Instruction Manual

February 1978
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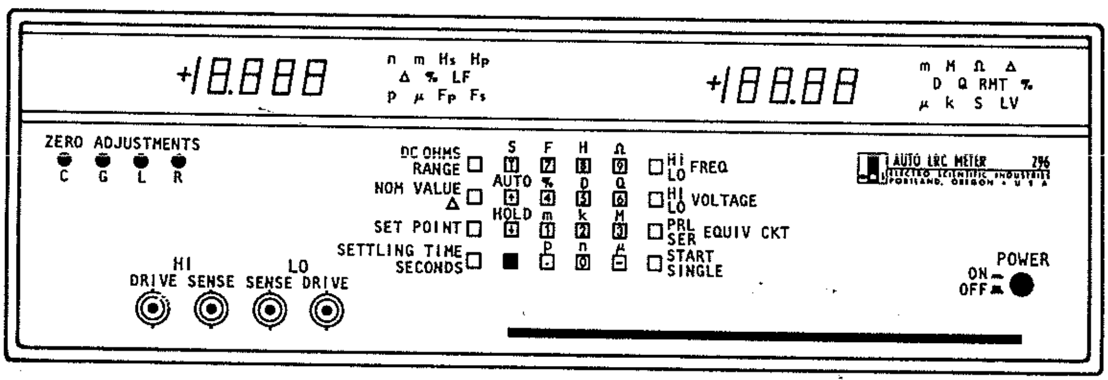
MODEL 296

Automatic LRC Meter

Ser# 850001



Part Number 41909

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ADDENDUM TO MODEL 296 MANUAL

ESI Model SP25Ø9-1 is a modified ESI Model 296. The low test frequency is 12ØHz and the high test frequency is changed to 2ØKHz. Specification changes for the SP25Ø9-1 are as follows:

12ØHz SPECIFICATIONS - As stated for low voltage or current mode in Section 1.2 of this manual.

2ØkHz SPECIFICATIONS

RANGES:

	Admittance Bridge		Impedance Bridge		
Range No.	Capicatance	Rs (ESR)	Inductance	Rs (ESR)	Range No.
Test Mode		1ØmΩ			
Ø	1.9999mF	19.999mΩ			
1	199.99µF	199.99mΩ	1.9999µH	1ØØ.ØØmΩ	1
2	19.999µF	1.9999Ω	19.999µH	1.ØØØØΩ	2
3	1.9999µF	19.999Ω	199.99µH	1Ø.ØØØΩ	3
4	199.99nF	199.99Ω	1.9999mH	1ØØ.ØØΩ	4
5	19.999nF	1.9999kΩ	19.999mH	1.ØØØkΩ	5
6	1.9999nF	19.999kΩ	199.99mH	1Ø.ØØØkΩ	6
7	199.99pF	199.99kΩ	1.9999H	1ØØ.ØØkΩ	7
8	19.999pF	1.9999MΩ	19.999H	1.ØØØØMΩ	8

ACCURACY:

CAPACITANCE — ±Ø.5% of reading + 2 counts. Accuracy of ranges Ø, 1 and 2 are dependent upon cancellation of lead inductance by proper lead configuration and the amount of inductance in the unknown. Accuracy of Range 8 is ±Ø.1pF and requires careful adjustment of the C & G front panel zero controls.

INDUCTANCE — ±Ø.5% of reading + 2 counts. Accuracy of range 1 is ±Ø.Ø1µH and is dependent upon cancellation of lead inductance by proper lead configuration and the careful adjustment of the L and R front panel zero controls.

Rs (ESR) — ± (Ø.5% of reading + 2 counts) ±Ø.5mΩ.

Test Signal to Unknown:

HI voltage - Test signal level to the unknown is Ø.5V RMS.

LO voltage - not recommended for use.

HI current - Test levels, for inductance measurements, are reduced by one half.

LO current - Not recommended for use.

Test Lead Configurations

At higher frequencies, special attention to the test lead configuration is required to minimize errors caused by lead inductance. The current drive leads (HI drive and LO drive) should be shielded coax twisted with their shields connected together at the unknown. The HI and LO sense leads should also be shielded coax twisted together. If the sense leads have shield connections they should also be connected together at the unknown. This procedure replaces the description in Paragraph 1, Section 2.3.1.3 of this manual.

The normal cable set (ESI Part No. 23898) can be used by exchanging LO sense and LO drive labels and retwisting the leads in order to obtain the proper shield connections.

ESR MEASUREMENT

Measurements of capicatance and ESR (equivalent series resistance) can be made by the Model 296, in its admittance bridge configuration, as long as the D (dissipation factor) of the capacitor does not exceed a D of 2. Measurement of capacitors with greater than 2 is possible by programming special test mode ØØØ3.

Special test mode ØØØ3 measures a capacitor as an inductor (see section 2.3.9 of this manual) and automatically converts the results to capicatance using the formula:

$$C = \frac{-1}{L^2}$$

This test mode is also used to measure capacitors greater than 2ØØmF.

The sequence used to program the Model 296 for capicatance and ESR measurements is as follows:

1. Set the measurement functions; see Section 2.3 of this manual.
2. Set measurement frequency; see Section 2.3 of this manual.
3. Program special test mode ØØØ3 (for capacitors that exceed a D of 2); see Section 2.3.9 of this manual.
4. Select proper range; see Section 2.3 of this manual.

When in special test mode ØØØ3 it is very convenient to measure capicatance at low frequency and ESR at high frequency. This is accomplished first by measuring the capicatance at low frequency then pushing the HI FREQ button and reading the ESR.

Measuring ESR at high frequencies, while in test mode ØØØ3, may cause the Model 296's left hand display to blink even though the right hand display is presenting a valid result. This condition is caused by the capacitors actually being inductive at high frequency and the calculated value is too large or too small to be displayed (measurement range for test mode ØØØ3 is 18ØØ counts to 19999 counts on each range).

SECTION 1
DESCRIPTION

1.1 INTRODUCTION

Model 296 is a microprocessor-controlled automatic LRC meter. It makes high speed L, R, C, and G measurements and also calculates D and Q. Its two 4-1/2 digit readouts simultaneously display the reactive and loss components of the unknown. Measurement function programming is performed with the 24-button front panel keyboard which uses dual function buttons similar to those in pocket calculators to simplify function selection.

A wide range of features and options give the user maximum flexibility to tailor instrument operation to specific testing requirements. Model 296 operates as a stand-alone benchtop tester or can be used with auxillary handling equipment and easily fits into sophisticated automatic testing systems. Section 1.3 is a feature summary which lists features and the instruction manual section describing them.

1.2 SPECIFICATIONS

ADMITTANCE

C BRIDGE RANGE NUMBERS		0	1	2	3	4	5	6	7	8
RANGES FULL SCALE C_p, C_s	1 kHz	19.999 mF	1.9999 mF	199.99 µF	19.999 µF	1.9999 µF	199.99 nF	19.999 nF	1.9999 nF	199.99 pF
	120 Hz(1)	199.99 mF	19.999 mF	1999.9 µF	199.99 µF	19.999 µF	1999.9 nF	199.99 nF	19.999 nF	1999.9 pF
G_p	1 kHz and 120 Hz(1)	100.00 S	10.000 S	1.0000 S	100.00 mS	10.000 mS	1.0000 mS	100.00 µS	10.000 µS	1.0000 µS
R_s	1 kHz and 120 Hz(1)	19.999 mΩ	199.99 mΩ	1.9999 Ω	19.999 Ω	199.99 Ω	1.9999 kΩ	19.999 kΩ	199.99 kΩ	1.9999 MΩ
TEST SIGNAL	HI Voltage	0.001 VRMS	0.01 VRMS	0.1 VRMS	1 VRMS					
	LO Voltage				0.1 VRMS					
ACCURACY(3) ±(% of Reading + % of Full Scale)	HI Voltage	±[2.0% + (0.05%)(2)]	±[0.5% + (0.025%)(2)]	±[0.1% + (0.01%)(2)]	±[0.1% + (0.005%)(2)]					
	LO Voltage			±[0.1% + (0.01%)(2)]						±[0.1% + (0.025%)(2)]
SPECIAL C_s RANGE	120 Hz(1)	0.2 F to 2 F Manually Selected					Accuracy: ±5% of Reading			

IMPEDANCE

L BRIDGE RANGE NUMBERS		1	2	3	4	5	6	7	8
RANGES FULL SCALE L_s, L_p	1 kHz	19.999 µH	199.99 µH	1.9999 mH	19.999 mH	199.99 mH	1.9999 H	19.999 H	199.99 H
	120 Hz(1)	199.99 µH	1999.9 µH	19.999 mH	199.99 mH	1999.9 mH	19.999 H	199.99 H	1999.9 H
R_s	1 kHz and 120 Hz(1)	100.00 mΩ	1.0000 Ω	10.000 Ω	100.00 Ω	1.0000 kΩ	10.000 kΩ	100.00 kΩ	1.0000 MΩ
G_p	1 kHz and 120 Hz(1)	19.999 S	1.9999 S	199.99 mS	19.999 mS	1.9999 mS	199.99 µS	19.999 µS	1.9999 µS
TEST SIGNAL	HI Current	100 mA			10 mA	1 mA	100 µA	10 µA	1 µA
	LO Current	10 mA			1 mA	100 µA	10 µA	1 µA	0.1 µA
ACCURACY(3) ±(% of Reading +% of Full Scale) 1 kHz	HI Current	±(0.1% + 0.05%)	±(0.1% + 0.005%)						±(0.5% + 0.05%)
	LO Current		±(0.1% + 0.01%)					±(0.1% + 0.05%)	
120 Hz	HI Current		±(0.1% + 0.01%)					±(0.1% + 0.025%)	±(0.5% + 0.1%)
	LO Current		±[0.1% + (0.025%)(2)]					±(0.1% +0.05%)	±(0.5% + 0.25%)

DISSIPATION

		0	1	2–7	8
D RANGE, FULL SCALE		1.9999			
ACCURACY ±(% of Reading + Counts)	HI Test Signal	±(2.0% + 20 Counts + A(5))	±(1.0% + 10 Counts + A(5))	±(1.0% + 5 Counts + A(5))	
	LO Test Signal				±(1.0% + 10 Counts(6) + A(5))

Q

Q RANGE, FULL SCALE	1999.9

TEMPERATURE COEFFICIENT OF ACCURACY 23°C ±5°C	C, L, G and R	±(0.01% of Reading/C° + 0.001% of Full Scale/C°)
	D and Q	±(0.01% of Reading/C° + 0.3 Count/C°)

(1) 100 Hz for 50 Hz line frequency

(2) C and L derating for large loss: ±(0.05% of full scale) (counts of G, D, or R/10,000)

(3) Multiply by 2 for 120 Hz or single cycle measurement

(4) Multiply by 2 for 1 kHz and by 4 for 120 Hz or single cycle measurement

(5) $A = \left(\frac{20{,}000}{\text{C or L reading}}\right)(0.3 \text{ count})$

$A = \left(\frac{20{,}000}{\text{C or L reading}}\right)(0.03 \text{ count})$ for low D mode

(6) Multiply by 5 for 120 Hz or single cycle measurement

Table 1-1. Model 296 Specifications

Zero Adjustments: L - ±0.1µH; R - ±1mΩ (HI frequency only)
C - ±20pF; G - ±50nS (compensates for lead and test fixture effects)

Measurement Speed (See Figure 2-4): 1kHz - as low as 88ms
120Hz - as low as 133ms

Displays: Two, 4-1/2 digit, LED, with units symbols

Keyboard: 24-button (2 dual function keys)

Power: 120VAC (100, 220, 240VAC optional), 60Hz (50Hz optional), 100W

Dimensions: Height - 135mm (5.2 in.)
150mm (6 in.) with feet
Width - 430mm (17 in.)
Depth - 405mm (16 in.)

Weight: 14kg (30 lb)

Features: External Bias to 200V
Active Guard
Absolute and Percent Deviation
Ten Programmable Limits
120Hz and 1kHz Test Frequencies
Two Test Voltage/Current Levels
Charged Capacitor Protection
Autoranging

Options: IEEE 488-1975 Interface Bus (Part No. 42404)
High Speed Measurement (Part No. 42445)
DC Resistance Measurement (Part No. 42536)
Handler Interface (Part No. 42434)
Other Test Frequencies
TTY Interface (Part No. 42735)
Card Reader Interface (Part No. 42736)

1.3 FEATURE SUMMARY

Features and options available for Model 296 are listed below along with a brief description and instruction manual section to read for further information.

FEATURES

Dual Test Frequencies - 120Hz and ~~1kHz~~ 20KHZ standard, others available on special order; see Section 2.3

Dual Test Levels - two test levels; constant voltage for C, constant current for L; see Table 1-1 and Section 2.3. Alternate function allows constant voltage for L and constant current for C; see Section 2.3.9

Series or Parallel Equivalent Circuit Measurement - parallel or series measurement of reactance functions; see Section 2.3.1

Dual 4-1/2 Digit Displays - 20,000 counts full scale

Programmable Settling Time - operator can program settling time from 25ms to 1.2s; see Sections 2.3.1.2, 2.3.7 and 2.3.8

Autoranging or Range Hold - automatically selects range to give maximum resolution measurement; see Section 2.3.1

Continuous or Single Cycle - continuous measurements or single measurement cycle, with or without digital averaging; see Sections 2.3.1.2 and 2.3.9

Deviation Measurement - either percent or absolute deviation from a nominal; see Section 2.3.5

Multi-Limit Sorting - 10 limits for sorting components into tolerance bands, either percent or absolute limits; see Section 2.3.6

Digital Averaging - displayed value is calculated mean of 8 measurements; see Sections 2.3.1.2, 2.3.8 and 2.3.9

Test Mode Functions - alternate programming mode providing additional functions and alternate choices for standard functions; see Section 2.3.9

Active Guard - for measuring components in closed loop and buried node configuration; see Section 2.3.1.5

Front Panel Lock-out - eliminates accidental change of test conditions and functions; see Sections 2.3.9 and 2.4.3

External Bias to 200V - allows bias for electrolytic and tantalum capacitors; see Section 2.3.10

Charged Capacitor Protection - prevents damage if charged capacitor is connected to test leads; see Section 2.3.3

Front and Rear Panel Guarded Four-terminal Connections to Unknown - see Section 2.3.1.3

OPTIONS (Field-Installable)

IEEE 488-1975 Interface (GPIB) - allows operation with external equipment and controllers; see Section 2.4.3.1

High Speed Measurement - increases overall measurement speed; see Sections 2.3.8 and 2.4.2

DC Resistance Measurement - allows measurement of resistance with dc signal; see Section 2.4.1

Handler Interface - for operation with high speed parts handlers; see Section 2.4.3.4

Teletype Interface - for operation with serial bus devices with current loop, RS 232, or TTL levels; see Section 2.4.3.2

Card Reader Interface - simplifies programming and eliminates operator error; see Section 2.4.3.3

SECTION 2

OPERATION

2.1 FRONT PANEL CONTROLS

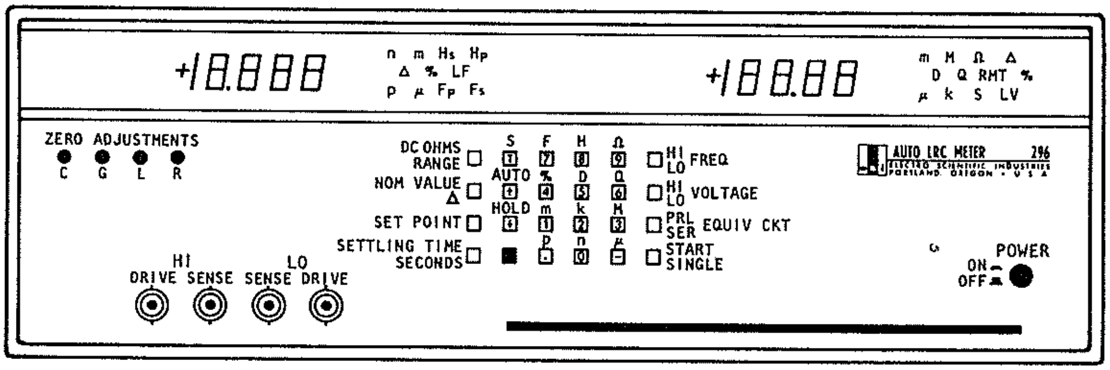


Figure 2-1. Model 296 Front Panel

2.1.1 Keyboard

The keyboard provides all control functions for Model 296. It consists of 24 buttons, 21 of which have two functions. Buttons with two functions have the alternate function represented in red lettering on the front panel. To select an alternate function, the red button must be pushed before the button with the desired function. The function of each button is described below.

./p - Decimal point and pico (10^{-12}) multiplier.
0/n - Zero numeral and nano (10^{-9}) multiplier.
-/μ - Minus sign and micro (10^{-6}) multiplier.
1/m - One numeral and milli (10^{-3}) muliplier.
2/k - Two numeral and kilo (10^{3}) multiplier.
3/M - Three numeral and mega (10^{6}) multiplier.
4/% - Four numeral. % key is used with the limits and deviation features to define and display % deviation.
5/D - Five numeral. D represents dissipation factor measurement function.
6/Q - Six numeral. Q represents quality factor measurement function.
7/F - Seven numeral. F represents farads (the units of capacitance) and capacitance measurement function.
8/H - Eight numeral. H represents henries (the units of inductance) and inductance measurement function.
9/Ω - Nine numeral. Ω represents ohms (the units of resistance) and resistance measurement function.

The above buttons are used to set ranges, desired units of display, and measurement functions. Multipliers allow combinations such as mH (millihenries) and nF (nanofarads) to be programmed. The ., - and 0 thru 9 keys are for setting ranges, nominal values, set points and other functions which require input of a specific number.

T/S - The S function provides the units for conductance (siemens) and selects that measurement function. T represents TEST. Pushing this button lights all the numerical displays as a check for burned out segments. It is also used to enter special test mode measurement functions. (See Section 2.3.9.)

↑/AUTO and ↓/HOLD - AUTO and HOLD refer to autoranging and range hold modes. Autoranging is automatically selected when the unit is first turned on. HOLD mode allows rapid checking of many unknowns in the same range. When in the HOLD mode, the ↑ and ↓ shift Model 296 up and down ranges. Pushing the ↑ or ↓ button when in AUTO mode puts the instrument in HOLD mode and shifts the range. AUTO returns unit to autoranging mode.

HI/LO FREQ and HI/LO VOLTAGE - Select the high and low test frequency and test voltage or current. High frequency is 1 kHz, low is 120 Hz (100 Hz for 50 Hz line frequency). High and low voltage and current settings are shown in Table 1-1.

PRL/SER EQUIV CKT - Selects parallel or series equivalent circuit measurement modes.

NOM VALUE/Δ - Sets the nominal value for deviation measurement. Δ selects absolute deviation.

SETTLING TIME/SECONDS - Function select and units for programmable settling time.

RANGE/DC OHMS - Begins range and function setting procedure, stops measurement, and turns off display. Measurement resumed by pushing START button. DC OHMS selects dc resistance measurement function when optional PC board is installed.

START/SINGLE - Begins measurement after it has been stopped by setting function and range. SINGLE makes one measurement and holds display.

Red Button - Selects alternate function of two-function buttons.

SET POINT - Sets limits bands for limits feature. Advances limits band to next band and prepares instrument to accept numbers and units for that band. Red button SET POINT toggles between indicating band number and normal measurement when set points have been entered.

2.1.2 Displays

The two 4-1/2 digit displays each have a set of units indicators which show the units and functions selected.

p, n, μ, m, k, M - Multiplier prefixes for the basic units programmed, such as nF (nanofarads) and mH (millihenries); p=pico, n=nano, μ=micro, m=milli, k=kilo, and M=mega.

Fp, Fs, Hp, Hs, Ω, S, D, Q, - Basic units for functions programmed: Fp=farads, parallel capacitance; Fs=farads, series capacitance; Hp=henries, parallel inductance; Hs=henries, series inductance; Ω=ohms (resistance); S=siemens (conductance); D=dissipation factor; and Q=quality factor.

LF and LV - Indicates the low frequency and low voltage modes have been selected.

RMT - Represents remote control operation. Remote operation is possible only when an interface option is installed. The front panel keyboard does not operate when the RMT light is on.

% - Indicates percent deviation display.

Δ - Indicates absolute deviation display.

2.1.3 Other Front Panel Controls

ZERO ADJUSTMENTS - The L, R, C and G zero adjustments on the front panel permit compensation for test fixture reactance (L and C) and loss (R and G) components (L and R zero function on HI frequency only).

HI and LO terminals - Four BNC connectors for guarded, four-terminal connection to the unknown.

POWER - Turns instrument on and off.

2.2 REAR PANEL CONTROLS

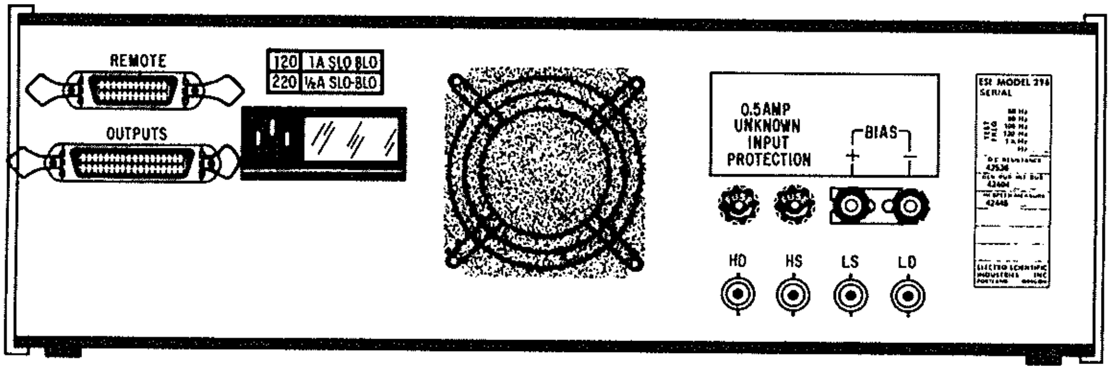


Figure 2-2. Model 296 Rear Panel

Line Cord Connector - The line cord connector meets IEC standards. It is fused and provides for selection of input voltage. <u>It does not allow line frequency changes.</u> Line frequency changes require replacement of internal components (see Section 2.3.2). Fuse ratings for 120 and 220 VAC input voltages are shown above connector.

REMOTE Connector - A 24-pin connector which allows connection to an interface option. Interface option required for operation.

OUTPUTS Connector - A 36-pin connector; outputs dependent on options.

HD, HS, LS, LD Connectors - BNC connectors for making guarded, four-terminal connection to unknown. Duplicates of front panel connectors. See Section 2.3.1.3.

BIAS - Terminals for connection of bias voltage up to 200V. Bias supply polarity must match terminal indications. When no bias supply is connected, terminals must be connected together with shorting lug provided. See Section 2.3.10.

Fuses - Protection for input. Two 0.5A 3AG fuses prevent damage to instrument if a charged capacitor is connected to input terminals. See Section 2.3.3.

2.3 OPERATING INSTRUCTIONS

Operation of Model 296 is divided into four areas of control: Measurement functions, test signal, measurement mode, and measurement display. The operator may select one or more setting from each area to tailor the test conditions to the exact requirements.

MEASUREMENT FUNCTIONS

Model 296 measures two reactance functions and four loss functions as shown below. The reactances may be measured either as parallel or series equivalent components, as can D and Q. Resistance is a series equivalent circuit component, conductance is a parallel component.

Function	Type	Units	Equivalent Circuit
Capacitance	Reactance	farads (F)	Parallel/Series
Inductance	Reactance	henries (H)	Parallel/Series
Dissipation Factor	Loss	(ratio)	Parallel/Series
Quality Factor	Loss	(ratio)	Parallel/Series
Resistance	Loss	ohms (Ω)	Series
Conductance	Loss	siemens (S)	Parallel

TEST SIGNAL

The signal applied to the unknown has two parameters selectable by the operator, frequency and level, shown below. Each has a choice between a high and a low level. High frequency is 1kHz in the standard Model 296, low frequency is 120Hz for the standard unit. Test signal level is selectable between a high and low level which are dependent on range and function (see specification chart, Table 1-1).

Test Signal Parameter	Level
Frequency	HI (1kHz for standard unit) LO (120Hz for standard unit)
Voltage/Current	HI LO dependent on range and function (see Table 1-1)

MEASUREMENT MODE

Factors that influence the measurement cycle are grouped under measurement mode functions.

Function	Alternate Choice
Continuous Measurement	Single measurement cycle
Autoranging	Range Hold
Digital Averaging	No Averaging
Settling Time	Default (initial turn-on) Time or Programmed Value

MEASUREMENT DISPLAY

Results of measurements may be displayed in four different manners: Direct reading, units (absolute) deviation, percent deviation, and limits sorting. Direct reading display refers to display of actual quantity as measured in its correct units. Percent and absolute deviation of measured quantities are calculated from a set nominal value. Section 2.3.5 describes this display mode. Limits sorting is also calculated from measured quantities. Limits are set by the user and the component is "sorted" into the appropriate limit band based on its measured value. See Section 2.3.6 for operation of limits display.

Function
Direct Reading
Units Deviation
Percent Deviation
Limits Sorting

Each of the four measurement control areas can easily be programmed with the front panel keyboard or remotely when an interface option is installed.

2.3.1 Basic Operation

Operating Model 296 is more similar to operating a pocket calculator rather than an impedance bridge. Functions are labeled on the front panel or on the buttons. Note that some buttons have labels for more than one function. These are called dual function buttons. Functions labeled on the button or in white are selected by pushing the button. Functions labeled in red are selected by pushing the red button first, then the button for the desired function.

2.3.1.1 Basic Operation Outline

To begin measurements follow the steps outlined below. Details for each step are contained in the section noted.

1. Connect test leads to Model 296 (see Section 2.3.1.3, Connections to Unknown).

2. Adjust instrument for proper line voltage and frequency (if necessary; see Section 2.3.2) and plug line cord into receptacle.

3. Turn instrument on and connect unknown to test leads (see Section 2.3.1.3, Connections to Unknown).

4. Select desired functions and test conditions (Section 2.3.1).

5. Push START (or SINGLE) button to begin measurement.

   NOTE: The instrument must be operated in its upright position because it contains mercury wetted relays. If it has been in another position (as can occur in shipping) the mercury must be shaken down by lifting the rear approximately 1/4 inch off the table and letting it drop. Do this three times.

2.3.1.2 Basic Instructions

When the instrument is turned on by depressing the POWER button, initial turn-on conditions are selected. Initial conditions for a standard unit for each of the four control areas are listed below.

Measurement Functions:	S (Conductance) Fp (parallel Capacitance)
Test Signal:	HI FREQ (lkHz for standard unit) HI VOLTAGE (see Table 1-1)
Measurement Mode:	Continuous measurement Autoranging Digital Averaging Default Settling Times (see Section 2.3.7)
Measurement Display:	Direct Reading

Since the instrument is in autoranging mode, if the test leads are open (not connected to anything) Model 296 will range down to the lowest range. If the test leads are shorted together, the instrument will autorange to the highest range and the displays flash to indicate the overload condition. If a component is connected to the leads, Model 296 will select the proper range for the component (unless the component value is too large for the highest range, which causes the displays to flash, indicating overload).

Selecting Test Conditions

To change from the initial conditions, just push the button for the desired function (red button first if it is labeled in red). The order of selection is not critical. The following examples illustrate only a few of the possible combinations and orders of selection. Throughout this instruction manual, an asterisk (*) represents pushing the red button, e.g., *F represents pushing red button then F button.

Measurement Functions

REACTANCE FUNCTIONS		LOSS FUNCTIONS: S (parallel)	Ω (series)	D	Q
PARALLEL	F	✓		✓	✓
PARALLEL	H	✓		✓	✓
SERIES	F		✓	✓	✓
SERIES	H		✓	✓	✓

✓ = allowed combinations

Table 2-1. Function Combinations

Reactance functions are programmable independently from loss functions, within the allowable combinations. (See Table 2-1.) The appropriate series or parallel reactance function is automatically programmed when a loss function is selected. For example, the initial conditions are Fp and S. If the operator wanted to measure Fs (series capacitance) and pushed the SER EQUIV CKT button (*EQUIV CKT), S would no longer be measured. The series loss function, Ω (resistance), would be selected in place of the parallel loss function S (siemens).

Examples (*represents Red Button)

Desired Functions	Sequence
From Initial to Fs, Ω	*EQUIV CKT (Ω is automatically programmed for series function)
Change to Fx, D	*D
Change to Fp, D	EQUIV CKT
Change to Hs, Q	*H, *EQUIV CKT, *Q
Change to Hs, S	(Cannot program S with Hs or Fs because S is a parallel function only. When S button is pressed Hp is selected.)

Test Signal

Test signals may be changed at any time. Note that changing test frequency changes measurement range (see Table 1-1). When setting a specific range (such as in deviation or limits measurements), it is important that the desired test frequency be selected before the desired range to avoid accidental range change.

Examples:

	Initial	Change To	Sequence
Frequency	HI	LO	*LO FREQ
VOLTAGE	HI	LO	*LO VOLTAGE

Measurement Mode

Continuous measurement is the initial mode selected. To perform a single measurement press *SINGLE for each measurement required. To return to continuous measurement just press START.

Autoranging mode is selected when the instrument is turned on. To hold the instrument on a particular range, press *HOLD. To return to autoranging, press *AUTO.

To make repeated measurements of similar value unknowns, it is sometimes desirable to set a particular range. The following procedure selects and holds a particular range.

1. Push RANGE button. Measurement is stopped and bridge put in range hold mode.

2. Push buttons for numerals of range.

3. Push red button, then buttons for multiplier (μ, m, etc.) and measurement functions (F, Ω, etc.). (Multiplier and function are treated as one command, so the red button must only be pressed once for the pair, e.g., *nF not *n*F.)

4. Push START button to resume measurements.

Example: Set range for 50nF capacitor, push: RANGE, 5, 0, *, n, F. The displays show the 199.99nF range is selected.

> NOTE: In the above example, the same range is selected if the digits 1, 0, 0 are pushed; any digits from 20 to 199 will select the 199 range. Digits for a range must be greater than 0.1999 to be valid. For instance, 0.019 causes the displays to flash and is not accepted as a proper range.

Digital averaging mode is programmed as initial condition. In this mode the displayed value is the calculated mean value of eight sample measurements. For a complete discussion of the digital averaging cycle see Section 2.3.8, Measurement Speed. Measurements without averaging can be programmed by either of two methods: Single cycle or special test mode (see Section 2.3.9). Single cycle is selected simply. It is the alternate function of START button (*SINGLE). The special test mode operation removes the averaging function from continuous measurements and is discussed in more detail in Section 2.3.9.

Settling Time

Settling time appropriate for the proper range chosen is programmed automatically. The user may select shorter or longer settling times to accomodate individual testing requirements. Section 2.3.7 gives more information on settling time.

Measurement Display

Initial turn-on display is direct reading measurement. Some of the initial conditions are indicated on the display, others are only indicated when the alternate condition is selected. The list below gives the initial display for the initial conditions.

Functions:	Condition	Display
	Capacitance (parallel)	Fp
	Conductance (parallel)	S
Test Signal:	HI frequency	NONE (LF displayed when LO selected)
	HI voltage/current	NONE (LV displayed when LO selected)
Measurement Mode:	Continuous measurement	NONE
	Autoranging	NONE
	Digital Averaging	NONE
	Settling Time	NONE

2.3.1.3 Connections to Unknown

Model 296 is a 6 terminal instrument. It provides separate shielded connection cables for current drive and voltage sense to the high and low side of the unknown and to the guard point. These cables are fully shielded to minimize zero capacitance. They are labeled HI DRIVE, HI SENSE, LO DRIVE and LO SENSE. GUARD DRIVE is the shield around HI DRIVE and GUARD SENSE is the shield around LO SENSE (see Figure 2-3 below). Drive and sense leads for each of the three sets must be connected together for accurate measurements.

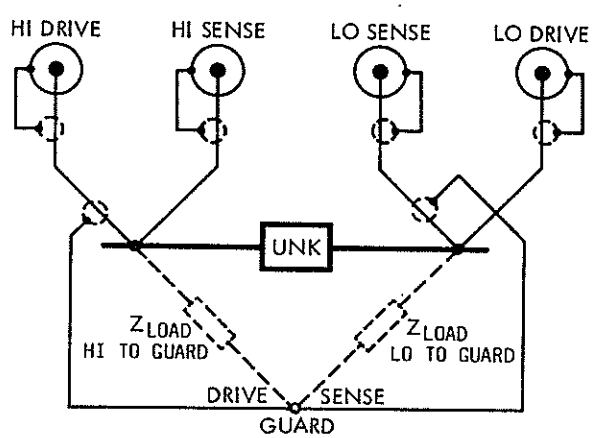


Figure 2-3. Connection to Unknown

Separate drive and sense connections are necessary to prevent lead resistance from becoming a part of the measured unknown. This is especially true for accurate measurements of low impedance unknowns. Separate drive and sense connections can be made to a single lead connected to the unknown if the lead is a small part of the unknown impedance ($R_{lead} < Z_{unk}/1000$ for <0.1% error). With proper connections as shown in Figure 2-3, for most measurements cable lengths up to 20 feet cause no loss of accuracy. Longer cable lengths or special test conditions may result in some accuracy loss. Consult ESI factory for advice on your application.

2.3.1.4 Front Panel Zero Adjustments

For accurate measurements (especially for units with optional test frequencies above 1kHz) it is necessary to cancel capacitance and inductance errors due to test leads and test fixtures. The standard cable set (ESI Part Number 23898) has been bundled for convenience in measuring mid-range unknowns. When measuring large capacitances (above 1000μF) or small inductances (below 1mH) best accuracy is achieved by modifying the cable set to insure proper cancellation of lead inductances.

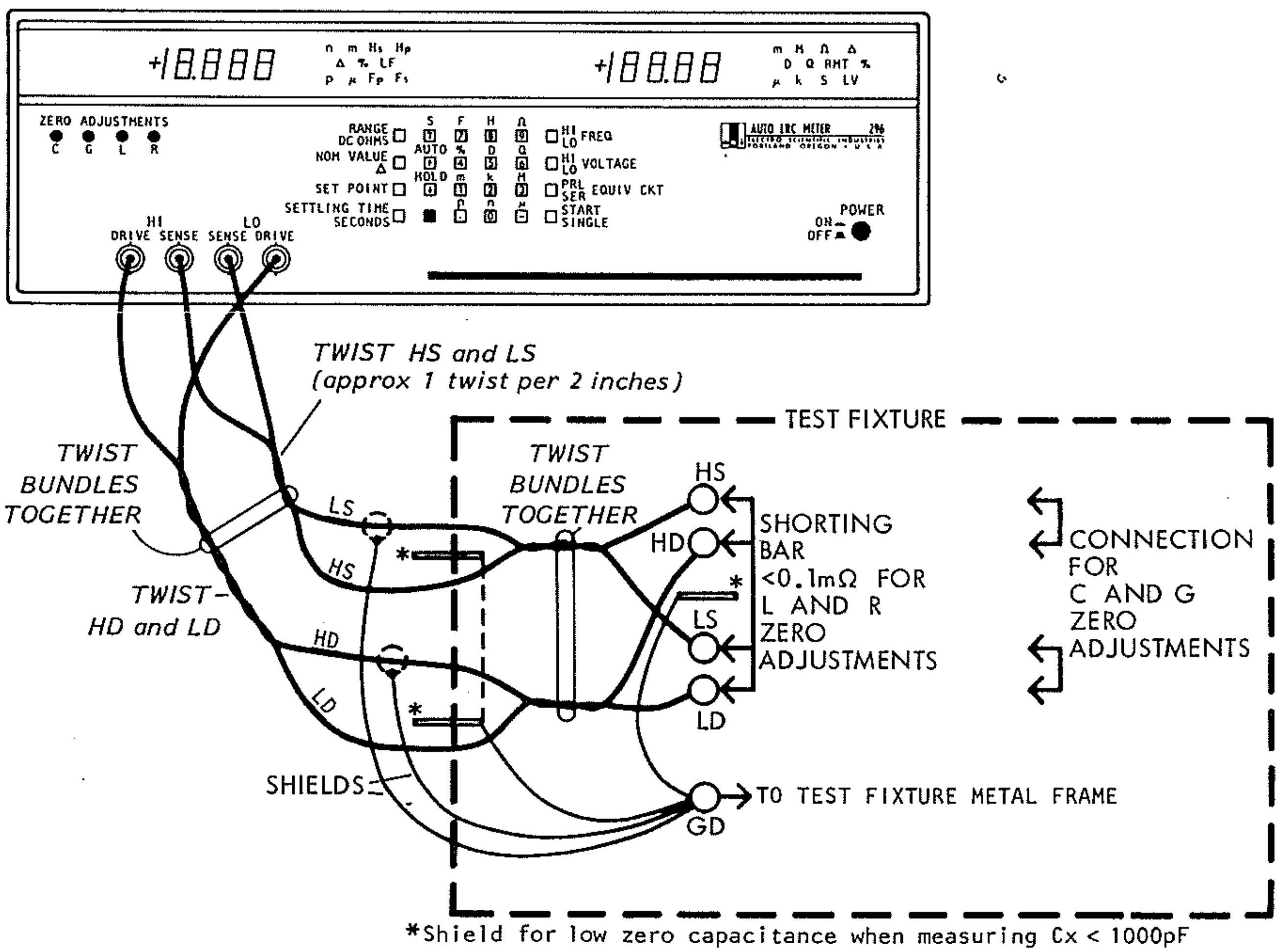


Figure 2-4

Cable Set and Test Fixture Cancellation: (See Figure 2-4)

1. Cut the cable ties fastening the standard cable set and twist the shielded HI DRIVE and LO DRIVE cables together (approximately 1 twist per 2 inches).

2. Twist HI SENSE and LO SENSE cables together.

3. Twist these two bundles together then connect to fixture.

4. Connect guard (GD) leads together, then to metal frame of fixture.

Inductance: (Not necessary for earlier units without L and R trimmers. L and R trimmers are active at the HI FREQ setting only).

1. Connect a shorting bar (<0.1mΩ) using a 4-terminal connection.

2. Set to LO FREQ, Hs, Ω and let unit autorange to lowest L and R range. If the inductance reading is more than ±2 counts move one of the sense leads closer to one of the drive leads until the counts are near zero. Secure the leads in this position.

3. Adjust front panel L and R trimmers for zero on both displays with Model 296 set to the following functions:

   a) HI frequency.
   b) L Series (Ls), R series (Rs). (Push *H then *Ω.)
   c) Lowest L and R range. (Unit will autorange to lowest range with shorting bar in place.)

Capacitance: (Not necessary for unknown above 1000pF)

1. Remove shorting bar.

2. Short LO DRIVE to LO SENSE.

3. Short HI DRIVE to HI SENSE.

4. Adjust front panel C and G trimmers for zero on both displays with Model 296 set to following conditions:

   a) Frequency and test level set as desired.
   b) C Parallel (Cp), G parallel (Gp).
   c) Lowest C range.

An alternate method of eliminating the effects of zero inductance and resistance is to subtract them from the reading by using the deviation function as described in Section 2.3.5.

2.3.1.5 Measurement of Delta Networks (Active Guard)

Model 296 has the ability to accurately measure an unknown with impedances from either end of the unknown to a point that can be connected to guard (see Figure 2-3). The accuracy of the measurement is determined by how low these loading impedances are with respect to the unknown. The basic instrument accuracy for this type of measurement is maintained as follows:

1. Load impedance from HI to GUARD: for capacitance or conductance measurements - stated accuracy maintained for loads >100Ω (500Ω on range zero) for inductance or resistance measurements - accuracy maintained for loads $\geq 2Z_{unk}$.

2. Load impedance from LO to GUARD: for capacitance, conductance, resistance and inductance measurements - additional counts in left and/or right display =

$$[Z_{unk}/(Z_{load}\text{ LO to GUARD } \times 100)][\times 5 \text{ for LO voltage}]$$

where Z_{load} to GUARD limited to >100Ω

2.3.2 Line Voltage and Frequency Selection

Input voltage selected for Model 296 must match the line voltage available. The line cord connector has provision for changing line voltage, as shown in Figure 2-5. Line voltage only is changed with the line cord connector. Line frequency changes require internal component changes.

To change line frequency to 50Hz operating, 50Hz line frequency kit (ESI Part Number 42537) must be installed. Follow the instructions below to install the kit and change to 50Hz operation.

> **NOTE:** When removing or inserting PC boards, instrument power must be off. Boards must be inserted with components facing front of instrument.

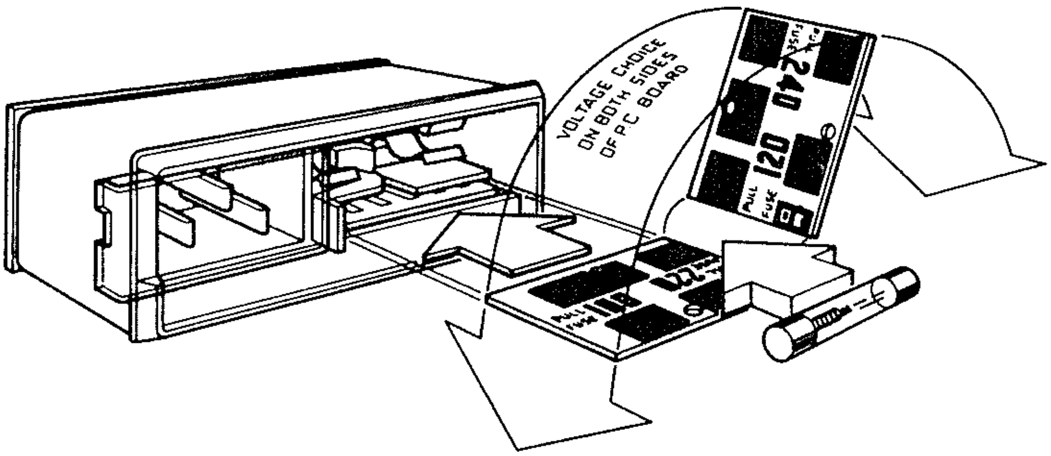
1. Remove crystal Y1 from A/D Converter assembly (board 15 in Figure 4-1, part number 40689). Replace with crystal included in kit (3.2768MHz, part number 24540).

2. Change 120Hz jumper W1 and W3 on Oscillator assembly (board 1 in Figure 4-1, part number 41196) to 100Hz jumpers W2 and W4.

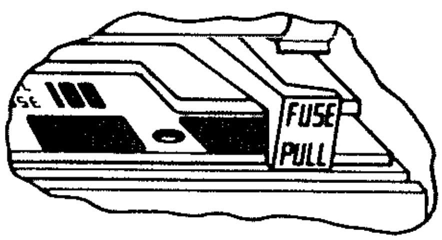
3. Check line voltage setting and change (if necessary) to match available line voltage (see Figure 2-5).

4. Reinstall both circuit assemblies.

5. Connect an oscilloscope to test point on oscillator assembly shown in Figure 5-12. Sync oscilloscope to line frequency and set sweep at 2ms to 10ms per division. Turn instrument on. Adjust R32 on oscillator assembly for maximum height wave form that remains locked to line frequency.



Operating voltage is shown in module window.



SELECTION OF OPERATING VOLTAGE

1. Open cover door and rotate fuse-pull to left.
2. Select operating voltage by orienting PC board to position desired voltage on top-left side. Push board firmly into module slot.
3. Rotate fuse-pull back into normal position and re-insert fuse in holders, using caution to select correct fuse value.

Figure 2-5. Line Voltage Selection

2.3.3 Input Protection

A circuit prevents damage to the instrument if a charged capacitor is connected to the input terminals. Protection limits can be calculated from the equation:

$$V_{MAX} = \sqrt{\frac{2}{C}}$$

where V = capacitor voltage in volts
C = capacitor value in farads

The protection circuit in Model 296 allows a maximum energy of 1 joule up to a maximum voltage of 1kV. Table 2-2 below gives examples of maximum voltages for various capacitance values.

1kV	0 to 2μF
315V	20μF
100V	200μF
31V	2mF
10V	20mF
3V	200mF
1V	2F

Table 2-2. Input Protection Limits

When limits are exceeded, fuses on the rear panel burn out and must be replaced with a 0.5A 3AG fuse. To prevent possible damage to the instrument use only the proper replacement fuse.

2.3.4 Resistance Measurement

Resistance should be measured in combination with inductance function rather than capacitance function. When in capacitance mode, a resistor is interpreted as a high loss capacitor and may cause the display to blink. Switching to inductance measurement allows measurement without display blinking.

2.3.5 Deviation Measurement

Two types of deviation measurement are possible with Model 296: deviation as a percent of nominal or absolute deviation from a nominal in units. Percent deviations may range up to ±100% with the nominal value between 1000 and 10,000 counts on a measurement range. Absolute deviations may range up to ±full scale (measured value of unknown must not exceed full scale value of measurement range, i.e., the measured value must be less than 19,999 counts on any range regardless of its deviation from nominal). Deviation calculations require a small amount of time to complete, so measurement speed is decreased slightly. The additional time required for a measurement is 1ms for absolute deviation, and 5ms for percent deviation.

To measure deviation, a nominal value must first be set. Absolute deviation requires a nominal for the desired function only; percent deviation requires a nominal for both displays when S and Ω are being measured. Nominal values are set as a selected number of counts in the desired display and are not a function of range. Therefore, it is important that the instrument be on the desired range. To set a nominal value, push NOM VALUE button, enter desired nominal and function (decimal point is controlled by measurement range selected and need not be entered). The nominal will appear in appropriate display window. Push START button to resume measurement. The unit will display absolute deviation from nominal automatically when START button is pushed. For percent deviation, push red button then % key. (D and Q functions display absolute deviation only.) To return to absolute deviation, push red button then Δ key (the Δ indicator will light to show deviation mode is restored). The unit is removed from deviation mode by programming nominal values of 0 for both reactive and loss functions.

To temporarily exit from deviation mode, push SET POINT then START. To return to deviation measurement with the same nominals, push NOM VALUE then START. If the unit had been measuring percent deviation before temporarily exiting, *% must be pushed to return to percent from absolute deviation.

After exiting deviation measurement mode by pushing SET POINT then START, it is possible to enter limits mode operation by entering desired limits (see Section 2.3.6). The nominals entered for deviation measurement are then used as nominals for % limits operation.

The nominals set can be examined by pushing the NOM VALUE button. The current nominal settings will appear in appropriate display windows.

For example, to set a nominal of 15nF, push the ↑ or ↓ button to range to the 20nF range. Press NOM VALUE, digits 1, 5, *F, START. To change to percent deviation, push *%. Since the decimal point position is fixed by the range selected, care must be taken to enter the correct sequence of numbers to achieve the desired nominal. Also note that the first digit on each display is a ±1 display only and cannot show a zero digit input. For example, to set a nominal D value of 0.001, press digits 0, 0, 0, 1. When the first 0 is pressed, the display will not show it since the digit is only capable of displaying a +, - or 1. After pressing the second 0, the display will echo the digits entered. To return to normal operation, press NOM VALUE, 0, *F, NOM VALUE, 0, *D, START.

2.3.6 Limits Operation

Limits mode operation allows unknowns to be sorted into tolerance bands based on limits set by the operator. There are ten limits, 1 through 10, which gives nine bands, numbered 0 through 8, plus one additional limit numbered 10 (See Figure 2-6). Limits can be arranged in two methods: nine bands for the reactance of the unknown and one maximum limit for its loss; or nine bands for the loss component of the unknown and one maximum limit for its reactance. The choice between these two arrangements is made when the first limit (number 1) is programmed. If a reactance function is programmed for limit one, the nine bands will be allotted for reactance component of unknowns and number 10 limit for loss component. Similarly, if a loss function is programmed for limit one, the nine bands are used for loss and number 10 for reactance components. For example, the first arrangement allows capacitors to be sorted into eight tolerance bands (Bands 1 through 8), with one out of tolerance band (Band 0) and one maximum limit on D value (Band 10). The second arrangement allows resistors to be sorted into nine bands with a maximum limit on their inductance. The calculations required for limits operation add 7ms to overall measurement time.

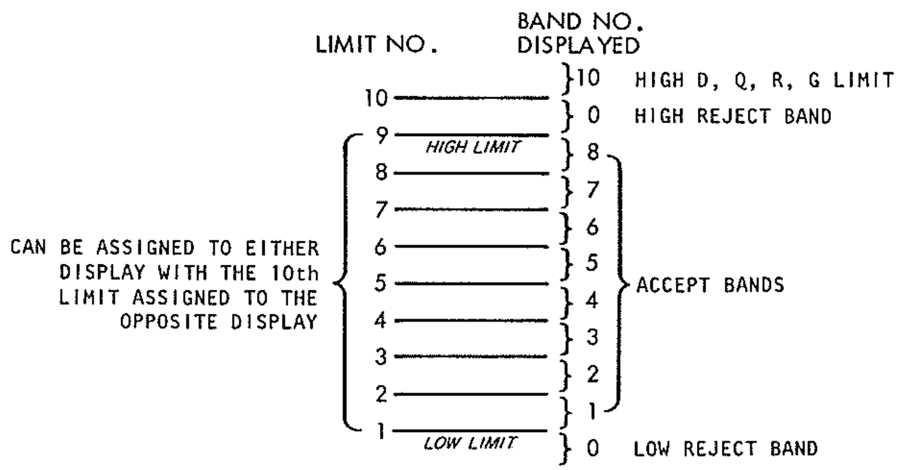


Figure 2-6

The limits may be set in units or percent. They are programmed in ascending order with each limit greater in value than the preceding. A limit equal to or less than the previous limit will not be accepted and will cause display blinking. The limits must not exceed the maximum allowable digits for a given function (see Table 1-1). When the instrument is turned on it initializes to the first limit (number 1). Each push of the set point button advances the limit number. The following procedures outline the process involved in setting and operating limits.

To set limits in units:

1. Set Model 296 to desired test frequency and range. Push SET POINT button. The left display will show the number of the limit being programmed (number 1).

2. Enter numerals for desired limit (numerals will appear in right-hand display). Push red button then function for desired limit. The function entered at this step chooses between the two arrangements for the limits (nine limits for reactance and one for loss, or nine limits for loss and one for reactance). Entries for the remaining limits (except limit 10) must be of the same function.

3. Push SET POINT again and repeat step 2 to set next limit. Repeat until all desired limits are set. At least two limits must be set.

4. To program number 10 limit, enter numerals and function as in other limits. Function must be of opposite type (reactance or loss) than the function for the other limits set. When the function is entered, number 10 limit is set. The number 10 limit is automatically set when its function is entered regardless of limit number previously showing.

5. Push *SET POINT then START button to begin measurement. Display will show band number. To show measured value of unknown, push *SET POINT. *SET POINT toggles between showing measured value and band number.

To set percent limits:

For percent limits operation, nominal values must first be set.

1. Set Model 296 to desired test frequency and range. Enter nominal values for reactance and loss components as in deviation measurement description, Section 2.3.5. One will be used for nominal on the nine bands, the other will be used for the maximum limit nominal. Push START button.

2. Push *%. Push SET POINT button. The left display will show the number of the limit being programmed (number 1).

3. Enter numerals for the desired percent limit. Numerals will appear in righthand display. Leading zeros must be entered, but trailing zeros may be left off. For example to enter 17% limit, digits 0, 1, 7 must be pushed. Figure 2-7 shows digit position required for desired percent limits.

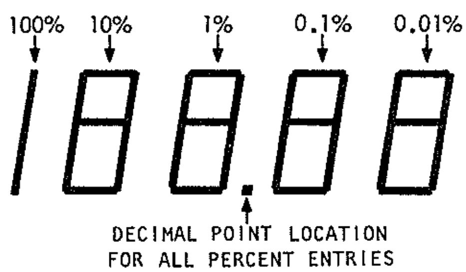


Figure 2-7

4. Push red button and function. When function button is pushed, the right display will be replaced with the measured value representing the entered percent limit. (The number showing may have a one count error due to round off in the calculation). The function entered for limit 1 is used for the nine band limits. Limits 1 through 9 must have the same function entered.

5. Push SET POINT button and repeat steps 3 and 4 for the remaining limits. At least two limits must be set.

6. To program number 10 limit, push SET POINT, digit 0, then function desired. Instrument will set limit 10 to nominal entered for that function in step 1 above.

7. When all limits are set, push *SET POINT then START to begin measurement.

When operating, the left display shows the proper band number for the unknown component. Band numbers shown indicate the component is greater than the displayed limit and less than the next higher limit. Band 0 indicates the component is either larger than the highest limit or smaller than the smallest limit set. Band 10 indicates component has exceeded number 10 limit.

To temporarily exit from limits mode into measuring the programmed functions, push *SET POINT. Again pushing *SET POINT toggles back into limits mode. Band sorting information is continuously provided to external handlers, even when the operator toggles out of limits mode, if the handler interface option is installed.

To completely exit from limits mode, limit 1 must be set to zero. If percent limits are set, the unit must be programmed to absolute limits (by pushing *Δ) before setting limit 1 to zero. To return to limits operation re-enter desired limits. When power is turned off, all set limits and nominal values are lost.

To examine set limits, push SET POINT repeatedly to display limits in ascending order.

Example: Sort 10nF capacitors at 1kHz into ±1%, ±5%, ±10% bands with maximum D of 0.005. Begin by setting proper frequency and range: push HI FREQ, and RANGE, 1, 0, *n, F. Next set nominal values: push NOM VALUE, 1, *F (trailing zeros may be left off, decimal is controlled by range selected). Push NOM VALUE, 0, 0, 0, 5, *D. Now to set the limits, in percent. Push *%. Push SET POINT (until limit 1 selected), -, 0, 1(-10%), *F, SET POINT, -, 0, 0, 5(-5%), *F; SET POINT, -, 0, 0, 1(-1%), *F; SET POINT, 0, 0, 1(+1%), *F; SET POINT, 0, 0, 5(+5%), *F; SET POINT, 0, 1(+10%), *F. This sets the capacitance limits, now for D limit. Push SET POINT, 0, *D. Push *SET POINT then START button to begin measurement. Band numbers will appear in the left display. To return to normal measurement, push *Δ, SET POINT (until limit 1 selected), 0, *F, START. This sets limit 1 to 0. Instrument remains in deviation mode until nominal values are set to zero.

2.3.7 Settling Time

Settling time may be programmed by the operator. If no settling time is set, the unit defaults to a settling time determined by measurement range and frequency (see Figure 2-8B). Settling times less than default times may cause autoranging to malfunction. To program settling time, push SETTLING TIME button, enter desired settling time in seconds, then push red and SECONDS buttons. Settling time entered must be between 25 milliseconds and 1.2 seconds to nearest 10 milliseconds. For example, to set settling time of 450 milliseconds, push SETTLING TIME, 0, 4, 5, *SECONDS. The display will show .45 seconds as settling time. The unit will accept another digit of resolution when entered, but will truncate it at the 10 millisecond digit.

2.3.8 Measurement Speed

Figure 2-8A shows measurement sequence for various function combinations and measurement types. Measurement and settling times are also shown. Measurement speed of Model 296 is dependent on the type of measurement, settling time, and the functions programmed. Two types of measurement are made: digital averaging and single cycle. Digital averaging is the normal mode of operation for the bridge. It is automatically selected in the continuous measurement mode. Eight measurements of each quantity are taken and the average is computed. The result is then displayed. For faster continuous mode measurements and autoranging, a non-averaged measurement may be selected by test code 0010 (see Section 2.3.9).

Single cycle measurement is the fastest measurement mode. It is useful for remote operation with automatic handlers. A single measurement of each quantity is made and necessary calculations performed. An averaged single cycle measurement can be made using test code 0012 (see Section 2.3.9). This increases measurement time but reduces noise effects.

Settling times for ranges and functions of Model 296 are shown in Figure 2-8B. Settling time is programmable over the range of 25 milliseconds to 1.2 seconds. The effect of settling time changes is shown in the measurement sequence illustrations, Figure 2-8A.

The effect of different function combinations on measurement speed is also shown in the measurement sequence illustrations. Depending on the functions desired, different combinations of quantities must be measured, which may add extra time.

Total measurement time of Model 296 consists of:

1. Settling Time
2. Digital Conversion time
3. Final Calculation Time
4. Special Function Execution Time (Options)
5. GPIB or TTY Data Transfer Period (Options)

Figure 2-8A.

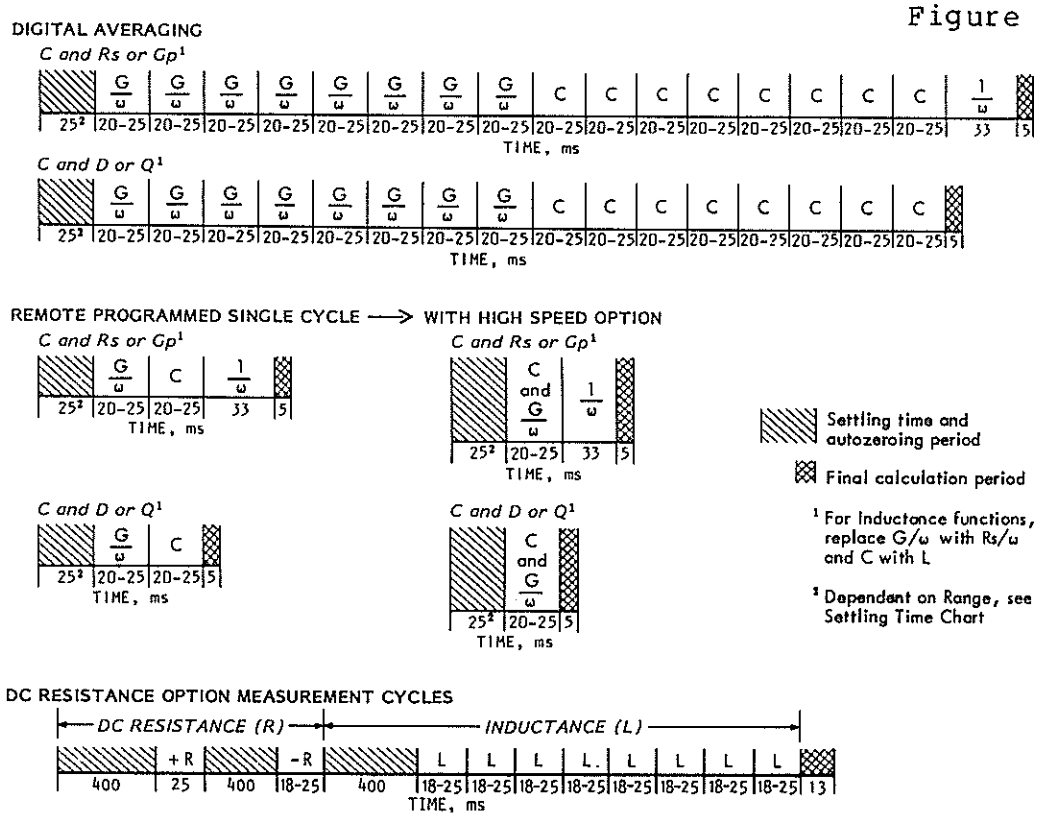


Figure 2-8B.

SETTLING TIME

C

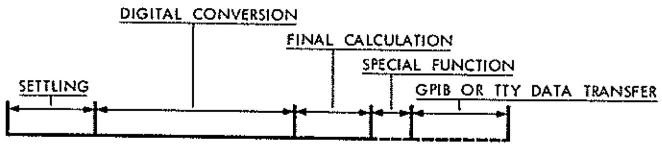
	HI FREQ RANGE	HI FREQ SETTLING TIME: STATED ACCURACY ①	C ±1% D ±0.005	C ±3% D ±0.02		LO FREQ RANGE	LO FREQ SETTLING TIME: STATED ACCURACY ①	C ±1% D ±0.005	C ±3% D ±0.02
②	200 mF	③			②	2 F	2000 ms④	⑤	
0	20 mF	210 ms	⑤	200 ms	0	200 mF	400 ms		350 ms
1	2 mF	150 ms		140 ms	1	20 mF	200 ms	150 ms	140 ms
2	200 µF	100 ms	50 ms	40 ms	2	2000 µF		100 ms	90 ms
3	20 µF	70 ms	40 ms		3	200 µF	120 ms	80 ms	70 ms
4	2 µF	25 ms⑥			4	20 µF	70 ms	25 ms⑥	
5	200 nF				5	2000 nF			
6	20 nF				6	200 nF			
7	2 nF				7	20 nF			
8	200 pF				8	2000 pF			

L

	HI FREQ RANGE	HI FREQ SETTLING TIME STATED ACCURACY ①		LO FREQ RANGE	LO FREQ SETTLING TIME STATED ACCURACY ①
1	20 µH	100 ms	1	200 µH	400 ms
2	200 µH		2	2000 µH	
3	2 mH		3	20 mH	
4	20 mH		4	200 mH	
5	200 mH		5	2000 mH	
6	2 H		6	20 H	
7	20 H		7	200 H	
8	200 H		8	2000 H	

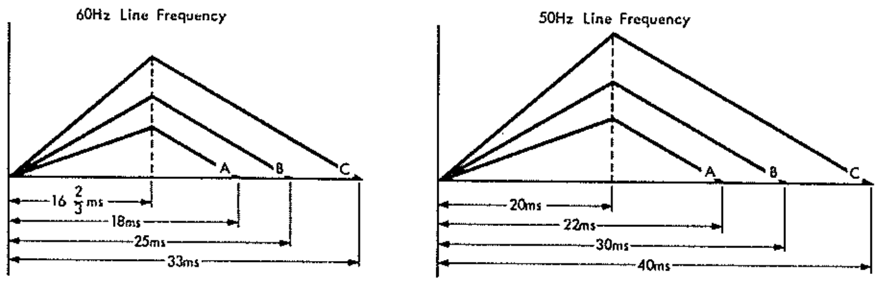
①Shown are default times, with no settling time programmed. Settling time can be programmed from the front panel or remotely from 25 ms to 1 s. For autoranging, add 100 ms to default times.
②Test mode only. See Section 2.3.9 of Model 296 Manual.
③Not a practical measurement at high frequency.
④Settling time can be reduced to 1000 ms by adding a 1 Ω resistor from high drive to guard.
⑤Not possible - less than stated accuracy.
⑥30 ms for 50 Hz line frequency. A shorted capacitor results in 33 ms for 60 Hz line frequency and 40 ms for 50 Hz line frequency.
NOTE: Default times are for initial instrument turn on mode.

Figure 2-8. Model 296 Measurement Speeds



1. Settling Time is the time required for the analog voltage representing the unknown to settle to the desired accuracy. Within this period the instrument is autozeroed. Settling times for Stated Accuracy, ±1% and ±3% accuracies are shown in Figure 2-8B.

2. Digital Conversion Times of each measurement depend on measured value, line frequency, displayed parameters and operating mode.



A = Full Scale Value   B = Zero Value   C = Shorted Capacitor Condition

Measurement conversion times are shortest for full scale values and longest for zero or negative values. The maximum conversion time is 25ms for 60Hz line frequency and 30ms for 50Hz line frequency, except for a shorted capacitor or negative value.

The conversion time therefore depends on what percent of full scale the unknown represents. The greater part of full scale, the faster the conversion time. Full scale is 20,000 counts.

The choice of displayed values and operating mode also influences measurement speed. C and D display require only two digital conversion periods while C and G display require an additional period for 1/ω conversion (33ms for 60Hz Line Frequency and 40ms for 50Hz Line Frequency).

Operating mode (single cycle or averaging) also influences measurement speed. The normal mode is averaging. Eight measurements of each parameter are averaged. The single cycle mode is only one measurement of each parameter.

Measurement time can be reduced with the high speed measurement option, ESI Part Number 42445. With this option, the conversion of the loss (G/ω or R/ω) and the reactance (C or L) are executed simultaneously, thus eliminating one conversion period. This option is very useful when interfacing Model 296 with automatic handlers and generally is used in single cycle mode.

3. **Final Calculation Time** is 13ms. This is the time required to calculate the programmed loss function.

4. Special Function Execution Time. Additional time is required to execute special functions.

Absolute deviation mode:	1ms
Percent deviation mode:	5ms
Limits mode:	7ms
Relay closure of handler interface:	1ms
TTL outputs of handler interface:	included within 7ms of limits mode

5. **GPIB or TTY Data Transfer Periods.** Time is required to output ASCII characters. This time is dependent on the bus system being used and the length of the command and data output character string. Baud rates for the TTY option are detailed in Section 2.4.3.2. Transfer of data on the GPIB is dependent on slowest device connected to bus.

Shorted Capacitors. A shorted capacitor measurement results in an overload condition which requires a longer recovery time than an in-range measurement. When in a high speed measurement mode, this can cause a good part following a shorted part to be rejected. To ensure the good part is not rejected, Model 296 automatically adds an additional 200ms to its settling time if the previous measurement was an overload. This slightly reduces overall throughput, but increases yield.

The extra 200ms settling time can be eliminated by programming clear averaging mode (See Section 2.3.9).

A shorted part also results in 33ms (40ms for 50Hz Line Frequency) digital conversion times for the zero, G/ω, and C measurements. To reduce this extra time, Model 296 will skip the C conversion cycles for the measurement when it senses an overload of G/ω.

2.3.9 Test Mode Functions

Test Mode is a special programming sequence which provides several additional operating functions. Table 2-3 lists these functions and their programming codes. Test Mode functions may be programmed with the interface options just as all other functions. (The keyboard unlock function is not programmable from the front panel, only remotely.)

Code	Function
0000	Unlock front panel (remotely programmable only; keyboard is ignored when locked)
0001	Lock front panel in remote mode
0002	Clear constant current capacitance and constant voltage inductance mode (default)
0003	Set constant current capacitance and constant voltage inductance mode
0004	Lock front panel in continuous measurement mode
0005	Set low D mode (special hardware required to implement)
0006	Clear low D mode (default)
0007	Not used
0008	Clear talk only mode (default)
0009	Set talk only mode (printer)
0010	Clear averaging mode (Also eliminates 200ms overload settling time, see Section 2.3.8)
0011	Restore normal averaging mode (default)
0012	Allow averaging on single cycle measurements

Table 2-3. Test Mode Functions and Codes

The front panel lockout feature is controlled by codes 0000 and 0001. This feature allows the controls to be set for the desired measurement operation and then the front panel locked to protect against accidentally changing the settings. After the front panel is locked a remote start signal is required to begin measurement. Since the front panel is inoperative when locked, it is not possible to unlock the front panel using the keyboard. Three methods can be used to unlock the front panel: turn the unit off then back on, remotely program an unlock command, or close a switch connected to the TTY option front panel unlock feature.

Codes 0002 and 0003 control a special calculated measurement mode. In this mode capacitance is calculated from measured inductance and inductance is calculated from measured capacitance. This extends the range of each function by a factor of ten (to 2F for capacitance, 20,000H for inductance). Capacitors are measured with constant current and inductors with constant voltage in this mode. (Normal measurements are made with constant voltage for capacitance, constant current for inductance). Note that since large capacitors are actually measured as small inductors, it is important to cancel the inductive effects of test fixtures and leads as described in front panel zero adjustment section (Section 2.3.1.4). An alternate method is to measure a known standard and correct the reading using the deviation function described in Section 2.3.5. Since functions in this test mode are calculated, values must be between approximately 1300 and 20,000 counts on a range. In addition to over-range indicated, values below approximately 1300 counts cause under-range overload indications. Autoranging feature may not operate in this mode in all cases. This mode is useful for measuring high loss series capacitances whose dissipation factor is too large to allow calculation of C_S and R_S on the normal function.

Code 0004 programs continuous measurement mode and locks the front panel. the panel may be unlocked by the methods listed for codes 0000 and 0001.

A special low dissipation factor (D) mode is controlled by codes 0005 and 0006. Additional hardware is required for operation of this function. It allows measurement of very low D components with higher resolution than provided by normal D measurement. Measured full scale D is reduced to 0.19999 when the low D test code is selected. This returns to 1.9999 when low D function is cleared. Special hardware is required for early units to operate properly in low D mode.

TALK only mode, designed for operation with a printer, is controlled by codes 0008 and 0009: Selection of code 0009 causes Model 296 to output its data to IEEE Bus or TTY immediately when measurement is finished.

Codes 0010, 0011 and 0012 control measurement averaging operation. In normal mode, Model 296 performs two types of measurement cycles: continuous and single cycle. Normal continuous measurements consist of eight measurements averaged then displayed. Single cycle normally consists of a single measurement. Code 0012 performs one eight-measurement averaged reading cycle each time measurement is initiated. Code 0010 allows continuous measurements without any averaging and eliminates 200ms overload settling time (see Section 2.3.8). Normal averaged continuous measurement or single cycle averaged measurement is restored by code 0011.

To program test mode functions, press T button. Normal test indication (all segments lit) will appear. Push 0 button and displays will blank except for decimal points. Enter code for desired function, then press *SECONDS. Selected function is now programmed. All measurement functions (except autoranging) are programmed and operate as in normal measurement mode.

2.3.10 Operation With Bias

Capacitance Measurements

A dc bias of up to 200V can be applied to the rear panel bias terminals (observe polarity). Bias supply must have low ripple with internal current limit of 100mA and its output impedance must be less than 50mΩ. Leakage current through the unknown can be measured by sampling the current from the bias source to the bias terminals with a low impedance ammeter. If the bias source impedance is not low compared to the unknown, a bypass capacitor whose impedance is 1/5 of the unknown at the operating frequency can be connected across the bias source and ammeter (if used).

Inductance Unknowns

A dc bias current can be supplied to the bias terminals from a high impedance supply limited to the HI test current listed in Table 1-1. Currents exceeding these values could cause damage to the instrument.

For constant current, the impedance of the supply should be greater than 10 times the unknown impedance and <u>must</u> be bypassed with a capacitor whose ac impedance is 1/5 of the unknown at the operating frequency.

2.4 OPTIONS OPERATION

Options for Model 296 are plug-in PC boards. Three sites are available for options plug-ins and are assigned functions as shown in Table 2-4. One option from each group can be plugged in at a time, to give a total of three. Options can be plugged into only the one site assigned. When plugging in or removing options, power should be off to avoid damage to circuitry. Refer to Section 3.4 for location of options.

OPTIONS GROUP	OPTION*
AUXILIARY FUNCTIONS GROUP	HIGH SPEED MEASUREMENT DC RESISTANCE MEASUREMENT
AUXILIARY OUTPUT GROUP	HANDLER INTERFACE
REMOTE PROGRAMMING GROUP	GPIB CARD READER INTERFACE TELETYPE INTERFACE

*Only one option from each group allowed at one time.

Table 2-4. Plug-in Options

2.4.1 DC Resistance Measurement Option

Model 296 normally applies an ac signal to the unknown, therefore the resistance measured is an ac quantity. The dc resistance measurement option allows dc resistance and ac inductance to be measured and displayed at the same time. With the dc resistance option PC board installed, this function is programmed in the same manner as other front panel functions. Inductance is the only other function allowed in combination with dc resistance measurement and is automatically selected when the DC OHMS button is pressed. DC resistance display is shown by both the D and Ω indicators lighting. The dc resistance option increases resistance measurement range to 10MΩ. Resistance alone is measured on the 10MΩ range and the lefthand display blinks.

Measurement accuracy for dc resistance is ±(0.05% + 2 counts)±1mΩ up to 1MΩ, ±(0.5% + 5 counts) for 10MΩ range.

The measurement cycle for dc resistance measurement is illustrated in Figure 2-8. DC resistance is measured first, then the ac inductance measurement is performed. The dc measurement is composed of two measurements, with the detector polarity switched after the first, to cancel offset errors. Normal averaging measurement takes place for the inductance part of the measurement cycle. Depending on the range and accuracy required, the measurement time can be reduced by programming less settling time. Another reduction in time may be achieved by eliminating the averaging on the inductance measurement, see Table 2-3 and Section 2.3.9 for information on how to eliminate averaging.

When the dc resistance option PC board is installed, zero adjustments must be set as described in Section 4.1.1. Periodic recalibration is described in Section 4.1.2.6.

2.4.2 High Speed Measurement Option

With the high speed option installed, Model 296 operates in the normal manner. Refer to Figure 2-8 and Section 2.3.8 for examples of the increase in speed with this option.

If this option is field installed, the following calibration must be performed. Periodic recalibration is described in Section 4.

1. Connect stable capacitor as unknown. (Value not important but should be 10,000 counts or greater e.g., 10nF.)

2. Set instrument to measure capacitance and autorange (*F, *S or *D, *AUTO).

3. Note reading in left display.

4. Turn off instrument - plug in optional A/D boards, turn on instrument.

5. Repeat step 2.

6. Adjust trimmer 2 on optional A/D (board 17, Figure 4-1) for same reading as step 3.

2.4.3 Remote Programming and Interface Options Operation

Table 2-5 gives programming commands for the GPIB, teletype and card reader interface options. With any of these interfaces installed, Model 296 may be programmed in the same manner as from the front panel.

The remote programming function characters listed in Table 2-5 must be transmitted to Model 296 only when a mode change is desired. Functions remain in effect until another function is transmitted or power turned off.

An X (red button) must precede each red button function just as for manual programming. An exception is when programming a range multiplier such as μF or mΩ. In this case only one X is required.

Output commands are very important to remote programming operation. The output commands dictate the method in which Model 296 sends its data to various peripheral devices. They must be a part of the programming command string. When addressed to TALK by the GPIB interface or receiving a TALK command (') through the TTY interface the following commands should be used:

(No output at any time.

) Output when addressed to TALK (or commanded to output information). This immediately outputs both displays. It is useful for examining functions entered such as nominal values, settling time, band limits, etc.

* Outputs data when addressed after a measurement is complete. It is useful when an external device is initiating single measurments and needs output data upon completion of measurement.

Two other output commands are available:

[Output when measurement complete. This command is equivalent to test code 0009. In this mode Model 296 outputs its data immediately after a measurement is completed. No TALK command need be sent. It is useful when the controlling device (such as a TTY or printer) requires output data after measurement without having to send a TALK command. This command is not recommended for IEEE Bus use because data usually cannot be handled until requested. It can be used to continuously output results of a changing measured value such as encountered in a temperature test.

] Cancels [so that output is again available only when addressed or commanded to TALK.

The & and X& commands serve an important function when programming limits operation. Each time the SET POINT command is sent (or button pushed) an internal counter is incremented. This counter monitors which set point is to be set next. Since limits must be set from limit 1 up, it is necessary to initialize the counter when setting limits to prevent accidentally programming the wrong limit. An X& command resets the counter so that the next press of the set point returns to number 1 set point, the & command clears all previously set limits and resets the counter. The X& command allows a single limit to be reset without affecting others by programming X& then the number of SET POINT commands necessary to increment the counter to the desired limit. Example: X&BBB - resets to limit 1 then steps to the third limit and is ready to accept a value to store as limit 3.

TTY (SERIAL) AND CARD READER
GPIB (IEEE 488)

ASCII CHARACTERS for GPIB (IEEE 488), TTY (SERIAL) and CARD READER			HOLLERITH TO ASCII												ASCII CHARACTER[2]	
ASCII CHARACTER	KEYBOARD FUNCTIONS WHITE	KEYBOARD FUNCTIONS RED[1]	9	8	7	6	5	4	3	2	1	0	-	&	■	III
F	HI FREQ	LO FREQ				■								■	F	
9 or O	9	Ω	■			III							III		9	O
8 or L	8	H		■					III				III		8	L
7 or C	7	F			■				III					III	7	C
T	T	S							■			■			T	
R	RANGE	DC OHMS	■										■		R	
V	HI VOLTAGE	LO VOLTAGE					■					■			V	
6 or Q	6	Q		III		■							III		6	Q
5 or D	5	D					■	III						III	5	D
4 or %	4	%		III				■ III				III			4	%
A or ↑	↑	AUTO							·		■			■	A	
=	NOM VALUE	Δ		■		■									=	
E	PRL EQUIV CKT	SER EQUIV CKT					■							■	E	
3 or M	3	M						III	■				III		3	M
2 or K	2	k								■					2	K
1	1	m									■				1	
H or ←	←	HOLD		■										■	H	
B	SET POINT									■				■	B	
G	START	SINGLE			■									■	G	
- or U	-	μ						III				III	■		-	U
0 or N	0	n					III					■	III		0	N
. or P	.	p		■	III				■				III	■	.	P
X	Red Button	Red Button			■							■			X	
S	SETTLING TIME	SECONDS								■		■			S	
CHARACTER	REMOTE PROGRAMMING FUNCTIONS															
(	no output			■			■							■	(	
)	output when addressed			■			■						■		)	
*	set service request[3]			■				■					■		*	
:	lock keyboard and turn on RMT light			■						■					:	
X:	unlock keyboard and turn off RMT light					program X first then :									X:	
&	delete all limits data, reset limits counter													■	&	
X&	reset limits counter					program X first then &									X&	
[	output when measurement is completed			■						■				■	[	
]	no output			■						■			■		]	
'	TALK command for TTY interface			■			■								'	
\	delete ECHO routine, set ECHO routine			■						■		■			\	

[1] An X must precede each character to obtain red button functions
[2] ■ or III indicates alternate choices. Example: In line 2 either 9 or O can be used; 9 is set as shown by ■, O is set as shown by III
[3] Output when addressed after measurement complete

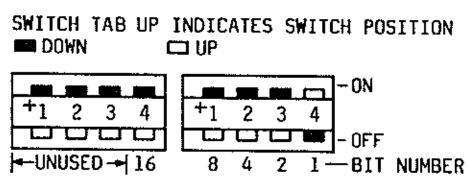
Table 2-5. Model 296 Programming Commands for GPIB, TTY and Card Reader Interfaces

2.4.3.1 GPIB General Purpose Interface Bus Option

The GPIB option is an interface that allows Model 296 to operate with an IEEE 488-1975 standard interface bus. Model 296 uses a 7 bit ASCII character format. Table 2-5 gives programming commands for functions and operation. All front panel controls and special codes are programmable via the GPIB.

An advantage of GPIB programming is that several instruments can be operated on a common bus with one controller. Each has a unique address which is only recognized by it. Bus addresses for Model 296 are set at the factory to 33 for TALK and 65 for LISTEN. Addresses may be changed with the switches on the interface PC board. Both TALK and LISTEN addresses are set by the same switch as shown in Figure 2-9. TALK address is achieved by adding 64 to the switch setting, LISTEN address by adding 32 to the switch setting. Switches operate in a BCD configuration. Only the five least significant bits (first five switches from the right) are used to set the address.

The second and third switches from the left should not be changed from their off position. The first switch from the left can be on to enable Model 296 to transfer data to a printer after measurement is completed. It must be off when Model 296 is used with the IEEE bus. Programming test code 0009 (see Section 2.3.9) is equivalent to setting the switch ON.



BIT 1 ON: LISTEN = 1 + 32 = 33 (DECIMAL)
TALK = 1 + 64 = 65 (DECIMAL)

FACTORY SET GPIB ADDRESS

	LISTEN	TALK
DECIMAL	33	65
OCTAL	41	101
ASCII	!	A

Figure 2-9.

Programming Model 296 via the GPIB follows the same sequence as programming from the front panel. A typical command string would look like this:

XFR100XUCXEXDXG*

where:
XF = low frequency (*FREQ)
R = range (also puts unit in range hold mode)
100XUC = 100μF
XE = series equivalent circuit
XD = dissipation factor
XV = low voltage
XG = single measurement mode
* = output data after measurement complete when addressed

This string programs the instrument to measure series capacitance on the 100μF range with D as loss function, in the range hold mode, low frequency, low voltage mode, and single measurement mode.

A Model 296 output string for the above example would look like this:

```
N FS+08534E-2,D+00025E-4

exponent for measured D value
decimal point position
5 digits, plus sign, for measured D value;
same as righthand front panel display
D for dissipation factor
Q for quality factor
R for resistance (ohms)
S for conductance (siemens)
separates reactance and loss measured quantities
exponent for measured FS value
decimal point position
5 digits, plus sign, for measured FS value
FS, FP, HS, HP indicating capacitance or inductance, series
or parallel; same as lefthand front panel display
N for normal measurement
O for overload
D for absolute deviation measurement
% for percent deviation measurement
```

Measured values are output in floating point format, 5 digits and an exponent. In the example the measured capacitance value is +08534E-2 which represents 8534 x 10^{-2}μF or 85.34μF. Values for capacitance are expressed in μF (microfarads) and values for conductance in μS (microsiemens). Inductance and resistance are expressed in H (henries) and Ω (ohms); μH for 10kHz and 20kHz options. Blank displays are transmitted as ? to indicate that display does not contain data.

An example of Model 296 operation through the GPIB bus by a Tektronix Graphics Terminal Model 4051 is shown below.

Program	Comments
`100 ON SRQ THEN 180`	Directs Model 4051 into interrupt routine if SRQ line is activated
`105 PRINT "COMMAND ?";`	
`110 INPUT A$`	Operator enters command string for range, etc.
`120 PRINT @1:A$`	Model 4051 outputs string to Model 296. Model 296 should at this point be set to all desired functions
`130 FOR N=1 TO 10`	Instructions to perform 10 measurements
`140 PRINT @1:"XG"`	4051 commands Model 296 to make a single non-averaged measurement.
`150 INPUT @1:A$`	4051 commands Model 296 to give it the measured data (Model 296 TALKS) after the SRQ line has been activated by Model 296 (end of measurement). An asterisk (*) must be a part of the command string for data output only after measurement complete.
`160 PRINT A$`	4051 prints measured data
`170 NEXT N`	
`180 RETURN`	

Results

Output	Comments
RUN	
COMMAND ?*	Very important character for this program. It instructs 296 to return measurement results only upon completion of the measurement initiated by "XG" (see Table 2-5).
R1500XPCXO	Range 1500pF, Series capacitance and resistance.
N FS+15384E-7,R-00001E+2 N FS+15384E-7,R+00000E+2 N FS+15385E-7,R+00000E+2 N FS+15383E-7,R+00000E+2 N FS+15384E-7,R+00000E+2 N FS+15383E-7,R-00001E+2 N FS+15384E-7,R+00000E+2 N FS+15384E-7,R+00000E+2 N FS+15383E-7,R+00000E+2 N FS+15383E-7,R+00000E+2	Measured data.

2.4.3.2 Teletype Interface Option

The teletype interface option (ESI Part Number 42735) is used to interface Model 296 to a three-wire serial bus system.

With this option Model 296 can interface with:

20mA current loop system
5V TTL level system
RS232, ±12V switched at ground system

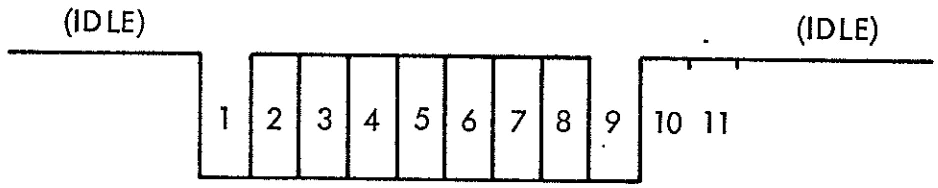


Figure 2-10

The character format is 11 bits (See Figure 2-10):

One start bit (1)
Seven data bits (2 thru 8)
Parity bit (no parity) (9)
Two stop bits (10, 11)

Available baud rates are:

75, 110, 135, 150, 200, 300, 600, 1200, 1800, 2400, 3600, 4800, 7200, 9600

Baud rates are selectable by changing jumper wires.

LISTEN and TALK baud rates are asynchronous and each can be at a different rate than the other, e.g., 2400 baud LISTEN, 9600 buad TALK, etc.

The TALK rate is controlled by the microprocessor and a character is not processed until the preceding character has been transmitted.

The LISTEN rate is character and character string dependent. Certain characters require more processing time, so care must be taken not to lose a character by transmitting characters to Model 296 faster than it can process them. Baud rates above 2400 baud experience this problem and it is recommended to insert a 3ms wait loop between each character.

Optimum transmission speed can be achieved by using the Echo routine. Since the LISTEN data line is buffered and will hold one character, the controller can operate in a handshake mode using the Echo character to initiate transmission of the next character.

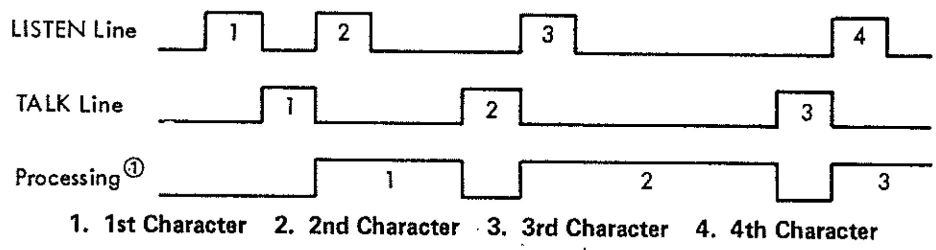


Figure 2-11

Processing time is variable and dependent on the character.

Characters are ASCII format and the output string is the same as GPIB Bus (see Section 2.4.3.1, GPIB interface option). The ' character is equivalent to the TALK command for the GPIB interface. The controller sends a ' when it is ready to receive data.

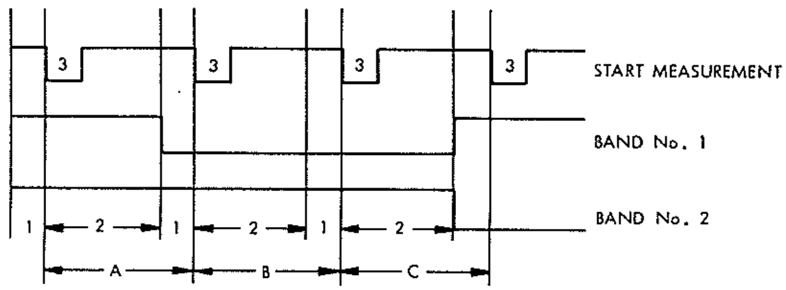
2.4.3.3 Card Reader Interface Option

The card reader interface option (ESI Part Number 42736) allows Model 296 to be programmed remotely with an HP1131A (modified 9870A) hollerith card reader. The interface PC board plugs into the ASCII BUS slot in the righthand mother board and the card reader connects to the REMOTE connector on the rear panel of the Model 296. Table 2-5 gives hollerith codes for all Model 296 functions.

To operate Model 296 with the card reader option, connect the units together, punch a card for the desired functions, and run the card through the card reader. For further operating instructions see the card reader instruction manual.

2.4.4 Handler Interface Option

The handler interface option (ESI Part Number 42436) enables Model 296 to operate with a mechanical handler. It accepts an input signal to initiate a measurement and outputs a signal which corresponds to one of the 10 displayed limit bands. The input signal required is an external contact closure or TTL low for a duration of 1μs minimum. The output signal is a relay closure which is held until reset by the closure of a different output relay. See Figure 2-12.



1. Handler Time – User dependent.
2. Measurement Time – Dependent on range and functions. See measurement speed section of the manual.
3. Initiate a measurement signal – 1 μs minimum.

A. First part was in band No. 1.
B. Second part was also in band No. 1.
C. Third part was in band No. 2.

Figure 2-12

The output relays are rated at 100VDC, 250mA switching current, 1.5A carrying current and 10 million operations. Higher currents can be switched with a possible reduction in operation life, especially if contacts arc on opening. Resistive loads are more desirable than inductive loads. For example, a 400mA, 15V, resistive load will not appreciably reduce life. Relays are on sockets for easy replacement.

5V TTL (open collector) output signals are available at the rear panel and require the addition of a jumper wire in place of each output relay. See Table 2-6.

Handler Interface Option

OUTPUTS Connector Wiring		
PCB Connector	**OUTPUTS Connector Pin Number**	**Function**
7	1	COMMON
J	2	BAND 0
H	3	BAND 1
F	4	BAND 2
E	5	BAND 3
D	6	BAND 4
C	7	BAND 5
B	8	BAND 6
A	9	BAND 7
6	10	BAND 8
5	11	BAND 10
	12	+5 V (SYSTEM) OUT
	13	SYSTEM GROUND
8	14	INTERRUPT IN (TTL)

Table 2-6

The handler interface option consists of a plug-in PC board which can be purchased with the instrument or added at a later date.

SECTION 3
CIRCUIT DESCRIPTIONS

3.1 INTRODUCTION

The Model 296 Impedance Meter consists of three major sections. The first is the analog system (located on the left half of the instrument) which produces dc voltages proportional to the reactive and resistive part of the unknown being measured. The second (located on the right half of the instrument) is the digital section which consists of the following circuit assemblies:

1. The A/D converter which converts the dc voltages produced by the analog system into digital information.

2. The central processing unit (CPU) which contains the microprocessor, memories, clock, bus drivers and other necessary components and performs the calculations necessary to derive the desired information about the unknown. The CPU also monitors the keyboard for input instructions and provides the signals for control of functions and ranges to all other circuit assemblies.

3. Various plug-in options such as IEEE bus, dc resistance measurement circuit, handler interface option for band sort indication, high speed option, etc.

The third major section is the operator interface consisting of the keyboard for input and the display circuit assembly for visual output of measured information.

A power supply located in the right rear of the instrument provides the necessary dc operating voltages.

Refer to Figures 3-1 and 3-2 for simplified circuit diagrams.

3.2 THE ANALOG SYSTEM

The analog system is an inverting operational amplifier circuit which has the component being measured (unknown) as the input impedance and a selectable standard resistor (SR located on assembly number 41223) as the feedback impedance. The operational amplifier consists of the Preamp Assembly, Part No. 41225; Sync Int Assembly, Part No. 41194 (used to increase the ac gain); and the Power Amp Assembly, Part No. 41192. The unknown is connected through the Discharge Protection Assembly, Part No. 41875, which protects the instrument from charged unknowns and static discharges. This assembly also contains the relays used to transfer the unknown connections from the ac bridge to the dc resistance option.

The unknown drive signal path is as follows:

1. Oscillator Assembly, Part No. 41196, produces two selectable frequencies, the lower being locked to the line frequency.

2. The unknown drive level regulator (on assembly number 41225) which holds the measurement circuit exitation at the proper level.

3. The Power Amp Assembly, Part No. 41192.

4. The drive transformer located on the left rear of instrument (on assembly number 41192).

5. Limiting resistors which are switched with the standard resistors to provide stability when measuring high reactance unknowns.

The voltage across the unknown is monitored by the Unknown Gain Assembly (UG), Part No. 40935, which has selectable gains of 1, 10, 100 and 1,000. It amplifies the small voltages across low impedance unknowns. The signal output of UG is labeled V_{unk}. These gains effectively decrease the value of the standard resistor.

The voltage across the standard resistor is monitored by the Standard Gain Assembly (SG) which is identical to the circuit assembly used for the unknown gain. These gains are used to amplify the small voltages across the range resistors when measuring high impedance unknowns and the signal output of SG is labeled V_{std}. These gains effectively increase the value of the standard resistor.

The signals V_{unk} and V_{std} are fed to the signal amplifier and Ref Gen Assembly, Part No. 40943. A switch (labeled Y/Z) selects the voltage to be used as a reference, and the one to be used as the measured signal (explained in Section 3.2.1, Measurement Modes). The measured signal (V_{sig}) is passed through a processing amplifier and is then fed to the phase rectifiers as Vs. The reference signal (V_{ref}) is used two places as follows:

1. V_{ref} is sent to the unknown drive level control where it is rectified and compared to a dc reference voltage. Any error between these signals is used to control a gain stage thus holding the exitation to the measurement system at the proper value.

2. V_{ref} is split into accurate 90° and 0° reference components used by the phase rectifiers to separate the reactive and resistive parts of the unknown signal Vs. These reference generators are adjustable in gain and phase for instrument calibration.

The phase rectifiers produce dc voltages proportional to the amplitude of the signal voltage (Vs) and the phase angle between the signal and the reference. This relationship is:

Vdc = K Vs Cos(Angle between Vs and Vr)

where K is a gain constant.

The four phase rectifiers produce the following dc voltages:

1. VsdcQ
A dc voltage proportional amplitude of the quadrature component (reactance) of the unknown. It is obtained by using the 90° generator as a reference.

2. VrdcQ
A dc voltage proportional to the amplitude of the 90° reference generator. It is obtained by using the 90° generator as a signal and reference.

The measured value of reactance is the ratio of these two signals taken by the A/D converters. By using this ratio method, any change in the measurement system exitation level or frequency, changes botn VsdcQ and VrdcQ leaving their ratio unchanged. This provides excellent immunity to changes in drive level and frequency.

3. VsdcP
A dc voltage proportional to the amplitude of the in-phase component (resistive or conductive) derived as in 1 above except using the 0° generator as a reference.

4. VrdcP
A dc voltage proportional to the amplitude of the 0° reference generator derived as in 2 except using the 0° reference generator.

Outputs of the phase rectifiers are fed to four active filters on circuit assembly number 41221. The A/D converter (A/D Lin Assembly, part No. 40702, and A/D Digital Assembly, Part No. 40689) under control of the CPU, first measures the offset voltages, then measures the ratio of selected dc voltages. This provides the CPU with digital information proportional to the value of the selected measurement and offset voltages. The CPU subtracts the voltage offsets from the actual measurement. A second set of A/D converters (available as a

High Speed Option, Part No. 42445) decreases the total measurement time by allowing the measurement of two quantities at the same time. The measured quantities are as follows:

$$\text{Offset Voltages} = \frac{\text{ZERO}}{\text{VrdcQ}}$$

$$\text{Cp or Ls} = K\,\frac{\text{VsdcQ}}{\text{VrdcQ}}$$

$$\frac{Gp}{\omega} \text{ or } \frac{Rs}{\omega} = K\,\frac{\text{VsdcP}}{\text{VrdcQ}}$$

$$\frac{1}{\omega} = K\,\frac{\text{VrdcP}}{\text{VrdcQ}}$$

3.2.1 Measurement Modes

The analog system is operated in an admittance (Y) or impedance (Z) mode.

The Y mode measures parallel susceptance and conductance by applying a constant voltage across the unknown. This voltage is amplified by gain channel UG where it is called V_{unk}. V_{unk} is further processed to become the reference voltage. The voltage across the unknown produces a current proportional to the parallel conductance and susceptance of the unknown. This current is converted to a signal voltage by allowing it to flow through the standard resistor (SR) and is amplified by selectable gain channel SG. This voltage (V_{std}) is then a measure of the unknown admittance and is:

$$V_{std} = (I_{unk})(SR)(SG) = (V_{unk})(SR)(SG/UG)(Y_{unk}) = (V_{unk})(SR)(SG/UG)(Gp+JBp)$$

$$\text{where } Gp = \begin{array}{c}\text{Parallel Conductance}\\ \text{of unknown}\end{array} = \frac{1}{\text{Parallel Resistance}}$$

$$\text{and } Bp = \begin{array}{c}\text{Parallel Susceptance}\\ \text{of unknown}\end{array} = \frac{1}{\text{Parallel Reactance}}$$

UG = Unknown Gain   SG = Standard Gain

The phase rectifiers produce dc voltages proportional to Gp and Bp. The actual measured values are parallel capacitance (Cp) derived from Bp, and Gp/ω derived from Gp by the A/D converter using ratio techniques.

The Z mode measures series reactance and resistance by applying constant voltage to the standard resistor which produces a constant current. This current is allowed to flow through the unknown producing a signal which is a measure of the unknown impedance and is:

$$V_{unk} = (I_{ref})(Z_{unk})(UG) = (V_{std}/R_{std})(Z_{unk})(UG/SG)$$

$$= (V_{std}/Rs)(UG/SG)(Rs + JXs)$$

The phase rectifiers produce dc voltages proportional to Rs and Xs. The actual measured values are series inductance (Ls) derived from Xs, and Rs/ω derived from Rs by the A/D converter using ratio techniques.

Quantities Measured and Calculated

Table 3-1 lists quantities that are measured and those calculated by the microprocessor.

	ADMITTANCE (Y BRIDGE) FUNCTION (CONSTANT VOLTAGE ACROSS UNKNOWN)			IMPEDANCE (Z BRIDGE) FUNCTION (CONSTANT CURRENT THRU UNKNOWN)		
	LEFT DISPLAY	RIGHT DISPLAY	OTHERS	LEFT DISPLAY	RIGHT DISPLAY	OTHERS
MEASURED QUANTITIES	Cp	Gp / ω	1/ω	Ls	Rs / ω	1/ω
CALCULATED QUANTITIES (Calculated from Measured Quantities Above)	$Cs^* = Cp\,(1 + D^2)$	$D = \frac{Gp}{\omega Cp}$ $Q = \frac{\omega Cp}{Gp}$ $Rs = \frac{D}{\omega Cs}$ $Gp = \frac{Gp}{\omega} \times \omega$		$Lp^* = Ls\,(1 + D^2)$	$D = \frac{Rs}{\omega Ls}$ $Q = \frac{\omega Ls}{Rs}$ $Gp = \frac{D}{\omega Lp}$ $Rs = \frac{Rs}{\omega} \times \omega$	
TEST MODE CALCULATED QUANTITIES (See Section 2.3.9)	$Lp = \frac{-1}{\omega^2 Cp}$ $Ls^* = \frac{-1}{\omega^2 Cs}$	$Gp = \frac{Gp}{\omega} \times \omega$ $D = \frac{Gp}{\omega Cp}$ $Q = \frac{\omega Cp}{Gp}$		$Cs = \frac{-1}{\omega^2 Ls}$ $Cp^* = \frac{-1}{\omega^2 Lp}$	$Rs = \frac{Rs}{\omega} \times \omega$ $D = \frac{Rs}{\omega Ls}$ $Q = \frac{\omega Ls}{Rs}$	

*NOT CALCULATED WHEN D > 1.9999 OR Q < 0.5

Table 3-1

3.3 THE DIGITAL SYSTEM

3.3.1 The CPU

The CPU Circuit Assembly, Part no. 41491, has complete control of all functions of the instrument and does all the calculations required to arrive at the desired measured quantity. It communicates with the instrument via an 8 bit bidirectional data bus. The CPU selects the circuit it needs to communicate with via a 16 bit address bus. Desired instrument functions such as range, frequency, etc., are selected on the appropriate circuit assembly by solid state switches or relays. Digital information to set these functions is stored by the CPU into temporary memory, called latches, located on the display board and other circuit assemblies as follows:

1. The CPU selects the proper latch via the address line.

2. The CPU outputs the proper bit pattern to set the desired function on the 8 bit data bus.

3. The CPU then sends a strobe pulse which stores this bit pattern into the selected latch.

3.3.2 The Display Circuit Assembly, Part No. 41329

This assembly contains the following circuits:

1. Temporary memory (latches) for the displays, units and their multipliers, keyboard decoding and instrument functions and ranges.

2. The displays with their units and multipliers.

3. A 1.6 millisecond oscillator interrupt used to multiplex the displays and keyboard.

4. The C, G, L and R ZERO ADJUSTMENT circuit.

3.3.2.1 <u>Displays and Keyboard</u>

The right and left displays and the keyboard are multiplexed at a 1.6 millisecond rate. The total time to multiplex through the display is then 10 milliseconds with each digit being energized for 16% of the total time. This 10 millisecond total time is also used for the settling time increments. Multiplexing is accomplished by the interrupt oscillator sending a pulse to the interrupt line of the CPU. Upon receiving this pulse, the CPU performs the following operations:

1. Fetches from memory the bit pattern for the next digit, unit and multiplier for the right and left display and stores it in the appropriate latch.

2. Transfers energizing current to the next display digits.

3. Examines the keyboard to determine if a key has been pressed.

If a key has been pressed, the CPU performs a debounce routine by requiring that the key be down for five successive total multiplexing times (50 milliseconds) before it will accept it.

3.3.2.2 C Zero, G Zero and L Zero, R Zero Circuits

C Zero, G Zero

The signal voltage from unknown high sense is buffered and applied to an inverting unity gain amplifier on the display PC board. This amplifier has two potentiometers spanning its input and output (the C Zero and G zero front panel trimmers) which send signals variable in amplitude and phase to the preamp and level regulator board. These signals are applied to the low side of the unknown through a resistor (G Zero) and a capacitor (C Zero) which is variable to increase or decrease the C zeroing range. This allows the addition or subtraction of capacitance or conductance to the measured unknown to compensate for open-circuit lead or test fixture offsets.

L Zero, R Zero

The signal current from unknown low drive is sensed and applied to an inverting unity gain amplifier on the display PC board. This amplifier also has two potentiometers spanning its input and output (the L zero and R zero front panel trimmers) and sends its signals, variable in amplitude and phase, to the unknown GAIN PC board. These signals are mixed with the voltage across the unknown being measured through a capacitor (L Zero) and a resistor (R Zero). This allows the addition or subtraction of inductance or resistance to the measured unknown to compensate for short-circuit lead or text fixture offsets. L and R zero circuitry affects high frequency measurements only. Early instruments did not have this feature.

3.4 OPTIONS

3.4.1 DC Resistance Option, Part No. 42536

The DC Resistance Circuit Assembly, Part No. 42596, is plugged into the location marked OPTIONAL A/D on the right side of the instrument. A logic signal is sent from this circuit assembly to actuate the relays on the discharge protection board which transfer the unknown connections from the LRC measuring circuitry of Model 296 to the dc resistance circuit. This option allows the operator to measure the inductance of the unknown and display it on the left display, then measure the dc resistance of the unknown and display it on the right display.

The dc resistance circuit is similar to the LRC measurement circuit in that it uses an operational amplifier circuit. The difference is that it uses dc drive to the unknown and does not require phase detecting circuits. Appropriate gain amplifiers and standard resistors provide the desired ranges. Thermal and offset voltages are cancelled in the detector portion of the circuit by making two measurements at reversed polarity for each measurement cycle.

3.4.2 High Speed Option, Part No. 42445

This option requires the addition of a second set of A/D converter circuit assemblies. The second A/D linear assembly (Part No. 40702) is plugged into the location marked A/D SAR and the second A/D digital assembly (Part No. 40689) is plugged into the location marked OPTIONAL A/D. This allows simultaneous measurement of the reactive and loss components of the unknown, decreasing the total measurement time as shown in Figure 2-4.

3.4.3 Handler Interface Option, Part No. 42434

This option requires the addition of circuit assembly number 42073 which is plugged into the location marked OPTION. It is used to sort components into operator selected tolerance bands when set points are programmed. It provides +5V and relay contact closures to the output plug on the rear panel for each selected band. The relays can be used to operate peripheral devices such as mechanical parts handlers, sorting bin openings, or external indicators.

3.4.4 General Purpose Interface Bus Option Part No. 42404 (IEEE or ASCII Bus)

This option requires the addition of the IEEE Circuit Assembly, Part No. 42132, plugged into the location marked ASCII BUS. It allows for remote control of all instrument functions and output of all measured data by use of the internationally adopted standard for digital interface of programmable instrumentation. This standard, as adopted by the IEC (International Electrotechnical Commission) and by the IEEE, is titled "IEEE Standard 488-1975".

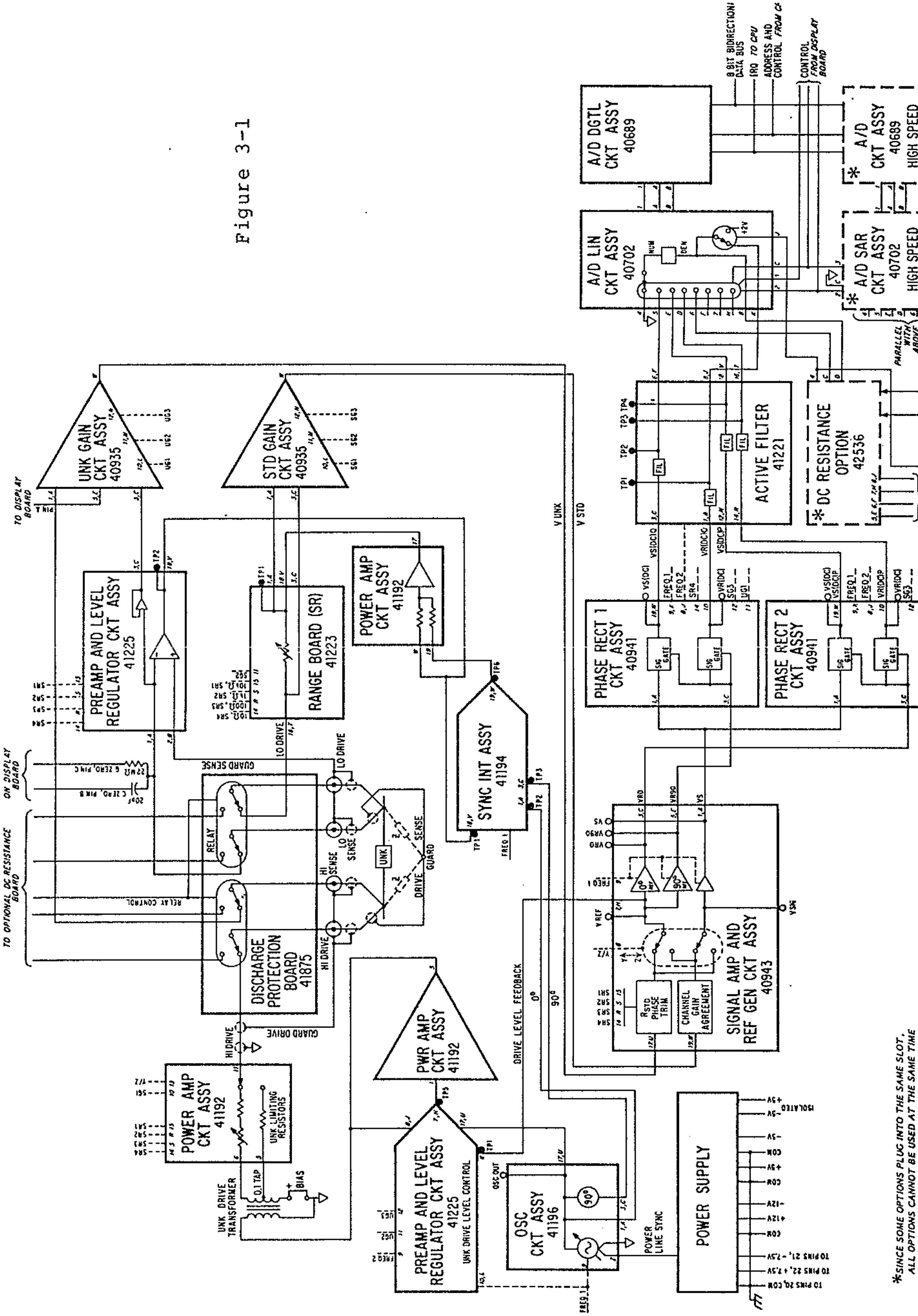
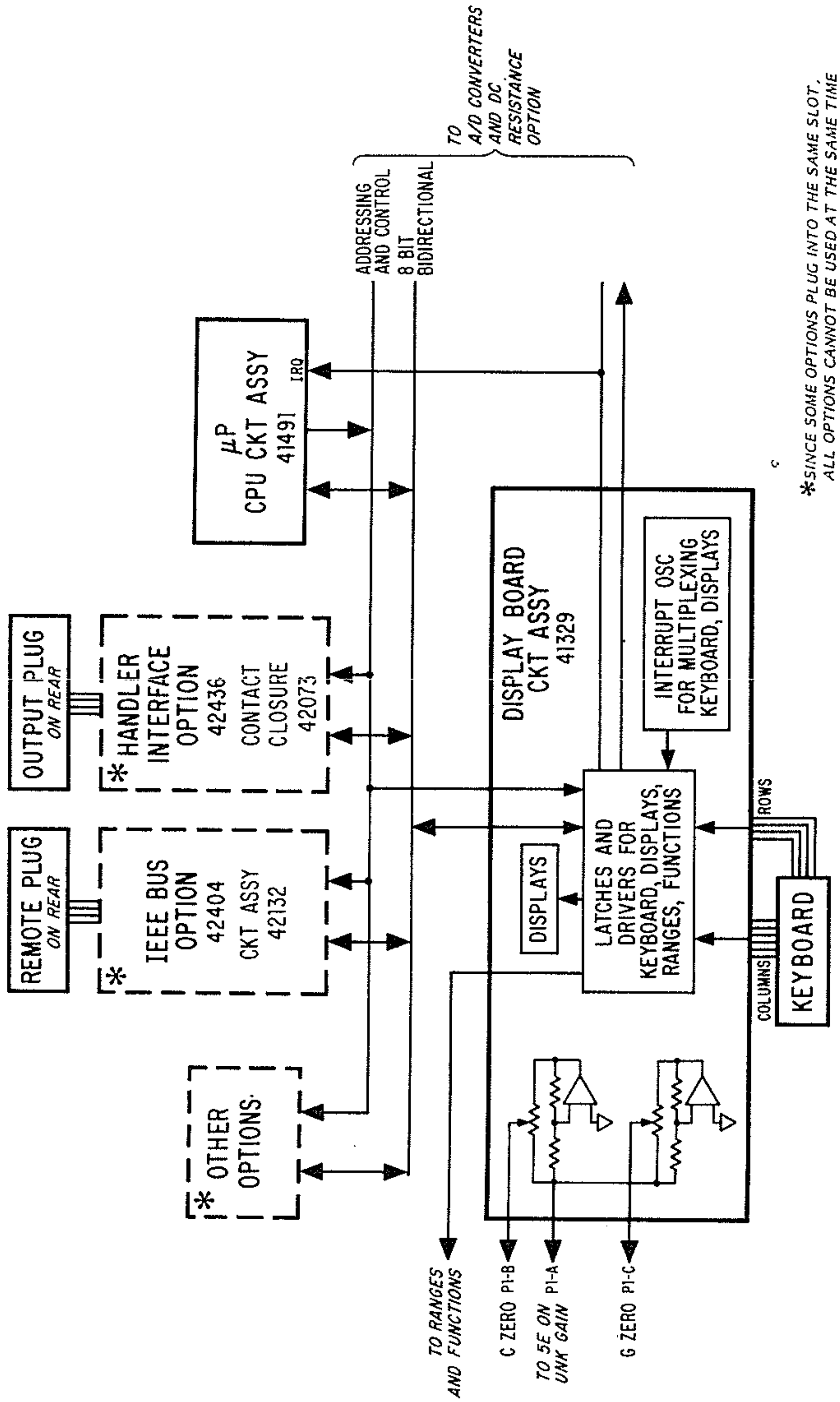

A/D DGTL CKT ASSY 40689
A/D LIN CKT ASSY 40702
A/D CKT ASSY 40689 HIGH SPEED OPTION 42445
A/D SAR CKT ASSY 40702 HIGH SPEED OPTION 42445
8 BIT BIDIRECTIONAL DATA BUS
IRQ TO CPU
ADDRESS AND CONTROL FROM CPU
CONTROL FROM DISPLAY BOARD
PARALLEL WITH ABOVE
ACTIVE FILTER 41221
DC RESISTANCE OPTION 42536
ADDRESS AND CONTROL BUS FROM CPU
DATA FROM CPU
RELAY CONTROL
UNK LEADS
TO DISCHARGE PROTECTION BOARD
UNK GAIN CKT ASSY 40935
STD GAIN CKT ASSY 40935
TO DISPLAY BOARD
V UNK
V STD
PREAMP AND LEVEL REGULATOR CKT ASSY 41225
RANGE BOARD (SR) 41223
POWER AMP CKT ASSY 41192
SYNC INT ASSY 41194
PHASE RECT 1 CKT ASSY 40941
PHASE RECT 2 CKT ASSY 40941
ON DISPLAY BOARD
TO OPTIONAL DC RESISTANCE BOARD
GUARD SENSE
LO DRIVE
RELAY CONTROL
DISCHARGE PROTECTION BOARD 41875
HI DRIVE
LO SENSE
HI SENSE
UNK
GUARD
SENSE
DRIVE
GUARD DRIVE
SIGNAL AMP AND REF GEN CKT ASSY 40943
CHANNEL GAIN AGREEMENT
DRIVE LEVEL FEEDBACK
PWR AMP CKT ASSY 41192
POWER AMP CKT ASSY 41192
UNK LIMITING RESISTORS
UNK DRIVE TRANSFORMER
BIAS
PREAMP AND LEVEL REGULATOR CKT ASSY 41225
UNK DRIVE LEVEL CONTROL
OSC CKT ASSY 41196
OSC OUT
POWER LINE SYNC
POWER SUPPLY
ISOLATED
*SINCE SOME OPTIONS PLUG INTO THE SAME SLOT, ALL OPTIONS CANNOT BE USED AT THE SAME TIME

Figure 3-1



TO A/D CONVERTERS AND DC RESISTANCE OPTION
ADDRESSING AND CONTROL
8 BIT BIDIRECTIONAL
μP CPU CKT ASSY 41491
IRQ
OUTPUT PLUG ON REAR
* HANDLER INTERFACE OPTION 42436
CONTACT CLOSURE 42073
REMOTE PLUG ON REAR
* IEEE BUS OPTION 42404
CKT ASSY 42132
* OTHER OPTIONS
DISPLAY BOARD CKT ASSY 41329
INTERRUPT OSC FOR MULTIPLEXING KEYBOARD, DISPLAYS
DISPLAYS
LATCHES AND DRIVERS FOR KEYBOARD, DISPLAYS, RANGES, FUNCTIONS
ROWS
COLUMNS
KEYBOARD
TO RANGES AND FUNCTIONS
C ZERO P1-B
TO 5E ON UNK GAIN P1-A
G ZERO P1-C
*SINCE SOME OPTIONS PLUG INTO THE SAME SLOT, ALL OPTIONS CANNOT BE USED AT THE SAME TIME

Figure 3-2

SECTION 4
MAINTENANCE

When performing any calibration or maintenance operation, do not remove or replace circuit boards while the power is turned on.

4.1 CALIBRATION

The calibration procedure is divided into two sections:

Section 4.1.1 (3 month intervals) is operational amplifier voltage offset and zero capacitance and conductance trims. They should not need adjustment for long periods of time because of the high quality op amps used in the instrument. They should however, be checked occasionally to account for normal aging.

Section 4.1.2 (6 month intervals) trims compensate for operational amplifier and passive component aging and should be checked periodically. Section 4.1.1 should always be done prior to Section 4.1.2.

A third section consists of factory trims which need adjustment only if a circuit assembly has been replaced. Consult factory for details.

Refer to Figure 4-1 for board and trimmer locations.

Required Equipment:

DC Voltmeter with 1mV resolution
100Ω, 1kΩ, and 10MΩ resistance standards (100Ω and 10MΩ for dc resistance option only)
1nF to 1μF low D standard capacitor (value known to ±0.01%, D known to 0.0002)

4.1.1 Zero Adjustments

1. Turn power on.
2. Let unit autorange.
3. Push ↓4 times to 1.9999μF range.
4. Separate leads for minimum capacitance (approximately 4 inches).
5. Adjust trimmer 1 on board 5 for zero on left display.

6. Adjust trimmer 1 on board 7 for zero on right display.

7. Change to LO FREQ (*FREQ).

8. Adjust trimmer 2 on board 5 for zero on left display.

9. Adjust trimmer 2 on board 7 for zero on right display.

10. Return to HI FREQ (push FREQ).

11. Set to autorange (*AUTO) and let it range to lowest capacitance range. Adjust front panel G ZERO and C ZERO.

12. Connect standard capacitor.

13. Put Model 296 in D mode.

14. Let unit autorange then uprange (↑) once so that C reading is one tenth full scale.

15. Adjust trimmers used in Steps 6 (Set to HI FREQ) and 9 (Set to LO FREQ) for known D reading. [Note that D resolution is

$$\frac{20{,}000}{\text{counts of C}} \times (0.3)]$$

16. Set instrument to HI FREQ, then to low D mode (not available in earlier models) as follows:

Push T, 0
Push 0005
Push *SECONDS

NOTE: In this mode the D resolution is improved by a factor of 10 to $\frac{20{,}000}{\text{counts of C}} \times (0.03)$.
The maximum D allowed is reduced from 1.9999 to 0.2. To return to normal D mode repeat steps above with code 0006 instead of 0005, or turn instrument off then on.

17. Uprange (↑) once so that C reading is approximately one tenth full scale (1000 counts).

18. Adjust trimmer 1 on board 18 (active filter) for known D value ±2 counts.

19. Set to LO FREQ and adjust trimmer 2 on board 7 for known D value ±2 counts.

4.1.2 Accuracy Adjustments

4.1.2.1 A/D Converter

1. Connect dc voltmeter between circuit board ground (shield or right side of board) and TP1 on board 16. Adjust trimmer number 3 for zero ±1mV.

2. Repeat for board 17 if optional A/D is in place. (At time of installation calibration described in Section 2.4.3 must be performed.)

All further adjustments are on circuit board 6.

4.1.2.2 HI Frequency Capacitance (press FREQ)

Set bridge to *F, *D, and *AUTO.

1. Connect standard capacitor.
2. Adjust trimmer 4 for known C value ±2 counts.
3. Adjust trimmer 7 for known D value ±2 counts.

4.1.2.3 LO Frequency Capacitance (press *FREQ)

1. Repeat step 1 in Section 4.1.2.2.
2. Repeat step 2, Section 4.1.2.2, adjusting trimmer 2.
3. Repeat step 2, this section, adjusting trimmer 5.

4.1.2.4 HI Frequency Resistance (press FREQ)

Set bridge to *F, *S, *AUTO.

1. Connect 1kΩ low reactance standard resistor and let unit autorange.

2. Hold range (*HOLD) and alternate Model 296 between *S, *F and *H, *Ω. Adjust trimmer 3 for equal counts from zero in left display (should be less than ±10 counts). Note that one reading is negative and one positive.

3. Set Model 296 to *H, *Ω and adjust trimmer 8 for known resistor value in right display ±2 counts.

4.1.2.5 LO Frequency Resistance (press *FREQ)

1. Repeat step 1 in Section 4.1.2.4.
2. Repeat step 2, Section 4.1.2.4, adjusting trimmer 1.
3. Repeat step 3, Section 4.1.2.4, adjusting trimmer 6.

Repeat Sections 4.1.2.2 through 4.1.2.5 as necessary.

4.1.2.6 DC Resistance Option (press *DC OHMS)

1. Connect the 1kΩ resistance standard and adjust left trimmer on the option board for actual value of the standard on the right display.

2. Connect the 100Ω standard and adjust the second trimmer for the actual value.

3. Connect the 10MΩ standard and adjust the third trimmer for the actual value on the right display. The fourth trimmer is a factory adjustment.

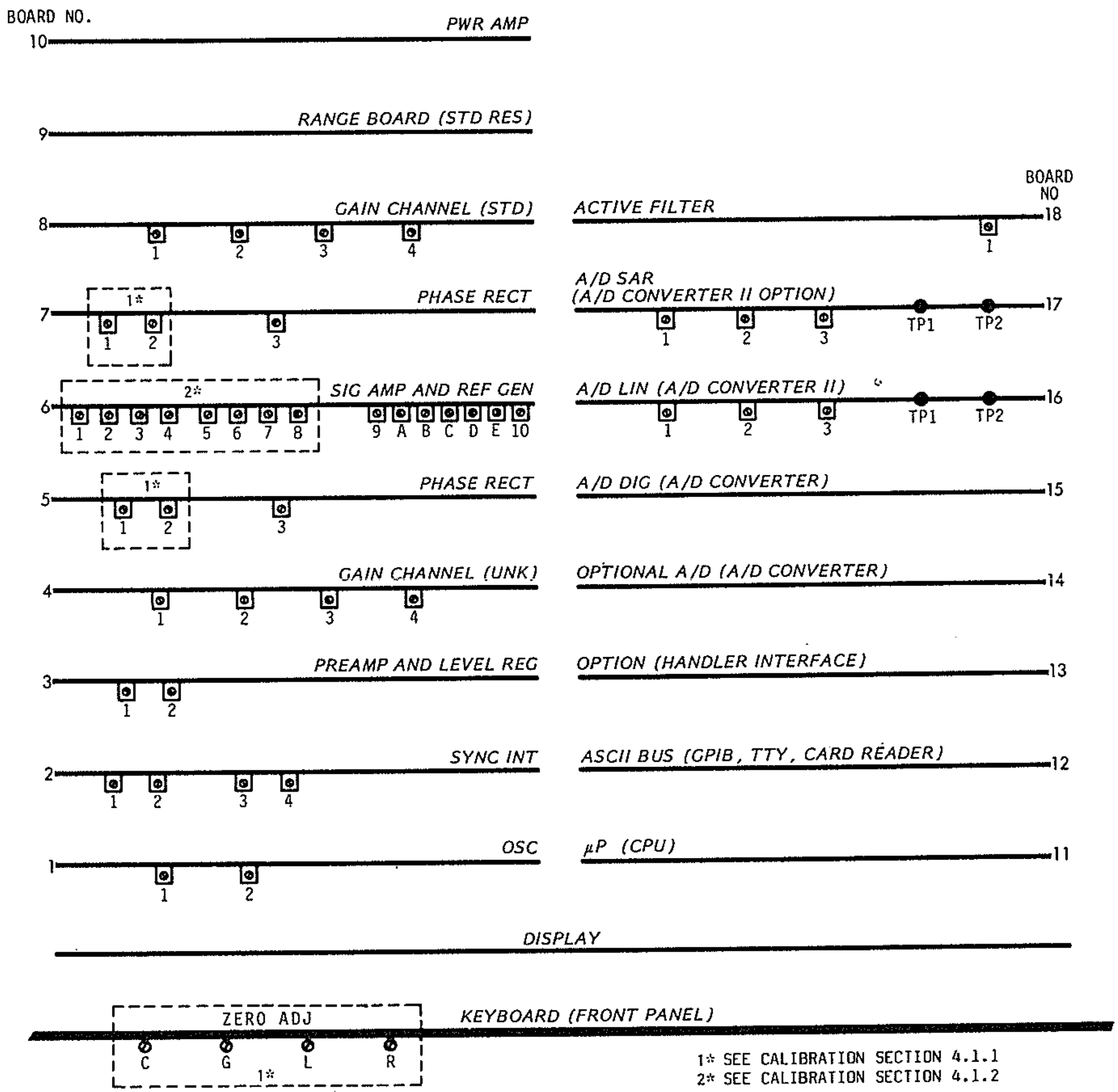

BOARD NO.
10 PWR AMP
9 RANGE BOARD (STD RES)
8 GAIN CHANNEL (STD) 1 2 3 4
7 PHASE RECT 1* 1 2 3
6 SIG AMP AND REF GEN 2* 1 2 3 4 5 6 7 8 9 A B C D E 10
5 PHASE RECT 1* 1 2 3
4 GAIN CHANNEL (UNK) 1 2 3 4
3 PREAMP AND LEVEL REG 1 2
2 SYNC INT 1 2 3 4
1 OSC 1 2
BOARD NO
ACTIVE FILTER 18 1
A/D SAR (A/D CONVERTER II OPTION) 17 1 2 3 TP1 TP2
A/D LIN (A/D CONVERTER II) 16 1 2 3 TP1 TP2
A/D DIG (A/D CONVERTER) 15
OPTIONAL A/D (A/D CONVERTER) 14
OPTION (HANDLER INTERFACE) 13
ASCII BUS (GPIB, TTY, CARD READER) 12
µP (CPU) 11
DISPLAY
ZERO ADJ C G L R 1*
KEYBOARD (FRONT PANEL)
1* SEE CALIBRATION SECTION 4.1.1
2* SEE CALIBRATION SECTION 4.1.2

Figure 4-1.

SECTION 5

PARTS LIST AND DIAGRAMS

5.1 MAINFRAME PARTS

CIRCUIT NO.	DESCRIPTION	ESI PART NO.
F1	Fuse 0.1A, Slo-Blo	333-09227
F2, F3	Fuse, 0.5A	333-01802
FL1	Filter, Receptacle, Fused	504-40002
S1	Switch, Power	330-23164
T1	Transformer, Power	340-41226
T2	Transformer, Coupling	340-41450
	Circuit Assembly, A/D Converter	505-40689
	Circuit Assembly, A/D Converter II	505-40702
	Circuit Assembly, Gain Channel	505-40935
	Circuit Assembly, Phase Rectifier	505-40941
	Circuit Assembly, Sig Amp and Ref Gen	505-40943
	Circuit Assembly, Power Amp	505-41192
	Circuit Assembly, Synchronous Integrator	505-41194
	Circuit Assembly, Oscillator	505-41196
	Circuit Assembly, Active Filter (old)	505-41221
	Circuit Assembly, Active Filter (new)	505-42978
	Circuit Assembly, Range Resistors	505-41223
	Circuit Assembly, Preamp and Level Regulator	505-41225
	Circuit Assembly, Keyboard	505-41269
	Mother Board, Righthand Assembly	505-41279
	Mother Board, Lefthand Assembly	505-41284
	Circuit Assembly, Display Board	505-41329
	Circuit Assembly, CPU Card	505-41492
	Circuit Assembly, Power Supply Board	505-41693
	Circuit Assembly, Protection Board	505-42675
	Front Panel	708-41295
	Back Panel	708-41282
	Top Cover	721-41264
	Bottom Cabinet	721-41265
	Bezel	710-41263
	Side Cabinet	711-41266
	PCB Rail	710-41307
	Card Guide Rail 13.0 Inch	711-41496
	Card Guide Rail 9.0 Inch	711-41495
	Front Panel, Display	708-41744
	Keyboard Kit	330-41369
	Button (White)	330-41191
	Button (Red)	330-41557
	Center Rail, Lefthand	710-41697
	Center Rail, Righthand	711-41698
	Card Guide	422-41846
	Instruction Card, Pull-out	130-42032
	Bracket, Power Switch	710-41487

CIRCUIT NO.	DESCRIPTION	ESI PART NO.
	Strip, Cover	710-42415
	Bail, 12 Inch	436-24007
	Feet	436-08739
	Bracket, Transformer Mounting	710-41595
	Pushrod	710-24866
	Fan	345-27829
	BNC Connector	504-41820
	Finger Guard, Fan	345-41552
	Panel, Binding Post	710-41848
	Display Panel (Plastic)	422-41847
	Binding Post	112-01435
	Line Cord	520-24077
	Instruction Manual	130-41909
	Filter, Fan	422-41527
	Cover, Receptacle	710-42285
	Heatsink, Regulator	329-41706
	Diode, MR1121	321-25688
	Diode, Mounting Kit	329-29534
	Insulator, Mica	329-41215
	Insulator, Mica	329-24328
	Socket	329-12262
	Capacitor, 0.22μF, Disc, 100V, 10%	311-13680
	Regulator, LM323k	327-24010
	Regulator, LM340T-5	343-20699
	Regulator, LM34/P-12 or MC78M12-CP	327-41877
	Regulator, LM320T-5 or MC7905-CP	327-41876
	Capacitor, 2.2μF, 20V, Tant	314-13283
	Connector, 24 Pin, IEEE Receptacle	504-42407
	Connector, 36 Pin, Receptacle	504-15739
	ESI Medallion	130-01946
	Fuse Post	334-03074
	Capacitor, 8000μF, 15V	314-21216
	Resistor, 100Ω, 1/4W, 10%	307-13907

5.2 A/D CONVERTER CIRCUIT ASSEMBLY (Part No. 40689)

CIRCUIT NO.	DESCRIPTION	ESI PART NO.
C1	Capacitor, 20pF, 600V, Poly	313-20926
C2	Capacitor, 6.8µF, 35V, Tant	314-25339
C3-C5	Capacitor, 0.01µF, 50V, Disc	311-12144
R1	Resistor, 560Ω, 10%, 1/4W, CC	307-13916
R2	Resistor, 820Ω, 10%, 1/4W, CC	307-13919
U1	IC, 6820	350-41292
U2	IC, 7404	343-20695
U3, U9	IC, 7473	343-20613
U4-U7	IC, 74193	343-20677
U8	IC, 7400	343-20600
Y1	Crystal, 3.93216MHz (60Hz)	321-24399 (Std)
	Crystal, 3.2768MHz (50Hz)	327-24540 (Opt)
	Socket, Crystal	504-24444

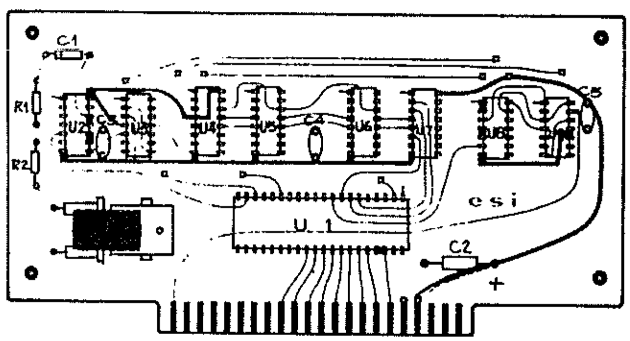
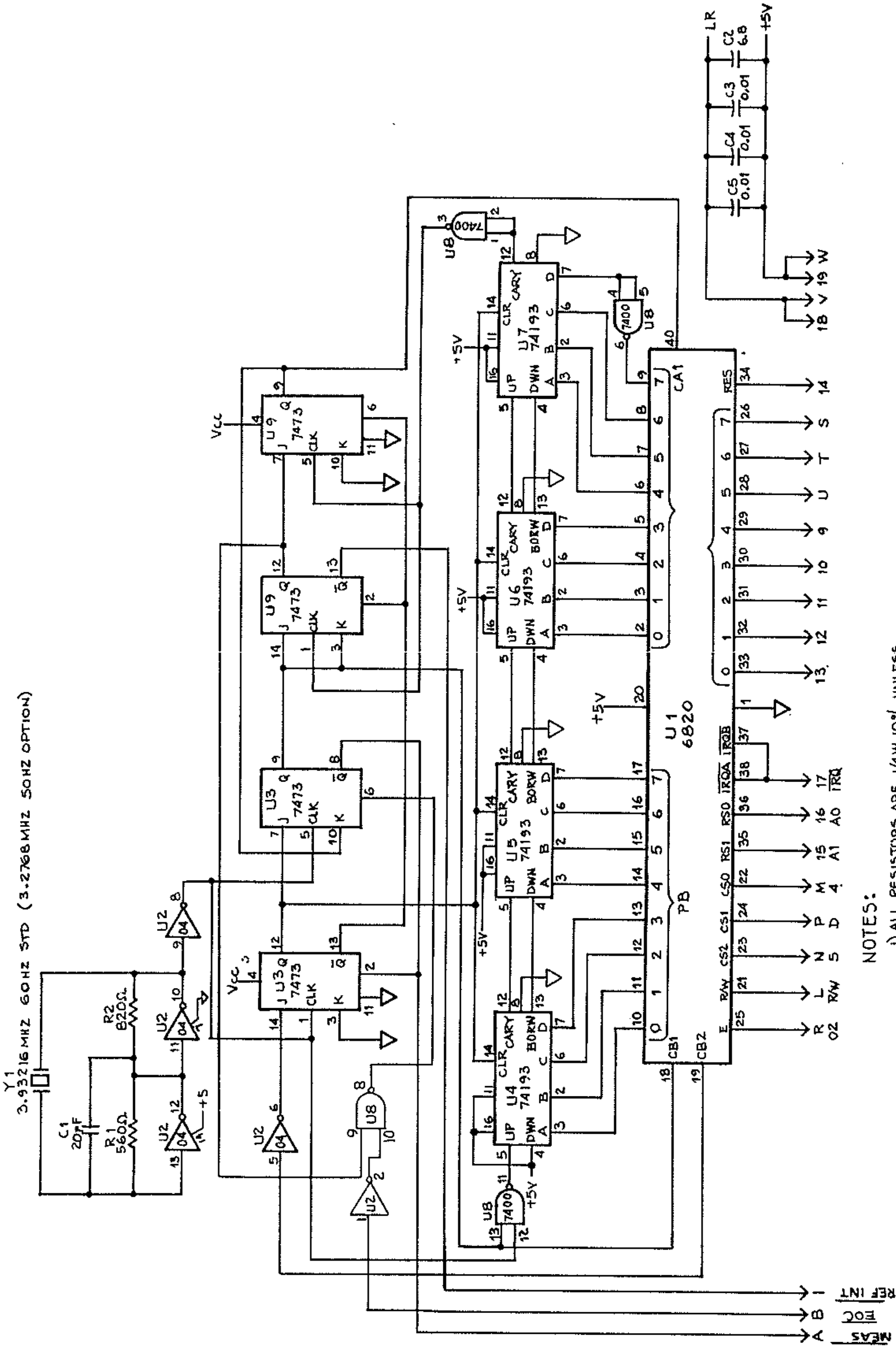


Figure 5-1. Part No. 40689



NOTES:

1) ALL RESISTORS ARE 1/4W, 10% UNLESS OTHERWISE SPECIFIED.

2) ALL CAPACITORS ARE MEASURED IN μF UNLESS OTHERWISE SPECIFIED.

Figure 5-2. Part No. 40689

5.3 A/D CONVERTER II CIRCUIT ASSEMBLY (Part No. 40702)

CIRCUIT NO.	DESCRIPTION	ESI PART NO.
C2	Capacitor, 0.033µF, 400V, Poly	313-26097
C3	Capacitor, 25pF, 500V, Disc	311-01924
C4-C15, C22	Capacitor, 0.01µF, 50V, Disc	311-12144
C16-C20	Capacitor, 6.8µF, 35V, Tant	314-25339
C21	Capacitor, 0.05µF, 50V, Disc	311-12116
C24	Capacitor, 500pF, 50V, Disc	311-12043
CR1	Diode 1N825	321-20868
CR2, CR4, CR5	Diode 1N914A	321-12356
Q1, Q2	Transistor, 2N3906	321-18754
R3	Resistor, 3.9kΩ, 0.01%, ESI Q	240-42875
R6	Resistor, 2kΩ, 0.01%, ESI Q	240-42630
R8	Resistor, 100Ω, 10%, 1/4W	305-21720
R10	Resistor, 1kΩ, 0.01%, ESI Q	240-42631
R11	Resistor, 124kΩ, 1%, 1/4W, Film	305-21751
R12	Potentiometer, 20kΩ	306-21199
R13	Resistor, 470Ω, 10%, 1/4W	307-13915
R14	Resistor, 220kΩ, 10%, 1/4W	307-13949
R15	Resistor, 100Ω, 10%, 1/4W	307-13907
R16, R17, R19, R21, R22, R24	Resistor, 4.7kΩ, 10%, 1/4W	307-13927
R18, R20, R23	Resistor, 1kΩ, 10%, 1/4W	307-13920
R25	Resistor, 6.8kΩ, 10%, 1/4W	307-13930
R26-R30	Resistor, 10Ω, 10%, 1/2W	304-02039
R31	Resistor, 750Ω, 1%, 1/8W	305-25999
R32	Resistor, 16.9kΩ, 1%, 1/8W	305-25290
R33	Potentiometer, 100Ω	306-26853
R34	Resistor, 8.45kΩ, 1%, 1/4W	305-83288
R35, R36	Resistor, 1%, 1/4W	Select
R37	Resistor, 10kΩ, 10%, 1/4W	307-13933
R38	Potentiometer, 200Ω	306-12083
U1, U3	Op-Amp, 741K	353-21625
U2	Op-Amp, AD504J	353-20697
U4	CMOS Switch, 4016AE	343-20711
U5	Op-Amp, LF356	352-41473
U6	Op-Amp, 301A	343-20669
U7	Op-Amp, 311N	353-29544
U8	CMOS Gate, 4001AE	350-40842
U9	CMOS Switch, 4051AE	350-40841
U10	CMOS Switch, CD4053	350-20744
W1, W2	Wire	

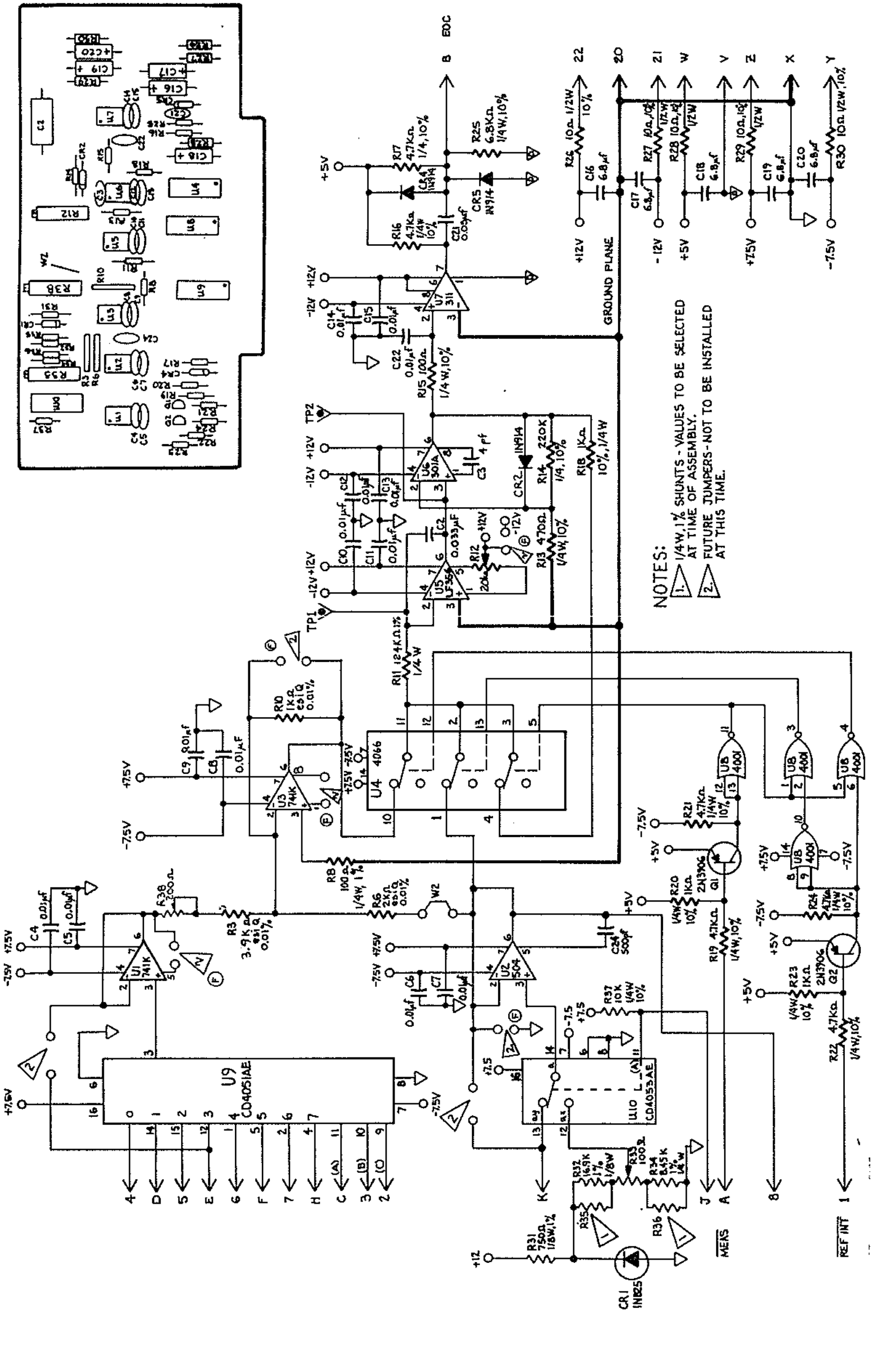


Figure 5-3. Part No. 40702

5.4 GAIN CHANNEL CIRCUIT ASSEMBLY (Part No. 40935)

CIRCUIT NO.	DESCRIPTION	ESI PART NO.
C1	Capacitor, 1µF, 200V, MMW	313-18843
C2	Capacitor, 22µF, 15V, Tant	314-18852
C3-C6, C10, C11, C14, C15, C18, C19	Capacitor, 0.01µF, 50V, Disc	311-12144
C12, C16, C20	Capacitor, 100pF	313-18760
C24-C26	Capacitor, 150pF, 600V, Poly	313-29606
C22, C23	Capacitor, 100µF, 12V	314-06157
CR1-CR4	Diode, 1N914A	321-12356
R1	Resistor, 499kΩ, 1%, 1/8W	305-21757
R2, R24, R25	Potentiometer, 10kΩ	306-20145
R3	Resistor, 10kΩ, 10%, 1/4W	307-13933
R4	Potentiometer, 50kΩ	306-12091
R5-R8, R11-R13, R15-R17, R19-R21	Resistor, 10kΩ, 0.01%, ESI QB	240-41673
R10, R14, R18	Resistor, 1kΩ, 0.01%, ESI QP	240-41471
R22, R23	Resistor, 10Ω, 10%, 1/2W	304-02039
U1-U5	Op-Amp, LF356	352-41473
U6, U7	IC, CD4053, Switch	350-20744
	Shield, PC Board	710-41469
	Socket, 8 Pin DIP	504-22410

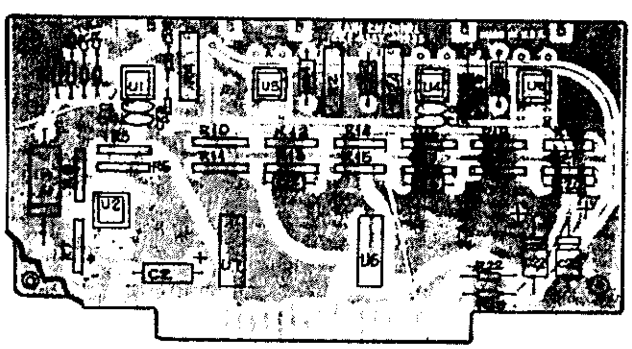
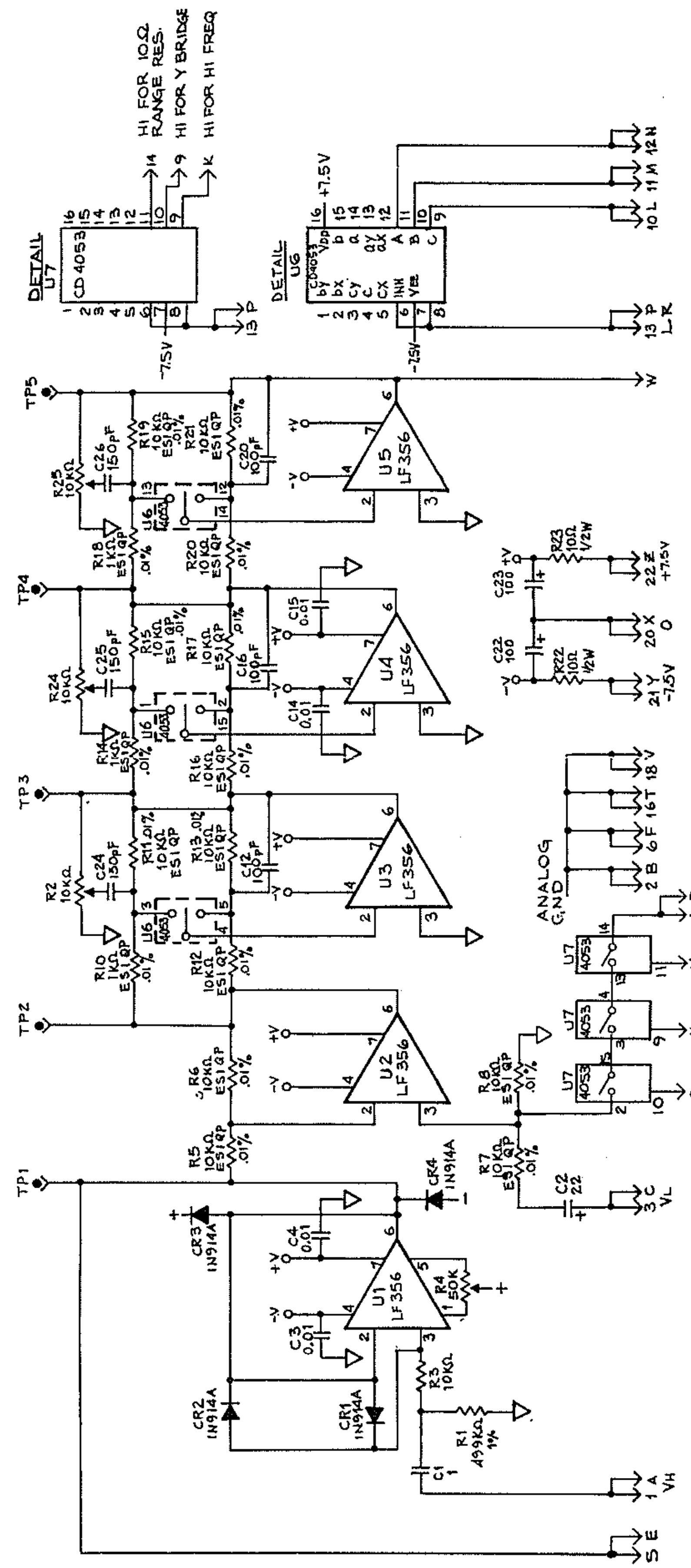


Figure 5-4. Part No. 40935

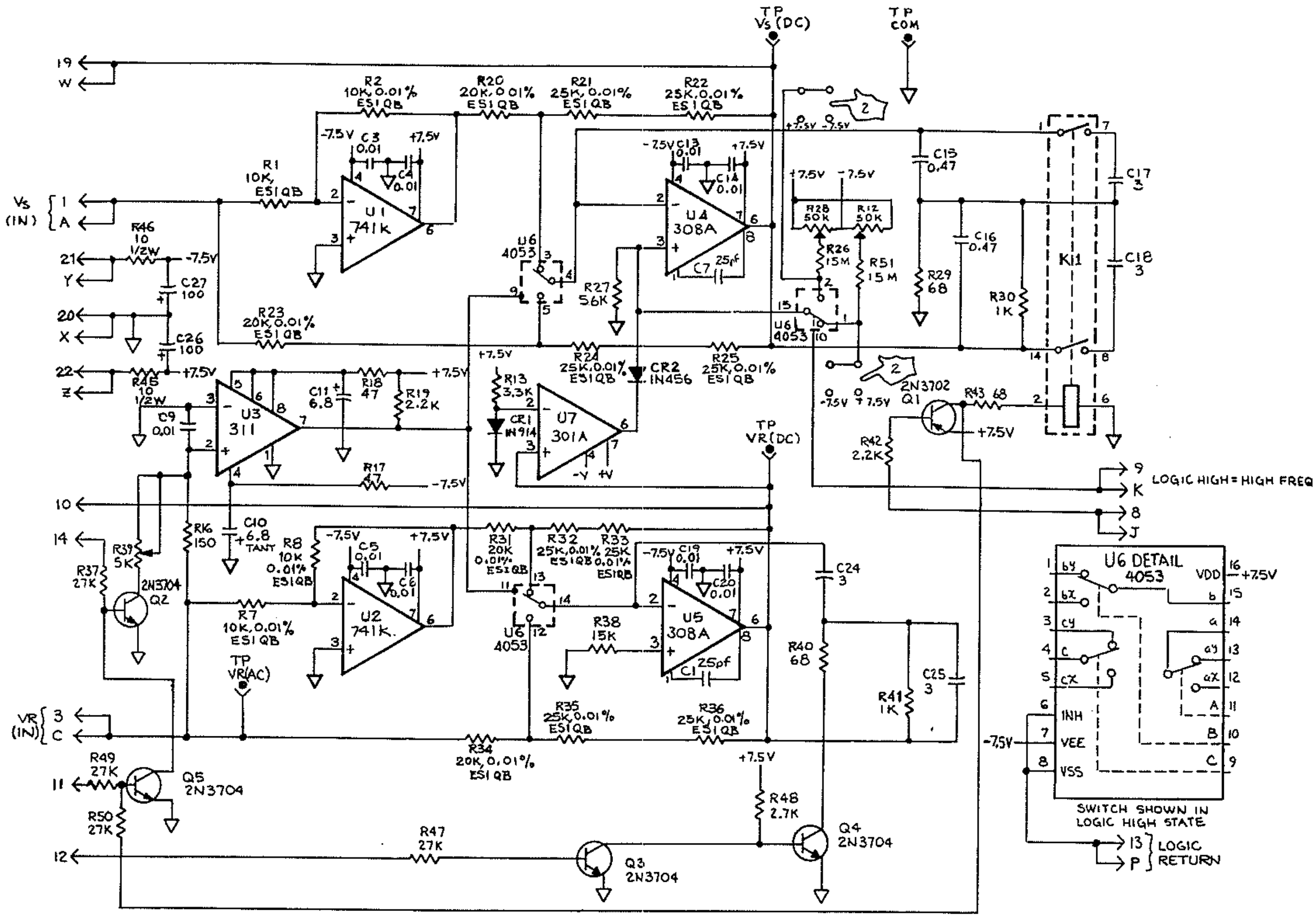


1) ALL CAPACITORS ARE IN μF UNLESS OTHERWISE STATED
2) ALL RESISTORS ARE 1/4W, 10% UNLES OTHERWISE STATED

Figure 5-5. Part No. 40935

5.5 PHASE RECTIFIER CIRCUIT ASSEMBLY (Part No. 40941)

CIRCUIT NO.	DESCRIPTION	ESI PART NO.
C1, C7	Capacitor, 25pF, 1kV, Disc	311-01924
C3-C6, C9, C13, C14, C19, C20	Capacitor, 0.01µF, 50V, Disc	311-12144
C10, C11	Capacitor, 6.8µF, 35V, Tant	314-25339
C15, C16	Capacitor, 0.47µF, 50V	313-13653
C17, C18, C24, C25	Capacitor, 3µF, 50V	313-12358
C26, C27	Capacitor, 100µF, 12V	314-06157
CR1	Diode, 1N914	321-12356
CR2	Diode, 1N456	321-09155
K1	Relay, GB822A-2	332-26667
Q1	Transistor, 2N3702	321-12041
Q2-Q5	Transistor, 2N3704	321-12077
R1, R2, R7, R8	Resistor, 10kΩ, 0.01%, ESI QB	240-41673
R12, R28	Trimpot, 50kΩ	306-12091
R13	Resistor, 3.3kΩ, 10%, 1/4W	307-13926
R16	Resistor, 150Ω, 10%, 1/4W	307-13909
R17, R18	Resistor, 47Ω, 10%, 1/4W	307-13901
R19, R42	Resistor, 2.2kΩ, 10%, 1/4W	307-13924
R20, R23, R31, R34	Resistor, 20kΩ, 0.01%, ESI QB	240-23647
R21, R22, R24, R25, R32, R33, R35, R36	Resistor, 25kΩ, 0.01%, ESI QB	240-41676
R26	Resistor, 15MΩ, 10%, 1/4W	307-13976
R27, R38	Resistor, 15kΩ, 10%, 1/4W	307-13935
R29, R40, R43	Resistor, 68Ω, 10%, 1/4W	307-13902
R30, R41	Resistor, 1kΩ, 10%, 1/4W	307-13920
R37, R47, R49, R50	Resistor, 27kΩ, 10%, 1/4W	307-13938
R39	Trimpot, 1kΩ	306-18469
R45, R46	Resistor, 10Ω, 10%, 1/2W	304-02039
R48	Resistor, 2.7kΩ, 10%, 1/4W	307-13925
U1, U2	Op-Amp 741K	343-21625
U3	Op-Amp, 311N	353-29544
U4, U5	Op-Amp, LM308A	352-23957
U6	Switch, CD4053	350-20744
U7	Op-Amp, 301A	343-20669
XK1	Socket, PC, 14 Pin DIP	504-19189
XU1-XU5, XU7	Socket, 8 Pin DIP, PC Mtg	504-22410
XU6	Socket, 16 Pin DIP, PC Mtg	504-20860
	Shield, PCB	710-41469



NOTE:
1. ALL RESISTOR VALUES ARE IN OHMS
ALL RESISTORS ARE 1/4 W 10% UNLESS OTHERWISE STATED
ALL CAPACITORS ARE IN μF UNLESS OTHERWISE STATED
2 FOR FUTURE OPTION

Figure 5-6. Part No. 40941

5.6 SIGNAL AMP AND REFERENCE GENERATOR CIRCUIT ASSEMBLY (Part No. 40943)

CIRCUIT NO.	DESCRIPTION	ESI PART NO.
C1	Capacitor, 220pF, 600V	313-29297
C2	Capacitor, 100pF, 500V	313-18760
C6, C7, C14, C15, C24, C25	Capacitor, 0.01µF, Disc, 50V	311-12144
C9, C10	Capacitor, 1µF, 200V	313-18843
C19, C31	Capacitor, 0.001µF, 1%, 500V	312-02157
C20, C21, C27, C28	Capacitor, 150pF, 600V	313-29606
C22, C23, C29, C30	Capacitor, 0.01µF, 1%	312-01929
C26	Capacitor, 0.002µF, 1%, 500V	312-02158
C32	Capacitor, Select	
CR1-CR6	Diode, 1N914A	321-12356
R1, R2, R8, R9	Resistor, 10kΩ, ±0.01%, ESI Q, ±5ppm/C°TC	240-41673
R3-R7, R11, R13	Trimpot, 20kΩ	306-21199
R10	Resistor, 1MΩ, ±10%, 1/4W	307-13960
R12	Resistor, 40.2kΩ, 1%, 1/8W	305-21746
R14	Resistor, 49.9kΩ, 1%, 1/4W	305-21747
R17, R18, R27, R33, R34	Resistor, 20kΩ, ±0.01%, ESI QB, ±5ppm/C°TC	240-23647
R19	Resistor, 40kΩ, ±0.01%, ESI QB, ±5%/C°TC	240-21112
R20	Trimpot, 1kΩ	306-18469
R21-R23, R29, R36-R40	Resistor, 200kΩ, 1%, 1/8W	303-41674
R24-R26, R31, R32	Trimpot, 10kΩ	306-20145
R28	Trimpot, 500Ω	306-12093
R30	Trimpot, 5kΩ	306-12092
R35	Resistor, 40.5kΩ, ±0.01%, ESI QB, ±5%/C°TC	240-43022
R41	Resistor, 15kΩ, 10%, 1/4W	307-13935
R42, R43	Resistor, 47kΩ, 10%, 1/4W	307-13941
R44	Resistor, 4990Ω, 1%, 1/4W	305-21737
U1-U7	OP Amp LF356	352-41473
U8-U10	Switch CD4053	350-20744
	Shield, PC Board	710-41469
	Socket, 8 pin DIP	504-22410

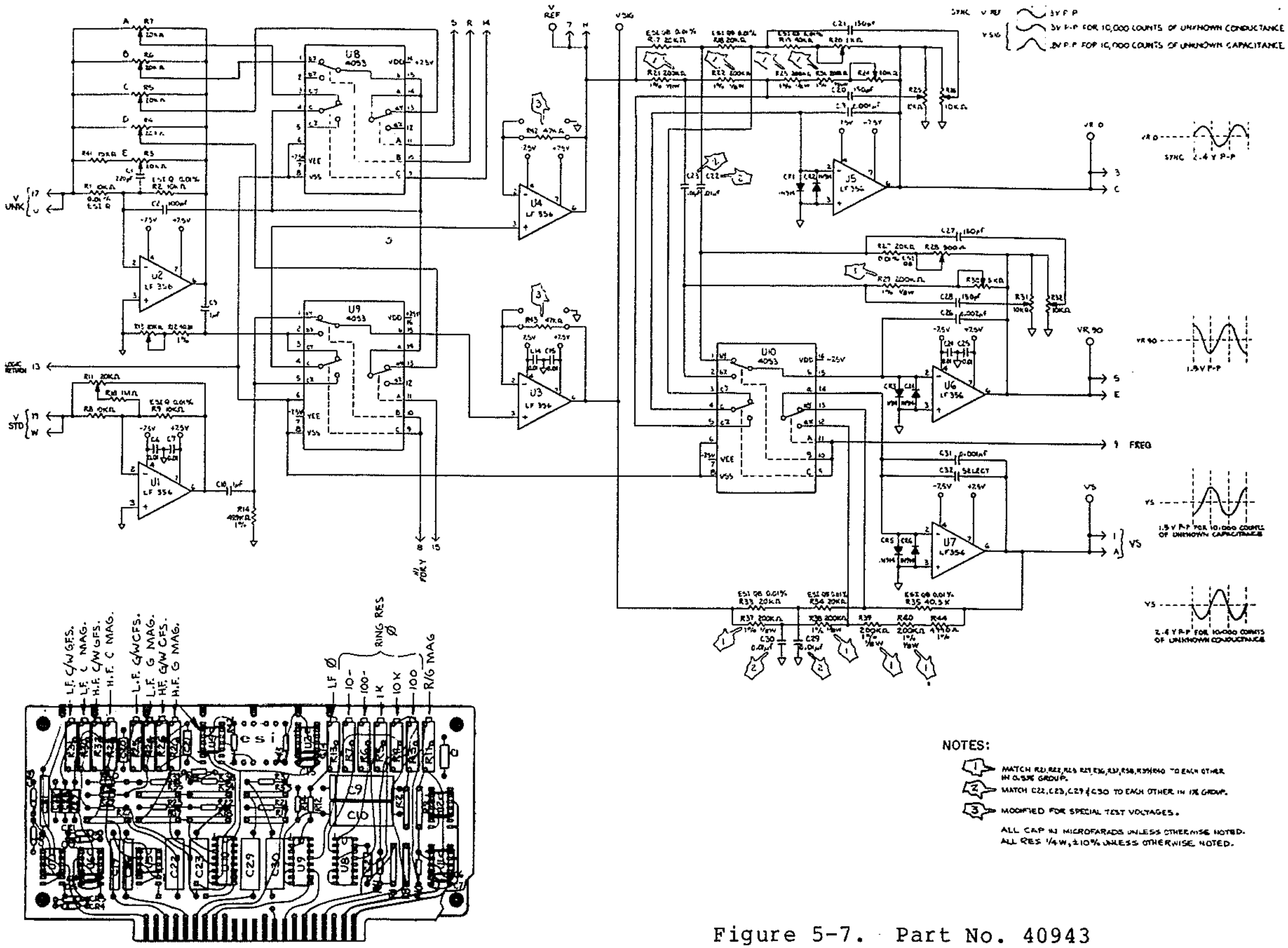


Figure 5-7. Part No. 40943

5.7 POWER AMP CIRCUIT ASSEMBLY (Part No. 41192)

CIRCUIT NO.	DESCRIPTION	ESI PART NO.
C1-C3, C5-C8	Capacitor, 0.01µF, 50V, Disc	311-12144
CR1-CR4, CR7-CR10 CR13, CR14	Diode, 1N914A	321-12356
CR11, CR12	Diode, 1N4005	321-01779
K1, K5	Relay, Mercury Wetted	332-42634
K2-K4	Relay, GB821A-2	332-27841
Q1, Q7, Q13-Q16, Q18	Transistor, 2N3702	321-12041
Q2, Q8, Q17	Transistor, 2N3704	321-12077
Q3, Q9	Transistor, 2N3053	321-12232
Q4, Q10	Transistor, 2N4037	321-13590
Q5, Q11	Transistor, MJE371 (2N4918)	321-18753
Q6, Q12	Transistor, 2N4921	321-18752
R1, R5, R8, R10, R18, R21	Resistor, 1kΩ, 10%, 1/4W	307-13920
R2, R9, R11, R19, R20	Resistor, 100Ω, 10%, 1/4W	307-13907
R3, R6, R12, R16	Resistor, 4.7Ω, 10%, 1/4W	307-13890
R4, R7, R13, R17	Resistor, 1Ω, 10%, 1/2W	304-12448
R14, R33	Resistor, 3.3kΩ, 1/4W, 10%	307-13926
R15, R34, R35	Resistor, 4.7kΩ, 10%, 1/4W	307-13927
R22	Resistor, 10kΩ, 10%, 1/4W	307-13933
R23	Resistor, 100kΩ, 10%, 1/4W	307-13945
rR24	Resistor, 68Ω, 10%, 1/4W	307-13902
R25, R26	Resistor, 27kΩ, 10%, 1/4W	307-13938
R27	Resistor, 1Ω, 10%, 1/2W	304-01977
R28-R30	Resistor, 2.7Ω, 10%, 1/4W	307-13887
R31, R32	Resistor, 39Ω, 10%, 1/4W	307-21219
U1	IC, CD4011	350-20725
	Shield, PCB	710-41469
	Socket, Relay, 14 Pin	504-19189
	Heat Sink	329-22859
	Washer, Mica, for Q5,6,11,12	329-41215

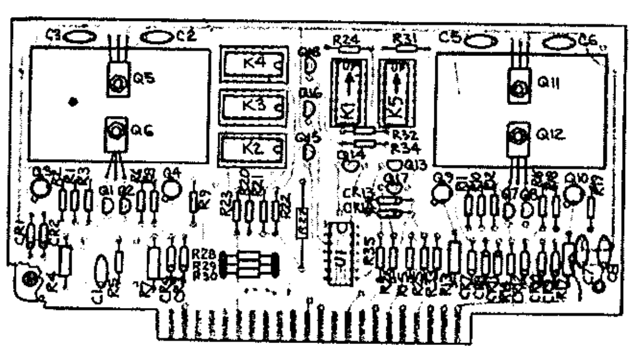


Figure 5-8. Part No. 41192

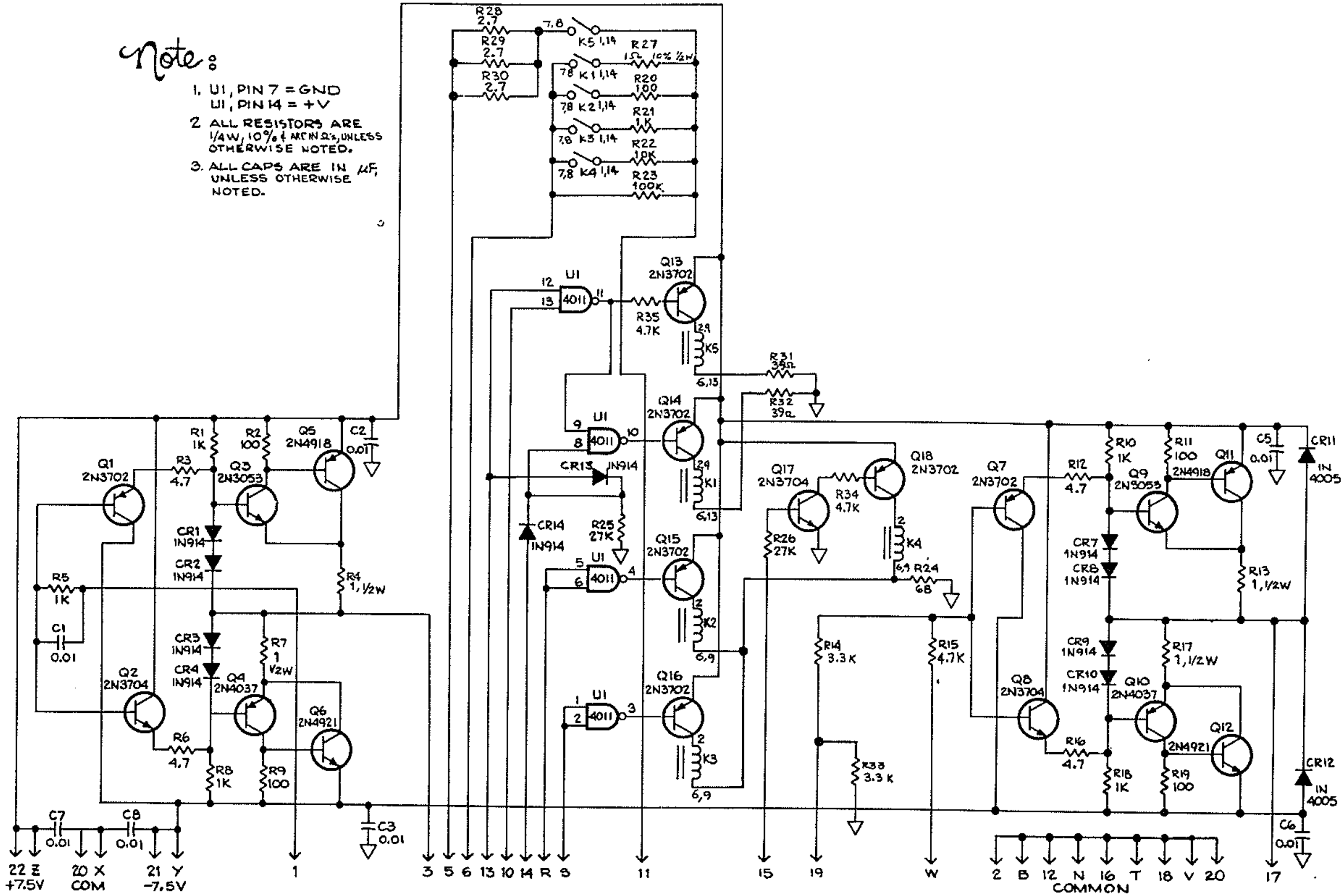


Figure 5-9. Part No. 41192

5.8 SYNCHRONOUS INTEGRATOR CIRCUIT ASSEMBLY (Part No. 41194)

CIRCUIT NO.	DESCRIPTION	ESI PART NO.
C1, C6, C8, C9	Capacitor, 0.1μF, 100V, WMF	313-06470
C2, C5, C10, C13	Capacitor, 0.001μF, 1kV, Disc	311-21215
C3, C11	Capacitor, 0.047μF, 200V, MMW	313-12239
C4, C7, C12	Capacitor, 25pF, 1kV, Disc	311-01924
C14, C15	Capacitor, 100μF, 12V	314-06157
R1, R3, R5, R11, R19, R21, R22, R24, R26, R32	Resistor, 100kΩ, 10%, 1/4W	307-13945
R2, R13, R23, R34	Resistor, 100Ω, 10%, 1/4W	307-13907
R4, R15, R25, R36	Resistor, 10Ω, 10%, 1/4W	307-13895
R6, R14, R16, R27 R35	Resistor, 47kΩ, 10%, 1/4W	307-13941
R7, R28	Trimpot, 100kΩ	306-21455
R8, R29	Resistor, 4.7kΩ, 10%, 1/4W	307-13927
R9, R18, R30	Resistor, 330kΩ, 10%, 1/4W	307-13951
R10, R31	Trimpot, 50kΩ	306-12091
R12, R33, R38	Resistor, 270kΩ, 10%, 1/4W	307-20432
R17	Resistor, 220kΩ, 10%, 1/4W	307-13949
R20	Resistor, 1MΩ, 10%, 1/4W	307-13960
R37	Resistor, 33kΩ, 10%, 1/4W	307-13937
R39, R40	Resistor, 10Ω, 10%, 1/2W	304-02039
R41, R42	Resistor, 470kΩ, 1/4W	307-13955
U1, U2, U4, U5, U8, U9, U11, U12	IC, 3080 CDA	352-20723
U3, U6, U7, U10	IC, 741 Op-Amp	343-20668
U13	IC, 4053 Switch	350-20744
	Shield, PC Board	710-41469

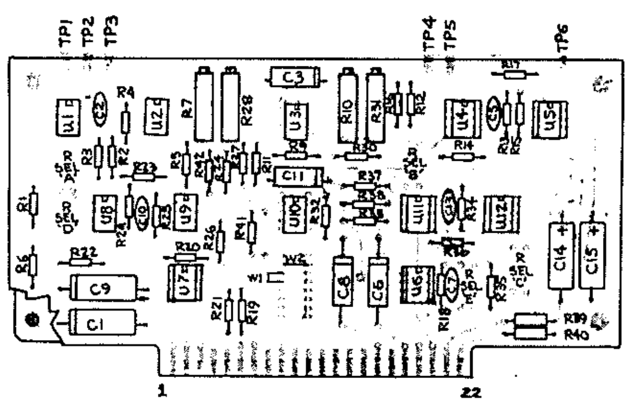


Figure 5-10. Part No. 41194

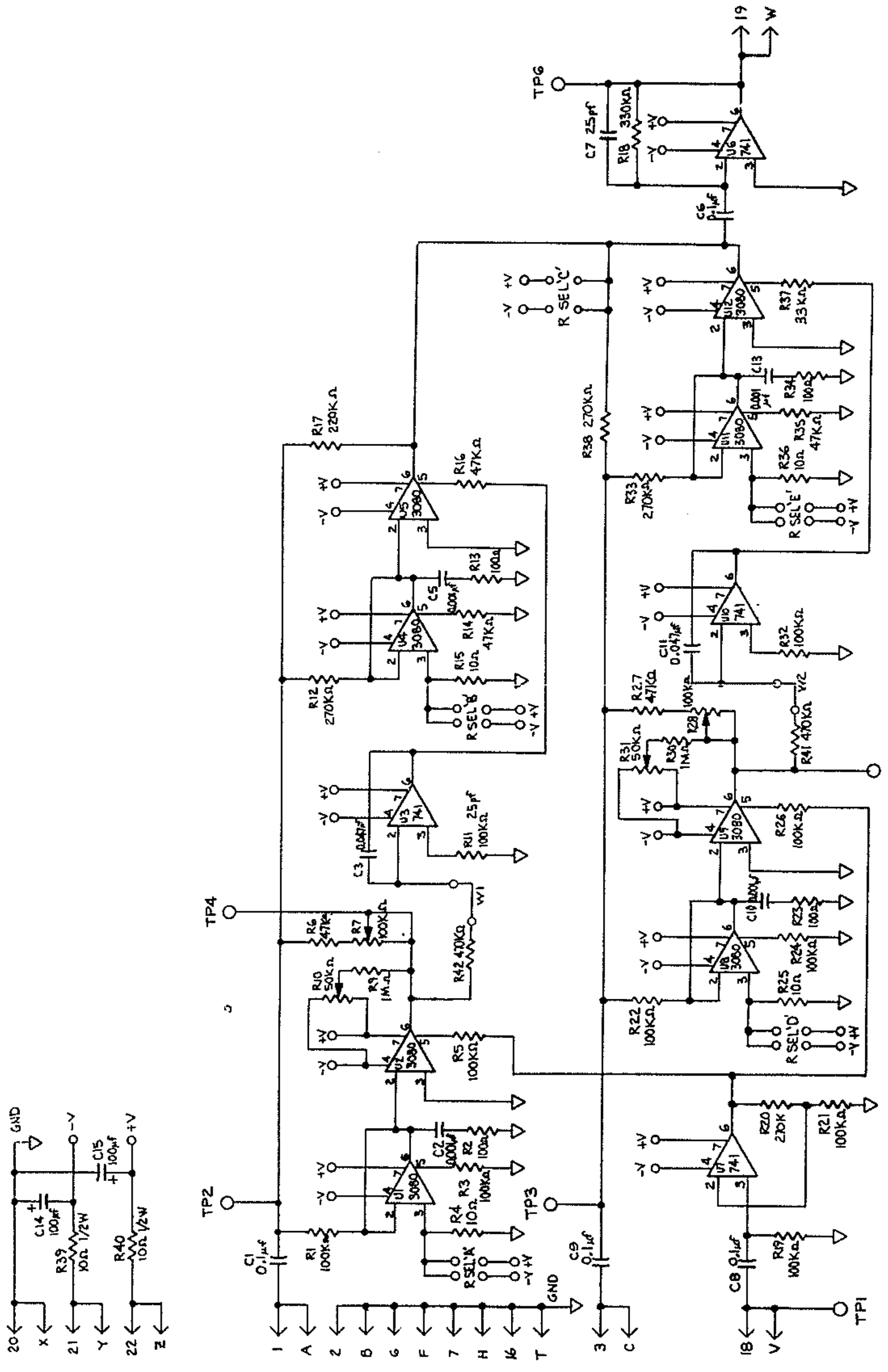
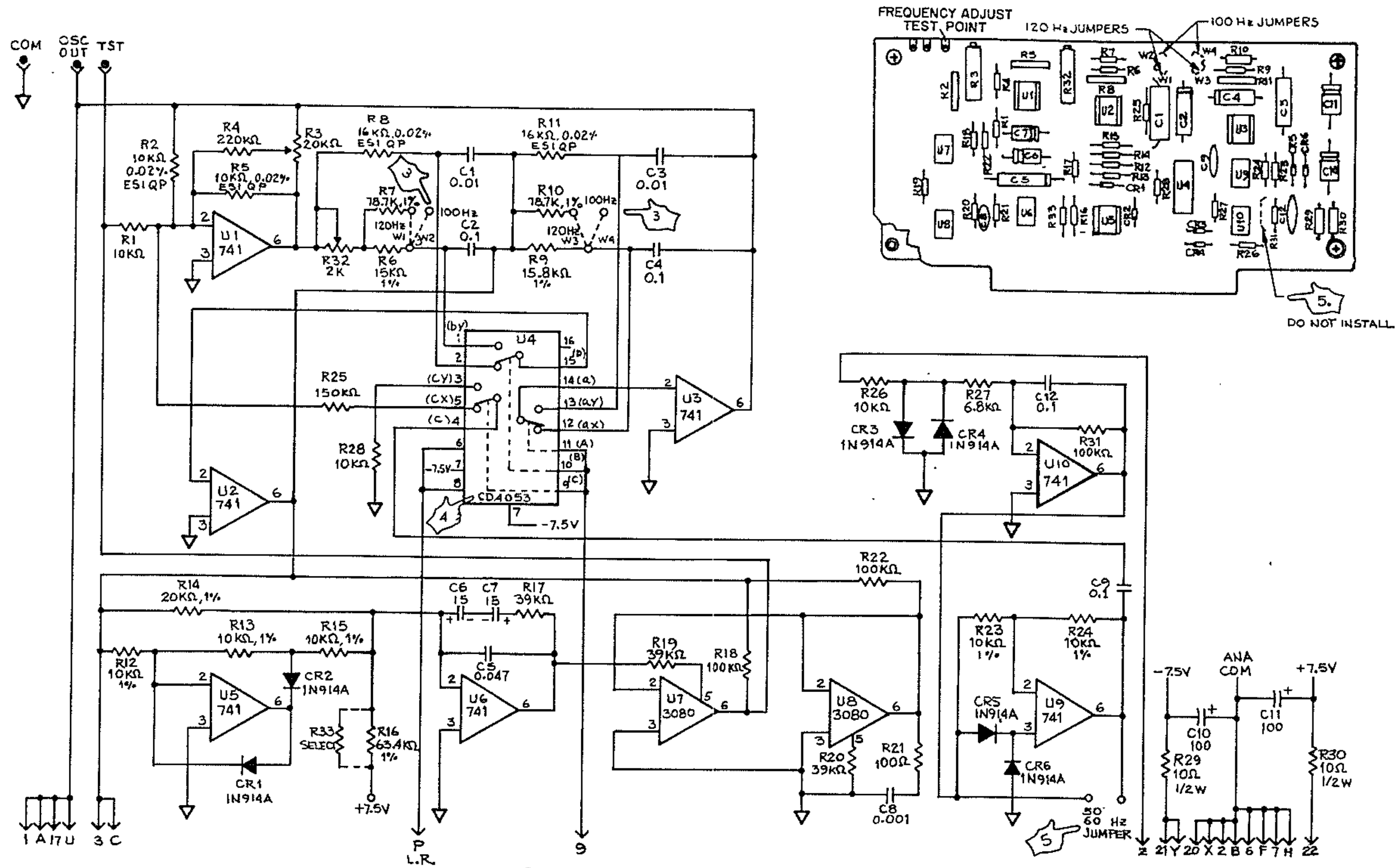


Figure 5-11. Part No. 41194

Figure 5-11. Part No. 41194

5.9 OSCILLATOR CIRCUIT ASSEMBLY (Part No. 41196)

CIRCUIT NO.	DESCRIPTION	ESI PART NO.
C1, C3	Capacitor, 0.01μF, 1%, Mica	312-01929
C2, C4	Capacitor, 0.1μF, 100V	313-12139
C5	Capacitor, 0.047μF, 100V, WMF	313-01776
C6, C7	Capacitor, 15μF, 12V	314-09916
C8	Capacitor, 0.001μF, 1kV, Disc	311-21215
C9, C12	Capacitor, 0.1μF, 100V, Disc	311-24395
C10, C11	Capacitor, 100μF, 12V	314-06157
CR1-CR4, CR5, CR6	Diode, 1N914A	321-12356
R1, R26, R28	Resistor, 10kΩ, 10%, 1/4W	307-13933
R2, R5	Resistor, 10kΩ, 0.02%, ESI QP	240-23613
R3	Trimpot, 20kΩ	306-21199
R4	Resistor, 220kΩ, 10%, 1/4W	307-13949
R6	Resistor, 15kΩ, 1%, 1/4W	305-21198
R7, R10	Resistor, 78.7kΩ, 1%, 1/4W	305-13166
R8, R11	Resistor, 16kΩ, 0.02%, ESI QP	240-41466
R9	Resistor, 15.8kΩ, 1%, 1/4W	305-21742
R12, R13, R15, R23, R24	Resistor, 10kΩ, 1%, 1/4W	305-21740
R14	Resistor, 20kΩ, 1%, 1/4W	305-21743
R16	Resistor, 63.4kΩ, 1%, 1/4W	305-21748
R17, R19, R20	Resistor, 39kΩ, 10%, 1/4W	307-13940
R18, R22, R31	Resistor, 100kΩ, 10%, 1/4W	307-13945
R21	Resistor, 100Ω, 10%, 1/4W	307-13907
R25	Resistor, 150kΩ, 10%, 1/4W	307-13947
R27	Resistor, 6.8kΩ, 10%, 1/4W	307-13930
R29, R30	Resistor, 10Ω, 10%, 1/2W	304-02039
R32	Trimpot, 2kΩ	306-12084
R33	Resistor, Select	
U1-U3, U5, U6, U9, U10	Op-Amp, 741	343-20668
U4	Switch, CD4053	350-20744
U7, U8	Op-Amp, 3080	352-20723
W1-W4	Wire	
	Shield, PCB	710-41469



NOTE:

1. ALL RESISTORS ARE 1/4W 10% UNLESS OTHERWISE STATED
2. ALL CAPACITORS ARE IN µF UNLESS OTHERWISE STATED

(3) JUMPER FOR 120 Hz OR 100Hz OPERATION

(4) CONTROL; LOGIC HI, SWITCH TO Y FOR HI FREQ

(5) FUTURE OPTION

Figure 5-12. Part No. 41196

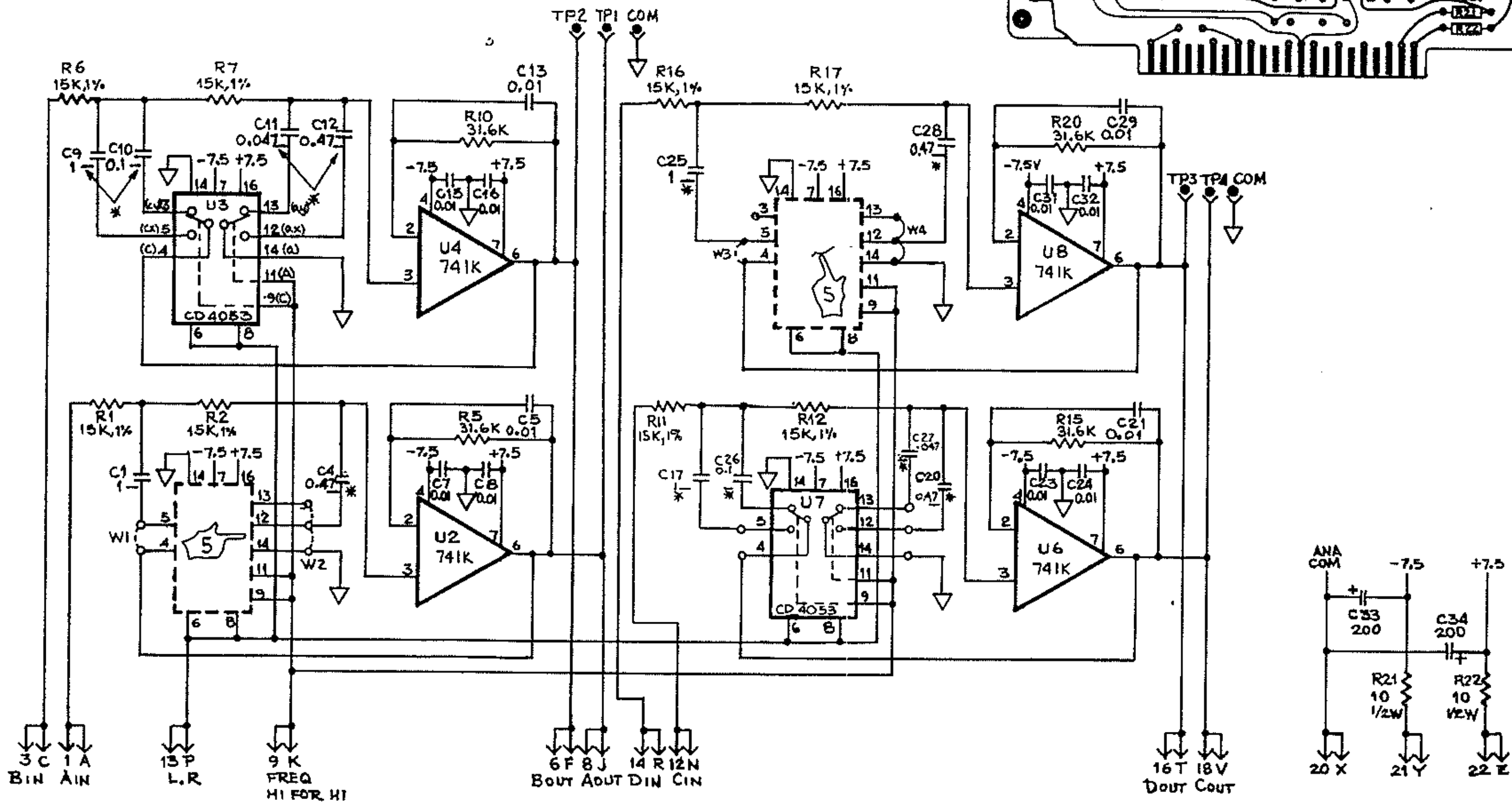
5.10 ACTIVE FILTER CIRCUIT ASSEMBLY (Part No. 41221) (Old)

CIRCUIT NO.	DESCRIPTION	ESI PART NO.
C1, C9, C17, C25	Capacitor, 1μF, 200V	313-18843
C4, C12, C20, C28	Capacitor, 0.47μF, 100V	313-13238
C5, C7, C8, C13, C15, C16, C21, C23, C24, C29, C31, C32	Capacitor, 0.01μF, 50V, Disc	311-12144
C10, C26	Capacitor, 0.1μF, 200V	313-12121
C11, C27	Capacitor, 0.047μF, 200V	313-12239
C33, C34	Capacitor, 200μF, 15V	314-15838
R1, R2, R6, R7, R11, R12, R16, R17	Resistor, 15kΩ, 1%	305-21198
R5, R10, R15, R20	Resistor, 31.6kΩ, 1%, 1/4W	305-21745
R21, R22	Resistor, 10Ω, 10%, 1/2W	304-02039
U2, U4, U6, U8	Op-Amp, 741K	353-21625
U3, U7	IC, CD4053	350-20744
W1-W4	Wire	
	Shield, PCB	710-41469
	IC Socket, 8 Pin	504-22410

ACTIVE FILTER CIRCUIT ASSEMBLY (Part No. 42978) (New)

CIRCUIT NO.	DESCRIPTION	ESI PART NO.
C1, C9, C17, C25	Capacitor, 1μF, 200V	313-18843
C4, C12, C20, C28	Capacitor, 0.47μF, 100V	313-13238
C5, C7, C8, C13, C15, C16, C21, C23, C24, C29, C31, C32, C35-38	Capacitor, 0.01μF, 50V, Disc	311-12144
C10, C26	Capacitor, 0.1μF, 200V	313-12121
C11, C27	Capacitor, 0.047μF, 200V	313-12239
C33, C34	Capacitor, 200μF, 15V	314-15838
R1, R2, R6, R7, R11, R12, R16, R17	Resistor, 15kΩ, 1%	305-21198
R5, R10, R15, R20	Resistor, 31.6kΩ, 1%, 1/4W	305-21745
R21, R22	Resistor, 10Ω, 10%, 1/2W	304-02039
R23	Resistor, 1kΩ, ESI, QB, 0.01%	240-27193
R24	Resistor, 9kΩ, ESI, QB, 0.01%	240-22032
R25	Trimpot, 20kΩ	306-21199
R26	Resistor, 10MΩ, 1/4W, 10%	307-13974
U2, U4, U6, U8	Op Amp, 741K	353-21625
U3, U7	IC, CD4053	305-20744
U9	Op Amp, LH0044CH	353-28187
W1-W4	Wire	
	Shield, PCB	710-41469
	Socket, 8 PIN	504-22410

Notes:
1. * ARE THE LINES OUTSIDE OF FOIL
2. ALL RESISTOR VALUES ARE IN OHMS
3. ALL RESISTORS ARE 1/4 W 10% UNLESS OTHERWISE STATED
4. ALL CAPACITORS ARE IN µF UNLESS OTHERWISE STATED
5. FUTURE OPTION



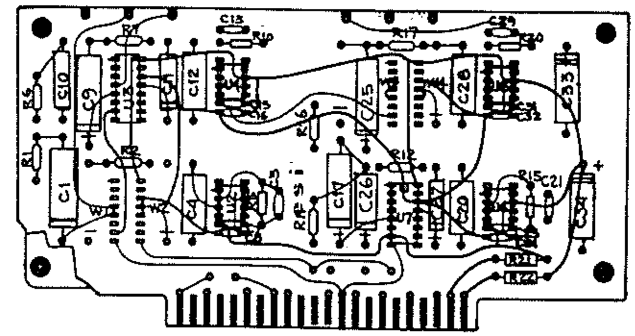
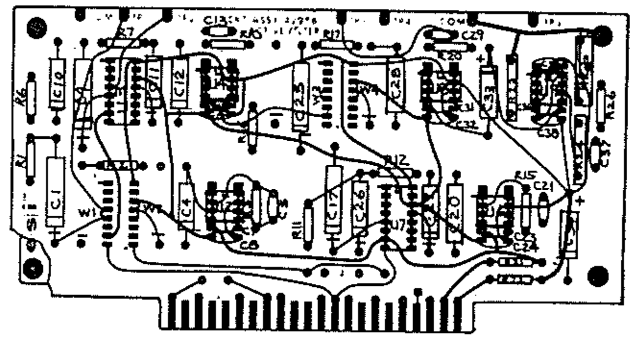


Figure 5-13. Part No. 41221 (Old)

NOTES:

1. * ARE THE LINES OUTSIDE OF FOIL
2. ALL RESISTOR VALUES ARE IN OHMS
3. ALL RESISTORS ARE 1/4 W 10% UNLESS OTHERWISE STATED
4. ALL CAPACITORS ARE IN μF UNLESS OTHERWISE STATED
5. ☞ FUTURE OPTION



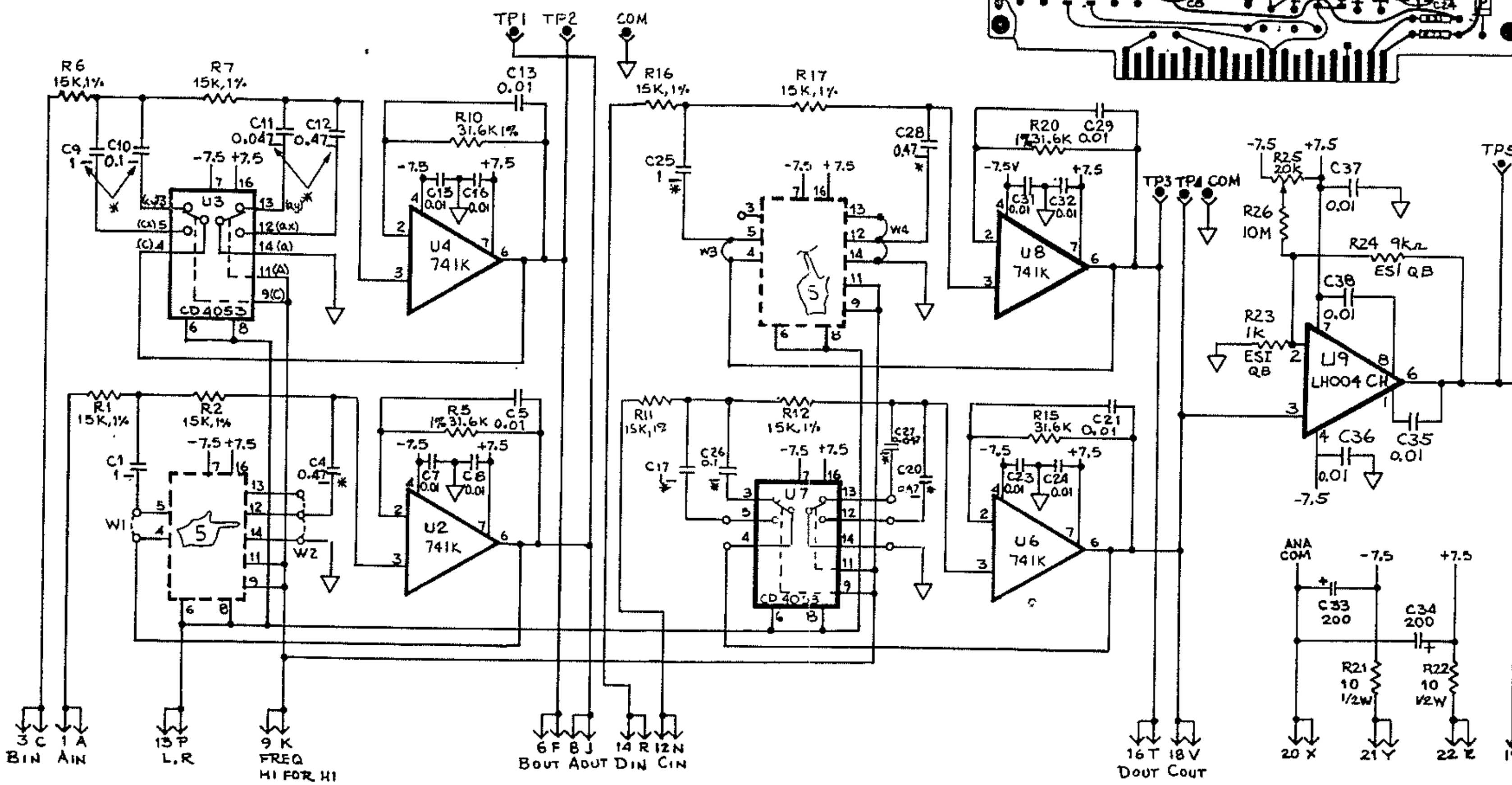


Figure 5-14. Part No. 42978 (New)

5.11 RANGE BOARD CIRCUIT ASSEMBLY (Part No. 41223)

CIRCUIT NO.	DESCRIPTION	ESI PART NO.
C3	Capacitor, 100pF, 500V	313-18760
C4	Capacitor, 0.001µF, 500V	313-07094
C5	Capacitor, 0.01µF, 100V	313-12260
C6	Capacitor, 0.1µF, 200V	313-12121
C7, C12	Capacitor, 39µF, 10V	314-06473
C8, C11	Capacitor, 0.01µF, 50V, Disc	311-12144
C9	Capacitor, 25pF, 1kV, Disc	311-01924
K1-K3	Relay, GB-822A-2	332-26667
K4-K6	Relay, GB-821A-4	332-27841
Q1-Q4	Transistor, 2N3704	321-12077
Q5	Transistor, 2N3702	321-12041
R1	Resistor, 100kΩ, 0.01%, ±5ppm/°C, ESI F, Bobbin	240-42547
R3	Resistor, 11.111Ω, 0.01%, ±5ppm/°C, ESI QB	240-41680
R4, R21, R29	Resistor, 1kΩ, 10%, 1/4W	307-13920
R5	Resistor, 1.0101kΩ, 0.01%, ±5ppm/°C, ESI QB	240-41679
R6, R22, R24, R28	Resistor, 100Ω, 10%, 1/4W	307-13907
R7	Resistor, 100.100Ω, 0.01%, ±5ppm/°C, ESI QB	240-41678
R8, R14	Resistor, 10Ω, 10%, 1/4W	307-13895
R9-R12	Resistor, 40Ω, 0.01%, ±5ppm/°C, ESI QB	240-41677
R13	Resistor, 1Ω, 10%, 1/2W	304-12448
R15-R20	Resistor, 68Ω, 10%, 1/4W	307-13902
R23, R25-R27, R30	Resistor, 2.2kΩ, 10%, 1/4W	307-13924
U1	Op-Amp 301	343-20669
U2	IC 4016	343-20711
	Shield, PCB	710-41469
	Socket, 14 Pin	504-19189

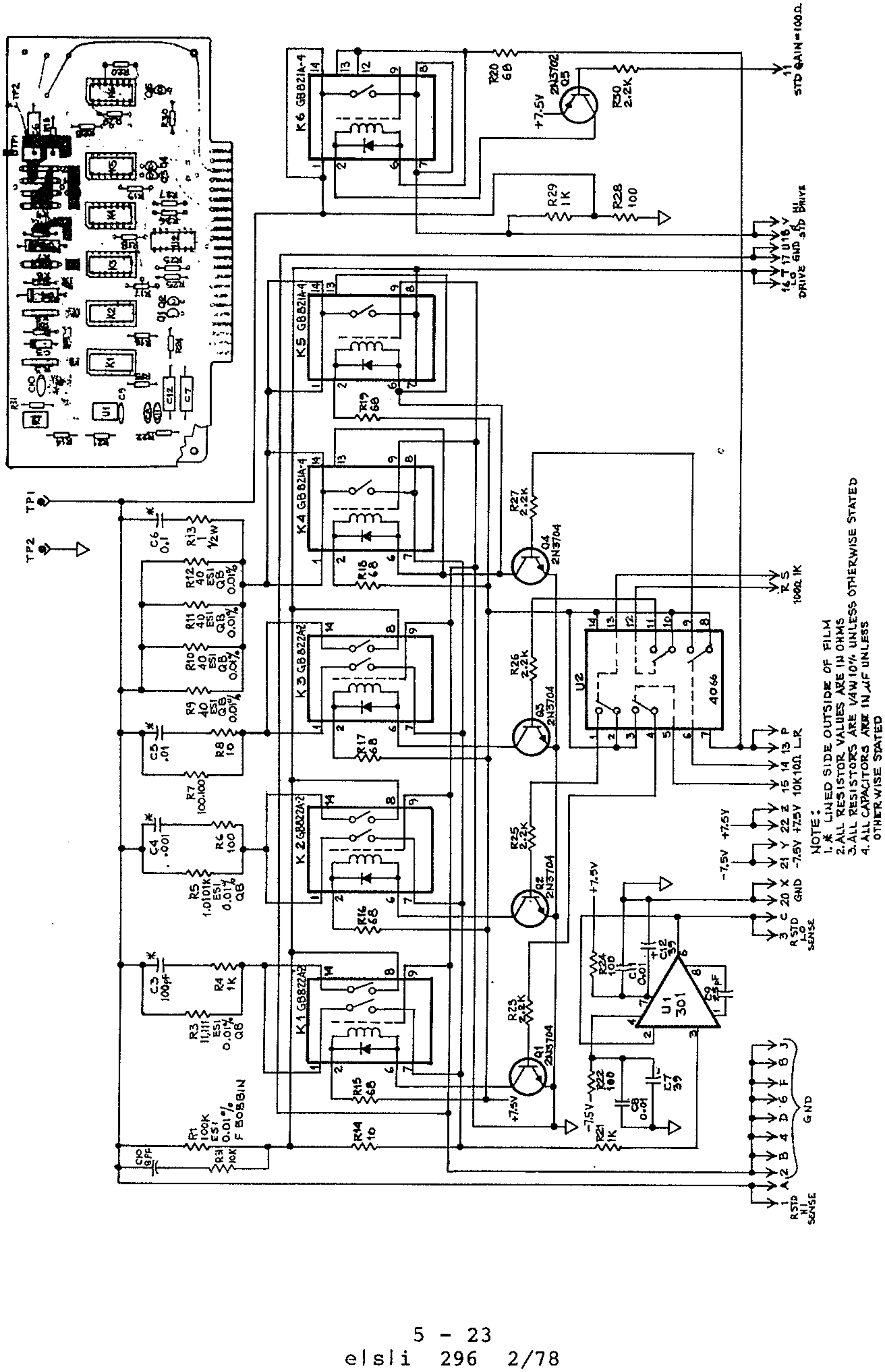
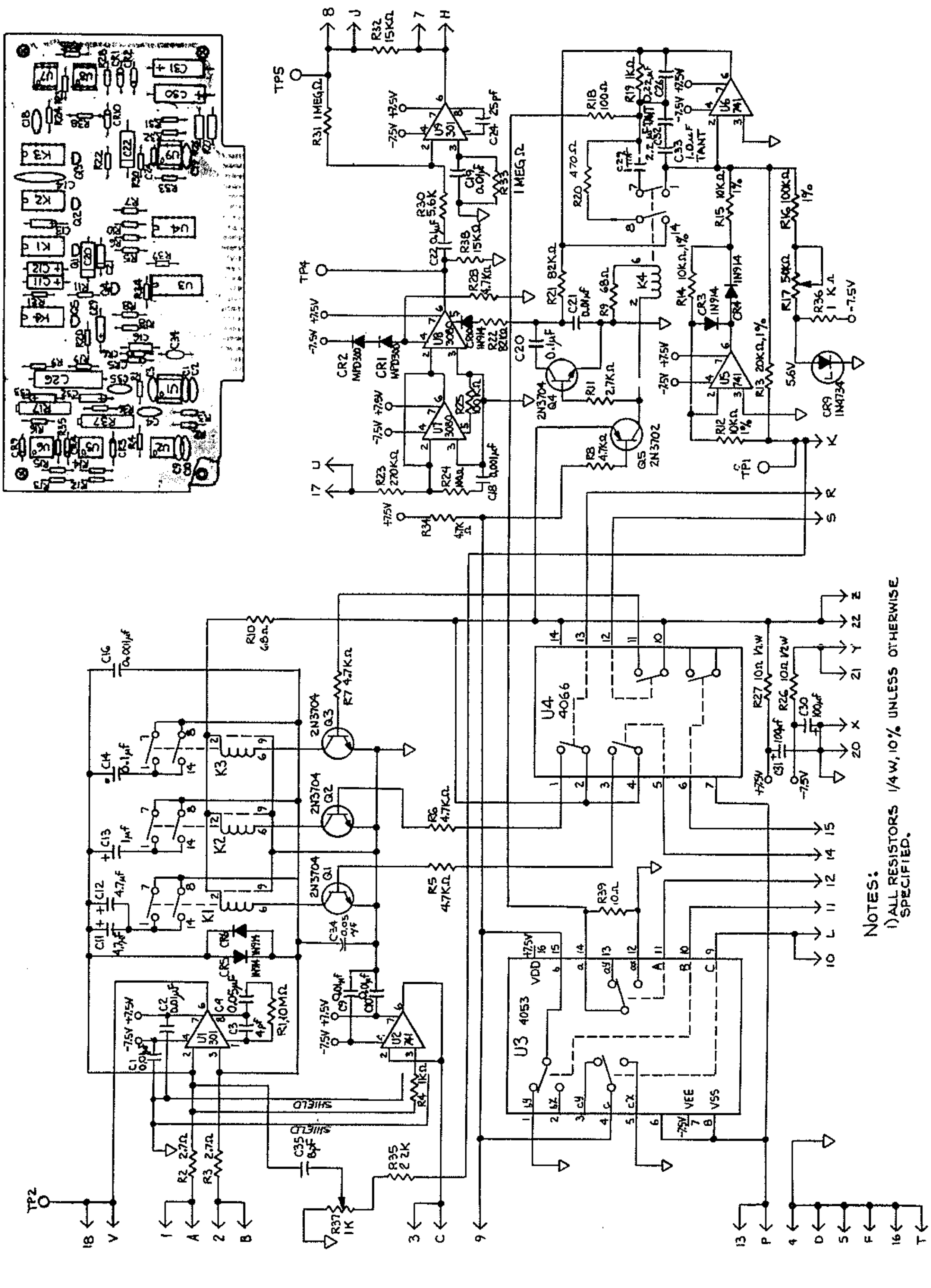


Figure 5-15. Part No. 41223

5.12 PREAMP AND LEVEL REGULATOR CIRCUIT ASSEMBLY (Part No. 41225)

CIRCUIT NO.	DESCRIPTION	ESI PART NO.
C1, C2, C9, C10, C19	Capacitor, 0.01μF, 50V, Disc	311-12144
C3	Capacitor, 4pF, 500V, Disc	311-02126
C4, C34	Capacitor, 0.05μF, 50V, Disc	311-12116
C11, C12,	Capacitor, 4.7μF, 50V	314-25965
C13, C29, C33	Capacitor, 1μF, 35V	314-06472
C14, C20, C22	Capacitor, 0.1μF, 200V	313-12121
C16, C18	Capacitor, 0.001μF, 1kV, Disc	311-21215
C21	Capacitor, 0.01μF, 100V	313-12260
C24	Capacitor, 25pF, 1kV, Disc	311-01924
C26	Capacitor, 0.22μF, 200V	313-12238
C30, C31	Capacitor, 100μF, 12V	314-06157
C32	Capacitor, 2.2μF, 20V, Tant	314-13283
C35	Capacitor, 8pF, Disc	311-02127
CR1, CR2	Diode, MPD300	321-13639
CR3-CR6, CR10	Diode, 1N914	321-12356
CR9	Diode, 1N4734	321-12258
K1-K4	Relay, GB822A-2	332-26667
Q1-Q4	Transistor, 2N3704	321-12077
Q5	Transistor, 2N3702	321-12041
R1	Resistor, 10MΩ, 10%, 1/4W	307-13974
R2, R3	Resistor, 2.7Ω, 10%, 1/4W	307-13887
R4, R19, R36	Resistor, 1kΩ, 10%, 1/4W	307-13920
R5-R8, R28, R34	Resistor, 4.7kΩ, 10%, 1/4W	307-13927
R9, R10	Resistor, 68Ω, 10%, 1/4W	307-13902
R11	Resistor, 2.7kΩ, 10%, 1/4W	307-13925
R12, R14, R15	Resistor, 10kΩ, 1%, 1/4W	305-21740
R13	Resistor, 20kΩ, 1%, 1/4W	305-21743
R16	Resistor, 100kΩ, 1%, 1/4W	305-21750
R17	Trimpot, 50kΩ	306-12091
R18, R24	Resistor, 100Ω, 10%, 1/4W	307-13907
R20	Resistor, 470Ω, 10%, 1/4W	307-13915
R21, R22	Resistor, 82kΩ, 10%, 1/4W	307-24812
R23	Resistor, 270kΩ, 10%, 1/4W	307-20432
R25	Resistor, 100kΩ, 10%, 1/4W	307-13945
R26, R27	Resistor, 10Ω, 10%, 1/2W	304-02039
R30	Resistor, 5.6kΩ, 10%, 1/4W	307-13928
R31, R33	Resistor, 1MΩ, 10%, 1/4W	307-13960
R32, R38	Resistor, 15kΩ, 10%, 1/4W	307-13935
R35	Resistor, 22kΩ, 10%, 1/4W	307-13937
R37	Trimpot, 1kΩ	306-18469
R39	Resistor, 10Ω, 10%, 1/4W	307-13895
U1, U9	Op-Amp, 301	343-20669
U2, U5, U6	Op-Amp, 741	343-20668
U3	IC, CD4053	350-20744
U4	IC, CD4066AE	343-41761
U7, U8	Op-Amp, CDA3080	352-20723
	Shield, PCB	710-41469



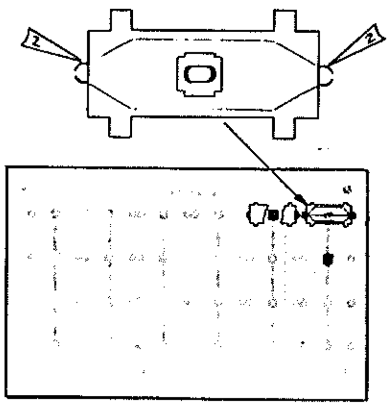
NOTES:
1) ALL RESISTORS 1/4W, 10% UNLESS OTHERWISE SPECIFIED.

Figure 5-16. Part No. 41225

5.13 KEYBOARD CIRCUIT ASSEMBLY (Part No. 41269)

CIRCUIT NO.	DESCRIPTION	ESI PART NO.
	Keyboard Switch	330-41656
	Switch Contact	330-41655

DETAIL -A-



NOTE:

1. INSTALL SWITCH CONTACT (ITEM 3) TO MOUNT FLUSH AGAINST PCB AND ALIGNED WITH SWITCH (ITEM 2), SEE DETAIL A.

2. INSTALL SWITCH (ITEM 2) USEING TOOL # 41269 (REWORKED MANUFACTURE SUPPLIED TOOL). IF HAND INSTALLATION IS NECESSARY; APPLY PRESSURE ON SWITCH MTG BARREL 2, DO NOT PRESS IN THE CENTER OF THE SWITCH.

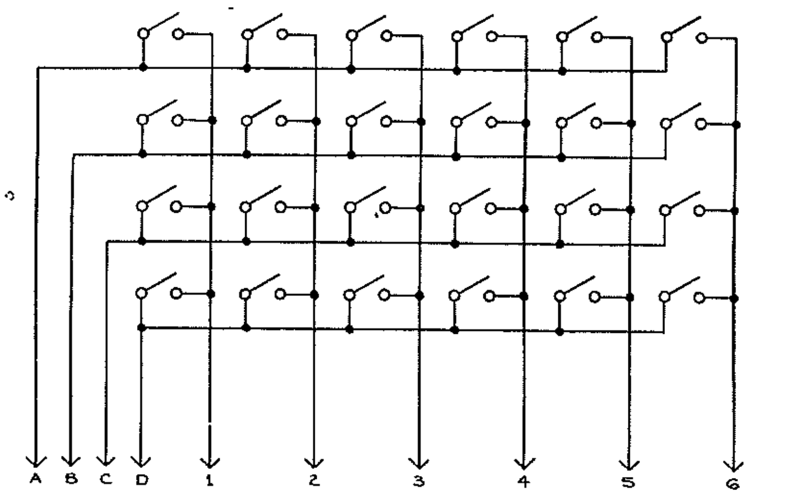


Figure 5-17. Part No. 41269

5.14 RH MOTHER BOARD CIRCUIT ASSEMBLY (Part No. 41279)

CIRCUIT NO.	DESCRIPTION	ESI PART NO.
	Connector, 44 Pin	504-27817

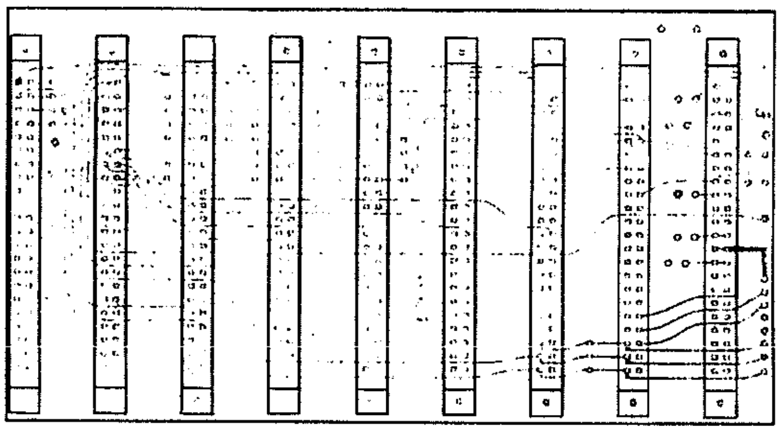


Figure 5-18. Part No. 41279

5.15 LH MOTHER BOARD CIRCUIT ASSEMBLY (Part No. 41284)

CIRCUIT NO.	DESCRIPTION	ESI PART NO.
A1	Assembly, R-L Network	343-29524
C1	Capacitor, 0.22µF, 100V, WMF	313-09950
C2	Capacitor, 0.47µF, 200V, MMW	313-12122
C5	Capacitor, 20pF, 600V, Poly	313-20926
CR1	Diode, 1N4005	321-01779
CR2-CR4	Voltage Clamp, 9VDC	321-42632
R1	Resistor, 22MΩ, 10%, 1/4W	307-13978
R2	Resistor, 100Ω, 10%, 1/4W	307-13907
	Connector, 44 Pin	504-27817

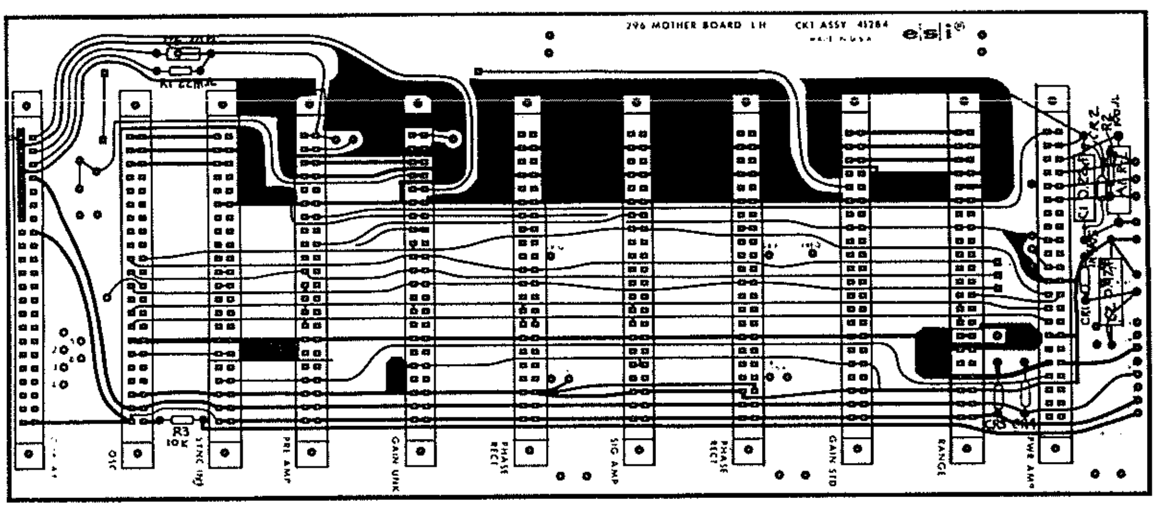
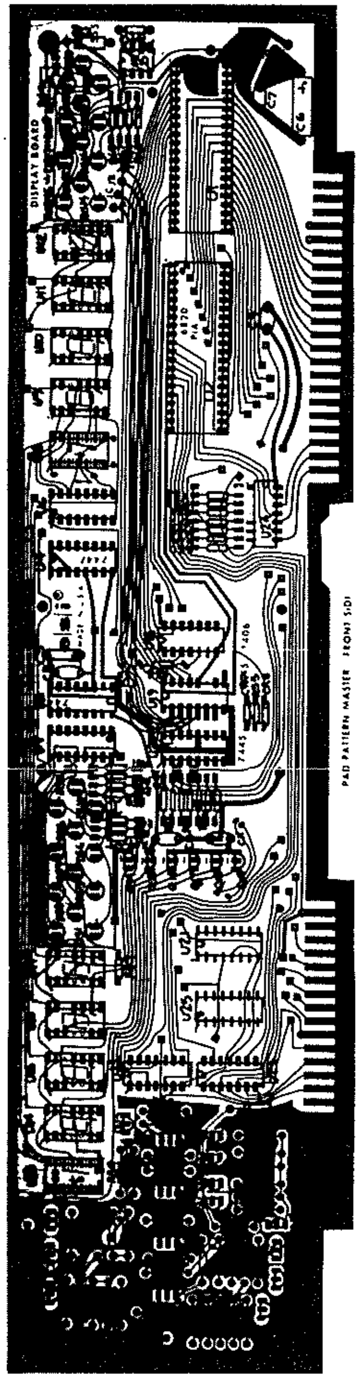


Figure 5-19. Part No. 41284

5.16 DISPLAY BOARD CIRCUIT ASSEMBLY (Part No. 41329)

CIRCUIT NO.	DESCRIPTION	ESI PART NO.
C2-C5	Capacitor, 39µF, 10V, Tant	314-06473
C6	Capacitor, 100µF, Electrolytic, 12V	314-06157
C7-C11	Capacitor, 0.01µF, Disc Ceramic, 50V	311-12144
C12	Capacitor, 0.01µF, 100V, WMF	313-18817
CR1, CR2, CR5-CR8	Diode, 1N914A	321-12356
DS1-DS24	LED, PC Mount	336-41377
Q1-Q3, Q5, Q7-Q9, Q11	Transistor, 2N3904	321-18751
Q4, Q10, Q12-Q18	Transistor, 2N3906	321-18754
R1, R4, R15, R18, R46-R55	Resistor, 2.2kΩ, 5%, 1/4W	307-13924
R2, R5, R41-R45	Resistor, 220Ω, 5%, 1/4W	307-13911
R3, R6, R17, R20	Trimpot, 10kΩ, 20 Turn	306-41902
R7, R8, R21, R22	Resistor, 2kΩ, 1%, 1/4W	305-21733
R10, R11, R24, R25, R56-R69	Resistor, 10Ω, 10%, 1/4W	307-13895
R12, R26	Resistor, 6.8kΩ, 10%, 1/4W	307-13930
R13, R27	Resistor, 15kΩ, 10%, 1/4W	307-13935
R14, R28-R30	Resistor, 680Ω, 10%, 1/4W	307-13917
R16, R19, R31, R32	Resistor, 150Ω, 10%, 1/4W	307-13909
R33, R34	Resistor, 806Ω, 1%, 1/4W	305-21729
R40	Resistor, 316kΩ, 1%, 1/4W	305-21755
R71, R72	Resistor, 2.49kΩ, 1%, 1/4W	305-21734
U1, U2	IC, 6820, PIA, AMI, 40 Pin	350-41292
U3	IC, 555, Timer	351-20721
U4, U5	IC, 7447, BCD to Seven Segment Decoder	351-20691
U6, U7	Resistor, DIP Pack, 8 ea, 100Ω	327-20714
U8, U13	Display, ±1, Monsanto 4630	327-41349
U9-U12, U14-U17	Display, Seven Seg., Monsanto 4610	327-41350
U18	IC, 7406, Hex Inverter, Open Coll	343-20678
U19, U20	IC, 7445, BCD to Decimal Decoder	343-20609
U21	IC, 74148, Priority Encoder	350-41347
U22-U24	IC, 7407	350-24076
U25	Resistor, DIP Pack, 15 ea, 3.3kΩ	327-22947
	Socket, 14 Pin DIP, PC Mount	504-19189
	Socket, 40 Pin DIP, PC Mount	504-41342
	LED Alignment Block, Lefthand	422-42398
	LED Alignment Block, Righthand	422-42397
	Shield, PC Board	710-41467



P2

P1

Figure 5-20. Part No. 41329

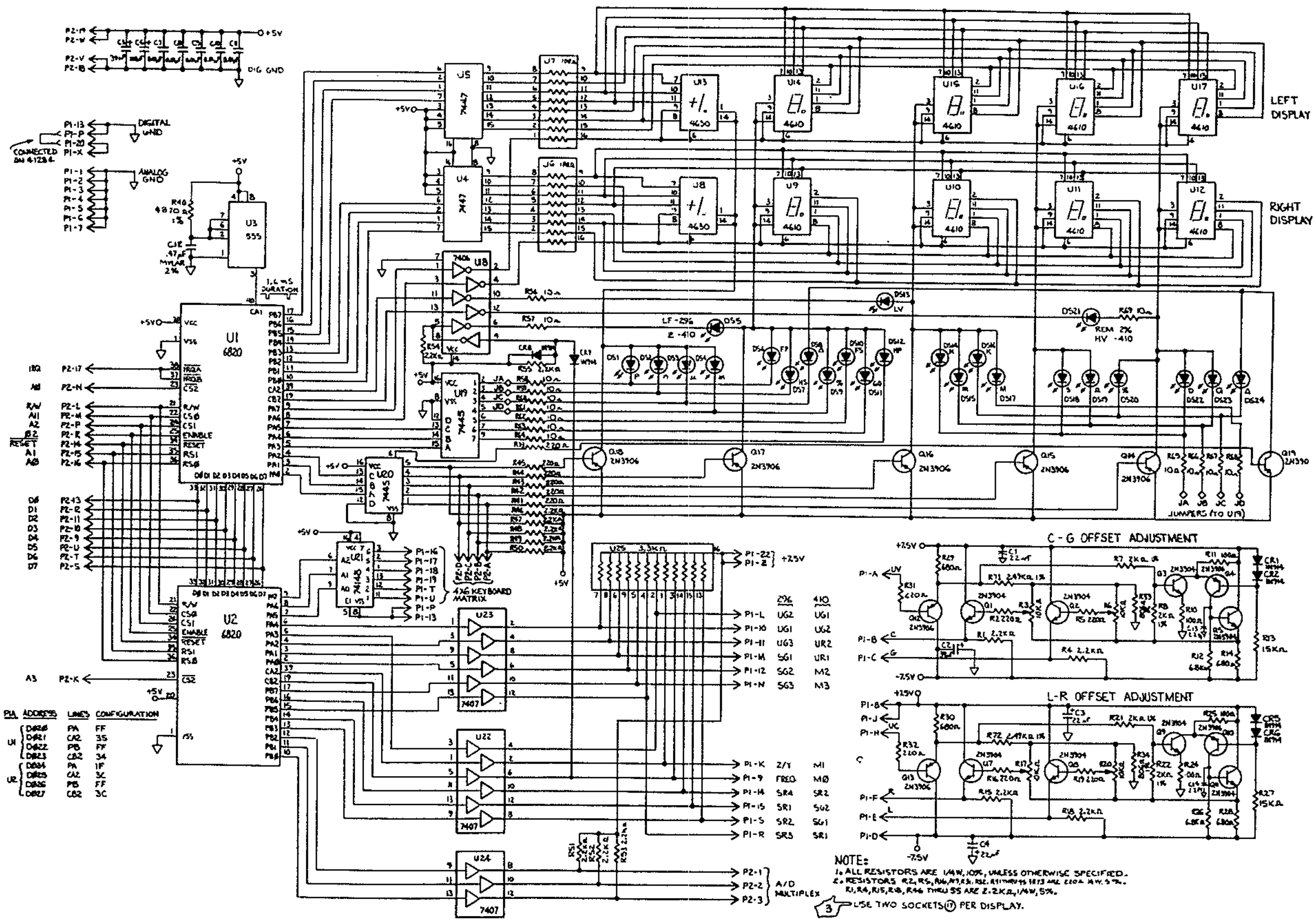


Figure 5-21. Part No. 41329

5.17 CPU BOARD CIRCUIT ASSEMBLY (Part No. 41491)

CIRCUIT NO.	DESCRIPTION	ESI PART NO.
C1, C2	Capacitor, 0.1μF, 200V, Mylar	313-12121
C3, C4	Capacitor, 200pF, 600V, Poly	313-24354
C5	Capacitor, 0.47μF, 50V	313-13653
C6-C8, C10	Capacitor, 0.01μF, 50V, Ceramic	311-12144
C9	Capacitor, 100μF, Electrolytic, 12V	314-06157
R1	Resistor, 3.3kΩ, 10%, 1/4W	307-13926
R2, R3	Resistor, 1MΩ, 10%, 1/4W	307-13960
R4-R6	Resistor, 1.2kΩ, 10%, 1/4W	307-13921
R7, R8	Resistor, 12.4kΩ, 1%, 1/4W, Metal Film	305-21741
R9	Resistor, 4.7kΩ, 10%, 1/4W	307-13927
R10	Resistor, 3.9kΩ, 10%, 1/4W	307-13929
U1-U4	IC, 2708, Electrically Reprogrammable ROM	355-41512
U5	IC, 6800, Microprocessor	350-41290
U6, U7	IC, 6810, RAM	350-41291
U8	IC, 8602	350-41514
U10	IC, 7400	343-20600
U11	IC, 555, Timer	351-20721
U12	IC, MC3459, HI Cap Driver	350-41513
U13, U19	IC, 7442, Decoder	343-20608
U14-U17	IC, 8T97, Hex Bus Buffer	350-41515
	Socket, 24 Pin DIP, Solder Tail	504-41492
	Socket, 40 Pin DIP, Solder Tail	504-41342

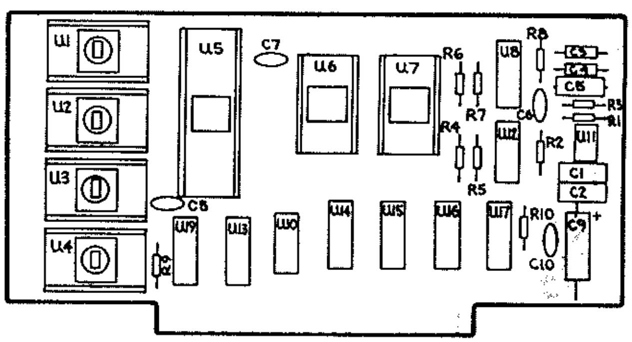


Figure 5-22. Part No. 41491

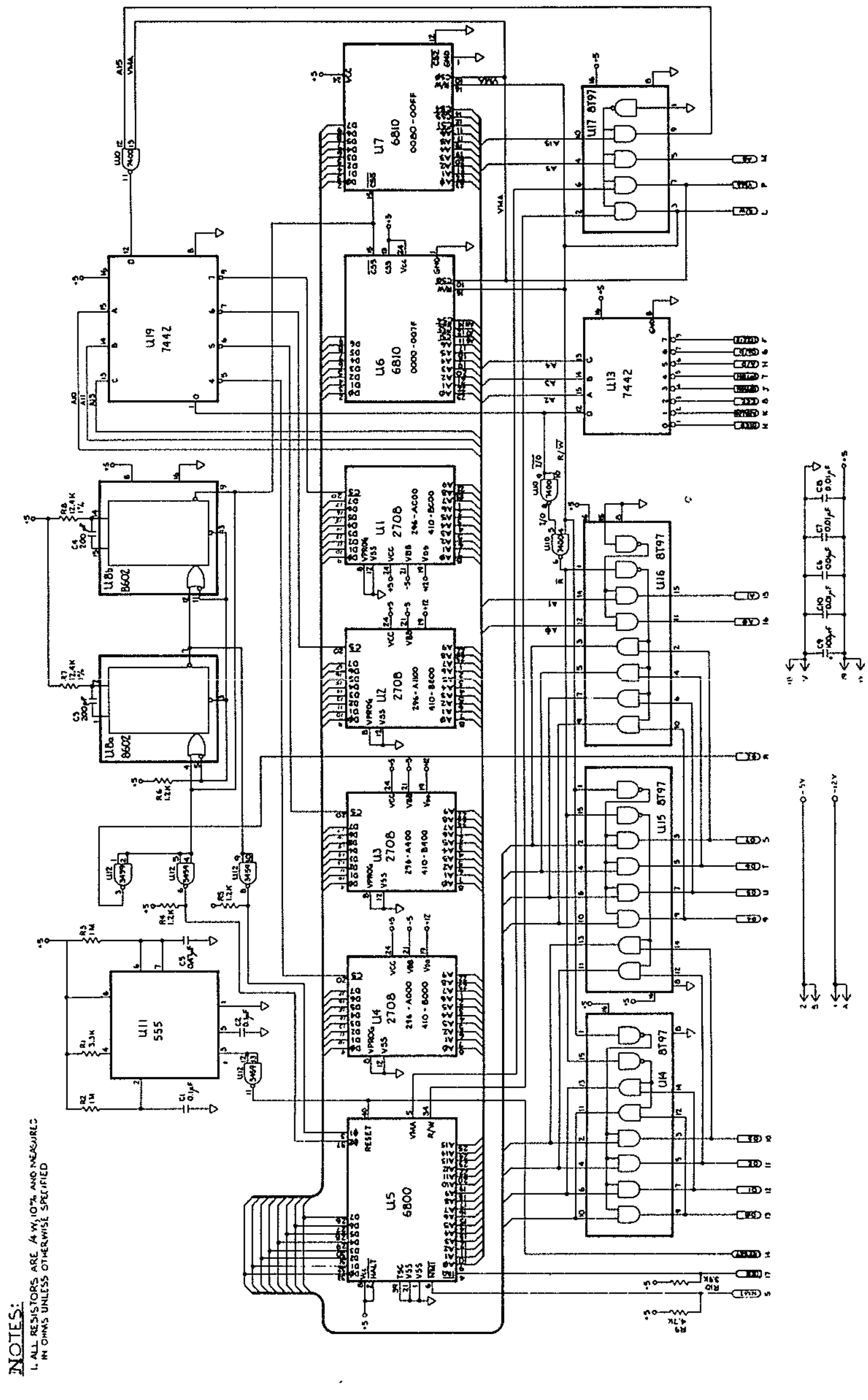
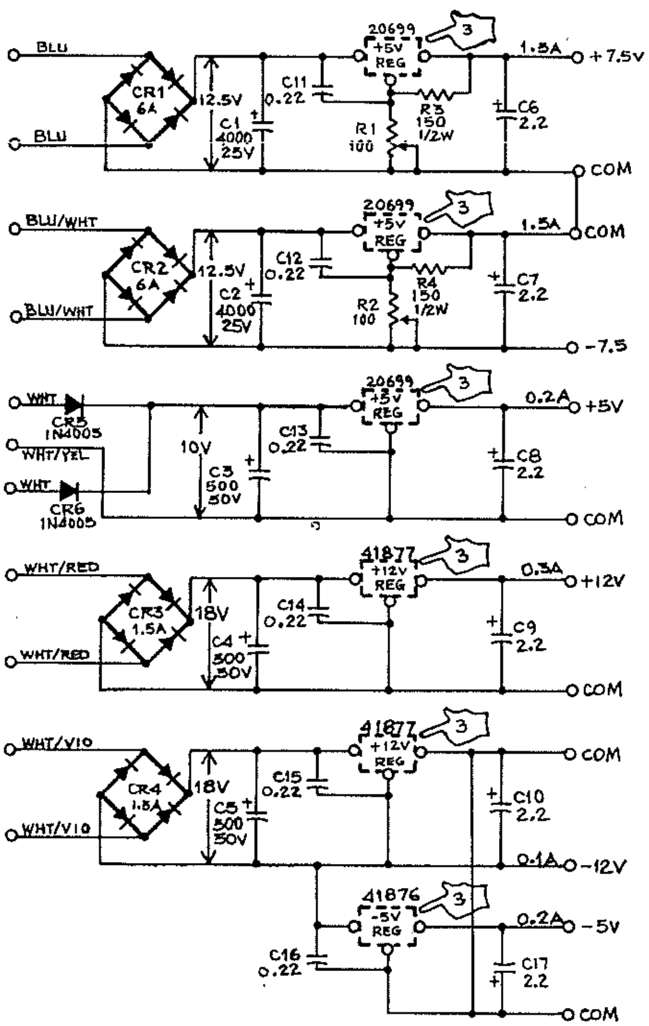


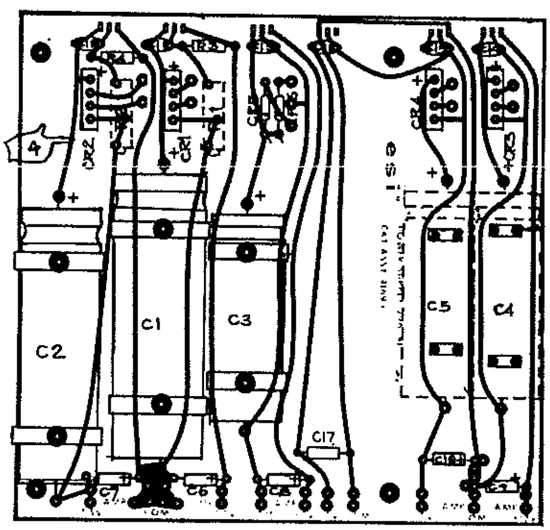
Figure 5-23. Part No. 41491

5.18 POWER SUPPLY CIRCUIT ASSEMBLY (Part No. 41693)

CIRCUIT NO.	DESCRIPTION	ESI PART NO.
C1, C2	Capacitor, 4000μF, 25V	314-26082
C3-C5	Capacitor, 500μF, 50V	314-01942
C6-C10, C17	Capacitor, 2.2μF, 20V, Tant	314-13283
C11-C16	Capacitor, 0.22μF, Disc	311-13680
CR1, CR2	Rectifier, Bridge, 6A, FLWD 200	327-27824
CR3, CR4	Rectifier, Bridge, 1.5A	321-21236
CR5, CR6	Diode, 1N4005	321-01779
R1, R2	Trimpot, 100Ω	
U22-U24	IC, MC3446, Quad Interface Bus Tran	352-42704
U26	IC, 7407, TTL Open Coll Hex Inverter	350-24076

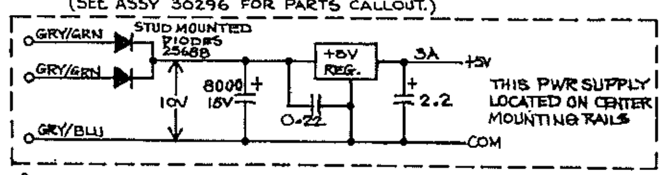
ALL VOLTAGES AT NOMINAL LINE AND FULL LOAD





NOTE;

1. ALL RESISTOR VALUES ARE IN OHMS
2. ALL CAPACITORS ARE IN μF UNLESS OTHERWISE STATED
3. POWER SUPPLY COMPONENTS & SECTIONS NOTED BELOW ARE NOT LOCATED ON ASSY 41693 & ARE SHOWN FOR REF. ONLY (SEE ASSY 30296 FOR PARTS CALLOUT.)

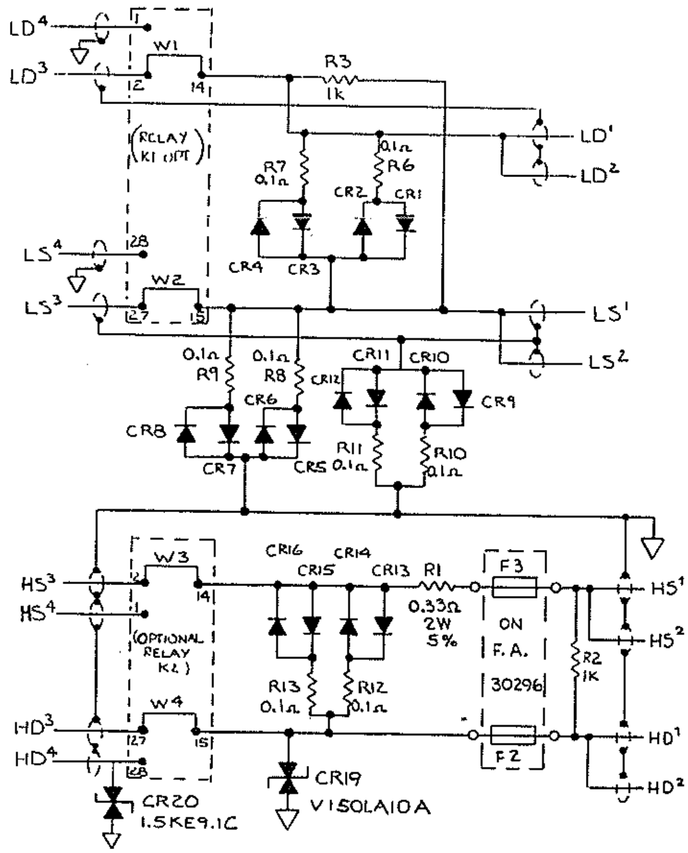


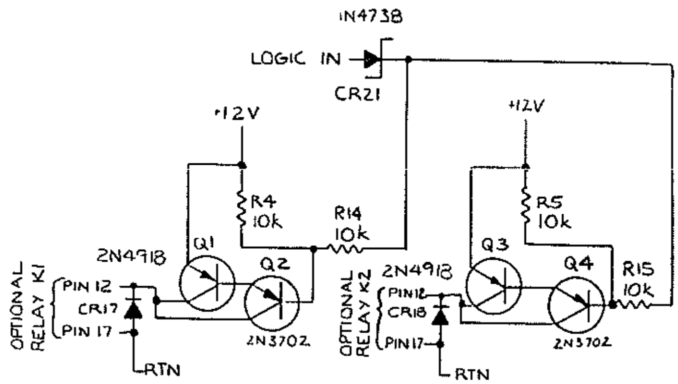
4. C4 AND C5 MOUNTED ON BACK SIDE OF BOARD. R1 AND R2

Figure 5-24. Part No. 41693

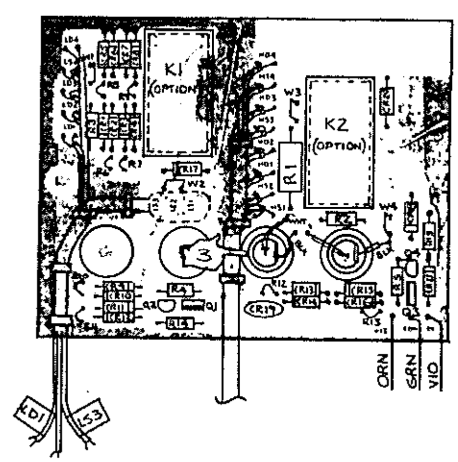
5.19 PROTECTION BOARD CIRCUIT ASSEMBLY (Part No. 42675)

CIRCUIT NO.	DESCRIPTION	ESI PART NO.
CR1-CR18	Diode, 1N4005	321-01779
CR19	Surge Protector	321-42633
CR20	Surge Protector, 8V	321-42632
CR21	Zener Diode, 1N4738, 8.2V	321-12160
Q1, Q3	Transistor, 2N4918	321-18753
Q2, Q4	Transistor, 2N3702	321-12041
R1	Resistor, 0.33Ω, 5%, 2W	303-13711
R2, R3	Resistor, 1kΩ, 10%, 1/4W	307-13920
R4, R5, R14, R15	Resistor, 10kΩ, 10%, 1/4W	307-13933
R6-R13	Resistor, 0.1Ω, Manganin	602-05937
W1-W4	Wire	
	Sockets, Special Modified, 28 Pin	504-26859





DRIVER CKTS FOR OPTIONAL RELAYS



NOTES:

1. ALL DIODES, EXCEPT CR19,20,21 ARE IN4005
2. R6-13 ARE MANGANIN RESISTOR STOCK
3. R2,3,4,5,14 & 15 ARE 1/4 W, ±10%

Figure 5-25. Part No. 42675

5.20 OPTIONS CIRCUIT ASSEMBLIES

5.20.1 IEEE Interface Option Circuit Assembly (Part No. 42132)

CIRCUIT NO.	DESCRIPTION	ESI PART NO.
C1, C2	Capacitor, 100µF, 25V	314-13683
Q1-Q12	Transistor, 2N3904	321-18751
R1-R5	Resistor, 6.8kΩ, 1/4W Carbon	307-13930
R6-R8	Resistor, 4.7kΩ, 1/4W, 10%	307-13927
S1, S2	Switch, SPST, DIP, Rocker	330-41519
U1, U2	IC, 6820, PIA	350-41292
U3-U16	IC, MCT6, Optoisolator	325-24008
U17, U25	Resistor, 1kΩ, DIP	327-20700
U18	Resistor, 3.3kΩ, DIP	327-22947
U19	Resistor, 470Ω, DIP	327-20795
U21	Resistor Network, 470Ω and 3.3kΩ	505-43000
U22-U24	IC, MC3446, Quad Interface Bus Tran	352-42704
U26	IC, 7407, TTL Open Coll Hex Inverter	350-24076
W1-W5	Wire	
	Shield, PCB	710-41469
	Socket, 8 Pin DIP	504-22410
	Socket, 40 Pin DIP	504-41342

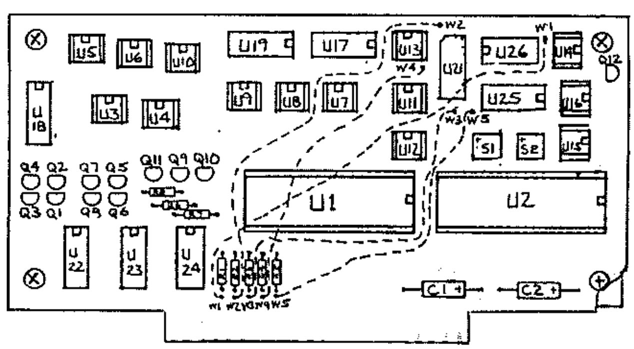


Figure 5-26. Part No. 42132

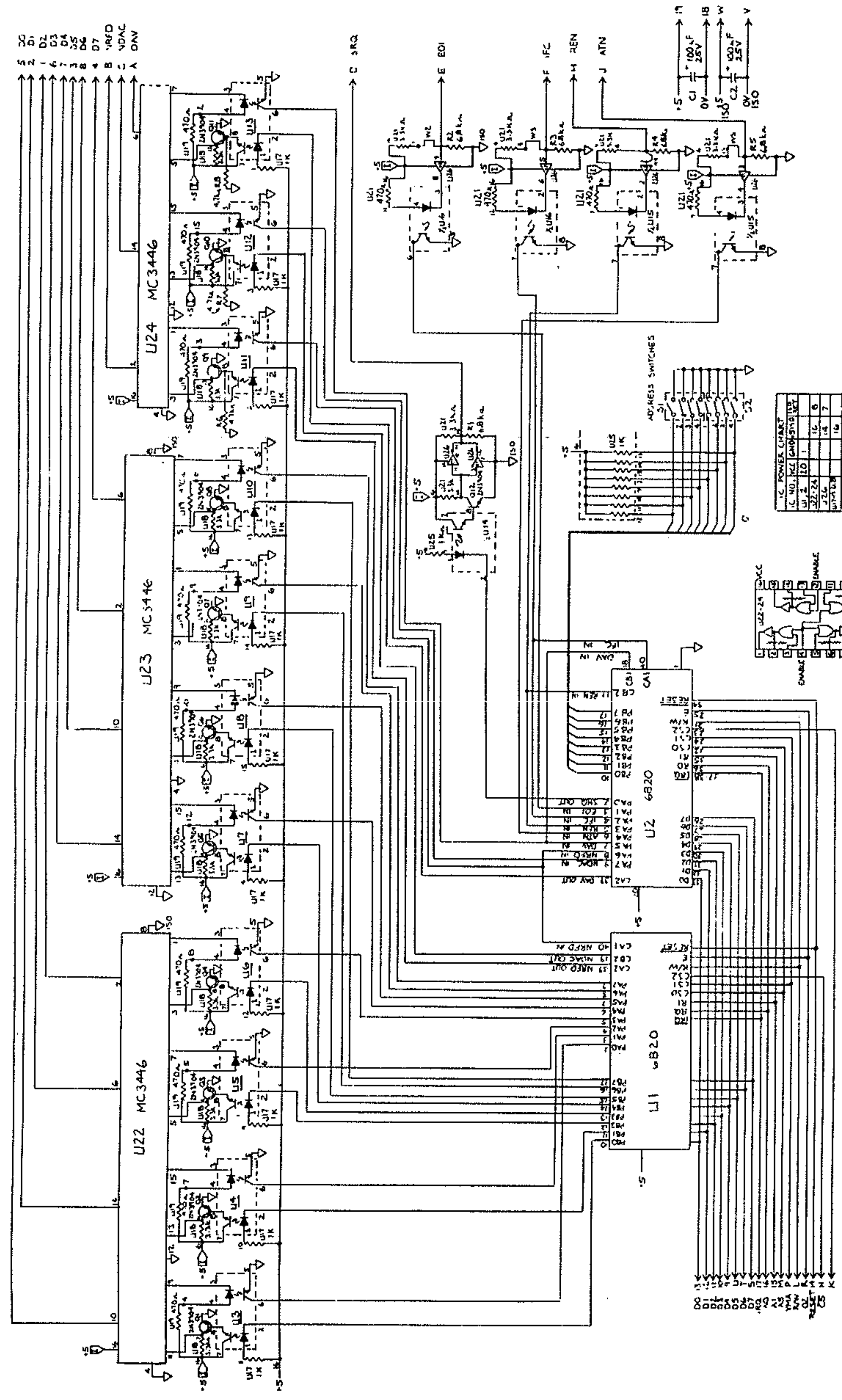


Figure 5-27. Part No. 42132

5.20.2 Handler Interface Option Circuit Assembly (Part No. 42073)

CIRCUIT NO.	DESCRIPTION	ESI PART NO.
C-1	Capacitor, 100µF, Electrolytic, 16V	314-13683
C2, C3	Capacitor, 0.01µF, Disc Ceramic	311-12144
K1-K10	Relay, GB821A	332-27841
U11	Resistor, 3.3kΩ, DIP	327-22947
U12, U13	IC, 7406, Hex Inverter	343-20678
U14	IC, 6820, PIA	350-41292
	Socket, 14 Pin DIP	504-19189
	Socket, 40 Pin DIP	504-41342

BACK PANEL WIRING 36 PIN CONN [1]

CARD EDGE CONNECTOR	36 PIN CONNECTOR PIN No.	FUNCTION
7	1	COM
J	2	BAND 0
H	3	BAND 1
F	4	BAND 2
E	5	BAND 3
D	6	BAND 4
C	7	BAND 5
B	8	BAND 6
A	9	BAND 7
6	10	BAND 8
5	11	BAND 10
	12	+5V(SYSTEM)OUT
	13	SYSTEM GND
8	14	INTERRUPT IN

[1] SEE MANUAL FOR DESCRIPTION OF THESE FUNCTIONS.

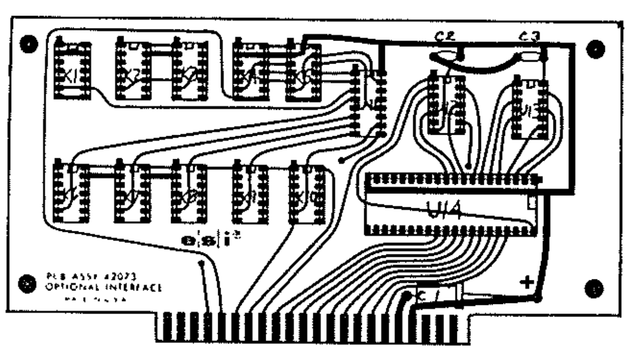


Figure 5-28. Part No. 42073

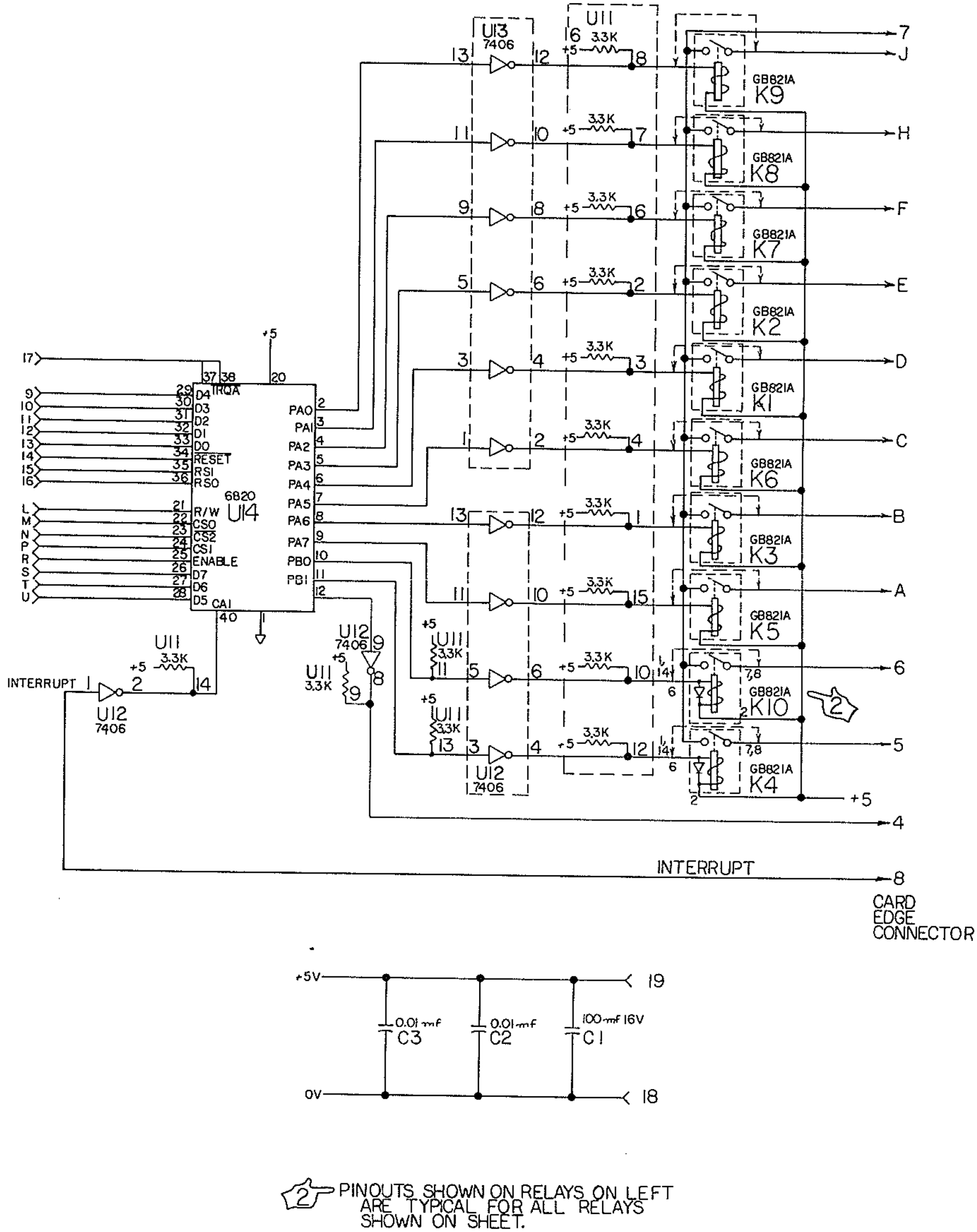


Figure 5-29. Part No. 42073

5.20.3 Card Reader Interface Circuit Assembly (Part No. 43399)

CIRCUIT NO.	DESCRIPTION	ESI PART NO.
C1	Capacitor, 6.8µF, Tant, 35V	314-25339
R1-R3	Resistor, 3.3kΩ, 10%, 1/4W	307-13926
U1	IC, 6820, PIA	350-41292
U2, U4	IC, 7423	
U3	IC, 7400	350-20600
U5	IC, 7402	350-20604
	Socket, 40 Pin DIP	504-41342

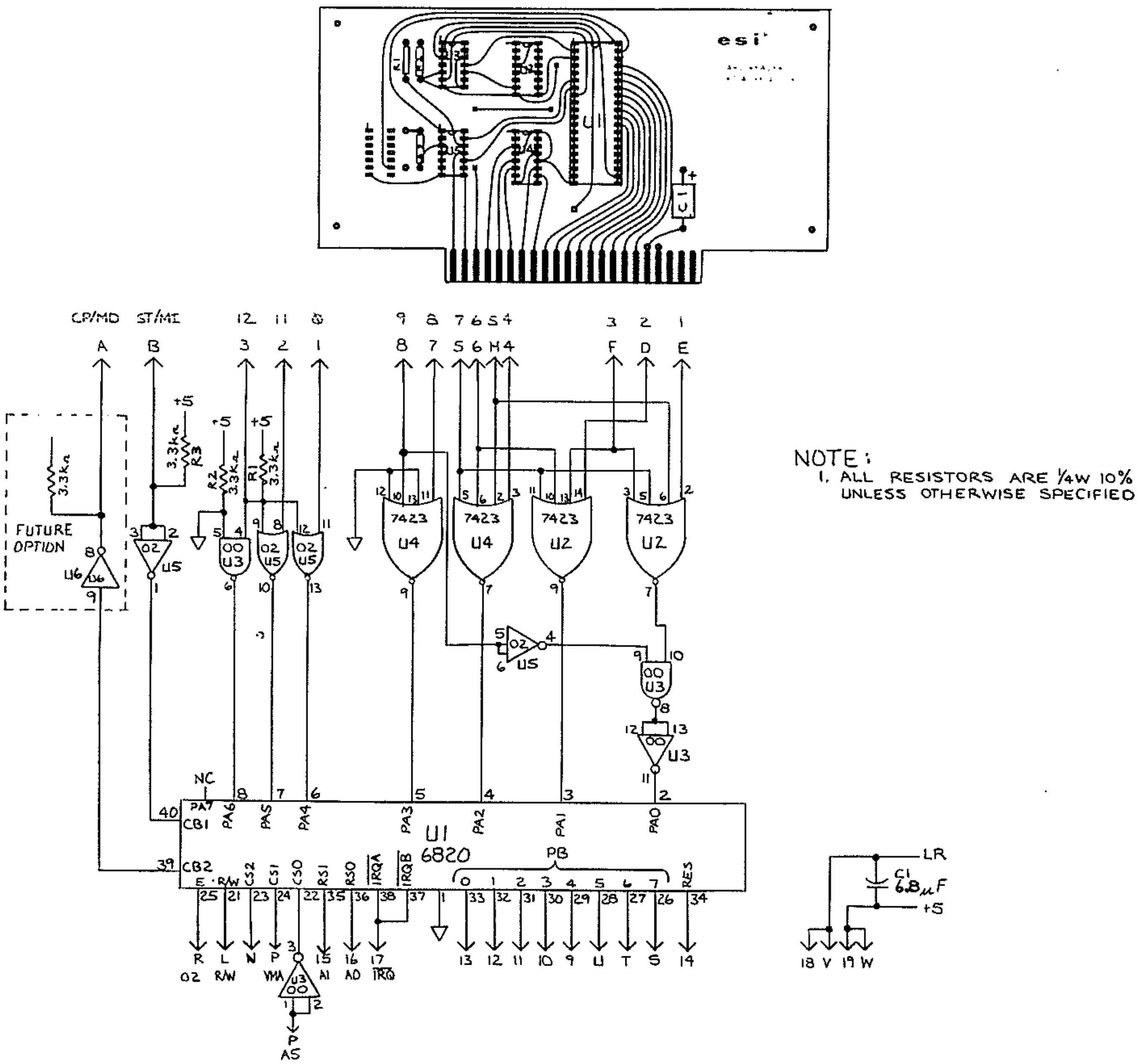


Figure 5-30. Part No. 43399

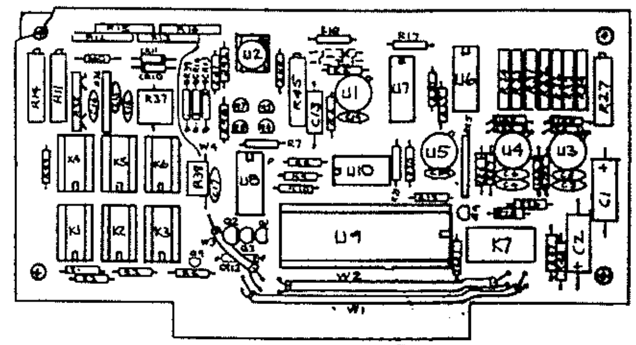
5.20.4 DC Resistance Circuit Assembly (Part No. 42596)

CIRCUIT NO.	DESCRIPTION	ESI PART NO.
C1, C2	Capacitor, 39μF, Tant, 10V	314-06473
C3, C12, C16, C17, C19, C20	Capacitor, 0.01μF, Disc, 50V	311-12144
C13	Capacitor, 0.22μF, Mylar	313-09950
C14	Capacitor, 0.47μF, Poly, 100V	313-06471
C15	Capacitor, 0.05μF, Disc, 50V	311-12116
CR1	Diode, 1N4005	321-01779
CR2-CR14	Diode, 1N914A	321-12356
K1-K3	Relay, DIP, 1 Form A	332-27841
K4-K6	Relay, DIP, 2 Form A	332-26667
K7	Relay, Thermosen, DM2C	332-41517
Q1-Q4, Q9	Transistor, 2N3704	321-12077
Q5, Q7	Transistor, 2N3904	321-18751
Q6, Q8	Transistor, 2N3906	321-18754
R1, R49	Resistor, 100Ω, 10%, 1/4W, CC	307-13907
R2, R8, R19, R40	Resistor, 1kΩ, 10%, 1/4W, CC	307-13920
R3, R9, R10, R20, R21,R26,R28-30	Resistor, 10kΩ, 10%, 1/4W, CC	307-13933
R4, R44	Resistor, 100kΩ, 10%, 1/4W, CC	307-13945
R5, R17, R18	Resistor, 5.6kΩ, 10%, 1/4W, CC	307-13928
R6	Resistor, 4.7kΩ, 10%, 1/4W, CC	307-13927
R7, R46	Resistor, 220Ω, 10%, 1/4W, CC	307-13911
R11, R14	Trimpot, 200Ω	306-12083
R12, R15	Resistor, 9.9kΩ, ESI QB, ±0.01%	240-43292
R16	Resistor, 1kΩ, ESI QB, ±0.01%	240-43293
R22, R31	Resistor, 588.24Ω, ESI QB, ±0.01%	240-43285
R23, R32	Resistor, 4.4118kΩ, ESI QB, ±0.01%	240-43288
R24, R33	Resistor, 15kΩ, ESI QB, ±0.01%	240-43295
R25, R34, R13	Resistor, 10kΩ, ESI QB, ±0.01%	240-43294
R27	Trimpot, 20kΩ	306-21199
R35	Resistor, 10Ω, ESI QB, ±0.01%, 4T	240-43284
R36	Resistor, 1.0010kΩ, ESI QB, ±0.01%	240-43287
R37	Resistor, 111.111kΩ, F Bobbin, ±0.01%	240-43291
R38	Resistor, 1MΩ, F Bobbin, ±0.01%	240-73103
R39, R42	Resistor, 470Ω, 10%, 1/4W, CC	307-13915
R41	Resistor, 22MΩ, 10%, 1/4W, CC	307-13978
R43	Resistor, Select	
R45	Trimpot, 50kΩ	306-12091
R47, R48	Resistor, 10Ω, 10%, 1/2W, CC	304-02039
U1, U5	Op Amp, LH0044	353-28187
U2	Op Amp, 356A	352-42816
U3, U4	Op Amp, 356	352-41473
U6-U8	CMOS Switch, CD4052	350-20743
U9	PIA, 6820	350-41292
U10	Hex Inverter, 7406	343-20678
W1-W3	Coaxial Wire	
W4	Wire	
	Socket, 14 Pin	504-19189
	Socket, 40 Pin	504-41342
	Socket, 8 Pin DIP	504-22410

I C	VCC	GND
LH0044	7	4
356	7 (+7.5)	4 (-7.5)
356A	7 (+12)	4 (-12)

NOTE:

1. C3-C6 ARE BYPASS CAPACITORS ON U1→U5
2. ALL CAPACITOR VALUES ARE MFD.
3. ALL DIODES ARE IN914A EXCEPT AS NOTED.
4. ALL RELAYS SHOWN IN DE-ENERGIZED POSITION
5. RELAYS ARE ACTUATED AS FOLLOWS: K1 & K4 ACTUATED BY Q1, K2 & K5 ACTUATED BY Q2, K3 & K6 ACTUATED BY Q3
6. ALL RESISTORS ARE IN OHMS & 1/4 W 10% UNLESS OTHERWISE SPECIFIED.



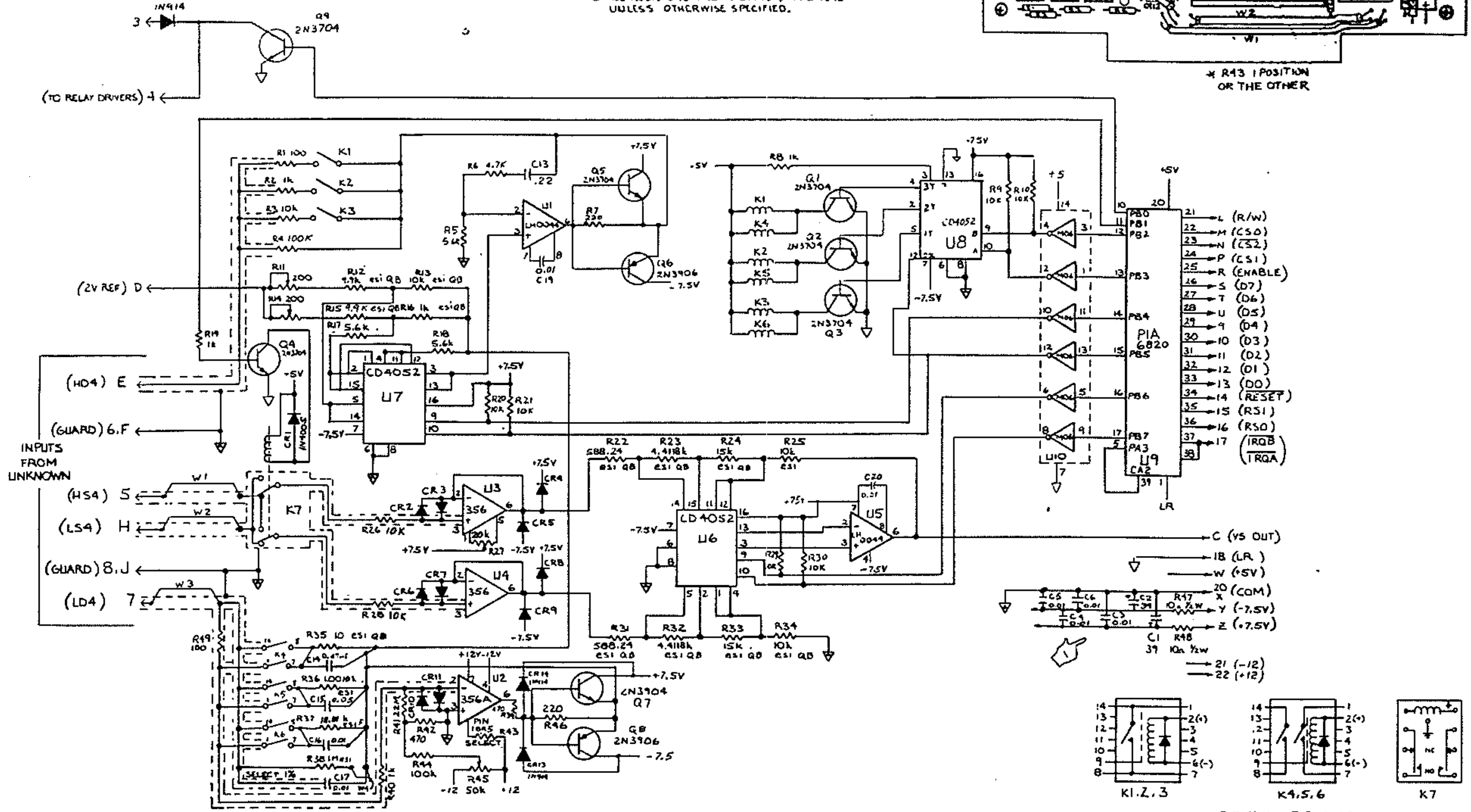


Figure 5-31. Part No. 42596

5.20.5 Teletype Interface Circuit Assembly (Part No. 42763)

CIRCUIT NO.	DESCRIPTION	ESI PART NO.
C1	Capacitor, 0.1μF, Disc, 100V	311-24395
C3	Capacitor, 8pF, Disc Ceramic	311-02127
C4	Capacitor, 100μF, 25V, Electrolytic	314-13683
CR1-7	Diode, 1N4005	321-01779
Q1, Q2	Transistor, 2N3904	321-18751
R1, R2, R5, R6, R10, R11	Resistor, 1kΩ, 1/4W, 10%	307-13920
R3, R9, R14, R18	Resistor, 2.2kΩ, 1/4W, 10%	307-13924
R4	Resistor, 1.5kΩ, 1/4W, 10%	307-13922
R7	Resistor, 120Ω, 1/4W, 10%	307-13908
R8	Resistor, 6.8kΩ, 1/4W, 10%	307-13930
R12	Resistor, 100Ω, 1/4W, 10%	307-13907
R13	Resistor, 10kΩ, 1/4W, 10%	307-13933
R15	Resistor, 4.7kΩ, 1/4W, 10%	307-13927
R16	Resistor, 3.9kΩ, 1/4W, 10%	307-13929
R17	Resistor, 15MΩ, 1/4W, 10%	307-13976
U1	IC, 7406, TTL	343-20678
U2	IC, 7404, TTL	343-20695
U3	IC, 7400, TTL	343-20600
U4	4411, Baud Rate Gen	350-42933
U5	6850, ACIA	350-42968
U6	Op Amp, 301	343-20669
Y1	Crystal, 1.8432MHz, 0.05%	327-43268
	Socket, 24 Pin	504-41492
	Socket, Crystal, HC6-U Size	504-24444
	Socket, 8 Pin	504-22410
	Socket, 14 Pin	504-19189

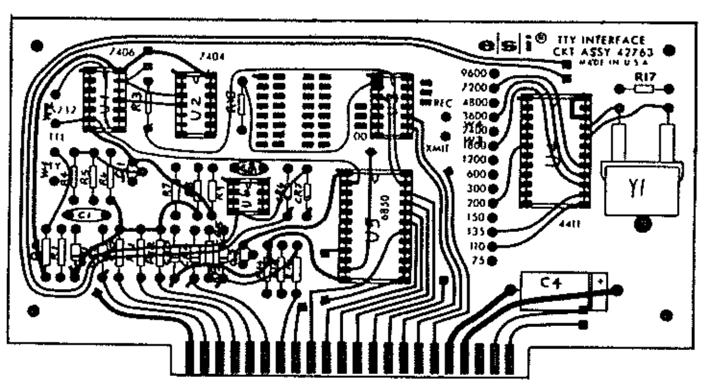


Figure 5-32. Part No. 42763

NOTES:

1. SOFTWARE MUST BE WRITTEN FOR ÷16 CLOCK IN ACIA.
2. J1 INSTALLED FOR TTY (20 MA LOOP). J2 INSTALLED FOR RS232. NO JUMPER INSTALLED FOR TTL
3. ALL RESISTORS ARE ¼ W 10%, & IN OHMS UNLESS OTHERWISE SPECIFIED
4. ALL CAPACITORS ARE IN µF UNLESS OTHERWISE SPECIFIED.

BAUD RATE	FREQUENCY
9600	153.6 K
7200	115.2 K
4800	76.8 K
3600	57.6 K
2400	38.4 K
1800	28.8 K
1200	19.2 K
600	9600
300	4800
200	3200
150	2400
134.5	2153.3
109.9	1758.8
75	1200

	RS232	TTL DATA	TTY DATA
MARK	-12	+5	20MA
SPACE	+12	ØV	ØMA

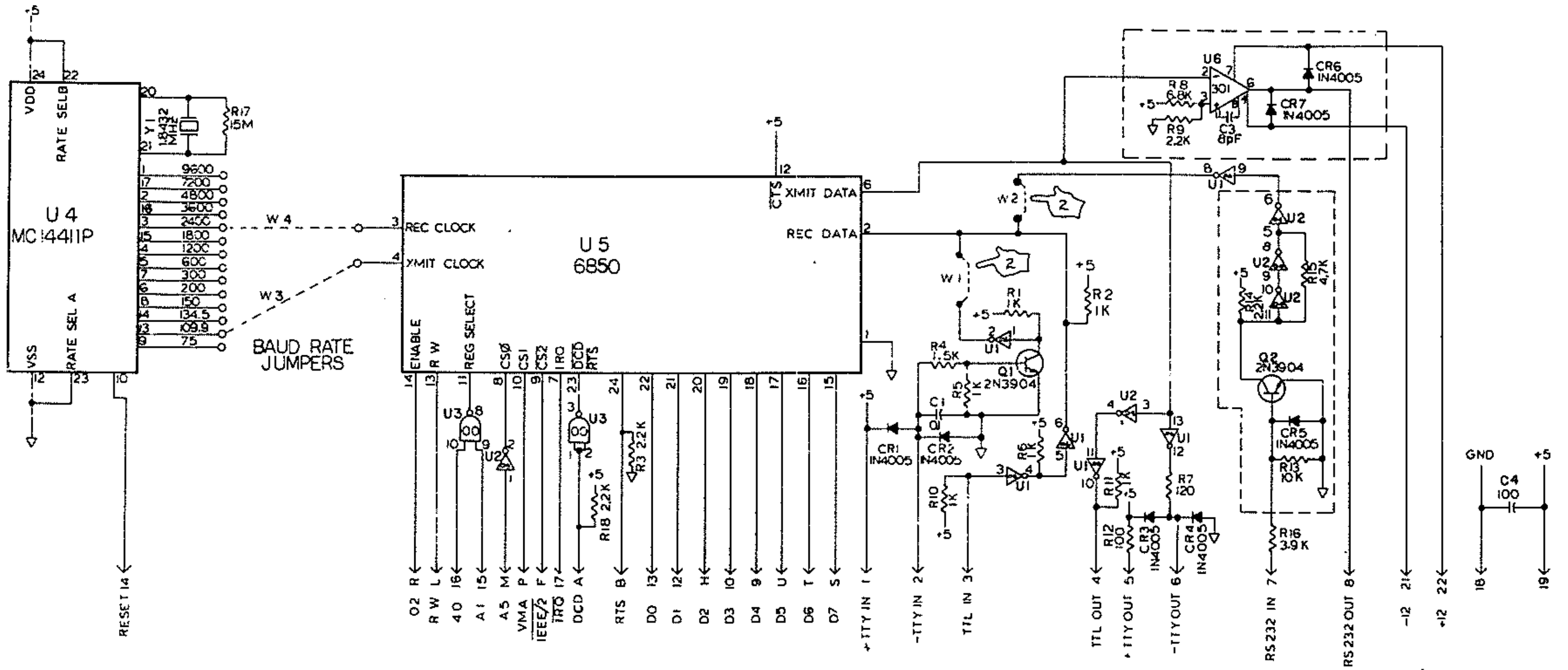


Figure 5-33. Part No. 42763

Electro Scientific Industries, Inc.

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Portland, Oregon 97229
Phone (503) 641-4141
Telex 36-0273

WARRANTY OF TRACEABILITY

Electro Scientific Industries, Inc. maintains reference standards of measurement which are compared with the U. S. National Standards through frequent tests by the U. S. National Bureau of Standards.

ESI working standards and testing apparatus used are calibrated against the ESI reference standards in a rigorously maintained program of measurement control.

The manufacture and final calibration of all ESI instruments are controlled by use of the ESI reference and working standards and testing apparatus in accordance with established procedures and documented results. (Reference MIL-C-45662)

Final calibration of this instrument was performed with reference to the mean values of the ESI reference standards or to ratio devices that were verified at the time and place of use.

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1. Two years for components and instruments using passive circuitry. One year for repairs of out-of-warranty items.
2. One year for components and instruments using active circuitry (see ESI Metrology Catalog). Six months for repairs of out-of-warranty items.

During the in-warranty periods, we will service or, at our option, replace any device that fails in normal use to meet its published specifications. Batteries, tubes and relays that have given normal service are excepted.

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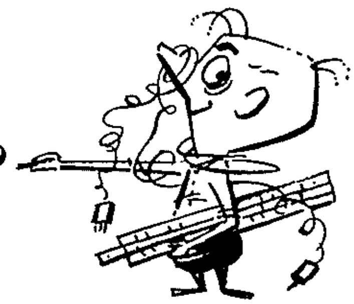
Would you like more information?



ESI technical publications are listed on the back of this page. If you would like any of these, simply check the appropriate box and fill in your address below. Also, please add any comments you have concerning the instrument or instruction manual. We value your feedback to help us improve or correct our manuals.

Instrument Description: Model No. ____________ Serial No. ____________
(Please Print)

Name ______________________ Title ____________

Department ______________________ Mail Stop ________

Company ______________________________

Address ______________________________

City ______________ State __________ Zip Code ______

Comments or corrections ______________________

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Attention: Literature Department

esi Part No. 1872A 10/75

- applications data
- technical articles
- engineering bulletins

☐ EB10 Effects of Output Loading on Resistive Voltage Dividers, *October 1969*

☐ EB15 Low Input Resistance Voltage Dividers, *February 1970*

☐ EB17 Accuracy vs. Frequency of Models 290B and 250DE Universal Impedance Bridges, *(revised May 1969)*

☐ EB26 International System of Units, *August 1969*

☐ EB29 DC and Low Frequency AC Ratio Measurements, *Dr. Merle L. Morgan, September 1962*

☐ EB30 Traceability of Resistance Measurement, *Jack Riley, January 1964*

☐ EB34 Resistance Transfer Technique, *Lawrence H. White, (revised April 1968)*

☐ EB35 An Improved Technique for Establishing Resistance Ratios, *R. M. Pailthorp and J. C. Riley, November 1962*

☐ EB41 Derivation of Electrical Units from Fundamental Standards, *R. D. Kuykendall and R. M. Pailthorp, July 1964*

☐ EB44 DC Measurements Using Ratio Techniques, *Jack C. Riley, September 1965*

☐ TA2 A Ratio Transformer Bridge for Standardization of Inductors and Capacitors, *D. L. Hillhouse and H. W. Kline, August 1960*

☐ TA6 The Accuracy of Series and Parallel Connections of Four-Terminal Resistors, *Jack C. Riley, April 1965*

☐ TA8 AC Measurements Using Ratio Techniques, *Jack C. Riley, May 1965*

☐ TA9 Strength for the Weak Spot in DC Potentiometry, *George D. Vincent and M. L. Roberts, October 1965*

☐ TA14 The Advantages of a Ten Kilohm Transportable Resistance Standard, *Robert M. Pailthorp, September 1967*

☐ TA16 Which Bridge for Precise Resistance Measurements? *Edward J. Swenson and George D. Vincent, December 1967*

☐ TA17 Experimental Verification of the Five-Terminal, Ten-Kilohm Resistor as a Device for Dissemination of the Ohm, *R. M. Pailthorp and George Vincent, December 1968*

☐ TA22A Laser Resistance Trimming from the Measurement Point of View, *Arthur G. Albin and Edward J. Swenson, June 1971*

☐ TA23 Precision Measurement of Resistor Networks, *Robert M. Pailthorp and Jack C. Riley, June 1971*

☐ TA24 Predictive Adjustment of Tantalum Film Resistors by Anodization, *Donald R. Cutler and Edward J. Swenson, July 1971*

☐ TA25 Laser Trimming Analysis Using a Resistive Sheet Analogy, *Swenson, Vincent, Riley, December 1972*

☐ TA26 The Effects of Laser Trimming on Birox and 1100 Series Thick Film Composition, *N. S. Spann, R. Headley, G. D. Vincent and E. J. Swenson, October 1971*

☐ TA27 Laser Trimming Thin Film Precision Resistor Networks with an Automated System, *Leonhard Groth, January 1974*

☐ TA28 YAG Laser Trimming of Thick Film Resistors, *Headley, Popowich, Anders January 1974*

☐ TA29 An Overview of Laser Functional Trimming Techniques, *Gunnar Hurtig III and Edward J. Swenson, August 1974*

☐ TA30 Measurement Subsystem for an AC Network Laser Trimmer, *R. A. Schomburg, August 1974*

☐ TA31 A Method of Obtaining Optimum Trimming Performance from a Laser System, *Paul F. Parks and Thomas W. Richardson, October 1974*