Digiquartz® Precision Pressure Instrumentation

Programming and Operation Manual for SDI-12 Instruments

- PS-2 Water Stage Sensors
- Series 1000 / 6000 / 9000 Intelligent Transmitters
- Series 8DP / 8WD / 8B Intelligent Depth Sensors
- SDI-12 Interface Boards
- Model 710 Display

Document No: 8139-001
Revision E November, 1994

Paroscientific, Inc.
4500 148th Ave N.E.
Redmond, WA 98052
Tel: (206) 883-8700
Fax: (206) 867-5407

Table of Contents

Introduction

The Paroscientific SDI-12 Digiquartz® Intelligent Instruments provide direct digital pressure and depth output in the users choice of engineering units to a data logger or computer or to an optional stand-alone readout display.

The instruments are available in various differential and absolute full scale pressure ranges and in various external packaging for laboratory, outdoor, or submersible applications.

The transmitter receives commands from a data logger or user computer via a standard SDI-12 data bus and returns via the same bus. The SDI-12 data bus is a 1200 baud, multi-drop two-wire data bus using 0 and 5 volt logic levels. The transmitters are fully compatible with SDI-12 Version 1.0 and USGS Specification HIF-S-02. (U.S. Department of the Interior, Hydrologic Instrumentation facility, Building 2101, Stennis Space Center, MS 39529).

The transmitters can be used with all standard SDI-12 data loggers as a stand-alone system. They can also be used with any computer with an RS-232 serial port using a simple diode and resistor logic level shifter (Appendix B).

Powerful, easy to use program commands allow the user to address any or all transmitters on the bus and control data sampling rates, integration time, and other operating parameters.

Pressure values are output in any of eight standard sets of engineering units or in user definable units. Output is fully compensated for temperature effects over the operating temperature range shown on the specification control drawing for your model.

Hardware Description

The Digiquartz® Intelligent Transmitter consists of a standard Paroscientific pressure transducer and a digital interface board in an integral package. The digital board has a microprocessor-controlled counter and an SDI-12 port. The microprocessor operating program is stored in permanent memory (EPROM) and user controllable parameters are stored in user writable memory (EEPROM). The user interacts with the transmitter via the two-way SDI-12 bus.

The pressure transducer provides two continuous frequency output signals, one corresponding to the pressure and the other to the sensor internal temperature. The digital board uses these two signals to calculate fully temperature compensated pressure. The equations used are described in Appendix G.

The microprocessor monitors incoming commands from the computer or data logger. When a measurement command in received, the microprocessor selects the appropriate frequency signal source and makes a period measurement using a 4.2 MHz timebase counter. The counter integration time is user selectable. Some commands require both temperature and pressure signals. In that case, the temperature period is measured first, followed by the pressure period. When the period measurement is completed, the microprocessor makes the appropriate calculations and holds the result for retrieval by a data command.

Specifications

SDI-12 BUS	Serial ASCII, multi-drop Baud Rate: 1200 Signal levels: 0 and 5 volts nominal Data framing: 7 data bits, even parity, 1 stop bit
POWER REQUIRED	6 to 16 VDC Total current drain: 1.5 mA r.m.s. quiescent 6 mA r.m.s. during measurement
SAMPLING COMMANDS	M Measure pressure. M2 Measure temperature. M3 Measure period of the pressure sensor. M4 Measure period of the temperature sensor.
SAMPLE INTEGRATION TIME	User selectable in approximately 3 ms steps from 3 ms to 30 s.
RESOLUTION	Depends on integration time. User selectable in 15000 steps. Typically 1 ppm of full scale for 5 second integration.
PRESSURE UNITS	User selectable. Choice of psi, mbar, bar, kPa, MPa, inches of Hg, Torr, meters of water, or user definable.

How to Get Started

Transmitters are shipped fully configured and ready to operate on standard SDI-12 systems. They can also be used with computers with a standard RS-232 serial port. Units are shipped set for address 0.

Hook-up

SDI-12 is a simple multi-drop two-wire data bus. Connections for typical installations are shown in Appendix A. For most installations, only three wires need to be connected to the transmitter pins corresponding to power, ground and data. Additional pins provide outputs for an optional remote digital display or for shaft encoder data loggers, as described in other sections. The transducer requires a single DC supply between 6 and 16 volts DC. Current drain is approximately 1.5 mA in standby and 6 mA during measurements.

If you are using the transmitter with an SDI-12 data logger, connect its data and ground pins directly to the data bus.

If you are using the transmitter with a computer RS-232 serial port, connect the RS-232 receive and transmit lines to the transmitter data line through a simple diode level shifter. An inexpensive level shifter is easily constructed (see Appendix B) or may be purchased from Paroscientific.

Alternatively, the user computer can send messages via a serial port to an SDI-12 data logger for relay to SDI-12 transducers in the "transparent mode" (see your data logger users manual). In effect, the data logger replaces the level shifter. In our experience, this mode of operation is generally less convenient than using a level shifter because the "transparent mode" data logger commands vary from manufacturer to manufacturer and the command syntax can be cumbersome.

Types of Measurements

The SDI-12 standard provides for standard measurement and data commands. All SDI-12 transducers must respond to the same commands. The Paroscientific SDI-12 transmitters support the following standard SDI-12 measurement commands:

M	Measure pressure.
M2	Measure temperature.
M3	Measure period of the pressure sensor.
M4	Measure period of the temperature sensor.

After a measurement, data is collected with the D0 command. These and other SDI-12 commands are described more fully in the section Command Descriptions.

Configuration Commands

In addition to the standard SDI-12 commands, Paroscientific transmitters support an extended command set which allows users to set device address, select different pressure units, make offset adjustments, change measurement integration time, and optimize the device configuration for specific user applications. More experienced users are referred to the individual command descriptions. Some of the more commonly used commands are:

AD	Change device address.
UF	Change pressure output scaling factor.
UA	Change output offset level.
UN	Change pressure units.
PR	Change pressure integration time.
TR	Change temperature integration time.
MD	Turns shaft encoder output on/off. Turns external display on/off.

Units are shipped preconfigured with address 0 (AD = 0), shaft encoder and display off (MD=00), and service request activated (SR=1). The values of all parameters are shown on the status printout shipped with each transducer. Users wishing to reconfigure their systems should be familiar with the X command which gives access to the extended command set, the EW command which enables the writing to the EEPROM, and the appropriate configuration commands (AD, SR, MD, etc.). Examples are given in the section Command Descriptions.

SDI-12 Command Format

All commands consist of serial ASCII strings of the form: (break) aCCCCC!
All transmitter responses are serial ASCII strings of the form: aRRRRR<cr><lf>

1. (break) is a special signal sent by a data logger to wake up the transducers. Serial port users may precede commands by character * (ASCII 42) instead of the hardware break signal.

2. a is the device address. Legal values are 0 through 9 and lower case a through y.

3. CCCCC is a command string of zero or more upper case ASCII characters.

4. Commands must end with an exclamation point.

5. Data framing is 1200 baud, even parity, one stop bit.

6. Commands must be set as a continuous string with no gaps or pauses.

7. A device responds only to messages addressed to it.

8. Transmitter responses begin with the address and end with <cr><lf>.

9. RRRRR is a reply string of 0 to 30 characters.

10. Undefined commands and commands with bad parity are ignored.

Sample Program for Measurements Via an RS-232 Port

The following program illustrates how messages are exchanged between the transmitter and a user computer or data logger.

With a simple diode level shifter (Appendix B), you should be able to key this program into your computer and talk to the transmitter via any RS-232 serial port. Note that the commands (lines 100 and 150) start with an * (ASCII 42). This character replaces the SDI-12 break character when using a serial port.

The program assumes that the transmitter sends a service request when a measurement is ready (SR=1). If you have configured your transmitters to turn off the service request, replace lines 120 and 140 with an appropriate wait loop.

```
10   REM            Program to make measurement and show on screen
20   REM            This program written for address 0.
30   REM            For others, change command address in lines 100 and 150.
40   CLS
50   OPEN "COM1:1200,E,7,1,CS,DS" AS #1
100 PRINT #1,  "*0M!";              ' send M command to address 0
110 GOSUB 800                       ' get command and reply from bus
120 PRINT A$                        ' print command and reply
125 REM ---------------------------------------------------------------------------
130 GOSUB 800                       ' wait for service request
140 PRINT A$                        ' print service request
145 REM ---------------------------------------------------------------------------
150 PRINT#1,  "*0D0!";              ' send D0 command to get data
160 GOSUB 800                       ' get command and data from bus
170 PRINT A$;                       ' print command and data
175 REM ---------------------------------------------------------------------------
180 B$=MID$(A$,7)                   ' extract data from string
190 PRINT "         data = " ;B$
200 REM ---------------------------------------------------------------------------
300 PRINT : PRINT
310 GOTO 100                        ' repeat loop
800 REM   Subroutine to read data until a line feed
805 REM   returns message in A$
810 A$=""
820 B$=INPUT$(1,1)
830 IF B$=CHR$(13) THEN GOTO 820
840 IF B$=CHR$(10) THEN GOTO 860
850 A$=A$+B$:  GOTO 820
860 RETURN
```

The program shows you the action on the SDI-12 bus as the computer sends a measurement (M) command, the transmitter replies and then later sends a service request, the computer sends a D0 data command, and the transmitter sends the data.

Notes:

1. Everything sent on the RS-232 transmit line also appears on the receive line. This is because SDI-12 is a transceive bus, and the level shifter ties the two lines together.

2. The program is written for device address 0. For others, change the address in the M and D0 commands on lines 100 and 150.

3. The program uses serial communications port number 1 (COM1:). Change if appropriate.

4. The semicolons at the end of the PRINT#1 statements on lines 100 and 150 avoid sending spurious carriage returns on the SDI-12 bus.

SDI-12 is normally used for fairly slow speed data collection. For faster sampling, read the sections on Resolution and Faster Sampling.

Demonstration Program Disk

Included with your SDI-12 transmitter is a computer floppy disk with demonstration programs. This disk will run on an IBM compatible computer with an RS-232 serial port in conjunction with a level shifter. One program that is especially useful is an interactive terminal program, TERMSDI, which lets the user try any command and observe the results. TERMSDI automatically inserts the "*" character at the start of each command as a substitute for a break. The status program, STATSDI, lets the user check the current configuration of the transmitter, change various control parameters, and make measurements. The SAMPLE program from the previous section is also included. The programs on the disk work with DOS Version 2.1 and higher and BASICA, GWBASIC, QUICKBASIC, and QBASIC.

Command List

Regular SDI-12 commands:

D0	Send data.
I	Identify. Send transducer identifying information.
M	Measure pressure.
M2	Measure temperature.
M3	Measure period of the pressure sensor.
M4	Measure period of the temperature sensor.
V	Verify. Check PROM checksum.
X	Enter eXtended command mode. Next regular SDI-12 command cancels the extended mode.

Configuration commands (extended commands):

EW Enable EEPROM Write for one command.

AD Change Device Address.
PR Read/enter Pressure Resolution.
TR Read/enter Temperature Resolution.
UN Read/enter choice of engineering UNits.

0. User defined	3. bar	6. inches Hg
1. psi	4. kPa	7. Torr
2. mbar or hPa	5. MPa	8. meters H_2O

UA User Adder. User defined offset for UN=0.
UF User Factor. User defined scale factor for UN=0.

DP Decimal Place. Controls the number of decimal places sent.
MD MoDe Controls the display, shaft encoder, and power down options.
SR Service Request. Activates Service Request.

Special commands to control the Model 710 display (extended commands):

DC Display Check.
DD Display Distance.
DR Display Right adjusted data from computer.
DV Display Value from computer, left adjusted.

Special diagnostic commands (extended commands):

CX Check crystal for microprocessor clock.

Calibration commands (extended commands):

ZA Zero Adjust.

SN Model and Serial Number information.

PA Pressure Adder (offset adjustment)
PM Pressure Multiplier (span adjustment)

TC Timebase Correction.

U0 Read/enter U_0 coefficient.
Y1 Read/enter Y_1 coefficient.
Y2 Read/enter Y_2 coefficient.
Y3 Read/enter Y_3 coefficient.

C1 Read/enter C_1 coefficient.
C2 Read/enter C_2 coefficient.
C3 Read/enter C_3 coefficient.

D1 Read/enter D_1 coefficient.
D2 Read/enter D_2 coefficient.

T1 Read/enter T_1 coefficient.
T2 Read/enter T_2 coefficient.
T3 Read/enter T_3 coefficient.
T4 Read/enter T_4 coefficient.
T5 Read/enter T_5 coefficient.

Command Descriptions

In the following descriptions, device address is indicated by lower case a. Legal addresses are 0 to 9 and lower case a to y. Carriage return is indicated by <cr> and line feed by <lf>.

Regular SDI-12 Commands:

a Acknowledge active.
A short command intended for polling which devices are active. The is command "a!". Response is "a<cr><lf>".

Typical command and reply:
0! 0<cr><lf>

D0 Send data.
Causes the transducer to send results of previous measurement or verify command. The response is "a<values><cr><lf>". Repeating the command causes the same data to be sent again. Data values have the form "pd.d" where p is the polarity (+ or -) and d.d is the data value. Data values may have up to 7 digits and may include a decimal point anywhere in the field. Some types of measurements may return several values with a single D0 command. The response to a D0 command may be up to 33 characters. A return with no data means that the measurement was aborted and a new measurement command must be sent.

Typical command and reply:
4D0! 4+14.12<cr><lf>

I Identify.

Send device identification. The response is "annccccccccmmmmmmvvvxxxxxx<cr><lf>, where "nn" is the SDI-12 compatibility level, "cccccccc" is the device manufacturer, "mmmmmm" is a six character model name, "vvv" is the manufacturer version, and "xxxxxx" is a six character serial number.

Typical command and reply:
2I! 210PAROSCI_1030G_101_35082<cr><lf>

M Measure pressure.

Initiates pressure measurement. Starts sensor warm-up, calculates how long warm-up plus measurement will take, sends reply of form "atttn<cr><lf>", where "ttt" is the time in seconds when data will be available and "n" is the number of data values that will be sent. The device then completes sensor warm-up, takes data, calculates final value, updates display or shaft encoder output (if active), sends a service request (if active), stores data awaiting a D0 command, and returns to a low power sleep state. The service request has form "a<cr><lf>". Service requests can be disabled with the SR command. Sensor warm-up is 1 second. To speed up the reply, the transmitter can be configured to keep the sensor powered between readings using the MD command. This increases the standby current draw to approximately 6 mA. If the transmitter is interrupted by another command addressed to it before a measurement is finished, the measurement is aborted and subsequent data commands will return no data.

Typical command and reply:

1M! 10021<cr><lf>	data in 2 seconds, 1 value
1<cr><lf>	service request
1D0! 1+14.62<cr><lf>	send data

M2 Measure temperature.
Initiates measurement of the transmitter internal temperature.
Similar to the M command. Starts warm-up, sends reply, completes measurement, sends service request (if active), stores result awaiting data command, and returns to sleep.

Typical command and reply:

3M2! 30021<cr><lf>	data in 2 seconds, 1 value
3<cr><lf>	service request
3D0! 3+23.014<cr><lf>	send data

M3 Measure period of pressure sensor in microseconds.
Similar to the M command. Starts warm-up, sends reply, completes measurement, sends service request (if active), stores result awaiting data command, and returns to sleep.

Typical command and reply:

3M3! 30021<cr><lf>	data in 2 seconds, 1 value
3<cr><lf>	service request
3D0! 3+28.12345<cr><lf>	send data

M4 Measure period of temperature sensor in microseconds.
Similar to the M command. Starts warm-up, sends reply, completes measurement, sends service request (if active), stores result awaiting data command, and returns to sleep.

Typical command and reply:

2M4! 20021<cr><lf>	data in 2 seconds, 1 value
2<cr><lf>	service request
2D0! 2+5.12346<cr><lf>	send data

V Verify.

Computes EPROM checksum to verify that the operating program is intact. Response is "atttn<cr><lf>", where "ttt" is time in seconds when data will be available and "n" is the number of data values. Sends a service request (if active), stores result awaiting data command, and returns to sleep. A data value of +1 means the EPROM is good. A data value of 0 means the EPROM is defective.

Typical command and reply:

0V! 00011<cr><lf>	data in 2 seconds, 1 value
0<cr><lf>	service request
0D0! 0+1<cr><lf>	send data

X Enter extended mode.

The transmitter has two types of commands: regular commands and extended commands. Normally, only the regular commands are accessible and extended commands will be ignored. All measurement and data commands are regular commands. Extended commands are used for configuring transmitters (setting addresses, integration time, pressure units, etc.) and for recalibration. The X commands cause the transmitter to enter the extended command mode. In this mode, the transmitter searches the extended command table before searching for regular commands. The transmitter remains in the extended mode until the next regular command is received. Thus, a sequence of extended commands can be sent without reentering the extended mode each time. Note that the MD command allows the user to configure the transmitter so that all the commands are accessible without entering the extended mode. (MD=10).

Typical command and reply:

3X! 3<cr><lf>

Extended Commands: (Accessible only in the extended command mode.)

EW Enable Write for one command.
Set the flag allowing EEPROM write on the next command. The flag is cleared after the next command is received. Note that it may take up to 0.3 seconds for an EEPROM write to be completed. During this time, the transmitter will not respond to other commands.

Typical command and reply:

0X! 0<cr><lf>	enter extended mode
0EW! 0<cr><lf>	enable write
0PR=200! 0<cr><lf>	set PR=200

AD Set Device Address.
Legal addresses are 0 to 9 and lower case a through y. Each device on the bus must have a unique address. Note that the device replies to the AD command with the old address but all subsequent commands must use the new address.

Typical command and reply: (Change the address from 0 to 4.)

0X! 0<cr><lf>	enter extended mode
0EW! 0<cr><lf>	enable write
0AD=4! 0<cr><lf>	change address to 4

PR Read or enter the Pressure Resolution.
The pressure integration time = 100 × PR × Period of the pressure oscillator in microseconds. Legal values of PR are 1 to 16383. Note that TR is automatically set to 4×PR whenever PR is changed.

Typical command and reply:

0X! 0<cr><lf>	enter extended mode
0PR! 000200<cr><lf>	PR is currently 200
0EW! 0<cr><lf>	enable write
0PR=100! 0<cr><lf>	change PR to 100
0PR! 000100<cr><lf>	PR is now 100

TR Read or enter the Temperature Resolution.
The temperature integration time = 100 × TR × Period of the temperature oscillator in microseconds. Legal values of TR are 1 to 65535. Note that TR is automatically set to 4×PR whenever PR is changed but overwritten by this command.

Typical command and reply:

0X! 0<cr><lf>	enter extended mode
0TR! 000200<cr><lf>	TR is currently 200
0EW! 0<cr><lf>	enable write
0TR=300! 0<cr><lf>	change TR to 300
0TR! 000300<cr><lf>	TR is now 300

UN Read or Enter the choice of pressure engineering UNits.
This function selects the engineering unit conversion factor by which all computed pressures are multiplied before output. UN=0 chooses the user defined multiplier which is set with command UF and the user defined offset which is set with command UA.

UN	UNITS	MULTIPLY PSI BY
1	psi	1.000000
2	mbar or hPa	68.94757
3	bar	0.06894757
4	kPa	6.894757
5	MPa	.00689476
6	inches of Hg	2.036021
7	Torr	51.71493
8	meters of H_2O	0.7030696
0	User Defined	Set by UF and UA

Typical command and reply:

0X! 0<cr><lf>	enter extended mode
0UN! 02<cr><lf>	UN is currently 2 (mbar or hPa)
0EW! 0<cr><lf>	enable write
0UN=8! 0<cr><lf>	change UN to 8 (meters of water)

UA User Adder.
A user defined offset which is in effect only when UN=0.
When units UN=0, the computed output from the M command = UF × psi + UA. Output from commands M2, M3, and M4 is not affected. The value of UA is read or set with the UA command.

Typical command and reply:

0X! 0<cr><lf>	enter extended mode
0UA! 0+12.30<cr><lf>	UA is currently 12.30
0EW! 0<cr><lf>	enable write
0UA=12.25! 0+12.25<cr><lf>	change UA to 12.25

UF User Factor.
A user defined multiplier which is in effect only when UN=0. When units UN=0, the computed output from the M command = UF × psi + UA. Output from commands M2, M3, and M4 is not affected. The value of UF is read or set with the UF command.

Typical command and reply:

0X! 0<cr><lf>	enter extended mode
0UF! 0+2.308<cr><lf>	UF is currently 2.308
0EW! 0<cr><lf>	enable write
0UA=2.256! 0+2.256<cr><lf>	change UF to 2.256

DP Decimal Places.

Reads or sets the number of decimal places sent by an M command on the SDI-12 data bus and to a Model 710 display. There is a maximum number of decimal places available which corresponds to one least count of the counter timebase and depends upon the pressure units selected and the PR integration time. Generally this limit is approximately 9 ppm of full scale for PR=100. If a user requests more decimal places than are available, the transmitter will send fewer decimal places than are requested. The user should then increase the PR setting. The relation between PR and clock least count is described in the section on Resolution and Integration Time.

Typical command and reply:

0X! 0<cr><lf>	
0DP! 0+3<cr><lf>	Three decimal places
0M! 00021<cr><lf>	
0<cr><lf>	Service request (if active)
0D0! 0+14.123<cr>lf>	Note the 3 decimal places
0X! 0<cr><lf>	
0EW! 0<cr><lf>	Enable write
0DP=2! 0<cr><lf>	Set to 2 decimal places
0M! 00002<cr><lf>	
0<cr><lf>	
0D0! 0+14.12<cr>lf>	Note the 2 decimal places

MD Operating MoDe.
Controls the display, shaft encoder, and other options.
The MD parameter is stored in EEPROM as two hexadecimal characters. The high order character controls power-down and extended commands. The low order character controls the operation of the digital display and shaft encoder outputs.

First	8-bit	not used
Hex	4-bit	not used
Char	2-bit	keep sensor powered in between measurements
	1-bit	allow extended commands without X command

Second	8-bit	not used
Hex	4-bit	activate background update mode
Char	2-bit	activate shaft encoder output on M command
	1-bit	activate display output on M command

Some common settings are tabulated below:

MD Value	Mode of Operation
00	No shaft encoder or display output. (Standard mode, power down)
01	Display on and updated with each M command.
02	Shaft encoder on and update with each M command.
05	Display on and updating continuously.
06	Shaft encoder on and updating continuously.
10	Extended command set always accessible.
20	Sensor powered between measurements.

Note: Keeping the sensor powered between measurements or activating the background update mode increases current drain. For hardware reasons, the display and shaft encoder outputs may not be operated at the same time. Read the sections on Background Tasks, Model 710 Digital Display, and Shaft Encoder Output for additional information.

SR Service Request.
Reads or sets the value of the SR parameter. This parameter controls whether the transmitter sends a service request when data are ready. If SR=1, service request is sent. If SR=0, service request is not sent.

Typical command and response:

2X! 2<cr><lf>	
2SR! 2+0<cr><lf>	No service request
2EW! 2<cr><lf>	Enable write
2SR=1! 2<cr><lf>	Turn on service request

Special Commands to Control the Model 710 Display:

DC Display Check.
Causes the display to cycle through all of its segments to check the display. Active only when the display is turned on with the MD command. Display commands are disabled when the shaft encoder output is turned on.

Typical command and reply:
1X! 1<cr><lf>
1DC! 1<cr><lf>

DD Display Distance
Reads or sets the display driving distance. The DD parameter controls the display clocking rate. The default, DD=0, is usually adequate for displays located within 100 to 200 feet of the transmitter using shielded cable for the display lines. For longer distances or if noisy readings appear on the display, set DD = 1. Slower clocking of the display allows longer cables but slows down the data sampling rate by a slight amount. The extra time to clock the display is not usually significant for PR values 30 or greater.

Typical command and reply:

0X!0<cr><lf>	
0DD!00<cr><lf>	DD is set to 0
0EW!0<cr><lf>	
0DD=1!0<cr><lf>	Set DD = 1
0DD!01<cr><lf>	Verify new value

DR Display Right adjusted data from computer.
Displays any number specified by the computer on the display. Messages are right adjusted and may be up to six characters plus a decimal point. Legal characters are .-0123456789 . Decimal point position is determined by the DP command. Display commands are disabled when the shaft encoder output is turned on.

Typical command and response:
1X! 1<cr><lf>
1DR=14.543! 1<cr><lf> Displays 14.543 (depends on DP)

DV Display Value sent from computer, left adjusted.
Displays any number specified by the computer on the display. Messages are left adjusted and may be up to six characters plus a decimal point. Legal characters are .-0123456789 and uppercase letters ABCDEF. Decimal point position is not affected by the DP command. Display commands are disabled when the shaft encoder output is turned on.

Typical command and response:
0X! 0<cr><lf>
0DV=23.25F! 0<cr><lf> Displays 23.25F
For a special display with colons, send six characters followed by 0 or 1.
0X! 0<cr><lf> For a display with colons
0DV=1234560! 0<cr><lf> Displays 12:34:56
0DV=1234561! 0<cr><lf> Displays 12:3456

Special Diagnostic Commands:

CX Check crystal for the microprocessor clock.
Puts the microprocessor time base divided by 480 onto the display clock line (pin 6). Canceled by the next command. Active only when the display is turned on by the MD command. This is NOT a diagnostic command to check the pressure sensor quartz crystal.

Typical command and response:
0X! 0<cr><lf>
0CX! 0<cr><lf>

Calibration Commands:

CAUTION: CHANGING THE PARAMETERS BELOW PERMANENTLY ALTERS CALIBRATION. Generally, these values should be changed only by a qualified calibration laboratory and permanent records should be kept. The only exception is the ZA command, which can be used for a pressure offset adjustment under field conditions if true applied pressure is known.

ZA Zero Adjust

Performs a pressure zero adjustment if true applied pressure is known. This command must be preceded by an EW command. The transducer must be at temperature equilibrium and at a stable accurately know pressure at the time the ZA command is given. PR must be set to a value of 30 or greater so that resolution is sufficient for an accurate adjustment. The format of the command is aZA=ppppppp! where "a" is the device address, "ppppppp" is the true applied pressure in the same units for which UN is set. When the command is received, the transmitter measures indicated pressure, compares it with the specified true applied pressure, and changes the stored value of the PA parameter to make measured and true pressure agree. For UN= 1 to 8, PA is set so that the indicated pressure will equal "ppppppp" + UA. This command takes approximately one measurement time plus one second to execute. During execution, other commands are ignored.

Typical command and response:
0X! 0<cr><lf>
0EW! 0<cr><lf>
0ZA=14.52345! 0<cr><lf>

CAUTION: CHANGING THE PARAMETERS BELOW PERMANENTLY ALTERS CALIBRATION. Generally, these values should be changed only by a qualified calibration laboratory and permanent records should be kept. All of the below values are extended commands and require an EW to change values.

SN Read/enter the model and Serial Number information.
Reply format is ammmmmmssssss<cr><lf> where "a" is the device address, "mmmmmm" is a six character ASCII string representing the model number and "ssssss" is a six character ASCII string representing serial number.

PA Read/enter a Pressure Adder in units determined by the UN setting. This offset is intended as an adjustment for transducer zero drift. USE THE UA PARAMETER FOR ALL OTHER TYPES OF OFFSETS. When UN is changed, PA is automatically adjusted so that the offset is correct in the new units.

PM Read/enter a Pressure Multiplier.
PM is intended for span correction of the pressure transducer. Do not use PM to define other pressure units. Use UF instead.

TC Read/enter the Timebase Correction factor.

U0 Read/enter U_0 coefficient.
Y1 Read/enter Y_1 temperature coefficient.
Y2 Read/enter Y_2 temperature coefficient.
Y3 Read/enter Y_3 temperature coefficient.

C1 Read/enter C_1 pressure coefficient.
C2 Read/enter C_2 pressure coefficient.
C3 Read/enter C_3 pressure coefficient.

D1 Read/enter D_1 pressure coefficient.
D2 Read/enter D_2 pressure coefficient.

T1 Read/enter T_1 pressure coefficient.
T2 Read/enter T_2 pressure coefficient.
T3 Read/enter T_3 pressure coefficient.
T4 Read/enter T_4 pressure coefficient.
T5 Read/enter T_5 pressure coefficient.

Resolution and Integration Time

The resolution of the transmitter is determined by the counter integration time. Resolution can also be limited by the number of digits sent on the SDI-12 bus. This may be set using the DP command.

Users can adjust the integration time to optimize resolution, noise rejection, and sample rate for a wide variety of applications by using the PR command. The PR and TR settings as shipped from the factory are shown on the configuration status report shipped with each unit.

The relationship between PR, integration time, and pressure resolution for an M command is shown in the table below.

PR	TR	Signal Counting Time	Pressure Resolution ppm Full Scale
20	80	0.1 s	43 ppm
100	400	0.5 s	9 ppm
1000	4000	5.1 s	0.9 ppm
10000	40000	51 s	0.1 ppm

The values above are for a typical transmitter with a pressure signal period (Pper) of 28 microseconds and a temperature period signal (Tper) of 5.8 microseconds. Values may vary by about 20% for different transmitters of the same model and by a factor of two for different models.

Resolution and integration time may be calculated for all models using the equations below, where sensor periods are in microseconds:

Pressure Resolution / F.S. = $1 / (42 \times PR \times Pper)$

Temperature Resolution (deg C) = $8.2 / TR$

Pressure Signal Integration (sec) = $(PR \times Pper) / 10{,}000$

Temperature Signal Integration (sec) = $(TR \times Tper) / 10{,}000$

In addition to the integration time, there is a sensor warm-up wait of 1 second and a calculation time of approximately 0.3 seconds. See the section on faster sampling for ways to speed things up.

Faster Sampling

SDI-12 is normally a slow speed system designed to minimize power consumption. Standby current for our transmitters is typically less than 1.5 mA. In a normal measurement sequence, power is applied to the transducer and 1 second is allowed for warm-up before a measurement is taken. In addition, numerical calculations take approximately 0.3 seconds. This means that the shortest pressure measurements in this mode take about 1.3 seconds plus the integration time (see previous section). Users can configure the transmitter with the MD command so that the pressure sensor remains powered between readings. This increases the standby current to approximately 5 mA. In this mode, up to 2.5 readings per second can be taken.

Current Drain

The transmitter has been designed to minimize current drain. Normally, the transmitter turns off the sensor between readings. In this standby state, typical current drain is less than 1.5 mA. Current drain during sampling is approximately 6 mA. The time per sample is determined by the parameters PR and TR.

Users can configure the transmitter to speed up sampling by keeping the transducer powered between readings to save the warm-up time. See the MD command. This increases standby current to approximately 5 mA.

Users can also program the transmitter to perform background tasks such as continuous display or continuous shaft encoder updating between measurements (see MD command). These background tasks increase standby current to 6 to 8 mA.

Background Tasks

The transmitter gives priority to computer commands. In between commands, it normally goes to a low power standby state. However, users can configure the transmitter to carry out background tasks such as continuous updating of the display or shaft encoder output instead of going to a standby state. These background tasks are momentarily interrupted whenever SDI-12 commands are received.

These background modes also allow stand-alone operation of the transmitter shaft encoder outputs or display without any computer or SDI-12 data logger on line.

The mode parameter MD activates operation of the display and shaft encoder output and also controls the background modes. The MD parameter is stored in EEPROM as two hexadecimal characters. The action of various bits in these characters is described in the Command Description section for the MD command.

Because of a hardware conflict, only one background task can be in effect at a time: *i.e.* either shaft encoder output or display output, but not both.

CAUTION: Activating the background task bit increases standby current.

CAUTION: Because computer tasks have priority, there is one unusual situation when display or shaft encoder updating can be interrupted for a significant amount of time by host computer requests. If on-line commands keep the transmitter fully occupied carrying out commands other than pressure measurements (for example, continuous period measurements), the display or shaft encoder output is frozen at the last value sent. No warning is given. Normal operation will resume when a pause in the command stream occurs.

Digiquartz® Model 710 Display

The Model 710 display is a six digit LCD display in a standard 1/8 DIN size panel mount enclosure. It displays pressure data from an SDI-12 intelligent transmitter. The display operates either as a stand-alone device with a transmitter or with a computer on-line. Extra transmitter commands (MD, DP, DR, DV, DD, and DC) have been added to control the display.

For stand-alone operation, the display shows pressure whenever power is applied to the transmitter. The lower order character of the MD parameter stored in the EEPROM must be set to 5 (1 bit plus 4 bit).

When a computer is on-line, the Model 710 can also be used to display other data calculated in the user computer (filtered data values, time, temperature, error messages, etc.). These functions work any time except when the MD 2-bit is on. When using the computer to control the display, it may be most convenient also to turn off the 1-bit and 4-bit to prevent automatic updating of the display by pressure measurements.

Operation of the display is controlled by the MD parameter. When the pressure display is activated (MD parameter, 1-bit) the display is automatically updated after each M command. In addition, if the background mode is activated, (4-bit plus 1-bit, hex 5) the transmitter makes measurements and updates the display whenever is it not busy processing bus commands. When background mode is activated, transmitter current drain is approximately 6 to 8 mA.

For hardware reasons, the shaft encoder output and the display cannot both be active at the same time. Do not activate the display when the shaft encoder data logger is on-line.

Installation instructions for the display are in Appendix D.

Shaft Encoder Output

The SDI-12 transmitter can provide a shaft encoder output that fully emulates the output of a Handar Model 436A shaft encoder and is fully compatible with Model 550A shaft encoder data loggers manufactured by Handar, Inc. of Sunnyvale, California.

The shaft encoder output is on 4 signal lines on the transmitter electrical connector. All four shaft encoder output lines are optically isolated from the SDI-12 interface. Technical information about the output may be found in Appendix C.

Two modes of operation can be selected with the MD command: If the 2-bit is on, the shaft encoder output is updated after each M command. This has a negligible effect on total current drain.

If both the 2-bit and 4-bit are turned on, the output is updated continuously in the background mode at a rate determined by the sampling time (depends on PR and TR). In this configuration, the transmitter can be used as a stand-alone device with a shaft encoder data logger. No computer or SDI-12 commands are required. Note that in this mode, transmitter standby current increases to 6 to 8 mA.

Interfacing with the Stevens Electro-Chart-Drive (ECD)*.

All Paroscientific SDI-12 instruments may be interfaced with the Stevens ECD. Installation requires 3 wires, power, ground, and SDI-12 data. The ECD may be configured to operate as a stand-alone device or with an SDI-12 data logger. Consult your Stevens ECD operations manual for specific information. If the ECD is used with a data logger, the transmitter should be configured as it would be for a standard data logger application.

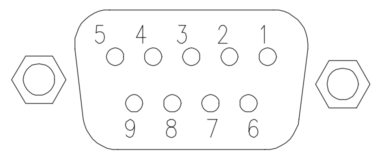
* Manufactured by Leupold & Stevens, Inc. of Beaverton, Oregon

Appendix A: SDI-12 Device Pinouts

The pinouts listed below cover the majority of instrument pinouts. Please consult your instrument Specification Control Drawing for specific information.

9 Pin D Connector -   Series 1000 / 6000 / 9000 SDI-12 Transmitters
SDI-12 Intelligent Interface Board

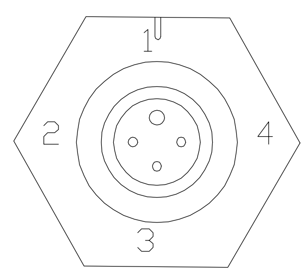
Pin	Function
1	Shaft Encoder Return
2	SDI-12 Data
3	Shaft Encoder Gate
4	Shaft Encoder Gated A
5	Signal and Power Ground
6	Display Clock Line
7	Shaft Encoder Gated B
8	Display Data Line
9	Power 6 to 16 VDC @ 15mA



Notes:
- The SDI-12 data bus is pins 2 and 5. Transducer power should be applied to pin 9.
- The Model 710 display connects to pins 5, 6, 8, and 9.
- The Shaft Encoder data logger connects to pins 1, 3, 4, and 7. These pins are optically isolated from all others.

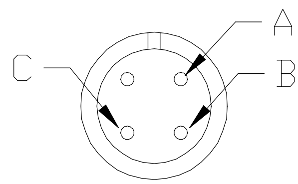
4 Pin Depth Sensor Pinouts - SDI-12 Series 8DP / 8WD / 8B

Pin	Function
1	Not Used
2	SDI-12 Data
3	Ground
4	Power



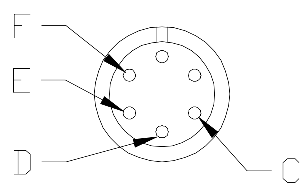
PS-2 Water Stage Sensor Pinouts

Connector Pinouts - SDI-12 I/O



Pin	Function
A	SDI-12 Data
B	Power
C	Ground
D	Blank

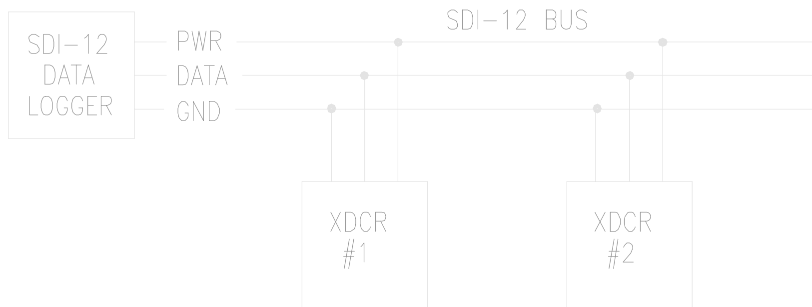
Connector Pinouts - Auxiliary I/O



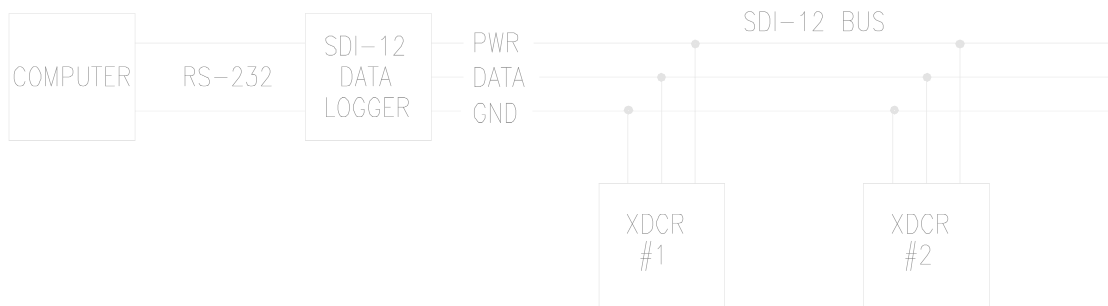
Pin	Function
A	Blank
B	Blank
C	Aux I/O Gate
D	Aux I/O Gate B
E	Aux I/O Gate A
F	Aux I/O Gate Return

Note: Consult your Specification Control Drawings for specific PS-2 level shifter pinout information and display information.

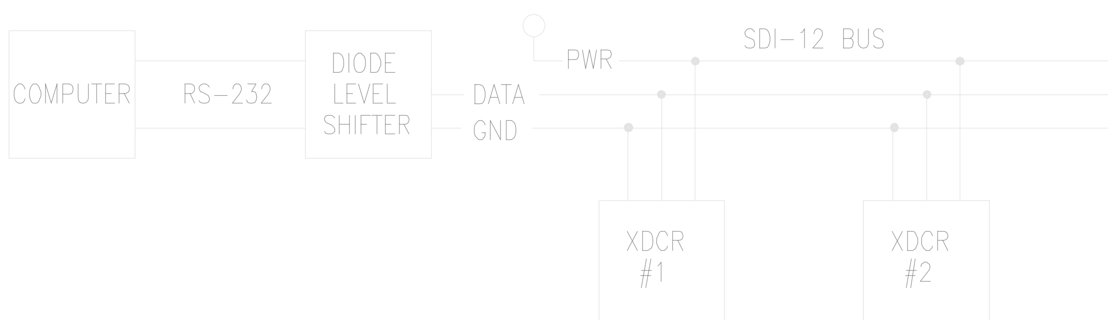
SDI-12 DATA LOGGER



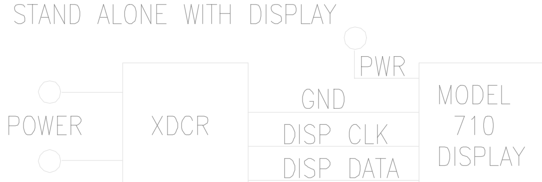
COMPUTER AND SDI-12 DATA LOGGER IN "TRANSPARENT" MODE



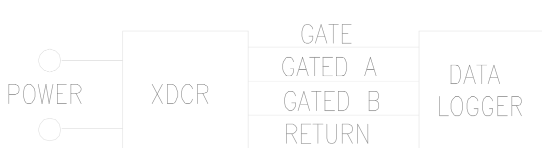
COMPUTER SERIAL PORT (Note: Precede all commands with *)



STAND ALONE WITH DISPLAY

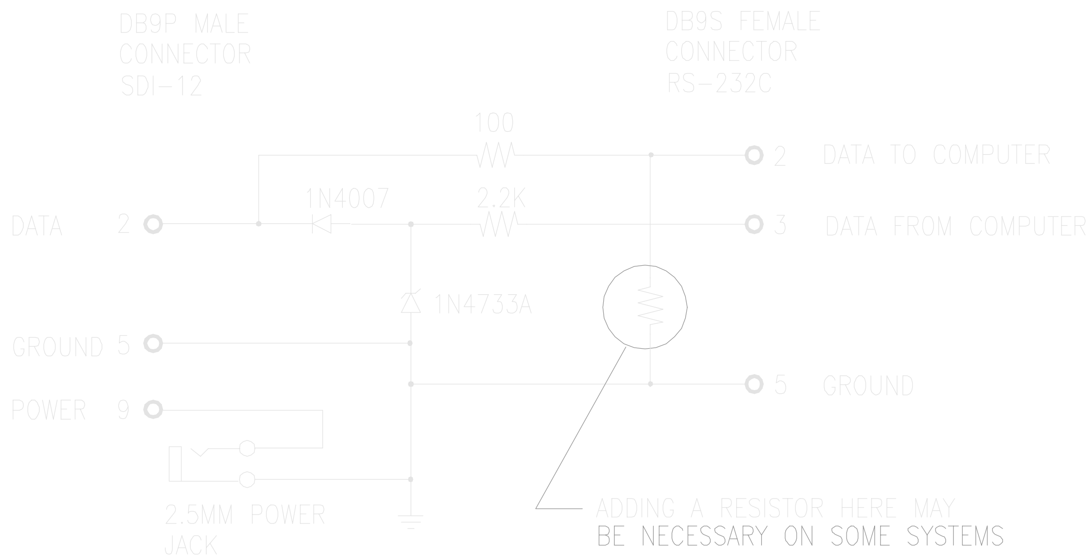


STAND ALONE WITH SHAFT ENCODER DATA LOGGER



Appendix B: Level Shifter / RS-232 Communication

The diode level shifter below works with most RS-232 serial ports. However, some serial ports with high input impedance require an additional resistor (typically 5K or 3K) between the *data to computer* pin and *signal ground*.



SCHEMATIC DIAGRAM
FOR LEVEL SHIFTER

SDI-12 TO RS-232C
LEVEL SHIFTER
PN 6505-001

Appendix B: Level Shifter / RS-232 Communication (continued)

A simple diagram showing hookup requirements using a serial port and level shifter is shown in Appendix A. Some commercial PS-2 Water Stage Sensors have a built-in level shifter.

A pigtail connector is provided which mates to the transmitter. Hookup consists of attaching power to pin 9, ground to pin 5. Connect the SDI-12 data line from the level shifter to pin 2. Connect the RS-232 transmit data, receive data, and signal ground lines to the level shifter.

These connections are all that the transmitter requires; however, depending on the user computer and how a program opens up the RS-232 port, the user may need to provide handshaking signal levels by jumpering pins on the computer connector. If you cannot communicate with the transmitter, your computer may be waiting for handshake signals (CTS, DSR, CD) which the transmitter does not provide. On most computers, you can choose to ignore these signals when you open up the communications channel. See the programming examples in this text. If your computer insists on these signals, you can provide them by jumpering back the DTR signal to the CTS, DSR, and CD pins on the same connector.

Most computer RS-232 serial ports have either a male or female 9 or 25 pin connector. Typical pin connections are shown below. However, the user should check his computer manual to verify them.

IBM PC AT 9 Pin	Standard RS-232 25 Pin
3 Data from Computer	2 Data from Computer
2 Data to Computer	3 Data to Computer
5 Signal Ground	7 Signal Ground
4 DTR	20 DTR
8 CTS	5 CTR
6 DSR	6 DSR
1 CD	8 CD
	1 Frame Ground

Appendix C: Shaft Encoder Technical Information

Note: Appendix C is copied from USGS Solicitation No. 7573, Attachment A (1989).

6.2 INCREMENTAL SHAFT ENCODER AND COMPATIBLE DATA LOGGER

The pressure sensor is intended to replace null-balance manometer systems at sites where the US Geological Survey (USGS) and the National Weather Service (NWS) conduct joint data collection efforts. The manometers provide output shafts that rotate at the rate of one revolution per foot measured change in stream-surface elevation. They are key elements in the joint efforts, serving as the basic sensor for both organizations.

The USGS collects data from the manometers with shaft-input, punched-paper-tape recorders. The NWS collects the data with incremental shaft encoders (Model 436A) and data loggers (Model 550A), manufactured by Handar, Inc.

The USGS plans to replace its mechanical recorders with electronic recorders with SDI-12 compatible sensor interfaces. The NWS, which has no plans to replace its data loggers, has requested outputs on the USGS pressure sensors that simulate the operation of their encoders and are suitable for direct acquisition by their data loggers.

With the exception of being designed for low power consumption, acquisition of data from the incremental encoder follows standard techniques. Data is transferred as events which mark the occurrences and directions (CW or CCW) of incremental changes in the angular position of the encoder's input shaft. The data logger responds to each such event by incrementing or decrementing an internal data register. Users can preset the register to establish an absolute value.

The manner in which this data acquisition operation is actually performed is illustrated in Figure 6-2. Signals A and B are logical wave forms existing within the encoder. Ideally, they are rectangular in shape and 90-degrees out of phase with each other. When the encoder's shaft rotates in a clock-wise direction the phase is such that A leads B. When it rotates in a counter clock-wise direction, B leads A.

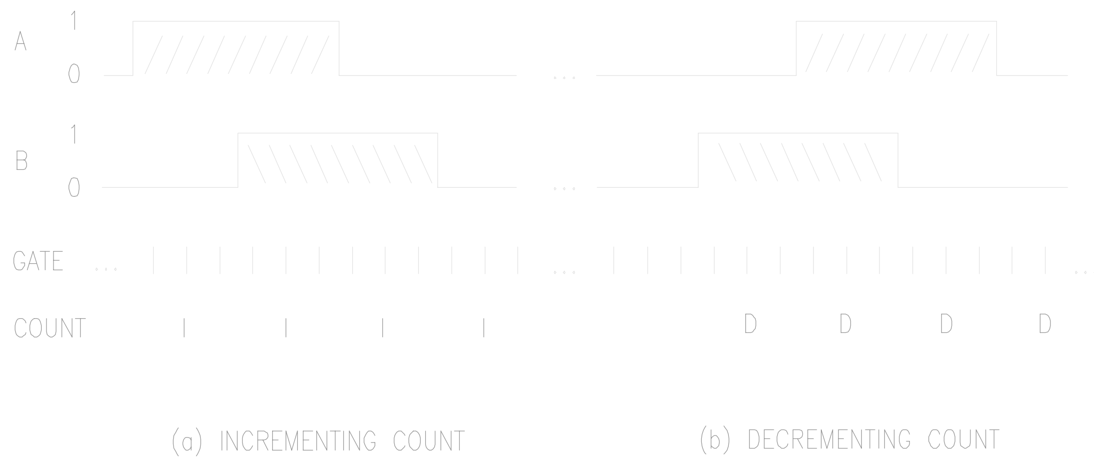


Figure 6-2 Encoder Signals.

The wave form transitions mark the occurrences of incremental changes in angular position of the shaft. The least angle is defined by two contiguous transitions of alternate waveforms (i.e. a transition in waveform A followed by a transition in waveform B, or vice-versa). Two contiguous transitions of the same waveform signal a reverse in the direction of shaft movement.

To minimize total power consumption, the data logger provides a gate signal with which it samples the electrical signals representing waveforms A and B. The data logger updates its internal data register on the trailing edge of the second such gate signal following the transition of a waveform. This operation is illustrated in Figure 6-2, (a) and (b). The waveforms in (a) have a phase relationship that indicates an incrementing (I) count and those in (b) indicate a decrementing (D) count.

The following signal lines are used to support data acquisition. Voltages and currents are referenced to the line between the encoder and its data logger.

Figure 6-3 Encoder to Datalogger Signals

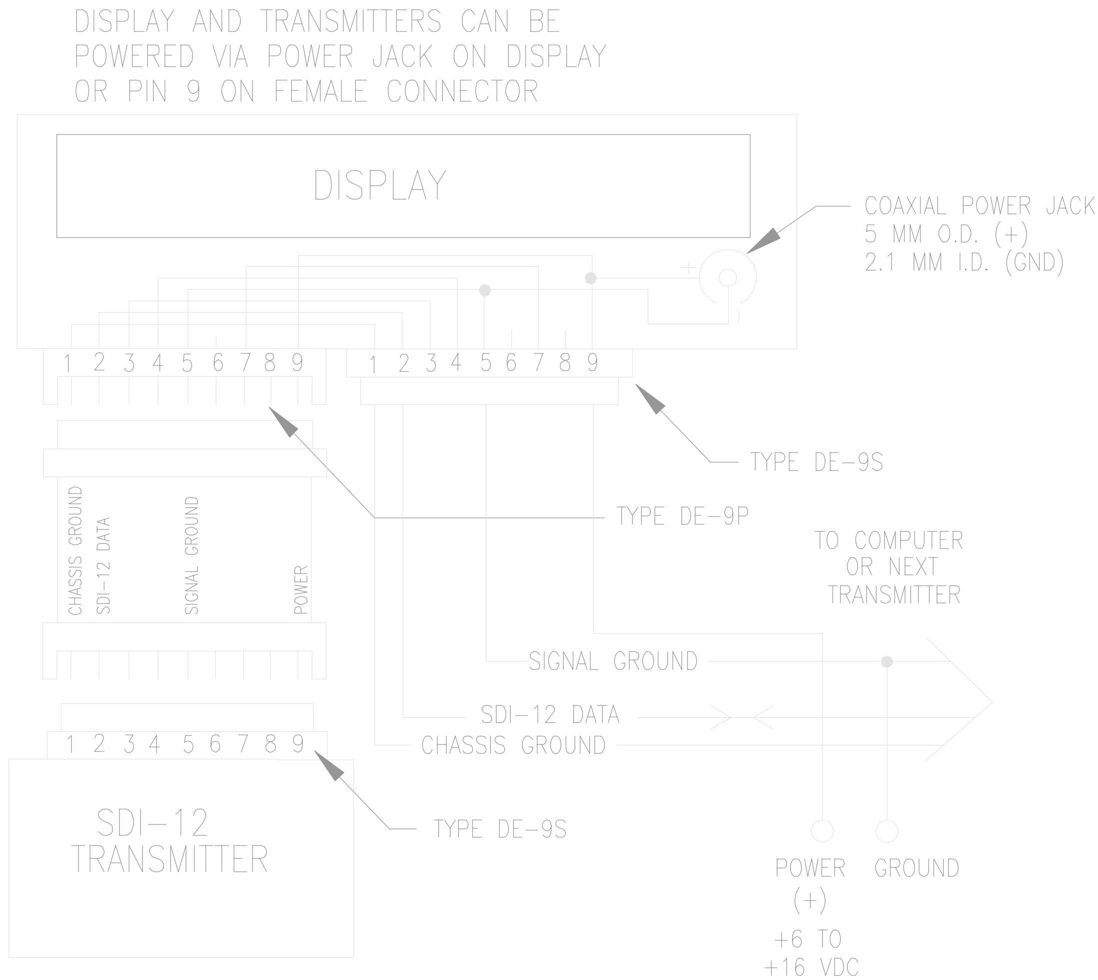
The "gate" is a pulsed signal provided from the data logger. It is normally "off", and switches "on" for approximately 10 microseconds at the rate of 4000 pulses per second (a duty cycle of about 5 percent). The "off" state is represented by an open-circuit output and the "on" state by an output voltage in the range from +4.5 to +5 volts. When "on", the output can source up to 20 milliamperes.

The "gated A and B" signals are determined by the "gate" and logical states of the encoder waveforms A and B, as shown in table 6-1.

Gate	A,B	Gated A,B
Off	1 -------- 0	Outputs in high impedance state; V(in) = logic supply voltage of the data logger (+4.5 to +5.5 volts) through a pullup resistor of 2.2 K-ohms.
On	1 -------- 0	+4.5 to +5.5 volts, or high impedance, as above -0.5 to +1.0 volt; I(in) @ 0 volts = 0.25 ma

Table 6-1 Gated A and B Signal Characteristics.

Appendix D: Model 710 Display Connections



Appendix E: Programming Hints

1. If you are unable to talk to the transmitter, you may be using the wrong address. Try all legal addresses 0 to 9 and lower case a to y, or run the STATSDI program on the demonstration disk and it will find the address for you. Keep track of the address when you change it.

2. If the transducer does not seem to work properly, run the STATSDI program from the demonstration disk and compare the output with the status printout shipped with the transmitter. Someone else may have reconfigured your transmitter for a different test.

3. The terminal program TERMSDI from the demonstration disk is a good way to practice using various commands.

4. When using an RS-232 serial port with a level shifter, remember to precede each command with an "*".

5. The level shifter in Appendix B works with most serial ports. However, some serial ports may require installing an extra resistor at the location shown in the drawing.

6. If the shaft encoder output or the display does not work, check the MD command and make sure it is set to the proper value.

7. When writing control parameters to the EEPROM (e.g. PR, UN, UA, etc.) always wait at least 0.4 seconds for the write to be completed before sending other commands. The transmitter will not respond to other commands until it finishes writing because interrupting an EEPROM write could leave the transmitter in an unknown state. The ZA command takes slightly longer than other EEPROM writes. After a ZA command, allow the time of one measurement command plus one second.

8. Do not routinely rewrite to the EEPROM at the start of every program. Check the values and change only what needs changing. A given register in the EEPROM is guaranteed only for 10,000 writes.

Appendix F: Useful IBM BASIC Instructions

References :	IBM BASIC REFERENCE MANUAL, Appendix C
	IBM BASIC HANDBOOK, Chapter 2

When calling BASIC from the system, the communications buffer size can be changed using the /C option.

Example: BASICA/C:2048 sets the buffer to 2048 bytes.

In BASIC, the following instructions are useful:

OPEN"COMn:"	Opens communication file n.
CLOSE n	Closes file n.
LOC(n)	Function to find out how many characters are in the input buffer for file n.
INPUT#	Input up to <cr> or comma
LINE INPUT#	Input up to <cr>
INPUT$	Input a specified number of characters.
PRINT#	Send data from computer.
WRITE#	Send data from computer. Not recommended as quotes are inserted around the string.
GET	Get a specific number of characters from the buffer.
PUT	Put a specific number of bytes into the output buffer.
ON COM(n)	Detects activity on the communications port.

String manipulation instructions.

INSTR	Find a specific character in the string.
LEFT$	
RIGHT$	
MID$	
VAL	Convert the string to a numeric value..
STR$	Convert a numeric value to a string.

Appendix G: Calculation of Temperature and Pressure from Period Measurements

The transmitter calculates temperature and pressure from period measurements of two frequency signals. The equations used in the calculations are given below:

$$\text{Temperature} = Y_1U + Y_2U^2 + Y_3U^3 \text{ degrees C}$$

$$P = C(1 - T_0^2/Tau^2)\,[1 - D(1 - T_0^2/Tau^2)] \text{ psi}$$

Where Tau = pressure period in microseconds.

$U = \text{(temp period in microseconds)} - U_0$

$C = C_1 + C_2U + C_3U^2$

$D = D_1 + D_2U$

$T_0 = T_1 + T_2U + T_3U^2 + T_4U^3 + T_5U^4$

These equations express temperature and pressure in terms of the transducer calibration coefficients:

Temperature coefficients: U_0 Y_1 Y_2 Y_3

Pressure coefficients: C_1 C_2 C_3 D_1 D_2 T_1 T_2 T_3 T_4 T_5

These coefficients are stored in EEPROM and can be obtained from the transmitter via the SDI-12 bus.

Final output is computed from the above using the following equation:

For UN= 1 to 8 $P_{output} = PM\,[\text{(Units Multiplier)} \times P + PA]$
For UN = 0 $P_{output} = PM\,[UF \times P + PA] + UA$

When units are changed using the UN or UF commands, PA is automatically recalculated to be correct in the new units.

Appendix H: Command List

Regular SDI-12 commands:

D0	Send data.
I	Identify. Send transducer identifying information.
M	Measure pressure.
M2	Measure temperature.
M3	Measure period of the pressure sensor.
M4	Measure period of the temperature sensor.
V	Verify. Check PROM checksum.
X	Enter eXtended command mode. Next regular SDI-12 command cancels the extended mode.

Configuration commands (extended commands):

EW Enable EEPROM Write for one command.

AD Change Device Address.
PR Read/enter Pressure Resolution.
TR Read/enter Temperature Resolution.
UN Read/enter choice of engineering UNits.

0. User defined	3. bar	6. inches Hg
1. psi	4. kPa	7. Torr
2. mbar or hPa	5. MPa	8. meters H_2O

UA User Adder. User defined offset for UN=0.
UF User Factor. User defined scale factor for UN=0.

DP Decimal Place. Controls the number of decimal places sent.
MD MoDe. Controls the display, shaft encoder, and power down options.
SR Service Request. Activates Service Request.

Commands to control the Model 710 display (extended commands):

DC Display Check.
DD Display Distance.
DR Display Right adjusted data from computer.
DV Display Value from computer, left adjusted.

Special diagnostic commands (extended commands):

CX Check crystal for microprocessor clock.

Calibration commands (extended commands):

ZA Zero Adjust.

SN Model and Serial Number information.

PA Pressure Adder (offset adjustment)
PM Pressure Multiplier (span adjustment)

TC Timebase Correction.

U0 Read/enter U_0 coefficient.
Y1 Read/enter Y_1 coefficient.
Y2 Read/enter Y_2 coefficient.
Y3 Read/enter Y_3 coefficient.

C1 Read/enter C_1 coefficient.
C2 Read/enter C_2 coefficient.
C3 Read/enter C_3 coefficient.

D1 Read/enter D_1 coefficient.
D2 Read/enter D_2 coefficient.

T1 Read/enter T_1 coefficient.
T2 Read/enter T_2 coefficient.
T3 Read/enter T_3 coefficient.
T4 Read/enter T_4 coefficient.
T5 Read/enter T_5 coefficient.