
- Panel Cutout Required: 1.682" x 3.924" (42.72 x 99.67mm)

WEIGHT
- 12 ounces (340 grams)

ORDERING GUIDE[4]




DISPLAY LENS OPTIONS[5]
- Lens 7 – Red with ADI logo
- Lens 8 – Red without ADI logo

CONNECTOR (OPTIONAL)

30 pin, 0.156 spacing card edge connector, Amphenol 225-21524-601 (117) or equivalent

Optional: Order AC2611

NOTES
[1] Guaranteed at +25°C.
[2] Guaranteed
[3] No control inputs or data outputs can be used when the AD2016 is floated on the power supply transformer at high common mode voltages.
[4] Only one AC power supply input and input range may be specified. The "B" option can be ordered with any combination of power and range options.
[5] Lens 7 is supplied if no lens option is specified.

Specifications subject to change without notice.

**Wiring Connections**

Figure 1 is a wiring diagram for AD2016 applications. The "limited differential" input uses a 47Ω resistor to isolate the analog input from the digital and power supply sections to prevent ground loop problems. The analog ground must be connected to Pin 10 only, since there may be up to 200mV voltage difference between the input and digital ground.

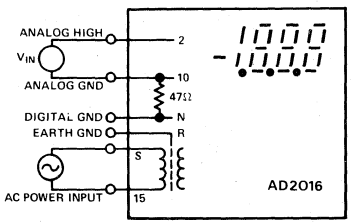



*Figure 1. AD2016 Wiring Interconnections*

**Decimal Points**

Grounding, or Logic "0", applied to the appropriate pin will illuminate the desired decimal point. External drive circuitry, if used, must sink 50mA at a 25% duty cycle when the decimal point is turned on.

**Display Blanking**

Grounding, or Logic "0", blanks the entire AD2016 display with the exception of the decimal points on the tens and hundreds digit. The display is valid immediately upon removal of a blanking signal.

**Converter Hold**

Grounding, or Logic "0", causes the DPM to cease conversions and display the data from the last conversion. After a "Converter Hold" input is removed, the auto zero circuitry requires one or two conversions before the display and data outputs are again valid.

**Data Hold (AD2016/B only)**

Grounding, or Logic "0", on this input inhibits updating of the parallel BCD outputs of the AD2016/B. If the parallel data is interfaced to a printer, comparators, or a computer, requiring the data to be held stable for proper operation, the Data Hold input should be used to prevent data updating, but the DPM itself will continue making conversions. After a Data Hold input is removed, the BCD data will be updated at the end of the conversion cycle.

**Extended Range Measurements**

Although the full scale range of the AD2016 is 2000 counts, and it flashes the display to indicate overrange beyond this point, it actually makes measurements up to approximately 3000 counts. Beyond this point, it will flash a constant number. Thus, one can use this extra measurement range as a guide to reducing the input to the normal range. Note that the display will flash only the three full digits, since it is impossible to flash a "2" on the overrange readout. Thus, a reading of 2.300V or 230.0mV on an AD2016 will read as "300" and will be flashing.

BCD outputs on the standard AD2016 also will be valid up through the 3000 count range, but the BCD parallel outputs of the AD2016/B will indicate overload beyond 1999 counts.

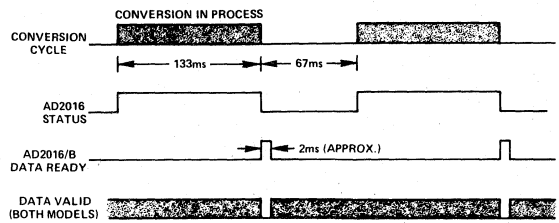



*Figure 2. AD2016 Timing Diagram*

**Interfacing Data Outputs – Character Serial Data**

The BCD data outputs standard on the AD2016 are in a bit parallel character serial format. There are four BCD bit outputs (1, 2, 4, 8) and four digit outputs ($10^0$, $10^1$, $10^2$, $10^3$) called D1, D2, D3 and D4 respectively. The BCD bits are gated onto the output lines sequentially in the order D1, D3, D2, D4 and the BCD bits are valid for the digit whose digit line is high. The serial output data is valid except when it is being updated, which occurs within 2 milliseconds after the Status line goes low, indicating the end of a conversion.

**Interfacing Data Outputs – Parallel Data**

The AD2016/B has data outputs in a full parallel BCD format. The output data is latched and is valid except for a 2ms period at the end of conversion when the "Data Ready" output is high (Logic "1"). As described above, the "Data Hold" input can be used to inhibit updating of the parallel data outputs without affecting the conversion of the DPM.

**Calibration Procedures**

A precision voltage reference is needed for the calibration of the AD2016. The location of the calibration potentiometers is shown in Figure 5. Always adjust the zero offset before the gain if zero adjustment is necessary.

Zero Adjustment: Short the signal inputs (Pins 2 and 10) and adjust the zero offset potentiometer until the meter reads 000.

Gain Adjustment: Apply an input of +1.800V (+180.0mV on AD2016/S, or +18.00V on AD2016/V) and adjust the gain potentiometer until the meter reads 1800 exactly.

## PIN DESIGNATIONS

### AD2016 CHARACTER SERIAL

| PIN REF | PIN FUNCTION |
|---|---|
| 1 | NC |
| 2 | SIGNAL INPUT |
| 3 | STATUS ($\overline{\text{PRINT}}$) |
| 4 | POLARITY |
| 5 | NC |
| 6 | D4 |
| 7 | BCD $2^3$ |
| 8 | BCD $2^1$ |
| 9 | CLOCK OUTPUT |
| 10 | SIGNAL GROUND |
| 11 | NC |
| 12 | D3 |
| 13 | DISPLAY BLANK |
| 14 | NC |
| 15 | AC LINE HIGH |

KEY

| PIN REF | PIN FUNCTION |
|---|---|
| A | NC |
| B | NC |
| C | NC |
| D | CONVERTER HOLD |
| E | D2 |
| F | NC |
| H | BCD $2^0$ |
| J | BCD $2^2$ |
| K | D1 |
| L | DP3 XX.X |
| M | DP2 X.XX |
| N | DIGITAL GROUND |
| P | DP1 .XXX |
| R | SHIELD (EARTH GROUND) |
| S | AC LINE LOW |

(NC = NO CONNECTION)

*Figure 3.*

### AD2016/B

| PIN REF | PIN FUNCTION |
|---|---|
| 1 | DATA HOLD |
| 2 | SIGNAL INPUT |
| 3 | DATA READY |
| 4 | POLARITY |
| 5 | BCD 8 |
| 6 | BCD 2 |
| 7 | BCD 80 |
| 8 | BCD 20 |
| 9 | BCD 800 |
| 10 | SIGNAL GROUND |
| 11 | BCD 400 |
| 12 | BCD 200 |
| 13 | DISPLAY BLANK |
| 14 | OVERRANGE |
| 15 | AC LINE HIGH |

KEY

| PIN REF | PIN FUNCTION |
|---|---|
| A | NC |
| B | NC |
| C | OVERLOAD |
| D | CONVERTER HOLD |
| E | BCD 1 |
| F | BCD 4 |
| H | BCD 10 |
| J | BCD 40 |
| K | BCD 100 |
| L | DP3 XX.X |
| M | DP2 X.XX |
| N | DIGITAL GROUND |
| P | DP1 .XXX |
| R | SHIELD (EARTH GROUND) |
| S | AC LINE LOW |

*Figure 4.*

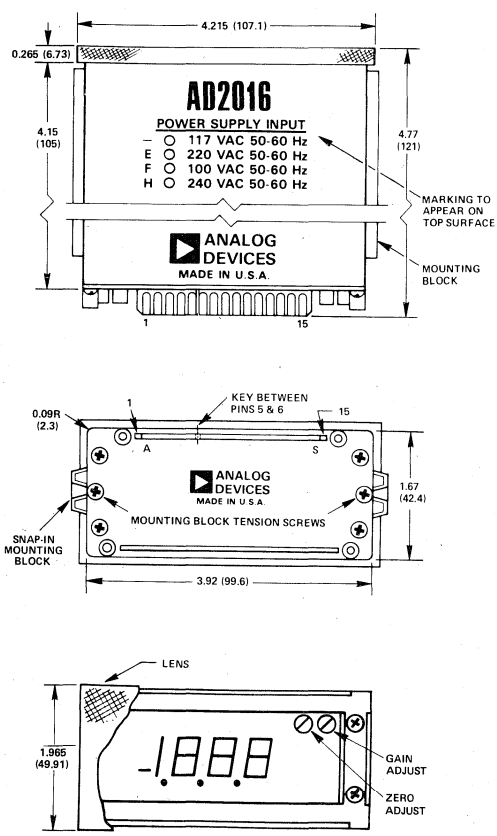



*Figure 5. AD2016 Mechanical Outline (Dimensions shown in inches and (mm))*

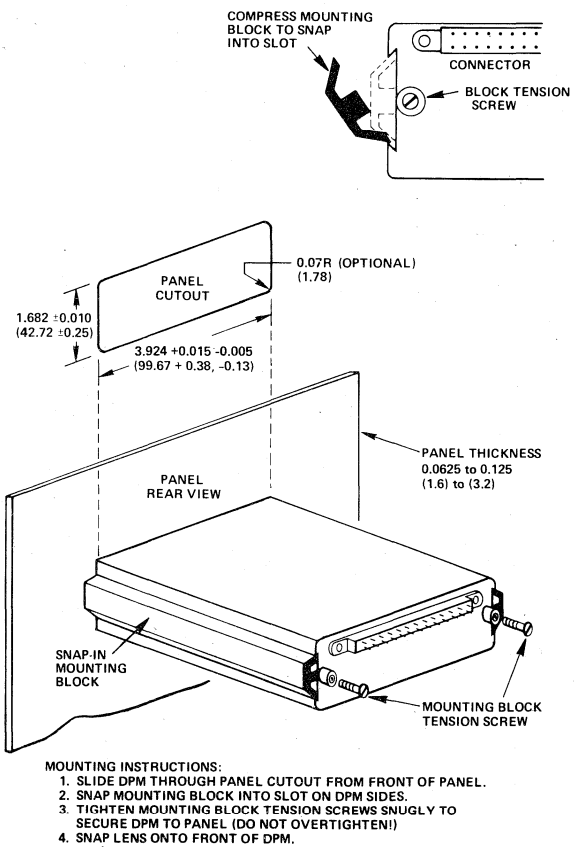



*Figure 6. AD2016 Mounting Instructions (Dimensions shown in inches and (mm))*

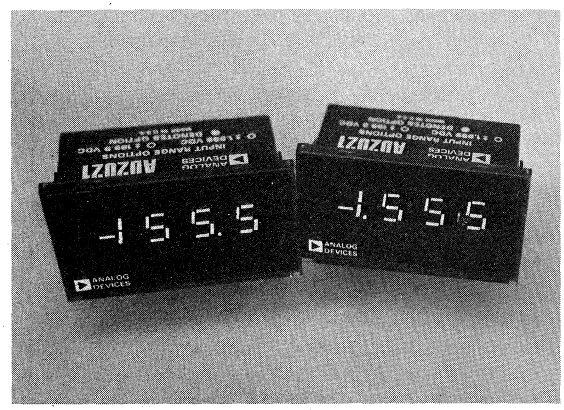
# ANALOG DEVICES

# Low Cost 3½ Digit Logic Powered DPM With LED Displays

# AD2021

**FEATURES**
**"Second Generation" MOS-LSI Design**
**Large 0.5" (13mm) LED Displays**
**+5VDC Logic Powered**
**±1.999V, ±199.9mV or ±19.99V Full Scale Ranges**
**Limited Differential Input**
**Low Power Consumption: 2.0 Watts**
**Small Size, Industry Standard Case Design**

**APPLICATIONS**
**General Purpose Logic Powered DPM Applications**
**Portable Applications Requiring Low Power Consumption**



## GENERAL DESCRIPTION

The AD2021 is a low cost, 3½ digit, +5V dc logic powered digital panel meter with large LED displays. While designed for general purpose DPM applications, the small size, light weight and low power consumption of the AD2021 make it an ideal digital readout for modern, compact instrument designs.

## THE BENEFITS OF "SECOND GENERATION" DESIGN

The AD2021 is designed around MOS-LSI (Metal-Oxide-Semiconductor, Large Scale Integration) integrated circuits, which greatly reduce the number of components, and thereby the size, and reduce power consumption to 2.0 watts. Both the lower power consumption and fewer interconnections between components promise greatly increased reliability, and the circuit design maintains the performance and features of earlier DPMs. Large 0.5 inch (13mm) LED displays offer the visual appeal of gas discharge displays with the ruggedness and lifetime of all solid state devices.

## EXCELLENT PERFORMANCE AND EASY APPLICATION

The AD2021 measures input voltage over a full scale range of ±1.999V dc or ±199.9mV dc ("S" option) with an accuracy of ±0.05% reading ±0.025% full scale ±1 digit. Using the "limited differential" input first used on Analog Devices' AD2010, the AD2021 prevents ground loop problems and provides 35 to 50dB of common mode rejection at common mode voltages up to ±200mV. Normal mode rejection is 40dB at 50Hz to 60Hz.

BCD data outputs are provided in a bit parallel, character serial format compatible to CMOS logic systems. For those applications requiring parallel BCD data, schemes for making the serial to parallel conversion are available. Controls to hold readings, select decimal points and blank the display are provided.

## DESIGNED AND BUILT FOR RELIABILITY

The AD2021 is packaged in Analog Devices' logic powered DPM case size, only 1.25 inches (32mm) deep. The small size of this DPM makes it easy to accommodate in any instrument design, and since several other manufacturers now use the same panel cutout for logic powered DPMs, this industry standardization allows mechanical second sourcing. In addition, the AD2021 uses the same pin connections as the AD2010 (except in BCD outputs, of course) as a convenience to allow updating designs to take advantage of the second generation design and larger display of the AD2021. Each AD2021 receives a full one week failure free burn-in before shipment.

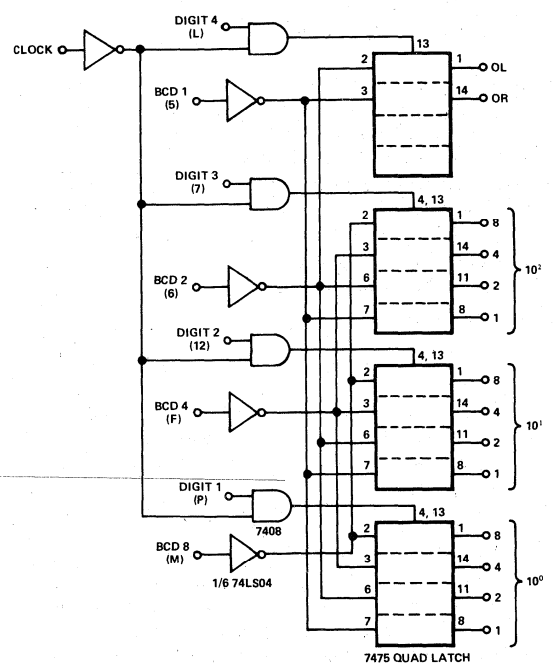



*Figure 1. AD2021 Bit Parallel Character Serial to Full Parallel Data Conversion. AD2021 Pin Connections are Shown in Parentheses.*

**For detailed information, contact factory.**

# SPECIFICATIONS (typical at +25°C and nominal power supply voltage)

DISPLAY OUTPUT
- Light emitting diode, planar seven segment display readouts, 0.5″ (13mm) high for three data digits, 100% overrange and negative polarity indication. Overload indicated by flashing display, polarity remains valid.
- Decimal points selectable at input connector.
- Display blanking on three data digits (does not affect overrange digit, polarity sign of decimal points).

ANALOG INPUT
- Configuration: bipolar, limited differential
- Full Scale Range: ±1.999V or ±199.9mV ("S" option) ±19.99V ("V" option)
- Automatic Polarity
- Auto Zero
- Input Impedance: 100MΩ (1MΩ – "V" option)
- Bias Current: 50pA
- Overvoltage Protection: ±50V dc, sustained

ACCURACY
- ±0.05% reading ±0.025% full scale ±1 digit[1]
- Resolution: 1mV, 10mV ("V" option) or 100μV ("S" option)
- Temperature Range[2]: 0 to +50°C operating; -25°C to +85°C storage
- Temperature Coefficient: Gain: 50ppm/°C
  Zero: auto zero
- Warm-Up Time to Rated Accuracy: less than one minute
- Settling Time to Rated Accuracy: 0.4 second

NORMAL MODE REJECTION
- 40dB at 50–60Hz

COMMON MODE REJECTION
- AD2021: 35dB (dc -10kHz)
- AD2021/S: 50dB (dc -10kHz)
- AD2021/V: 15dB (dc -10kHz)

COMMON MODE VOLTAGE
- ±200mV

CONVERSION RATE
- 5 conversions per second
- Hold and read on command

CONTROL INPUTS
- Display Blanking: (TTL, DTL compatible, 2 TTL loads). Logic "0" or grounding blanks the three data digits only, not the decimal points, overrange digit (if on) and polarity sign. Logic "1" or open circuit for normal operation. Display blanking has no effect on output data and the display reading is valid immediately upon removal of a blanking signal.
- Hold: (CMOS, DTL, TTL compatible, 1LP TTL load). Logic "0" or grounding causes the DPM to cease conversions and display the data from the last conversion. Logic "1" or open circuit for normal operation. After the "Hold" input is removed, one to two conversions are needed before the reading is valid.
- Decimal Points: Grounding or Logic "0" will illuminate the desired decimal point. External drive circuitry must sink 35mA peak at a 25% duty cycle when the decimal points are illuminated.

DATA OUTPUTS (See Application Section for details on data outputs)
- BCD Data Outputs: (CMOS, LP TTL or LP Schottky compatible), bit parallel, character serial format.
- Digit Strobe Outputs: (CMOS, DTL, TTL compatible, one TTL load). Logic "1" on any of these lines indicates the output data is valid for that digit.
- Polarity Output: (CMOS, TTL, DTL compatible, one TTL load). Logic "1" indicates positive polarity input, logic "0" indicates negative polarity.
- Status: (CMOS or LP TTL compatible). When this signal is at Logic "1", the output data is valid.
- Clock: (CMOS, DTL, TTL compatible, one TTL load). The clock signal is brought out to facilitate conversion from character serial to parallel data.
- INTERFACING DATA OUTPUTS. The BCD data outputs are in a bit parallel, character serial format. There are four BCD bit outputs (1, 2, 4, 8) and four digit outputs ($10^0$, $10^1$, $10^2$, $10^3$). The BCD digits are gated onto the output lines sequentially, and the BCD bits are valid for the digit whose digit line is high. The data is valid except when being updated which occurs within 2 milliseconds after the status line goes low.

REFERENCE OUTPUT
- A 6.4V ±5% analog reference output is made available. This reference should be buffered and filtered if use in external circuitry is desired.

POWER INPUT
- +5V dc ±5%, 1.45 watts

CALIBRATION ADJUSTMENTS (See Application Section for calibration instructions)
- Gain
- Zero
- Recommended recalibration interval: six months

SIZE
- 3″W x 1.8″H x 1.33″D (76 x 46 x 34mm)
- 1.90″ (48mm) overall depth to rear of card edge connector.
- Panel cutout required: 3.175″ x 1.810″ (80.65 x 45.97mm).

WEIGHT
- 4 ounces, (115 grams)

OPTIONS – ORDERING GUIDE
- Input Voltage Range: AD2021 – 1.999V dc Full Scale
  AD2021/S – 199.9mV dc Full Scale
  AD2021/V – 19.99V dc Full Scale
- Display Lens Option[3]: Lens 5 – Red with ADI logo
  Lens 6 – Red without ADI logo

CONNECTOR
- 30 pin, 0.156″ spacing card edge connector. Viking 2VK15D/1-2 or equivalent.
- Optional: Order AC1501

NOTES
[1] Guaranteed at 25°C and nominal supply voltage
[2] Guaranteed
[3] If no lens is specified, Lens 5 will be supplied.

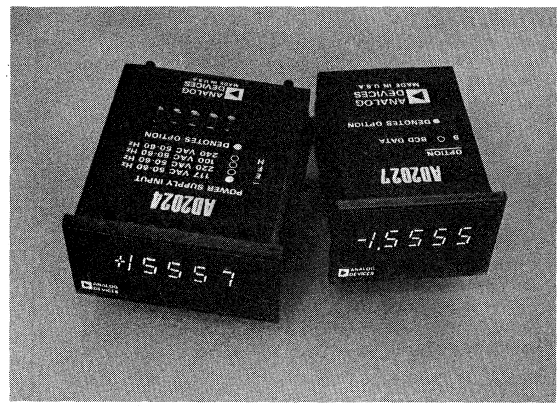
**Specifications subject to change without notice.**

# Low Cost 4½ Digit DPMs With LED Displays

# AD2024/AD2027

**FEATURES**
**"Second Generation" MOS-LSI Design**
**Large 0.43" (11mm) LED Displays**
**4½ Digit Resolution – 20,000 Counts Full Scale**
**Limited Differential Input**
**Either Line Powered (AD2024) or Logic Powered (AD2027)**
**Industry Standard Case Designs**

**APPLICATIONS**
**High Resolution/High Accuracy Readout for:**
- **Test Equipment**
- **Process Control Instrumentation**
- **Analytical and Scientific Instruments**




## GENERAL DESCRIPTION

The AD2024 and AD2027 are low cost 4½ digit DPMs with large LED displays. Both units offer the same features and identical performance, but the AD2024 is ac line powered and the AD2027 is +5V dc powered.

## THE BENEFITS OF SECOND GENERATION DESIGN

The AD2024 and AD2027 are designed around MOS-LSI (Metal Oxide Semiconductor, Large Scale Integration) integrated circuits which greatly reduce the number of components and interconnections required to provide the performance and features expected in a high resolution 4½ digit DPM.

This "Second Generation" design, therefore, offers greatly increased reliability and significantly lower cost at little compromise in performance. The large 0.43 inch (11mm) LED displays offer the brightness and readability previously available only with gas discharge displays with the added advantage of an all solid state component.

## HIGH RESOLUTION AND VERSATILE FEATURES

These DPMs measure dc input voltages over a full scale range of ±1.9999V with an accuracy of ±0.005% reading ±0.005% of full scale ± 1 digit. Using the "limited differential" input first used by Analog Devices on the AD2010, the AD2024 and AD2027 prevent ground loop problems and provide 50dB of common mode rejection at common mode voltages up to ±200mV. Normal mode rejection is 25dB at 50–60Hz.

BCD data outputs are provided in a bit parallel, character serial format compatible with CMOS logic systems. When applications require parallel BCD data, such as interfaces to printers, comparators or slave displays, parallel BCD output options are available that are compatible to standard TTL logic systems.

External power supply outputs at +5V and -25V (-25V only on the AD2027) are made available for powering external circuitry. In addition, control inputs for conversion "Hold", display blanking and decimal point selection are provided.

## INDUSTRY STANDARD CASE DESIGNS

Although both the AD2024 and AD2027 have identical electrical designs, they are packaged in the case sizes that have become industry standards for ac line powered and +5V dc logic powered DPMs respectively. The AD2024 fits the 3.924" x 1.682" (99.67 x 42.74mm) panel cutout common to most ac line powered DPMs, and the AD2027 fits the 3.175" x 1.810" (80.65 x 45.97mm) panel cutout of the Analog Devices logic power case design, now used by several other manufacturers of logic powered DPMs. Thus, interchangeability is assured, allowing mechanical second sourcing for both these DPMs.

## DESIGNED AND BUILT FOR RELIABILITY

Even beyond the reliability advantages of the LSI-IC design and LED displays, the AD2024 and AD2027 have had extreme care taken in their design and manufacture to insure reliability. Manufacturing processes are monitored by continual quality assurance inspections to insure proper workmanship and testing. Automatic test equipment is used to test each DPM thoroughly and without error. And each AD2024 and AD2027, like every Analog Devices DPM, receives a full one week failure-free burn-in before shipment.



**For detailed information, contact factory.**

# SPECIFICATIONS

DISPLAY OUTPUTS
- Seven Segment LED Display, 0.43″ (11mm) high, for four data digits, 100% overrange and polarity indication.
- Overload indication by blanking all digits, polarity sign remains valid.
- Decimal points (4) selectable at input.
- Display Blanking

ANALOG INPUT
- Configuration: Bipolar, limited differential
- Full Scale Range: ±1.9999V (±19.999V, "V" Option)
- Automatic Polarity
- Input Impedance: 100MΩ (1MΩ, "V" Option)
- Bias Current: 30nA (3nA, "V" Option)
- Overvoltage Protection: 120V rms sustained

ACCURACY
- ±0.005% reading ±0.005% full scale ±1 digit [1]
- Resolution: 100μV
- Temperature Range[2]: 0 to +50°C operating. -20 to +85°C storage. (AD2024/B: 0 to +45°C operating)
- Temperature Coefficient: Gain: ±30ppm/°C. Zero Offset: ±10μV/°C (±40ppm/°C & ±100μV/°C, "V" Option)
- Warmup Time: One minute to rated accuracy
- Settling Time to Rated Accuracy: 450ms

NORMAL MODE REJECTION
- 25dB at 50–60Hz

COMMON MODE REJECTION
- 50dB, dc to 1kHz, ±200mV common mode voltage
- AD2024 (floated on power supply transformer if data outputs and control signals are not used) – 110dB at 120V rms common mode voltage, 1kΩ imbalance at input.

CONVERSION TIME
- 180ms for full scale reading
- 210ms for overload conversion

CONVERSION RATE
- 5 conversions per second

DIGITAL INTERFACE SIGNALS
- Inputs

  Display Blank – (DTL/TTL Compatible, 4 TTL Loads). Logic "0" or grounding blanks display, including polarity sign, but not decimal points. The display is valid immediately upon removal of the blanking signal.

  Hold – (DTL/TTL Compatible, 2 TTL Loads). Logic "0" or grounding causes the DPM to hold and display the last conversion. Upon removal of the hold, the DPM resumes conversions.

  Decimal Points – (Not TTL Compatible). Logic "0" or grounding turns on appropriate decimal point. External circuitry must sink 60mA when a decimal point is illuminated.
- Outputs

  DTL/TTL Compatible[3] – Status. Logic "1" indicates conversion in process. All digital outputs are valid when status is at logic "0". 5 TTL loads. – Polarity. Logic "1" indicates positive polarity, latched. 5 TTL loads.

  CMOS and LP Schottky Compatible – Overload, Logic "1" indicates overload (≥ 20,000), latched. – BCD outputs. 4½ BCD digits, character serial, bit parallel, 1 LP Schottky Load.

  Digital Strobe Outputs – (CMOS or LP Schottky Compatible) Logic "1" on any of these line indicates the output data is valid for that digit, 1 LP Schottky Load.

  Parallel BCD Output (Option "B"). – 4½ BCD digits, positive true, latched. Drives 5 TTL loads. – Data Ready. Logic "1" indicates output data is valid. Drives 2 TTL loads.

EXTERNAL POWER SUPPLY OUTPUTS
- AD2024: +5V at 25mA, -25V at 5mA
- AD2027: -25V at 5mA

POWER SUPPLY INPUTS
- AD2024: ac line, 50-60Hz, 4.2W
- AD2027: +5V dc, ±5% at 850mA

CALIBRATION ADJUSTMENTS
- Gain
- Zero
- Recommended recalibration interval: 6 months

SIZE
- AD2024: 3.92″W x 1.67″H x 4.48″D (100 x 42 x 114mm)
  Panel cutout: 3.930″ x 1.682″ (99.8 x 42.7mm)
- AD2027: 3″W x 1.8″H x 4″D (76 x 46 x 102mm)
  Panel cutout: 3.175″ x 1.810″ (80.65 x 45.97mm)

WEIGHT
- AD2024: 14 ounces (395 grams)
- AD2027: 10 ounces (280 grams)

OPTIONS – ORDERING GUIDE
- AD2024

  AC Power Inputs

  AD2024 – 117V ac
  AD2024/E – 220V ac
  AD2024/F – 100V ac
  AD2024/H – 240V ac
  } ±10%

  Input Range Options
  AD2024 – ±1.9999V Full Scale
  AD2024/V – ±19.999V Full Scale

  Data Output Options (available with any power input options)
  AD2024 – Character serial data outputs
  AD2024/B – Parallel BCD option

  Display Lens Options[4]
  Lens 7 – Red with ADI logo
  Lens 8 – Red without ADI logo

  Connector – 36 pin, 0.156″ spacing, card edge connector, Viking 2VK18D/1-2 or equivalent. – Optional: Order AC2610.

  AD2024/B option also requires a 30 pin, 0.156″ spacing, card edge connector, Viking 2VK15D/1-2 or equivalent. – Optional: Order AC1501.
- AD2027

  Input Range Options
  AD2027 – ±1.9999V Full Scale
  AD2027/V – ±19.999V Full Scale

  Data Output Options
  AD2027 – Character serial data outputs
  AD2027/B – Parallel BCD option

  Display Lens Options[4]
  Lens 5 – Red with ADI logo
  Lens 6 – Red without ADI logo

  Connector – AC1501 (see above) or equivalent. AD2027/B option requires two each.

NOTES
[1] Guaranteed at +25°C and nominal power supply voltage.
[2] Guaranteed.
[3] For CMOS compatibility, 3.3k pullup resistors to the +5V output of the DPM are required.
[4] If no lens is specified, Lens 5 or 7 is supplied as appropriate.
Specifications subject to change without notice.

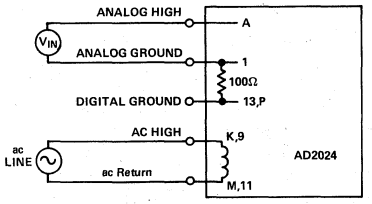



*Figure 1. AD2024 Wiring Interconnections*

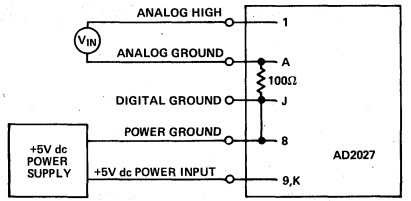


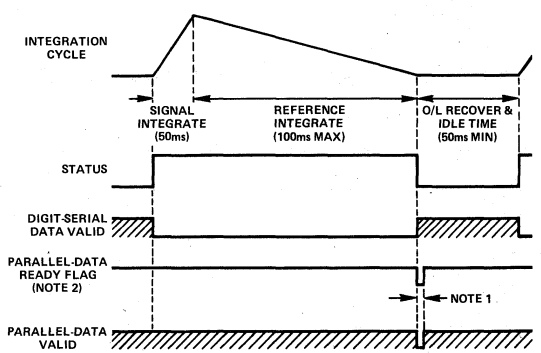

*Figure 2. AD2027 Wiring Interconnections*

## Interfacing Data Outputs

The standard data outputs are in a bit parallel character serial format compatible to CMOS and LP Schottky logic systems. The BCD outputs are multiplexed, and a digit output is provided for each of the five digits of output. Thus, the four BCD lines on the output at a given time are valid for the digit whose digit line is currently high. The bit parallel character serial data is valid when the DPM status line is low for a period of 50ms between each conversion cycle. The overload line is latched output which is at logic "1", whenever the input exceeds the full 20,000 count range.

Optional parallel BCD outputs ("B" option) are available on a separate card which is internally connected to the DPM. The output data then is presented in a full parallel format and is latched. The parallel data is valid whenever the data ready output is high.

Pin connections for the "B" option are shown in the interconnection tables and a full timing diagram is shown in Figure 3.




NOTE 1. APPROX. 5ms REQUIRED TO LOAD PARALLEL-OUT REGISTERS.
NOTE 2. B OPTION.

*Figure 3. AD2024/AD2027 Timing Diagram*

| PIN | FUNCTION | PIN | FUNCTION |
|---|---|---|---|
| 1 | Analog Ground | A | Analog High |
| 2 | $10^1$ Digit | B | $10^0$ Digit (LSD) |
| = KEY | | = KEY | |
| 3 | BCD 2 | C | $10^2$ Digit |
| 4 | $10^3$ Digit | D | BCD 4 |
| 5 | BCD 8 | E | BCD 1 |
| 6 | Mux Step 1 | F | $10^4$ Digit (MSD) |
| 7 | +5V dc (Out) | H | -25V dc (Out) |
| 8 | NC | J | NC |
| 9 | ac High | K | ac High |
| 10 | NC | L | NC |
| 11 | ac RETURN | M | ac Return |
| 12 | NC | N | NC |
| 13 | Digital Ground | P | Digital Ground |
| 14 | NC | R | Status |
| 15 | Polarity | S | Hold |
| 16 | Display Blank | T | DP1.XXXX |
| 17 | DP1XXX.X | U | DP1X.XXX |
| 18 | Overload | V | DP1XX.XX |

*AD2024 – Signal and Pin Connections*

| PIN | FUNCTION | PIN | FUNCTION |
|---|---|---|---|
| 1 | Analog High | A | Analog Ground |
| 2 | $10^0$ Digit (LSD) | B | Mux Step 1 |
| 3 | BCD 8 | C | BCD 1 |
| 4 | BCD 2 | D | BCD 4 |
| 5 | $10^4$ Digit (MSD) | E | $10^1$ Digit |
| 6 | $10^3$ Digit | F | $10^2$ Digit |
| 7 | NC | H | -25VDC (Out) |
| 8 | Power Ground | J | Digital Ground |
| 9 | +5V (In) | K | +5V (In) |
| 10 | NC | L | NC |
| = KEY | | = KEY | |
| 11 | Display Blank | M | NC |
| 12 | Hold | N | Polarity |
| 13 | Overload | P | Status |
| 14 | DP1.XXXX | R | DP1X.XXX |
| 15 | DP1XX.XX | S | DP1XXX.X |

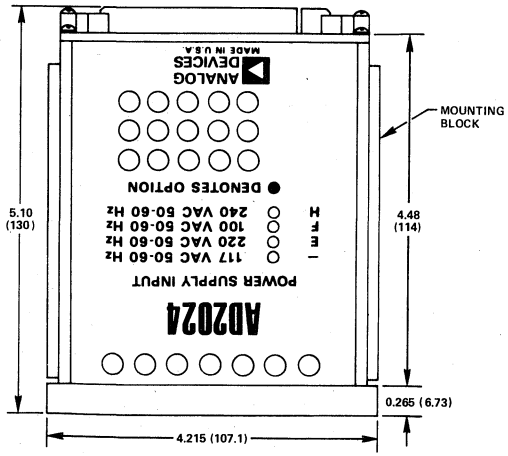
NOTE 1: BCD multiplexer clock pulse available for remote placement of BCD option.

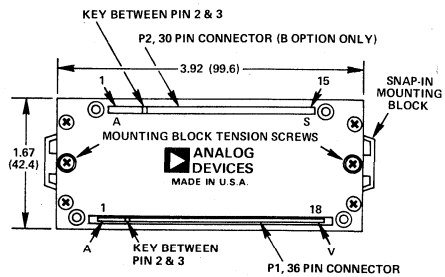
*AD2027 – Signal and Pin Connections*

| PIN | FUNCTION | PIN | FUNCTION |
|---|---|---|---|
| 1 | +5V dc (In) | A | NC (Do Not Use) |
| 2 | BCD 1 (In) | B | BCD 8 (In) |
| = KEY | | = KEY | |
| 3 | BCD 4 (In) | C | BCD 2 (In) |
| 4 | BCD 2000 | D | BCD 4 |
| 5 | BCD 40 | E | BCD 80 |
| 6 | BCD 800 | F | BCD 8000 |
| 7 | BCD 100 | H | BCD 1000 |
| 8 | BCD 10,000 | J | BCD 200 |
| 9 | BCD 20 | K | BCD 2 |
| 10 | BCD 8 | L | BCD 10 |
| 11 | BCD 1 | M | BCD 4000 |
| 12 | BCD 400 | N | $10^4$ Digit (In) |
| 13 | Data Ready | P | Status (In) |
| 14 | Polarity (In) | R | Mux Step (In) |
| 15 | Polarity (Out) | S | Digital Ground |

NOTES: 1) Overload output is on main DPM connector.
2) Pins marked "In" are made available for remote placement of BCD option card and are not normally used since all connections are interval.

*AD2024/AD2027 BCD Options – Signal and Pin Connections*




**PANEL CUTOUT: 3.930 X 1.682 (99.82 X 42.72)**

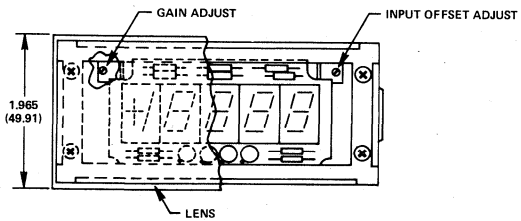
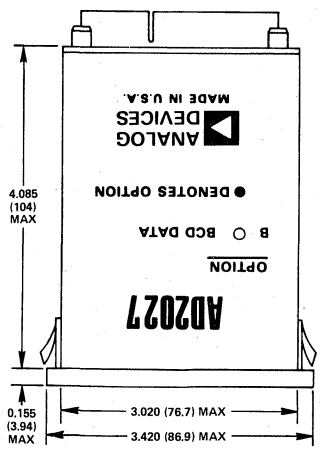
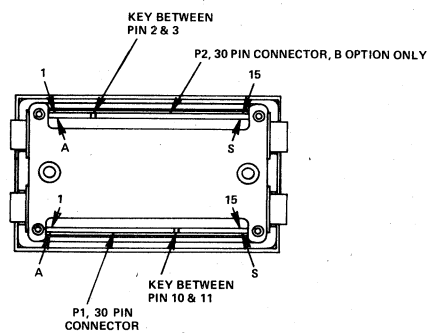
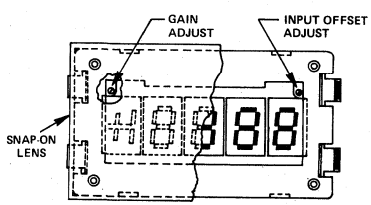



*Figure 4. AD2024 Mechanical Outline (Dimensions shown in inches and (mm))*




**PANEL CUTOUT: 3.175 X 1.180 (80.65 X 45.97)**



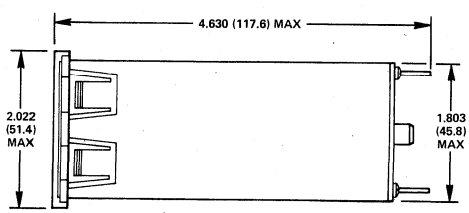




*Figure 5. AD2027 Mechanical Outline (Dimensions shown in inches and (mm))*

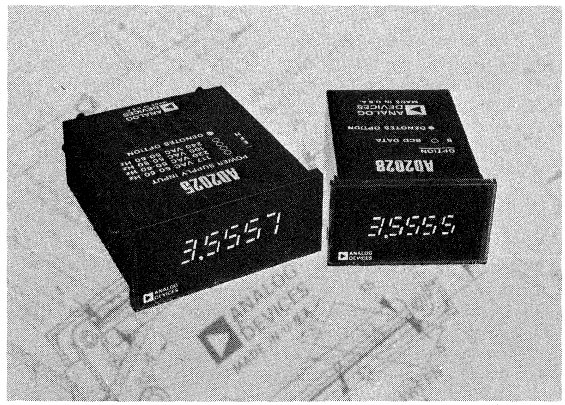
# Low Cost 4¾ Digit DPMs With LED Displays

# AD2025/AD2028

**FEATURES**
- "Second Generation" MOS-LSI Design
- Large 0.43" (11mm) LED Displays
- 4¾ Digit Resolution – 40,000 Counts Full Scale
- Limited Differential Input
- Either Line Powered (AD2025) or Logic Powered (AD2028)
- Interchangeable with 4½ Digit DPMs (AD2024 or AD2027)
- Industry Standard Case Designs

**APPLICATIONS**

High Resolution/High Accuracy Readout for:
- Test Equipment
- Process Control Instrumentation
- Analytical and Scientific Instruments




## GENERAL DESCRIPTION

The AD2025 and AD2028 are low cost 4¾ digit DPMs with large LED displays. Both units offer the same features and identical performance, but the AD2025 is ac line powered and the AD2028 is +5V dc powered.

The AD2025 and AD2028 are interchangeable with two 4½ digit DPMs available from Analog Devices, the AD2024 and AD2027 respectively. Thus, they can be used in applications where either a 4¾ or 4½ digit display may be desirable in one basic application.

## THE BENEFITS OF SECOND GENERATION DESIGN

The AD2025 and AD2028 are designed around MOS-LSI (Metal Oxide Semiconductor, Large Scale Integration) integrated circuits which greatly reduce the number of components and interconnections required to provide the performance and features expected in a high resolution 4¾ digit DPM.

This "Second Generation" design, therefore, offers greatly increased reliability and significantly lower cost at little compromise in performance. The large 0.43 inch (11mm) LED displays offer the brightness and readability previously available only with gas discharge displays with the added advantage of an all solid state component.

## HIGH RESOLUTION AND VERSATILE FEATURES

These DPMs measure DC input voltages over a full scale range of ±3.9999V or ±39.999V with an accuracy of ±0.005% reading ±0.005% of full scale ±1 digit. Using the "limited differential" input first used by Analog Devices on the AD2010, the AD2025 and AD2028 prevent ground loop problems and provide 50dB of common mode rejection at common mode voltages up to ±200mV. Normal mode rejection is 25dB at 50–60Hz.

BCD data outputs are provided in a bit parallel, character serial format compatible with CMOS logic systems. When applications require parallel BCD data, such as interfaces to printers, comparators or slave displays, parallel BCD output options are available that are compatible to standard TTL logic systems.

External power supply outputs at +5V and -25V (-25V only on the AD2028) are made available for powering external circuitry. In addition, control inputs for conversion "Hold", display blanking and decimal point selection are provided.

## INDUSTRY STANDARD CASE DESIGNS

Although both the AD2025 and AD2028 have identical electrical designs, they are packaged in the case sizes that have become industry standards for ac line powered and +5V dc logic powered DPMs respectively. The AD2025 fits the 3.924" x 1.682" (99.67 x 42.74mm) panel cutout common to most ac line powered DPMs, and the AD2028 fits the 3.175" x 1.810" (80.65 x 45.97mm) panel cutout of the Analog Devices logic power case design, now used by several other manufacturers of logic powered DPMs. Thus, interchangeability is assured, allowing mechanical second sourcing for both these DPMs.

## DESIGNED AND BUILT FOR RELIABILITY

Even beyond the reliability advantages of the LSI-IC design and LED displays, the AD2025 and AD2028 have had extreme care taken in their design and manufacture to insure reliability. Manufacturing processes are monitored by continual quality assurance inspections to insure proper workmanship and testing. Automatic test equipment is used to test each DPM thoroughly and without error. And each AD2025 and AD2028, like every Analog Devices DPM, receives a full one week failure-free burn-in with power cycling before shipment.



**For detailed information, contact factory.**

# SPECIFICATIONS (typical at +25°C and nominal power supply voltage)

DISPLAY OUTPUTS
- Seven Segment LED Display, 0.43″ (11mm) high, for four data digits and 300% overrange.
- Overload indication by blanking all digits except overrange, which indicates "0".
- Decimal points (5) selectable at input.
- Display Blanking

ANALOG INPUT
- Configuration: Bipolar, limited differential
- Full Scale Range: ±3.9999V (±39.999V, "V" option)
- Automatic Polarity (See applications section for details on polarity display)
- Input Impedance: 100MΩ (1MΩ, "V" option)
- Bias Current: 30nA (3nA, "V" option)
- Overvoltage Protection: 120V rms sustained

ACCURACY
- ±0.005% reading ±0.005% full scale ±1 digit[1]
- Resolution: 100μV (1mV, "V" option)
- Temperature Range[2]: 0 to +50°C operating. -20 to +85°C storage. (AD2025/B: 0 to +45°C operating)
- Temperature Coefficient: Gain: ±30ppm/°C. Zero Offset: ±10μV/°C (±40ppm/°C and ±100μV/°C, "V" option)
- Warmup Time: One minute to rated accuracy
- Settling Time to Rated Accuracy: 450ms

NORMAL MODE REJECTION
- 25dB at 50–60Hz

COMMON MODE REJECTION
- 50dB, DC to 1kHz, ±200mV common mode voltage
- AD2025 (floated on power supply transformer if data outputs and control signals are not used) – 110dB at 120V rms common mode voltage, 1kΩ imbalance at input.

CONVERSION TIME
- 300ms for full scale reading
- 400ms for overload conversion

CONVERSION RATE
- 3 conversions per second

DIGITAL INTERFACE SIGNALS
- Inputs

  Display Blank – (open collector TTL Compatible, 4 TTL Loads). Logic "0" or grounding blanks display, but not decimal points. The display is valid immediately upon removal of the blanking signal.

  Hold – (DTL/TTL Compatible, 2 TTL Loads). Logic "0" or grounding causes the DPM to hold and display the last conversion. Upon removal of the hold, the DPM resumes conversions.

  Decimal Points – (Not TTL Compatible). Logic "0" or grounding turns on appropriate decimal point. External circuitry must sink 35mA when a decimal point is illuminated.
- Outputs

  DTL/TTL Compatible[3] – Status. Logic "1" indicates conversion in process. All digital outputs are valid when status is at logic "0". 4 TTL loads. – Polarity. Logic "1" indicates positive polarity, unlatched. 6 TTL loads. – Overload, Logic "1" indicates overload (≥40,000), unlatched 4 TTL Loads.

  CMOS and LP Schottky Compatible – BCD outputs, 4¾ BCD digits, character serial, bit parallel, 1 LP Schottky load.

  Parallel BCD Output (Option"B"). – 4¾ BCD digits, positive true, latched. Drives 5 TTL loads. – Data Ready. Logic "1" indicates output data is valid. Drives 2 TTL loads. – Polarity. Logic "1" indicates positive polarity, latched, Drives 2 TTL loads.

  Digit Strobe Outputs – (CMOS or LP Schottky Compatible) Logic "1" on any of these lines indicates the output data is valid for that digit, 1 LP Schottky load.

EXTERNAL POWER SUPPLY OUTPUTS
- AD2025: +5V at 25mA, -25V at 5mA
- AD2028: -25V at 5mA

POWER SUPPLY INPUTS
- AD2025: ac line, 50–60Hz, 4W
- AD2028: 5V dc, ±5% at 800mA

CALIBRATION ADJUSTMENTS
- Gain
- Zero
- Recommended recalibration interval: 6 months

SIZE
- AD2025: 3.92″W x 1.67″H x 4.48″D (100 x 42 x 114mm)
  Panel cutout: 3.930″ x 1.682″ (99.8 x 42.7mm)
- AD2028: 3″W x 1.8″H x 4″D (76 x 46 x 102mm)
  Panel cutout: 3.175″ x 1.810″ (80.65 x 45.97mm)

WEIGHT
- AD2025: 14 ounces (395 grams)
- AD2028: 10 ounces (280 grams)

OPTIONS – ORDERING GUIDE[4]
- AD2025

  AC Power Inputs – No cost option

  AD2025 – 117V ac
  AD2025/E – 220V ac
  AD2025/F – 100V ac
  AD2025/H – 240V ac
  } ±10%

  Input Range Options – No cost option
  AD2025 – ±3.9999V Full Scale
  AD2025/V – ±39.999V Full Scale

  Data Output Options – See pricing guide
  AD2025 – Character serial data outputs
  AD2025/B – Parallel BCD option

  Display Lens Options[5]
  Lens 7 – Red with ADI logo
  Lens 8 – Red without ADI logo

  Connector – 36 pin, 0.156″ spacing, card edge connector, Viking 2VK18D/1-2 or equivalent. – Optional: Order AC2610.

  AD2025/B option also requires a 30 pin, 0.156″ spacing, card edge connector, Viking 2VK15D/1-2 or equivalent. – Optional: Order AC1501.
- AD2028

  Input Range Options – No cost option
  AD2028 – ±3.9999V Full Scale
  AD2028/V – ±39.999V Full Scale

  Data Output Options – See pricing guide
  AD2028 – Character serial data outputs
  AD2028/B – Parallel BCD option

  Display Lens Options[5]
  Lens 5 – Red with ADI logo
  Lens 6 – Red without ADI logo

  Connector – AC1501 (see above) or equivalent. AD2028/B option requires two each.

NOTES
[1] Guaranteed at +25°C and nominal power supply voltage.
[2] Guaranteed.
[3] For CMOS compatibility, 3.3k pullup resistors to the +5V output of the DPM are required.
[4] Only one AC Power Input and/or Input Range option may be specified. The "B" option can be ordered with any combination of power and range options.
[5] If no lens is specified, Lens 5 or 7 is supplied as appropriate.

Specifications subject to change without notice.

## APPLYING THE AD2025 AND AD2028

### Wiring Connections

Figures 1 and 2 are wiring diagrams for AD2025 and AD2028 applications. The "limited differential" input uses a 100Ω resistor to isolate the analog input from the digital and power supply sections to prevent ground loop problems. The analog input must be connected between the "analog high" and "analog ground" inputs only, since in some applications there may be up to a ±200mV CMV difference between analog and digital grounds.

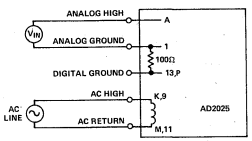



*Figure 1. AD2025 Wiring Interconnections*

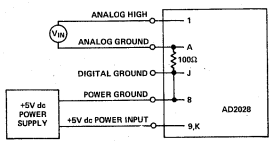



*Figure 2. AD2029 Wiring Interconnections*

### Polarity Indication

No direct polarity indication is provided on the AD2025 or AD2028 although both DPMs measure bipolar inputs. If indication of negative polarity is desired, the "polarity" output can be connected to the far left hand decimal point (DP .XXXXX) provided. When the polarity is negative, this decimal point will then be illuminated.

### Interfacing Data Outputs

The standard data outputs are in a bit parallel character serial format compatible to CMOS and LP Schottky logic systems. The BCD outputs are multiplexed, and a digit output is provided for each of the five digits of output. Thus, the four BCD lines on the output at a given time are valid for the digit whose digit line is currently high. The bit parallel character serial data is valid when the DPM status line is low for a period of 150ms between each conversion cycle. The overload line is latched output which is at logic "1", whenever the input exceeds the full 40,000 count range.

Optional parallel BCD outputs ("B" option) are available on a separate card which is internally connected to the DPM. The output data then is presented in a full parallel format and is latched. The parallel data is valid whenever the data ready output is high.

Pin connections for the "B" option are shown in the interconnection tables and a full timing diagram is shown in Figure 3.

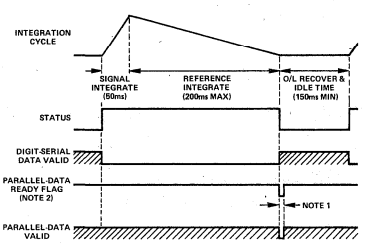



*Figure 3. AD2025/AD2028 Timing Diagram*

| PIN | FUNCTION | PIN | FUNCTION |
|---|---|---|---|
| 1 | Analog Ground | A | Analog High |
| 2 | $10^1$ Digit | B | $10^0$ Digit (LSD) |
| = KEY | | = KEY | |
| 3 | BCD 2 | C | $10^2$ Digit |
| 4 | $10^3$ Digit | D | BCD 4 |
| 5 | BCD 8 | E | BCD 1 |
| 6 | Mux Step[1] | F | $10^4$ Digit (MSD) |
| 7 | +5V dc (Out) | H | -25V dc (Out) |
| 8 | NC | J | NC |
| 9 | AC High | K | AC High |
| 10 | NC | L | NC |
| 11 | AC Return | M | AC Return |
| 12 | NC | N | NC |
| 13 | Digital Ground | P | Digital Ground |
| 14 | DP .XXXXX | R | Status |
| 15 | Polarity | S | Hold |
| 16 | Display Blank | T | DPX.XXXX |
| 17 | DPXXXX.X | U | DPXX.XXX |
| 18 | Overload | V | DPXXX.XX |

**NOTE 1: BCD multiplexer clock pulse available for remote placement of BCD option.**

*AD2025 – Signal and Pin Connections*

| PIN | FUNCTION | PIN | FUNCTION |
|---|---|---|---|
| 1 | Analog High | A | Analog Ground |
| 2 | $10^0$ Digit (LSD) | B | Mux Step[1] |
| 3 | BCD 8 | C | BCD 1 |
| 4 | BCD 2 | D | BCD 4 |
| 5 | $10^4$ Digit (MSD) | E | $10^1$ Digit |
| 6 | $10^3$ Digit | F | $10^2$ Digit |
| 7 | NC | H | -25V dc (Out) |
| 8 | Power Ground | J | Digital Ground |
| 9 | +5V (In) | K | +5V (In) |
| 10 | NC | L | NC |
| = KEY | | = KEY | |
| 11 | Display Blank | M | DP.XXXXX |
| 12 | Hold | N | Polarity |
| 13 | Overload | P | Status |
| 14 | DPX.XXXX | R | DPXX.XXX |
| 15 | DPXXX.XX | S | DPXXXX.X |

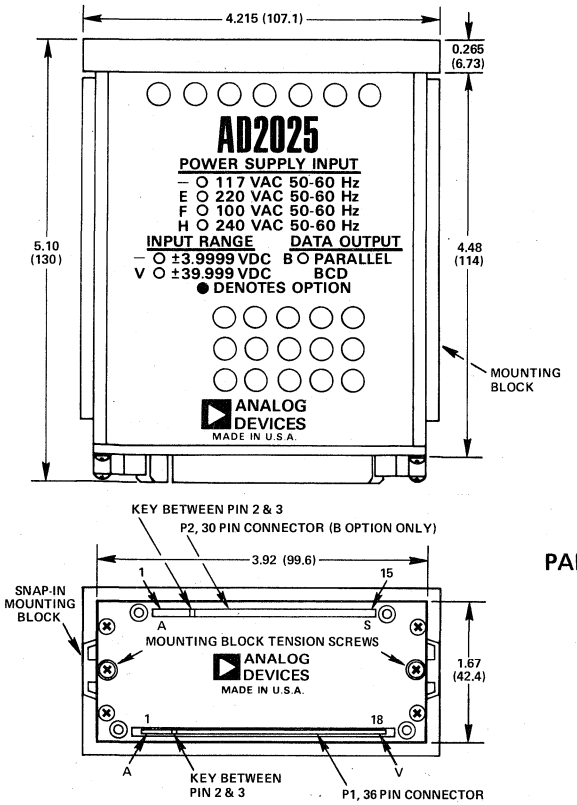
*AD2028 – Signal and Pin Connections*

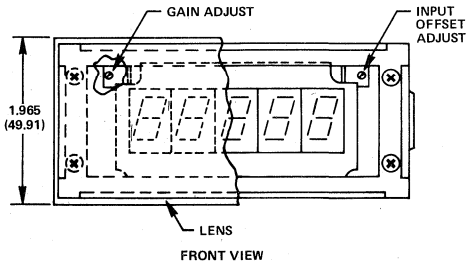
| PIN | FUNCTION | PIN | FUNCTION |
|---|---|---|---|
| 1 | +5V dc (in) | A | BCD 20,000 |
| 2 | BCD 1 (In) | B | BCD 8 (In) |
| = KEY | | = KEY | |
| 3 | BCD 4 (In) | C | BCD 2 (In) |
| 4 | BCD 2000 | D | BCD 4 |
| 5 | BCD 40 | E | BCD 80 |
| 6 | BCD 800 | F | BCD 8000 |
| 7 | BCD 100 | H | BCD 1000 |
| 8 | BCD 10,000 | J | BCD 200 |
| 9 | BCD 20 | K | BCD 2 |
| 10 | BCD 8 | L | BCD 10 |
| 11 | BCD 1 | M | BCD 4000 |
| 12 | BCD 400 | N | $10^4$ Digit (In) |
| 13 | Data Ready | P | Status (In) |
| 14 | Polarity (In) | R | Mux Step (In) |
| 15 | Polarity (Out) | S | Digital Ground |

NOTES: 1) Overload output is on main DPM connector.
2) Pins marked "In" are made available for remote placement of BCD option card and are not normally used since all connections are internal.

*AD2025/AD2028 BCD Options – Signal and Pin Connections*

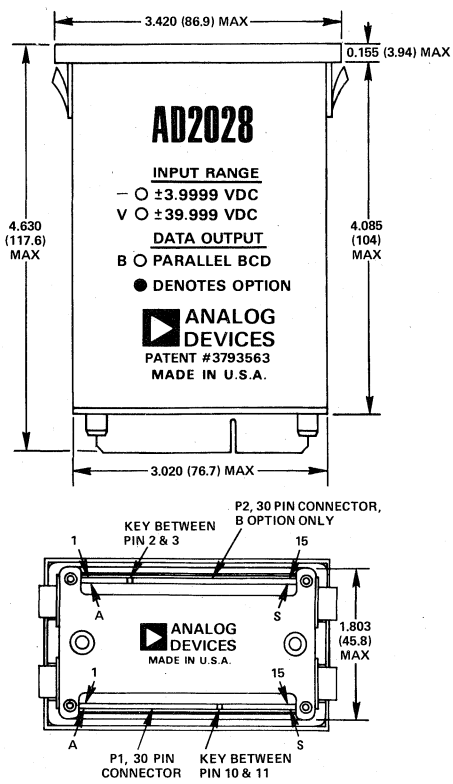
16

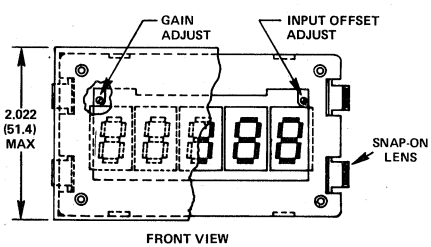



**PANEL CUTOUT: 3.930 X 1.682 (99.82 X 42.72)**

*Figure 4. AD2025 Mechanical Outline (Dimensions shown in inches and (mm))*



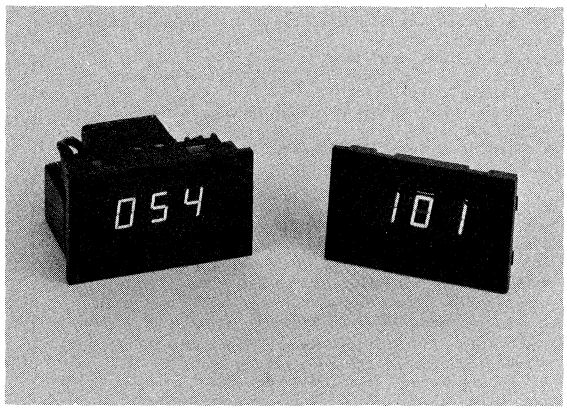

**PANEL CUTOUT: 3.175 X 1.810 (80.65 X 45.97)**

*Figure 5. AD2028 Mechanical Outline (Dimensions shown in inches and (mm))*

# Low Cost 3 Digit AC Line or Logic Powered DPM

# AD2026*

**FEATURES**
**Third Generation $I^2L$ LSI Design**
**Either Line Powered or Logic Powered**
**Large 0.56″ Red Orange LEDs**
**Balanced Differential Input/Floating 1000V, CMV**
**Terminal Block Interface (ac Version)**
**High Reliability: > 250,000 Hour MTBF**
**Small Size and Weight**
**Low Cost**




## GENERAL DESCRIPTION

The AD2026 is specifically designed to provide a digital alternative to analog panel meters. The AD2026 is available either logic powered (+5V dc) or ac line powered. Most of the analog and digital circuitry is implemented on a single $I^2L$ LSI chip, the AD2020. Only 13 additional components are required to complete the AD2026 +5V dc version. The entire dc version is mounted on a single 3″ X 1 5/8″ PCB. AC line power is achieved with the addition of a second PCB containing the ac power transformer and power supply circuitry.

The AD2026, on both the ac line and logic powered versions, offers as a standard feature, 0.56″ high LED Displays. Brightness is enhanced on both versions due to the Red Orange lens. In addition to the Red Orange lens, the AD2026 is also available with a dark red lens for applications where maximum brightness is not required and minimum backlighting is desired.

A unique patented case design utilizes molded-in fingers, both to capture the PCB in the case and to provide snap-in mounting of the DPM in a standard panel cutout. No mounting hardware of any kind is used. The dc version occupies less than 1″ of space behind the panel. The line powered version offers the same mounting features but occupies 2 1/2″ of behind-panel space.

## EXCELLENT PERFORMANCE

The AD2026 offers the instrument designer digital accuracy, resolution and use of readout while occupying less space than its analog counterpart. Other features of analog meters such as reliability and instantaneous response are retained in the AD2026.

The AD2026 measures and displays inputs from -99mV to +999mV, with an accuracy of 0.1% of reading ±1 digit. Zero shift is less than one bit over the full operating temperature range, resulting in the same performance as a DPM with auto zero. The balanced differential input of the dc powered AD2026 rejects common mode voltages up to 200mV, enough to eliminate most ground loop problems. The floating differential input inherent in the ac line powered version offers 1000V of common mode voltage rejection.

***Covered by patent numbers: 4,092,698; 29,992; 3,872,466; and 3,887,863.**

Optional 10.0V full scale (F.S.) range is available on the ac line version that will accept inputs from -0.99V to 9.99V.

## WIRING CONNECTIONS

For Balanced Differential operation with the AD2026 dc version, connect input as shown in Figure 1. The common mode loop must provide a return path for the bias currents internal to the AD2026. The resistance of this path must be less than 100kΩ and total common mode voltages must not exceed 200mV.

For applications where attenuation is required, scaling resistors can be connected between pins 6 and 7 and between pins F and H. Pin 5 must be used as the High Analog Input when scaling resistors are used and pin 4 when they are not. Pin E is the Analog Low Input.

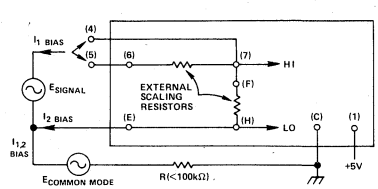



*Figure 1.*

Connection to the ac line powered AD2026 is via the terminal strip on the rear. AC line power is connected to terminals 4 and 5 and the signal input is connected to terminal 1 (Analog HI) and 2 (Analog Ground).

16

# SPECIFICATIONS (typical at +25°C and nominal supply voltage unless otherwise noted)

DISPLAY OUTPUT
- Light emitting diode, planar seven segment display readouts, 0.56″ (14.6mm) high (orange)
- Overload Indication: EEE
- Negative Indication: -XX
- Negative Overload Indication: ———
- Decimal Points: three (3) selectable at input connector (dc version); internally on ac version

ANALOG INPUT
- Configuration: balanced differential input (dc version) single ended isolated (ac version)
- Full Scale Range: -99mV to +999mV
  -0.99V to +9.99V (10V option on ac version)
- Automatic Polarity
- Input Impedance: 100MΩ; 100kΩ (10V option)
- Bias Current: 100nA
- Overvoltage Production: ±15V dc, sustained

ACCURACY
- ±0.1% ±1 digit[1]
- Resolution: 1mV or 10mV
- Temperature Range[2]: -10°C to +60°C operating; -25°C to +80°C storage
- Temperature Coefficient: Gain: 50ppm/°C
  Zero: 10μV/°C (essentially auto zero)
- Warm-Up Time to Rated Accuracy: Instantaneous
- Settling Time to Rated Accuracy: 0.3 second for full input voltage swing (dc version); 0.75 second for full input voltage swing (ac version)

COMMON MODE REJECTION (1kΩ source imbalance, dc to 1kHz)
- 50dB, ±200mV common mode voltage (dc version)
- 116dB (96dB on 10V range); 1000V rms max CMV (ac version)

NORMAL MODE REJECTION
- 30dB at 50-60Hz (ac version)

CONVERSION RATE
- 4 conversions per second
- Hold and read on command (dc version only)

CONTROL INPUTS

Display Blanking/Display Power Input, (dc version only): The display of the AD2026 can be blanked by removal of power to the display power input, with no effect on conversion circuitry. If external logic switching is used, the display requires 110mA peak (85mA average) when illuminated.

Hold (dc version only): When the Hold input is at Logic "0", grounded or open circuit, the AD2026 will convert at 4 conversions per second. If a voltage of 0.6V to 2.4V is applied to this input, the DPM will stop converting and hold the last reading. A 12kΩ resistor in series with this input to +5V will provide the proper voltage input. (Consult factory for "HOLD" on ac version.)

DECIMAL POINT
- To illuminate decimal points on dc version, ground appropriate pin (A, B or 3).
- To illuminate decimal points on ac version, remove shroud and bridge appropriate solder pad (A, B or 3).

POWER INPUT LOGIC POWER[3]
- Converter: +5V ±5%, 0.2 watts typ; 0.33 watts max
- Display: +5V ±40%, 0.45 watts typ; 0.75 watts max

POWER INPUT AC LINE POWER
- AC line, 50-60Hz, 1.5 watts

CALIBRATION ADJUSTMENTS
- Gain
- Zero
- Recommended recalibration interval: six months

SIZE[4]
- 3.43″W X 2.0″H X 0.85″D (87 X 52 X 22mm)
- 0.88″ (22mm) overall depth to rear of connector
- Panel cutout required: 3.175 ±0.015″ X 1.810 ±0.015″ (80.65 ±0.38 X 45.97 ±0.38mm)

WEIGHT
- 1.8 ounces (53 grams) (dc version)
- 7 ounces (198 grams) (ac version)

CONNECTIONS

A 10-pin T&B/Ansley 609-1000M with two feet of 10 conductor ribbon cable is available. Order AC2618 (dc version, only).

Conductor to pin A is color coded. Sequence of ribbon connections is A, 1, B, 2, C, 3, etc.

The AD2026 ac version is complete with terminal strip for easy interface.

ORDERING GUIDE

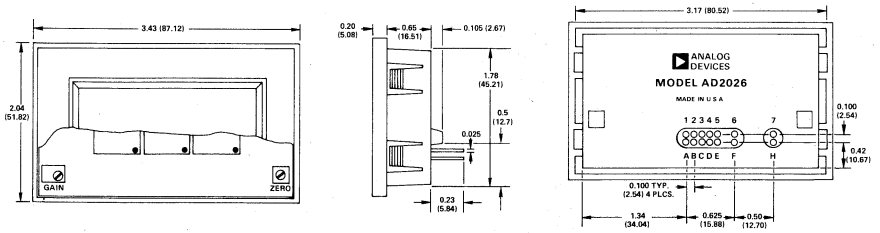
AD2026

| | | |
|---|---|---|
| Power Input | | |
| +5V dc | 1 | ENTER |
| 90-129V ac | 2 | |
| 198-264V ac | 3 | |
| Full Scale Input[5] | | |
| 1V dc Full Scale | 1 | ENTER |
| 10V dc Full Scale[6] | 2 | |
| Lens[5] | | |
| Red Lens | 1 | ENTER |
| Red Orange Lens | 2 | |

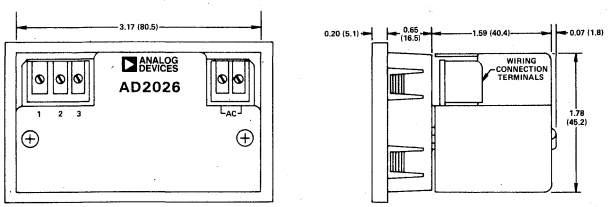
NOTES
[1] Guaranteed at +25°C and nominal supply voltage.
[2] Guaranteed.
[3] When the same power supply is used to power both display and converter, +5V, ±5%, 0.65 watts typical, 0.9 watts max is required.
[4] Dimensions for ac line powered version: 3.43″W X 2.0″H X 2.44″D (87mm X 52mm X 63mm)
[5] No Charge Options
[6] 10V dc full scale option is available on ac power only
Specifications subject to change without notice.

## OUTLINE DIMENSIONS

Dimensions shown in inches and (mm).




## AC VERSION




## PIN CONNECTIONS

### AC VERSION

| PIN | FUNCTION |
|---|---|
| 1 | Input |
| 2 | Analog Ground |
| 3 | NC |
| 4 | AC HI |
| 5 | AC LO |

### DC VERSION

| PIN | FUNCTION |
|---|---|
| 1 | +5V Power |
| 2 | +5V Display Power |
| 3 | Decimal Point X.XX |
| 4 | Input (When Scaling Resistors Not Used) |
| 5* | Input (When Scaling Resistors Are Used) |
| 6* | Series Arm of Scaling Resistor Divider |
| 7* | Series Arm of Scaling Resistor Divider |

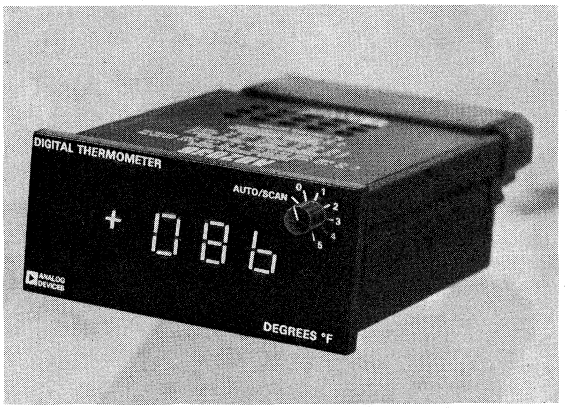
| PIN | FUNCTION |
|---|---|
| A | Decimal Point XX.X |
| B | Decimal Point XXX. |
| C | Power Ground |
| D | Hold |
| E | Analog Ground |
| F* | Shunt Arm of Scaling Resistor Divider |
| H* | Shunt Arm of Scaling Resistor Divider |

*NOT NORMALLY USED. ALLOWS CONVENIENT MOUNTING OF SCALING RESISTORS.

ANALOG DEVICES

# 6 Channel Scanning Digital Thermometer

# AD2036




## FEATURES

**Automatic/Manual Scan of 6 Thermocouples (TCs)**
**External Channel Selection by BCD Code**
**J, K, or T Thermocouple**
**°C or °F Readout**
**Self-Contained Linearization**
**Isolated Analog Input**
**Parallel BCD Output**
**1° Resolution, 0.1° Optional**
**AC Line or dc Powered**
**+5V dc at 10mA for External Logic**

## APPLICATIONS

**Multi-Point Temperature Measurements for Remote Data Acquisition and Data Logging**
**Temperature Monitoring in Design, Laboratory, Manufacturing and Quality Control**

## GENERAL DESCRIPTION

The AD2036 is a low cost 3½ digit, ac line or dc powered digital readout temperature meter. Inputs for six thermocouples of identical types, either J, K, or T and calibrated temperature ranges in °C or °F, make up a total of six available models.

Cycling on an internal clock, the AD2036 can continually scan 6 input channels. Individual channels can be manually selected via a small switch on the front. Channel selection can also be made via an external BCD input at the rear connector. A separate channel select output identifies the selected channel independent of selection mode. The channel select output together with the BCD Output provides complete information for automatic data collection. The Isolated Parallel BCD Output provides an easy interface to conventional recording and controlling instruments. For applications where there are high common mode voltages (CMV) present, the AD2036 has as a standard feature a floating opto isolated analog front end that will withstand CMV's up to 250V rms.

The AD2036 displays readings on large 0.5″ (13mm) high LED displays. Both (+) and (–) polarities are indicated. Controls are provided for blanking the display.

## AUTO/SCAN

The AD2036, while in the Auto/Scan mode, will permit unattended scanning of all six input channels. The rate of the channel select is 3.2 seconds, 1.6 seconds or 0.8 seconds. The AD2036 can be used as a stand-alone instrument and with the Scan input held high will continually scan six channels. When the Scan input is brought low the AD2036 will continue to cycle and stop at channel 0. When used with a printer the channel select number in addition to the converted BCD value can be recorded.

## MANUAL CHANNEL SELECTION

A switch on the front enables the user to manually select an individual thermocouple. As in the Auto/Scan mode, the BCD Output of the selected channel and the channel number are available. Selection of an individual TC channel automatically disables Scan and external channel selection is overridden. The Mode Output pin indicates when the switch is in this condition. On special order, meters can be supplied with card edge control for disabling the switch.

## EXTERNAL CHANNEL SELECTION

For remote control of channel selection the AD2036 provides an input for an external BCD code selection. This feature enables external BCD switch, automatic microprocessor or computer control.

## STANDARD PACKAGING

The AD2036 is packaged in Analog Devices' ac line powered DPM case which uses the same panel cutout as most other ac line powered DPM's from other manufacturers. In addition, the pin connections for the AD2036 converter board are the same as for the AD2022, AD2009, AD2016 and DPM's available from several other manufacturers.

16

**For detailed information, contact factory.**

# SPECIFICATIONS (typical @ +25°C and nominal line voltage unless otherwise specified)

TYPES OF THERMOCOUPLE (TCs): J, K, or T

ACCURACY[1]

| °C | | Error ±½LSB | °F | | Error ±½LSB |
|---|---|---|---|---|---|
| J | -60 to 0 | ±1.4 | J | -76 to 32 | ±2.5 |
| | 0 to 500 | ±1.4 | | 32 to 932 | ±2.5 |
| | 500 to 760 | ±2.2 | | 932 to 1400 | ±4.0 |
| K | -60 to 0 | ±1.4 | K | -76 to 32 | ±2.5 |
| | 0 to 150 | ±1.4 | | 32 to 302 | ±2.5 |
| | 150 to 1350 | ±2.6 | | 302 to 2000 | ±4.7 |
| T | -100 to 0 | ±1.3 | T | -148 to 32 | ±2.3 |
| | 0 to 250 | ±1.5 | | 32 to 450 | ±2.7 |
| | 250 to 400 | ±2.0 | | 450 to 752 | ±3.6 |

DISPLAY OUTPUT
- Light emitting diode (LED), seven segment display readouts, 0.5″ (13mm) high for 3 data digits, 100% overrange and polarity indication. Overload >1999 indicated by flashing display, polarity remains valid. There is no overload indication for out of range readings.
- Decimal points (3) selectable at input connector.
- Display Blanking

SIGNAL INPUT
- Input Impedance: 100MΩ
- Bias Current: 10nA
- Overvoltage Protection Between Channels: ±18V peak max
- Common Mode Voltage: ±350V peak max
- CMV Between Channels: ±6V peak max
- Temperature Coefficient: Span: +temp, 100ppm; -temp, 120ppm Zero: 0.03degrees/degree C or F
- Settling Time to Rated Accuracy: 2.0 seconds (full span step input)
- Normal Mode Rejection: 60dB at 50 – 400Hz
- Common Mode Rejection: 120dB @ 250V rms max CMV (Between TC's and digital gnd), $dv_{cm}/dt < 10^6$ V/sec, 250Ω imbalance

CONVERSION RATE
- 5 conversions per second
- Hold and read on command

CONTROL INPUTS

Display Blanking (TTL Compatible, 3 LSTTL Load) - Logic "0" or grounding blanks entire display except for decimal points; Logic "1" or open circuit for normal operation. Display blanking has no effect on output data. Display is valid immediately upon removal of blanking input.

$\overline{\text{Converter Hold}}$ (CMOS, TTL Compatible, 1 LSTTL Load) - Logic "0" or grounding causes DPM to cease conversions and display data from last conversion; Logic "1" or open circuit for normal operation. After "Converter Hold" is removed, one or two conversions are needed before reading and BCD are valid.

Decimal Points (Not TTL Compatible) - Logic "0" or grounding illuminates desired decimal point. External drive circuitry must sink 35mA peak at a 25% duty cycle, when decimal point is illuminated.

$\overline{\text{Data Hold}}$ (TTL Compatible, 1 TTL Load) - Logic "0" or grounding inhibits updating of latched parallel output data of AD2036. Logic "1" or open circuit allows data to be updated after each DPM conversion. This input has no effect on the normal conversion of the DPM and its display.

Scanner Enable (CMOS/TTL Compatible 1 LSTTL Load) - Logic "1" will enable Scanner to control the channel selection: External channel input BCD lines can remain connected. A Logic "0" enables external channel selection.

Scan ($\overline{\text{Scan}}$) (CMOS/TTL Compatible, 1 LSTTL Load) - A Logic "1" ("0") for <4 seconds will initiate a scan of six channels. To use $\overline{\text{Scan}}$ input, the Scan input must be a Logic "0". Both inputs have debounce circuitry. A momentary scan pulse while in the switch or external selection mode will initiate a sequence of six readings of the channel that is addressed then stop.

Channel BCD Input (CMOS/TTL Compatible 1 LSTTL Load) - Logic "0" on Scanner Enable will allow use of external control. All other control inputs remain the same.

Channel Increment (CMOS/TTL Compatible 1 LSTTL Load) - Positive going edge will initiate sequence to the next channel.

Spare Inverter Input (CMOS, TTL Compatible 1 LSTTL Load) - Spare inverter supplied for customer convenience.

DATA OUTPUTS

Isolated Parallel BCD Outputs - 3 BCD digits, Overrange, $\overline{\text{Overload}}$ and Data Ready Outputs (TTL Compatible, 4 TTL Loads). BCD data outputs are latched positive true logic. Overrange Output is Logic "1" for data display greater than 999. $\overline{\text{Overload}}$ Output is Logic "0" for inputs greater than full scale range, Logic "1" when other data outputs are valid. Polarity Output (TTL Compatible, 4 TTL Loads latched) indicates positive polarity when high (Logic "1"). Digital outputs are fully isolated from input circuitry; all logic levels are referenced to digital ground.

Channel BCD Outputs (CMOS/TTL Compatible 2 TTL Loads) - BCD Channel number data outputs are positive true.

Mode Output (CMOS/TTL Compatible 2 TTL Loads) - Logic "1" indicates channel selection is by switch. Logic "0" indicates selection is by scanner or external control, useful in microcomputer interface.

Data Ready ($\overline{\text{Data Ready}}$) (CMOS/TTL Compatible 2 TTL Loads) - Logic "1" ("0") indicates data from Temperature Card is ready. Data remains valid until next clock pulse (198ms).

Spare Inverter Output (CMOS/TTL Compatible 2 TTL Loads) - Spare inverter supplied for customer convenience.

Clock OUT (CMOS, TTL Compatible, 2 TTL Loads) - Indicates E.O.C. When Clock pulse is high latches are being updated, data is invalid. Data is valid on negative going edge. Clock OUT pulse is disabled when $\overline{\text{DATA HOLD}}$ line is low.

Analog Output - Nonlinear Error ±0.5% ±1mV
$V_{OUT}$, °C = (1.784mV/°C) Temperature
$V_{OUT}$, °F = (0.991mV/°F)(T-32)

TEMPERATURE RANGE[2]
- 0 to +50°C Operating
- -25°C to +85°C Storage

POWER OUTPUT
- +5V dc @ 10mA

POWER INPUT
- AC line 50 – 400Hz, See Voltage Options below
- Power Consumption - 5.8W @ 50 – 400Hz
- 12V dc +20% - 10%, 4.8W
- 5V dc ± 5%, 4W

CALIBRATION ADJUSTMENTS
- Span
- Zero
- Recommended Recalibration Interval: six months

SIZE
- 3.92″ x 1.67″H x 5.80″D (100 x 42 x 147mm)
- Panel cutout 3.930″ x 1.682″ (99.8 x 42.7mm)

WEIGHT
- 1.25 pounds (0.568 kg)

DISPLAY LENS[4]

Lens 22-1: Red, °C with ADI Logo
Lens 22-2: Red, °F with ADI Logo

Lens 23-1: Red, °C without ADI Logo
Lens 23-2: Red, °F without ADI Logo

CONNECTORS(2)

2 each, 30 pin, 0.156″ spacing card edge connector
Viking 2VK15D/1-2 or equivalent.
Optional: Order AC1501.

ORDERING GUIDE

AD2036 □ – □ □ □ □

THERMOCOUPLE TYPE[3]
- J
- K
- T

– ENTER

POWER INPUT[3]

| | |
|---|---|
| 117V ac ±10% | 1 |
| 220V ac ±10% | 2 |
| 100V ac ±10% | 3 |
| 240V ac ±10% | 4 |
| 5V dc ±5% | 5 |
| 12V dc +20%, -10% | 6 |

– ENTER#

SCAN RATE[3]

| | |
|---|---|
| 3.2sec | 1 |
| 1.6sec | 2 |
| 0.8sec | 3 |

– ENTER#

DEGREE READOUT[3]

| | |
|---|---|
| °C | 1 |
| °F | 2 |

– ENTER#

RESOLUTION[3]

| | |
|---|---|
| 1.0° | 1 |
| 0.1° | 2 |

– ENTER#

NOTES
[1] For 0.1° resolution accuracy remains the same. Range is limited to 200.0°
[2] Guaranteed
[3] Only one option may be specified.
[4] Lens 22 is supplied if no lens option is specified.

Specifications subject to change without notice.

# 6 Channel Scanning Digital Voltmeter/ Thermometer

# AD2037/AD2038

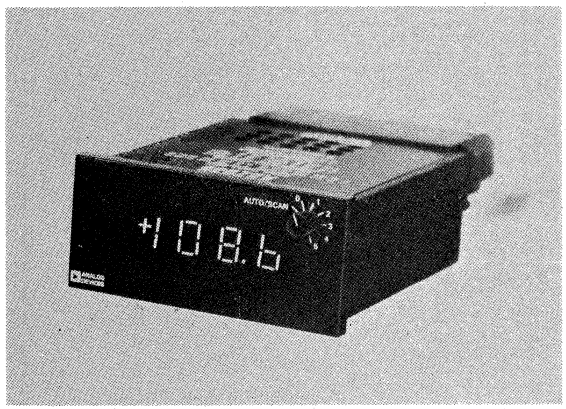
**FEATURES**

**Automatic Scan of 6 Channel Inputs**
**Manual Selection of Individual Channel**
**External Channel Selection by BCD Code**
**±199.9mV or ±1.999V dc Full Scale Range**
**Isolated Analog Input**
**Parallel BCD Output**
**Accessible Gain Points for Implementation of Selectable Gain, to 6V dc F.S.**
**±12V dc and +5V dc for External Use**
**AD2038: High Accuracy Temperature Measurements Used with AD590/AC2626 Transducer/Probe 0.1° Resolution; 6 Channels -55.0°C to +150.0°C (-67.0°F to +199.9°F)**

**APPLICATIONS**

**AD2037: Multi-point Measurements for Data Acquisition, Logging and Control**
**Data Processing from: Pressure and Flow Transducers; RTD and Thermistor Transducers; AD590 Temperature Transducers; LVDT and Level Transducers; Voltage and Current Sources.**

**AD2038: Temperature Monitoring in Laboratory, Manufacturing, and Quality Control**




**AD2037 GENERAL DESCRIPTION**

The AD2037 is a low-cost 3 1/2 digit, ac line powered, 6 channel digital scanning voltmeter designed to interface to printers, computers, serial data transmitters, telephone lines, etc., for display, control, logging or transmission of multi-channel analog data. With appropriate external signal conditioning on each channel, the AD2037 becomes a versatile building block for a broad range of data acquisition, data logging, or control applications.

Channel selection is made via three methods: manual, using the switch provided on the front; Auto/Scan, where the AD2037 cycling on an internal clock can continually scan the 6 input channels; or External selection, where control inputs provided on the rear connector enables channel selection via external BCD code.

A separate channel select output identifies the selected channel independent of selection mode. The channel select output together with converted BCD output provides complete information for automatic data collection. For applications where there are high common mode voltages (CMV) present, the AD2037 has as a standard feature, a floating opto isolated analog front end that will withstand CMV's up to 250V rms. The ±199.9mV full scale range or ±1.999V dc full scale range are user selectable via a jumper on the rear connector. Other full scale ranges, to 6V dc, are programmable, via one (1) external resistor.

**AD2038 GENERAL DESCRIPTION**

The AD2038 is a dedicated 6 channel digital scanning thermometer. Based on the AD2037 and designed to be used in conjunction with Analog Devices' AD590 Temperature Transducer or Analog Devices' AC2626 Temperature Probe, the AD2038 retains all of the input/output features of the AD2037 as well as the channel selection methods.

The AD2038 and AD590/AC2626 will measure and display temperatures to ±1.3°C accuracy over the temperature range of -55.0°C to +150.0°C (-67.0°F to 200.0°F), over limited temperature ranges around a calibration point, accuracies approach a few tenths of a degree.

The AD590 is a laser trimmed, two terminal IC Temperature Sensor. Its output is a current (1μA per °K) linearly proportional to absolute temperature thus eliminating the need for linearization and cold junction compensation.

Due to the AD590's high impedance current output, it is insensitive to voltage drops over long lines thus enabling remote monitoring with no need for costly transmitters or special wire.

For normal applications the AD590J can be used and calibrated at a single temperature point. Where better linearity or sensor interchangeability is needed, the "K" and "L" versions are available. All versions are available to MIL-STD-883A Class B processing. In addition, the AC2626 (an AD590JF mounted in a 3/16 inch diameter, by 6 inch long stainless steel probe) is available. The probe is supplied with 3 feet of wire for easy interface to the AD2038.

**For detailed information, contact factory.**

# SPECIFICATIONS (typical @ +25°C and nominal power supply voltage)

DISPLAY OUTPUT
- Light emitting diode (LED), seven segment display readouts, 0.5" (13mm) high for 3 data digits, 100% overrange and polarity indication. Overload indicated by flashing display, polarity remains valid. There is no indication of out of sensor range on AD2038.
- Decimal Points (3) Selectable at Input Connector
- Display Blanking
- Sensor Disconnect Indication same as overload.

ANALOG INPUT
- Opto/Transformer Isolated
- Configuration: Differential, isolated
- ±1.999V dc and ±199.9mV dc Full Scale Range
- Full Scale Range Programmable to 6V dc
- Input Impedance: 250MΩ
- Bias Current: 1.5nA
- Overvoltage Protection: (Continuous Without Damage)
  Normal Mode: ±30V pk
  Channel to Channel: ±30V pk

ACCURACY
AD2037
- ±0.05% Reading ±1 digit[1]
- Resolution: Programmable
- Temperature Range: 0 to +50°C operating; -25°C to +85°C storage
- Temperature Coefficient: Gain: 50ppm/°C
  Zero: 1.5μV/°C
- Warm-up Time to Rated Accuracy: Less than 5 minutes
- Settling Time to Rated Accuracy: 0.6 seconds ( - full scale to + full scale)
- Max Voltage Between Channels: ±199.9mV FS; ±6.1V pk
  ±1.999V FS; ±2.5V pk

ACCURACY
AD2038
- Resolution 0.1°
- Range -55°C to +150°C
  -67°F to +200°F
- Accuracy: (±0.1° digitizing error)[2]

| | AD590J | AD590K | AD590L |
|---|---|---|---|
| Sensor calibrated at +25°C (over range) | ±2.2°C max | ±1.2°C max | ±1.2°C max |
| Uncalibrated Error at +25°C | ±5.2°C max | ±2.2°C max | ±1.2°C max |
| Uncalibrated Error (over range) | ±9.2°C max | ±4.0°C max | ±2.6°C max |
| Nonlinearity (over range) | ±2.0°C max | ±0.5°C max | ±0.5°C max |

- Temperature Coefficient: Span: 50ppm/°C
  Offset: 0.01 degrees/degree

NORMAL MODE REJECTION
- 50dB at 50 - 60Hz (Additional capacitor filtering may be added between pins A and 4 with degradation of response time)

COMMON MODE REJECTION
- Floated on Power Supply: 120dB at 250V rms max CMV, $dV_{cm}/dt$ $10^6$ V/sec max, 1kΩ Imbalance

CONVERSION RATE
- 5 Conversion/sec
- Hold and Read on Command

POWER INPUT
- AC Line 50 - 400Hz, see Voltage Options Below
- Power Consumption - 5.8W @ 50 - 400Hz

ANALOG OUTPUTS
- ±12V dc ±10% @ 10mA (Referenced to Isolation Analog Grd.)
- +5V dc ±5% @ 30mA
- Reference Voltage +6.4V ±1% (Referred to Analog Grd.) 25ppm/°C @ 50μA max output

DATA OUTPUTS

Isolated Parallel BCD Outputs - 3 BCD digits, overrange, overload outputs (TTL Compatible, 4 TTL Loads). BCD data outputs are latched positive true logic. Overrange output is Logic "1" for data display greater than 999. Overload output is Logic "0" for inputs greater than full scale range, Logic "1" when other data outputs are valid. Polarity output (TTL compatible, 4 TTL Loads latched) indicates positive polarity when high (Logic "1"). Digital outputs are fully isolated from input circuitry; all Logic levels reference to digital ground.

Channel Address Outputs (CMOS/TTL Compatible 2 TTL Loads) - BCD Channel number data outputs are positive true.

Mode Output (CMOS/TTL Compatible 2 TTL Loads) - Logic "1" indicates channel selection is by switch. Logic "0" indicates selection is by scanner or external control, useful in Microcomputer Interface.

Data Ready (Data Ready) CMOS/TTL Compatible 2 TTL Loads) - Logic "1" ("0") indicates data from Scan Card is ready. Data remains valid until next clock pulse.

Spare Inverter Output (CMOS/TTL Compatible 2 TTL Loads) - Spare inverter supplied for customer convenience.

Clock Out (CMOS/TTL Compatible, 2 TTL Loads) - Indicates EOC. When clock pulse is high, latches are being updated, data is invalid. Data is valid on negative going edge for 198ms. Clock Out pulse is disabled when Data Hold line is low.

ANALOG OUTPUT (P2 Pin A): 1mA max output

AD2037: $V_O = K V_{IN}$
Where K is gain of programmable input amplifier. (K = 1 for 1.999V F.S. and K = 10 for 199.9mV)

AD2038: $V_O = (18.95mV/°C)T$ for T = °C
$V_O = (10.53mV/°F)(T-32)$ for T = °F
error = ±6mV

CONTROL INPUTS

Display Blanking (TTL Compatible, 3 LSTTL Load) - Logic "0" or grounding blanks entire display except for decimal points; Logic "1" or open circuit for normal operation. Display blanking has no effect on output data. Display is valid immediately upon removal of blanking input.

Converter Hold (CMOS/TTL Compatible, 1 LSTTL Load) - Logic "0" or grounding causes DPM to cease conversions and display data from last conversion; Logic "1" or open circuit for normal operation. After "Converter Hold" is removed, one or two conversions are needed before reading and BCD are valid.

Decimal Points (Not TTL Compatible) - Logic "0" or grounding illuminates desired decimal point. External drive circuitry must sink 35mA peak at a 25% duty cycle, when decimal point is illuminated.

Data Hold (TTL Compatible, 1 TTL Load) - Logic "0" inhibits updating of latched parallel output data. Logic "1" or open circuit allows data to be updated after each DPM conversion. This input has no effect on normal conversion of the DPM and its display.

Scanner Enable (CMOS/TTL Compatible 1 LSTTL Load) - Logic "1" will enable Scanner to control the channel selection. External channel input BCD lines can remain connected. A Logic "0" enables external channel selection.

Scan (Scan)(CMOS/TTL Compatible; 1 LSTTL Load) - A Logic "1" ("0") for <4 seconds will initiate a scan of six channels. To use Scan input, the Scan input must be a Logic "0". Both inputs have debounce circuitry. A momentary scan pulse while in the switch or external mode will initiate a sequence of six readings of the channel that is addressed then stop.

Channel Address Input (CMOS/TTL Compatible 1 LSTTL Load) - Logic "0" on Scanner Enable will allow use of external control. All other control inputs remain the same.

Channel Address Increment (CMOS/TTL Compatible 1 LSTTL Load) - Positive going edge will initiate sequence to the next channel.

Spare Inverter Input (CMOS/TTL Compatible 1 LSTTL Load) - Spare inverter supplied for customer convenience.

CALIBRATION ADJUSTMENTS
- Gain
- Offset, Course
- Offset, Fine
- Span/per Channel (AD2038 only)
- Recommended Recalibration Interval: Six Months

SIZE
- 3.92" x 1.67"H x 5.80"D (100 x 42 x 147mm)
- Panel Cutout 3.930" x 1.682" (99.8 x 42.7mm)

WEIGHT
- 1.25 pounds (0.563 kg)

OPTIONS[3]

AD2037 Lens: 28 Red with ADI Logo
Lens: 27 Red without ADI Logo

AD2038 Lens 22-1, Red °C with ADI Logo
Lens 22-2, Red °F with ADI Logo
Lens 23-1, Red °C without ADI Logo
Lens 23-2, Red °F without ADI Logo

CONNECTORS (2)
2 each, 30 pin, 0.156" Spacing Card Edge Connector
Viking 2Vk 15/1-2 or Equivalent
Optional: Order AC1501

ORDERING GUIDE

AD2037 or AD2038 - □ □ □

POWER INPUT[4]
117V ac ±10% 1
220V ac ±10% 2
100V ac ±10% 3
240V ac ±10% 4
} Enter

SCAN RATE[4]
3.2 sec 1
1.6 sec 2
0.8 sec 3
} Enter

TEMPERATURE SCALE READOUT (AD2038 Only)[4]
°C 1
°F 2
} Enter

NOTES
[1] Guaranteed at 200mV full scale at +25°C and nominal power supply.
[2] Overall accuracy of meter plus sensor over entire sensor range (guaranteed max) Meter is factory calibrated for ideal sensor.
[3] Lens 22 (AD2038) Lens 28 (AD2037) supplied if no lens option is specificed.
[4] Only one option may be specified.

Specifications subject to change without notice.

# ANALOG DEVICES

# Low Cost Temperature Indicator

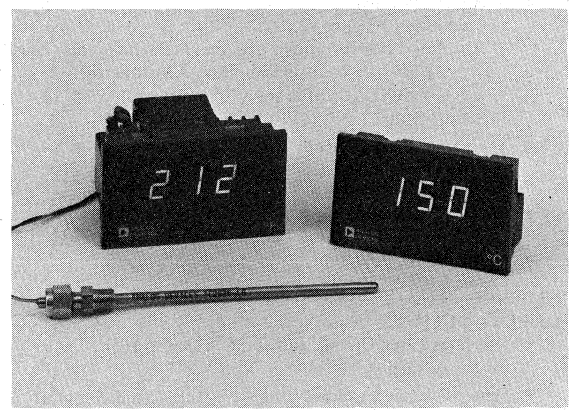
# AD2040

## FEATURES

**Low Cost**
**Direct Interface to AD590 or AC2626 Sensors**
**Large 0.56″ Red Orange LED Display**
**Accuracy to ±1.0° ±1 Digit**
**Either ac Line or +5V dc Powered**
**Temperature Range: -55°C to +150°C**
**-67°F to +302°F**
**1000V rms Isolation (ac)**
**Terminal Block Interface**
**Small Size, Panel Mount**

## APPLICATIONS

**Temperature Monitoring in Design, Laboratory, Manufacturing and Quality Control for Both +5V dc or Line Powered Applications**




## GENERAL DESCRIPTION

The AD2040 is a low-cost 3 digit temperature indicator. Based on the highly successful AD2026 low-cost DPM and designed to be used in conjunction with Analog Devices' AC2626 general purpose probe or the AD590 temperature transducer, the AD2040 is available in both 5V logic-powered, or ac line-powered versions.

The 5V powered AD2040-12 reads out directly in °C, °F, °R or K. A precision voltage reference, resistor network, and span and zero adjusts, needed to implement display of the different temperature scales, are all self-contained. User selectable degree readout, as well as all other connections, i.e., +5V power and sensor or probe interface, are all made via a terminal block on the rear.

For many stand-alone temperature measurement applications, i.e., in factories, labs, ovens, inspection stations, etc., +5V dc power is not available. For these applications, the AD2040 is available in an ac version. The ac-powered version retains all of the features of the 5V version, with the exception of the user selectable degree readout. °C or °F must be specified when ordering (see Ordering Guide).

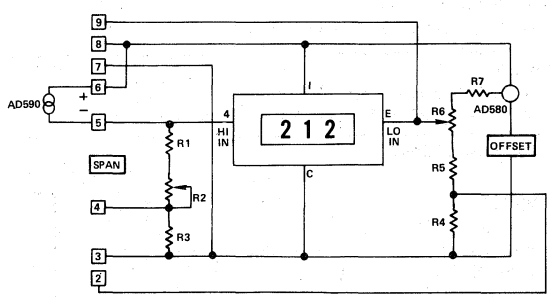
If required, calibration adjustments are easily accessible. No mounting hardware of any kind is used.

The AD2040 and AC2626 or AD590 will measure and display temperatures on large 0.56″ orange LED displays from -55°C to +150°C (-67°F to +302°F) with accuracy to ±1.0° ±1 digit. Reliability is assured with the inherent simplicity and accuracy of the sensor, combined with the highly efficient design of the AD2040.

## THE SENSOR

The AD590 is a laser-calibrated, two terminal IC temperature transducer. Its output is a current (1μA per K) linearly proportional to absolute temperature, thus eliminating the need for costly linearization and cold junction compensation.

Due to the AD590's high impedance current output, it is insensitive to voltage drops over long lines thus enabling remote monitoring with no need for costly transmitters or special wire.




*AD2040-12 (dc) Block Diagram*

Above is a block diagram of the AD2040-12, showing the AD2026 DPM input, the current-to-voltage conversion resistors (R1, R2, R3), the offsetting resistance network (R4, R5, R6, R7), and the connections to the terminal strip. Attenuated voltage from the AD580, 2.5V reference, provides the offsets for readout on the °F and °C scales. On the AD2040-12 dc version, jumpers are connected by the user at the terminal strip to select the appropriate units of temperature for display. °C or °F must be specified when ordering the ac version (see Ordering Guide).

16

# SPECIFICATIONS (typical @ +25°C and nominal supply unless otherwise specified)

ACCURACY

- Resolution: 1°
- Range: −55°C to +150°C
  −67°F to 302°F
  218K to 423K
  425°R to 793°R
- Accuracy: (±1 digit)[1]

| | AC2626J/ AD590J | AC2626K/ AD590K | AC2626L/ AD590L |
|---|---|---|---|
| Calibration Error @ +25°C | ±5.0°C max | ±2.5°C max | ±1.0°C max |
| Absolute Error (overrated performance temperature range) | | | |
| Without External Calibration Adjustment | ±10.0°C max | ±5.5°C max | ±3.0°C max |
| With +25°C Calibration Error Set to Zero | ±3.0°C | ±2.0°C max | ±1.6°C max |
| Nonlinearity | ±1.5°C | ±0.8°C max | ±0.4°C max |

- Temperature Coefficient:
  Offset: 0.03 degrees/degree
  Span: 70ppm/°C
- Common Mode Rejection (ac)
  117dB, 1000V rms max Common Mode Voltage
- Normal Mode Rejection
  30dB @ 50-60Hz

DISPLAY OUTPUT[2]

- 7 Segment, Red Orange, LED 0.56″ (13mm) High for 3 Data Digits
- Sensor Disconnect Indication: ––– (for °C and °F only)
- DPM Positive Overload: EEE
- DPM Negative Overload: –––
- No Indication of Out of Sensor Range

INPUT IMPEDANCE

- °C, K: 1.0KΩ
- °F, °C: 1.8KΩ

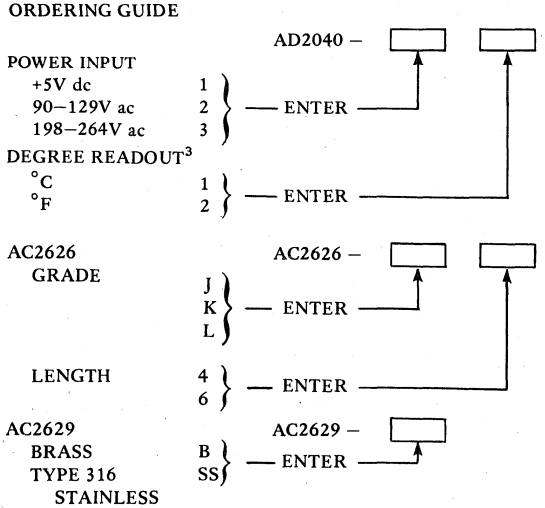
CONVERSION RATE

- 4 Conversions Per Second

POWER INPUT

- +5.0V ±5%; 160mA (dc version)
- AC Line 50-400Hz; See Voltage Options Below

ORDERING GUIDE




POWER INPUT (ac Line Power)

- AC Line Power, 50-60Hz, 1.5 Watts

CALIBRATION ADJUSTMENTS

- Span
- Gain
- Zero
- Offset
- Recommended Recalibration Interval: Six Months

SIZE

- 3.43″W X 2.0″H X 1.65″D (87 X 52 X 42mm)
- Panel Cutout Required: 3.175 ±0.015″ X 1.810 ±0.015″ (80.65 ±0.38 X 45.97 ±0.38mm)

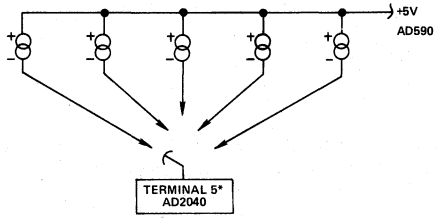
WEIGHT

- 3 ounces (88 grams) (+5V dc)
- 7 ounces (198 grams) (ac Line Powered)

NOTES

[1] Overall accuracy of meter plus sensor over entire range.
[2] Leading zero cannot be blanked.
[3] Select Degree Readout when ordering ac version only. (+5V dc version offers user selectable temperature scales—see Table I. For +5V dc version enter 2, e.g., AD2040-12.)

Specifications subject to change without notice.

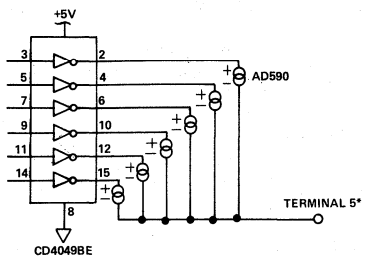



*TERMINAL 5 IS -SENSOR INPUT ON THE +5V DC VERSION.
THIS TERMINAL IS TERMINAL #2 ON THE AC VERSION.

*Figure 1. Manual Switching with Multiple Inputs*

## MULTIPLE SENSOR INPUTS

Expansion to multiple sensors via manual switching is shown in Figure 1. The sensor selected will pass a signal current through the current measuring circuitry, internal to the AD2040. Similarly automatic switching, shown in Figure 2 is accomplished. A low level input on an inverter input will allow selection of the appropriate AD590.




*TERMINAL 5 IS -SENSOR INPUT ON THE +5V DC VERSION.
THIS TERMINAL IS TERMINAL #2 ON THE AC VERSION.

*Figure 2. Automatic Switching*

| SCALE | TERMINAL 2 | TERMINAL 3 | TERMINAL 4 | TERMINAL 9 |
|---|---|---|---|---|
| °C | X | X | X | |
| °F | | | | |
| K | | X | X | X |
| °R | | X | | X |

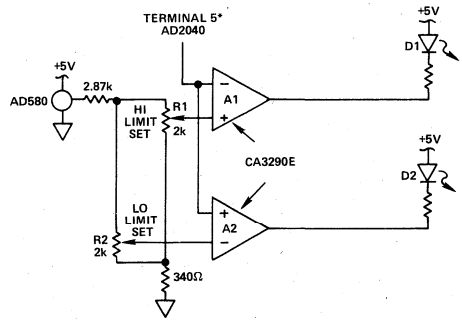
*Table I. Temperature Scale Selection (+5V dc Only)*

## TEMPERATURE SCALE SELECTION

As shown in Table I any of the standard temperature scales may be displayed using the +5V dc AD2040-12.

The AD2040-12dc version is factory calibrated in degrees Fahrenheit. Readout in degrees Celsius, Rankine or Kelvin are achieved via simple jumper connections on the terminal block, listed in the above table. (Connect terminals marked X.)

Figure 3 shows how the AD2040, in conjunction with 4 resistors, 2 trim pots, and a dual comparator, can be used to control as well as monitor particular applications via high and low set points. When the voltage at the AD2040 sense terminal (terminal 5) goes higher than the Hi Limit Set Voltage, the




*TERMINAL 5 IS -SENSOR INPUT ON THE +5V DC VERSION.
THIS TERMINAL IS TERMINAL #2 ON THE AC VERSION.

*Figure 3. Hi and Low Set Points*

output of A1 goes low and D1 is illuminated. Similarly when the voltage at terminal 5 goes below the Lo Limit Set Voltage, the output of A2 goes low illuminating D2.

To set the high limit, replace the AD590 with a variable resistor. Adjust the resistor until the desired high temperature set point is displayed on the meter. Adjust R1 until D1 is just turning on. Repeat procedure for R2 (Lo Limit Set).

## CALIBRATION PROCEDURE

The AD2040 is factory calibrated using an ideal sensor. The dc version is calibrated in °F and the ac version is calibrated to order. If sensor accuracy is adequate, no calibration is required (see note). If a lower grade sensor is used (i.e., J) and calibration is required, adjust Span Adjust on the rear with sensor at a known temperature for that temperature, e.g. for °F place sensor in Ice Bath at 32°F and adjust span for reading of 32.

Recalibration may be required after six (6) months; if so, proceed as follows:

1. With AD590 disconnected, short input of AD2040 (terminal 5 to 9 on dc version, or 2 to 3 on ac version). Remove AD2040 lens and adjust Front Panel ZERO Adjust to display 000.
2. Attach AD590 sensor and stabilize at a known Reference Temperature; e.g., Ice Bath. Connect terminal 9 to terminal 3 (on dc version) or terminal 3 to access port (on ac version) and adjust Rear SPAN Adjust for a display of 273 plus Reference Temperature for °C or 460 plus Reference Temperature for °F.
3. Remove jumper between terminals 9 and 3 (dc version) or 3 and access port (ac version). Adjust the Rear OFFSET Adjust for Reference Temperature. (For K or °R omit step 3.)

For optimum linearity calibration for °C, repeat steps two (2) and three (3) with Reference Temperature at 0. Then with sensor at 100°C adjust Front Panel GAIN Adjust for a meter display of 100. Other high end temperatures may be used with this procedure as long as they are known to be accurate.

For °F repeat steps two and three with Reference Temperature at 32°F. Then with sensor at the high temperature, adjust Front Panel GAIN Adjust for readout equal to high temperature. The above temperature can be selected for optimum linearity over user's temperature range.

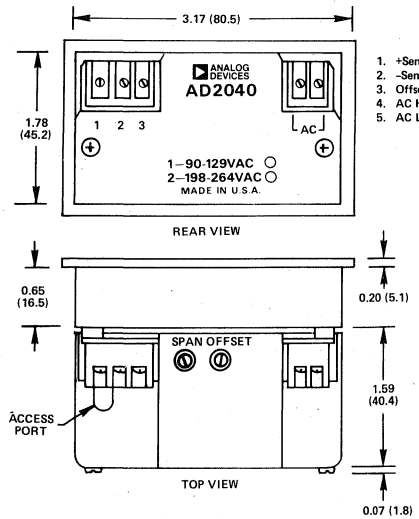
NOTE: If other than °F readout on the dc version is desired, follow step 2 and 3 of Recalibration Procedure.

16

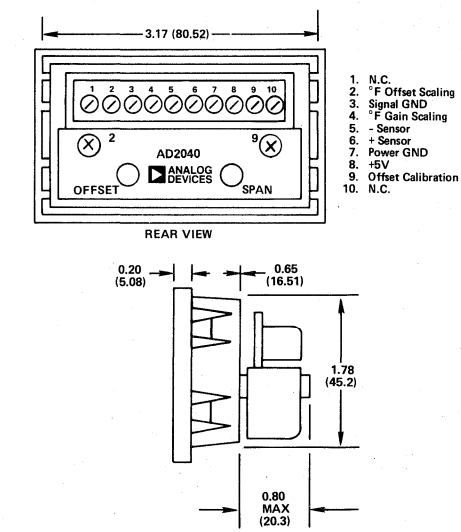
## OUTLINE DIMENSIONS

Dimensions shown in inches and (mm).

### AD2040 (ac)




### AD2040 (dc)




### THE AC2626

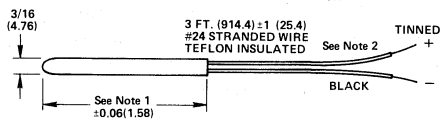
The AC2626 is a stainless steel tubular probe measuring 3/16 inch (4.76mm) in outside diameter and is available in 6 inch (152.4mm) or 4 inch (101.6mm) lengths. Based on the new AD590F, the probe is available in linearity grades of 0.4°C, 0.8°C or 1.5°C.

The probe is designed for both liquid and gaseous immersion applications as well as temperature measurements in refrigeration or any general temperature monitoring application.

For taking measurements in pipes or other closed vessels, the AD2629 compression fitting is available. The AC2629 may be applied anywhere along the probe and is supplied in two materials. The low cost AC2629B is constructed of brass and the higher priced AC2629SS is made of stainless steel.

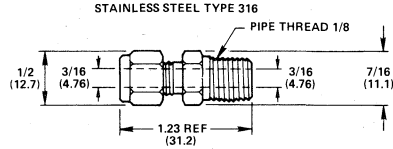
### AC2626

3/16 STAINLESS STEEL TUBING TYPE 316
FILLED WITH THERMALLY CONDUCTIVE EPOXY




### AC2629

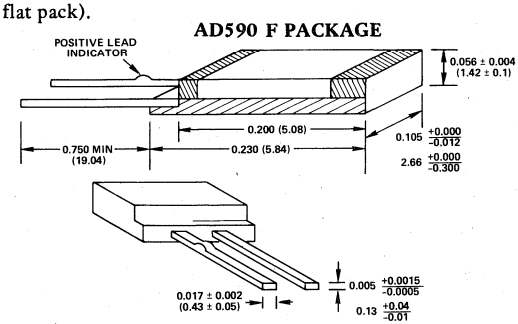
COMPRESSION FITTING (See Note 3)
STAINLESS STEEL TYPE 316



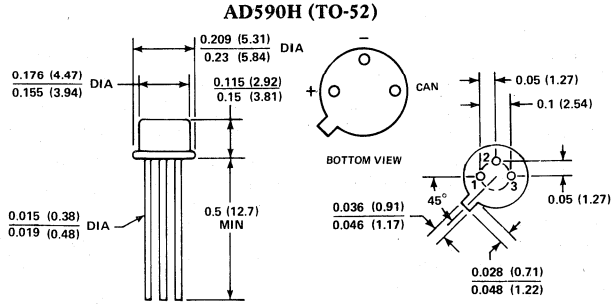

NOTES
1. PROBES ARE AVAILABLE IN 4-INCH OR 6-INCH LENGTHS.
2. + LEAD WIRE IS COLOR CODED: J, YELLOW; K, ORANGE; L, BLUE.
3. WHEN ASSEMBLING COMPRESSION FITTING (AC2629) TO PROBE, TIGHTEN THE 1/2" NUT 3/4'S OF A TURN FROM FINGER TIGHT.

The AD590 temperature transducer is available in two packages—the "H" package (TO-52) and the "F" package (ceramic flat pack).

### AD590 F PACKAGE




### AD590H (TO-52)



# Microprocessor Based Thermocouple Meters

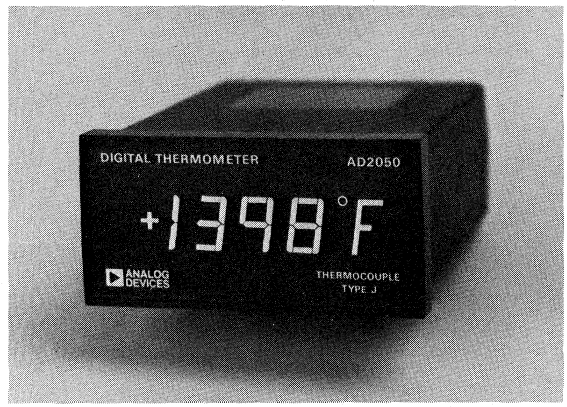
# AD2050/AD2051

**FEATURES**

- **Automatic Self-Calibration for Gain, Offset, Cold Junction Compensation and Thermocouple Linearization**
- **J, K, T, E, R, S Thermocouple Selections (AD2050) Universal Meter (AD2051), User Programmable**
- **Character Serial ASCII Digital Output**
- **Optional Linearized Analog Output: 1mV/degree**
- **Optional Isolated 20mA Loop/TTL Serial Outputs**
- **Meets DIN/NEMA Dimension Specifications**
- **Temperature Ranges: −265°F to +1999°F**
  **−165°C to +1760°C**
- **Power Options: 120V ac, 240V ac, +7.5V dc to +28V dc**

**APPLICATIONS**

- **Temperature Monitoring in Laboratory, Manufacturing, and Quality Control Environments**
- **Process Control Temperature Measurements**
- **Remote Data Logging**




## GENERAL DESCRIPTION

The AD2050 and AD2051 are high performance single channel 3½ digit thermocouple meters that can measure temperatures accurately between −265 and +1999 in degrees Celsius or Fahrenheit. The AD2050 is supplied factory programmed to interface directly with any of the following six thermocouple types: J, K, T, E, R and S. The AD2051 is a universal instrument in which the user selects one of the six thermocouple types via switch programming. Being microprocessor based, all gain and offset error correction, cold junction compensation, thermocouple linearization, and °C/°F scaling are automatically performed in firmware.

The AD2050 and AD2051 display temperature information on large 0.56″ (14.3mm) high LEDs. Digital information is provided in standard ASCII character serial format with rate selection for easy interface to printers, terminals, and other peripherals. For remote data acquisition applications, an optional isolated 20mA serial loop/TTL compatible interface is available. Also an optional analog output linearized to 1mV/degree is provided for driving recorders and other analog instruments. Selection of °C or °F scaling is accessed by removing the front panel lens and setting the selector switch to its proper position.

The AD2050 and AD2051 can also be ordered with any of the following power versions: 120V ac, 240V ac, or +7.5V dc to +28V dc. Input overvoltage protection for 300V peak (thermocouple to ac line shorts) and common mode voltages as high as 1400V peak (ac version) with overrange and open thermocouple detection are provided. These instruments are rated for operation over the +10°C to +40°C temperature range. Testing is performed per MIL-STD-202E Method 103B to insure specified operation over various relative humidity conditions. The AD2050 and AD2051 are supplied in rugged high impact plastic cases that meet DIN/NEMA standard dimensions.

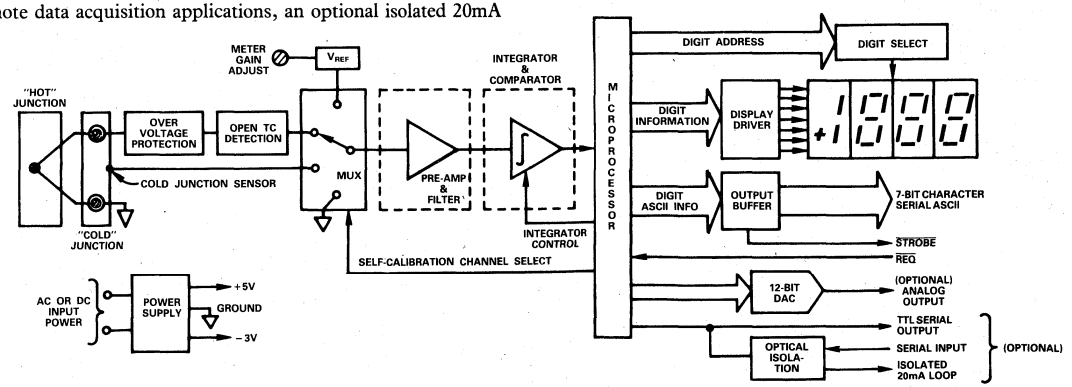



*Figure 1. AD2050 & AD2051 Functional Block Diagram*

16

# SPECIFICATIONS (typical @ +25°C and rated supply voltages unless otherwise specified)

THERMOCOUPLE INPUTS
- Thermocouple Types: J, K, T, E, S, R
- Input Impedance: >100MΩ
- External (Lead) Resistance Effect: <20μV per 350Ω of Lead Resistance
- Cold Junction Compensation Error: ±0.5°C max (10°C to +40°C)
- Open Thermocouple: +EEE Display; +EEEE ASCII Digital Output; +2.048V Analog Output
- Thermocouple Short to ac Line: Internal Protection Provided to 300V peak (200V ac rms)
- Common Mode Voltage: 1400V peak (dc or ac), between Input and Power Line Ground (ac Versions)
- Common Mode Rejection Ratio: >130dB with 250Ω Source Imbalance (ac Versions); (dc to 60Hz)
- Normal Mode Rejection Ratio: >80dB @ 50/60Hz

DIGITAL OUTPUTS
- Character Serial ASCII
  Data: Nine transmitted characters, (each 7 bits plus strobe)
  Drive Capability: 2TTL loads, CMOS/TTL compatible
  $\overline{\text{Strobe}}$: Negative transition determines when character serial data is valid. CMOS/TTL compatible.
  Character Rate: Selectable on J1 (pin 32)
  Grounded: 25 characters/sec. (SLOW)
  Open: 100 characters/sec. (FAST)
- Isolated Serial Output (Optional)
  Data: Asynchronous ASCII 20mA current loop
  (Optically isolated to ±600V peak)
  Baud Rate: Selectable on J1 (Pin 32)
  Grounded: 300 baud (SLOW)
  Open: 1200 baud (FAST)
  Distance: 10,000 ft. max
- Serial Output (Nonisolated, Optional)
  Data: Serial ASCII
  Drive Capability: 2TTL Loads, CMOS/TTL compatible
  Baud Rate: (same as Isolated Serial Output)
- Overrange: ±EEEE
- Minimum Time Between New Data Update: 150ms

DIGITAL INPUTS
- $\overline{\text{REQ}}$: Low-Level Triggered: Must go low at any time other than during data transmission to be recognized. $\overline{\text{REQ}}$ line taken low during data transmission will not be acknowledged and the ASCII digital output transmission will not occur. Display readings are not effected by $\overline{\text{REQ}}$.
- $\overline{\text{SERIAL INPUT}}$ (Optional): Edge Triggered, Current On to Current Off: Must be triggered at any time other than during data transmission to be recognized. $\overline{\text{Serial Input}}$ triggered during data transmission will not be acknowledged and the 20mA isolated/TTL compatible serial output transmission will not occur. Display readings are not effected by $\overline{\text{Serial Input}}$.

ANALOG OUTPUT (OPTIONAL)
- Voltage: 1mV/degree, linearized
- Current: ±2mA max drive
- CMV: 1400V peak (ac or dc) Peak between Analog Output Ground & ac Power Line Ground
- Overrange: +2.048V, −0.512V

ACCURACY
- Temperature Resolution: 1°C/1°F
- All Ranges are Guaranteed Monotonic
- Range Temperature Coefficient: ±25ppm/°C typ, ±60ppm/°C max
- Readout Accuracy @25°C:

| Sensor Type | Range | Accuracy | |
|---|---|---|---|
| J | −165°C to 760°C | ±0.7°C | ±1/2LSD |
| J | −265°F to 1400°F | +1.3°F | ±1/2LSD |
| K | −50°C to 1250°C | ±0.9°C | ±1/2LSD |
| K | −58°F to 1999°F | ±1.6°F | ±1/2LSD |
| T | −150°C to 400°C | ±0.8°C | ±1/2LSD |
| T | −238°F to 752°F | ±1.4°F | ±1/2LSD |
| E | −100°C to 870°C | ±1.0°C | ±1/2LSD |
| E | −148°F to 1598°F | ±2.0°F | ±1/2LSD |
| S, R | +300°C to 1760°C | ±1.5°C | ±1/2LSD |
| | 0° to 299°C | ±6.0°C | ±1/2LSD |
| S, R | +572°F to 1999°F | ±3.0°F | ±1/2LSD |
| | +32°F to 571°F | ±12.0°F | ±1/2LSD |

ANALOG TO DIGITAL CONVERSION
- Technique: Offset Dual Slope with Gain and Offset Error Correction
- Rate: 2.5 Conversions/Second Typical
- Input Integration Period: 100ms for 50/60Hz Noise Rejection

POWER REQUIREMENTS (Choice of Three Supply Ranges)
- ac: 90V ac to 132V ac @ 25mA (47Hz to 500Hz)
  198V ac to 264V ac @ 12.5mA (47Hz to 500Hz)
- dc: +7.5V to +15V dc @ 200mA (Protected Against Supply Reversals)

DISPLAY
- Type: Seven Segment Orange LED 0.56" (14.3mm) high
- Polarity Indication: "+" or "−" displayed
- Overrange Indication: ±EEE
- Display Test: At Power Turn-On, 3 Second Display of "+1888" Tests all Segments of Display

ENVIRONMENTAL
- Rated Temperature Range: +10°C to +40°C
- Operating Temperature Range: −10°C to +50°C
- Storage Temperature Range: −40°C to +85°C
- Relative Humidity: Meets MIL-STD-202E, Method 103B

DIMENSIONS
- Case: 3.78" × 1.89" × 5.13" (96.8mm × 48.9mm × 131.3mm), high impact molded plastic case. DIN/NEMA Standard
- Weight: 15.2 oz (431 grams) max, ac powered
  12.0 oz (341 grams) max, dc powered.

RELIABILITY
- Burn In: 168 Hours at +50°C and Power ON/OFF Cycles.
- Calibration: NBS Traceable
- Recalibration: Recommended 15-Month Intervals
- Warranty: 12 months

CONNECTOR
One 44 pin 0.1" (2.54mm) spacing card edge connector
Viking 3VH22/1 JN5 or equivalent
Optional: Order AC2630

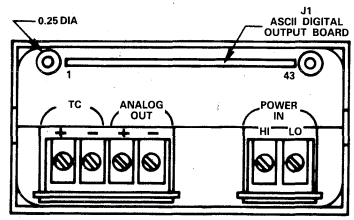
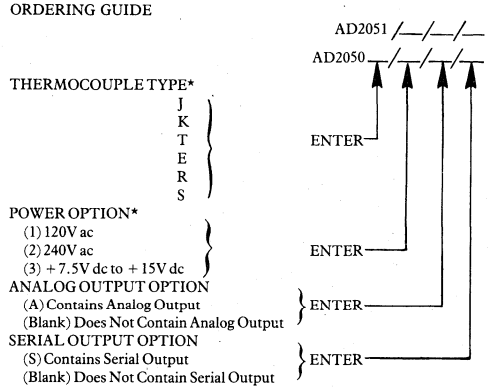



*Figure 2. Rear Panel View*

ORDERING GUIDE




*Only one option can be ordered. The thermocouple type does not need to be specified when ordering the AD2051 since it is user programmable.

Specifications subject to change without notice.

# Microprocessor Based Autoranging RTD/Thermistor Meter

# AD2060/AD2061

**FEATURES**

**Temperature Ranges: −328°F to +1562°F**
**−200°C to +850°C**
**Autoranging: 0.1° from −199.9° to +199.9°; 1°≥200°**
**Sensor Selection (AD2060): RTD 100Ω Platinum**
**α = 0.00385, 0.00390, 0.00392 or 2252Ω Thermistor**
**Universal Meter (AD2061) Sensor User Programmable**
**Switch Selectable Sensor Configuration: 2, 3 or 4-wire**
**7-Bit ASCII Character Serial Data Output**
**Automatic Self-Calibration for Gain, Offset, Excitation and Sensor Linearization**
**Optional Linearized Analog Voltage Output: 1mV/degree**
**Optional Isolated 20mA ASCII Loop/TTL Serial Outputs**

**APPLICATIONS**

**Temperature Monitoring in Laboratory, Manufacturing and Quality Control Environments**
**Process Control Temperature Measurements**
**Remote Data Logging**




**GENERAL DESCRIPTION**

The AD2060/AD2061 are high performance single channel 3½ digit RTD/Thermistor meters that can measure temperature accurately between −328°F and +1562°F (−200°C and +850°C). Both meters offer autoranging from 0.1°C/F to 1°C/F. The AD2060 is supplied factory programmed for one of four sensor types: 100Ω Platinum RTDs: α = 0.00385, 0.00390, 0.00392 or a 2252Ω Thermistor. The AD2061 is a universal meter in which the user selects one of the four sensor types via switch programming. The microprocessor based AD2060/AD2061 provides gain, offset and excitation error correction, linearization and °C/°F scaling in firmware. The AD2060/AD2061 display temperature information on large 0.56"(14.3mm) high LEDs. Digital information is provided in 7-bit standard ASCII character serial format with baud rate selection for easy interface to printers, terminals and other peripherals. For remote data acquisition applications, an optional isolated 2-wire 20mA ASCII serial loop/TTL compatible interface is available. For driving recorders or other analog instruments, an optional linearized analog voltage output of 1mV/degree is available. Selection of °C or °F scaling is accessed by removing the front panel lens and setting the selector switch to its proper position.

The AD2060/AD2061 can be ordered in one of the following power versions: 120V ac, 240V ac or +7.5V dc to +28.0V dc. Input voltage protection of 180V peak (RTD short to ac line), common-mode voltage to 1400V peak (ac version) with overrange and open sensor detection is provided. These meters are rated for operation over the 0 to +40°C temperature range. Each AD2060/AD2061 is burned-in for 168 hours @ 50°C with on/off power cycles for increased reliability. The AD2060/AD2061 are supplied in rugged molded plastic cases that meet UL94V-0 and DIN/NEMA standard dimensions.

PRELIMINARY TECHNICAL DATA

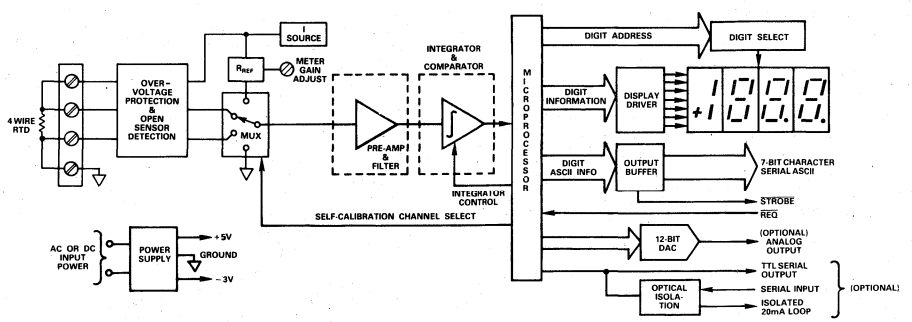



*Figure 1. AD2060 & AD2061 Functional Block Diagram*

16

# SPECIFICATIONS (typical @ +25°C and rated supply voltages unless otherwise specified)

RTD INPUTS
- RTD Types: 100Ω Platinum
  α = 0.00385 (Per DIN 43760)
  α = 0.00390
  α = 0.00392
- Configuration: 2, 3 or 4 Wire
- Excitation Current: 0.25mA nominal
- External Lead Resistance Effect: Automatically Compensated for 3 & 4 wire configurations
- Lead Resistance: 50Ω/Lead max; RTD + Lead Resistance must be less than 400Ω
- 3 Wire Error: 2.8°C/Ω of impedance imbalance
- Open Sensor: DISPLAY +EEE
- RTD Short to ac Line: Internal protection provided to 180V peak (130V rms)
- Maximum Common-Mode Voltage: 1400V peak (ac or dc) between input and power line ground (ac version)
- Common-Mode Rejection Ratio: 100dB ac power to RTD input
- Normal Mode Rejection: 60dB @ 50/60Hz

THERMISTOR INPUTS
- Thermistor Type: Series 400 R = 2252Ω
- Configuration: 2 Wire
- Open Sensor: DISPLAY -EEE

ACCURACY
- Temperature Resolution: Autoranging (0.1° from −199.9° to +199.9°, 1°≥200°)
- All Ranges Guaranteed Monotonic
- Range Temperature Coefficient: 20ppm/°C typ, 30ppm/°C max
- Readout Accuracy* @ +25°C

| Sensor | Range | Accuracy |
|---|---|---|
| 100Ω RTD α = 0.00385 | −200°C to +850°C | ±0.3°C ± 1/2LSD |
| | −328°F to +1562°F | ±0.6°F ± 1/2LSD |
| 100Ω RTD α = 0.00392 | −200°C to +640°C | ±0.3°C ± 1/2LSD |
| | −328°F to +1184°F | ±0.6°F ± 1/2LSD |
| 100Ω RTD α = 0.00390 | −200°C to +640°C | ±0.3°C ± 1/2LSD |
| | −328°F to +1184°F | ±0.6°F ± 1/2LSD |
| Thermistor R = 2252Ω | −30°C to +100°C | ±0.4°C ± 1/2LSD |
| | −22°F to +212°F | ±0.8°F ± 1/2LSD |

*Readout Accuracy: Includes Gain and Offset Errors. Recommended Recalibration Interval 15-MONTHS.

DIGITAL OUTPUTS
- Character Serial ASCII
  Data: Eleven transmitted characters, (each 7 bits plus strobe)
  Drive Capability: 2TTL loads, CMOS/TTL compatible
  $\overline{\text{Strobe}}$: Negative transition determines when character serial data is valid. CMOS/TTL compatible.
  Character Rate: Selectable on P1 (Pin 32)
  Grounded: 25 characters/sec. (SLOW)
  Open: 100 characters/sec. (FAST)
- Isolated Serial Output (Optional)
  Data: Asynchronous ASCII 20mA current loop (Optically isolated to ±600V peak)
  Baud Rate: Selectable on J1 (Pin 32)
  Grounded: 300 baud (SLOW)
  Open: 1200 baud (FAST)
  Distance: 10,000 ft. max
- Nonisolated Serial Output (Optional)
  Data: Serial ASCII
  Drive Capability: 2TTL Loads, CMOS/TTL compatible
  Baud Rate: (same as Isolated Serial Output)
- Overrange: ±EEE.E
- Minimum Time Between New Data Update: 150ms

DIGITAL INPUTS
- $\overline{\text{REQ}}$: Low-Level Triggered: Must go low at any time other than during data transmission to be recognized. $\overline{\text{REQ}}$ line taken low during data transmission will not be acknowledged and the ASCII digital output transmission will not occur. Display readings are not effected by $\overline{\text{REQ}}$.
- $\overline{\text{SERIAL INPUT}}$ (Optional): Edge Triggered, Current On to Current Off: Must be triggered at any time other than during data transmission to be recognized. $\overline{\text{Serial Input}}$ triggered during data transmission will not be acknowledged and the 20mA isolated/TTL compatible serial output transmission will not occur. Display readings are not effected by $\overline{\text{Serial Input}}$.

ANALOG OUTPUT (OPTIONAL)
- Voltage: 1mV/degree, linearized
- Current: ±2mA max drive
- CMV: 1400V peak (ac or dc) between Analog Output Ground & ac Power Line Ground
- Overrange: +2.048V, −0.512V
- Accuracy: ±2mV from Display Reading

Specifications subject to change without notice.

ANALOG TO DIGITAL CONVERSION
- Technique: Offset Dual Slope with Gain and Offset Error Correction
- Rate: 2.5 Conversions/Second Typical
- Input Integration Period: 100ms for 50/60Hz Noise Rejection

POWER REQUIREMENTS (Choice of Three Supply Ranges)
- ac: 90V ac to 132V ac @ 25mA (47Hz to 500Hz)
  198V ac to 264V ac @ 12.5mA (47Hz to 500Hz)
- dc: +7.5V to +28V dc @ 200mA (Protected Against Supply Reversals)

DISPLAY
- Type: Seven Segment Orange LED 0.56" (14.3mm) high
- Polarity Indication: "+" or "−" displayed
- Overrange Indication: ±EEE
- Display Test: At Power Turn-On, 3 Second Display of "+188.8." Tests all Segments of Display

ENVIRONMENTAL
- Rated Temperature Range: 0 to +40°C
- Operating Temperature Range: −10°C to +50°C
- Storage Temperature Range: −40°C to +85°C
- Relative Humidity: Meets MIL-STD-202E, Method 103B (0 to 90%, Noncondensing)

DIMENSIONS
- Case: 3.78" × 1.89" × 5.13" (96.8mm × 48.9mm × 131.3mm), rugged molded plastic case. Meets UL94V-0 and DIN/NEMA Standard dimensions
- Weight: 15.2 oz (431 grams) max, ac powered
  12.0 oz (341 grams) max, dc powered.

RELIABILITY
- MTBF: >55,000 hours calculated
- Burn In: 168 Hours at +50°C and Power ON/OFF Cycles.
- Calibration: NBS Traceable
- Recalibration: Recommended 15-Month Intervals
- Warranty: 12 months

CONNECTOR
One 44 pin 0.1" (2.54mm) spacing card edge connector Viking 3VH22/1 JN5 or equivalent
Optional: Order AC2630

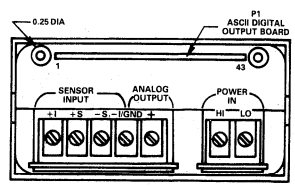
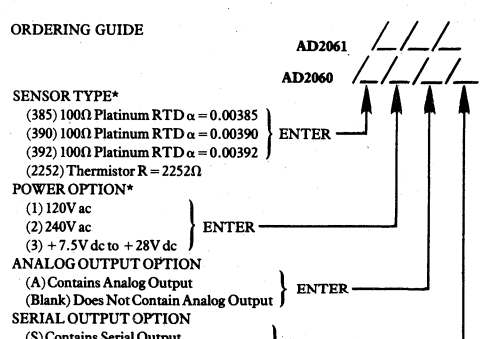



*Figure 2. Rear Panel View*

ORDERING GUIDE




*Only one option can be ordered. The sensor type does not need to be specified when ordering the AD2061 since it is user programmable.

# Microcomputer Analog I/O Subsystems

## Contents


| | Page |
|---|---|
| Selection Guide | 17-2 |
| •RTI-600 VME-Compatible Analog Input Board | 17-5 |
| •RTI-602 VME-Compatible Analog Output Board | 17-5 |
| •RTI-711 MULTIBUS™ Compatible Analog Input Board | 17-7 |
| •RTI-724 MULTIBUS™ Compatible Analog Output Board | 17-7 |
| •RTI-732 MULTIBUS™ Compatible Combination I/O Board | 17-7 |
| RTI-1225 STD Bus-Compatible Combination I/O Board | 17-9 |
| RTI-1226 STD Bus-Compatible Analog Input Board | 17-9 |
| RTI-1230 Motorola-Compatible Analog Input Board | 17-11 |
| RTI-1231 Motorola-Compatible Analog I/O Board | 17-11 |
| RTI-1232 Motorola-Compatible Analog-Digital Output Board | 17-11 |
| RTI-1240 Texas Instruments-Compatible Analog Input Board | 17-13 |
| RTI-1241 Texas Instruments-Compatible Analog I/O Board | 17-13 |
| RTI-1242/3 Texas Instruments-Compatible Output Boards | 17-13 |
| RTI-1250 DEC LSI-11/2-Compatible Analog Input Board | 17-15 |
| RTI-1251 DEC LSI-11/2-Compatible Combination I/O Board | 17-15 |
| RTI-1252 DEC LSI-11/2-Compatible Output Board | 17-15 |
| RTI-1260 STD Bus-Compatible Analog Input Board | 17-17 |
| RTI-1262 STD Bus-Compatible Analog Output Board | 17-17 |
| •RTI-1270 STD Bus-Compatible Sensor Based Data Acquisition Subsystem | 17-19 |


MULTIBUS is a trademark of Intel Corporation
•New product since publication of *1982–1983 Databook Update.*

17

# Selection Guide
## Microcomputer Analog I/O Subsystems

Analog Devices Real-Time Interface (RTI) products provide a direct memory-mapped interface between popular microcomputers and analog input and output signals. Each RTI board is electrically and mechanically compatible with the bus it is designed to interface with. No additional interface logic or power are required for the board, which plugs directly into the microcomputer card cage.

As the Selection Guide indicates, there are Input-only, Output-only, and—in most cases—Input/Output cards available for each bus type. Within each card family, there are optional features available to provide a close fit to the individual user's application.

For STD-bus users, there is a "smart" subsystem, the A/D-CPU Base Card and RTI-1271 Signal-Conditioning Cards. Included are sensor signal conditioning and on-board intelligence to perform scaling, linearization, and conversion to engineering units for up to 16 channels of low- or high-level analog input.

The Selection Guide provides selection information in capsule form, permitting card types to be matched to desired features. Additional information and complete specifications are provided on the individual card or family data sheets.

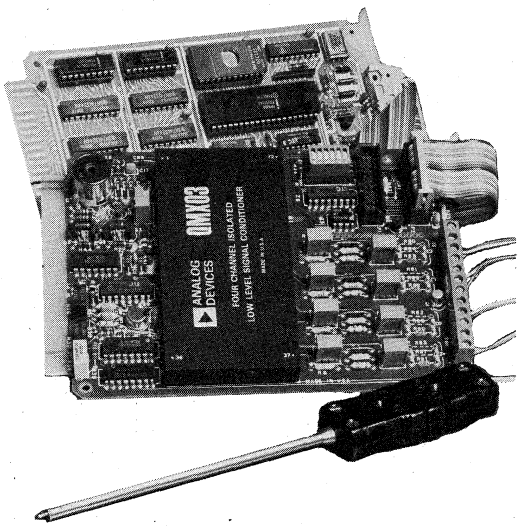
**FEATURE SELECTION CHART**

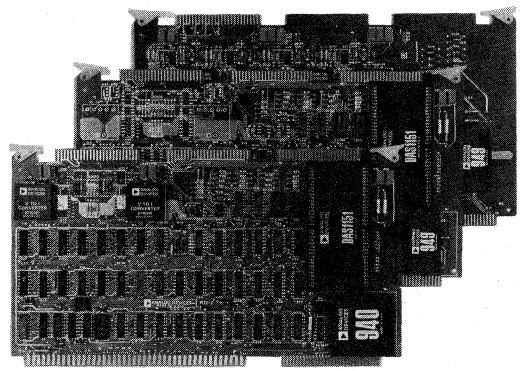
| | | MICROCOMPUTER BUS COMPATIBILITY | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | VMEbus MOTOROLA SIGNETICS MOSTEK | | | MULTIBUS™(IEEE-796)[1] INTEL NATIONAL | | | STD BUS PRO-LOG MOSTEK | | | |
| | | RTI-600 | RTI-602 | RTI-711 | RTI-724 | RTI-732 | RTI-1226 | RTI-1225 | RTI-1260 | RTI-1262 | RTI-1270 |
| Board Type | Input | • | | • | | • | • | | • | | • |
| | Input/Output | | | | | | | • | | | |
| | Output | | • | | • | | | | | • | |
| Channel Capacity | Input (Single ended/ differential) | 32/16 | | 32/16 | | 32/16 | 16/8 | 16/8 | 32/16 | | 16/16 |
| | Output | | 4 | | 4 | 2 | | 2 | | 4 | |
| Input Resolution | 10 Bits | | | | | | • | • | | | |
| | 12 Bits | • | | • | | • | | | • | | • |
| Output Resolution | 8 Bits | | | | | | | • | | | |
| | 12 Bits | | • | | • | • | | | | • | |
| Additional Features | | | | | | | | | | | |
| DC/DC Converter | | • | • | • | • | • | • | • | • | • | •[2] |
| Software PGA | | | | | | | | | | | • |
| Gains of 1, 2, 4, 8V/V | | | | • | | • | | | | | |
| Resistor PGA | | | | | | | | | | | |
| Gains of 1 to 1000V/V | | • | | | | | | | • | | |
| 4-20mA Output | | | • | | • | • | | | | • | |
| Digital Output Drivers | | | | | | | | | | | |
| Direct Sensor Interface | | | | | | | | | | | |
| Thermocouples, RTDs | | | | | | | | | | | • |
| Volume II Page | | 17-5 | 17-5 | 17-7 | 17-7 | 17-7 | 17-9 | 17-9 | 17-17 | 17-17 | 17-19 |

NOTES
[1] RTI-1200, 1201 and 1202 I/O boards not listed, but still available.
[2] This product includes sensor signal conditioning and on-board intelligence to perform scaling, linearization and conversion to engineering units.

**Shading indicates new product since publication of *1982–1983 Databook Update*.**

MULTIBUS is a trademark of Intel Corporation.



## FEATURE SELECTION CHART

| | | MICROCOMPUTER BUS COMPATIBILITY | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | MICROMODULE BUS MOTOROLA | | | | TM990 BUS TEXAS INSTRUMENT | | | LSI BUS DEC | | |
| | | RTI-1230 | RTI-1231 | RTI-1232 | RTI-1240 | RTI-1241 | RTI-1242 | RTI-1243 | RTI-1250 | RTI-1251 | RTI-1252 |
| Board Type | Input | • | | | • | • | | | • | | |
| | Input/Output | | • | | | | | | | • | |
| | Output | | | • | | | • | • | | | • |
| Channel Capacity | Input (Single ended/ differential) | 32/16 | 32/16 | | 32/16 | 32/16 | | | 32/16 | 16/8 | |
| | Output | | 2 | 4 | | 2 | 4 | 8 | | 2 | 4 |
| Input Resolution | 10 Bits | | | | | | | | | | |
| | 12 Bits | • | • | | • | • | | | • | • | |
| Output Resolution | 8 Bits | | | | | | | | | | |
| | 12 Bits | | • | • | | | • | • | | • | • |
| Additional Features | | | | | | | | | | | |
| DC/DC Converter | | • | • | • | • | • | • | • | • | • | • |
| Software PGA | | | | | | | | | | | |
| Gains of 1, 2, 4, 8V/V | | • | • | | • | • | | | • | | |
| Resistor PGA | | | | | | | | | | | |
| Gains of 1 to 1000V/V | | • | | | • | • | | | • | • | |
| 4-20mA Output | | | | • | | • | | | | | |
| Digital Output Drivers | | | | • | | | • | • | | | • |
| Direct Sensor Interface | | | | | | | | | | | |
| Thermocouples, RTDs | | | | | | | | | | | |
| Volume II Page | | 17-11 | 17-11 | 17-11 | 17-13 | 17-13 | 17-13 | 17-13 | 17-15 | 17-15 | 17-15 |

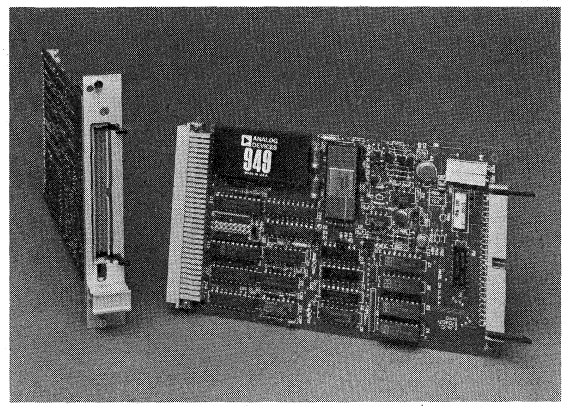
# Low Cost VMEbus Compatible Analog I/O Boards

## RTI-600 Series

**FEATURES**
**RTI-600 ANALOG INPUT BOARD**
**32SE/16D Input Channels**
**User Configurable Gains of 1 to 1000**
**12-Bit A/D Resolution (AD574)**

**RTI-602 ANALOG OUTPUT BOARD**
**4 Analog Output Channels**
**12-Bit D/A Resolution (AD7541)**
**Optional 4-20mA Output**

**GENERAL**
**Low Cost**
**Compatible with All VME Microcomputers**
**Interfaces through Primary Connector (P1)**
**Memory Mapped into VME Short I/O Address Space**
**Single Eurocard Format (100 × 160mm)**
**Single +5V Power Requirement**
**0 to +70°C Temperature Range**



### GENERAL DESCRIPTION

The RTI-600 Series products from Analog Devices are high performance analog input and output boards compatible with the VMEbus. They provide a cost effective and convenient means of interfacing your microcomputer to the real (i.e., analog) world. The boards feature 12-bit resolution, programmable gain for low-level signals, analog channel expansion, 4-20mA outputs, and on-board dc/dc converter.

The series consists of an analog input board (RTI-600) and an analog output board (RTI-602); each of which interfaces to the VMEbus P1 connector, as a block of contiguous address locations (memory mapped interface) in the VMEbus short I/O address space.

The RTI-600 Analog Input Board provides data acquisition for 16 single-ended or 8 differential channels with optional expansion to 32 single-ended or 16 differential. The instrumentation amplifier is user configurable for gains of 1 to 1000. Combining this with a sample-hold circuit and 12-bit A/D converter, the data acquisition section features ±0.01% accuracy, 12-bit resolution and conversion rates up to 25kHz. The RTI-602 Analog Output Board uses four, 12-bit D/A converters to provide independently programmed voltage output channels. In addition, two channels can be configured for 4-20mA outputs by using optional voltage to current converters which install on the board.

Analog signal connections are made using reliable socket and header connectors which enables flat ribbon cable to be combined with gas tight and corrosion resistant connectors. An optional screw termination panel is also offered for simple and convenient field wire connections.

All boards are single height (100 × 160mm), require +5V power and have an operating temperature range of 0 to +70°C.

### OPTIONAL SIGNAL CONDITIONING

For low-level analog signal conditioning such as sensor-based applications, Analog Devices 3B Series Signal Conditioning I/O Subsystem offers rail-mounted industrial hardened analog signal interface modules with a single channel format and high level analog output. Optional sensor signal conditioning, transformer isolation of ±1500V, high common-mode and normal-mode noise rejection and 130V input protection makes the 3B series an ideal for analog input and output signal conditioning for the RTI-600 series.

Whether you require sensor signal conditioning, analog I/O boards or both, Analog Devices is the source of the widest selection of solution for any measurement and control application control application. They are key elements in factory automation, process control, laboratory applications as well as OEM usages.

17

| | | INPUT | | | | OUTPUT | | |
|---|---|---|---|---|---|---|---|---|
| | | Channel Capacity | | | A/D | | D/A | 4-20mA |
| Card Type | Model No. | STD | OPT | Gain Range | Resolution | Channel Capacity | Resolution | (OPT) |
| Analog Input | RTI-600 | 16SE/8D | 32SE/16D | 1-1000 | 12 Bits | ← N/A → | | |
| Analog Output | RTI-602 | ← N/A → | | | | 4 | 12 Bits | 2 |

*RTI-600/602 Function Chart*

**This two-page data summary contains key specifications to speed your selection of the proper solution for your application. Additional information on this product can be obtained from your local sales office.**

# SPECIFICATIONS (typical @ +25°C with nominal supply voltage unless otherwise noted)

| | |
|---|---|
| **RTI-600 ANALOG INPUT CARD** | |
| Number of Input Channels | 16 Single-Ended or 8 Differential (Jumper Selectable)<br>Expandable to 32 Single-Ended or 16 Differential using<br>two plug-in multiplexers (ADI Part #OA10) |
| Input Overvoltage Protection[1] | ±35V (Dielectrically Isolated) |
| Input Impedance | $>10^8\Omega$ |
| Input Current | ±50nA |
| Analog Connector | 50 pin IDE |
| A/D Input Ranges[2] | 0 to +10V, ±10V |
| A/D Resolution | 12 Bits (4096 Counts) |
| A/D Output Codes[2] | Binary, Offset Binary, Two's Complement |
| Instrumentation Amplifier Gain Ranges | 1 to 1000V/V (Resistor Programmable Gain) |
| Gain Equation | $G = 1 + \frac{20k\Omega}{R_G}$ |
| A/D Conversion Time | 25µs |
| System Throughput[3] | 25,000 Channels/sec (G<150)<br>20,000 Channels/sec (150<G>300)<br>11,000 Channels/sec (G=1000) |
| Common Mode Voltage (CMV) | ±10V min |
| Common Mode Rejection (CMR) | 78dB |
| Linearity | ±1/2LSB |
| Differential Nonlinearity | ±1LSB |
| Total System Errors | ±0.01% of FSR (G=1 to 10)<br>±0.05% of FSR (G=100)<br>±0.1% of FSR (G=1000) |
| Temperature Coefficient | |
| Gain | ±30ppm/°C of FSR (G=1) |
| Offset | ±100ppm/°C FSR (G=1000)<br>±10ppm/°C FSR (G=1)<br>±100ppm/°C of FSR (G=1000) |
| **RTI-602 ANALOG OUTPUT CARD** | |
| Number of Output Channels | 4 |
| D/A Resolution | 12 Bits (4096 Counts) |
| D/A Input Codes[2] | Binary, Offset Binary |
| Output Voltage Range[2] | 0V to +5V, 0V to +10V, ±5V, ±10V @ 5mA |
| Output Current Range[4] | 4-20mA using 2 V/I converters |
| (Optional–2 Channels Only) | (ADI Part #OA08) |
| Analog Connector | 26 pin IDE |
| Nonlinearity | ±1/2LSB |
| Differential Nonlinearity | ±1/2LSB |
| Output Settling Time | 25µs (to ±1/2LSB) |
| Gain Error (Adjustable to Zero) | ±0.01% of FSR |
| Offset Error (Adjustable to Zero) | ±0.02% of FSR |
| Temperature Coefficient | |
| Gain | ±15ppm/°C of FSR |
| Offset | ±25µV/°C |
| **INTERFACE PARAMETERS** | |
| Compatibility | Meets all electrical and mechanical VMEbus specifications |
| Implementation | Memory mapped I/O, compatible with all CPU types |
| Address Selection | |
| RTI-600 | 2 contiguous bytes in a 256 byte block. (Jumper selectable in the VMEbus short I/O space) |
| RTI-602 | 8 contiguous bytes in a 256 byte block (Jumper selectable in the VMEbus short I/O space) |
| **POWER REQUIREMENTS** | |
| RTI-600 | +5V ±5% @ 650mA typ, 700mA max |
| RTI-602 | +5V ±5% @ 550mA typ, 650mA max<br>(on-board dc/dc converter generates an isolated ±15V to power the data acquisition components.) |
| **TEMPERATURE** | |
| Operating | 0 to +70°C |
| Storage | −55°C to +85°C |
| **RELATIVE HUMIDITY** | Meets or exceeds MIL-STD 202 Method 103 |

NOTES
[1]Specified with power applied, ±20V with power off.
[2]User selectable with wire-wrap jumpers.
[3]Does not include CPU latency time. Throughput = multiplexer + amplifier settling time + A/D conversion time.
[4]Solder in option, +16V to +30V loop power required.
FSR = Full Scale Range.

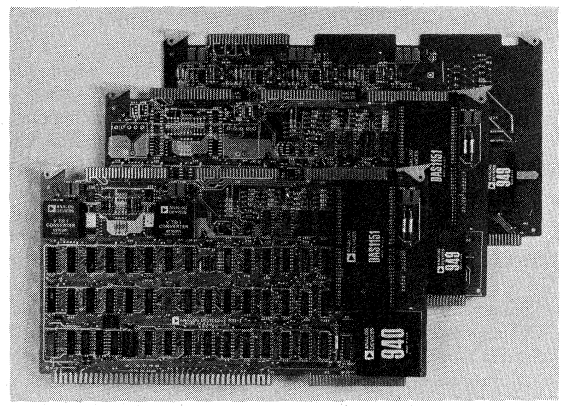
Specifications subject to change without notice.

# MULTIBUS™ (IEEE-796) Compatible Analog Input/Output Boards

# RTI-711, 724, 732

**FEATURES**

- **Direct Plug-In Replacements With Industry Standard 711/724/732 Analog I/O Boards**
- **RTI-711 Input Board**
  - **32SE/16D Input Channels**
  - **Programmable Gain Amplifier**
  - **12-Bit A/D Resolution**
- **RTI-724 Output Board**
  - **4 Output Channels**
  - **12-Bit D/A Resolution**
  - **4-20mA Current Loop Outputs (Optional)**
- **RTI-732 Input/Output Board**
  - **(Same as 711 and Includes)**
  - **2 Output Channels**
  - **12-Bit D/A Resolution**
  - **4-20mA Current Loop Outputs (Optional)**
- **General**
  - **Compatible With All MULTIBUS (IEEE-796) Microcomputers**
  - **Memory-Mapped I/O Operation Over 24-Bit Address Range**
  - **Operates Under Intel's RMX-80 Real-Time Multitasking Exec**
  - **Single +5V Power Requirement**



## GENERAL DESCRIPTION

Analog Devices RTI-711, RTI-724, and RTI-732 are complete, single board analog input/output subsystems that interface with any MULTIBUS (IEEE-796) compatible microcomputer. These boards provide measurement and control capability to a wide range of data acquisition and voltage actuated applications.

The series is comprised of an input only board (RTI-711), an output only board (RTI-724) and a combination I/O board (RTI-732); each of which interfaces to the microcomputer as a block of address locations (memory mapped interface). All data bus, control bus and address bus connections to the microcomputer are made by simply plugging the board into the computer card cage.

All boards are direct replacements for industry's standard 711/724/732 analog I/O boards. In addition, Analog Devices boards offer extended memory-mapped addressing over the entire 24-bit address range. This extended memory permits direct compatibility to SBC-80, SBC-86, SBC-88, or any other 8- or 16-bit microcomputer that requires address capability up to 16M byte. In addition, the RTI-711, 724, 732 boards are designed to operate under Intel's RMX-80 analog software drivers.

A compatible signal conditioning subsystem (3B Series) is also offered by Analog Devices which provides signal conditioning necessary for direct connections to thermocouples, RTDs and strain gages.

| | | INPUT | | | | OUTPUT | | |
|---|---|---|---|---|---|---|---|---|
| | | Channel Capacity | | Gain | A/D | Channel | D/A | 4-20mA |
| Model | Board Type | Standard | Optional | Range | Resolution | Capacity | Resolution | Output |
| RTI-711 | Analog Input | 16SE/8D | 32SE/16D | 1,2,4,8 | 12 Bits | ← N/A → | | |
| RTI-732 | Analog Input/Output | 16SE/8D | 32SE/16D | 1,2,4,8 | 12 Bits | 2 | 12 Bits | 2 |
| RTI-732-V | Analog Input/Output | 16SE/8D | 32SE/16D | 1,2,4,8 | 12 Bits | 2 | 12 Bits | – |
| RTI-724 | Analog Output | ← N/A → | | | | 4 | 12 Bits | 4 |
| RTI-724-V | Analog Output | ← N/A → | | | | 4 | 12 Bits | – |

*RTI-711/724/732 Functional Chart*

**MULTIBUS RMX-80 is a trademark of Intel Corporation.**

**This two-page data summary contains key specifications to speed your selection of the proper solution for your application. Additional information on this product can be obtained from your local sales office.**

# SPECIFICATIONS (typical @ 25°C with nominal supply voltage unless otherwise noted)

| | |
|---|---|
| **ANALOG INPUT (RTI-711, 732)** | |
| Number of Input Channels | 16 Single-Ended or 8 Differential (Jumper Selectable) Expandable to 32 Single-Ended or 16 Differential Using Two Plug-In Multiplexers (ADI P/N OA10) |
| Input Overvoltage Protection[1] | ±35V (Dielectrically Isolated) |
| Input Impedance | $>10^8\Omega$ |
| Input Bias Current | ±50nA |
| Analog Connector | 50 pin (Mating Connector 3M #3415-000) |
| A/D Input Voltage Ranges[2] | 0 to +5V, 0 to +10V, ±5V, ±10V |
| A/D Resolution | 12 Bits (4096 Counts) |
| A/D Output Codes[2] | Binary, Offset Binary, Two's Complement |
| Instrumentation Amplifier Gain Ranges | 1, 2, 4, 8 (Software Programmable) |
| A/D Conversion Speed | 40kHz |
| System Accuracy[3] | 0.05% FSR ±1/2LSB (Gain = 1)<br>0.07% FSR ±1/2LSB (Gain = 2,4,8) |
| System Temperature Coefficient | 0.0025% FSR/°C (Gain = 1)<br>0.0030% FSR/°C (Gain = 2,4,8) |
| Common Mode Rejection (CMR) | 60dB (Differential Input) |
| Common Mode Voltage (CMV) | ±10.24V (Signal Plus Common Mode) |
| System Throughput[4] | |
| Sample Rate (Single Channel) | 33,000 Channels/sec |
| Channel to Channel Rate | 25,000 Channels/sec |
| External Trigger | TTL Compatible, 1.5μs (min) Pulse Width |
| Pacer Clock | Crystal Controlled Accuracy 0.05%<br>Divider Range of $\frac{1000}{2^n}$ ms where n = 0 to 10 |

| | |
|---|---|
| **ANALOG OUTPUT (RTI-724, 732)** | |
| Number of Output Channels | 4 (RTI-724)<br>2 (RTI-732) |
| D/A Resolution | 12 Bits |
| D/A Input Codes[2] | Binary, Offset Binary, Two's Complement |
| Output Voltage Ranges[2] | 0 to +5V, 0 to +10V, ±5V, ±10V @ ±5mA |
| Output Current Range (RTI-724, 732) | 4-20mA |
| Output Connector | 50 Pin (Mating Connector 3M #3415-000) |
| Slew Rate | 10V/μs |
| Accuracy[3] | 0.05% FSR ±1/2LSB |
| Temperature Coefficient | ±50ppm of FSR/°C |
| INTERFACE PARAMETERS | |
| Compatibility | Meets all Electrical and Mechanical MULTIBUS (IEEE-796) Specifications |
| Implementation | Memory Mapped I/O Compatible With all CPUs |
| Addressing | Reserved a Block of Contiguous Memory Locations Relative to a Jumper Selectable Memory Base Address |
| POWER REQUIREMENT | |
| RTI-711 | +5V ±5% 0.8A |
| RTI-724 | +5V ±5% 0.6A |
| RTI-732 | +5V ±5% 1.2A |
| TEMPERATURE RANGE | |
| Operating | 0 to +70°C |
| Storage | −55°C to +85°C |
| RELATIVE HUMIDITY | Meets or Exceed MIL-STD-202 Method 103 |

NOTES
[1]Specified with power applied, ±20V with power off.
[2]User selectable with wire-wrap jumpers.
[3]Includes 3 sigma noise, linearity, offset gain and dynamic response errors.
[4]Assuming 8MHz CPU clock includes time required to transfer data from RTI to system memory.

Specifications subject to change without notice.

# ANALOG DEVICES

# Low Cost, STD Bus Compatible Analog I/O Subsystems

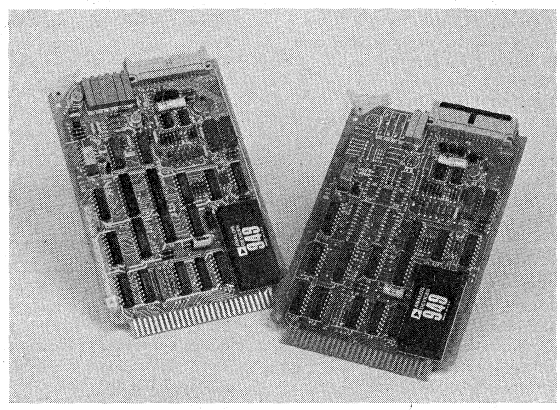
## RTI-1225/1226

**FEATURES**
**RTI-1225 ANALOG INPUT/OUTPUT CARD**
**16 Single-Ended/8 Differential Input Channels**
**2 Output Channels**
**10-Bit A/D and 8-Bit D/A Resolution**

**RTI-1226 ANALOG INPUT CARD**
**16 Single-Ended/8 Differential Input Channels**
**10-Bit A/D Resolution**

**GENERAL**
**Low Cost**
**Single +5V Power Requirement**
**Memory Mapped or I/O Selectable**
**Compatible with All STD CPU Cards**

*NEW FEATURE*
*Memory Mapped or Port I/O Selectable*



### SERIES DESCRIPTION

Analog Devices' RTI-1225 series products handle analog inputs and outputs for STD Bus microcomputer systems. These subsystems provide a cost effective solution to interfacing with the analog world by minimizing the hardware development time and providing low function cost.

The RTI-1225 combines both analog input and output functions on a single card, thus reducing components count. This design provides data acquisition of analog signals from 8 differential or 16 single-ended, jumper-selectable voltage inputs and 2 independent voltage outputs. Also included is a differential amplifier, a sample and hold circuit and a 10-bit A/D converter (AD571). Throughputs of 25,000 channels per second are achievable. The analog output section consists of two 8-bit D/A converters. Each channel has a user selectable output range of 0 to +10V, ±5V and ±10V.

The RTI-1226 Analog Input Card provides the same analog functions as the RTI-1225, but does not include the two channels of 8-bit analog output. An ideal choice when only analog inputs are required, this card can be configured for 0 to +10V, ±5V and ±10V input ranges.

Reliable analog connections are made using 3M's "Scotchflex" socket and header connectors which enable a flat ribbon cable to be combined with gas tight and corrosion resistant connectors. An optional screw termination panel is also offered for simple and convenient field wire connections.

The RTI-1225 series cards come complete with their own dc/dc converters, allowing the cards to operate directly from the microcomputers +5V supply. Configured as a block of contiguous memory locations (memory mapped interface), these products simplify the task of interfacing STD Bus microcomputers to the real world.

| | | INPUT | | OUTPUT | |
|---|---|---|---|---|---|
| Card Type | Model No. | Channel Capacity | A/D Resolution | Channel Capacity | D/A Resolution |
| Analog Input/ Output | RTI-1225 | 16SE/8D | 10 Bits | 2 | 8 Bits |
| Analog Input | RTI-1226 | 16SE/8D | 10 Bits | ← N/A → | |

*RTI-1225/1226 Function Chart*

17

This two-page data summary contains key specifications to speed your selection of the proper solution for your application. Additional information on this product can be obtained from your local sales office.

# SPECIFICATIONS (typical @ 25°C with nominal supply voltage unless otherwise noted)

| | |
|---|---|
| INPUT | |
| Number of Output Channels | 16 Single-Ended or 8 Differential (Jumper Selectable) |
| Input Overvoltage Protection[1] | ± 35V (Dielectrically Isolated) |
| Input Impedance | $>10^8\Omega$ |
| Input Current | ± 50nA |
| Input Voltage Ranges[2] | 0V to + 10V, ± 5V, ± 10V |
| Input/Output Connector | 3M #3493, 34 pin |
| A/D Resolution | 10 Bits (1024 Counts) |
| A/D Output Codes[2] | Binary, Offset Binary, Two's Complement |
| Instrumentation Amplifier Gain Range | 1V/V |
| A/D Conversion Time | 25µs |
| System Throughput | 25,000 channels/sec |
| Common Mode Voltage (CMV) | ± 10V min |
| Common Mode Rejection (CMR) | 60dB |
| Linearity | ± 1/2LSB |
| Differential Nonlinearity | ± 1/2LSB |
| Total System Error (Adjustable to Zero) | ± 0.1% of FSR |
| Temperature Coefficient | |
| Gain | ± 50ppm/°C of FSR (Full Scale Range) |
| Offset | ± 25ppm/°C of FSR |
| OUTPUT (RTI-1225 Only) | |
| Number of Output Channels | 2 |
| D/A Resolution | 8 Bits (256 Counts) |
| D/A Input Codes[2] | Binary, Offset Binary, Two's Complement |
| Output Voltage Ranges | 0V to + 10V, ± 5V, ± 10V @ 5mA |
| Output Settling Time | 25µs (to ± 1/2LSB) |
| Nonlinearity | ± 1/2LSB |
| Differential Nonlinearity | ± 1/2LSB |
| Total Error (Adjustable to Zero) | ± 0.4% |
| Temperature Coefficient | |
| Gain | ± 50ppm/°C of FSR |
| Offset | ± 30µV/°C |
| INTERFACE PARAMETERS | |
| Compatibility | Meets all Electrical and Mechanical STD Bus Specifications |
| Implementation | Memory Mapped I/O Compatible with All CPU Types<br>Port Mapped I/O Compatible with 8080, 8085, 8086 and Z-80 Family of CPUs. |
| Address Selection | 5 Contiguous Bytes in a 16 Byte Block. (Jumper Selectable in Any One of 256 Locations in 64K of Memory Space.) |
| Port Selection | 5 Contiguous Ports in a 16 Port Block. (Jumper Selectable on Any 16 Port Boundary in Either an 8-Bit or 16-Bit Port Image.) |
| Expansion Options | MEMEX and IOEXP Fully Supported with Jumper Selectable Enable High, Enable Low and Ignore Expansion Options. |
| POWER REQUIREMENT | + 5V ± 5% @ 750mA<br>(On-Board dc/dc Converter Generates An Isolated ± 15V to Power the Data Acquisition Components) |
| TEMPERATURE | |
| Operating | 0 to + 70°C |
| Storage | − 55°C to + 85°C |
| RELATIVE HUMIDITY | Meets or Exceeds MIL-STD 202 Method 103 |

NOTES
[1]Specification with power applied, ± 20V with power off.
[2]User selectable with wire-wrap jumpers.
Specifications subject to change without notice.

## ORDERING GUIDE

| ADI Model No. | Description | Used On |
|---|---|---|
| Cards | | |
| RTI-1225 | Analog Input/Output Card | – |
| Mating Connectors | | |
| AC1562 | 34-pin flat cable connector with 3′ color coded cable | |
| | Analog Input/Output | RTI-1225 |
| | Analog Input | RTI-1226 |
| Screw Termination Panel | | |
| AC1585-3 | Screw terminal for field wiring. | RTI-1225/1226 |
| User's Manual* | | |
| AC1564 | User's Manual for RTI-1225/1226 | – |

*A user's manual is furnished with each shipment. Additional copies are available under this part number.

# Micromodule Motorola Compatible Analog I/O Subsystems

# MODELS RTI-1230, 1231, 1232

**FEATURES**

- Complete Analog I/O Systems for OEM Applications
- Motorola Micromodule and EXORcisor Compatible
- Memory Mapped I/O Interface
- Convenient Address and Features Selection
- 12-Bit ADC
- Direct Operation from ±12V, +5V Bus Power
- Analog Input Subsystem RTI-1230
  - Up to 32 Input Channels
  - Each Input Channel Protected to $V_{CC}$ +20 Volts
  - Software or Resistor Programmable Gain
  - Software Controlled EOC Interrupt
  - Auto Scan Capability
  - 0-20mA Current Loop Input
- Analog Combination I/O Subsystem RTI-1231
  - Same Analog Input Features Plus:
    - Two 12-Bit D/A Converters
    - 4 Quadrant Multiplication
    - On-Board or External Reference Capability
- Analog Output Subsystem RTI-1232
  - Four Independent 12-Bit Analog Outputs
  - Four Software Controlled, High Current Logic Driver Outputs
  - Optional 4-20mA Current Loop Converter Outputs
  - DAC and Logic Driver Reset
  - Remote Load Sensing

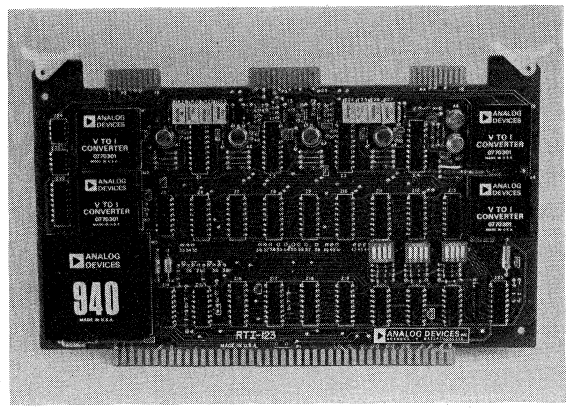
## SERIES DESCRIPTION

The RTI-1230 series are complete 12-bit analog I/O subsystems which are electrically and mechanically compatible with the Motorola EXORcisor Development System and Micromodule single board microcomputer. The series is comprised of an input only board (RTI-1230), an output only board (RTI-1232), and a combination I/O board (RTI-1231); each of which interfaces to the microcomputer as a block of 16 address locations (memory mapped interface). All data bus, control bus and address bus connections to the microcomputer are made by simply plugging the board into the computer card cage. The analog signals connect at the opposite board edge from the digital bus connector.

Many additional features and options reduce both the hardware and the software effort required to interface analog signals to the microcomputer, freeing the designer to spend more time and effort on his particular application.

## RTI-1230 ANALOG INPUT SUBSYSTEM

The basic function of the RTI-1230 input subsystem is to digitize analog signals and transfer the converted digital data to the microcomputer. The design includes protected input multiplexers, either a resistor-programmable-gain or a software programmable-gain instrumentation amplifier, a sample and hold amplifier, a 12-bit analog to digital (A/D) converter (RTI-1230-R and RTI-1230-S) and the associated digital interface logic.




## RTI-1231 COMBINATION ANALOG I/O SUBSYSTEM

The RTI-1231 provides the same analog input functions as the RTI-1230 *plus* two channels of high resolution, 12-bit analog voltage output. The 12-bit digital to analog converters are capable of full 4 quadrant multiplication. Four output voltage ranges can be jumper selected independently for each output channel, by using the on-board references.

## RTI-1232 ANALOG OUTPUT SUBSYSTEM

The RTI-1232 output subsystem provides 4 channels of 12-bit analog output and 4 high current, digital logic driver outputs. The four digital outputs are software controlled, open collector drivers capable of sinking 300mA and sustaining voltages up to +30V. They can be used to provide "ON/OFF" system functions for driving relays, solenoids, and valve control.

The DAC's used are 4 quadrant multiplying 12-bit DAC's. Each DAC input code and output range are jumper selectable.

The analog output channels can also be ordered with optional 4-20mA current loop outputs ideal for use in process and industrial control applications. These high compliance voltage to current (V/I) converter modules (P/N 0A08) meet all the requirements of ISA-S50.1 compatibility of signal for Type 3, Class L, nonisolated 4-20mA current loop transmitters.



**This two-page data summary contains key specifications to speed your selection of the proper solution for your application. Additional information on this product can be obtained from your local sales office.**

# SPECIFICATIONS (typical @ +25°C and +5V, ±15V unless otherwise noted)

| ANALOG INPUT | | | |
|---|---|---|---|
| Model Numbers - | Input Boards: | RTI-1230-R | RTI-1230-S |
| | Combo I/O Boards: | RTI-1231-R | RTI-1231-S |
| Input Channels: | Basic Board | 16 SE, 16 PD, 8 Diff. | * |
| | with On-Board Expansion | 32 SE, 32 PD, 16 Diff. | * |
| | with Off-Board Expansion | 256 Total | * |
| Input Range at Card Edge | | 10mV F.S. to ±10V F.S. | 0.625V F.S. to ±10V F.S. |
| Current Loop Inputs | | Resistor Selectable | * |
| Input Protection | | ±($V_{CC}$ +20V) | * |
| Switching Characteristics | | Break-Before-Make | * |
| Instrumentation Amplifier Gain | | Resistor Programmable | Software Programmable |
| Gain Range | | 1V/V to 1000V/V | 1, 2, 4, 8V/V |
| CMV Range | | ±10V min | * |
| CMRR (dc to 500Hz) | | 78dB min | * |
| Input Settling Time (G = 1) | | 15µs max | 10µs max |
| Input Impedance | | $>10^8\Omega$ | * |
| Input Bias Current | | ±50nA | ±5nA max |
| 0 to +70°C | | ±70nA max | ±50nA max |
| ADC Resolution | | 12 Bits | 12 Bits |
| Conversion Time | | 25µs max | * |
| Throughput Rate | | 40K Channels/sec | * |
| ADC Input Ranges | | ±5V, ±5.12V, ±10V, ±10.24V ±2.5V, +5V, +10V, +10.24V | * |
| ADC Output Codes | | BIN, OBN, 2SC | * |
| Nonlinearity Error | | ±1/2LSB typ (±1LSB max) | * |
| Offset Error | | Adj. to Zero | * |
| Offset TC (RTI) | | $\left(1+\frac{50}{G}\right)$ µV/°C | ±50µV/°C |
| Gain Error | | Adj. to Zero | * |
| Gain TC (RTI) | | ±25ppm of RDG./°C | * |
| Noise Error (G = 1) | | ±1/4LSB max | * |
| Overall Error (G = 1) | | ±1LSB max | * |
| Overall Error | | ±1LSB at G = 100 | ±1.5LSB at G = 8 |

| ANALOG OUTPUT | | |
|---|---|---|
| Model Numbers - | | |
| Combo I/O Boards: | RTI-1231-R, S | |
| Output Boards: | | RTI-1232 |
| Output Channels | 2 | 4 |
| DAC Resolution | 12 Bit | * |
| Nonlinearity Error | ±0.05% FSR | * |
| Settling Time for a 20V Step | 10µs max | * |
| Output Ranges | ±5V, ±10V, +5V, +10V | * |
| Output Current | 5mA @ 10V | * |
| Offset Error | Adj. to Zero | * |
| Offset TC | ±25µV/°C | * |
| Gain Error | Adj. to Zero | * |
| Gain TC | ±25ppm/°C | * |
| External Reference Range | −10V to +10V | * |
| Input Impedance | 10kΩ Each DAC | * |
| DAC Input Codes | BIN, OBN, 2SC | * |
| DAC Updating | Double Buffered | * |
| Load Sensing | Each DAC | * |

| CURRENT LOOP OUTPUTS (RTI-1232) | (Option P/N 0A08) |
|---|---|
| Type | ISA-S50.1, Type 3, Class L |
| Number | One per DAC |
| Output Current Range | 4-20mA (Nonisolated) |
| Supply Voltage Range | +15V to +30V |
| Load Resistance Range | 0Ω to 475Ω |
| Offset TC | ±0.4µA/°C |
| Gain TC | ±30ppm/°C |
| Nonlinearity | ±1/2LSB |
| Settling Time | 50µs max to 0.05% |

| DIGITAL OUTPUTS (RTI-1232) | |
|---|---|
| Type | Open Collector Peripheral Driver |
| Number | 4(Independently Controlled) |
| Current Range | 300mA max Sink Current at 0.1V |
| Supply Voltage Range | 30V max at the Collectors |

| MECHANICAL | |
|---|---|
| Size | 9.75" x 6.00" x 0.6" (247.6mm x 156.2mm x 15.2mm) |
| Weight | 14 oz (500gm) |

| TEMPERATURE RANGE | |
|---|---|
| Operating 0 to +70°C | 0 to +70°C |
| Storage | −25°C to +85°C |

NOTES
*Same specifications as for RTI-1231-R.
Specifications subject to change without notice.

POWER REQUIREMENTS

| Without dc-dc Option | Input Boards | Output Boards | Combo Boards | 0A08(2) |
|---|---|---|---|---|
| ±15V/±3% | 30mA | 50mA | 50mA | 10mA |
| −15V/±3% | 30mA | 40mA | 45mA | 2mA |
| +5V/±5% | 700mA | 350mA | 900mA | 0mA |
| With dc-dc Option | | | | |
| +5V/±5% | 1100mA | 950mA | – | - |

## ORDERING GUIDE

| MODEL NUMBER | DESCRIPTION |
|---|---|
| RTI-1230-R | Input Board with 12 Bit A/D and Resistor Programmable Gain Amplifier |
| RTI-1230-S | Input Board with Software PGA |
| RTI-1231-R | I/O Board with Resistor Programmable Gain Amplifier |
| RTI-1231-S | I/O Board with Software PGA |
| RTI-1232 | Output Board with 4 DAC's |
| **ACCESSORIES** | |
| 0A08 | 4–20mA V/I Module |
| 0A09 | DC-DC Converter |
| 0A10 | Multiplexer Expansion Kit |
| **CONNECTORS** | |
| AC1556 | 20 Pin, Card Edge* |
| AC1557 | 50 Pin, Card Edge* |
| AC1559 | 26 Pin, Card Edge* |

*ALL CONNECTORS HAVE 3' OF COLOR CODED CABLE ATTACHED

# TM990 Compatible Analog I/O Boards

## RTI-1240 Series

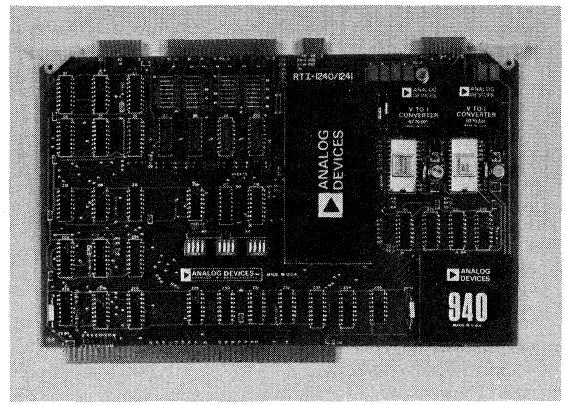
**FEATURES**

**RTI-1240 Input Board**
- 32SE/16D Input Channels
- Programmable Gain Amplifier
- 12-Bit A/D Resolution

**RTI-1241 Input/Output Board**
- (Same as RTI-1240 and Includes)
- 2 Output Channels
- 12-Bit D/A Resolution
- 4-20mA Current Loop Outputs (optional)

**RTI-1242, 1243 Output Boards**
- 4 or 8 Output Channels
- 12-Bit D/A Resolution
- 8 Logic Drivers

**GENERAL**
- Compatible to all TM990 Microcomputers
- Selectable 64K, 1M or 16M Address Space
- Single +5V Power Requirement (Optional)




The RTI-1240 Series boards provide a cost effective solution to interfacing to the real world and feature 12-bit resolution, programmable gain for low level signals, analog channel expansion, 4-20mA output, high current logic driver outputs and on-board power supplies.

### GENERAL DESCRIPTION

Analog Devices RTI-1240 Series are complete, 12-bit resolution, analog input, output and combination input/output subsystems that interface to any Texas Instruments TM990 Microcomputer Module. These boards provide analog measurement and control capability in a wide range of data acquisition and voltage actuated applications. These products simplify the task of interfacing a digital microcomputer to the analog world and incorporate design techniques which maximize the performance.

The series is comprised of an input board (RTI-1240), a combination input/output board (RTI-1241) and two output boards (RTI-1242, 1243); each of which interfaces to the TM990 microcomputer as a block of contiguous address locations (memory mapped interface). The boards are electrically and mechanically compatible to any TM990 microcomputer.

### APPLICATIONS

In a typical application there are several transducers which convert real world variables such as temperature, pressure, and flow into changing electrical units such as voltage, current and resistance. The analog input board allows the microcomputer to measure these varying signals. The computer collects and digitally processes the data and makes decisions based on these measurements according to programs stored in memory. The analog output board receives a digital word from the microcomputer and converts it into an analog signal that can be used to drive chart recorders, proportional valves, positioners, and motors.

| | | INPUT | | | | | OUTPUT | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Channel Capacity | | Gain Range | | A/D | Channel | D/A | 4-20mA |
| Model | Board Type | Standard | Optional | –S | –R | Resolution | Capacity | Resolution | Output |
| RTI-1240 | Analog Input | 16SE/8D | 32SE/16D | 1,2,4,8 | 1–1000 | 12 Bits | ← N/A → | | |
| RTI-1241 | Analog Input/Output | 16SE/8D | 32SE/16D | 1,2,4,8 | 1–1000 | 12 Bits | 2 | 12 Bits | 2 |
| RTI-1242 | Analog Output | ← N/A → | | | | | 4 | 12 Bits | – |
| RTI-1243 | Analog Output | ← N/A → | | | | | 8 | 12 Bits | – |

*RTI-1240 Series Functional Chart*

17

**This two-page data summary contains key specifications to speed your selection of the proper solution for your application. Additional information on this product can be obtained from your local sales office.**

# SPECIFICATIONS (typical @ +25°C and nominal supply voltage)

| | | |
|---|---|---|
| ANALOG INPUT (RTI-1240, RTI-1241) | | |
| Input Channels[1] | 16-Single Ended or 8 Differential<br>Expandable to 32-Single Ended or 16 Differential Using<br>two plug-in multiplexers (ADI P/N OA10) | |
| Input Overvoltage Protection | ±35V (Dielectrically Isolated) | |
| Input Impedance | $>10^8\Omega$ | |
| Input Bias Current | ±50nA max | |
| Input Connector | 50 pin (Mating Connector 3M#3415-000) | |
| A/D Input Voltage Ranges[1] | 0 to +10V, 0 to +10.24V<br>±5V, ±5.12V, ±10V, ±10.12V<br>0 to +5V, 0 to +10V, 0 to +10.12V | |
| A/D Resolution | 12 Bits (4096 Counts) | |
| A/D Output Codes[1] | Binary, Offset Binary, Two's Complement | |
| | **RTI-1240-R, RTI-1241-R** | **RTI-1240-S, RTI-1241-S** |
| Instrumentation Amplifier Gain Range | 1 to 1000V/V Resistor Programmable | 1, 2, 4, 8 V/V Software Programmable |
| System Accuracy | ±0.025% FSR max (Gain = 1)<br>±0.05% FSR max (G = 200) | ±0.025% FSR max (Gain = 1, 2, 4, 8) |
| System Temperature Coefficient | | |
| Offset Error (RTI) | $\pm\left(1+\frac{50}{G}\right)\mu V/°C$ | ±30μV/°C |
| Gain Error | ±25ppm of Reading/°C | ±20ppm of Reading/°C |
| Common Mode Rejection (CMR) | 76dB min | * |
| Common Mode Voltage (CMV) | ±10.24V (Signal Plus Common Mode) | * |
| System Throughput[2] | | |
| Single Channel Rate | 33,000 Conversions/sec | * |
| Channel to Channel Rate | 25,000 Channels/sec | * |
| A/D Conversion Speed | 40kHz | * |
| External Trigger | TTL Compatible, 1.5μs (min) Pulse Width | * |
| ANALOG OUTPUT (RTI-1241, RTI-1242, RTI-1243) | | |
| Number of Output Channels | 2 (RTI-1241)<br>4 (RTI-1242)<br>8 (RTI-1243) | |
| D/A Resolution | 12-Bits | |
| D/A Input Codes[1] | Binary, Offset Binary, Two's Complement | |
| Output Voltage Ranges[1] | 0 to +10V, 0 to +10V, ±5V, ±10V @ ±5mA | |
| Output Current Range[3] (Optional 2 Channel on RTI-1241 Only) | 4-20mA Using V/I Converter (P/N OA08) | |
| Nonlinearity | ±0.01% max | |
| Differential Nonlinearity | <1LSB | |
| Gain Error (adjustable to zero) | ±0.01% of FSR (Full Scale Range) | |
| Offset Error (adjustable to zero) | ±0.02% of FSR | |
| Temperature Coefficient | | |
| Gain | ±30ppm of FSR/°C | |
| Offset | ±25μV/°C | |
| Output Connector | 50 pin (Mating Connector 3M #3415-000) | |
| INTERFACE PARAMETERS | | |
| Compatibility | Meets all TM990 Module Mechanical and<br>Electrical Specifications | |
| Addressing | Memory Mapped I/O Module (64K, 1M or 16M byte address space) or parallel I/O | |
| Implementation | Reserves a Block of Contiguous Memory or Parallel I/O Locations Relative to<br>a jumper selectable base address. | |
| Power Requirements | | |
| Using OA09 | +5V ±5% @ 1.6A | |
| External Power | +5V ±5% @ 1.1A<br>+15V ±3% @ 50mA<br>−15V ±3% @ 40mA (RTI-1240)<br>−15V ±3% @ 80mA (RTI-1241, RTI-1242)<br>−15V ±3% @ 150mA (RTI-1243) | |
| TEMPERATURE | | |
| Operating | 0 to +70°C | |
| Storage | −55°C to +85°C | |

NOTES

*Specifications same as RTI-1240-R, RTI-1241-R.

[1]User selectable with wire-wrap jumpers.

[2]The effective throughput rate is determined by software data handling routine, processor type and gain setting.

[3]V/I converter requires +16V to +30V loop power.

Specifications subject to change without notice.

# DEC LSI-11 LSI-11/2 and LSI-11/23 Compatible Analog I/O Subsystems

## MODELS RTI-1250, 1251, 1252

**FEATURES**

**Complete Analog I/O Subsystems**
**Digital Equip. Corp. 16-Bit LSI-11/2 and 11/23 Compatibility**
**Memory Mapped I/O Interface**
**12-Bit Resolution and Accuracy**
**Single +5V Power Requirement**
**4-20mA Current Loop I/O Capability**
**Convenient Wire Wrap Feature Selection**

**RTI-1250 Analog Input Subsystem**
- **16 Input Channels – Expandable On-Board to 32 Channels**
- **Input Overvoltage Protection to ±35 Volts**
- **Resistor or Software Programmable Gain Amplifier**
- **Software Control of Interrupt, Channel Scanning and External Trigger**

**RTI-1251 Analog I/O Subsystem**
- **16 Input Channels and 2 12-Bit Analog Output Channels**
- **Four Quadrant Multiplying DAC's**
- **On-Board Reference**

**RTI-1252 Analog Output Subsystem**
- **2- or 4-, 12-Bit Analog Output Channels**
- **Field Expandable from 2 to 4 DAC Outputs**
- **4 High Current Digital Logic Drivers**
- **Optional 4-20mA Current Loop Outputs**
- **Selectable DAC and Logic Driver Reset**

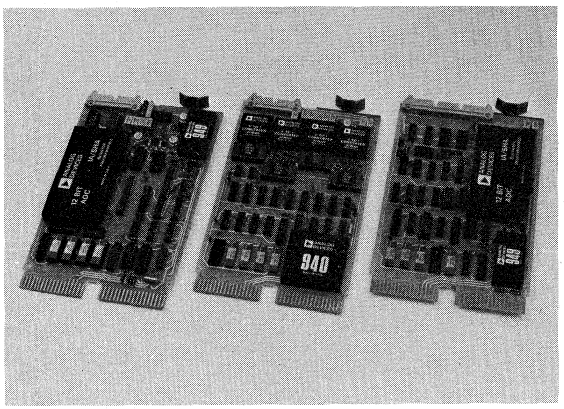
### SERIES DESCRIPTION

The RTI-1250 Series products are complete, 12-bit resolution, analog I/O subsystems which are electrically and mechanically compatible with the Digital Equipment Corp. LSI-11, LSI-11/2, and LSI-11/23 single board microcomputers. The series is comprised of an input only board, an output only board, and a combination I/O board; each of which interfaces to the microcomputer as a block of 4 address locations (memory mapped interface). All bus connections to the microcomputer are made by simply plugging the board into the computer card cage. The analog signals connect at the opposite board edge from the digital bus connector.

Many additional capabilities, features and options are included to reduce both the hardware and software effort required to interface analog signals to the microcomputer.

### RTI-1250 ANALOG INPUT SUBSYSTEM

The basic function of the RTI-1250 is to convert analog signals into a digital format and to present this digital data to the microcomputer. The design includes a protected input multiplexer for switching up to 32 single-ended inputs, either a software or resistor programmable gain instrumentation amplifier, a sample and hold amplifier, a 12-bit A/D converter and the associated digital interface logic.



### INPUT MULTIPLEXER

The RTI-1250 is available with up to 32 single-ended/16 differential protected input channels on board. The multiplexer (MUX) channel can be randomly selected by writing to the MUX ADDRESS BYTE in the memory map. Also, in the AUTO MUX INC mode the MUX can be automatically incremented to the next channel following the receipt of a convert command. This auto increment feature is enabled by a software command which allows sequential scanning and random channel addressing to be mixed under software control.

### INSTRUMENTATION AMPLIFIER/SAMPLE AND HOLD AMPLIFIER

The RTI-1250 is available with two types of instrumentation amplifiers (IA) which provide 12-bit compatible CMRR and CMV specifications. The software-programmable-gain (1-2-4-8) IA provides dynamic range expansion through subranging as well as the flexibility of using different gains for each input channel to accommodate different signal levels. The resistor-programmable gain IA may be used for input ranges from 10mV F.S. to ±10V F.S.

The sample and hold amplifier (SHA) allows sampling of high slew rate signals and is automatically switched to the hold mode upon receipt of a convert command. The RTI-1250 also has a built-in provision which delays the convert command to allow the input section to fully settle following a gain change or channel change. For very high gain applications, the convert command delay can be increased either through software or by addition of a single resistor.

17

**This two-page data summary contains key specifications to speed your selection of the proper solution for your application. Additional information on this product can be obtained from your local sales office.**

# SPECIFICATIONS (typical @ +25°C and nominal supply voltages unless otherwise noted)

| | INPUT ONLY BOARDS | | COMBINATION I/O BOARDS |
|---|---|---|---|
| **ANALOG INPUT** | | | |
| Model Numbers | RTI-1250-R | RTI-1250-S | RTI-1251 |
| Input Channels | | | |
| Basic Board | 16 SE, 16 PD, 8 Diff.[1] | * | * |
| Expansion On-Board | 32 SE, 32 PD, 16 Diff.[1] | * | None |
| FS Input Range[2] | ±10mVFS to ±10VFS | ±0.625VFS to ±10VFS | ±10mVFS to ±10VFS |
| Current Loop Inputs[3] | 0 to 50mA, 0-20mA, etc. | * | * |
| Input Protection | $\pm(V_{CC}$ +20V) | * | * |
| Mux Switching | Break-Before-Make | * | * |
| Input Impedance | $>10^8\,\Omega$ | * | * |
| Input Bias Current | ±50nA max | ±5nA max | ±50nA max |
| 0 to +70°C | ±70nA | ±50nA | ±70nA |
| Instrumentation Amplifier | Resistor Programmable Gain | Software Programmable Gain | Resistor Programmable Gain |
| Gain Range | 1 to 1000V/V | 1, 2, 4, 8V/V | 1 to 1000V/V |
| CMV Range | ±10V min | * | * |
| CMRR (dc – 500Hz) | 76dB min | * | * |
| Input Settling Time[4] | 20µs max (G = 1) | 15µs max (G = 1 to 8) | 20µs max (G = 1) |
| ADC Input Ranges | ±2.5V, ±5V, ±10V, 0 to 10V, 0 to 5V | * | ±5V, ±10V, 0V to +10V |
| Resolution | 12 Bits | * | * |
| Conversion Time | 25µs max | * | * |
| Throughput Rate[5] | 30,000 Channel/sec. | * | * |
| Output Codes[1] | Binary, Offset Binary, Two's Complement | * | * |
| Nonlinearity Error | ±1/2LSB typ (±1LSB max) | * | * |
| Offset Error[6] | Adj. to Zero | * | * |
| Gain Error[6] | Adj. to Zero | * | * |
| Offset TC | $\pm\left(1+\frac{50}{G}\right)\mu V/^\circ C$ (RTI) | ±30µV/°C (RTI) | $\pm\left(1+\frac{50}{G}\right)\mu V/^\circ C$ (RTI) |
| Gain TC | ±20ppm of rdg./°C (RTI) | ±25ppm of rdg./°C (RTI) | ±20ppm of rdg./°C (RTI) |
| Noise Error[7] | ±1/4LSB max | * | * |
| Overall Error @ G = 1[8] | ±1LSB max | * | * |
| SHA Aperture Delay | 90ns | * | * |
| SHA Aperture Width | 20ns | * | * |
| SHA Aperture Uncertainty | 5ns | * | * |

| | | |
|---|---|---|
| **ANALOG OUTPUT** | | |
| Model Number | RTI-1251 | RTI-1252-2 |
| Output Channels | 2 | 2 expandable to 4 |
| Resolution | 12 Bits | ** |
| Output Ranges[1] (with on board Ref) | +5V, +10V, ±5V, ±10V | +5V, +10V, ±2.5V, ±5V, ±10V |
| Output Current | ±5mA min. @ ±10V | ** |
| Nonlinearity Error | ±0.01% max | ±0.01% |
| Offset Error | Adj. to Zero | ** |
| Gain Error | Adj. to Zero | ** |
| Offset TC[10] | ±25µV/°C | ±25µV/°C |
| Gain TC[10] | ±25ppm/°C | ±15ppm/°C |
| Settling Time[8] (for 20V step to ±0.01%) | 10µs max | ** |
| Input Codes | Binary, Two's Complement, or Offset Binary | ** |
| Reference[11] | -10.00V or -5.00V | +6.3V ±2% |
| **OTHER OUTPUTS (RTI-1252 ONLY)** | | |
| Type | V/I Current Loop Converter (Option 0A08) | 4 Logic Drivers |
| Output Current Range[9] | ISA-S50.1, Type 3, Class L | Open Collector |
| Supply Voltage Range | 4-20mA | 300mA sink @ 0.7V |
| Input Voltage Range | +15V to +30V | +30V max |
| Offset Error | 0V to +10V | |
| Gain Error | Adj. to Zero | |
| Offset TC[12] | Adj. to Zero | |
| Gain TC[12] | ±0.4µA/°C | |
| Nonlinearity Error[12] (V/I Only) | ±30ppm/°C | |
| Settling Time[12] | ±0.01% max | |
| | 50µs max to 0.02% | |

| **POWER REQUIREMENTS** | | | | |
|---|---|---|---|---|
| Model Number | RTI-1250 | RTI-1251 | RTI-1252 | V/I (2) |
| +5V ±5% | 1.4A | 1.5A | 1.4A | 1.7A |

**MICROCOMPUTER INTERFACE**
Complies with D.E.C. bus loading and electrical specifications

| | |
|---|---|
| **TEMPERATURE RANGE** | |
| Operation | 0 to +70°C (0 - 95% RH non-condensing) |
| Storage | -55° C to +85°C |
| **MECHANICAL** | |
| Size | 5" X 8.5" (per D.E.C. Drawing) |
| Weight | 10 ounces |
| Connectors | See Ordering Guide |

*Same as for RTI-1250-R
**Same as for RTI-1251-R

Specifications subject to change without notice.

## ORDERING GUIDE

| MODEL NUMBER | DESCRIPTION |
|---|---|
| RTI-1250-R | Input Board with Resistor Programmable Gain Amplifier |
| RTI-1250-S | Input Board with Software Programmable Gain Amplifier |
| RTI-1251 | I/O Board with Resistor Programmable Gain Amplifier and Two Multiplying DAC's |
| RTI-1252-2 | Output Board with Two Trimmed DAC's |
| RTI-1252-4 | Output Board with Four Trimmed DAC's |
| **ACCESSORIES** | |
| 0A08 | 4-20mA V/I Module |
| 0A10 | Multiplexer Expansion Kit (2 ea. HI-0508A-5) |
| 0A12 | 12-Bit DAC for RTI-1252-2 |
| **CONNECTORS** | |
| AC1553 | 50 Pin, Flat Cable Connector* |
| AC1554 | 26 Pin, Flat Cable Connector* |
| AC1560 | 14 Pin, Dip Plug Connector* |

*All Connectors Have 3' of Color Coded Cable Attached

NOTES
[1] User selectable by wire-wrap jumpers.
[2] The full scale input signal range is the A/D converter range divided by the gain of the instrumentation amplifier.
[3] The user may install one resistor per channel (4 max with RTI-1251, 8 max with RTI-1250) to convert the input current to the proper voltage range. Any input current span can therefore be accommodated.
[4] This time can overlap A/D conversion period. The settling time increases to 50µs @ G = 1000.
[5] The effective throughput rate is determined by the user's software data handling capability. The max throughput rate listed is exclusive of the CPU interface operations which may or may not be completed during the subsystem's conversion time. The user's software and interface time must be added to the conversion time to determine the maximum effective throughput rate.
[6] For any one programmable gain setting, maximum offset shift of ±1LSB or gain shift of ±0.02% when using a programmable gain setting other than the one used during calibration.
[7] Noise error increased to ±1/2LSB max @ G = 8 for the SPG models and to ±1LSB @ G = 100 for the RPG models.
[8] Overall error increases to ±2LSB max @ G = 8 for the SPG models and 2LSB max @ G = 500 for the RPG models.
[9] The current loop load resistance range is 0Ω to 450Ω with a +15V supply. A load resistance of 500Ω may be used with >+18V supply.
[10] Temperature coefficients are specified for the ±10V full scale range.
[11] The on-board references are also available at the card edge. Users must limit any current load to less than 2mA. External reference inputs have an input impedance of greater than 5kΩ.
[12] Specified for V/I module only (P/N 0A08).

# ANALOG DEVICES

# High Performance STD Bus Compatible Analog I/O Subsystems

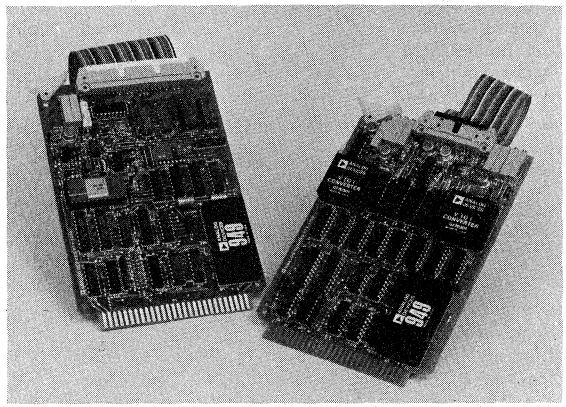
## RTI-1260/1262

**FEATURES**
**RTI-1260 ANALOG INPUT CARD**
**32 Single-Ended/16 Differential Channels**
**User Configurable Gains of 1 to 1000**
**12-Bit A/D Resolution**

*NEW FEATURE Memory Mapped or Port I/O Selectable*

**RTI-1262 ANALOG OUTPUT CARD**
**4 Analog Output Channels**
**12-Bit D/A Resolution**
**Optional 4-20mA Current Loop Outputs**

**GENERAL**
**Low Cost**
**Single +5V Power Requirement**
**Memory Mapped or Port I/O Selectable**
**Compatible with All STD CPU Cards**



### GENERAL DESCRIPTION

The RTI-1260 Series products from Analog Devices are high performance analog input and output cards compatible with the STD bus. They provide a cost effective and convenient means of interfacing your microcomputer to the real (i.e., analog) world. The cards feature 12-bit resolution, resistor programmable gain for low-level signals, analog channel expansion capabilities, 4-20mA outputs and on-board dc/dc converter.

The series consist of an analog input card (RTI-1260) and an analog output card (RTI-1262). The cards interface to the STD bus as either a memory mapped or an I/O port peripheral through a user-selection jumper option.

The RTI-1260 Analog Input Card provides data acquisition for 16 single-ended or 8 differential channels with optional expansion to 32 single-ended or 16 differential channels. The instrumentation amplifier is user configurable for gains of 1 to 1000. Combining this with a sample-hold circuit and 12-bit a/d converter, the data acquisition section features ±0.01% accuracy, 12-bit resolution and throughput rates up to 25kHz.

The RTI-1262 Analog Output Card uses four 12-bit d/a converters to provide independently programmed voltage output channels. In addition, two channels can be converted to 4-20mA outputs by using optional voltage-to-current modules which install on the board.

Reliable analog connections are made using 3M's "Scotchflex" socket and header connectors which enables a flat ribbon cable to be combined with gas tight and corrosion resistant connectors. An optional screw termination panel is also offered for simple and convenient field wire connections.

All cards have an operating temperature range of 0 to +70°C and come complete with dc/dc converter, allowing them to operate from the microcomputer's +5V supply.

### ORDERING GUIDE

| ADI Model No. | Description | Used On |
|---|---|---|
| Cards | | |
| RTI-1260 | Analog Input Card | – |
| RTI-1262 | Analog Output Card | – |
| Accessories | | |
| OA08 | V/I converter provides 4-20mA output from D/A. One required per channel. | RTI-1262 (2 max) |
| OA10 | Multiplexer Expansion Kit expands channel capacity from 16SE/8D to 32SE/16D. One required per board. | RTI-1260 |
| Mating Connectors | | |
| AC1553 | 50-pin flat cable connector with 3' color coded cable (Analog Input). | RTI-1260 |
| AC1554 | 26-pin flat cable connector with 3' color coded cable (Analog Input). | RTI-1262 |
| AC1585-6 | 3B01 to RTI-1260 | RTI-1260 |
| AC1585-7 | 3B01 to RTI-1262 | RTI-1262 |
| Screw Termination Panel | | |
| AC1585-1 | Screw terminal connection to field wiring. | RTI-1260 |
| AC1585-2 | Screw terminal connection to field wiring. | RTI-1262 |
| User's Manual* | | |
| AC1563 | User's Manual for RTI-1260/1262 | |

NOTE *A user manual is furnished with each shipment. Additional copies are available under this part number.

| | | INPUT | | | | OUTPUT | | |
|---|---|---|---|---|---|---|---|---|
| | | Channel Capacity | | | A/D | | D/A | 4-20mA |
| Card Type | Model No. | STD | OPT | Gain Range | Resolution | Channel Capacity | Resolution | (OPT) |
| Analog Input | RTI-1260 | 16SE/8D | 32SE/16D | 1-1000 | 12 Bits | ← N/A → | | |
| Analog Output | RTI-1262 | ← N/A → | | | | 4 | 12 Bits | 2 |

*RTI-1260/1262 Function Chart*

**This two-page data summary contains key specifications to speed your selection of the proper solution for your application. Additional information on this product can be obtained from your local sales office.**

# SPECIFICATIONS (typical @ 25°C with nominal supply voltage unless otherwise noted)

| | |
|---|---|
| **RTI-1260 ANALOG INPUT CARD** | |
| Number of Input Channels | 16 Single-Ended or 8 Differential (Jumper Selectable)<br>Expandable to 32 Single-Ended or 16 Differential Using<br>Two Plug-In Multiplexers (ADI Part #OA10) |
| Input Overvoltage Protection[1] | ±35V (Dielectrically Isolated) |
| Input Impedance | $>10^8\Omega$ |
| Input Bias Current | ±50nA |
| Analog Connector | 3M #3433, 50 pin |
| A/D Input Ranges[2] | 0 to +10V, ±10V |
| A/D Resolution | 12 Bits (4096 Counts) |
| A/D Output Codes[2] | Binary, Offset Binary, Two's Complement |
| Instrumentation Amplifier Gain Ranges | 1 to 1000V/V (Resistor Programmable Gain) |
| Gain Equation | $G = 1 + \frac{20k\Omega}{R_G}$ |
| A/D Conversion Time | 25µs |
| System Throughput[3] | 25,000 Channels/sec (G < 150)<br>20,000 Channels/sec (150 < G > 300)<br>11,000 Channels/sec (G = 1000) |
| Common Mode Voltage (CMV) | ±10V min |
| Common Mode Rejection (CMR) | 78dB |
| Linearity | ±1/2LSB |
| Differential Nonlinearity | ±1LSB |
| Total System Error (Adjustable to Zero) | ±0.01% of FSR (Gain = 1 to 10)<br>±0.05% of FSR (Gain = 100)<br>±0.1% of FSR (Gain = 1000) |
| Temperature Coefficient | |
| Gain | ±30ppm/°C of FSR (G = 1) |
| Offset | ±100ppm/°C of FSR (G = 1000)<br>±10ppm/°C of FSR (G = 1)<br>±100ppm/°C of FSR (G = 1000) |
| **INTERFACE PARAMETERS** | |
| Compatibility | Meets all Electrical and Mechanical STD Bus Specifications |
| Implementation | Memory Mapped I/O Compatible with All CPU Types<br>Port Mapped I/O Compatible with 8080, 8085, 8086 and Z-80 Family of CPUs |
| Address Selection | 3 Contiguous Bytes in a 16 Byte Block. (Jumper Selectable in Any One of 256 Locations in 64K of Memory Space.) |
| Port Selection | 3 Contiguous Ports in a 16 Port Block (Jumper Selectable on Any 16 Port Boundary in Either an 8-Bit or 16-Bit Port Image.) |
| Expansion Options | MEMEX and IOEXP Fully Supported with Jumper Selectable Enable High, Enable Low or Ignore Expansion Options. |
| **POWER REQUIREMENTS** | +5V ±5% @ 450mA (On-Board dc/dc Converter Generates an Isolated ±15V to Power the Data Acquisition Components.) |
| **TEMPERATURE** | |
| Operating | 0 to +70°C |
| Storage | −55°C to +85°C |

NOTES
[1]Specified with power applied, ±20V with power off.
[2]User selectable with wire-wrap jumpers.
[3]Does not include CPU latency time.
Specifications subject to change without notice.

# ANALOG DEVICES

# STD Bus Compatible Sensor Based Data Acquisition Subsystem

# RTI-1270 Series

**FEATURES**

**Direct Analog Connection**
- **Thermocouples, RTDs, mV and V Signals, Strain Gages, Process Currents (4-20mA)**

**Complete Signal Conditioning**
- **Input Protection, Filtering, Isolation, Amplification**
- **Cold Junction Compensation, Excitation**

**Microcomputer Based**
- **Linearization, Conversion to Engineering Units**

**Single +5V Power Requirement**

**APPLICATIONS**

**Industrial Process Control**
**Laboratory and Scientific Data Acquisition**
**Food Process Equipment**
**Medical Equipment**
**Production Machinery**
**Energy Monitoring**
**Data Logging**

## GENERAL DESCRIPTION

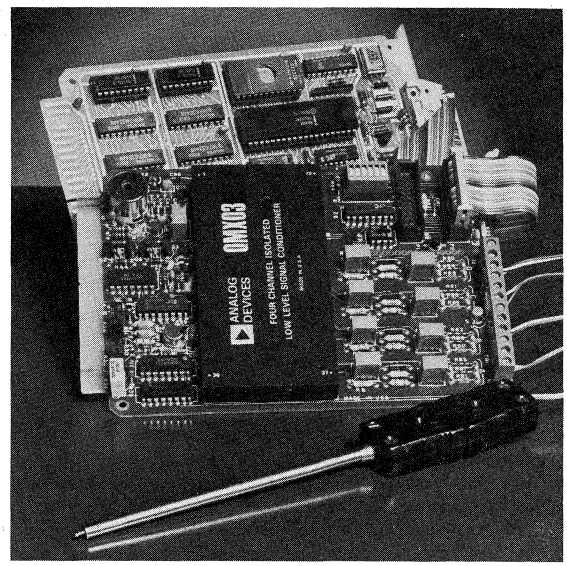
The RTI-1270 Series is the first easy-to-use, easy-to-implement analog subsystem optimized for temperature and low level signal measurements. This series consist of an RTI-1270 A/D-CPU Base card and two RTI-1271 Signal Conditioning/Multiplexer cards.

This subsystem is a complete solution to system integrators who must interface thermocouples (J, K, S, T, R, E, B, W type), RTDs (100Ω platinum), strain gage mV, V or mA signal to the STD bus in the presence of electrical noise, ground loops and high common mode voltages.

The RTI-1270 Subsystem include screw terminal connection, sensor signal conditioning, optional ±1000V isolation, 16-channel analog multiplexing, 13-bit A/D conversion, data manipulation (cold junction compensation, linearization, conversion to engineering units) and maps as a contiguous block of memory onto the STD bus.

All signal conditioning is already done with cold junction compensation provided for thermocouples and excitation for RTDs. The input data is scaled, linearized and converted to engineering units which allows you to simply connect your sensors via industrial screw terminals, plug the cards into the STD bus and go. Modular design permits the ability to mix and match on a four-channel bases and expand to a sixteen channel input subsystem.

The on-board intelligence performs all data acquisition control and preprocesses the data, thus reducing the software overhead by the STD bus host CPU. The RTI-1270 Subsystem requires a single +5V power supply and will operate with any STD bus system employing a Z80 or 8085 CPU.




## APPLICATIONS

The RTI-1270 Subsystem can be easily integrated into a broad range of industrial and laboratory measurement applications. Whether it be on-line food canning process monitoring or recording temperatures in a research lab, this subsystem is an ideal choice.

## USER BENEFITS

**Ease of Use:** Direct sensor interface via screw terminal connectors, output in engineering units provide fast and easy system implementation.

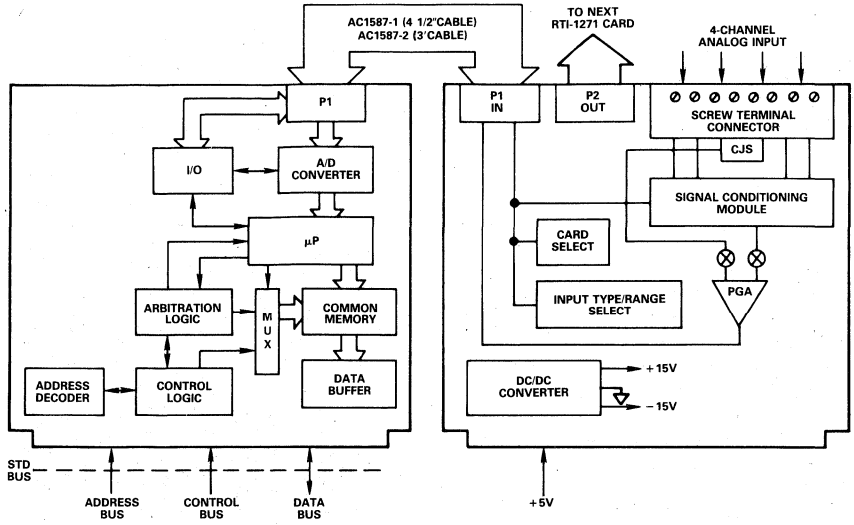
**Integral Signal Conditioning:** High quality signal conditioning provides input protection and isolation, cold junction compensation for thermocouples, RTD excitation, and sensor linearization and scaling, eliminating the need for expensive external signal conditioning.

**Flexible:** Modular design allows the mix and match of different input types on a four-channel basis and up to sixteen analog signals per subsystem.

**Reliability:** State-of-the-art design combines high performance with reliability using transformer-isolated analog input multiplexers. This provides common mode voltages of ±1000V and normal mode input protection to 130V rms.



**This two-page data summary contains key specifications to speed your selection of the proper solution for your application. Additional information on this product can be obtained from your local sales office.**




**RTI-1270**
**A/D-CPU BASE CARD**

**RTI-1271**
**SIGNAL CONDITIONING CARD**

*Figure 1. Functional Block Diagram*

## FUNCTIONAL DESCRIPTION

### RTI-1270 SUBSYSTEM

The RTI-1270 and RTI-1271 are a multicard subsystem which interfaces analog signals to the STD bus. The subsystem consists of an RTI-1270 A/D-CPU base card and up to four RTI-1271 signal conditioning/multiplexer cards. All cards are electrically and mechanically compatible with the STD bus with the exception being the RTI-1271's component height. This requires the use of a backplane with 0.75" spacing or the use of two card slots.

The RTI-1271-A and RTI-1271-B are signal conditioning/multiplexer cards which accommodate a wide range of input ranges and signal types. Each card accepts 4 differential analog signals and provides analog signal conditioning for the RTI-1270. These high performance signal conditioning cards include input protection, isolation (RTI-1271-B) and common mode rejection, multiplexing, filtering and amplification. The cards can be configured to accept a wide range of inputs by simple DIP switch programming. Connection to the RTI-1270 is made through a flat 20-pin ribbon cable.

The RTI-1270 base card is the heart of the subsystem. It includes the A/D converter, a μP and bus interface logic. The 13-bit, integrating A/D converter offers excellent noise immunity of 50/60Hz noise pickup and can be set to continuously convert at either 15 or 30 conversions per second. The onboard μP runs independent of the STD bus host and controls all data acquisition functions. The resultant data, stored in 1k of common RAM can then be read by the STD CPU HOST.

### RTI-1271 SIGNAL CONDITIONING CARD SELECTION

All four channels of the RTI-1271 are dedicated to a single input range and accept the input ranges listed in Table I. The specific input range/type for the individual cards is switch selectable. Upon initialization, the switch is read by the μP and its code is stored in RAM. This information is used to direct the execution of linearization and unit conversion routines. Although the input range/type cannot be mixed on a card, several RTI-1271 cards each having a different input can be supported by the RTI-1270 A/D-CPU card.

| Input Type/Span | Signal Conditioning Card RTI-1271-A (Nonisolated) | RTI-1271-B (Isolated) |
|---|---|---|
| dc, ±25mV, ±50mV, ±100mV | √ | √ |
| dc, ±1V, ±5V, ±10V* | √ | √ |
| dc 0-1mA, 0-20mA, 4-20mA** | √ | √ |
| Type J,K,S,T,R,E,B,W Thermocouple | √ | √ |
| 100Ω Platinum RTD | √ | |
| Strain Gage ±30mV, ±100mV Inputs | √ | |
| AD590, AC2626 Temperature Sensor | √ | |

*Requires resistor divider kit.
**Requires shunt resistor kit.

*Table I. Signal Conditioning Card Selection*

### Isolated vs. Nonisolated Inputs

The RTI-1270-A accepts many of the same input types/ranges as the RTI-1271-B; however, the RTI-1271-B includes ±1000V isolation to eliminate ground loops and solve common mode voltage problems. A reliable transformer isolation design is used and the analog inputs meet the IEEE Standard for transient voltage protection (472-1974:SWC). This card is recommended for industrial applications such as measuring grounded thermocouples.

### Analog Connections

The RTI-1271 provides the signal conditioning for a wide range of sensor and analog input ranges. Field wiring connections are made by means of industrial screw terminals which handle up to 14 gauge wire. A temperature sensor is mounted next to the screw terminal to monitor the temperature and provide cold junction compensation for thermocouple inputs.

### Signal Conditioning

The RTI-1271 is optimized for high performance measurements by providing normal mode input protection (130V rms), ±1000V common mode voltage isolation (RTI-1271-B), low pass filtering and low drift amplification. Signal integrity is further preserved by excellent normal mode rejection and high immunity to electromagnetic fields and RFI.

# μMAC-4000

**FEATURES**

**Analog Inputs**
- **Thermocouples, RTDs, Strain Gages, AD590s**
- **High and Low Level Voltages, Current Loops**
  - **±1000V Isolated and Nonisolated**

**Analog Outputs**
- **Voltage and Current**
  - **±1000V Isolated and Nonisolated**

**Digital Inputs/Outputs**
- **Contact Closures**
- **ac and dc Signals (High and Low Level)**

**Microcomputer Based**
- **Linearization, Unit Conversion, Limit Checking**
- **Powerful Command Set**

**Serial Communications**
- **20mA or RS-232C**

**Integral Power Supply**
- **ac or +24V dc**

## GENERAL DESCRIPTION

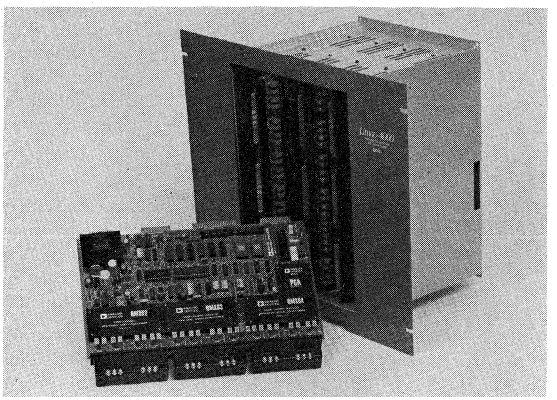
The μMAC-4000 Measurement and Control System is a complete, low cost solution designed to simplify process to computer interface in a wide range of industrial automation applications.

The μMAC-4000 offers an unprecedented set of hardware and software capabilities that can be easily tailored to virtually any automation application. Modular design permits expansion within the system and the flexibility to accept a variety of analog and digital input and output functions.

The μMAC-4000 is optimized for high performance measurement and control. Analog inputs handling capability offers reliable operation in harsh, electrically noisy, industrial environments. The high performance is assured by high quality signal conditioning featuring input protection, ±1000V channel-to-channel and input-to-output isolation, high common mode rejection, filtering, low drift amplification and 13-bit A/D conversion. A unique plug-in module approach allows the selection of standard signal conditioning modules for direct connection to a wide range of sensors. The μMAC-4000 scales, linearizes and converts the input data to engineering units.

Both analog and digital control capability is provided by the μMAC-4000 system. Analog outputs feature 12-bit resolution, voltage and 4-20mA/0-20mA current outputs with ±1000V isolation, as well as increment/decrement and bumpless transfer for precise control in either manual or computer mode. Digital I/O offers direct interface to contact closures, TTL levels or high level ac and dc voltages.

The μMAC-4000 system is designed to operate with any host computer which has a 20mA or RS-232C serial port. The μMAC-4000 can be either used as a local front end or located up to 10,000 feet from the host. A powerful command set is included in the μMAC's firmware which allows control via the serial interface bus. Once the command is executed, the results are transmitted back to the host in an ASCII format–at speeds up to 9600 baud.



The μMAC-4000 system requires either ac line power or +24V dc. Circuitry is provided to detect intermittent ac power losses and switch automatically to an external battery backup mode.

A wide variety of packaging options are available to match user requirements. These options include single board enclosures, card cage/rack mounting or NEMA enclosures.

## APPLICATIONS

The μMAC-4000 is a versatile, self-contained measurement and control system designed for a broad range of industrial and laboratory applications. It is extremely useful in both control room and remote locations where monitoring and control of temperature, pressure, flow, analog and digital signals are required.

## DESIGN FEATURES AND USER BENEFITS

**Ease of Use:** Direct sensor interface via screw terminal connectors, output in engineering units, powerful command set, make the μMAC-4000 extremely easy to use.

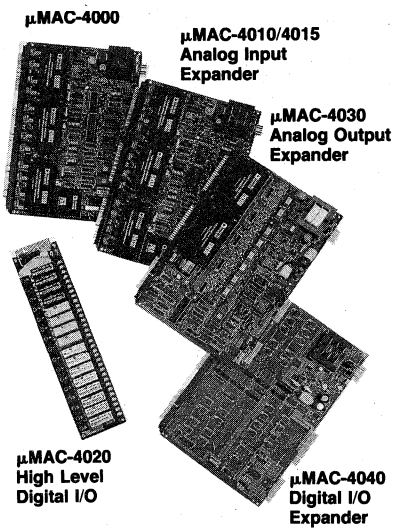
**Integral Signal Conditioning:** High quality signal conditioning provides input protection and isolation, cold junction compensation for thermocouples, RTD excitation, and sensor linearization and scaling, eliminating the need for expensive external signal conditioning.

**High Noise Rejection:** The μMAC-4000 preserves high system accuracy in electrically noisy environments, providing excellent common mode and normal mode noise rejections and RFI/EMI immunity.

**Control Capability:** Analog and digital outputs are provided to control motor speeds, dictate valve positions and drive actuators.

Features such as isolation, bumpless transfer and DAC readback are included in the design.

**Expandability:** Expansion capability to 384 analog input channels, 256 analog output channels, 1088 digital inputs and 1088 digital outputs on one 20mA serial line using the μMAC-4000 with expander boards.

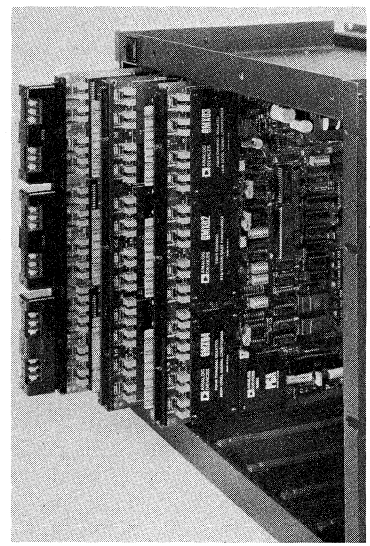



### μMAC-4000 System Configuration

The μMAC-4000 system consists of a family of boards providing the measurement and control functions through interfaces to analog and digital inputs and outputs and the host computer.

The system includes: the μMAC-4000 Master Board, the μMAC-4010 Analog Input Expander, the μMAC-4030 Analog Output Expander, the μMAC-4040 Digital I/O Expander, and the μMAC-4020 High Level Digital I/O Subsystem. You select only the functions which are required.

A typical configuration can consist of a single μMAC-4000 Master Board which accepts 4, 8 or 12 analog inputs and includes 8 digital inputs and 8 digital outputs. A multiple board configuration (cluster) consists of one μMAC-4000 Master Board and up to six Expander Boards selected in any combination from up to three μMAC-4010's and/or μMAC-4015's, up to four μMAC-4030's and up to four μMAC-4040's. A μMAC-4000 Master Board must reside in each cluster since it contains the communications and intelligence.



## μMAC-4000 System Specifications

### INPUT/OUTPUT

**Analog Inputs**
Thermocouples: J, K, T, S
RTDs: 100Ω Platinum
Solid State Temperature Sensors: AD590 or AC2626
Strain Gage Transducers: ±30mV and ±100mV spans
dc Voltage: ±25mV, ±50mV, ±100mV, ±1V, ±5V, ±10V
dc Current: 4 to 20mA, 0 to ±1mA, 0 to ±20mA
Common Mode Voltage: ±1000V pk (chan/chan/gnd)–isolated input modules
Input Protection: 130V rms continuous IEEE-472 (SWC) transient
A/D Converter: 13-Bit Dual Slope
Scan Rate: 15 or 30 chan/sec

**Analog Outputs**
Voltage: ±5V, ±10V 0 to ±15V, 0 to ±10V
Current: 4 to 20mA, 0 to 20mA
Resolution: 12-Bits
Isolation: ±1000V pk (chan/chan/gnd)–current outputs
Output Protection: 130V rms

**Digital Inputs**
Compatibility: TTL signals or contact closures and μMAC-4020 for high level inputs
Isolation: ±300V pk

**Digital Outputs**
Compatibility: TTL signal and μMAC-4020 for high level outputs

**Channel Capacity per Board**
**μMAC-4000 and μMAC-4010**
12 Analog Inputs
8 Digital Inputs
8 Digital Outputs
**μMAC-4015**
12 Analog Inputs
**μMAC-4030**
8 Analog Outputs
**μMAC-4040**
32 Digital Inputs
32 Digital Outputs
**μMAC-4020**
16 High Level Digital Inputs and Outputs

**Capacity per Cluster**
48 Analog Inputs
32 Analog Outputs
152 Digital Inputs
152 Digital Outputs

**Total System Capacity**
8 addressable clusters on one serial communication port

### COMMUNICATIONS

Mode: 4 wire full duplex
20mA current loop or RS-232C
Format: Serial Asynchronous ASCII
Rate: Selectable from 110 to 9600 baud
Distance: RS-232C: 50 ft (15m)
20mA, 10,000 ft (3048m)
Protocol: Command/Reply (prompted)

### POWER

100/115/220/240V ac, 50/60Hz or +24V dc

### MECHANICAL

Single Board: 9.5″ × 13″ (241.3 × 330.2mm)
4-Slot Card Cage: 14.8″ × 11.2″ × 10.3″ (376.0 × 284.5 × 261.6mm)
7-Slot Card Cage: (15.75″ × 19″ × 11″ (400.0 × 482.6 × 279.4mm)

### ENVIRONMENTAL

Operating Temperature: 0 to +60°C
Humidity: meets MIL-STD 202, Method 103
Vibration: meets MIL-STD 167-1
Magnetic Field Immunity: 200 gauss
RFI Immunity: 5W @27MHz @3 ft.

ANALOG DEVICES

# Complete BASIC Programmable Stand-Alone Measurement and Control System

# μMAC-5000

## FEATURES/BENEFITS

**Low Cost, Completely Integrated Measurement and Control System On a Single Board**

- **Wide Selection of Functionally Complete Analog and Digital I/O**
- **Operates from ac or dc Power**

**Integral Signal Conditioning Allows Direct Connection to a Wide Variety of Signal Sources**

- **Sensors: Thermocouples, RTDs, Strain Gages, Load Cells, AD590/AC2626**
- **Millivolt and Voltage Sources**
- **4-20mA/0-20mA Process Current Inputs**
- **Counter or Pulse Inputs Provide for Frequency or Event Counting**

**Powerful Measurement and Control μMACBASIC Language**

- **Programs Developed and Run On Board**
- **Analog and Digital I/O Are Performed By Key Words In BASIC**
- **Program Storage in PROM or Battery Backed-Up RAM**

**Advanced μMACBASIC Features**

- **Functions and Procedures Allow User Defined Key Words**
- **Advanced Block Structures Allow Modular, Self-Documenting Programs**

**Powerful Communications Capabilities**

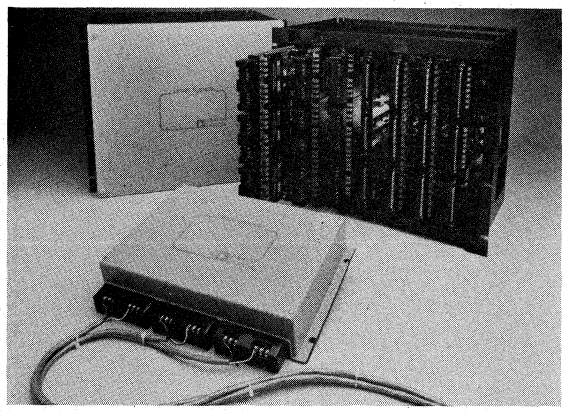
- **Supports Communications in RS-232C, 20mA, RS-422 and RS-423**
- **Supports Asynchronous Communications**
- **Protocol Emulation Easily Accomplished with μMACBASIC**

## GENERAL DESCRIPTION

The μMAC-5000 Measurement and Control System is a complete, low cost solution designed to solve a broad range of industrial measurement and control problems. It can be used in applications requiring distributed intelligence or as a local front end.

The μMAC-5000 offers an unprecedented set of hardware and software capabilities that can be easily tailored to virtually any measurement and control application. Modular design permits expansion within the system and the flexibility to accept a variety of analog and digital input and output functions. A powerful Measurement and Control BASIC language, μMACBASIC, is provided with each product.

The μMAC-5000 is optimized for high performance measurement and control. Analog input handling capability offers reliable operation in harsh, electrically noisy, industrial environments. The high performance is assured by high quality signal conditioning featuring input protection, ±1000V channel-to-channel and input-to-output isolation, high common mode noise rejection,



filtering, low drift amplification and 14-bit A/D conversion (13 bits + sign). A unique plug-in module approach allows the selection of standard signal conditioning modules for direct connection to a wide range of sensors. The μMAC-5000 scales, linearizes and converts the input data to engineering units.

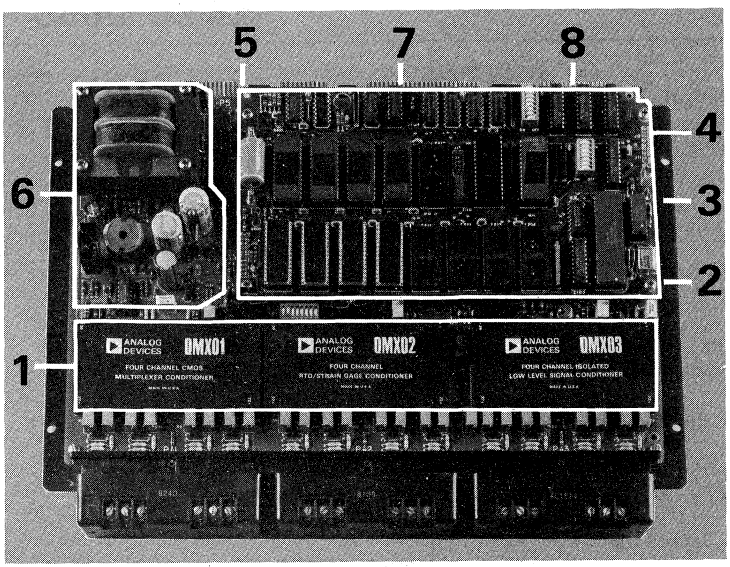
Both analog and digital control capability are provided by the μMAC-5000 system. Analog outputs, provided by the μMAC-4030 Analog Output Expander, feature 12-bit resolution, voltage and 4-20mA/0-20mA current outputs with ±1000V isolation, as well as the capability of either auto or manual operation with bumpless transfer and programmable slew rate. Digital I/O offers direct interface to contact closures, TTL levels or high level ac and dc voltages. Two pulse accumulator or frequency inputs are available on each μMAC-5000 and both have a 32-bit counter and operate over a 0 to 20kHz frequency range.

The μMAC-5000 board is designed to operate efficiently in stand-alone applications. The μMAC-5000, which has two serial ports, can be used with any host computer. The local port can communicate in RS-232C, RS-422, or RS-423 and is primarily used for program development or for supporting a local printer or terminal. The remote port supports RS-232C, 20mA, RS-422, and RS-423. In supervisory control applications, the μMAC-5000 can be used either as a local front end or located up to 10,000 feet from a host and can operate at speeds up to 19.2K baud in an asynchronous mode.

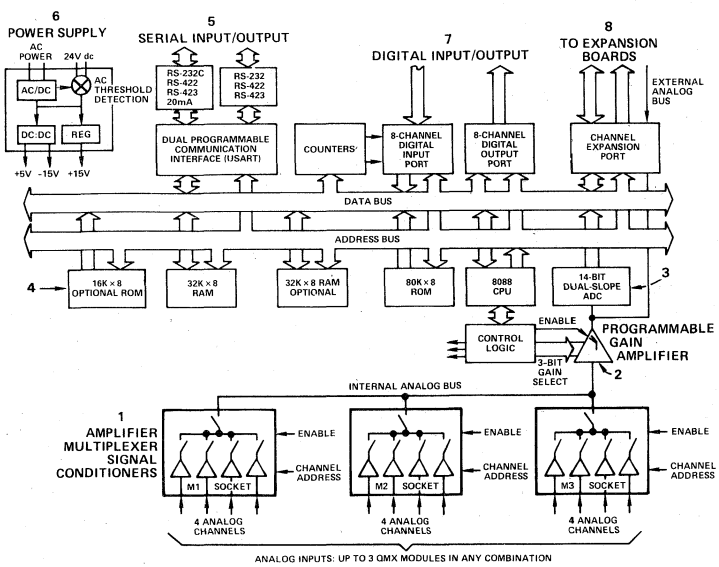
The μMACBASIC language was designed to address the needs of both the experienced and inexperienced programmers. The language provides the less experienced programmer with a powerful version of the popular BASIC programming language which allows programmers with only a fundamental knowledge of BASIC to easily write programs. μMACBASIC also provides the experienced programmer with a truly modular, structured language which simplifies the task of writing larger, more complex programs and provides higher quality programs.

18

**This four-page data summary contains key specifications to speed your selection of the proper solution for your application. Additional information on this product can be obtained from your local sales office.**




Photograph of the µMAC-5000, showing the system architecture.




System functional block diagram.

**LEGEND**

1) **Multiplexed Signal-Conditioning Modules.** Three plug-in 4-channel signal conditioning modules provide multiplexing, preamplification, and optional transformer isolation and bridge excitation. Four mix-matchable module types are available to handle many input sources: thermocouples, RTDs, strain gages, 4-20mA current loops, and millivolt, volt, and milliampere signals.

2) **Programmable-Gain Amplifier (PGA).** Digital logic sets the gain of the PGA to amplify the preamplified input signal to the full-scale range of the a/d converter (hidden).

3) **A/D Converter.** An integrating converter provides resolutions from 14 bits (13 bits + sign) to 11 bits, depending on the desired number of conversions per second (hidden).

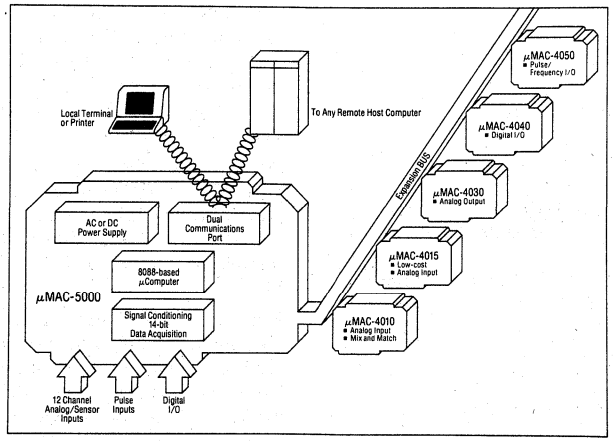
4) **Intelligence.** A 16-bit µC with 80K bytes of ROM and 32K bytes of battery backed-up RAM supports stand-alone applications. Plug-in sockets support an optional 16K Bytes of ROM and 32K bytes of RAM. The µMAC BASIC compiler and operating system use 80K bytes of ROM and 12K bytes of RAM. A DIP-switch option permits running programs from either ROM or RAM.

5) **Communications.** Two serial ports connect the µMAC-5000 to any host computer. Local and remote ports communicate in RS-232C, RS-422, or RS-423. The remote port also supports 20-mA current loops.

6) **Power Supply.** An ac/dc converter and dc/dc converter generate +5V and ±15V system voltages from an ac power line or +24V dc source. Using both, the system can detect brownouts or power outages and switch to dc without disturbing program execution. Factory-set line-voltage options are: 100V, 115V, 220V, or 240V.

7) **Digital I/O.** 8 digital inputs, optically isolated for 300V peak, can sense contact closures or accept TTL signals. The 8 latched-TTL outputs can sink up to 24mA. The µMAC-4020, connected to the digital I/O port, controls and monitors digital signals at line voltages. Two counters provide for pulse accumulator and frequency inputs.

8) **Expansion Port.** The expansion port provides for up to 6 mix/match expansion boards to greatly increase the number of available analog and digital I/O channels.




## SYSTEM CONFIGURATION

A single board system configuration consists of one µMAC-5000 Programmable Master Board which accepts 4, 8, or 12 analog inputs and includes 8 digital inputs and 8 digital outputs. Two of the digital inputs can optionally be used as pulse accumulators or frequency inputs.

A multiple board configuration (cluster) consists of one µMAC-5000 programmable Master Board and up to six Expander Boards. The µMAC-4000 Series of expander products provides a wide range of analog and digital I/O capability and a cost effective solution to large point applications (see Table I). A µMAC-5000 must reside in each cluster since it contains the communications capability and intelligence. A network using up to 16 clusters in a multidrop configuration allows your host computer to monitor and control up to 1344 analog or 4864 digital points or varying combinations of both types from a single 20mA or RS-422 communications line.

## COMMUNICATIONS

The µMAC-5000 System is designed to operate in stand-alone applications and can communicate with any host computer or terminal that has a 20mA, RS-232C, RS-422, or RS-423 port. The µMAC-5000 has two serial communication ports. Both ports have 256 byte RAM-buffers. A full duplex USART is used to receive and transmit data at selectable baud rates. The µMAC-5000's serial link allows use of either a party line (Figure 1) or radial system configuration.

The local communications port is primarily used for program development and will support RS-232C, RS-422, and RS-423. It can also be used to support a printer or terminal in a run time environment. This port is capable of communicating from 150 to 19.2K baud in an asynchronous mode. The local port can be used in either a full duplex or half duplex mode and can be used in a party line configuration when RS-422 is used.

The remote communication port supports RS-232C, 20mA, RS-422 and RS-423. In the asynchronous mode, it can operate from 110 to 19.2K baud. This port can be used in either a full duplex or half duplex mode and can be used in either a party line or radial configuration. The remote port has control lines (RTS, DCD, DTR, and CTS) which allow connection to a modem for long distance communications. The 20mA loop is optically coupled for harsh industrial environments.

| Model | Function | Description |
|---|---|---|
| µMAC-4010 | –Analog input<br>–Digital I/O | –Up to 12 channels using QMX modules<br>–16 channels digital I/O |
| µMAC-4015 | –Isolated analog input | –Low cost, 12 channels of same input type<br>–1500V isolation |
| µMAC-4030 | –8 channels analog output | –Voltage or isolated 4-20mA outputs<br>–Readback, bumpless transfer |
| µMAC-4040 | –Digital I/O | –32 channels isolated digital inputs<br>–32 channels digital outputs (TTL) |
| µMAC-4050 | –Multi-function digital I/O<br>–8 channels, mixed function | –Pulse accumulator input<br>–Frequency input<br>–Pulse output<br>–Time proportional output |
| µMAC-4020 | –Interface subsystem to high level ac and dc voltages and currents | –Solid state relay subsystem 16 channels, mix of input and output functions |

*Table I. µMAC Series Expander Boards (See Data Sheet)*

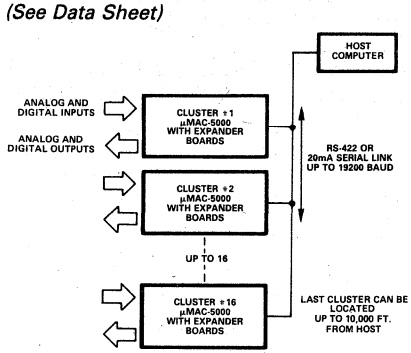



*Figure 1. Party Line Connection (Multidrop)*

## SPECIFICATIONS

### μMAC-5000 Board Features

**Input Types**
12 channels, mix and match
Thermocouples: J,K,T,S,R,E,B,W (linearized)
RTD: 100Ω Platinum (linearized)
Strain Gage: 30mV and 100mV spans
DC Voltage: 25mV to 10V
Process Currents: 0-1mA, 4-20mA, 0-20mA
Inputs Selectable by 4-channel QMX module—mix 3 types per board
QMX03, 04 modules isolated to 1000V channel-to-channel, input-to-output with IEEE–472 (SWC) transient protection
A/D Converter: 14-bit integrating

**Digital I/O**
8 channels isolated digital or contact closure inputs
8 channels digital outputs
Connector-compatible with μMAC-4020 high-level solid-state relay subsystem

**Pulse Inputs** (optional use of two digital inputs)
2 channels of frequency or pulse accumulator inputs
32 bits pulse accumulation: 20kHz max frequency

**Two Communication Ports.**
4-wire full duplex
256 byte RAM buffered; asynchronous
Selectable baud rate: 110 to 19,200 baud
Distance: 20mA-10,000 ft. (3048m)
RS-232—50 ft. (15m)
RS-422—10,000 ft. (3045m)
RS-423—1,000 ft. (305m)

**8088-Based Microcomputer**
32K RAM – expandable
80K PROM
16K user PROM socket

**Power**
On-board ac power supply: 100V/115V/220V/240V or +24V dc (used as primary power or back-up to ac line)

**Environmental**
Operating Temperature: 0 to +60°C
Humidity: meets MIL-STD 202, method 103
Vibration: meeds MIL-STD 167-1
Magnetic Field Immunity: 200 gauss
RFI Immunity: 5W @ 27MHz @ 3 feet

**Mechanical**
μMAC-5000 Board: 9.5″ × 13″(241.3 × 330.2mm)
μMAC-5000 Board Enclosure:
9.2″ × 14.3″ × 3″(234.2 × 363.2 × 76.2mm)
2-Board Enclosure: 10″ × 15″ × 6″(254.0 × 381.0 × 152.4mm)
4-Board Card Cage:
14.8″ × 11.2″ × 10.3″(376.0 × 284.5 × 261.6mm)
7-Board Card Cage: 15.75″ × 19″ × 11″(400.0 × 482.6 × 279.4mm)

## μMAC-5000 APPLICATIONS

**Industrial Process Control and Monitoring:** Temperature, pressure, flow and digital I/O measurements, and PID loop control are readily performed on the μMAC-5000 in stand-alone applications. μMACBASIC allows for the creation of proprietary algorithms that can be hidden from the end user.

**Machine/Boiler/Furnace Control:** High immunity to electrical noise, 1000V isolation, 60°C operation, and single board packaging provide highly reliable operation in harsh industrial environments. The μMAC-5000 is an ideal replacement for programmable controllers where analog I/O is required in addition to digital I/O.

**Remote Terminal Units** for data acquisition and control in pipe line, utilities and oil field applications. μMAC-5000 can readily emulate existing protocols with μMACBASIC and is readily integrated into applications requiring distributed intelligence. μMAC-5000 can also be used with modems in remote applications.

**Energy Management:** The μMAC-5000 is a low cost solution for small point counts requiring a high degree of I/O flexibility in distributed monitoring and control applications – making it a natural for energy management applications.

**Industrial, Government or University R&D:** μMAC-5000's broad functionality, low cost and ease of use make it the logical choice for monitoring or controlling experiments or pilot plants in a lab environment. Programs can be developed and edited with a dumb terminal and stored in battery backed-up RAM or PROM.

**Personal Computers as Data Loggers:** The μMAC-5000 is an ideal intelligent "front end" to a personal computer which allows it to be used to acquire, log, process, store and display data from a lab experiment or remote process. The μMAC-5000 with a printer can be used as a stand-alone data logger with the capability of sending exception messages to a host. Personal Computers can also be used as program development work stations for the μMAC-5000.

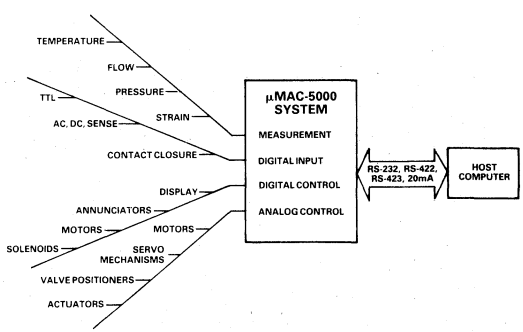



*Figure 2. μMAC-5000 Measurement and Control Concept*

# MACSYM

## THE MACSYM 150

**A 16-bit 8086 CPU combined with an 8087 math processor provide the power necessary for real-time measurement and control.**

**MACBASIC 3 – a real-time multitasking BASIC optimized for Measurement and Control applications. Special commands have been added to standard BASIC which simplify real-world data acquisition, graphic presentation and control signal output.**

**High resolution graphics (640 × 240 pixels) with either a black and white or color display.**

## THE MACSYM 200

**A specialized measurement and control front end and I/O card provide for fast, accurate analog and digital measurements.**

**A family of over 30 analog and digital I/O cards for direct connection to sensors, actuators and contact devices.**

**Sampling rates to 30kHz.**

**Auto calibration and 12- or 16-bit resolution for accurate measurement of up to 512 inputs per MACSYM 200.**

**Configure up to 15 MACSYM 200's over 5000'.**

The MACSYM family of Measurement and Control Systems is configured around the powerful MACSYM 150 work station. The MACSYM 150 is a 16-bit microcomputer with integral floppy and/or external Winchester disk storage, and internal RAM up to 512K bytes. Specialized I/O cards (Series 100 cards) plug into a six slot internal backplane providing analog, digital, communications I/O and memory expansion.

The MACSYM 350 combines the processing power of the MACSYM 150 with the accuracy, sampling speed, signal conditioning, and local data storage of the MACSYM 200. The MACSYM 200 is an intelligent measurement and control front end which greatly extends the analog/digital capability of the MACSYM 150. The MACSYM 200 provides for software selectable high speed 12-bit or high resolution 16-bit A/D conversion, and has a 16-bit CPU which controls the analog/digital I/O backplane and handles local data processing needs. Analog and digital I/O cards (ADIO cards) can plug directly into the 16 slot backplane of the MACSYM 200. Over thirty ADIO cards are available for interfacing to virtually any real-world sensor, transducer, or actuator. Communication between the MACSYM 150 and the MACSYM 200 is completely transparent to the user.

Because of this flexible and modular design, a stand-alone MACSYM 150 can be upgraded into a MACSYM 350 with the addition of a MACSYM 200. This results in a system with unprecendented power and flexibility. The system has the capability of addressing an extremely wide range of complex computerized measurement and control applications.

The MACSYM product line has four major elements: the MACSYM 150 work station, the Series 100 family of I/O cards, the MACSYM 200 intelligent front end and the ADIO (Analog/Digital Input/Output) family of I/O cards.

The MACSYM 150 is a 16-bit computer work station with integral disk storage, up to 512K bytes of RAM, black and white or color graphics, and an 82 key detached keyboard.

Series 100 I/O Cards plug directly into the backplane of the MACSYM 150 and provide analog and digital input and output, serial communications, IEEE-488 bus control, RAM memory expansion, and a Winchester disk interface.

The MACSYM 200 is an intelligent measurement and control front end designed around the 8088 16-bit microprocessor and featuring dual mode 12/16-bit A/D conversion, 12-bit sampling rates up to 33,000 samples per second burst mode, and a capacity for monitoring up to 512 channels of I/O.

ADIO (Analog Digital Input Output) Cards plug directly into the MACSYM 200 I/O backplane and provide signal conditioning for a wide range of sensors, transducers and actuators.

# SPECIFICATIONS

| MACSYM 150 | Standard | Optional |
|---|---|---|
| CPU | 8086 5MHz 16-bit CPU<br>8087 math coprocessor | |
| RAM | 256K bytes RAM | Up to 512K bytes<br>Hamming Code Error Correction |
| MASS STORAGE | 5 1/4″ disk drive single-sided, 96 tpi<br>320K bytes formatted storage<br>250K bits/sec transfer rate | Second 5 1/4″ disk drive for a total of 640K bytes of floppy disk storage<br><br>10M byte Winchester disk |
| VIDEO DISPLAY GENERATOR | | |
| Text | 24 lines × 80 characters<br>blinking, underline, reverse video attributes | Black and white with gray scale<br><br>8-color |
| Graphics | 640 × 240 high resolution<br>320 × 240 medium resolution | Black and white with gray scale<br><br>8-color |
| VIDEO DISPLAY | High resolution 12″ green phosphor monitor | |
| KEYBOARD | 82 key detached keyboard with 12 cursor control and editing keys and 10 user definable special function keys | |
| COMMUNICATIONS | TTL ASCII: Keyboard to console interface<br>RS-422: MACSYM 150 to MACSYM 200 interface | RS-232<br>RS-422, RS-423,<br>20mA current loop,<br>IEEE-488 |
| DATA ACQUISITION | | 16/32 channel 12-bit analog input card,<br>4/8 channel analog output card,<br>16 channel digital I/O card |

| MACSYM 200 | | |
|---|---|---|
| CPU | 5MHz 8088 CPU | |
| RAM/PROM | 26K bytes | Up to 48K bytes |
| COMMUNICATIONS | 307K baud RS-422: dedicated for communicating with the MACSYM 150 | |
| DATA ACQUISITION | | |
| 12-Bit Successive Approximation | 0.024% accuracy<br>25μs conversion speed<br>33,000 samples/sec burst mode | |
| 16-Bit Integrating Mode | 0.024% accuracy<br>16.6ms conversion (60Hz systems)<br>20.0ms conversion (50Hz systems) | |
| Calibration* | Self calibration minimizes RTI, RTO and gain errors over changing environmental conditions. | |
| Temp. Coefficient* | ± 3ppm/°C max | |
| Long Term Stability* | 25ppm/1000 hours | |

**ANALOG DIGITAL I/O**

MEASUREMENT INPUT
- Isolated and Nonisolated Analog Inputs
- Thermocouple Inputs (J,K,T,E,R,S)
- Strain Gage Input
- RTD Input

ANALOG OUTPUT
- Unipolar and Bipolar Voltage Output
- Current Output
- Loop Powered Analog Output

DIGITAL INPUT/OUTPUT
- Isolated ac and dc Input
- Isolated Solid State Input/Output
- Isolated Digital Output
- Form "A" and "C" Relay Output

PULSE INPUT/OUTPUT
- Pulse Counter and Output
- Frequency Input
- Priority Interrupt

MISCELLANEOUS
- Watchdog Timer
- Speech Synthesizer
- Setpoint/Alarm
- Blank Breadboard

Specifications subject to change without notice

# Modular AC/DC Power Supplies

Analog Devices' ac/dc Power Supplies are designed to provide OEMs and circuit designers with a broad line of high reliability, regulated and short circuit protected power supplies at low overall cost. These modules are available with 5 volt to 15 volt outputs (single, dual and triple) and current ratings from 25mA to 2 amps. Most Analog Devices' Power Supplies are available from stock in both large and small quantities. Substantial discounts apply on quantity orders.

### ADVANTAGES

Packaged circuit modules have found wide acceptance. Engineers have discovered the convenience and economy of plug-in building blocks . . . op amps, logic cards, miniature A/D and D/A converters are now available in wide varieties. Now a complete line of modular power supplies is available from Analog Devices. These encapsulated units are shipped ready to use, at prices below the internal manufacturing cost of most OEM users.

### TRIPLE OUTPUT SUPPLIES

Analog Devices offers four triple output ac/dc designs which are particularly useful in A/D, D/A and signal conditioning applications. Using a triple output supply is often less expensive than purchasing two separate supplies and also saves on space.

Models 972 and 926 provide ±15V @ ±150mA and +5V @ 300mA. Models 974 and 927 provide ±15V @ ±150mA and +5V @ 1000mA. Models 972 and 974 are chassis-mountable while models 926 and 927 are printed-circuit mountable.

### 5 VOLT 3 AMP SUPPLY

Models 976 and 928 supplies combine the primary advantages of switching linear regulated supplies in a single, compact package. This +5V 3 amp supply is available in PC-mountable (928) and chassis-mountable models (976).

### AC/DC POWER SUPPLIES FEATURES

- Current limited short circuit protection
- PC mounted and chassis mount designs
- Single, dual and triple output designs
- Current outputs of 25mA to 500mA for dual output supplies, 250mA to 3A for single output supplies
- Free-air convection cooling—no external heat sink required

### GENERAL SPECIFICATIONS FOR ALL MODELS

Input Voltage: 105V ac to 125V ac, 50 to 400Hz
Temperature Coefficient: 0.02%/°C
Input Isolation: 50MΩ
Breakdown Voltage: 500V rms, minimum
Operating Temperature: -25°C to +71°C
Operating at elevated temperatures may require derating. Consult factory.
Storage Temperature: -25°C to +85°C
Short Circuit Protection: All of the ac/dc Power Supplies employ current limiting. They can withstand substantial overload including direct shorts. Prolonged operation should be avoided since excessive temperature rises will occur.

**SPECIFICATIONS** (typical @ +25°C and 115V ac 60Hz unless otherwise noted; higher voltage inputs available, consult factory.)

| | Type | Model | Output Voltage Volts | Output Current mA | Line Reg. Max % | Load Reg. Max % | Output Voltage Error Max | Ripple & Noise mV rms Max | Dimensions Inches |
|---|---|---|---|---|---|---|---|---|---|
| PC Board Mounted | Dual Output | 915 | ±15 | ±25 | 0.2 | 0.2 | ±1% | 1 | 3.5×2.5×0.875 |
| | | 904 | ±15 | ±50 | 0.02 | 0.02 | ±200mV −0mV | 0.5 | 3.5×2.5×0.875 |
| | | 902 | ±15 | ±100 | 0.02 | 0.02 | +300mV −0mV | 0.5 | 3.5×2.5×1.25 |
| | | 902-2 | ±15 | ±100 | 0.02 | 0.02 | +300mV −0mV | 0.5 | 3.5×2.5×0.875 |
| | | 920 | ±15 | ±200 | 0.02 | 0.02 | +300mV −0mV | 0.5 | 3.5×2.5×1.25 |
| | | 925 | ±15 | ±350 | 0.02 | 0.02 | ±1% | 0.5 | 3.5×2.5×1.62 |
| | | 921 | ±12 | ±240 | 0.02 | 0.02 | +300mV −0mV | 0.5 | 3.5×2.5×1.25 |
| | Single Output | 906 | 5 | 250 | 0.02 | 0.04 | ±1% | 1 | 3.5×2.5×0.875 |
| | | 903 | 5 | 500 | 0.02 | 0.04 | ±1% | 1 | 3.5×2.5×1.25 |
| | | 905 | 5 | 1000 | 0.02 | 0.05 | ±1% | 1 | 3.5×2.5×1.25 |
| | | 922 | 5 | 2000 | 0.02 | 0.05 | ±1% | 1 | 3.5×2.5×1.62 |
| | | 928 | 5 | 3000 | 0.05 | 0.10 | ±2% | 5 (typ) | 3.5×2.5×1.25 |
| | Triple Output | 923 | ±15 | ±100 | 0.02 | 0.02 | ±1% | 0.5 | 3.5×2.5×1.25 |
| | | | +5 | 500 | 0.02 | 0.05 | ±1% | 0.5 | |
| | | 926 | ±15 | ±150 | 0.02 | 0.02 | ±2% | 0.5 (typ) | 3.5×2.5×1.62 |
| | | | +5 | 300 | 0.02 | 0.10 | ±2% | 1.0 (typ) | |
| | | 927 | ±15 | ±150 | 0.02 | 0.02 | ±2% | 0.5 (typ) | 3.5×2.5×1.62 |
| | | | +5 | 1000 | 0.02 | 0.10 | ±2% | 1.0 (typ) | |
| | | 2B35J | ±15 | ±65 | 0.08 | 0.1 | (−0, +300mV) | 0.5 | 3.5×2.5×1.25 |
| | | | +1 to +15* | 125 | 0.08 | 0.1 | | 0.25 | |
| | | 2B35K | ±15 | ±65 | 0.01 | 0.02 | (−0, +300mV) | 0.5 | 3.5×2.5×1.25 |
| | | | +1 to +15* | 125 | 0.01 | 0.02 | | 0.25 | |
| Chassis Mounted | Dual Output | 952 | ±15 | ±100 | 0.05 | 0.05 | ±2% | 1 | 4.4×2.7×1.44 |
| | | 970 | ±15 | ±200 | 0.05 | 0.05 | ±2% | 1 | 4.4×2.7×1.44 |
| | | 973 | ±15 | ±350 | 0.05 | 0.05 | ±2% | 1 | 4.4×2.7×2.00 |
| | | 975 | ±15 | ±500 | 0.05 | 0.05 | ±2% | 1 | 4.4×2.7×2.00 |
| | Single Output | 955 | 5 | 1000 | 0.05 | 0.15 | ±2% | 2 | 4.4×2.7×1.44 |
| | | 976 | 5 | 3000 | 0.05 | 0.10 | ±2% | 5 (typ) | 4.75×2.7×2.00 |
| | Triple Output | 972 | ±15 | ±150 | 0.02 | 0.02 | ±2% | 0.5 (typ) | 4.75×2.7×1.45 |
| | | | +5 | 300 | 0.02 | 0.10 | ±2% | 1.0 (typ) | |
| | | 974 | ±15 | ±150 | 0.02 | 0.02 | ±2% | 0.5 (typ) | 4.75×2.7×1.45 |
| | | | +5 | 1000 | 0.02 | 0.10 | ±2% | 1.0 (typ) | |

*Resistor Programmable

20

# Modular DC/DC Converters

Analog Devices' compact dc-dc converters satisfy a wide variety of floating power requirements in analog (Computational Circuits, Op Amps, Instrumentation Amps) and digital (a-d/d-a) applications. Available in five power levels of 1 watt, 1.8 watt, 4.5 watt, 6 watt and 12 watt, these designs offer accurate (±0.05% max error), regulated outputs with very low noise. Most models are high efficiency (typically over 60% at full load) that feature complete 6-sided continuous shielding for EMI/RFI protection.

### DUAL OUTPUT MODELS

Logic to analog power conversion is available with several models delivering floating power (±12V and ±15V) from logic power sources (+5V). This permits analog networks to be separated from digital systems in order to avoid intersystem grounding problems. Model 945 derives regulated ±15V outputs from any combination of inputs between 23 and 31 volts. The 945 can be powered from dual 12 volt, dual 15 volt, +24 volt or +28 volt power supplies.

### DC/DC CONVERTERS FEATURES

- Inaudible (>20kHz) converter switching frequency
- Continuous, six-sided EMI/RFI shielding except on 1 watt and 1.8 watt models
- Free air convection cooling—no external heat sink or specification derating is required over operating temperature range
- Output short circuit protection (either output to common) for at least 8 hrs. at $T_A$ = +71°C
- Automatic restart after short condition removed
- Automatic starting with reverse current injected into outputs

### GENERAL SPECIFICATIONS FOR 4.5W, 6W, 12W MODELS

Line Regulation—full range: ±0.05% max (±0.02% max, 960 series)
Load Regulation—no load to full load: ±0.05% max (±0.02% max, 960 series)
Output Noise and Ripple: 1mV rms max
Breakdown Voltage: 500V dc minimum
Input Filter Type: π
Operating Temperature Range: −25°C to +71°C
Storage Temperature Range: −40°C to +100°C

### GENERAL SPECIFICATIONS FOR 1W AND 1.8W MODELS

Line Regulation—full range: ±0.3% (±1% max, 949)
Load Regulation—no load to full load: 30% (±0.5% max, 949)
Output Noise and Ripple: 20mV p-p (with 15μF tantalum capacitor across each output), (1mV rms max, 949)
Breakdown Voltage: 300V dc (500V dc min, 949)
Input Filter Type: π (models 958, 960, 962, 964)
Operating Temperature Range: −25°C to +71°C
Storage Temperature Range: −40°C to +100°C

**SPECIFICATIONS** (typical @ +25°C over the full range of input voltages unless otherwise noted)

| Model | Output Voltage Volts | Output Current mA | Input Voltage Volts | Input[1] Voltage Range Volts | Input Current Full Load | Output Voltage Error Max | Temperature Coefficient /°C Max | Efficiency Full Load Min | Dimensions Inches |
|---|---|---|---|---|---|---|---|---|---|
| 943 | 5 | 1000 | 5 | 4.75/5.25 | 1.52A | ±1% | ±0.02% | 62% | 2.0×2.0×0.38 |
| 957* | 5 | 100 | 5 | 4.5/5.5 | 200mA | ±5% | ±0.01% (typ) | 50% | 1.25×0.8×0.4 |
| 958 | 5 | 100 | 5 | 4.5/5.5 | 200mA | ±5% | ±0.01% (typ) | 50% | 1.25×0.8×0.4 |
| 941 | ±12 | ±150 | 5 | 4.75/5.25 | 1.17A | ±0.5% | ±0.01% | 58% | 2.0×2.0×0.38 |
| 959* | ±12 | ±40 | 5 | 4.5/5.5 | 384mA | ±5% | ±0.01% (typ) | 50% | 1.25×0.8×0.4 |
| 960 | ±12 | ±40 | 5 | 4.5/5.5 | 384mA | ±5% | ±0.01% (typ) | 50% | 1.25×0.8×0.4 |
| 961* | ±15 | ±33 | 5 | 4.5/5.5 | 396mA | ±5% | ±0.01% (typ) | 50% | 1.25×0.8×0.4 |
| 962 | ±15 | ±33 | 5 | 4.5/5.5 | 396mA | ±5% | ±0.01% (typ) | 50% | 1.25×0.8×0.4 |
| 963* | ±15 | ±33 | 12V | 10.8/13.2 | 165mA | ±5% | ±0.01% (typ) | 50% | 1.25×0.8×0.4 |
| 964 | ±15 | ±33 | 12V | 10.8/13.2 | 165mA | ±5% | ±0.01% (typ) | 50% | 1.25×0.8×0.4 |
| 965 | ±15 | ±190 | 5V | 4.65/5.5 | 1.7A | ±1% | ±0.005% (typ) | 62% (typ) | 2.0×2.0×0.38 |
| 966 | ±15 | ±190 | 12V | 11.2/13.2 | 710mA | ±1% | ±0.005% (typ) | 62% (typ) | 2.0×2.0×0.38 |
| 967 | ±15 | ±190 | 24V | 22.3/26.4 | 350mA | ±1% | ±0.005% (typ) | 62% (typ) | 2.0×2.0×0.38 |
| 968 | ±15 | ±190 | 28V | 26/30.8 | 300mA | ±1% | ±0.005% (typ) | 62% (typ) | 2.0×2.0×0.38 |
| 949 | ±15 | ±60** | 5 | 4.65/5.5 | 0.6A | ±2% | ±0.03% | 58% | 2.0×1.0×0.375 |
| 940 | ±15 | ±150 | 5 | 4.75/5.25 | 1.35A | ±0.5% | ±0.01% | 62% | 2.0×2.0×0.38 |
| 953 | ±15 | ±150 | 12 | 11/13 | 0.6A | ±0.5% | ±0.01% | 62% | 2.0×2.0×0.38 |
| 945 | ±15 | ±150 | 28 | 23/31 | 250mA | ±0.5% | ±0.01% | 61% | 2.0×2.0×0.38 |
| 951 | ±15 | ±410 | 5 | 4.65/5.5 | 3.7A | ±0.5% | ±0.01% | 62% | 3.5×2.5×0.88 |

NOTES
*Unfiltered Models
**Single-ended or unbalanced operation is permissible such that total output current load does not exceed a total of 120mA.
[1]Models 940 and 941 will deliver up to 120mA output current (and model 943 will deliver up to 600mA) over an input voltage range of 4.65 and 5.5 V dc.

# Contents of Volume I



## Ordering Guide – Section 3

Page

## Operational Amplifiers – Section 4


Selection Guides

General Purpose Op Amps . . . . 4 – 2

High Accuracy Op Amps . . . . 4 – 3

Fast/Wideband Op Amps . . . . 4 – 4

General Information . . . . 4 – 5

Selection Principles and Process . . . . 4 – 5

Definitions of Specifications . . . . 4 – 13

Brief Bibliography on Op Amps . . . . 4 – 16

AD101A/201A/301A/301AL General-Purpose IC Op Amps . . . . 4 – 17

AD380J/K/L/S Wideband, Fast-Settling FET Operational Amplifier . . . . 4 – 21

AD381J/K/L/S High Speed, Low Drift FET Operational Amplifier . . . . 4 – 27

AD382J/K/L/S High Speed, Low Drift FET Operational Amplifier . . . . 4 – 27

AD503J/K/S FET-Input IC Op Amps . . . . 4 – 35

AD504J/K/L/M/S High-Accuracy Low-Drift IC Op Amps . . . . 4 – 49

AD506J/K/L/S FET-Input IC Op Amps . . . . 4 – 35

AD507J/K/S Wideband, Fast Slewing, General-Purpose IC Op Amps . . . . 4 – 47

AD509J/K/S High-Speed Fast-Settling IC Op Amps . . . . 4 – 51

AD510J/K/L/S Low Cost, Laser Trimmed Precision IC Op Amps . . . . 4 – 55

AD515J/K/L Electrometer IC Op Amps . . . . 4 – 59

AD517J/K/L/S High-Accuracy, Low Cost, Low Drift IC Op Amps . . . . 4 – 65

AD518J/K/S Fast Wideband IC Op Amps . . . . 4 – 71

AD542J/K/L/S Trimmed Implanted FET (TRIFET) IC Op Amps . . . . 4 – 75

AD544J/K/L/S Trimmed Implanted FET (TRIFET) IC Op Amps . . . . 4 – 79

AD545J/K/L/M Low Bias Current FET IC Op Amps . . . . 4 – 83

AD547J/K/L/S Ultra Low Drift BIFET Operational Amplifiers . . . . 4 – 87

•AD611J/K Low Cost, Implanted FET-Input Op Amp . . . . 4 – 91

AD642J/K/L/S Dual AD542 Trimmed Implanted FET (TRIFET) Op Amps . . . . 4 – 95

AD644J/K/L/S Dual High-Speed Implanted FET-Input Operational Amplifiers . . . . 4 – 99

AD647J/K/L/S Ultra-Low Drift BIFET Operational Amplifiers . . . . 4 – 103

AD741/C/J/K/L/S Internally Compensated IC Op Amps . . . . 4 – 107

AD3554A/B/S Wideband, Fast-Settling FET-Input Op Amps . . . . 4 – 111

AD9685B Ultra-Fast Single Comparator . . . . 4 – 117

AD9687B Ultra-Fast Dual Comparator . . . . 4 – 117

ADLH0032G/CG Ultra-Fast FET Operational Amplifiers . . . . 4 – 121

ADLH0033G/CG High-Speed Buffer Amplifiers . . . . 4 – 125

AD OP-07/A/D/C/E Ultra-Low Offset Voltage IC Op Amp . . . . 4 – 129

•AD OP-27A/B/C/E/F/G Ultra-Low Noise Precision IC Op Amps . . . . 4 – 135

•AD OP-37A/B/C/E/F/G Ultra-Low Noise, High Speed, Precision Op Amps . . . . 4 – 143

HOS-050/050A/050C Ultra Fast Video Hybrid IC Op Amps . . . . 4 – 147

HOS-060S Low Offset, Fast Settling Video Op Amp . . . . 4 – 153

HOS-100A/S Wide Bandwidth, High-Speed Buffer Amplifiers . . . . 4 – 157


•New product since publication of *1982 – 1983 Databook Update.*

## Instrumentation & Isolation Amplifiers – Section 5


Page

Selection Guides
- Instrumentation Amplifiers . . . . . 5 – 2
- Isolation Amplifiers . . . . . 5 – 4

General Information . . . . . 5 – 8
AD293A/B Hybrid Industrial Isolation Amplifier . . . . . 5 – 13
AD294A Hybrid Medical Isolation Amplifier . . . . . 5 – 13
AD521J/K/L/S Monolithic IC Resistor-Programmable Amplifier . . . . . 5 – 21
AD522A/B/S Hybrid IC Resistor-Programmable Amplifier . . . . . 5 – 27
AD524A/B/C/S Precision Instrumentation Amplifier . . . . . 5 – 31
AD624A/B/C/S High Precision Low Noise Instrumentation Amplifier . . . . . 5 – 43
• AD625A/B/C/S Programmable Gain Instrumentation Amplifier . . . . . 5 – 55


## Analog Signal Processing Components – Section 6


Selection Guides
- Multipliers . . . . . 6 – 2
- Dividers . . . . . 6 – 4
- Log-Antilog Amplifiers . . . . . 6 – 5
- RMS-to-DC Converters . . . . . 6 – 6
- Modulators/Demodulators . . . . . 6 – 8

General Information . . . . . 6 – 9
Definitions of Specifications . . . . . 6 – 15
AD532J/K/S General-Purpose Internally Trimmed IC 4-Quadrant Multiplier/Divider . . . . . 6 – 17
AD533J/K/L/S Lowest Cost IC 4-Quadrant Multiplier/Divider . . . . . 6 – 23
AD534J/K/L/S/T Highest Performance Internally Trimmed IC 4-Quadrant Multiplier/Divider . . . . . 6 – 27
AD535J/K High Performance Internally Trimmed IC 2-Quadrant Divider . . . . . 6 – 37
AD536AJ/K/S True RMS-to-DC IC Converter . . . . . 6 – 43
AD539J/K/S Wideband Dual-Channel Linear Multiplier/Divider . . . . . 6 – 49
AD630J/K Balanced Modulator/Demodulator . . . . . 6 – 57
AD632A/B/S/T Internally Trimmed Precision IC Multiplier . . . . . 6 – 67
AD636J/K Low Level True RMS-to-DC Converter . . . . . 6 – 71
AD637J/K/S High Precision Wideband RMS-to-DC Converter . . . . . 6 – 77


•New product since publication of *1982–1983 Databook Update.*

## Voltage References – Section 7


Page

Selection Guide . . . . . 7 – 2
Orientation and Definitions of Specifications . . . . . 7 – 3
AD580J/K/L/M/S/T/U 2.5V Monolithic IC Positive Voltage References . . . . . 7 – 5
AD581J/K/L/S/T/U 10V Pretrimmed Monolithic IC Voltage References . . . . . 7 – 9
AD584J/K/L/S/T Pretrimmed 10V, 7.5V, 5V, 2.5V Monolithic IC Multiple-Voltage References . . . . 7 – 17
AD589J/K/L/M/S/T/U Two-Terminal IC 1.2V References . . . . . 7 – 25
AD1403/AD1403A +2.5V Monolithic IC Voltage References in Mini-DIP Package . . . . . 7 – 29
AD2700J/L/S/U +10V Precision Hybrid IC Positive Voltage References . . . . . 7 – 33
AD2701J/L/S/U −10V Precision Hybrid IC Negative Voltage References . . . . . 7 – 33
AD2702J/L/S/U ±10V Precision Hybrid Dual Voltage References . . . . . 7 – 33
AD2710, AD2712K/L +10.000V, ±10.000 Volt Ultra High, Precision References . . . . . 7 – 37
AD7560 CMOS Monolithic DC-DC Voltage Converter & Reference . . . . . 7 – 41


## Temperature Measurement Components – Section 8


Selection Guides
- Temperature Transducers . . . . . 8 – 2
- Temperature Transducer Signal Conditioners . . . . . 8 – 3
- Voltage-to-Current Converters . . . . . 8 – 4
- Transducer Signal Conditioners . . . . . 8 – 5
- Isolated Transducer Signal Conditioners . . . . . 8 – 6
- Two-Wire Transmitters . . . . . 8 – 7
- Signal Conditioning I/O Subsystem . . . . . 8 – 9
- Alarm Limit Subsystem . . . . . 8 – 10

General Information . . . . . 8 – 11
AD590I/J/K Two-Terminal Temperature Transducer . . . . . 8 – 15
•AD592A/B/C Low Cost, Precision Temperature Transducer . . . . . 8 – 23
AD594A/C Monolithic Thermocouple (Type J) Amplifier with Cold Junction Compensation . . . . . 8 – 31
•AD595A/C Monolithic Thermocouple (Type K) Amplifier with Cold Junction Compensation . . . . . 8 – 31
•AD596 Thermocouple (Type J) Conditioner and Set-Point Controller . . . . . 8 – 39
•AD597 Thermocouple (Type K) Conditioner and Set-Point Controller . . . . . 8 – 39


•New product since publication of *1982–1983 Databook Update*.

# Digital-to-Analog Converters – Section 9


| | Page |
|---|---|
| Selection Guides | |
| General Purpose 8-Bit DACs | 9 – 3 |
| General Purpose 10-Bit DACs | 9 – 4 |
| General Purpose 12-Bit DACs | 9 – 5 |
| High Resolution DACs | 9 – 6 |
| CMOS Multiplying DACs | 9 – 8 |
| LOGDACs | |
| 8-Bit µP Compatible 8-Bit | 9 – 11 |
| 8-Bit µP Compatible DACs | 9 – 12 |
| 12-Bit µP Compatible DACs | 9 – 14 |
| Video Display DACs | 9 – 17 |
| Video Speed Current Output DACs | 9 – 19 |
| Video Speed Voltage Output DACs | 9 – 20 |
| General Information | 9 – 21 |
| Specifications and Terms | 9 – 22 |
| AD390 Quad 12-Bit µP-Compatible D/A Converter | 9 – 27 |
| AD558 Low-Cost Complete µP-Compatible 8-Bit D/A Converter | 9 – 35 |
| AD561 Low-Cost 10-Bit Complete Current-Output DAC | 9 – 43 |
| AD562 High Performance 12-Bit Current-Output DAC | 9 – 51 |
| AD563 High Performance 12-Bit Current-Output DAC Including Reference | 9 – 51 |
| AD565A Complete High-Speed 12-Bit Monolithic D/A Converter | 9 – 57 |
| AD566A Low-Cost High-Speed 12-Bit Monolithic D/A Converter | 9 – 65 |
| AD567 µP-Compatible 12-Bit D/A Converter | 9 – 73 |
| •AD569 Monolithic 16-Bit D/A Converter | 9 – 81 |
| •AD667 µP-Compatible 12-Bit D/A Converter | 9 – 83 |
| AD1408/1508 8-Bit Monolithic Multiplying D/A Converters | 9 – 89 |
| AD3860 Complete, Voltage-Output 12-Bit DAC | 9 – 93 |
| •AD6012 Low-Cost, Monolithic 12-Bit D/A Converter | 9 – 97 |
| AD7110 CMOS Digitally Controlled Audio Attenuator | 9 – 103 |
| AD7111 CMOS Logarithmic D/A Converter | 9 – 109 |
| AD7115 LOGDAC™ CMOS 0.1dB Step Attenuator | 9 – 115 |
| AD7118 CMOS Logarithmic D/A Converter | 9 – 123 |
| •AD7224 LC²MOS Double Buffered 8-Bit DAC | 9 – 129 |
| •AD7226 LC²MOS Quad 8-Bit D/A Converter | 9 – 133 |
| •AD7240 LC²MOS High-Speed 12-Bit Voltage DAC | 9 – 145 |
| AD7520 CMOS 10-Bit Multiplying DAC | 9 – 153 |
| AD7521 CMOS 12-Bit Multiplying DAC | 9 – 153 |
| AD7522 CMOS 10-Bit Double-Buffered Multiplying DAC | 9 – 161 |
| AD7523 CMOS 8-Bit Multiplying DAC | 9 – 167 |
| AD7524 CMOS 8-Bit Buffered Multiplying DAC | 9 – 171 |
| AD7525 CMOS 3½-Digit BCD Digitally Controlled Potentiometer | 9 – 177 |
| AD7528 CMOS Dual 8-Bit Buffered Multiplying DAC | 9 – 183 |


LOGDAC is a registered trademark of Analog Devices, Inc.
•New product since publication of *1982–1983 Databook Update*.

## Digital-to-Analog Converters – Section 9 (continued)


| | Page |
|---|---|
| AD7530 CMOS 10-Bit Monolithic Multiplying DAC | 9 – 191 |
| AD7531 CMOS 12-Bit Monolithic Multiplying DAC | 9 – 191 |
| AD7533 CMOS Low-Cost 10-Bit Multiplying D/A Converter | 9 – 195 |
| •AD7534 LC²MOS µP-Compatible 14-Bit DAC | 9 – 201 |
| AD7541 CMOS 12-Bit Monolithic Multiplying DAC | 9 – 203 |
| AD7541A CMOS 12-Bit Monolithic Multiplying DAC | 9 – 209 |
| AD7542 CMOS 12-Bit µP-Compatible D/A Converter | 9 – 215 |
| AD7543 CMOS 12-Bit Serial-Input DAC | 9 – 223 |
| AD7545 CMOS 12-Bit Buffered Multiplying D/A Converter | 9 – 231 |
| AD7546 High Resolution 16-Bit D/A Converter | 9 – 239 |
| •AD7548 LC²MOS 8-Bit µP-Compatible 12-Bit DAC | 9 – 247 |
| •AD9768 Ultra High-Speed D/A Converter | 9 – 261 |
| AD DAC-08 8-Bit Monolithic High-Speed Multiplying DAC | 9 – 265 |
| AD DAC71/72 High Resolution 16-Bit D/A Converter | 9 – 271 |
| AD DAC80 Low-Cost, 12-Bit Hybrid D/A Converter | 9 – 277 |
| AD DAC85 High Performance, 12-Bit Hybrid D/A Converter | 9 – 277 |
| AD DAC87 Wide Temperature Range 12-Bit Hybrid D/A Converter | 9 – 277 |
| AD DAC100 10-Bit Monolithic D/A Converter | 9 – 287 |
| HDD Series Hybrid Video Low Glitch D/A Converters | 9 – 295 |
| HDD-1206 12-Bit, Deglitched Voltage Output DAC | 9 – 301 |
| •HDD-1409 14-Bit, 200kHz D/A Converter | 9 – 305 |
| HDG Series Hybrid Video D/A Converters | 9 – 309 |
| •HDM-1210 Ultra High-Speed Multiplying D/A Converter | 9 – 315 |
| HDS/HDH 8-, 10-, and 12-Bit Video-Speed Hybrid Current and Voltage Output DACs | 9 – 317 |
| HDS-0810E, HDS-1015E Ultra High-Speed ECL Hybrid D/A Converter | 9 – 321 |
| HDS-1240E Ultra High-Speed ECL Hybrid D/A Converter | 9 – 323 |


## Analog-to-Digital Converters – Section 10


| | |
|---|---|
| Selection Guides | |
| 8-Bit A/D Converters | 10 – 2 |
| 10-Bit A/D Converters | 10 – 5 |
| 12-Bit A/D Converters | 10 – 8 |
| High Resolution A/D Converters | 10 – 12 |
| Video A/D Converters | 10 – 15 |
| General Information | 10 – 20 |
| Specifications & Terms | 10 – 22 |
| AD570J/S Low-Cost Complete Monolithic IC 8-Bit ADCs | 10 – 27 |
| AD571J/K/S Complete Monolithic IC 10-Bit ADCs | 10 – 31 |
| AD572A/B/S Complete Hybrid IC 12-Bit Successive-Approximation ADCs | 10 – 39 |
| AD573J/K/S Fast, Complete 10-Bit A/D Converter with Microprocessor Interface | 10 – 47 |
| AD574AJ/AK/AS/AT/AU Fast Complete 12-Bit A/D Converter with Microprocessor Interface | 10 – 55 |
| •AD575J/K/S Fast, Complete 10-Bit A/D Converter with Serial Output | 10 – 67 |


•New product since publication of *1982–1983 Databook Update*.

## Analog-to-Digital Converters – Section 10 (continued)


Page

AD578J/K/L Fast Complete Hybrid IC 12-Bit ADCs . . . . . 10 – 73
AD579J/K/T Very Fast, Complete 10-Bit A/D Converter . . . . . 10 – 79
•AD670J/K/A/B/S Low Cost, Signal Conditioning 8-Bit A/D Converter . . . . . 10 – 85
AD673J/S Complete 8-Bit A/D Converter with Microprocessor Interface . . . . . 10 – 95
•AD5010/AD6020 50/100MHz, 6-Bit Monolithic A/D Converters . . . . . 10 – 103
AD5200/5210 Series 12-Bit Successive Approximation High Accuracy A/D Converters . . . . . 10 – 105
AD5240K/B Very Fast, Complete 12-Bit A/D Converter . . . . . 10 – 111
AD7550B CMOS IC Quad-Slope Bus-Compatible 13-Bit ADC . . . . . 10 – 119
AD7552K CMOS 12-Bit Plus Sign Monolithic A/D Converter . . . . . 10 – 127
AD7571J/K/A/B/S/T CMOS μP Compatible 10-Bit Plus Sign A/D Converter . . . . . 10 – 139
AD7545J/K/A/B/S/T CMOS μP Compatible 8-Bit A/D Converter . . . . . 10 – 151
AD7581J/K/L/A/B/C CMOS μP Compatible 8-Bit 8-Channel DAS . . . . . 10 – 159
•AD9000 Series Ultra High-Speed 6-Bit Monolithic A/D Converter . . . . . 10 – 167
AD ADC71/72 Complete, High Resolution 16-Bit A/D Converters . . . . . 10 – 175
AD ADC80 Hybrid 12-Bit Successive Approximation A/D Converter . . . . . 10 – 183
AD ADC84/85 Fast, Complete 12-Bit A/D Converters . . . . . 10 – 191
•AD ADC-816K/B Ultra High Speed 10-Bit A/D Converter . . . . . 10 – 199
HAS-0802/1002/1202 Ultra-Fast Hybrid A/D Converters . . . . . 10 – 201
•HAS-1201S 12-Bit, 1MHz A/D Converter . . . . . 10 – 205
•HAS-1409 14-Bit 125kHz A/D Converter . . . . . 10 – 207


## Voltage-to-Frequency & Frequency-to-Voltage Converters – Section 11


Selection Guides
  Voltage-to-Frequency Converters . . . . . 11 – 2
  Frequency-to-Voltage Converters . . . . . 11 – 4
General Information . . . . . 11 – 5
AD537 IC Voltage-to-Frequency Converter . . . . . 11 – 7
AD650J/K/S Voltage-to-Frequency and Frequency-to-Voltage Converter . . . . . 11 – 15
ADVFC32KN/BH/SH Voltage-to-Frequency and Frequency-to-Voltage Converter . . . . . 11 – 27


## Digital Signal Processing Components – Section 12


Selection Guide . . . . . 12 – 2
General Information . . . . . 12 – 4
ADSP-1008 8 × 8-Bit CMOS Multiplier/Accumulator . . . . . 12 – 7
•ADSP-1009 12 × 12-Bit CMOS Multiplier/Accumulator . . . . . 12 – 13
ADSP-1010 16 × 16-Bit CMOS Multiplier/Accumulator . . . . . 12 – 19
•ADSP-1012 12 × 12-Bit CMOS Multiplier . . . . . 12 – 27
ADSP-1016 16 × 16-Bit CMOS Multiplier . . . . . 12 – 35
•ADSP-1024 24 × 24-Bit CMOS Multiplier . . . . . 12 – 43
ADSP-1080 8 × 8-Bit CMOS Multiplier . . . . . 12 – 51
•ADSP-1081 8 × 8-Bit Precision CMOS Multiplier . . . . . 12 – 57
•ADSP-1110 16 × 16-Bit CMOS Single Port Multiplier/Accumulator . . . . . 12 – 65


•New product since publication of *1982–1983 Databook Update.*

## Synchro & Resolver Converters – Section 13


| | Page |
|---|---|
| Selection Guide | 13 – 2 |
| General Information | 13 – 4 |
| DRC1745/1746 High Power Output, Hybrid Digital-to-Resolver Converters | 13 – 5 |
| DRC1765/1766 14- and 16-Bit Hybrid Digital-to-Resolver Converters | 13 – 13 |
| •IRDC1732 Hybrid, Tracking Inductosyn™ Resolver-to-Digital Converter | 13 – 17 |
| SDC/RDC1740/1741/1742 12- and 14-Bit Hybrid Synchro/Resolver-to-Digital Converters | 13 – 23 |
| •1S20/40/60/61 Hybrid, Tracking Resolver-to-Digital Converters | 13 – 29 |


## Sample/Track-Hold Amplifiers – Section 14


| | |
|---|---|
| Selection Guide | 14 – 2 |
| General Information | 14 – 8 |
| Definition of Specifications | 14 – 8 |
| AD346J/S High-Speed Sample-and-Hold Amplifier | 14 – 11 |
| •AD389K/B High Resolution Track-and-Hold Amplifier | 14 – 17 |
| AD582K/S Monolithic IC Sample-Hold Amplifier, Low Cost | 14 – 23 |
| AD583K Monolithic IC Sample-Hold Amplifier, High Speed | 14 – 27 |
| •AD585 Fast, Monolithic Sample-Hold Amplifier | 14 – 31 |
| ADSHC-85 Fast 0.01% Track/Sample-Hold Amplifiers | 14 – 37 |
| HTC-0300/A/M Ultra High Speed Hybrid Track-and-Hold Amplifier | 14 – 41 |
| HTC-0500AM/SM High Speed Hybrid Track-and-Hold Amplifier | 14 – 45 |
| HTS-0010K/S Ultra High Speed Hybrid Track-and-Hold Amplifier | 14 – 49 |
| HTS-0025/M Ultra High Speed Hybrid Track-and-Hold Amplifier | 14 – 55 |


## Data Acquisition Subsystems – Section 15


| | |
|---|---|
| Selection Guide | 15 – 3 |
| AD362 Hybrid-IC 16-to-8-Channel DAS Front End, for User-Chosen A/D Converter | 15 – 5 |
| AD363 Hybrid-IC 16-to-8-Channel 12-Bit Complete DAS | 15 – 13 |
| AD364 Hybrid-IC 16-to-8-Channel 12-Bit Complete μP-Compatible DAS | 15 – 25 |


•New product since publication of *1982–1983 Databook Update.*
Inductosyn is a registered trademark of Farrand Industries, Inc.

## CMOS Switches & Multiplexers – Section 16


Page

Selection Guide . . . . . 16 – 2
General Information . . . . . 16 – 3
AD7501 8-Channel Multiplexer, High Enables . . . . . 16 – 5
AD7502 4-Channel Differential Multiplexer . . . . . 16 – 5
AD7503 8-Channel Multiplexer, Low Enables . . . . . 16 – 5
AD7506 16-Channel Multiplexer . . . . . 16 – 9
AD7507 8-Channel Differential Multiplexer . . . . . 16 – 9
AD7510DI Dielectrically Isolated Quad SPST; Address High Closes Switch . . . . . 16 – 13
AD7511DI Dielectrically Isolated Quad SPST; Address Low Closes Switch . . . . . 16 – 13
AD7512DI Dielectrically Isolated Quad SPDT . . . . . 16 – 13
AD7590DI Dielectrically Isolated Quad SPST; Data Latches . . . . . 16 – 21
AD7591DI Dielectrically Isolated Quad SPST; Data Latches . . . . . 16 – 21
AD7592DI Dielectrically Isolated Dual SPDT; Data Latches . . . . . 16 – 21


## Monolithic Chips – Section 17

### BIPOLAR INTEGRATED CIRCUIT CHIPS


General Information . . . . . 17 – 3
AD517 Chips Low Cost, Laser Trimmed Precision IC Op Amp . . . . . 17 – 5
AD518 Chips Low Cost, High Speed, IC Op Amp . . . . . 17 – 7
AD521 Chips Precision Instrumentation Amplifier . . . . . 17 – 9
•AD524 Chips Precision Instrumentation Amplifier . . . . . 17 – 11
AD532 Chips Trimmed IC Multiplier . . . . . 17 – 13
AD534 Chips Trimmed Precision IC Multiplier . . . . . 17 – 15
AD536A Chips IC True rms-to-dc Converter . . . . . 17 – 17
AD537 Chips Low Cost IC V-to-F Converter . . . . . 17 – 19
AD540 Chips High Accuracy Low Cost FET-Input Op Amp . . . . . 17 – 21
AD542 Chips Precision Low Cost BIFET Op Amp . . . . . 17 – 23
AD544 Chips Precision High Speed BIFET Op Amp . . . . . 17 – 25
AD547 Chips Ultra Low Drift BIFET Operational Amplifier . . . . . 17 – 27
AD558 Chips DACPORT™ Low Cost Complete µP-Compatible 8-Bit DAC . . . . . 17 – 29
AD561 Chips Low Cost, High Speed 10-Bit D-to-A Converter with Reference . . . . . 17 – 31
AD570/AD571 Chips Low Cost Complete 8- and 10-Bit A-to-D Converter . . . . . 17 – 33
AD573 Chips Fast, Complete 10-Bit A-to-D Converter with Microprocessor Interface . . . . . 17 – 35
AD580 Chips Precision 2.5 Volt Reference . . . . . 17 – 37
AD581/AD584 Chips Programmable Precision Low-Drift Reference . . . . . 17 – 39
AD582 Chips Low Cost Precision Sample-and-Hold . . . . . 17 – 41
AD589 Chips Two-Terminal IC 1.2 Volt Reference . . . . . 17 – 43
AD590 Chips Two-Terminal IC Temperature Transducer . . . . . 17 – 45
•AD630 Chips Balanced Modulator/Demodulator . . . . . 17 – 47
AD642 Chips Precision Low Cost Dual BIFET Op Amp . . . . . 17 – 49
AD644 Chips Dual High Speed Implanted FET-Input Op Amp . . . . . 17 – 51


•New product since publication of *1982–1983 Databook Update.*
DACPORT is a registered trademark of Analog Devices, Inc.

## Monolithic Chips – Section 17 (continued)


Page

AD DAC-08 Chips High Speed 8-Bit D-to-A Converter . . . . . 17 – 53
AD OP-07 Chips Ultra-Low Offset Voltage Op Amp . . . . . 17 – 55
•AD OP-27 Chips Ultra-Low Noise Precision Op Amp . . . . . 17 – 57
•AD OP-37 Chips Ultra-Low Noise High Speed Precision Op Amp . . . . . 17 – 59

**CMOS INTEGRATED CIRCUIT CHIPS**

General Information . . . . . 17 – 61
Bonding Diagrams:
AD7501 . . . . . 17 – 64
AD7502 . . . . . 17 – 64
AD7503 . . . . . 17 – 64
AD7506 . . . . . 17 – 64
AD7507 . . . . . 17 – 65
AD7510 . . . . . 17 – 65
AD7511 . . . . . 17 – 65
AD7512 . . . . . 17 – 65
•AD7524 . . . . . 17 – 65
AD7533 . . . . . 17 – 66
AD7541A . . . . . 17 – 66
AD7542 . . . . . 17 – 66
AD7543 . . . . . 17 – 66
•AD7545 . . . . . 17 – 67
AD7574 . . . . . 17 – 67
AD7590 . . . . . 17 – 68
AD7591 . . . . . 17 – 68
AD7592 . . . . . 17 – 68


## Component Test Systems – Section 18

## Package Information – Section 19

## Application Notes – Section 20

•New product since publication of *1982–1983 Databook Update.*

# Product Families Not in This Databook (But Still Available)



The information published in this Databook is intended to assist the user in choosing components for the design of *new* equipment, using the most cost-effective products available from Analog Devices. The popular product types listed below may have been designed into your circuits in the past, but they are no longer likely to be the most economic choice for your new designs. Nevertheless, we recognize that it is often a wise choice to refrain from redesigning proven equipment, and we are continuing to make these products available for use in existing designs or in designs for which they are uniquely suitable. Data sheets on these products are available upon request.

| | | | | |
|---|---|---|---|---|
| AD108/208/308 | ADC-QU | DAS1150 | THS-0060 | 311 |
| AD108A/208A/308A | ADC-8S | DAS1151 | THS-0225 | 424 |
| AD111/211/311 | ADC-10Z | MAS-0801 | 40 | 426 |
| AD351 | ADC-12QZ | MAS-1001 | 42 | 428 |
| AD370/371 | ADC-14I/17I | MDA-10Z | 43 | 432 |
| AD502 | ADC-16Q | MDH-0870 | 44 | 433 |
| AD511 | ADC1100 | MDH-1001 | 45 | 434 |
| AD512 | ADC1102 | MDH-1202 | 46 | 435 |
| AD514 | ADC1103 | MDS-0815 | 48 | 436 |
| AD520 | ADC1105 | MDS-0815E | 52 | 440 |
| AD523 | ADC1109 | MDS-1020 | 105 | 441 |
| AD528 | ADC1111 | MDS-1020E | 118 | 450 |
| AD530 | ADC1133 | MDS-1240 | 119 | 452 |
| AD531 | ADG200 | MDSL-0825 | 141 | 454 |
| AD540 | ADG201 | MDSL-1035 | 146 | 456 |
| AD559 | BDM1615/1616/1617 | MDSL-1250 | 148 | 605 |
| AD801 | DAC-M | RTI-1200 | 165 | 606 |
| AD2003 | DAC-QG | RTI-1201 | 180 | 610 |
| AD2008 | DAC-QM | RTI-1202 | 183 | 751 |
| AD2009 | DAC-QS | RTI-1220 | 184 | 752 |
| AD2020 | DAC-QZ | RTI-1221 | 230 | 756 |
| AD2022 | DAC-10DF | SCM1677 | 232 | 934 |
| AD2023 | DAC-10Z | SDC1604 | 233 | 942 |
| AD2033 | DAC1009 | SHA-1A | 260 | 944 |
| AD7513 | DAC1106 | SHA-2A | 261 | 946 |
| AD7519 | DAC1108 | SHA-3 | 272 | 947 |
| AD7527 | DAC1118 | SHA-4 | 273 | 956 |
| AD7544 | DAC1125 | SHA-5 | 275 | |
| AD7555 | DAC1132 | SHA-1114 | 276 | |
| AD7570 | DAC1420 | SHA-1134 | 285 | |
| AD7583 | DAC1422 | THC-0750 | 288 | |
| ADC-QM | DAC1423 | THC-1500 | 310 | |

# Substitution Guide for Product Families No Longer Available

The products listed in the left-hand column are no longer available from Analog Devices. In many cases, comparable functions and performance may be obtained with newer models, but–as a rule–they are not directly interchangeable. The closest recommended Analog Devices equivalent, physically and electrically, is listed in the right-hand column. If no equivalent is listed, or for further information, get in touch with Analog Devices.

| Model | Closest Recommended Equivalent | Model | Closest Recommended Equivalent |
|---|---|---|---|
| AD501 | AD511 | 47 | 48 |
| AD505 | AD509 | 101 (module) | 45 |
| AD508 | AD517 | 102 | 48 |
| AD513 | AD503 | 106 | 118 |
| AD516 | AD506 | 107 | 118 |
| AD550 | None | 108 | 52 |
| AD551 | None | 110 | 48 |
| AD553 | None | 111 | AD308 |
| AD555 | AD7519 | 114 | 119 |
| AD810-813 | None | 115 | 43 |
| AD814-816 | None | 120 | 50 |
| AD818 | None | 142 | 48 |
| AD820-822 | None | 143 | 52 |
| AD830-833 | None | 149 | 50 |
| AD835-839 | None | 153 | AD517 |
| AD840-842 | None | 161 | 165 |
| AD7516 | AD7510DI | 163 | 165 |
| ADC1121 | AD7550 | 170 | 171 |
| ADM501 | ADM501/506 | 220 | 234 |
| ADP501 | ADP511 | 231 | 233 |
| DAC-10H | DAC-10Z | 274J | 284J |
| DAC1112 | DAC12QS | 279 | 286J |
| DAC1122 | AD7541 | 280 | 281 |
| IDC1703 | IRDC1730/1731 | 282J | 292A |
| MDA-LB | None | 283J | 292A |
| MDA-LD | None | 301 (module) | 52 |
| MDA-UB | None | 302 | 310 (module) |
| MDA-UD | None | 350 | None |
| MDA-8H | MDA-10Z | 427 | 424 |
| MDA-10H | MDA-10Z | 602J10 | AD524 |
| MDA-11MF | AD7521 | 602J100 | AD524 |
| MDS-0830 | HDS-0820 | 602K100 | AD524 |
| MDS-0850 | HDS-0820 | 603 | AD524 |
| MDS-1040 | HDS-1025 | 901 | 904 |
| MDS-1080 | HDS-1025 | 907 | 921 |
| MDSL-0802 | HDS-0820 | 908 | 921 |
| MDSL-1002 | HDS-1025 | 909 | 921 |
| MDSL-1201 | HDS-1250 | 931 | None |
| SERDEX | μMAC-5000 | 932 | None |
| SHA-6 | SHA1144 | 933 | None |
| TSDC1608-1611 | TSL1612 | 935 | None |
| 2N3954 | None | 948 | 947 |
| 2N5900 | None | 971 | 921 |
| 41 | AD515 | AD612 | AD524 |
| | | AD614 | AD524 |

Analog Devices provides a wide array of FREE technical publications. These include Data Sheets for all products; Catalogs; Application Notes and Guides; and three serial publications: *Analog Productlog*, a digest of new-product information, *MCDigest*, a quarterly digest of measurement-and-control-system applications, feedback, and information for (and from) system users, and *Analog Dialogue*, our technical magazine, with in-depth discussions of products, technologies, and applications.

In addition to the free publications, three technical handbooks, plus *Analog Digital Conversion Notes* and *Synchro & Resolver Conversion* are available at reasonable cost. System and subsystem products are supported with hardware and software documentation, at prices related to content.

Brief descriptions of typical publications appear below. For copies of any items, to subscribe to any of our free serials, or to request any other publications, please get in touch with Analog Devices or the nearest sales office.

**CATALOGS**

*DATA ACQUISITION PRODUCTS DATABOOK (this book)*
Two volumes of data sheets for all Analog Devices ICs, hybrids, modules, and subsystems recommended for new designs.

**APPLICATION NOTES AND GUIDES**

*ANGULAR AND LINEAR DATA CONVERSION*
A 12-page short-form guide to analog-digital conversion products for synchros, resolvers, and Inductosyns*, in forms ranging from hybrid ICs to instruments and systems.

*APPLICATION GUIDE FOR ISOLATION AMPLIFIERS*
A 16-page guide to specifications and applications of isolation amplifiers for industrial, instrumentation, and medical applications.

*APPLICATION GUIDE TO CMOS MULTIPLYING D-TO-A CONVERTERS*
This guide includes detailed information on the internal design and successful application of CMOS MDACs. Typical circuits discussed include measurement, function generation, programmable filters, and control of audio signals.

*A COOKBOOK TO DIGITAL FILTERING AND OTHER DSP APPLICATIONS*
A collection of reprints of papers that originally appeared in EDN Magazine, during 1983. Topics include FIR filtering, temporal averaging, multiband filters, IIR filtering, and implementing modern control theory with digital signal processing.

*DESIGNER'S GUIDE TO HIGH-RESOLUTION PRODUCTS*
20-page brochure describes how to use 14-, 16-, and 18-bit Data Converters and where to apply them.

*HIGH-SPEED DATA CONVERSION*
A 12-page short-form guide to video and other high-speed A/D and D/A converters and accessories, in forms ranging from monolithic ICs to card-level products.

*AN IC AMPLIFIER USER'S GUIDE TO DECOUPLING, GROUNDING, AND MAKING THINGS GO RIGHT FOR A CHANGE (8 pages)*
A down-to-earth application note on the often ignored topic of ground management in combined analog and digital systems.

*IC VOLTAGE-TO-FREQUENCY CONVERTER APPLICATION NOTES*
Twenty-four pages of V-to-F converter applications.

*MACSYM SYSTEM NOTES:*
Multitasking, RS-232 Interface, and P-I-D Control Loops

*MULTIPLIER (Analog) APPLICATION GUIDE*
Over 30 workable applications for the ubiquitous multiplier. Circuits, specifications and theory (50 pages).

*RMS-TO-DC CONVERSION APPLICATION GUIDE*
by Charles Kitchin and Lew Counts. Principles, specifications, and applications of true-rms-to-dc converters in monolithic-IC form (46 pages).

**BOOKS**

*SYNCHRO & RESOLVER CONVERSION (1980)*
*Edited by Geoffrey Boyes*
Everything you need to know about interfacing synchros, resolvers, and Inductosyns™ to digital and analog circuitry. $11.50

*TRANSDUCER INTERFACING HANDBOOK (1980)*
*A Guide to Analog Signal Conditioning*
*Edited by D.H. Sheingold*
A book for the electronic engineer who must interface temperature, pressure, force, level or flow transducers to electronics, these 260 pages tell how transducers work–as circuit elements–and how to connect them to electronic circuits for effective processing of their signals. Hardcover $14.50

*MICROPROCESSOR SYSTEMS HANDBOOK (1977)*
*by Dr. D. Philip Burton and Dr. A. L. Dexter*
Two hundred pages of concise explanation of microprocessor hardware and software. Hardcover $9.50

*ANALOG-DIGITAL CONVERSION NOTES (1977)*
*Edited by D.H. Sheingold*
A 250-page guide to A/D and D/A converters and their applications, illustrated by more than 275 diagrams and tables. $5.95

*NONLINEAR CIRCUITS HANDBOOK (1974)*
*Edited by D. H. Sheingold*
A 540-page guide to multiplying and dividing, squaring and rooting, rms-to-dc conversion, and multifunction modules with 325 illustrations. Principles, circuitry, performance, specifications, testing, and application of these devices. $5.95

*Inductosyn is a registered trademark of Farrand Industries, Inc.

# Worldwide Service Directory

## North America

**Alabama**
(205) 536-1506 (B)

**Alaska**
*(617) 329-4700 (B)
*(714) 641-9391 (B)
*(408) 947-0633 (S)

**Arizona**
*(714) 641-9391 (B)
(602) 949-0048 (C)

**Arkansas**
*(214) 231-5094 (C)
*(713) 664-6704 (C)
*(405) 840-5154 (S)

**California**
*(714) 641-9391 (B)
*(408) 947-0633 (B)
*(619) 268-4621 (C)

**Colorado**
*(714) 641-9391 (B)
*(303) 691-5582 (S)
(303) 443-5337 (C)

**Connecticut**
*(617) 329-4700 (B)
(516) 673-1900 (C)

**Delaware**
*(215) 643-7790 (B)

**Florida**
*(305) 851-3939 (C)
(305) 855-0843 (B)
(305) 724-6795 (S)
(813) 693-1076 (S)

**Georgia**
(404) 476-3107 (C)
(404) 449-7662 (S)

**Hawaii**
*(714) 641-9391 (B)

**Idaho**
*(206) 251-9550 (C)
*(303) 691-5582 (S)
(303) 443-5337 (C)

**Illinois**
*(312) 653-5000 (B)
(312) 945-8700 (C)

**Indiana**
*(312) 653-5000 (B)
(317) 244-7867 (C)

**Iowa**
*(312) 653-5000 (B)
*(314) 391-0052 (S)
(312) 945-8700 (C)

**Kansas**
*(312) 653-5000 (B)
*(314) 391-0052 (S)
(913) 888-3330 (C)

**Kentucky**
*(312) 653-5000 (C)
(615) 366-4009 (B)

**Louisiana**
*(713) 664-6704 (C)
*(713) 664-5866 (S)

**Maine**
*(617) 329-4700 (B)

**Maryland**
*(215) 643-7790 (C)
*(301) 992-1994 (S)
(301) 799-7490 (C)

**Massachusetts**
*(617) 329-4700 (B)

**Michigan**
*(312) 653-5000 (C)
*(313) 694-5450 (S)
(313) 882-1717 (C)

**Minnesota**
*(312) 653-5000 (C)
*(612) 944-5865 (S)
(612) 835-2414 (C)

**Mississippi**
(205) 536-1506 (B)

**Missouri**
*(312) 653-5000 (B)
*(314) 391-0052 (S)
(314) 725-5361 (C)

**Montana**
*(714) 641-9391 (C)
*(303) 691-5582 (S)
(303) 443-5337 (C)

**Nebraska**
*(312) 653-5000 (C)
*(314) 391-0052 (S)
(913) 888-3330 (C)

**Nevada**
*(408) 947-0633 (C)
*(714) 641-9391 (C)
*(303) 691-5582 (S)
(505) 262-1416 (C)

**New Hampshire**
*(617) 329-4700 (B)

**New Jersey**
*(215) 643-7790 (B)
*(617) 329-4700 (C)
*(201) 967-1126 (S)
(516) 673-1900 (C)

**New Mexico**
(505) 262-1416 (B)

**New York**
*(201) 967-1126 (S)
*(716) 634-7970 (S)
*(716) 425-4101 (C)
*(315) 437-5277 (C)
(516) 673-1900 (C)

**North Carolina**
(919) 273-3040 (C)
(919) 373-0380 (S)
(919) 787-0808 (S)

**North Dakota**
*(312) 653-5000 (B)
*(612) 944-5865 (S)
(612) 835-2414 (C)

**Ohio**
*(614) 764-8795 (C)
*(216) 562-3115 (S)
*(614) 764-8870 (S)
(216) 321-3328 (C)

**Oklahoma**
*(214) 231-5094 (C)
*(713) 664-6704 (C)
*(405) 840-5154 (S)

**Oregon**
*(206) 251-9550 (C)
(503) 641-4463 (S)

**Pennsylvania**
*(215) 643-7790 (B)
*(412) 885-6625 (S)
*(614) 764-8795 (C)
(412) 487-3801 (C)

**Rhode Island**
*(617) 329-4700 (B)

**South Carolina**
(919) 273-3040 (C)
(404) 449-7662 (S)
(919) 373-0380 (S)

**South Dakota**
*(312) 653-5000 (B)
*(612) 944-5865 (S)
(612) 835-2414 (C)

**Tennessee**
(205) 536-1506 (B)
(615) 366-4009 (S)

**Texas**
*(214) 231-5094 (C)
*(713) 664-6704 (C)
*(713) 664-5866 (S)

**Utah**
*(408) 947-0633 (B)
*(303) 691-5582 (S)
(801) 268-8707 (C)

**Vermont**
*(617) 329-4700 (B)

**Virginia**
*(804) 379-0905 (S)
(301) 799-7490 (C)

**Washington**
*(206) 251-9550 (C)
(206) 451-8223 (S)
(503) 641-4463 (S)

**West Virginia**
*(614) 764-8795 (C)
*(301) 992-1994 (S)
(412) 487-3801 (C)

**Wisconsin**
*(312) 653-5000 (B)
*(612) 944-5865 (S)
(414) 784-7736 (C)

**Wyoming**
*(408) 947-0633 (C)
*(303) 691-5582 (S)
(303) 443-5337 (C)

**Puerto Rico**
*(617) 329-4700 (B)
(305) 855-0843 (S)

**Canada**
(416) 625-7752 (C)
(613) 722-7667 (C)
(514) 694-5343 (C)
(604) 984-4141 (C)
(416) 451-0813 (S)
(514) 331-2032 (S)
(403) 468-1661 (S)

**Mexico**
*(617) 329-4700 (B)

# International

**Argentina**
(1) 379890 (C)

**Australia**
(2) 4393288 (B)
(3) 5807444 (B)

**Austria**
(222) 2355550 (B)

**Belgium**
*(3) 2374803 (B)

**Brazil**
(11) 2310277 (C)

**CMEA COUNTRIES**
(222) 859304 (C)
(Austria)

**Denmark**
*(2) 845800 (B)

**Finland**
(0) 372300 (B)

**France**
*(1) 6873411 (B)
*(76) 222190 (B)
*(61) 408562 (B)
*(99) 535200 (B)

**Holland**
*(1620) 51080 (B)

**Hong Kong**
(3) 903391 (B)

**India**
(11) 664850 (B)

**Ireland**
*(01) 9410466 (B)
(United Kingdom)

**Israel**
*(052) 28995 (B)

**Italy**
*(2) 6883831 (B)
(2) 9520551 (C)
(51) 555614 (C)
(49) 633600 (C)
(6) 316204 (C)
(55) 894105 (C)
(11) 6503271 (C)

**Japan**
*(3) 2636826 (B)
*(6) 3721814 (B)

**Korea**
(2) 4233101-5 (B)

**Malaysia**
(65) 2713163 (B)
(Singapore)

**New Zealand**
(9) 592629 (B)

**Norway**
(2) 123600 (B)

**People's Republic of China – Beijing**
890721 – Ext. 827 (B)

**Romania**
*(22) 318720 (B)
(Switzerland)

**Singapore**
(65) 2713163 (B)

**South Africa**
(11) 7868025 (B)

**Spain**
(3) 3017851 (B)
(1) 7338937 (B)
(4) 4150893 (B)

**Sweden**
*(8) 282740 (B)

**Switzerland**
*(22) 315760 (B)
*(22) 318720 (B)
*(01) 527766 (B)

**Taiwan**
(2) 7150940 (B)

**United Kingdom**
*(01) 9410466 (B)

**West Germany**
*(89) 570050 (B)
*(4) 187381 (B)
*(721) 616075 (B)
*(30) 316441 (B)
*(221) 686006 (B)

**Yugoslavia**
*(22) 318720 (B)
(Switzerland)

*ANALOG DEVICES, INC. DIRECT SALES OFFICES
B – ALL PRODUCT LINES
C – COMPONENT
S – SYSTEMS

**WORLDWIDE HEADQUARTERS**
**TWO TECHNOLOGY WAY • P.O. BOX 280 • NORWOOD, MASSACHUSETTS 02062–0280 U.S.A.**
**TEL: (617) 329-4700, FAX: (617) 326-8703, TWX: (710) 394-6577, TELEX: 924491**
**Cable: ANALOG NORWOODMASS**

# Product Index to Both Volumes

**Alpha-Numeric by Model Number**


| Model # | Vol. I | Vol. II |
|---|---|---|
| AC2626 | | 9 – 13 |
| AD101A | 4 – 17 | |
| AD201A | 4 – 17 | |
| AD293 | 5 – 13 | |
| AD294 | 5 – 13 | |
| AD301A | 4 – 17 | |
| AD301AL | 4 – 17 | |
| AD346 | 14 – 11 | |
| AD362 | 15 – 5 | |
| AD363 | 15 – 13 | |
| AD364 | 15 – 25 | |
| AD380 | 4 – 21 | |
| AD381 | 4 – 27 | |
| AD382 | 4 – 27 | |
| •AD389 | 14 – 17 | |
| AD390 | 9 – 27 | |
| AD503 | 4 – 35 | |
| AD504 | 4 – 39 | |
| AD506 | 4 – 35 | |
| AD507 | 4 – 47 | |
| AD509 | 4 – 51 | |
| AD510 | 4 – 55 | |
| AD515 | 4 – 59 | |
| AD517 | 4 – 65 | |
| AD518 | 4 – 71 | |
| AD521 | 5 – 21 | |
| AD522 | 5 – 27 | |
| AD524 | 5 – 31 | |
| AD532 | 6 – 17 | |
| AD533 | 6 – 23 | |
| AD534 | 6 – 27 | |
| AD535 | 6 – 37 | |
| AD536A | 6 – 43 | |
| AD537 | 11 – 7 | |
| AD539 | 6 – 49 | |
| AD542 | 4 – 75 | |
| AD544 | 4 – 79 | |
| AD545 | 4 – 83 | |
| AD547 | 4 – 87 | |
| AD558 | 9 – 35 | |
| AD561 | 9 – 43 | |
| AD562 | 9 – 51 | |
| AD563 | 9 – 51 | |
| AD565A | 9 – 57 | |
| AD566A | 9 – 65 | |
| AD567 | 9 – 73 | |
| •AD569 | 9 – 81 | |
| AD570 | 10 – 27 | |
| AD571 | 10 – 31 | |
| AD572 | 10 – 39 | |
| AD573 | 10 – 47 | |
| AD574A | 10 – 55 | |
| •AD575 | 10 – 67 | |
| AD578 | 10 – 73 | |
| AD579 | 10 – 79 | |
| AD580 | 7 – 5 | |
| AD581 | 7 – 9 | |
| AD582 | 14 – 23 | |
| AD583 | 14 – 27 | |
| AD584 | 7 – 17 | |
| •AD585 | 14 – 31 | |
| AD589 | 7 – 25 | |
| AD590 | 8 – 15 | |
| •AD592 | 8 – 23 | |
| AD594 | 8 – 31 | |
| •AD595 | 8 – 31 | |
| •AD596 | 8 – 39 | |
| •AD597 | 8 – 39 | |
| •AD611 | 4 – 91 | |
| AD624 | 5 – 43 | |
| •AD625 | 5 – 55 | |
| AD630 | 6 – 57 | |
| AD632 | 6 – 67 | |
| AD636 | 6 – 71 | |
| AD637 | 6 – 77 | |
| AD642 | 4 – 95 | |
| AD644 | 4 – 99 | |
| AD647 | 4 – 103 | |
| AD650 | 11 – 15 | |
| •AD667 | 9 – 83 | |
| •AD670 | 10 – 85 | |
| AD673 | 10 – 95 | |
| AD 741J/K/L/S | 4 – 107 | |
| AD1403/1403A | 7 – 29 | |
| AD1408 | 9 – 89 | |
| AD1508 | 9 – 89 | |
| AD2004 | | 16 – 9 |
| AD2006 | | 16 – 11 |
| AD2010 | | 16 – 15 |
| AD2016 | | 16 – 19 |
| AD2021 | | 16 – 23 |
| AD2024 | | 16 – 25 |
| AD2025 | | 16 – 29 |
| AD2026 | | 16 – 33 |
| AD2027 | | 16 – 25 |
| AD2028 | | 16 – 29 |
| AD2036 | | 16 – 35 |
| AD2037 | | 16 – 37 |
| AD2038 | | 16 – 37 |
| AD2040 | | 16 – 39 |
| AD2050 | | 16 – 43 |
| AD2051 | | 16 – 43 |
| •AD2060 | | 16 – 45 |
| •AD2061 | | 16 – 45 |
| AD2700/2701/2702 | 7 – 33 | |
| AD2710/2712 | 7 – 37 | |


•New product since publication of *1982–1983 Databook Update.*

| Model # | Vol. I | Vol. II |
|---|---|---|
| AD3554 | 4 – 111 | |
| AD3860 | 9 – 93 | |
| •AD5010 | 10 – 103 | |
| AD5200 | 10 – 105 | |
| AD5210 | 10 – 105 | |
| AD5240 | 10 – 111 | |
| •AD6012 | 9 – 97 | |
| •AD6020 | 10 – 103 | |
| AD7110 | 9 – 103 | |
| AD7111 | 9 – 109 | |
| •AD7115 | 9 – 115 | |
| AD7118 | 9 – 123 | |
| •AD7224 | 9 – 129 | |
| •AD7226 | 9 – 133 | |
| •AD7240 | 9 – 145 | |
| AD7501 | 16 – 5 | |
| AD7502 | 16 – 5 | |
| AD7503 | 16 – 5 | |
| AD7506 | 16 – 9 | |
| AD7507 | 16 – 9 | |
| AD7510DI | 16 – 13 | |
| AD7511DI | 16 – 13 | |
| AD7512DI | 16 – 13 | |
| AD7520 | 9 – 153 | |
| AD7521 | 9 – 153 | |
| AD7522 | 9 – 161 | |
| AD7523 | 9 – 167 | |
| AD7524 | 9 – 171 | |
| AD7525 | 9 – 177 | |
| AD7528 | 9 – 183 | |
| AD7530 | 9 – 191 | |
| AD7531 | 9 – 191 | |
| AD7533 | 9 – 195 | |
| •AD7534 | 9 – 201 | |
| AD7541 | 9 – 203 | |
| AD7541A | 9 – 209 | |
| AD7542 | 9 – 215 | |
| AD7543 | 9 – 223 | |
| AD7545 | 9 – 231 | |
| AD7546 | 9 – 239 | |
| •AD7548 | 9 – 247 | |
| AD7550 | 10 – 119 | |
| AD7552 | 10 – 127 | |
| AD7560 | 7 – 41 | |
| AD7571 | 10 – 139 | |
| AD7574 | 10 – 151 | |
| AD7581 | 10 – 159 | |
| AD7590DI | 16 – 21 | |
| AD7591DI | 16 – 21 | |
| AD7592DI | 16 – 21 | |
| •AD9000 Series | 10 – 167 | |
| AD9685/87 | 4 – 117 | |
| •AD9768 | 9 – 261 | |
| AD ADC71/72 | 10 – 175 | |
| AD ADC80 | 10 – 183 | |
| AD ADC84/85 | 10 – 191 | |
| •AD ADC-816 | 10 – 199 | |
| ADC1130/1131 | | 11 – 27 |
| ADC1140 | | 11 – 31 |
| •ADC1143 | | 11 – 35 |
| AD DAC-08 | 9 – 265 | |
| AD DAC71/72 | 9 – 271 | |
| AD DAC80 | 9 – 277 | |
| AD DAC85 | 9 – 277 | |
| AD DAC87 | 9 – 277 | |
| AD DAC100 | 9 – 287 | |
| ADLH0032 | 4 – 121 | |
| ADLH0033 | 4 – 125 | |
| AD OP-07 | 4 – 129 | |
| •AD OP-27 | 4 – 135 | |
| •AD OP-37 | 4 – 143 | |
| ADSHC85 | 14 – 37 | |
| ADSHM-5 | | 14 – 11 |
| ADSP-1008 | 12 – 7 | |
| •ADSP-1009 | 12 – 13 | |
| ADSP-1010 | 12 – 19 | |
| •ADSP-1012 | 12 – 27 | |
| ADSP-1016 | 12 – 35 | |
| •ADSP-1024 | 12 – 43 | |
| ADSP-1080 | 12 – 51 | |
| •ADSP-1081 | 12 – 57 | |
| •ADSP-1110 | 12 – 65 | |
| ADVFC32 | 11 – 27 | |
| API1620/1718 | | 13 – 5 |
| CAV-0920 | | 11 – 39 |
| •CAV-1040 | | 11 – 43 |
| CAV-1210 | | 11 – 45 |
| DAC-08 (see AD DAC-08) | | |
| DAC71/72 (see AD DAC71/72) | | |
| DAC80 (see AD DAC80) | | |
| DAC85 (see AD DAC85) | | |
| DAC87 (see AD DAC87) | | |
| DAC100 (see AD DAC100) | | |
| DAC1136 | | 10 – 27 |
| DAC1138 | | 10 – 27 |
| DAC1146 | | 10 – 35 |
| DAS1128 | | 15 – 5 |
| DAS1152 | | 15 – 13 |
| DAS1153 | | 15 – 13 |
| DAS1155 | | 15 – 17 |
| DAS1156 | | 15 – 17 |
| DRC1745/46 | 13 – 5 | |
| DRC1765/66 | 13 – 13 | |
| DSC1705 | | 13 – 9 |
| DSC1706 | | 13 – 9 |
| DTM1716 | | 13 – 13 |
| DTM1717 | | 13 – 13 |


•New product since publication of *1982–1983 Databook Update.*

| Model # | Vol. I | Vol. II |
|---|---|---|
| HAS Series | 10 – 201 | |
| •HAS-1201 | 10 – 205 | |
| •HAS-1409 | 10 – 207 | |
| HDD Series | 9 – 295 | |
| HDD-1206 | 9 – 301 | |
| •HDD-1409 | 9 – 305 | |
| HDG Series | 9 – 309 | |
| HDH Series | 9 – 317 | |
| •HDM-1210 | 9 – 315 | |
| HDS Series | 9 – 317 | |
| HDS-0810E | 9 – 321 | |
| HDS-1015E | 9 – 321 | |
| HDS-1240E | 9 – 323 | |
| HOS-050/050A/050C | 4 – 147 | |
| HOS-060 | 4 – 153 | |
| HOS-100 | 4 – 157 | |
| HTC Series | 14 – 41 | |
| HTC-0500 | 14 – 45 | |
| HTS-0010 | 14 – 49 | |
| HTS-0025 | 14 – 55 | |
| •IPA1751 | | 13 – 17 |
| IRDC1730 | | 13 – 21 |
| IRDC1731 | | 13 – 27 |
| •IRDC1732 | 13 – 17 | |
| IRDC1733 | | 13 – 21 |
| LTS-2010 | 18 – 1 | |
| MACSYM 150 | | 19 – 1 |
| MACSYM 200 | | 19 – 1 |
| MACSYM 350 | | 19 – 1 |
| MAH-0801 | | 11 – 49 |
| MAH-1001 | | 11 – 49 |
| MAS-0801 | | 11 – 53 |
| MAS-1001 | | 11 – 53 |
| MAS-1202 | | 11 – 53 |
| MATV Series | | 11 – 57 |
| •MCI1794 | | 13 – 31 |
| MDD Series | | 10 – 39 |
| MDMS Series | | 10 – 43 |
| MOD-1005 | | 11 – 61 |
| MOD-1020 | | 11 – 65 |
| MOD-1205 | | 11 – 69 |
| μMAC-4000 | | 18 – 1 |
| •μMAC-5000 | | 18 – 3 |

| Model # | Vol. I | Vol. II |
|---|---|---|
| •OSC1754 | | 13 – 17 |
| RCDX1623 | | 13 – 45 |
| RDC1721 | | 13 – 55 |
| RDC1740/1741/1742 | 13 – 23 | |
| RSCT1621 | | 13 – 65 |
| •RTI-600 | | 17 – 5 |
| •RTI-602 | | 17 – 5 |
| •RTI-711 | | 17 – 7 |
| •RTI-724 | | 17 – 7 |
| •RTI-732 | | 17 – 7 |
| RTI-1225 | | 17 – 9 |
| RTI-1226 | | 17 – 9 |
| RTI-1230 | | 17 – 11 |
| RTI-1231 | | 17 – 11 |
| RTI-1232 | | 17 – 11 |
| RTI-1240 | | 17 – 13 |
| RTI-1241 | | 17 – 13 |
| RTI-1242 | | 17 – 13 |
| RTI-1243 | | 17 – 13 |
| RTI-1250 | | 17 – 15 |
| RTI-1251 | | 17 – 15 |
| RTI-1252 | | 17 – 15 |
| RTI-1260 | | 17 – 17 |
| RTI-1262 | | 17 – 17 |
| •RTI-1270 | | 17 – 19 |
| RTM Series | | 13 – 33 |
| SAC1763 | | 13 – 37 |
| SBCD1752 | | 13 – 41 |
| SBCD1753 | | 13 – 41 |
| SBCD1756 | | 13 – 41 |
| SBCD1757 | | 13 – 41 |
| SCDX1623 | | 13 – 45 |
| SDC1700 | | 13 – 49 |
| SDC1702 | | 13 – 49 |
| SDC1704 | | 13 – 49 |
| SDC1721 | | 13 – 55 |
| SDC1725 | | 13 – 59 |
| SDC1726 | | 13 – 59 |
| SDC1740/1741/1742 | 13 – 23 | |
| SHA1144 | | 14 – 15 |
| SPA1695 | | 13 – 63 |
| SSCT1621 | | 13 – 65 |
| STM Series | | 13 – 33 |
| THC Series | | 14 – 19 |

| Model # | Vol. I | Vol. II |
|---|---|---|
| THS Series | | 14 – 19 |
| TSL1612 | | 13 – 69 |
| •1S20 | 13 – 29 | |
| •1S40 | 13 – 29 | |
| •1S60 | 13 – 29 | |
| •1S61 | 13 – 29 | |
| 2B20 | | 9 – 15 |
| 2B22 | | 9 – 19 |
| 2B23 | | 9 – 23 |
| 2B24 | | 9 – 27 |
| 2B30 | | 9 – 29 |
| 2B31 | | 9 – 29 |
| 2B34 | | 9 – 35 |
| 2B35 | | 9 – 39 |
| 2B50 | | 9 – 41 |
| 2B52 | | 9 – 45 |
| 2B53 | | 9 – 45 |
| 2B54 | | 9 – 47 |
| 2B55 | | 9 – 47 |
| 2B56 | | 9 – 53 |
| 2B57 | | 9 – 57 |
| 2B58 | | 9 – 61 |
| 2B59 | | 9 – 63 |
| 3B Series | | 9 – 65 |
| •4B Series | | 9 – 69 |
| 50/51 | | 4 – 17 |
| 52 | | 4 – 19 |
| 171 | | 4 – 21 |
| 234 | | 4 – 23 |
| 235 | | 4 – 23 |
| 277 | | 5 – 9 |
| 281 | | 5 – 11 |
| 284J | | 5 – 11 |
| 286J | | 5 – 11 |
| 289 | | 5 – 17 |
| 290A | | 5 – 21 |
| 292A | | 5 – 21 |
| 429 | | 6 – 9 |
| 442 | | 7 – 7 |
| 451 | | 12 – 7 |
| 453 | | 12 – 7 |
| 458 | | 12 – 13 |
| 460 | | 12 – 13 |

| Model # | Vol. I | Vol. II |
|---|---|---|
| 755N/P | | 8 – 7 |
| 757N/P | | 8 – 11 |
| 759N/P | | 8 – 7 |
| 902/902-2 | | 20 – 1 |
| 903 | | 20 – 1 |
| 904 | | 20 – 1 |
| 905 | | 20 – 1 |
| 906 | | 20 – 1 |
| 915 | | 20 – 1 |
| 920 | | 20 – 1 |
| 921 | | 20 – 1 |
| 922 | | 20 – 1 |
| 923 | | 20 – 1 |
| 925 | | 20 – 1 |
| 926 | | 20 – 1 |
| 927 | | 20 – 1 |
| 928 | | 20 – 1 |
| 940 | | 20 – 2 |
| 941 | | 20 – 2 |
| 943 | | 20 – 2 |
| 945 | | 20 – 2 |
| 949 | | 20 – 2 |
| 951 | | 20 – 2 |
| 952 | | 20 – 1 |
| 953 | | 20 – 2 |
| 955 | | 20 – 1 |
| 957 | | 20 – 2 |
| 958 | | 20 – 2 |
| 959 | | 20 – 2 |
| 960 | | 20 – 2 |
| 961 | | 20 – 2 |
| 962 | | 20 – 2 |
| 963 | | 20 – 2 |
| 964 | | 20 – 2 |
| 965 | | 20 – 2 |
| 966 | | 20 – 2 |
| 967 | | 20 – 2 |
| 968 | | 20 – 2 |
| 970 | | 20 – 1 |
| 972 | | 20 – 1 |
| 973 | | 20 – 1 |
| 974 | | 20 – 1 |
| 975 | | 20 – 1 |
| 976 | | 20 – 1 |


•New product since publication of *1982–1983 Databook Update.*




**COMPLETE DATABOOK IN TWO VOLUMES:**

**Volume I:** Integrated Circuits
**Volume II:** Modules and Subsystems

WORLDWIDE HEADQUARTERS

Two Technology Way, P.O. Box 280, Norwood, MA 02062 U.S.A.
Tel: (617) 329-4700, Twx: (710) 394-6577, Telex: 924491, Cable: ANALOG NORWOODMASS