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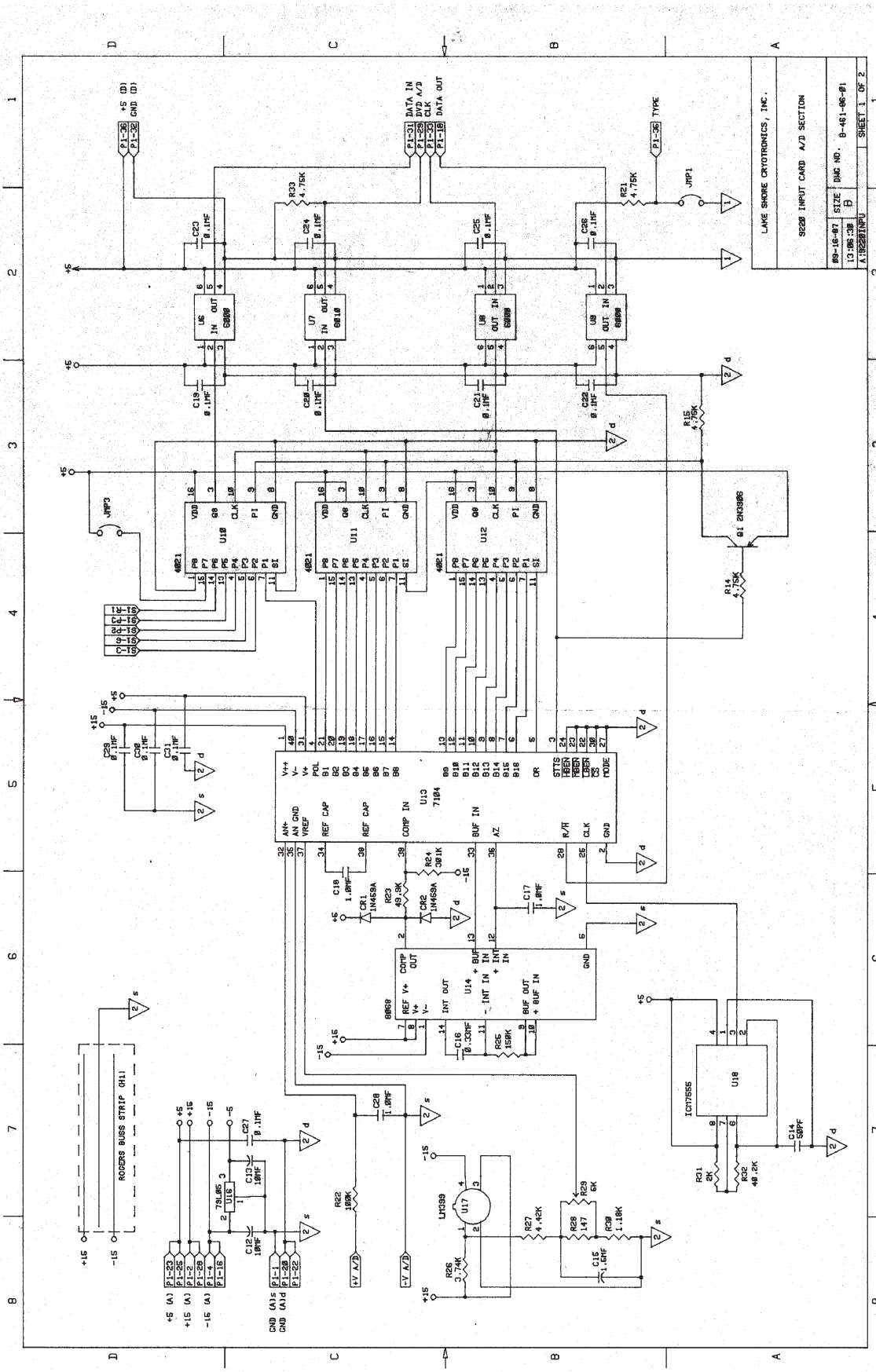
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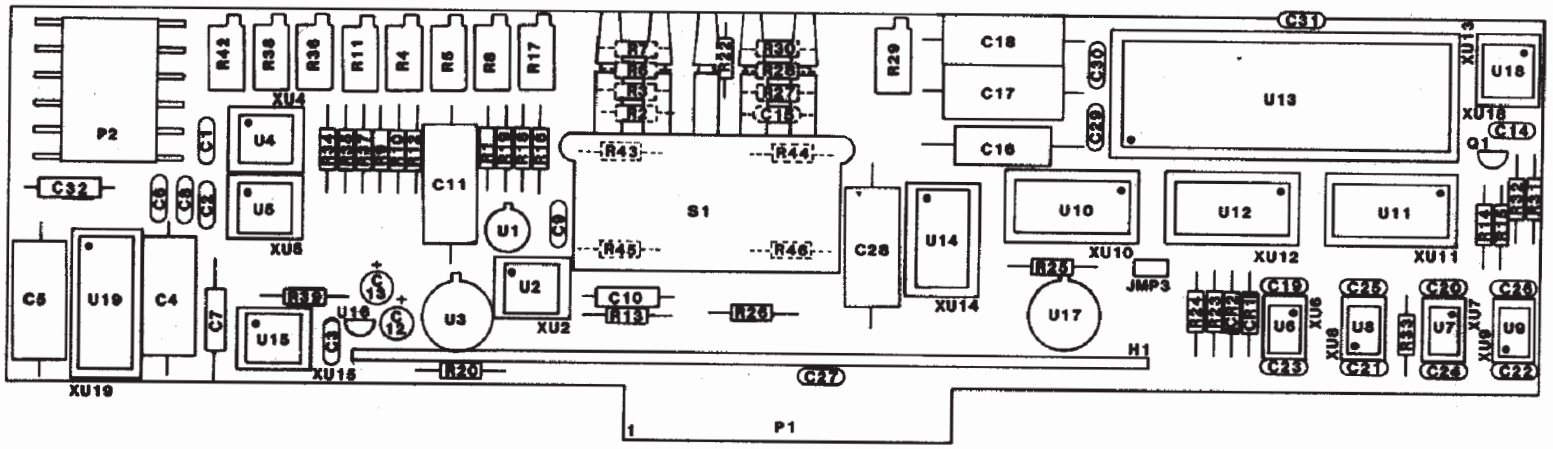
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Model 9220-1. Model 9220 User Configurable Input Card

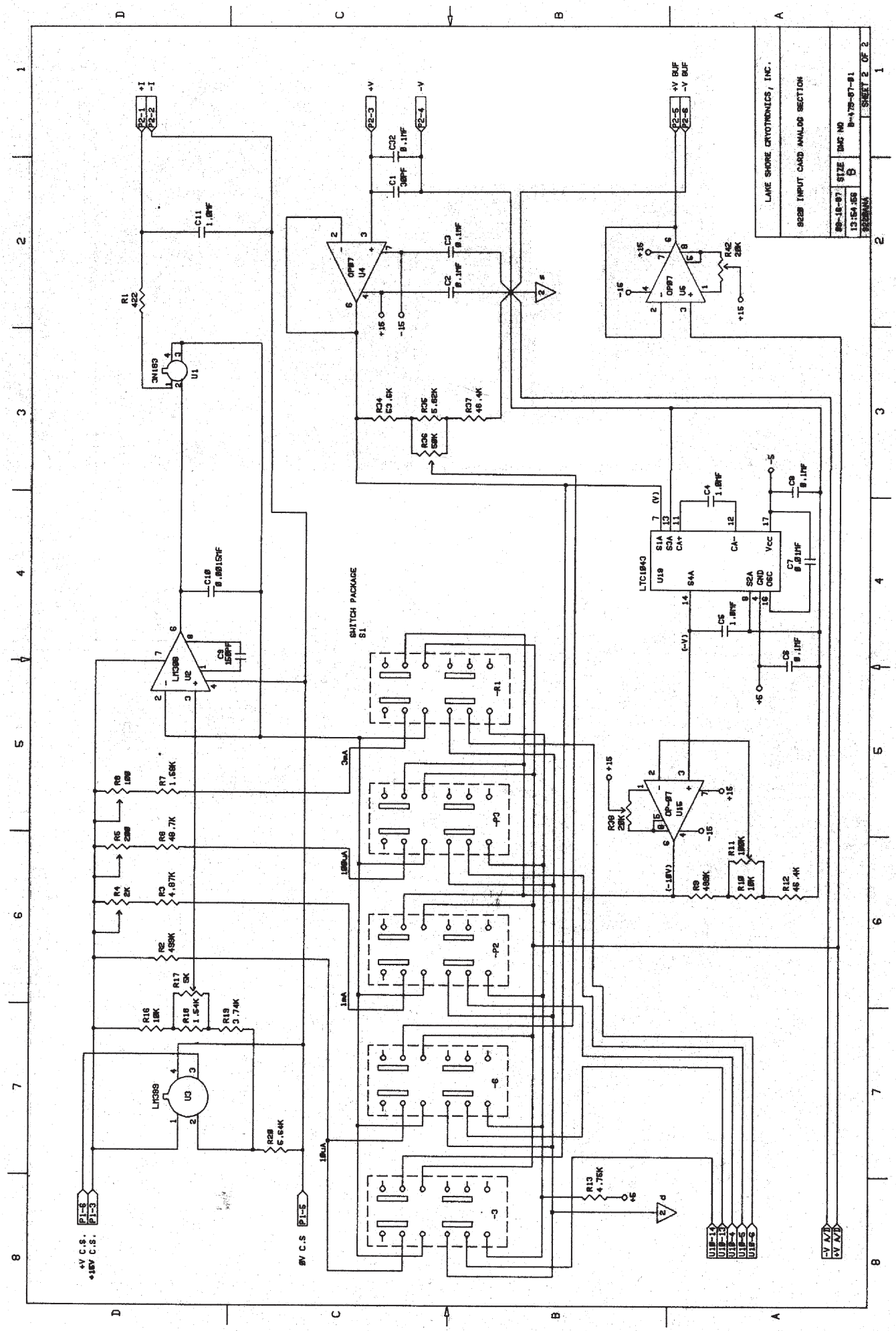
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REPLACEABLE PARTS LIST - 9220 ANALOG INPUT CARD

ITEM NO	LSCI Part Number	Qty	Description	MFR	MFR PART NO
C4,5,11 17,18,28	101-034	6	CAP,PP,1.0MF,100V	FDYNE	MPP2X-1.0-100-10
C16	101-025	1	CAP,PP,.33MF,100V	FDYNE	MPP-11.33MFD
P2	106-142	1	CONNECTOR, (IC TO BP) 6 POST LOCKING HEADER	MOL	2420-09-75-1061
Q1	102-072	1	TRANSISTOR,PNP,SIGNAL		2N3906
S1	105-649	1	SWITCH,2 POS,4 POLE INTERLOCKING	EGC	2XMTA7.5(NONE) 4UGRP
U1	102-074	1	MOSFET,P CHANNEL	SIL	3N163
U2	104-005	1	IC, OP-AMP		LM308
U3,17	102-043	2	VOLTAGE REFERENCE,6.95V	NAT	LM399H
U4,5,15	104-001	3	IC, OP AMP	PMI	OP07EP
U6,8,9	104-355	3	IC, OPTOCOUPLER	GI	740L6000
U7	104-356	1	IC, OPTOCOUPLER	GI	740L6010
U10-12	104-099	3	IC, P-S SHIFT REGISTER		CD4021BCN
U13	104-461	1	IC, A/D CONVERTER	ISL	ICL7104-16CPL
U14	104-460	1	IC, A/D REFERENCE	ISL	ICL8068ACPD
U16	102-020	1	REGULATOR, -5V	MOT	79L05CT
U18	104-051	1	IC, TIMER	ISL	ICM7555IPA
U19	104-078	1	IC, SWITCHED CAPACITOR	LT	LTC1043

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9305.1 INTRODUCTION

This section contains information pertaining to the Model 9305 Thermocouple Input Card. Included is a description and information on specifications, installation, operation and field calibration.

9305.2 DESCRIPTION AND SPECIFICATIONS

9305.2.1 Description

The Model 9305 Thermocouple Input Card is designed to be installed in a Lake Shore DRC-91C or DRC-93C Temperature Controller. It allows either Input A or Input B (or both with two cards) to accommodate thermocouple sensors. Chromel vs. Gold-0.03 at.% Fe, Chromel vs. Gold-0.07 at.% Fe, E, K, and T thermocouples are supported with internal curves that enable the controllers to operate in temperature units C, F and K, as well as voltage in millivolts.

The 9305 utilizes a secondary temperature sensor to monitor the Reference Junction (room) temperature and provide curve compensation. The Reference Junction Compensation can be disabled so the 9305 can be used with external compensation techniques.

An Offset Adjustment is provided adjacent to the Terminal Block to compensate for thermocouple variations and system irregularities.

9305.2.2 Specifications

Specifications for the Model 9305 Thermocouple Input Card are given in Table 9305-1.

The temperature range for each type of thermocouple is given in Table 9305-2.

9305.3 INSTALLATION

The 9305 can be installed in a DRC-91C or a DRC-93C as either Input A or Input B. The 9305 is installed prior to shipment if ordered with a controller. If only one card is ordered and its input is not specified when ordered, it is installed in Input A. When a card is ordered for field installation, the Input Card Configuration Table located on the first page of the Instruction Manual should be updated to keep documentation current.

Use the following procedure for the installation of the 9305 Thermocouple Input Card.

WARNING

To prevent shock hazard, turn off the instrument and disconnect it from AC line power and all test equipment before removing cover.

1. Set the POWER switch to OFF and disconnect the power cord from the unit. Remove the three top panel screws and slide the panel off. Note from the calibration cover the position of the Input Slot the 9305 will occupy.

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Table 9305-1. Specifications, Model 9305 Thermocouple Input Card

Input Voltage Range: Room Temperature Compensated: -10 to +10 millivolts. Uncompensated: -15 to +15 millivolts.

Temperature Range: Depends on Thermocouple type. Refer to Table 9305-2.

Thermocouples (Ordered Separately): Chromel vs. Au-0.03 at.% Fe, Chromel vs. Au-0.07 at.% Fe, Chromel vs. Constantan (E), Chromel vs. Alumel (K), and Copper vs. Constantan (T).

Thermocouple-EMF Tables: Curve tables are stored in the controller and accessed through normal curve selection. The curves are normalized to zero degrees Celcius and listed in Table 9305-4.

Input Resistance: Greater than 10^9 ohms

Terminal Block and Room Temperature Compensation: A secondary sensor is installed in the rear panel mounted Terminal Block to measure the Reference Junction Temperature. Compensation can be enabled or disabled.

Offset Adjustment: One-point hardware adjustment built into the Terminal Block.

Electronic Resolution: 1 microvolt

Electronic Accuracy: ± 3 μV for -10 to +10 millivolts, ± 5 μV up to the -15 and +15 millivolt full scales.

Overall Accuracy: Depends on conformity of the thermocouple to it's standard curve and system configuration.

Controllability: Typically ±0.2K in a properly designed system.

Display Resolution: 5 digits. Compensated and uncompensated voltage in millivolts from 0.000 to $\pm$15.000 or temperature in Celcius, Fahrenheit and Kelvin.
Note: When displaying millivolts, the unit V is shown.

Temperature Control Signal: Card processes an analog voltage output signal 200 times the thermocouple voltage. The instrument generates setpoint voltage based on the voltage or temperature entered by the user. If compensation is enabled, the setpoint voltage is modified to reflect the compensation required. Real-time analog comparison of these two voltages provides the required control error signal.

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Table 9305-2. 9305 Thermocouple Input Card Temperature Ranges

Thermocouple Type	Compensated	Uncompensated
Chromel vs. Au-0.03 at.% Fe	4 - 325 K	4 - 325 K
Chromel vs. Au-0.07 at.% Fe	1.4 - 325 K	1.4 - 325 K
E	3 - 425 K	3 - 475 K
K	3 - 525 K	3 - 575 K
T	3 - 485 K	3 - 575 K

2. Remove the four screws that secure the calibration cover to its clips and remove the cover.

3. If the 9305 is to replace an existing Input Card, unplug the Input Card which is to be replaced. Disconnect the wiring harness mating connector by lifting the locking tab on the Input Card and gently pulling on the body of the wiring harness mating connector.

4. Attach the Thermocouple Terminal Block into the Alternate Connector Slot J9 if the Card is Input A or in Alternate Connector Slot J11 if the Card is Input B with the wires facing the input card (Slots are shown in Figure 3.2). Uncovering the Connector Slot may require the removal of a plastic cover plate. If the JF mating connector on the main board interferes with installation of the Terminal Block remove it by lifting the locking tab and gently pulling the body of the connector. Be sure to lock the JF mating connector securely in place after this step is complete.

5. Connect the wiring harness from the Terminal Block to the (bottom) **P3** Connector on the 9305 Card. Also connect the J1 (Input A) or J2 (Input B) wiring harness mating connector to the (top) **P2** Connector on the 9305 Card. Make sure that the wiring harness locking tab is seated over the extended edge of the wiring harness mating connector.

   Plug the 9305 into the appropriate Input Card Slot with the component side facing to the left of the unit as viewed from the front. Make sure the card is thoroughly seated. Verify that the wiring harness is in place correctly by noting that the "A" or "B" on the harness connector is facing up (if it is not, review the harness installation again).

6. Replace the calibration cover making sure to align the cards so that their respective

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adjustment trimpots are accessible through the cover. Place the cover on top of the cover clips and start the screws. Carefully move any misaligned cards to their proper position and tighten the cover screws. Replace the top panel and three top panel screws.

9305.4 SENSOR ATTACHMENT

Thermocouple leads are attached to the Terminal Block by aluminum screws. Be sure to tighten the terminal screws carefully. Loose connections will result in unstable readings and control. The leads must be connected with the proper polarity or the 9305 will not operate properly. The positive terminal of the terminal block is marked with a plus sign and should correspond with the positive thermoelement listed for each type of thermocouple in Section 9305.5.

9305.5 NOTES ON THERMOCOUPLES

Lake Shore's 9305 Thermocouple Input Card supports the Chromel vs. Gold, E, K, and T type thermocouples.

9305.5.1 Gold-Chromel Thermocouples

The Gold Chromel thermocouple consists of a Gold(Au)-0.03 at.%, or 0.07 at.% Iron(Fe) alloy as the negative thermoelement and a Ni-Cr alloy (Chromel) as the positive thermoelement (KP). This type of thermocouple can be used at very low temperatures, even below 10 K.

9305.5.2 Type E Thermocouples

The ASTM (American Society for Testing and Materials) designation type E indicates a thermocouple pair consisting of a Ni-Cr alloy (Chromel) as the positive thermoelement (EP) and a Cu-Ni alloy (Constantan) as the negative thermoelement (EN). This thermocouple has the highest sensitivity of the three ASTM standard thermocouple types typically used for low temperature applications, types E, K, and T. The E thermocouple is the best choice for temperatures down to about 40 K. It is recommended for use in oxidizing environments, or in sulphurous or reducing atmospheres. It should not be used in environments that promote corrosion.

9305.5.3 Type K Thermocouples

The ASTM designation type K indicates a thermocouple pair consisting of a Ni-Cr alloy (Chromel) as the positive thermoelement (KP) and a Cu-Al alloy (Alumel) as the negative thermoelement (KN). It should not be used in sulphurous or reducing atmospheres, or in environments that promote corrosion.

9305.5.4 Type T Thermocouples

The ASTM designation type T indicates a thermocouple pair consisting of Cu (Copper) as the positive thermoelement (TP) and a Cu-Ni alloy (Constantan) as the negative thermoelement (TN). This type of thermocouple may be used in vacuum as well as oxidizing or reducing environments down to about 90 K. At temperatures below 80 K the thermoeletric properties of the positive thermoelement (TP) are very dependent on the impurity of iron.

9305.6 PRINCIPLE OF OPERATION

The 9305 Thermocouple Input Card has the capability of interfacing 5 different thermocouple types in

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Table 9305-2 to the Lake Shore DRC-91C and DRC-93C Temperature Controllers over their respective temperature ranges.

The thermocouple voltage is amplified by 100 by a circuit which is attached to the Terminal Block . The thermocouple voltage is further amplified by a factor of 2 (tunable) by the Control Amplifier on the 9305 Thermocouple Input Card.

The amplified signal is sent to the main board analog control circuitry and can be accessed from the Buffered Output line of the J3 Monitor Connector on the controllers back panel. In addition, the amplified thermocouple voltage is applied to a 15 bit A/D converter on the Thermocouple Input Card so that digitized thermocouple voltage can be sent to the main board microprocessor. The Thermocouple A/D converter has an auto-zero function which means that the only calibration required is for the relative gain.

A secondary diode temperature sensor is attached to the Terminal Block to monitor the reference junction temperature needed for Reference Junction Compensation. A constant current source on the 9305 Card is applied to the Secondary Sensor. A 15 bit A/D converter on the 9305 Card digitizes the secondary sensor voltage and sends the data to the main board microprocessor. The microprocessor on the main board of the controller calculates the reference junction temperature. The reference junction temperature is used in compensation to account for the difference between room temperature and the normalization temperature of the curves, zero degrees Celcius.

An Offset Adjustment is provided adjacent to the Terminal Block. This adjustment will zero out small voltage offsets that result from sensor lead attachment and differences from the internal curve.

9305.6.1 Display Operation

Digitized thermocouple and secondary sensor voltages on the 9305 card are sent to the main board of the controller. The secondary sensor temperature is computed from its voltage and a thermocouple voltage corresponding to the secondary sensor temperature is calculated. If correction is selected, the compensation value is added to the thermocouple voltage. Corrected voltage in millivolts is then used as a display value or converted to Celcius degrees, Fahrenheit degrees, or Kelvin for display.

9305.6.2 Control Operation

Control operation begins when the operator enters a Setpoint voltage in millivolts. If the Setpoint is in temperature, the main board computes an equivalent voltage using the built-in Thermocouple table. The main board microprocessor then checks to see if Reference Junction Compensation is enabled.

If the Reference Junction Compensation is disabled, a signal which is 200 times the digital value of Setpoint voltage is applied to the Setpoint D/A to obtain the Setpoint voltage for control.

If the Reference Junction Compensation is enabled, a voltage corresponding to the Terminal Block temperature is subtracted from the Setpoint voltage. A signal which is 200 times the digital value as

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calculated above is applied to the Setpoint D/A to obtain the Setpoint voltage for control.

The control analog hardware compares the Setpoint voltage from the Setpoint D/A converter and the amplified thermocouple voltage to obtain an error signal. The error signal is minimized through the PID control circuitry.

9305.7 OPERATING INSTRUCTIONS

9305.7.1 Thermocouple Curve Selection

Thermocouple Tables are chosen by selecting one of the Curves numbers given in Table 9305-3. The instruments detect the presence of the Thermocouple Input Card and then select the proper Thermocouple Table rather than the Standard Diode or Resistance curve listed in the Instruction Manual.

The SENSOR ID Switches on the rear panel of the DRC-91C are used to select curves as described in Instruction Manual Section 2.3.8. Curve selection can also be made over Computer Interface as described in Section 4.8.5.

On the DRC-93C the Thermocouple Table is selected by selecting the Curve # as described in the DRC-93C Instruction Manual Section 3.9.1. Curve selection can also be made over Computer Interface as described in Section 4.8.9.

9305.7.2 Selection of Reference Junction Compensation on the DRC-91C

Whether or not Reference Junction Compensation is used is selected using Switch 3 of the SENSOR ID.

When Switch 3 of the SENSOR ID is closed (1) the Reference Junction Compensated value of the thermocouple voltage is displayed. When Switch 3 of the SENSOR ID is open (0), the actual (measured) thermocouple voltage or uncompensated temperature is displayed. With the 9305 selected as the Display Sensor, hold the LOCAL key to show card type and curve number. If compensation is active the display will show +9305 and if it is inactive -9305.

Table 9305-3. Curve Numbers

Thermocouple Type	Standard Curve #
Chromel vs. Au-0.07 at.% Fe	00
Chromel vs. Au-0.03 at.% Fe	01
E	02
K	03
T	04

9305.7.3 Selection of Reference Junction Compensation on the DRC-93C

When a 9305 Thermocouple Input Cards is installed, pressing the SENSOR key will display either +9305 or -9305. The +9305 means that the thermocouple voltage is corrected for the Terminal Block temperature. The -9305 means that the thermocouple voltage is being displayed with no compensation.

To select whether Reference Junction Compensation is used or not is accomplished from the front panel by a combination of the SENSOR key, SCAN ( ) key and the key and key. The procedure is as follows.

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1. Press and hold the SENSOR key.

2. While holding the SENSOR key, press the SCAN ( ) key. You may now release the SENSOR key.

3. To change the sign if in the upper Display press the key while still holding down the SCAN ( ) key. Similarly, to change the sign if in the lower Display press the key while still holding down the SCAN ( ) key.

4. Release the key (or key) and then the SCAN ( ) key.

You should press the SENSOR key to verify that the sign is as desired.

9305.7.4 Selection of Reference Junction Compensation via the Computer Interface

To select or prevent Reference Junction Compensation via the IEEE interface, use the AC_1C_2 and BC_1C_2 commands described in the DRC-91C (Section 4.8.5) or DRC-93C (Section 4.8.9) Instruction Manual. The Reference Junction Compensation bit may be listed as Switch 3 or the Thermal Correction bit (used on the 9318C card). Turning on (1) that position turns on the compensation.

9305.7.5 Rear Panel Offset Adjustment

When a new or different thermocouple is attached to the instrument it is desireable to permit the addition of an offset to compensate for discrepancies in the thermocouple material, leads and connections. An Offset Adjustment trimpot is provided next to the Terminal Block on the Back Panel to allow quick calibration of the thermocouple without removal of the instrument cover.

The procedure is as follows.

1. Place the thermocouple in a reference bath of known temperature (liquid nitrogen, ice, etc.). Allow the system to stabilize to the Reference Temperature.

2. With the front panel of the instrument, select the thermocouple input and the desired temperature units.

3a. On the DRC-91C enable Reference Junction Compensation by closing (1) Switch 3 of the appropriate SENSOR ID on the rear of the instrument. Hold the LOCAL key and verify the display as +9305. See Section 9305.7.2.

3b. On the DRC-93C enable Reference Junction Compensation by using the SENSOR, SCAN ( ), and , or keys. The Display should show +9305 when the SENSOR key is pressed. See Section 9305.7.3.

4. Adjust the Offset Adjustment trimpot so that the Display reads the Reference Temperature.

Note: The Offset Adjustment compensates for the thermocouple used in the calibration. If another thermocouple is attached, or the thermocouple has aged, or the configuration of the system is changed, then the Offset Adjustment must be repeated.

9305.7.6 Curve Data Format

The 9305 Thermocouple Input Card will operate with a user defined curve as well as the Internal Curves listed in Table 9305-4. Temperature is calculated by linear interpolation between curve points.

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The card is hardware limited to reading input between -15 millivolts and +15 millivolts. All curves should be limited in temperature so not to exceed these voltage values. If Reference Junction Compensation is desired, the thermocouple curve must be normalized to zero degrees Celcius. Compensation also limits the practical range of the card by approximately the room temperature voltage of the thermocouple used.

The controllers are designed to operate on sensor curve data in the range of 0.00000 to 3.00000 volts so thermocouple voltage must be converted to this range before it is entered into a curve table. To obtain the proper table value from a thermocouple voltage it must be summed with 15 millivolts to make it positive and multiplied by one hundred to shift resolution.

$$V_{TABLE}(V) = 100 * (V_{THERMOCOUPLE}(mV) + 15(mV))$$

A -15.0000 millivolt thermocouple voltage will result in a 0.00000 volt table value and +15.0000 millivolts will result in 3.00000 volts.

Once the Thermocouple Curve has been converted, carefully read and follow the instructions in DRC-91C Manual Section 4.14 or DRC-93C Manual Section 4.16 on how to enter the data into a controller.

9305.8 CALIBRATION SCHEDULE AND EQUIPMENT

The design of the 9305 Thermocouple Input Card is such that calibration should not be required more often than every six to twelve months in order to keep the card within its accuracy specification. However, if calibration is required, the following equipment is needed:

1. Digital Voltmeter (DVM) - 5 1/2 digit resolution or better.

2. Precision Voltage Standard- capable of a 10 millivolt signal to within ±1 microvolt.

The accuracy of the calibration depends on the accuracy of the Digital Voltmeter (DVM) and the Voltage Standards used. Since very often these values will not be available to the user of this instrument, Lake Shore Cryotronics, Inc. offers a calibration service. Contact a factory representative for information concerning calibration.

NOTE: Setpoint calibration is described in Chapter 5 of the DRC-91C and DRC-93C Instruction manual. The only additional instructions required when calibrating the setpoint D/A converter with the 9305 card is to make sure that the Reference Junction Compensation is turned off (Section 9305.7.3).

9305.9 CALIBRATION

The controller should be allowed a one hour warm-up time to achieve rated specifications. Use the following procedure to begin calibration of the 9305 Thermocouple Input Card.

1. Remove the three top panel screws and slide the panel off.

2. Configure the controller so the card to be calibrated is the CONTROL input.

3. Locate the DIP switch S1 on the 9305 Input Card. Open (0) S1.1 for calibration. This forces the 9305 to update Secondary Sensor information every conversion cycle. Under normal operation (S1.1 closed (1))

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Secondary Sensor information is updated once every 25 cycles.

4. Locate the Secondary Sensor current sensing resistor terminals (I+ and I-), the Secondary current source adjustment (10μA) , the Control Amplifier Span adjustment (CNT V), and the A/D converter span adjustment (A/D) on the calibration cover for the 9305 Card.

5. Locate the Rear Panel Offset Adjustment on the Terminal Block.

6. Locate the test points TP24 (CNT V) and TP1 (GND(2s)) of the Calibration Card.

7. Avoid using clip on leads during calibration because they do not make good electrical connections. Attach test equipment lead wires with the terminal screws.

The calibration procedure is divided into three parts.

1. Calibration of the Secondary Sensor Current Source.

2. Calibration of the Control Signal Amplifier and Rear Panel Offset Adjustment.

3. Calibration of the Thermocouple and Secondary Sensor A/D converters on the 9305 Thermocouple card.

9305.9.1 Secondary Sensor Current Source Calibration

1. Connect the DVM plus lead to terminal I+ and the DVM minus lead to the I- terminal.

2. Adjust the trimpot labelled 10μA so that the DVM reads 1.000 volt ±0.001 volt.

9305.9.2 Control Amplifier and Rear Panel Offset Adjustment Calibration

1. With the front panel of the instrument, select the thermocouple input and place in the V (voltage) units.

2a. On the DRC-91C disable Reference Junction Compensation by opening (0) switch 3 of the appropriate SENSOR ID on the rear of the instrument. See Section 9305.7.2.

2b. On the DRC-93C disable Reference Junction Compensation by using the SENSOR, SCAN ( ), and , or keys. The Display should show -9305 when the SENSOR key is pressed. See Section 9305.7.3.

3. Connect the DVM plus and minus leads to the TP24 (CNT V) and TP1 (GND(2s)) found on the calibration card of the controller.

4. Apply a zero signal to the +V and -V Thermocouple Input terminals by shorting across the Terminal Block with a short jumper wire. Allow the Terminal Block temperature to settle for five minutes.

5. Adjust the Rear Panel Offset Adjustment on the Terminal Block until the output on the DVM is 0.0000 volt. Be sure to remove the jumper wire after this step.

6. Apply a +10 millivolt signal to the +V and -V Thermocouple Input terminals on the Terminal Block and allow the temperature to settle.

7. The DVM should read about -2 volts. Adjust the input card trimpot labeled CNT V (Control

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Voltage Span) until the output on the DVM is -2.000 volts ±0.0001 volt.

9305.9.3 Thermocouple and Secondary Sensor A/D Calibration

The Thermocouple and Secondary Sensor A/D converters have an auto-zero function which means that the only calibration required is for the relative gain (span). The procedure is as follows.

1. Make sure the instrument is setup as described in parts 1., 2a. (or 2b.) and 3. in the previous section (Control Amplifier Calibration).

2. Apply a +10 millivolt signal to the +V and -V Thermocouple Input terminals on the Terminal Block.

3. The Display should read about 10 millivolts. Adjust the trimpot labeled A/D (Thermocouple A/D Span) so that the voltage read on the Display is 10.000 millivolts.

4. This test is to verify that the A/D converter is symmetrical. Apply a -10 millivolt signal to the +V and -V Thermocouple Input terminals. The DVM should read +2.0000 ±0.0006 volt. The Display should read -10.000 ±0.003. If it does not meet these specifications, the unit should be returned to the factory for calibration.

9305.9.4 Reference Junction Test

This test is to verify that the Reference Junction Compensation circuitry is operating properly. If this test does not produce the following results please consult the factory.

1. Apply a zero volt signal to the +V and -V Thermocouple Input terminals by shorting across the Terminal Block with a short jumper wire.

2. Select the controller to display the 9305 card in temperature units.

3. Enable the Reference Junction Compensation as described in Section 9305.6. The reading on the display should read Room Temperature.

4. Disable the Reference Junction Compensation and the display should read Zero degrees Celcius (the normalization point of the curves).

9305.9.4 Calibration Completion

1. Close (1) S1.1 to return the 9305 to normal Secondary Sensor update operation.

2. Remove anything that may be shorting the two halves of the terminal block.

3. Verify that thermal correction is properly selected.

4. Slide the top cover onto the instrument and replace the three screws.

9305.10 OPTION COMPATIBILITY

The special nature of thermocouple sensors and their connections limits compatibility with Lake Shore options and accessories. Thermocouples must be attached directly to a terminal block. The 8229 Scanner Input Option and 8085 External Sensor Scanner are not adapted with terminal blocks so they can not be used with the 9305 Thermocouple Card. The 8225 Linerized Analog Output Option will function in temperature units only

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with a 9305 installed, giving an output of 10mV/K. The 8000 series Precision Calibration Options are not available from Lake Shore for thermocouple sensors.

9305.11 REPLACEABLE PARTS

Included in this section is Figure 9305-1 showing the Model 9305 Thermocouple Input Card Schematic, Replaceable Parts List and illustrated Component Layout. Also included is Figure 9305-2 showing the 9305 Terminal Block Schematic, Replaceable Parts List and Component Layout.

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Table 9305-4. 9305 Thermocouple Curves

Breakpoint Number	Chromel vs. Au-0.03 at.% Fe Temp(K)	V_{TC}(mV)	Chromel vs. Au-0.07 at.% Fe Temp(K)	V_{TC}(mV)
1	0.0	-15.0000	0.0	-15.0000
2	3.5	- 4.6676	1.4	- 5.2982
3	8.0	- 4.6067	3.0	- 5.2815
4	13.5	- 4.5259	4.8	- 5.2594
5	18.0	- 4.4571	7.0	- 5.2285
6	24.0	- 4.3703	10.5	- 5.1742
7	30.0	- 4.2869	19.0	- 5.0315
8	52.0	- 3.9928	26.0	- 4.9126
9	60.0	- 3.8830	48.0	- 4.5494
10	65.0	- 3.8126	58.0	- 4.3810
11	70.0	- 3.7411	70.0	- 4.1733
12	80.0	- 3.5948	80.0	- 3.9952
13	90.0	- 3.4436	90.0	- 3.8132
14	105.0	- 3.2026	100.0	- 3.6270
15	115.0	- 3.0374	110.0	- 3.4370
16	125.0	- 2.8689	120.0	- 3.2435
17	135.0	- 2.6957	135.0	- 2.9477
18	145.0	- 2.5184	150.0	- 2.6452
19	160.0	- 2.2468	165.0	- 2.3372
20	170.0	- 2.0615	180.0	- 2.0242
21	180.0	- 1.8725	200.0	- 1.6004
22	195.0	- 1.5839	220.0	- 1.1693
23	210.0	- 1.2905	245.0	- 0.6232
24	225.0	- 0.9912	270.0	- 0.0705
25	240.0	- 0.6847	300.0	+ 0.5986
26	265.0	- 0.1670	305.0	+ 0.7158
27	275.0	+ 0.0378	310.0	+ 0.8431
28	285.0	+ 0.2387	315.0	+ 0.9944
29	305.0	+ 0.6350	320.0	+ 1.1940
30	325.0	+ 1.0387	325.0	+ 1.4841
31	999.9	+15.0010	999.9	+15.0010

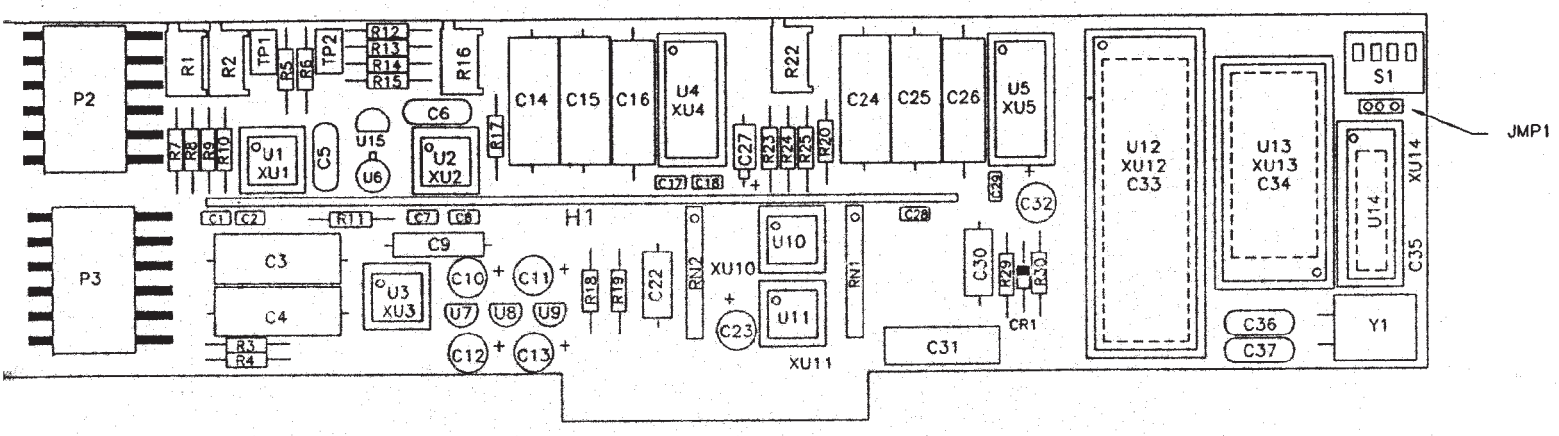
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Table 9305-4 (cont.). 9305 Thermocouple Curves

Breakpoint Number	Chromel vs. Constantan E		Chromel vs. Alumel K		Copper vs. Constantan T	
	Temp(K)	V_{TC}(mV)	Temp(K)	V_{TC}(mV)	Temp(K)	V_{TC}(mV)
1	0.0	-15.0000	0.0	-15.0000	0.0	-15.0000
2	3.0	- 9.8355	3.0	- 6.4582	3.0	- 6.2584
3	5.6	- 9.8298	6.0	- 6.4551	6.5	- 6.2523
4	9.0	- 9.8182	10.0	- 6.4486	11.0	- 6.2401
5	13.5	- 9.7956	14.5	- 6.4376	16.5	- 6.2184
6	19.0	- 9.7570	19.5	- 6.4205	22.0	- 6.1888
7	25.0	- 9.7013	25.0	- 6.3951	29.0	- 6.1404
8	32.0	- 9.6204	32.0	- 6.3529	38.0	- 6.0615
9	40.0	- 9.5071	40.0	- 6.2913	48.0	- 5.9535
10	50.0	- 9.3366	48.0	- 6.2149	60.0	- 5.7995
11	60.0	- 9.1345	58.0	- 6.1022	75.0	- 5.5753
12	70.0	- 8.9030	65.0	- 6.0099	90.0	- 5.3204
13	80.0	- 8.6475	75.0	- 5.8634	105.0	- 5.0337
14	90.0	- 8.3673	85.0	- 5.6989	120.0	- 4.7194
15	105.0	- 7.9064	95.0	- 5.5156	135.0	- 4.3767
16	120.0	- 7.3943	105.0	- 5.3166	155.0	- 3.8781
17	135.0	- 6.8386	120.0	- 4.9881	175.0	- 3.3278
18	150.0	- 6.2400	135.0	- 4.6240	195.0	- 2.7342
19	170.0	- 5.3831	150.0	- 4.2267	220.0	- 1.9295
20	190.0	- 4.4564	165.0	- 3.7994	245.0	- 1.0586
21	210.0	- 3.4702	185.0	- 3.1866	270.0	- 0.1254
22	235.0	- 2.1605	205.0	- 2.5259	300.0	+ 1.0616
23	260.0	- 0.7666	230.0	- 1.6463	330.0	+ 2.3247
24	290.0	+ 0.9948	260.0	- 0.5186	360.0	+ 3.6639
25	320.0	+ 2.8428	295.0	+ 0.8688	395.0	+ 5.3095
26	350.0	+ 4.7704	350.0	+ 3.1298	430.0	+ 7.0419
27	385.0	+ 7.1149	395.0	+ 4.9999	470.0	+ 9.1113
28	420.0	+ 9.5570	460.0	+ 7.6164	510.0	+11.2758
29	460.0	+12.4425	510.0	+ 9.6125	555.0	+13.8053
30	475.0	+13.5573	575.0	+12.2790	575.0	+14.9685
31	999.9	+15.0010	999.9	+15.0010	999.9	+15.0010

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REPLACEMENT PARTS LIST - MODEL 9305 INPUT CARD

LSCI PART NUMBER 099

ITEM NO	LSCI Part Number	Qty	Description	MFR	MFR PART NO
C3,4,14 15,24, 25	101-034	6	CAP,PP,1.0MF,100V	FDYNE	MPP2X-1.0-100-10
C9	101-001	1	CAP,POLY,.0015,100V	CDE	WMF1D15
C10-13, 23,32	101-137	6	CAP,TANT,10MF,35V	SPRG	119D106X0035DB1
C16,26	101-027	2	CAP,.47MF,100V	FDYNE	MPP-11.47MFD
C19,27	101-132	2	CAP,TANT,1.5MF,10V	SPRG	150D155X9010A2
CR1	102-064	1	DIODE,SWITCHING		1N914
P2,P3	106-142	2	CONNECTOR, 6 POST LOCKING RA HDR	MOL	2420-09-75-1061
R1,16, 21,22	103-077	4	TRIMPOT,2K	BOR	3299X-1-202
S1	105-403	1	SWITCH (4 DIP PIANO)	GYH	76PSB04
U1	104-081	1	IC, OP AMP	LT	LTC1050CN8
U2	104-005	1	IC, OP AMP	NAT	LM308
U3	104-001	1	IC, OP AMP	PMI	OP07EP
U4,5	104-465	2	IC, A/D CONVERTER	TDYN	TSC500CPE
U6	104-074	1	MOSFET, P CHANNEL	SIL	3N163
U7	104-020	1	REGULATOR, -5V	MOT	7905
U8	102-010	1	REGULATOR, +5V	MOT	7805
U9	102-041	1	VOLTAGE REFERENCE,2.5V	NAT	LM336BZ-2.5
U10,11	104-345	2	IC, OPTOCOUPLER	HP	HCPL-2731
U12	104-511	1	IC, MICROPROCESSOR	INT	P80C31
U13	104-660	1	IC, EPROM(PROGRAM)	INT	27C64-3
U14	104-528	1	IC, 8 BIT LATCH		P82C82
U15	102-040	1	VOLTAGE REFERENCE,1.22V	NAT	LM313
Y1	103-990	1	CRYSTAL,5.000M HZ	MTRON	MP1 5.000M HZ

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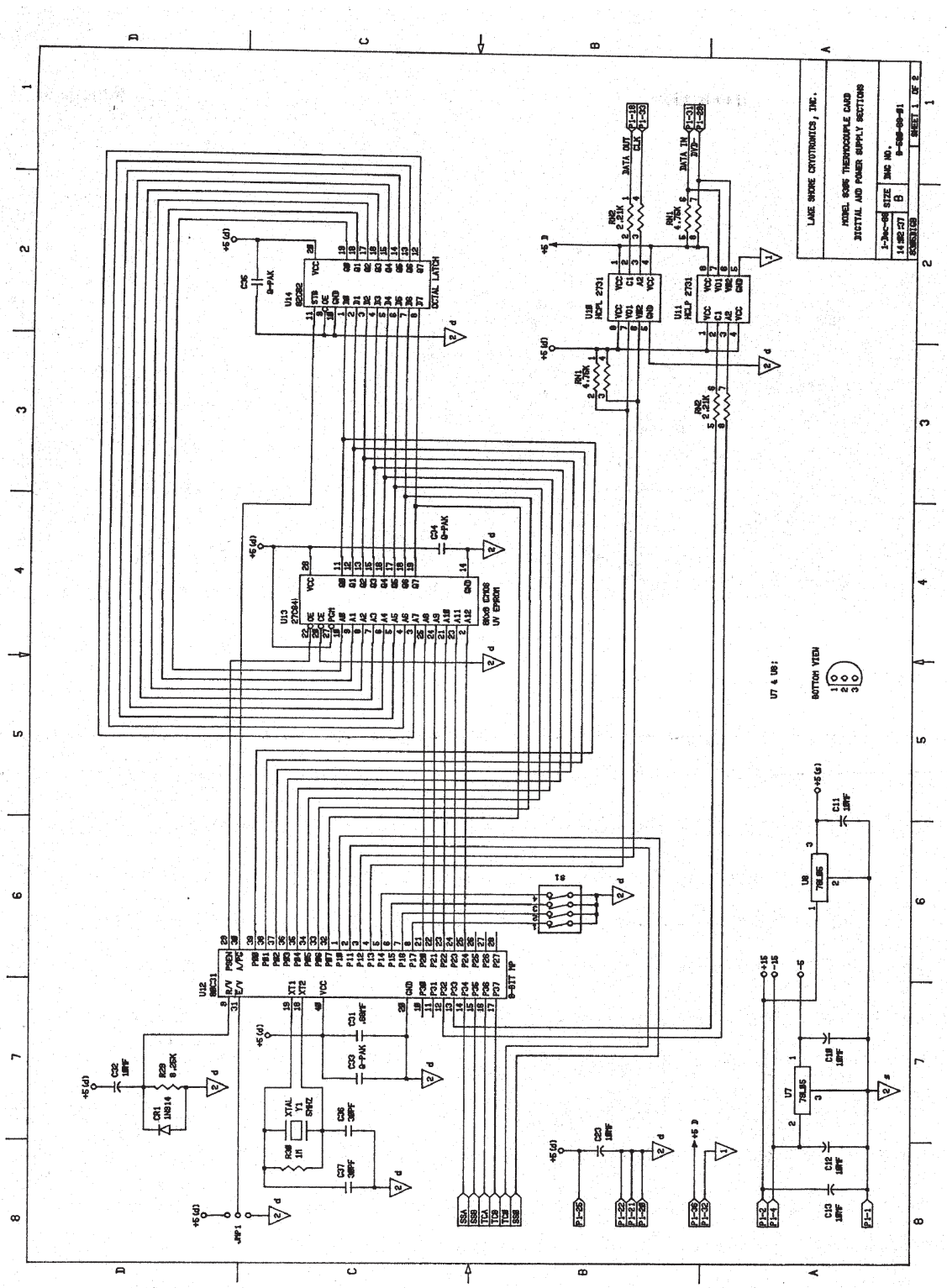


Figure 9305-1. Model 9305 Thermocouple Input Card

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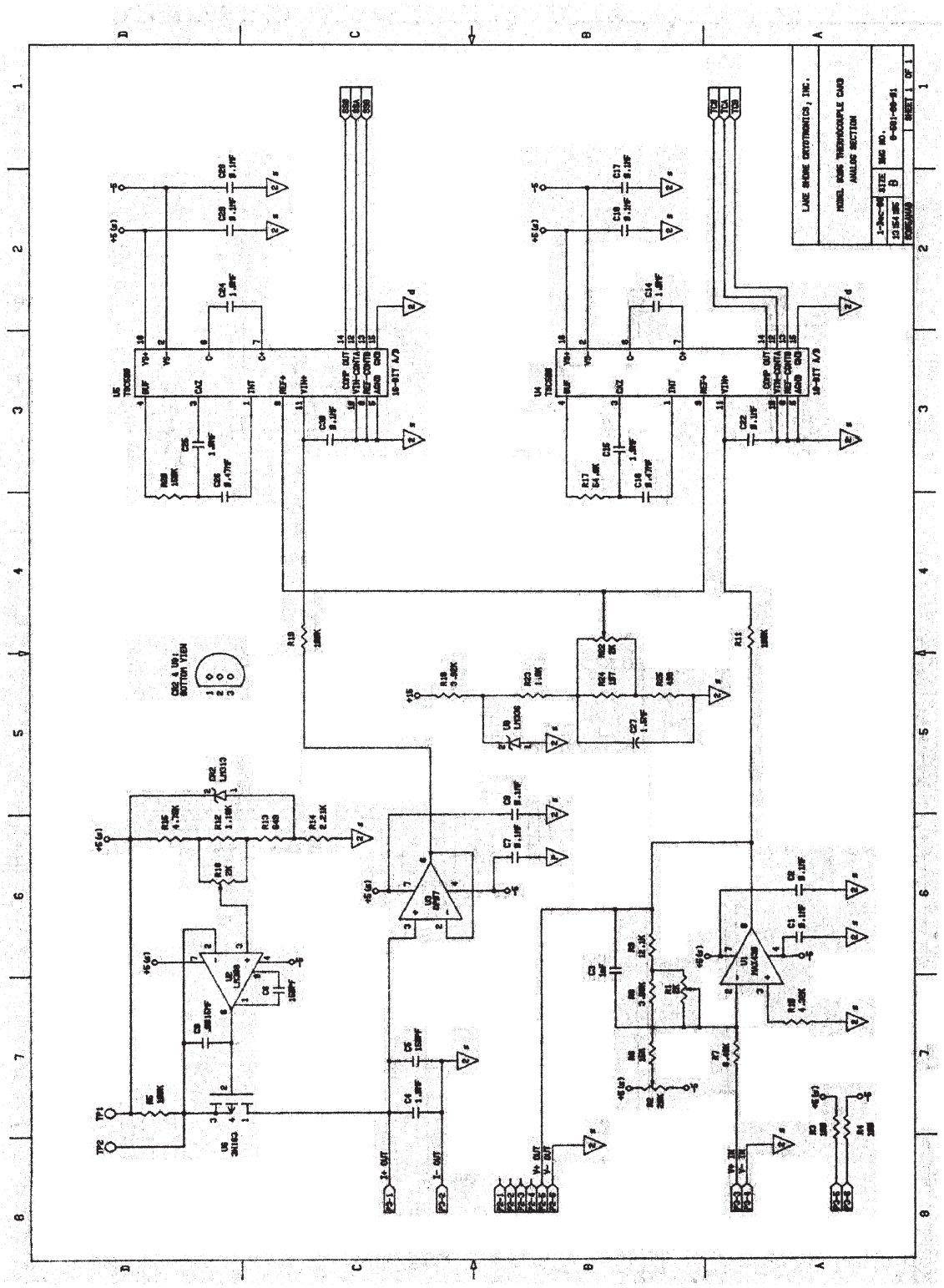
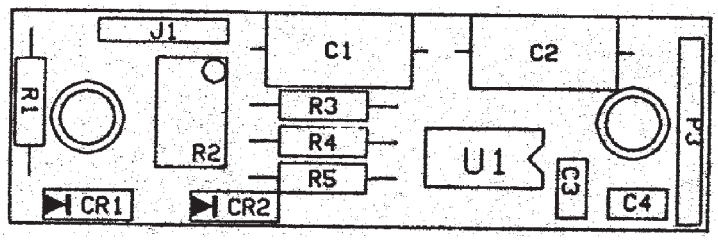


Figure 9305-2. Model 9305 Thermocouple Input Card

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REPLACEMENT PARTS LIST - MODEL 9305 INPUT MODULE BOARD

LSCI PART NUMBER 113-180

ITEM NO	LSCI Part Number	Qty	Description	MFR	MFR PART NO
C1,2	101-022	2	CAP,PP,0.1MF,100V	FDYNE	MPP11-0.1-100
CR1,2	102-064	2	DIODE.SWITCHING		1N914
P3	106-140	1	CONNECTOR.6 POS SOCKET	MOL	2L39139-09-50-3061
U1	104-081	1	IC, OP AMP	LT	LTC1050CN8

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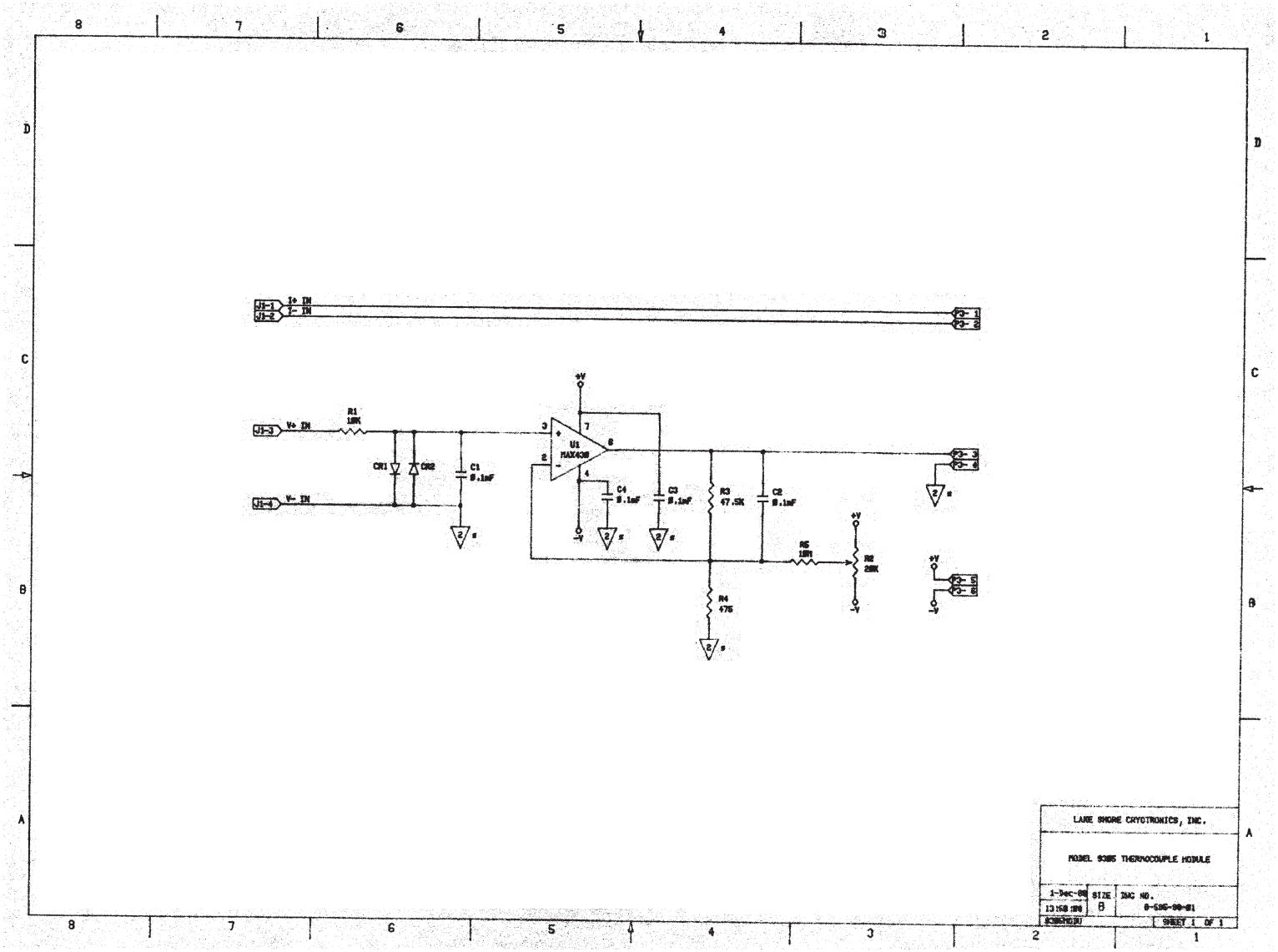


Figure 9305-3. Model 9305 Thermocouple Input Card Module

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9317C/9318C RESISTANCE INPUT CARD

9317C/9318C.1 INTRODUCTION

This section contains information pertaining to the Model 9317C/9318C Resistance Input Card. Included is a description, specifications, installation, operation and maintenance information.

9317C/9318C.2 DESCRIPTION

The Model 9317C/9318C Resistance Input Card is designed to be installed in a DRC-91C/93C to convert either Input A or Input B (or both with two cards) to accommodate sensors where the voltage level must be kept at levels on the order of 1 or 10 millivolts and where a thermal voltage may exist. The 9317C/9318C can be used with germanium, carbon glass or carbon resistors or any other negative temperature coefficient resistors. Both cards read in ohms from a full scale reading of 10 ohms with 1 milliohm resolution to a full scale reading of 10,000 ohms with 0.1 ohm resolution for the 9317C and 100,000 ohms with 1 ohm resolution for the 9318C. To read temperature accurately, a calibrated sensor and an 8000 Series Precision Option is required. Refer to Section 9317C/9318C-5 for a detailed description of the operation of the 9317C/9318C.

9317C/9318C.3 SPECIFICATIONS

Specifications for the Model 9317C/9318C Resistance Input Card are given in Table 9317C/9318C-1 of this Section.

9317C/9318C.4 INSTALLATION

The 9317C/9318C can be installed in a DRC-91C or a DRC-93C as either Input A or Input B (or both with two cards). The 9317C/9318C is installed prior to shipment if ordered with either controller. If only one 9317C/9318C is ordered and its input is not specified when ordered, it is installed in Input A. Use the following procedure for the installation of the 9317C/9318C Resistance Input Card. (Note: when a card is ordered for field installation, the Input Card Configuration Table located on the first page of the Instruction Manual should be updated to keep documentation current.

WARNING

To prevent shock hazard, turn off the instrument and disconnect it from AC line power and all test equipment before removing cover.

1. Set the POWER switch to OFF and disconnect the power cord from the unit. Remove the three top panel screws and slide the panel off. Note from the calibration cover the position of the Input Card the 9317C/9318C will occupy.

2. Remove the four screws that secure the calibration cover to its clips and remove the cover.

3. If the 9317C/9318C is to replace an existing Input Card, unplug the Input Card which is to be replaced. Disconnect the wiring harness mating connector by lifting the locking tab on the Input Card and gently pulling on the body of the wiring harness mating connector.

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Table 9317C/9318C-1. Specifications, 9317C/9318C Resistance Input Cards

Input Range:
9317C: Less than 1 ohm to 10,000 ohms with a resolution of 1 part in 10,000 and an accuracy of 0.1% of reading for resistances from 1 to 1,000 ohms and 0.5% of range for resistances from 1,000 to 10,000 ohms
9318C: Less than 1 ohm to 100,000 ohms with a resolution of 1 part in 10,000 and an accuracy of 0.05% of reading for resistances from 10 to 10,000 ohms and 0.25% of range for resistances less than 10 ohms and from 10,000 to 100,000 ohms.

Sensor Excitation: Current range is from 0.1 microampere to 1 milliampere. The current is varied automatically to maintain the voltage across the sensor at 1 millivolt for the 9317C and 10 millivolts for the 9318C. Current polarity is periodically reversed to allow for automatic digital correction for thermal EMFs in the sensor connections and leads.

Temperature Range: Depends on sensor type used. Sensor resistance scales from 1 to 10,000 ohms (9317C) or 100,000 ohms (9318C) can be accommodated.

Sensors (Ordered Separately): Card optimized for CGR Series Carbon Glass or GR Series Germanium Resistance Thermometers. Other negative temperature coefficient resistors (such as thermistors) can also be used.

Sensor Response Curve: The DRC-91C/93C display resistance in ohms directly. A calibrated sensor and an 8001 Precision Option curve generated using Lake Shore's proprietary Polynomial Interpolation Algorithm are required for the unit to display temperature accurately.

Input Resistance: Greater than 10^9 ohms (sensor voltage measurement).

Maximum Sensor Power Dissipation: Depends on sensor resistance. Voltage applied is 1 millivolt for the 9317C (power is 1/R in microwatts) or 10 millivolts for the 9318C (power is 100/R in microwatts).

Display Resolution: 5 digits. Displays 0.000 to 9999.9 ohms for the 9317C and 0.000 to 99999. ohms for the 9318C. Resultant temperature accuracy is a function of sensor characteristic and is the product of the input accuracy (in percent) times R (dT/dR) plus any transfer inaccuracy introduced by the sensor response curve.

Temperature Control Signal: Card generates an analog voltage output signal which is related to the sensor temperature. The instrument generates a similarly related set point voltage based on the set point resistance or temperature selected. Real-time analog comparison of these two voltages provides the required control signal.

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4. Connect the wiring harness mating connector to the 9317C/9318C Input Card making sure that the wiring harness locking tab is seated over the extended edge of the wiring harness mating connector. Plug the 9317C/9318C into the Input Card Slot with the component side facing to the left of the unit as viewed from the front. Make sure the card is thoroughly seated. Verify that the wiring harness is in place correctly by noting that the "A" or "B" on the harness connector is facing up (if it is not, review the harness installation again).

5. Install the calibration cover by reversing step 2.

6. Install the top panel.

9317C/9318C.5 OPERATION

The 9317C/9318C is a highly complex, microprocessor controlled Input Card. It's resistance measuring technique is distinctly different from the way a DMM would measure resistance. Most DMMs force a large enough signal across the device being measured to make any thermal offset negligible. Using this method in a cryogenic environment could add a significant amount of power, in the form of sensor self heating, to the test system. The 9317C/9318C Input Card limits the amount of power added to the system by limiting the voltage across the sensor to 1 (9317C) or 10 millivolts (9318C). The 9317C/9318C can also reverse the current polarity in order to correct for thermal EMFs in the sensor connections and leads.

The 9317C/9318C current source has four ranges: 0.1 to 1 microamperes (Range 1), 1 to 10 microamperes (Range 2), 10 to 100 microamperes (Range 3) and 100 to 1000 microamperes (Range 4). Each range has 64 independent current values. The ranges overlap each other (for example, Range 1 - Value 60 is equivalent to Range 2 - Value 6) so that a smooth transition from range to range can be made. The current value, as well as direction, is controlled by a 16 bit bipolar D/A converter. This current resolution is required to maintain as close to 1.05 (9317C) or 10.5 (9318C) millivolts across the sensor as possible. The on-card microprocessor stores calibration constants for each of the four ranges at the end point values of 6 and 60 for both the positive and negative directions (a total of 16 current calibration constants in all).

The resulting sensor voltage is converted from a differential to single ended signal and amplified by a factor of 1000 (9317C) or 100 (9318C). The amplified signal is digitized by a microprocessor controlled 15 bit A/D converter. The microprocessor also has calibration constants stored for the gain and offset of the input amplifier. As a result of the A/D resolution and calibration constant manipulation of the sensor signal, the sensor signal can be digitized with a resolution of 1 part in 10,000 over most of the resistance range the 9317C/9318C covers. There is also a sample-and-hold network on the card so that when the sensor signal is reversed for thermal correction while controlling, the correct polarity of the control signal is maintained.

9317C/9318C.5.1 Thermal Correction Selection for the DRC-91C

The control thermal correction function is enabled or disabled using switch 3 of the appropriate SENSOR ID located on the rear panel of the DRC-91C.

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When switch 3 of the SENSOR ID is CLOSED (ON) the thermal correction is enabled. When switch 3 is OPEN (OFF) the thermal correction is disabled. Pressing the LOCAL key for the appropriate channel will display either ±18 C or ±17 C. The plus (+) that the control thermal correction is enabled. The minus (-) means the control thermal correction is disabled.

9317C/9318C.5.2 Thermal Correction Selection for the DRC-93C

When a 9317C or 9318C Resistance Input Card is installed, pressing the SENSOR key will display either ±9317C or ±9318C for the appropriate channel. The plus (+) means the control thermal correction is enabled. The minus (-) means the control thermal correction is disabled.

Enable or disable the control thermal correction from the front panel by using a combination of the SENSOR, SCAN (↑-↓), ▲▲ and ▼▼ keys as follows:

1. Press and hold the SENSOR key.

2. While holding the SENSOR key, press the SCAN (↑-↓) key. The SENSOR key may be released.

3. To change the sign (change the enabled/disabled status) of the upper display press the ▲▲ key. Similarly, to change the sign of the lower display press the ▼▼ key.

4. Release the ▲▲ or ▼▼ key, then the SCAN (↑-↓) key.

5 Press the SENSOR key to verify that the proper sign is selected.

9317C/9318C.5.3 Operation as the Sample Input

When the input occupied by the 9317C/9318C is selected as the Sample Input (Sample only -not Control), the 9317C/9318C determines the sample resistance by forcing the voltage across the sensor to 1.05 (9317C) or 10.5 (9318C) millivolts as quickly as possible with the microprocessor controlled current source. Once the forward current range and value results in the desired voltage, the current is reversed and the thermal value determined. As long as the voltage across the sensor does not change more than 0.5% of reading from one reading to the next, the forward and reverse readings are taken each time the input card is asked for an update (approximately once a second) and a new thermal value is determined. If the voltage changes more than 0.5% of reading, the card stops reversing the current and uses the thermal value previously determined until the sensor signal stabilizes.

9317C/9318C.5.4 Operation as the Control Input

When the input occupied by the 9317C/9318C is selected as the Control Input (Control only, or Sample and Control) the operation of the card changes. Since the card has to provide a signal across the sensor that will control the heater power as well as measure resistance (or temperature), it can no longer force the sensor signal to 1.05 or 10.5 millivolts immediately.

When a set point is entered by the user, the DRC-91C/93C calculates its equivalent control sensor resistance. From this resistance and the calibration constants (current and voltage) for the 9317C/9318C input card, the set

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point voltage which will result in a sensor voltage as close to 1.05 or 10.5 millivolts as possible (when the control point is reached) is calculated. If the thermal correction is active and there has been a valid thermal value determined, it is included in the calculation. If no valid thermal has been determined, or the thermal correction is inactive, a thermal value of 0 is used. The resultant voltage is then sent to the main board of the controller as the set point voltage (or equivalent "resistance") for control.

The 9317C/9318C input card then determines if the control sensor resistance is above or below the equivalent set point "resistance". If the actual resistance is less than the set point "resistance", an over-temperature condition exists and the heater power should be off. The 9317C/9318C changes the current it applies to the sensor in order to maintain between 0.8 and 1.0 (9317C) or 8 and 10 (9318c) millivolts across it until the set point current range and value have been reached. In this way, the heater remains off until the actual sensor resistance approaches the set point "resistance". Once the final control sensor current value has been reached, the 9317C/9318C allows the sensor voltage to range as high as 1.3 (9317C) or 13 (9318C) millivolts. If the sensor voltage (and the equivalent resistance) continues to increase (an under-temperature condition exists), the 9317C/9318C then reduces the current to maintain between 1.1 and 1.3 (9317C) or 11 and 13 (9318C) millivolts across the sensor. The heater power remains on. Even though this operation takes the sensor voltage away from the optimum signal until it reaches the control point, the resulting error in the resistance determination is small. If the new set point results in an under-temperature condition, the opposite operation is performed.

If the thermal correction is active, the 91C/93C monitors the sensor resistance until it is within 0.5% of the set point resistance. Once it is, the 91C/93C signals the 9317C/9318C card to reverse the sensor current and update the thermal value. The 9317C/9318C card and the 91C/93C use this new thermal to determine the resistance and correct the set point. The thermal value is updated every 120 instrument update cycles (about 2 minutes) after the initial update. When the set point is changed, the previous thermal value is used until the correction criteria is met and the thermal updated again.

9317C/9318C.6 CALIBRATION SCHEDULE AND EQUIPMENT

The design of the 9317C/9318C Resistance Input Card is such that re-calibration should not be required more often than every six to twelve months in order to keep the card within its accuracy specification. However, if re-calibration is required, the following equipment is needed to re-calibrate the card:

1. Digital Voltmeter (DVM) - 5 1/2 digit resolution or better.

2. Five (5) Precision Standard Resistors which are accurate in value to at least 0.01%. Their values in ohms must be:

9317C: 1, 10, 100, 1K, 10K Ω
9318C: 10, 100, 1K, 10K, 100K Ω

3. Precision Voltage Standard-capable of a plus and minus 10 millivolt signal to within ±0.1 microvolt.

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Since very often these values will not be available to the user of this instrument, Lake Shore Cryotronics, Inc. offers a re-calibration service. Contact a factory representative for information concerning re-calibration. Note that the card believes that the correct resistance and voltage is applied during calibration, therefore the accuracy of the calibration depends on the accuracy of the standards used.

9317C/9318C.7 CALIBRATION

The 91C/93C should be allowed a one hour warm-up time to achieve rated specifications. References are made in the calibration procedure to eight calibration switches, CAL 8 through CAL 1. Refer to Table 9317C/9318C-2 for the hardware switch definitions of CAL 8 through CAL 1. References are made to test points, adjustments and calibration switches that are labeled on the calibration cover. Use the following procedure to calibrate the 9317C/9318C Resistance Input Card.

1. Remove the three top panel screws and slide the panel off.

2. Configure the input that contains the 9317C/9318C as the SAMPLE input only and make the units Ω. Turn off Digital Filtering and Thermal Correction (DIP switches of the appropriate SENSOR ID switches 2 and 3 to the OPEN (OFF) position for the DRC-91C or disable from the front panel on the DRC-93C).

3. **Current Source Zero** - Connect the 10K (9317C) ohm precision resistor across the +I and -I pins of the Resistance Input Card input connector and enable both CAL 8 and CAL 7 of the card. Attach the plus and minus leads of the DVM to the test points marked V+ and V- respectively of the 9317C/9318C PCB and adjust the trimpot marked **IZ** so that the voltage reads as close to zero as possible. If this voltage is not close to zero, it may effect the sensor current setting. Consequently, this operation should be performed before any current calibrations are performed. Disable CAL 7 and continue. Note that CAL 8 will remain enabled for all calibration operations.

4a. **Voltage Match or Span** - Connect the DVM plus and minus leads to the V+ and V-Sensor Output Signal terminals of the MONITORS connector for the input being calibrated. Apply a +1 (9317C) or +10 (9318C) millivolt signal to the +V and -V Sensor Input terminals. Enable CAL 6 on the card (CAL 8 is still enabled). The DVM should read about 1 volt and the display of the unit should read approximately **10000.** Adjust the trimpot labeled **A/D** so that the voltage read on the DVM matches the display of the unit (if the DVM reads 1.0085 make the display read **10085.**). If the trimpot is adjusted wait a minimum of 10 readings before disabling CAL 6.

4b. Apply a -1 (9317C) or -10 (9318C) millivolt signal to the input and enable CAL 5. Do not adjust any of the trimpots. Disable CAL 5 after approximately 30 seconds. When the display goes to **0.** the unit has completed determining the voltage input calibration constants and has stored them in the 9317C/9318C calibration EEPROM.

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5. **Current Range 1, Value 6-** Configure the 10K (9317C) or 100K (9318C) resistor to simulate the sensor. Enable CAL 4 and monitor the unit's display. The display should indicate the number **106.** for approximately 30 seconds and then display **0.** indicating the end of the calibration. Disable CAL 4 and continue.

6. **Current Range 1, Value 60 and Current Range 2, Value 6-** Substitute a 1K (9317C) or 10K (9318C) resistor for the previous resistor and re-enable CAL 4. The display will display the number **160.** for approximately 30 seconds, then the number **206.** for another 30 seconds and when complete, a **0.** will be displayed. Disable CAL 4 and continue.

7. **Current Range 2, Value 60 and Current Range 3, Value 6-** Substitute a 100 ohm (9317C) or 1K (9318C0 resistor for the previous resistor and enable CAL 3. The display will indicate **260.** for approximately 30 seconds, then **306.** for another 30 seconds and finally a **0.** Disable CAL 3 and continue.

8. **Current Range 3, Value 60 and Current Range 4, Value 6-** Substitute a 10 ohm (9317C) or 100 ohm (9318C) resistor for the previous resistor and enable CAL 2. The display will indicate **360.** then **406.** with each time period being approximately 30 seconds. When the **0.** appears, disable CAL 2 and continue.

9. **Current Range 4, Value 60-** Finally substitute the 1 ohm (9317C) or 10 ohm (9318C) resistor for the previous resistor and enable the last switch, CAL 1. The display will indicate **460.** for approximately 30 seconds and then a **0.** indicating that the calibration of the card is complete. Disable CAL 1 and then CAL 8.

10. **Set Point D/A Calibration** - A special set point calibration is required for a DRC-91C or DRC-93C with two 9317C/9318C Input Cards or if the 9317C/9318C is the only Input Card. Since the set point voltage is related to the set point resistance, and is determined with the individual card calibration constants, there is no way to enter a set point that results in a predetermined value for the set point. The Internal ID Switch (S7 on the Main Board) is used in the calibration. Note the position of the Internal ID switches before proceeding. Attach the plus and minus leads of the DVM to **TP25(SP V)** and **TP1(GND(2s))** respectively of the Calibration and Service Card. Make switch 7 CLOSED (ON). This forces the unit to output a set point of 0 volts. Adjust the **SP ZERO ADJ** trimpot until the DVM reads as close to zero as possible. Turn ON switch 6 of the Internal ID. This forces the unit to output a set point of-2.7 volts. Adjust the **SP SPAN ADJ** trimpot until the DVM reads as close to -2.7000 volts as possible. This procedure should be done until the 0 and -2.7 readings are as close as possible to the calibration values. Before returning to normal operation, make sure switches 7 and 6 of the Internal ID are OPEN (OFF).

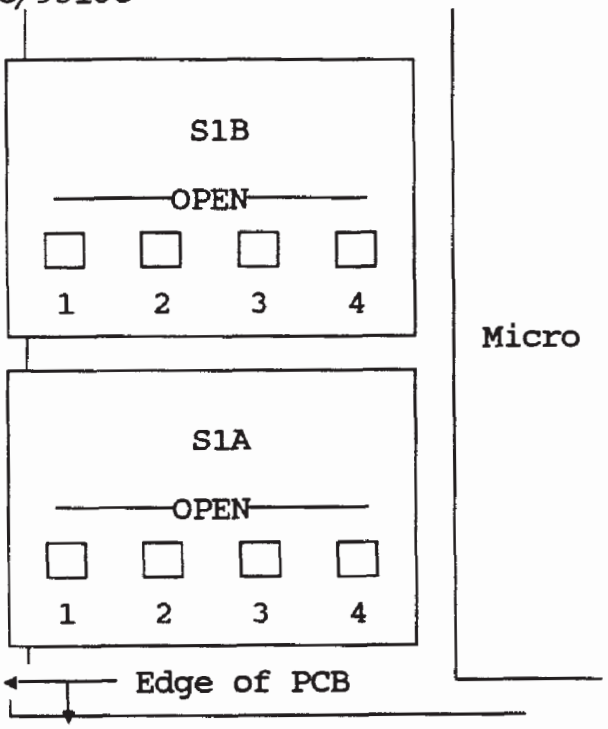
11. Replace the calibration cover and then the top cover.

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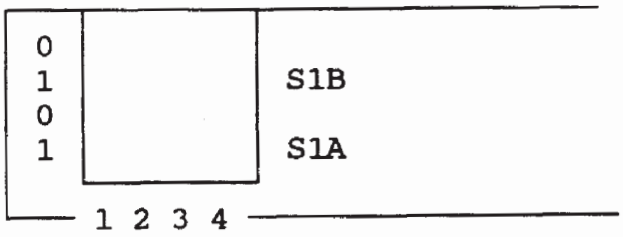
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Table 9317C/9318C-2. Calibration Switch Definitions

Viewed from the Component Side of 9317C/9318C



Viewed through Calibration Cover



Switch	CAL	Definition (switch closed)		
S1A-4	8	Calibration Enable		
S1A-3	7	Current Source DAC Zero		
		9317C	9318C	
S1A-2	6	+1mV	+10mV	Input A/D Cal
S1A-1	5	-1mV	-10mV	Input A/D Verify
S1B-4	4	1K/10K	10K/100K	Current Verify
S1B-3	3	100 ohm	1K ohm	Current Verify
S1B-2	2	10 ohm	100 ohm	Current Verify
S1B-1	1	1 ohm	10 ohm	Current Verify

9317C/9318C.8 SENSOR CURVE INFORMATION

The curves used with the 9317C/9318C Input Card are generated using a proprietary Polynomial Interpolation Algorithm developed by Lake Shore. The format for the data to be stored using the XCN_1N_2 command (as outlined in Section 4) is the same as for a standard curve except the resistance is converted to a LOG value (where 1000 ohms would look like 4.0000). Refer to APPENDIX B for a definition of the curve requirements. The curve data is in resistance order. The resistance and temperatures for the 9317C/9318C are in ohms up to 100,000 ohms and in kelvin up to 399.9

9317C/9318C.9 REPLACEABLE PARTS

Included in this section is Figure 9317C/9318C-1. It includes the Model 9317C/9318C Resistance Input Schematic, replaceable parts list and illustrated component layout. Refer to the manual for ordering information.

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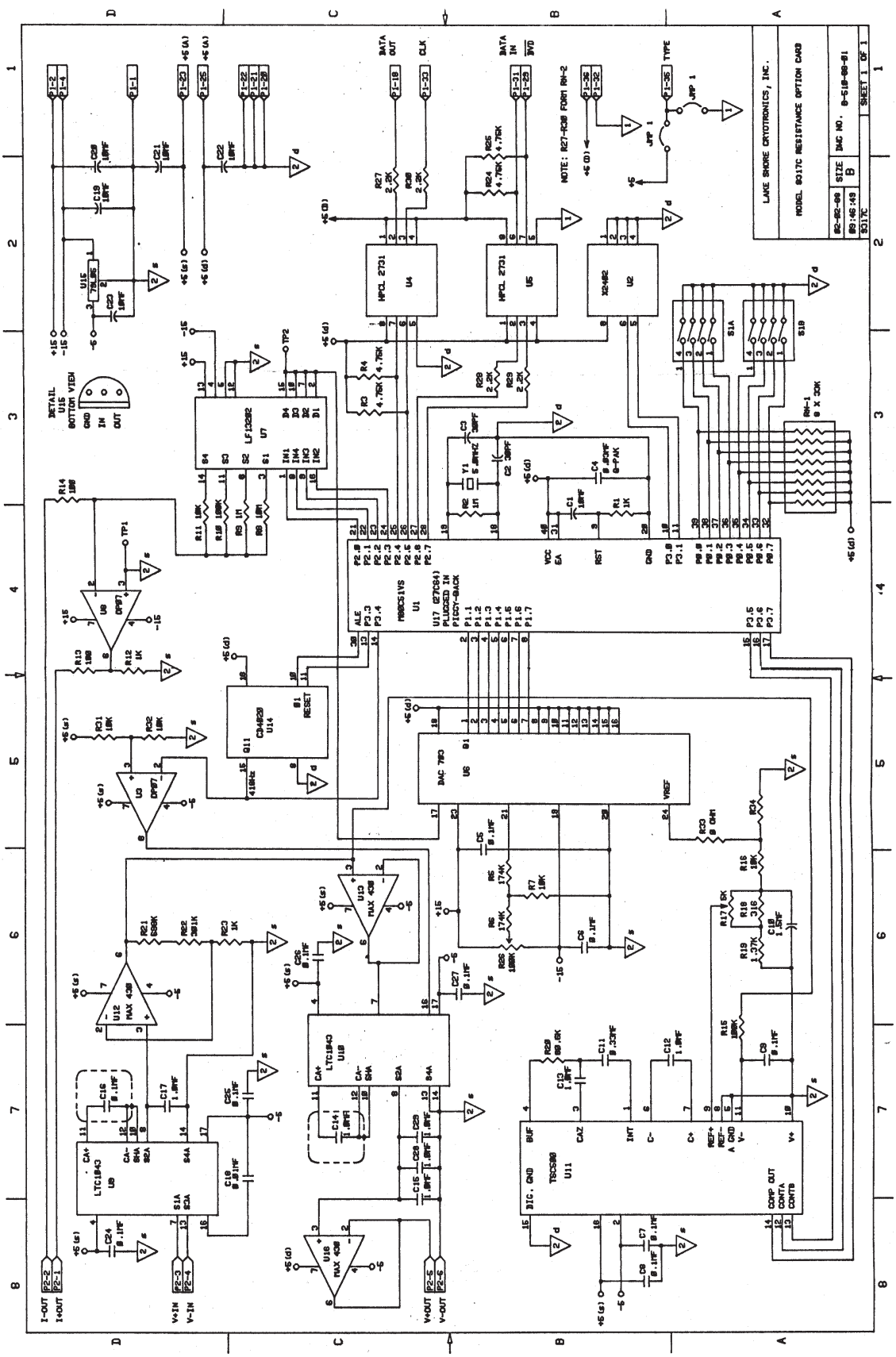
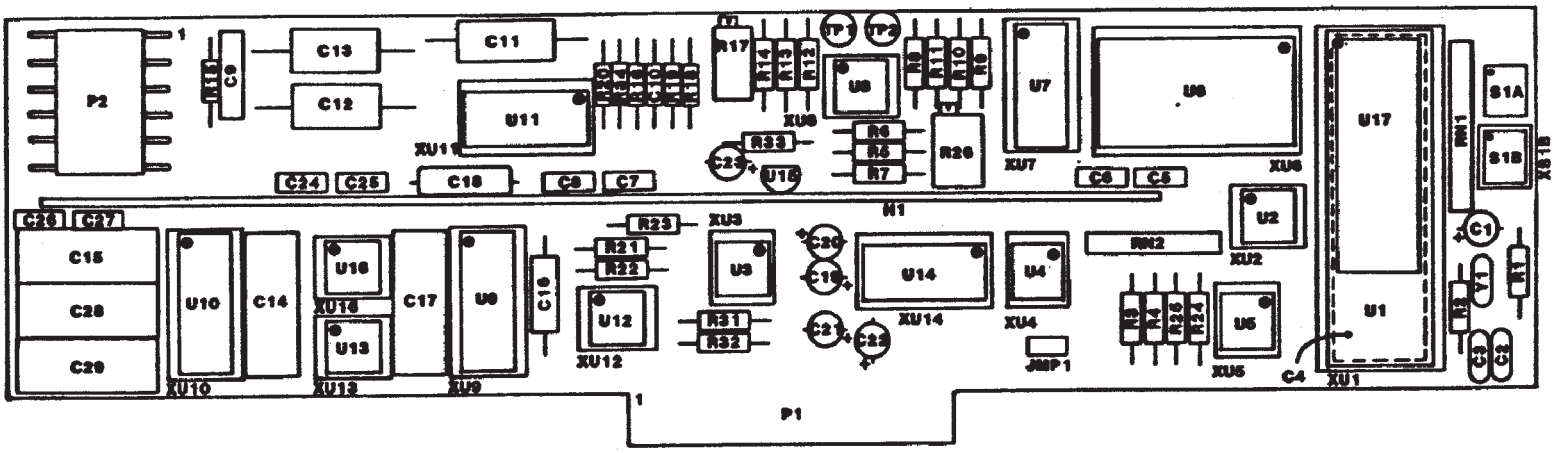


Figure 9317C-1. Model 9317C Resistance Input Card

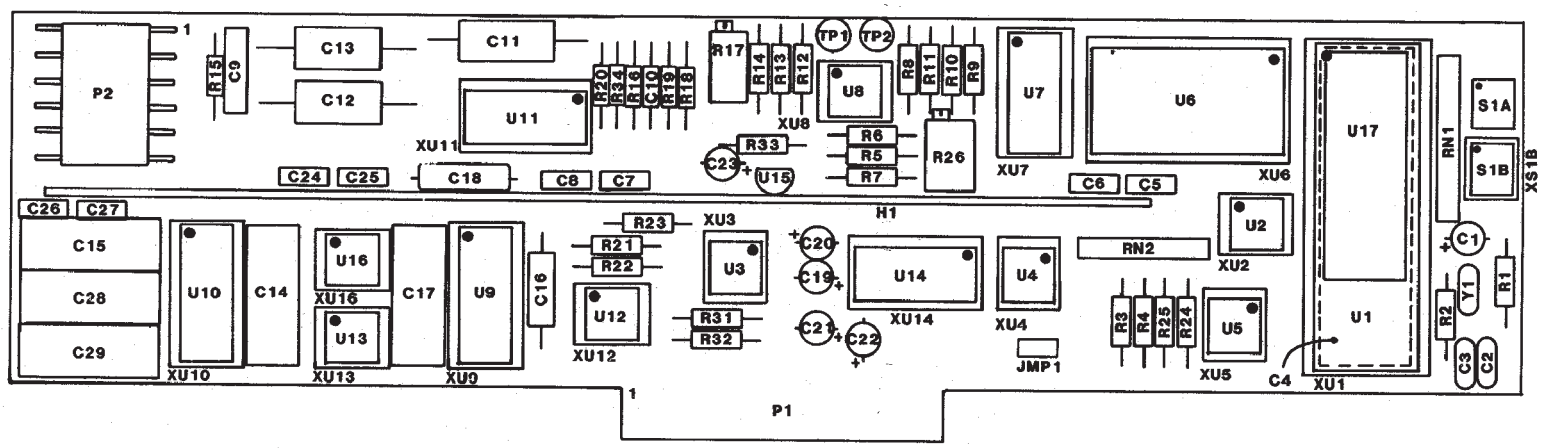
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REPLACEABLE PARTS LIST - 9317C RESISTANCE SENSOR INPUT CARD

ITEM NO	LSCI Part Number	Qty	Description	MFR	MFR PART NO
C1	101-137	1	CAP,TANT,10MF.35V	CDE	119D106X0035DB1
C2,3	101-067	2	CAP,CER,30PF,500V	CDE	CD15ED300J03
C11	101-025	1	CAP,PP,.33MF,100V	FDYNE	MPP-11 .33MFD
S1A,B	105-405	2	CAL ENABLE (4 DIP RA)	GYH	76PSB04
U1	104-509	1	IC,MICROPROCESSOR	OKI	M80C51VS
U2	104-652	1	IC,EEPROM	XICOR	X2404
U3,8	104-001	2	IC,OP AMP	PMI	OP07EP
U4,5	104-345	2	IC,OPTOCOUPLER	HP	HCPL-2731
U6	104-419	1	IC,D/A CONVERTER	BB	DAC703BH-5
U7	104-060	1	IC,ANALOG SWITCH	NAT	LF13202
U9,10	104-078	2	IC,SWITCHED CAPACITOR	LT	LTC1043
U11	104-465	1	IC,A/D CONVERTER	TDYN	TSC500CPE
U12,13 16	104-089	3	IC,OP AMP	MAX	MAX430CPA
U14	104-098	1	IC,BINARY COUNTER	NAT	CD4020BCN
U15	104-020	1	REGULATOR,-5V	MOT	79L05
U17	104-660	1	IC,EPROM	INT	27C64-3
Y1	103-990	1	CRYSTAL,5.000MHZ	MTRON	MP1 5.000MHZ
P2	106-142	1	CONNECTOR, 6 POST RA HDR	LSCI	

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REPLACEABLE PARTS LIST - 9318C RESISTANCE SENSOR INPUT CARD

ITEM NO	LSCI Part Number	Qty	Description	MFR	MFR PART NO
C1	101-137	1	CAP,TANT,10MF.35V	CDE	119D106X0035DB1
C2,3	101-067	2	CAP,CER,30PF,500V	CDE	CD15ED300J03
C11	101-025	1	CAP,PP,.33MF,100V	FDYNE	MPP-11 .33MFD
S1A,B	105-405	2	CAL ENABLE (4 DIP RA)	GYH	76PSB04
U1	104-509	1	IC,MICROPROCESSOR	OKI	M80C51VS
U2	104-652	1	IC,EEPROM	XICOR	X2404
U3,8	104-001	2	IC,OP AMP	PMI	OP07EP
U4,5	104-345	2	IC,OPTOCOUPLER	HP	HCPL-2731
U6	104-419	1	IC,D/A CONVERTER	BB	DAC703BH-5
U7	104-060	1	IC,ANALOG SWITCH	NAT	LF13202
U9,10	104-078	2	IC,SWITCHED CAPACITOR	LT	LTC1043
U11	104-465	1	IC,A/D CONVERTER	TDYN	TSC500CPE
U12,13 16	104-089	3	IC,OP AMP	MAX	MAX430CPA
U14	104-098	1	IC,BINARY COUNTER	NAT	CD4020BCN
U15	104-020	1	REGULATOR,-5V	MOT	79L05
U17	104-660	1	IC,EPROM	INT	27C64-3
Y1	103-990	1	CRYSTAL,5.000MHZ	MTRON	MP1 5.000MHZ
P2	106-142	1	CONNECTOR, 6 POST RA HDR	LSCI	

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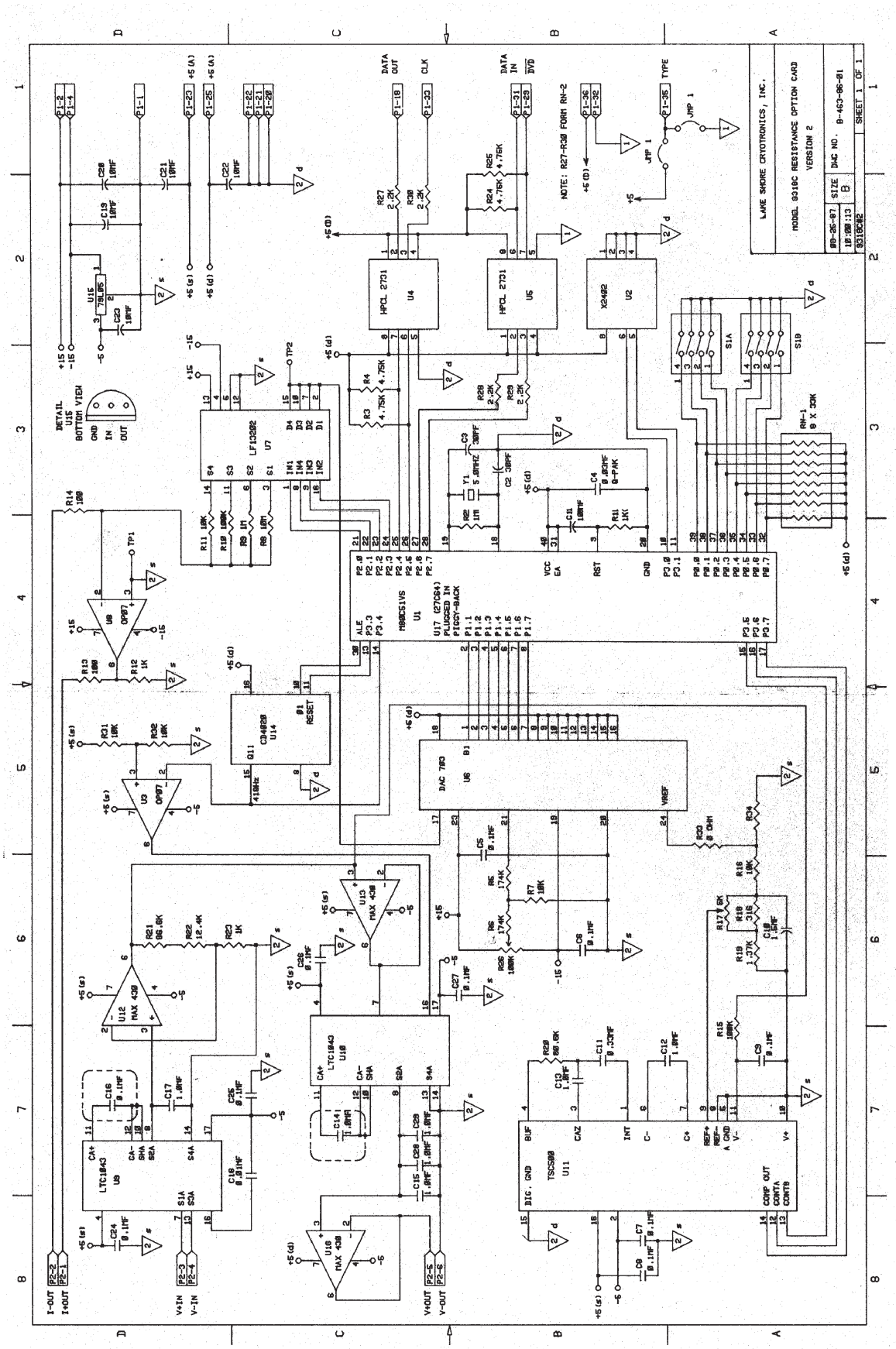


Figure 9318C–1. Model 9318C Resistance Input Card

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MODEL 8223 RS-232C INTERFACE

8223.1 INTRODUCTION

This Section contains information pertaining to the Model 8223 RS-232C Interface for the DRC-91C/93C Temperature Controller. Included is a description, specifications, installation, operation and maintenance information.

8223.2 DESCRIPTION

The 8223 RS-232C Interface is designed to be installed in a DRC-91C/93C and provide an interface with an external RS-232C instrument such as a computer, modem or CRT. The interface operates in a half duplex mode (it can only transmit and receive information in one direction at a time) and data transmission is asynchronous (each character is bracketed by start and stop bits that separate and synchronize the transmission and receipt of data). The baud rate is switch selectable at 300 or 1200 baud and the interface maintains EIA voltage levels for data transmission.

Figure 8223-2 gives a transmission format which shows the data bits framed by the start and stop synchronization bits. The data is transmitted using two voltage levels which represent the two binary states of the digit. A logic 0 (or SPACE) is +3 to +12 VDC. A logic 1 (or MARK) is -3 to -5 VDC. When data is not being transmitted, the line is held low (MARK state). When the transmission device is ready to send data, it takes the line to the high (SPACE) state for the time of one bit. This transition is called the start bit. The remaining data is then transmitted. If a parity bit is used, it follows the character. The parity bit is determined by the number of 1 bits in the character.

Refer to Table 8223-1 for parity determination.

Table 8223-1. Parity Determination

Number of "1"s in character	Parity Specified	Parity Bit
Odd	Odd	0
Even	Odd	1
Odd	Even	1
Even	Even	0

The Model 8223 RS-232C Interface has a 25 pin D style connector located on the rear panel. Pin Assignments are shown in Table 8223-2.

Table 8223-2. Connector Pin Assignments for RS-232C

Pin	Description	Signal
1	Protective Ground	AA
2	Transmitted Data	BA
3	Received Data	BB
4	Request to Send	CA
5	Clear to Send	CB
6	Data Set Ready	CC
7	Signal Ground	AB
8	Rcvd Ln Sgnl Dtctr	CF
20	Data Terminal Rdy	CD

The RS-232C signals are used in the following manner:

Protective Ground (AA) - conductor is taken to case ground potential and is common with the signal ground (AB).

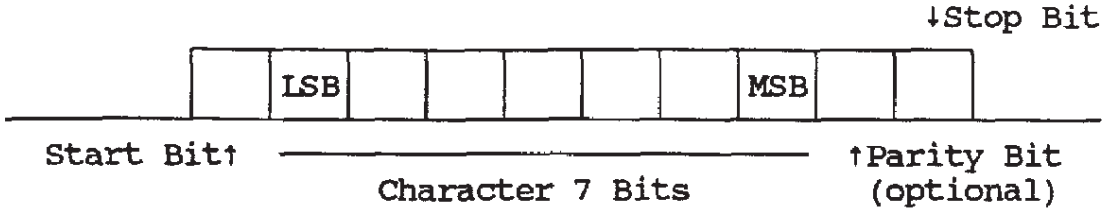
Transmitted Data (BA) - transmits data using the EIA voltage levels (+12V and -5V).

Received Data (BB) - accepts data using EIA voltage levels.

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Figure 8223-2. Word Structure



Request to Send (CA) - indicates to the host computer or terminal that the DRC-91C/93C Interface is ready to transmit data. The Interface transmits data on line BA when the "ON" state is maintained on CC, CB and CF, while a low level on these lines inhibits transmission by the Interface.

Clear to Send (CB) - indicates to the Interface that data transmission is allowed. Internally pulled up to maintain "ON" state when left disconnected.

Data Set Ready (CC) - indicates to the Interface that the host computer or terminal is not in a test mode and that power is ON.

Signal Ground (AB) - this line is the common signal connection for the Interface.

Received Line Signal Detector (CF) - this line is held positive ("ON") when the Interface is receiving signals from the host computer. When held low ("OFF") the BB line is clamped to inhibit data reception. Internally pulled up to maintain "ON" state when left disconnected.

Data Terminal Ready (CD) - asserted by the Interface whenever the DRC-91C/93C/8223 power is "ON" to indicate that the Interface is ready to receive and transmit data.

8223.3 Configuration of Dip Switches

8223.3.1 Selection of Baud Rate

The Model 8223 has a field selectable baud rate using DIP switch package S1 (8 switches) on the Interface card. The baud rate is selected by closing the switch position for the desired baud rate and making sure all other positions are open. Table 8223-3 gives the baud rate selection table. Only the 300 and 1200 baud rates have been tested and are fully supported.

Table 8223-3. Baud Rate Switch S1

Switch S1 1 2 3 4 5 6 7 8	Baud Rate
1 0 0 0 0 0 0 0	75
0 1 0 0 0 0 0 0	110
0 0 1 0 0 0 0 0	135
0 0 0 1 0 0 0 0	150
0 0 0 0 1 0 0 0	200
0 0 0 0 0 1 0 0	**300**
0 0 0 0 0 0 1 0	600
0 0 0 0 0 0 0 1	**1200**

8223.3.2 Word Structure Selection

The word structure is determined by switch settings for character length, parity and stop bits using DIP switch package S2 on the Interface Card (6 switches). Refer to Table 8223-4 for settings where "0" is OPEN and "1" is CLOSED.

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Table 8223-4. Word Structure Switch S2

Switch S2 1 2 3 4 5 6	Word Structure Choices
	Stop Bits
0 0 X X X X	Invalid
0 1 X X X X	1 Bit
1 0 X X X X	1½ (not supported)
1 1 X X X X	2 Bits
	Parity Genertn/Chck
X X 1 X X X	Even
X X 0 X X X	Odd
	Parity Enable
X X X 1 X X	Enable
X X X 0 X X	Disable
	Character Length Bits
X X X X 0 0	5 (not supported)
X X X X 0 1	6 (not supported)
X X X X 1 0	7 (Supported)
X X X X 1 1	8 (not supported)

Note: For the not supported settings, the interface will respond, but the card has not been tested with these settings at the factory. X is a don't care setting for that switch.

8223.4 SPECIFICATIONS

Specifications for the Model 8223 RS-232C Interface are given in Table 8223-5.

8223.5 INSTALLATION

The 8223 RS-232C Interface is factory installed if ordered with a DRC-91C Temperature Controller or can be field installed at a later date. If field installation is required, use the following procedure.

1. Configure the 8223 baud rate and word structure switches as outlined in Section 8223-3.

Table 8223-5. Model 8223 RS-232C Interface Specifications

Timing Format - Asynchronous
Transmission Mode - Half Duplex
Baud Rate - 300 or 1200 Bits/sec (Factory set to 300)
Bits per Character - 7(excluding start, stop or parity bits)
Parity Enable - Enabled/Disabled (Factory set Enabled)
Parity Select - Odd or Even (Factory set Odd)
Number of Stop Bits - 1 or 2 (Factory set to 1)
Data Interface Levels - Transmit or receive using EIA voltage levels (+12V and -5)

WARNING
To prevent shock hazard, turn off the instrument, disconnect it from AC line power and all test equipment before removing cover.

2. Set the POWER switch to OFF and disconnect the power cord from the unit. Remove the three top panel screws and slide the panel off. Note on the calibration cover the position of Option Slot 2 which the 8223 will occupy.

3. Remove the four screws that secure the calibration cover to its clips and remove the cover. Remove the two back panel mounting clips that secure the J10 blank cover plate to the interface opening and remove the plate.

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4. Remove the red jumper JMP6 on the Microprocessor Board. This is the jumper closest to the front edge of the microprocessor card.

5. Plug the internal interface cable into the 8223 printed circuit board (PCB) with the locking tab configured properly. Plug the 8223 PCB into Option Slot 2 with the component side to the left of the unit as viewed from the front. Gently thread the RS-232C internal cable along the inside edge of the rear panel so that it will not interfere with the installation of the calibration cover or top cover.

6. Position the 25 pin RS-232C Interface connector in the J10 opening on the back panel and secure it in place using the screws provided.

7. Install the calibration cover by reversing procedure 3.

8. Install the top panel.

8223.6 OPERATION

The 8223 RS-232C Interface has a 256 character FIFO buffer for input commands. The interface accepts commands, the same as for the IEEE-488 Interface, until it sees the End-of-Line (EOL) sequence. The 8223 requires a carriage return/line feed (CR)(LF) or just line feed (LF) as its input EOL and transmits carriage return/line feed (CR)(LF) as its output EOL. Following the EOL Sequence the command string is processed.

Operation of the Interface link is initiated by the computer. The computer will transmit either a Program Code or an Output Request to the 8223 Interface. The DRC-91C/93C will respond to the Output Request with the appropriate response or with the response and an error message (if an error was detected). The interface responds to Program Code Commands by storing the variables input.

The Programming Codes given in Tables 4-4, 4-7 and 4-8 are input only and do not result in a response from the interface. The Codes TN_1 and ZN_1 will be accepted and updated even though they have no relevance to the interface (the EOL terminator sequence is always (CF)(LF) and there is no EOI status). The MN_1 command can be considered the "OFF LINE" (Local) and "ON LINE" (Remote or Remote with Local Lockout) states. When "OFF LINE" (Local) parameters such as SENSOR ID (as well as Gain, Rate and Reset) are updated from the hardware settings while "ON LINE" these parameters can be updated from the computer only.

The Output Statement commands given in Tables 4-9 and 4-10 will result in the requested data being output immediately following the reception of the EOL sequence. If more than one Output Statement command is given, the last one received will be acknowledged. Programming Codes and Output Statements can be sent in the same command string. For example, the command string:

S24.5P40I20D25R2

would result in the Set Point being updated to 24.5, the Gain to 40, the Reset to 20, the Rate to 25 and the Heater Range to 10^{-3}. No Output Statement was given so no response will be output by the interface. The command string:

S24.5P40I20D25R2W0

will result in the W0 contents being output by the interface. (Refer to Section 4 for a detailed discussion of the Output Statement commands.)

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Tables 4-11 and 4-12 give the Program Curve Summary. The XDT, XDA and XDN_1N_2 commands are Output Statement style commands which result in a response from the interface. The balance of the commands are Programing Code style commands which do not result in a response from the interface. Care must be taken with the XCN_1N_2 command not to overrun the 256 character buffer of the 8223 interface. As in the IEEE operation, if a hardware problem is detected in modifying one of the memory locations, an ERR01 error will be displayed in the Display and instrument operation will be halted. Consult a factory representative if this error occurs.

There are three errors that could be detected by the 8223 interface as defined in Table 8223-6. Detection of an error does not effect the operation of the interface. The software that interprets the data tries to match the character input to the possible command inputs and processes the command. The error is also transmitted by the interface the next time it is asked for a response. The error is transmitted in addition to the Output Statement data output. For example, if a framing error were detected in a command string transmitted to a DRC-91C/93C as:

P50W3

the interface might respond with:

Err12
50.,25.,20.,2,047(CR)(LF)

If the error were detected in the transmission of the "P", the gain change would be ignored; if it was in the "50", one or two numerics may have been generated. If the error were detected in the "W", the interface may not respond, in which case it would need to see another Output Statement command. If the error was in the "3", the interface may or may not have responded with W3 data, it may default to W0. Although errors rarely occur, it is suggested that any commands sent to the 91C/93C be echoed back by sending the appropriate Output Statement command and inputting the stored parameters. Any error that is detected is cleared following the first transmission after the error.

Table 8223-6. Interface Error Codes

Number	Error/Possible Cause
Err10	Parity Error - may be caused by signal line transients or incorrectly specified parity.
Err11	Overrun Error - caused by the main processor not reading the input character before the next one becomes available. The overrun character(s) are lost.
Err12	Framing Error - may be caused by signal line transients or incorrectly specified stop bits or or character length.
Err13	Input Buffer Overrun - caused by more than 256 characters being input input to the FIFO buffer. Any characters received after the 256th character are lost.

8223.7 INTERFACING EXAMPLES

Example 1. HP-86B Computer, Half Duplex Without Handshake.

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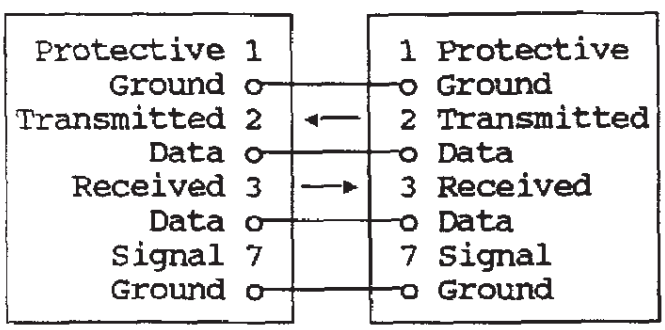
The HP82939A Serial Interface for the HP-86B is preset at the factory for the following default values:

1. Interface select code = 10
2. Baud rate = 300 Baud
3. Autohandshake = Off
4. Character Length = 7 bits
5. Parity = Odd
6. Stop bits = 1
7. Cable Option = Standard (25 pin socket)

Since the HP default Baud rate, character length, parity and stop bit configuration are the same as those of the 8223 Interface when shipped, none of the switches on the 8223 board need to be changed.

When connecting the HP-86B Serial Interface to the 8223 Interface, a transition cable needs to be made to connect the socket connector of the HP to the socket connector of the 8223 Interface. Figure 8223-3 shows the adapter cable that must be made. The arrows indicate the source and direction of signal flow.

Figure 8223-3. Half Duplex W/O Handshake



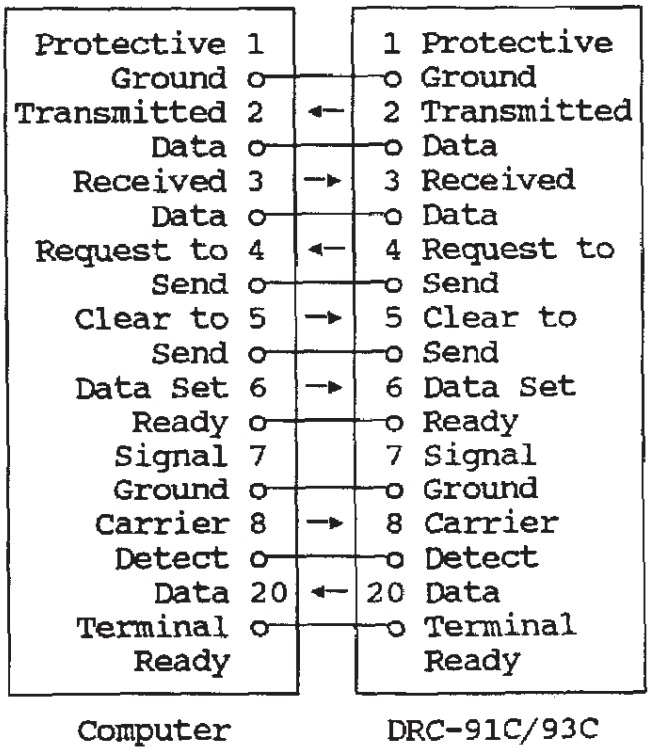
The following program will input a command from the keyboard and output it to the 8223. The program will then input the specified 8223's response, display it and return for another command.

```
10 REM HALF DUPLEX W/O HANDSHAKE
15 REM I/O TEST (RS232 TEST1)
20 DIM A$[256],B$[3000]
25 REM A$ IS OUTPUT, B$ IS INPUT
30 INPUT A$ ! MAKE SURE TO GIVE AN
35  ! OUTPUT STATEMENT COMMAND
40 OUTPUT 10 ; A$ ! OUTPUT COMMAND
50 ENTER 10 ; B$  ! INPUT THE DATA
55           ! FROM THE CONTROLLER
60 DISP B$   ! DISPLAY DATA
70 GOTO 30   ! RETURN FOR MORE
80 END
```

Example 2. HP-86B Computer, Half Duplex, with Handshake.

Figure 8223-4 shows the adapter cable for Half Duplex with handshake communications with an HP-86B Serial Interface. The arrows indicate the source and direction of signal flow.

Figure 8223-4. Half Duplex, with Handshake
Connector to HP-86B



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The Auto Handshake capability of the HP-86B Serial Interface must be enabled. The addition of the program line:

```
16 CONTROL 10,2;7 ! ENABLE DSR,DCD,CTS
```

to the program above enables the HP to receive and transmit in a handshake mode.

Example 3. General Serial Interface Interconnection.

The HP-86B Serial Interface Standard cable configuration already takes care of some of the interface interconnection problems to route signals to their proper pins. Figures 8223-5 and 8223-6 give more general interconnection configurations for Half Duplex with and without Handshake.

Figure 8223-5. General Serial Interface Interconnection for Half Duplex with Handshake

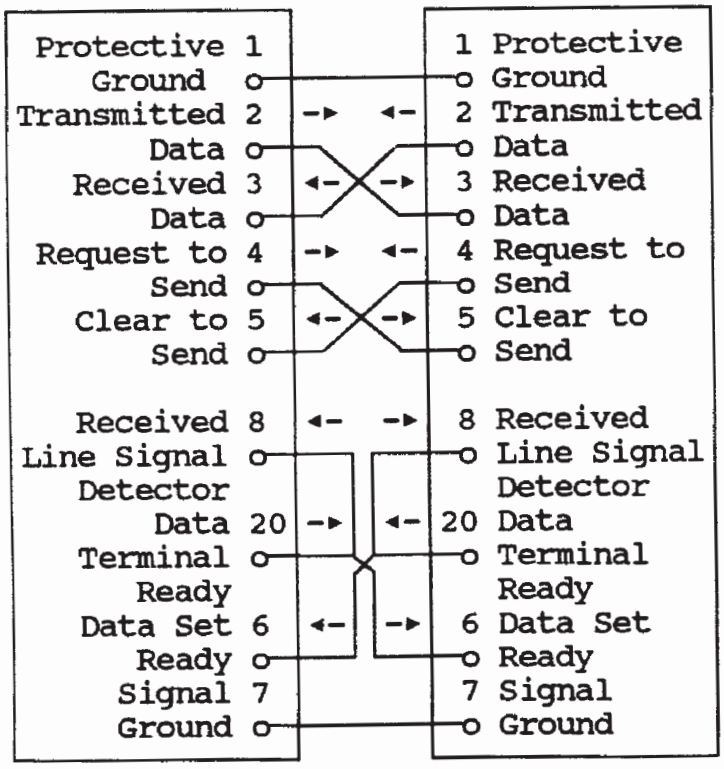
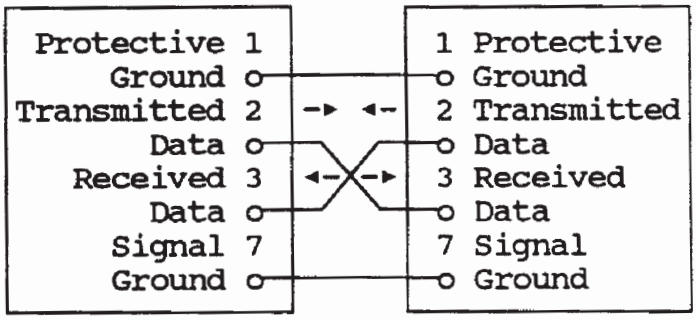


Figure 8223-6. General Serial Interface Interconnection for Half Duplex without Handshake



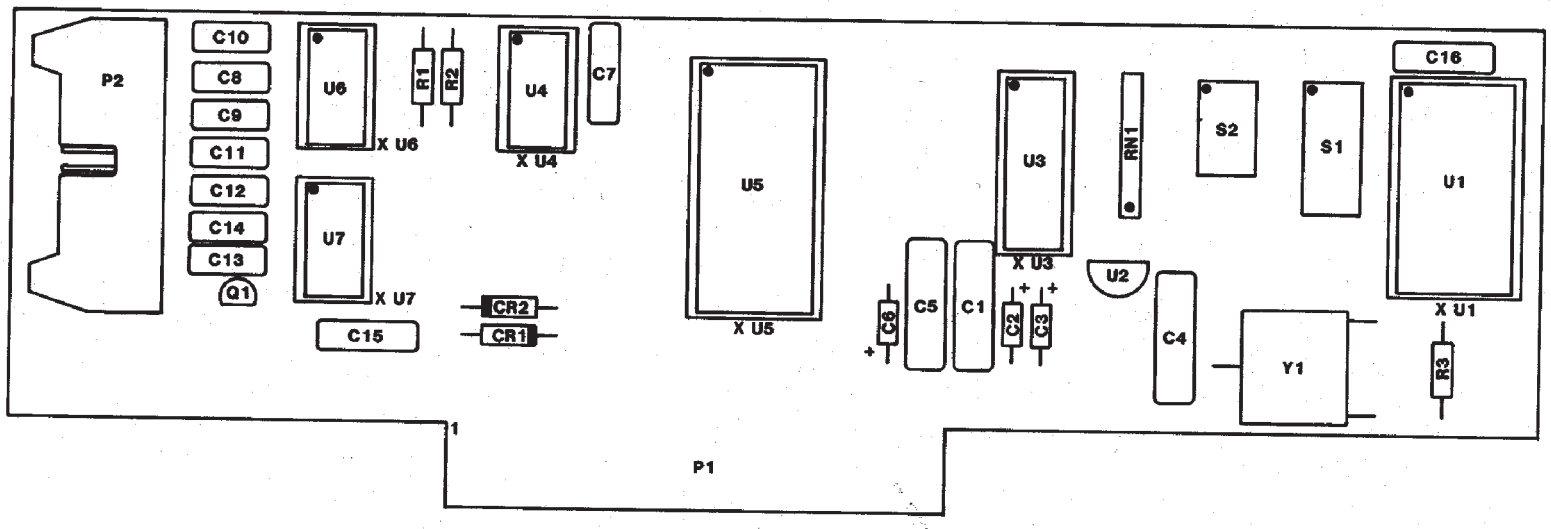
*Note: It may be necessary to jumper pins 5, 6, 8 and 20 to disable the handshake functions of the Host. This is not required for the 8223 Interface.

8223.8 REPLACEABLE PARTS

Included in this section is Figure 8223-1. It includes the Model 8223 RS-232C Interface Option Schematic, replaceable parts list and illustrated component layout. Refer to the manual for ordering information.

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REPLACEABLE PARTS LIST - MODEL 8223 RS-232C INTERFACE OPTION

ITEM NO	LSCI Part Number	Qty	Description	MFR	MFR PART NO
J1	106-253	1	25 PIN D STYLE PLUG	TRW	DB-25S
Q1	102-071	1	XSTR, GEN PURP NPN		2N5225
S1	105-408	1	DIP SWITCH 8 POS	GYH	76B08
S2	105-406	1	DIP SWITCH 6 POS	GYH	76SB06
U1	104-053	1	IC, BAUD GENERATOR	MOT	MC14411
U2	102-018	1	REGULATOR, +12	MOT	78L12
U3	104-310	1	IC, 8 BIT MUX	NAT	DM81LS95AN
U4	104-203	1	IC, QUAD 2 INPUT NOR		74LS02
U5	104-523	1	IC, UART	INT	P8251A
U6	104-720	1	IC, TRANSCEIVER	MOT	MC1488L
U7	104-721	1	IC, TRANSCEIVER	MOT	MC1489NL

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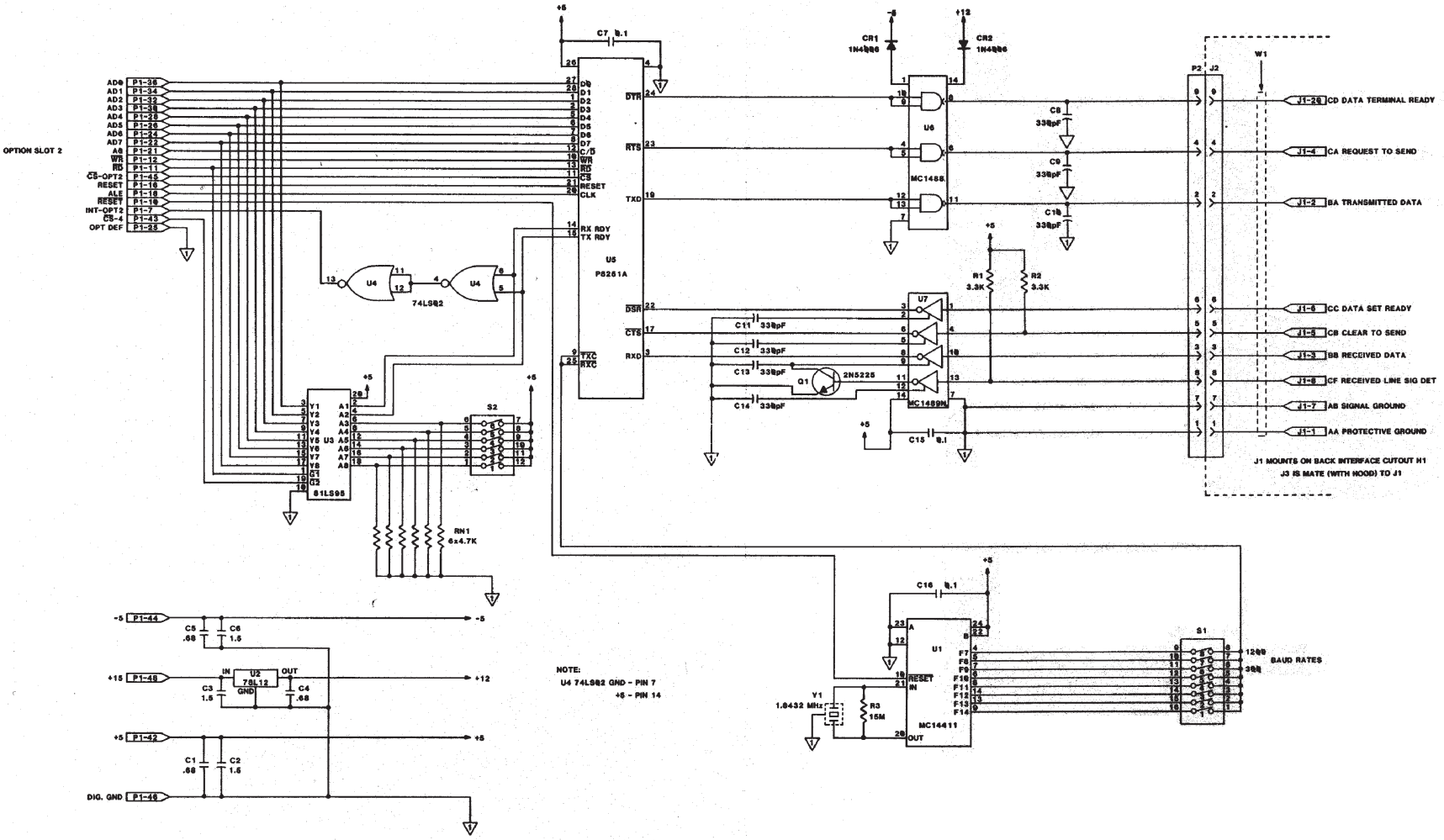


Figure 8223-1. Model 8223 RS-232C Interface Option

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MODEL 8225 ANALOG OUTPUT

8225.1 INTRODUCTION

This section contains information pertaining to the Model 8225 Analog Output for the DRC-91C/93C Temperature Controller. Included is a description, specifications, installation, operation and maintenance information.

8225.2 DESCRIPTION

The 8225 Analog Output is designed to be installed in a DRC-91C/93C and provide an analog output proportional to the Kelvin temperature of the display or control sensor for the purpose of recording, either with a strip chart recorder or other similar device, the sensor temperature.

The analog output is present on the J3 MONITORS connector on the 91C/93C back panel with pin C being the V+ output and pin D being the V- output.

8225.3 SPECIFICATIONS

Specifications for the Model 8225 Analog Output are given in Table 8225-1.

8225.4 INSTALLATION

The 8225 can be installed in the DRC-91C/93C Option Slot 1 or Option Slot 2 (if a Model 8223 RS-232C Interface is not present). The 8225 Analog Output is factory installed if ordered with a DRC-91C/93C or can be field installed at a later date. If field installation is required use the following procedure.

1. Configure the red jumper on the 8225 printed circuit board for SAMPLE (Display Sensor) or CONTROL (Control Sensor).

Table 8225-1. Model 8225 Analog Output Specifications

Output Range - 0.000 to +10.000 V
Output Resolution - 1mV out of 10V
Output Resistance - Less than 10Ω
Output Equivalence
Temperature (for all Input Cards): - Output: 0.000 to 9.999 V for display of 0 to 999.9 K - Sensitivity: 10 mV/K
Voltage (for 9210 and 9220) - Output: 0.0000 to 6.554 V for display 0.0000-6.5535 V - Sensitivity: 1 V/V.
Resistance (9220-P2, -P3 and -R1)[a] -P2: - Output - 0.000 to 3.000 V for display 0.00 - 300.00 Ω - Sensitivity - 10 mV/ohm -P3: - Output - 0.000 to 3.000 V for display 0.0 - 3000.0 Ω - Sensitivity - 1 mV/ohm -R1 - Output - 0.000 to 10.000 V for display 0.000 - 99.999 Ω - Sensitivity - 100 mV/ohm

Note a: The resistance of the 9317C and 9318C Input Cards is not output by the 8225 because of the number of orders of magnitude the display can cover. The analog output of temperature displayed by these Input Cards is available if a Precision Option is present for the sensor.

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WARNING
To prevent shock hazard, turn off the instrument and disconnect it from AC line power and all test equipment before removing cover.

2. Set the power switch to OFF and disconnect the power cord from the unit. Remove the three top panel screws and slide the panel off. Note on the calibration cover the position of Option Slot 1 or 2 which the 8225 will occupy.

3. Remove the four screws that secure the calibration cover to its clips and remove the cover.

4. Plug the 8225 printed circuit board into Option Slot 1 or 2 with the component side to the left of the unit as viewed from the front. Thread the two black and white wires from the 8225 along the inside edge of the rear panel and solder the white wire to MONITOR connector J3-Pin C and black wire to Pin D.

5. Install the calibration cover by reversing procedure in 3.

6. Install the top panel.

8225.5 OPERATION

The output resolution and equivalence is given in Table 8225-1. For a temperature display of 100.00 K the 8225 would output 1.000 V. The output is rounded to the equivalent unit for the 1 mV output. A display of 23.42 K would result in an output of 0.234 V and a display of 23.47 K would result in an output of 0.235 V.

8225.6 CALIBRATION

The Model 8225 has been calibrated to specification prior to shipment. If re-calibration is needed, use to the following procedure. The following equipment is used to calibrate the 8225 Analog Output:

1. Digital Voltmeter/Multimeter (DVM) - 4½ digit resolution or better.

2. Precision Standard Resistor to simulate the input sensor or a Precision Voltage Source with an output resolution of 100 uV out of 3 V or better.

The unit should be allowed one hour to warm up to achieve rated specifications. Use the following procedure to calibrate the 8225 Analog Output:

1. Remove the three top panel screws and slide the panel off.

2. Connect the DVM plus lead to the J3 MONITORS connector pin C and the minus lead to pin D.

3. With the load resistors, or the voltage standard, to simulate the input sensor go to a low temperature and adjust the trimpot labeled Z (for Zero) on the calibration cover until the voltmeter reading corresponds to 10 mV/K. Go to a high temperature and adjust the trimpot labeled S (for Span).

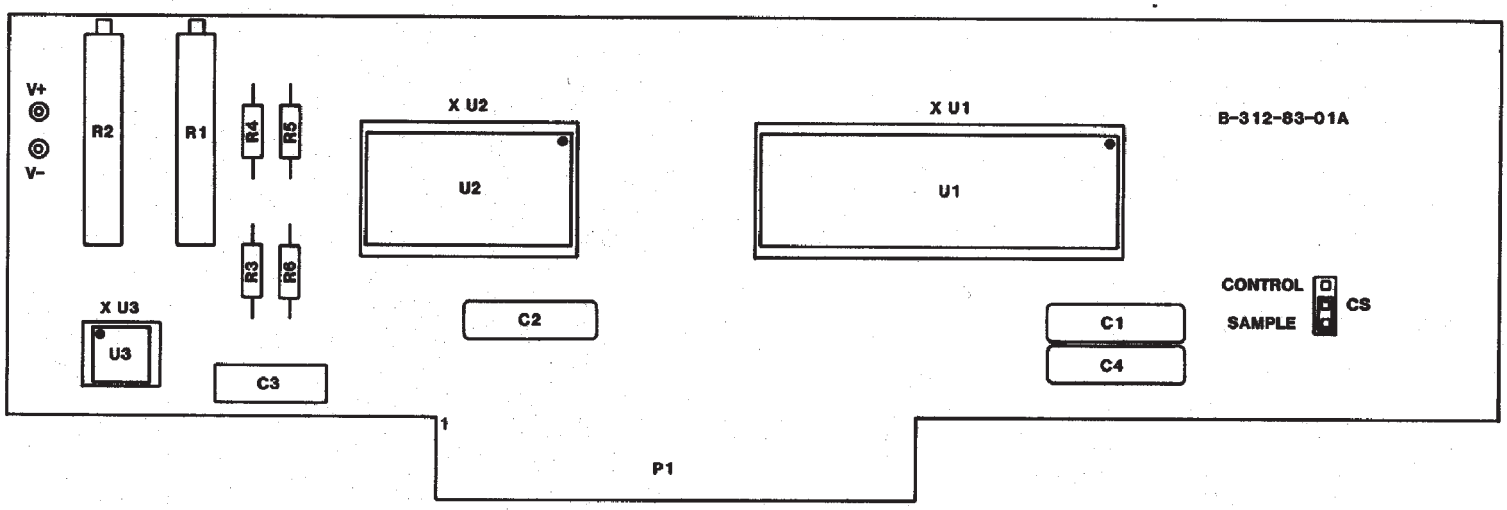
4. Repeat procedure in paragraph 3 until there is no further Zero or Span adjustment required.

5. Install the top panel.

8225-7 REPLACEABLE PARTS

Included in this Section is Figure 8225-1. It includes the Model 8225 Analog Output schematic, replaceable parts list and illustrated component layout. Refer to the manual for ordering information.

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REPLACEABLE PARTS LIST - MODEL 8225 ANALOG OUTPUT OPTION

ITEM NO	LSCI Part Number	Qty	Description	MFR	MFR PART NO
U1	104-524	1	IC, PORT EXPANDER	INT	P8255A-5
U2	104-425	1	IC, 4 DIGIT DAC	BB	DAC71-CCD-V
U3	104-001	1	IC, OP AMP	PMI	OP07EP

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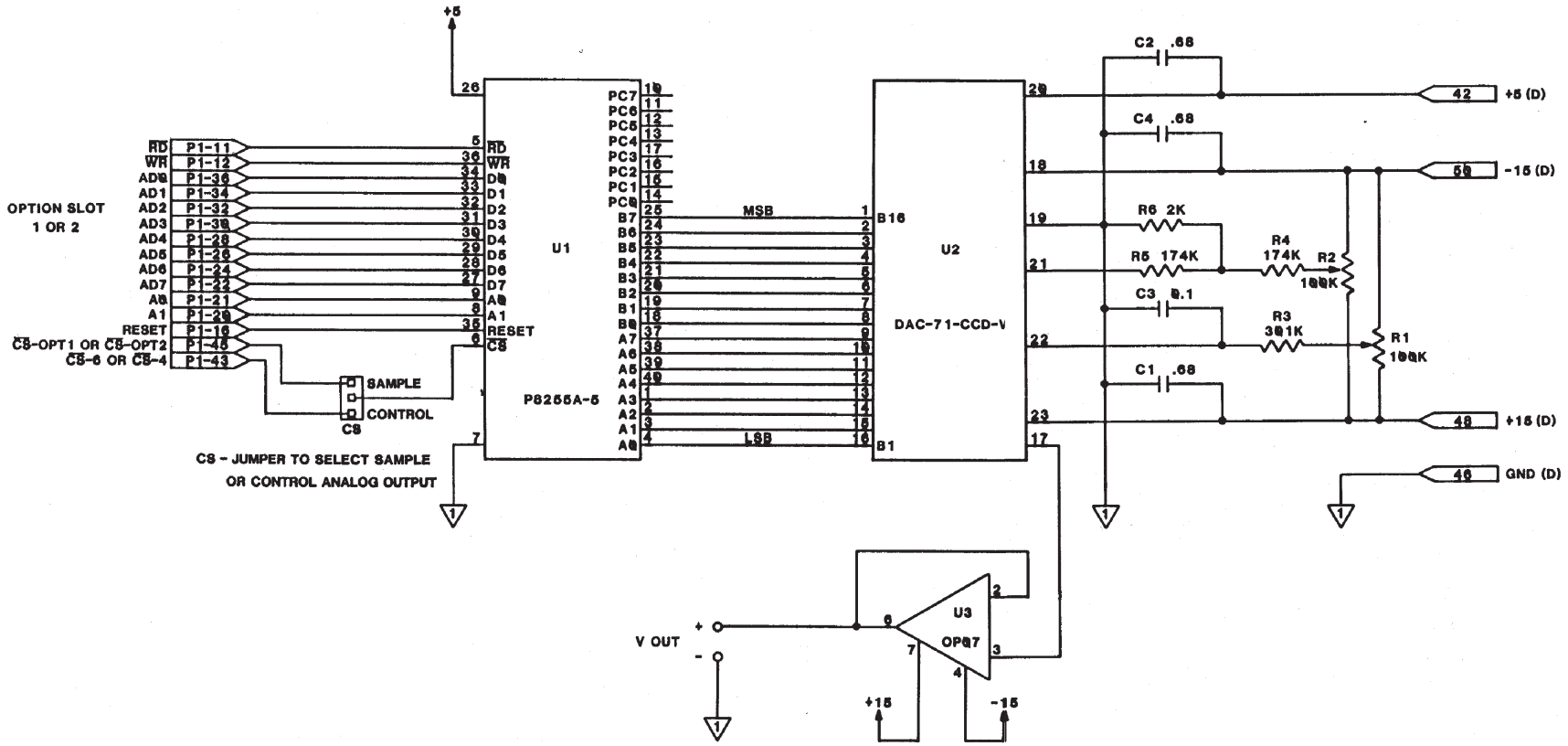


Figure 8225-1. Model 8225 Analog Output Option

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8229 SCANNER CONVERSION OPTION

8229.1 INTRODUCTION

This Section contains information pertaining to the Model 8229 Scanner Conversion for the DRC-91C/93C Temperature Controller. Included is a description, specifications, installation, operation and maintenance information.

8229.2 DESCRIPTION

The 8229 Scanner Conversion is designed to be installed in a DRC-91C/93C and provides four additional channels of sensor input to Input A. The 8229 inputs are designated A1 through A4 and their selection is identified in the display window at the left of the display. With the 8229 installed, the DRC-91C/93C is expanded from the standard dual sensor input to handle six input sensors.

The 8229 A1 through A4 channels can be selected directly (using the SENSOR A key) or included in the SCAN sequence. An independent Dwell time (0 to 99 seconds) can be assigned to each of the additional inputs.

The A1 through A4 channels of the Model 8229 Scanner are accessed through a 24 pin "D" style connector located in the J9 Option Port on the 91C/93C rear panel. Pin assignments for the connector are shown in Table 8229-1.

The pin configuration for this connector is identical to the pin configuration for the IEEE-488 connector.

Even though the Input A contacts are not on the J9 connector, the sensor signal from Input A is routed through the 8229 Scanner.

Table 8229-1. J9 8229 Scanner Conversion Option Connections

Pin	Function	Pin	Function
1	+V Channel A1	13	+I Channel A1
2	-V Channel A1	14	-I Channel A1
3	+V Channel A2	15	+I Channel A2
4	-V Channel A2	16	-I Channel A2
5	+V Channel A3	17	+I Channel A3
6	-V Channel A3	18	-I Channel A3
7	+V Channel A4	19	+I Channel A4
8	-V Channel A4	20	-I Channel A4
9	Shield	21	B0 LSB
10	Shield	22	B1 Out
11	Shield	23	B2 MSB
12	Shield	24	Digital Grnd

In essence, the 8229 routs the sensor signals from all five Input A channels to the A Input Card. The A1 through A4 8229 inputs are designed for four lead measurements and have independent pairs of current and voltage leads. The current leads have a make-before-break switching action and the voltage leads are break-before-make. The B0 through B2 outputs on J9 are a BCD representation of the channel selected with B0 being the least significant bit and B2 the most significant bit (a 0 represents logic LO and a 1 logic HI with respect to the Digital Ground on J9). Logic 000 represents channel A0, 001 channel A1, 010 channel A2, 011 channel A3 and 100 represents channel A4 on B2, B1 and B0 respectively.

8229.3 SPECIFICATIONS

Specifications for the Model 8229 Scanner Conversion Option are given in Table 8229-2.

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Table 8229-2. Model 8229 Scanner Conversion Specifications

Number of Channels: 4 (in addition to the existing Inputs, A and B), designated A1 through A4.

Contact Configuration: 4 pole (2 current poles make-before-break, 2 voltage poles break-before-make).

Maximum Input Voltage: 32 volts DC or peak AC.

Maximum Current: 10 milliamperes.

Thermal Offset: Less than 3 microvolts per contact on break-before-make poles, less than 50 microvolts on others.

Contact Resistance: Less than 1 Ω.

Open Channel Isolation: $>10^{10}$ ohms

Input/Output: 24 pin "D" style connector, mate supplied.

Channel Selection: Front panel SENSOR A key increments A0, A1, A2, A3, A4, A0, etc. each time it is pressed or automatically in the SCAN mode. All front panel operations can be duplicated over the remote interfaces.

Switch Contact Life: $>10^6$ operations at rated load.

Configuration: Channels A0 through A4 are configured as Remote Position A00 through A04 with respect to Sensor. Curve selection with 8229 present.

Channel Selected Data: Chnnl selected present in BCD form on J9 connector.

8229.4 INSTALLATION

The 8229 Scanner Conversion is factory installed if ordered with an DRC-91C Temperature Controller or can be field installed at a later date. If field installation is required, use the following procedure.

WARNING
To prevent shock hazard, turn off instrument and disconnect it from AC line power and all test equipment before removing cover.

1. Set the POWER switch to OFF and disconnect the power cord from the unit. Remove the three top panel screws and slide the panel off. Note on the calibration cover the position of Option Slot 2 which the 8229 will occupy.

2. Remove the four screws that secure the calibration cover to its clips and remove the cover. Remove the two back panel mounting clips that secure the J9 blank cover plate to the interface opening and remove the plate.

3. Plug the internal sensor lead cable into the 8229 printed circuit board (PCB) with the locking tab configured properly. Plug the 8229 PCB into Option Slot 2 with the component side to the left of the unit as viewed from the front. Thread the 8229 internal cable along the inside edge of the rear panel so that it won't interfere with the installation of the calibration cover or top cover.

4. Position the 24 pin 8229 Scanner connector in the J9 opening on the back panel and secure it in place using the screws provided.

5. Disconnect the Input Card wiring harness from the A Input Card by lifting the locking tab on the Input Card connector and pulling on the body of the wiring

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harness mating connector. Plug the Input Card wiring harness into the 8229 input making sure that the wiring harness locking tab is seated properly. Thread the 8229 output cable along the component side of the 8229 and plug the cable into the Input Card making sure the locking tab is seated properly.

6. Install the calibration cover by reversing procedure 2.

7. Install the top cover panel.

8229.5 OPERATION

Operation of the 8229 Scanner Conversion can be implemented either locally, from the front panel, or remotely through the remote interfaces.

8229.5.1 Local 8229 Operation

The 8229 A1 through A4 channels are accessed locally using the SENSOR A key. The Display Sensor is incremented each time the SENSOR A key is pressed in the sequence A, A1, A2, A3, A4, A etc.

8229.5.1.1 Channel Dwell Times

The dwell times for the A1 through A4 channels are selected the same as for A and B. See Sections 3.8.3 and 3.8.4 for a complete description of this operation.

8229.5.1.2 Units

The units for the A1 through A4 channels are the same as for Input A and are defined by the A Input Card. Selection of units is covered in Section 3.8.5.

8229.5.1.3 Resolution

Resolution is by input card and not channel. Consequently, resolution is the same for all scanner channels. See Section 3.8.6 for a discussion of how to set resolution.

8229.5.2 Remote 8229 Operation

The remote operation of the 8229 Scanner is covered in Section 4, REMOTE OPERATION. See Table 4-7 and Section 4.11 entitled THE OPTIONAL SCANNER CARD.

8229.5.3 Curve Selection

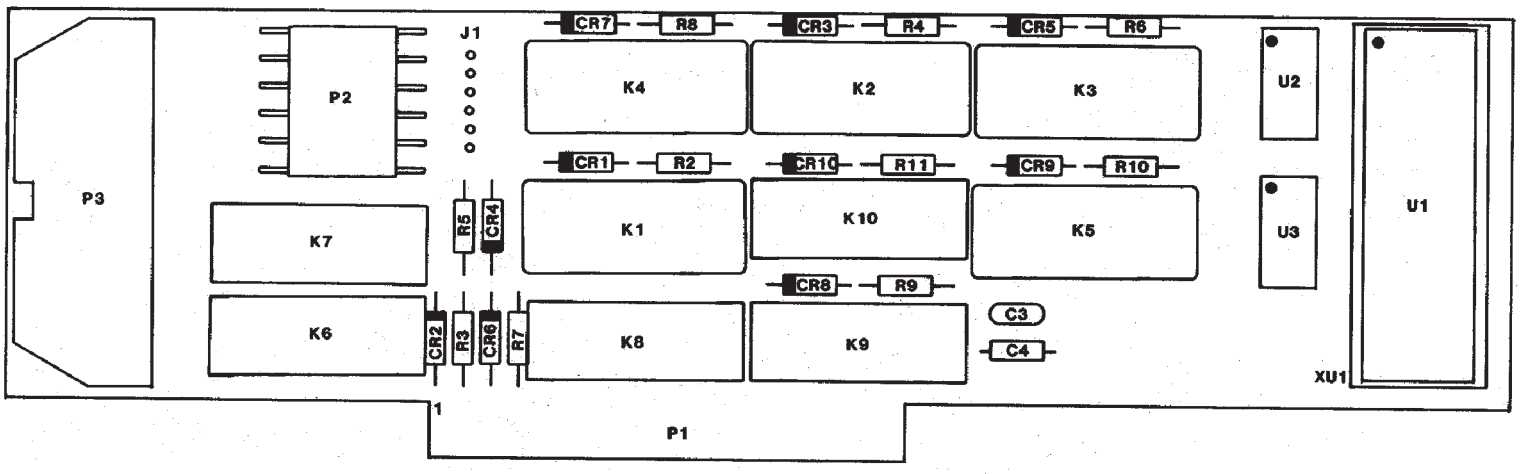
The 8229 is considered an internal Remote Position. The A0 through A4 channels are interpreted as Remote Position A00 through A04 for curve selection when the SENSOR A ID Switch 4 is OPEN (0). The curve for the input is then determined from Table 3-4 (the Curve Number to Position Number Correlation Table). A complete discussion of curve selection is given in Section 3.9 and in particular Section 3.9.2.1.

8229.6 REPLACEABLE PARTS

Included in this Section is Figure 8229-1. It includes the Model 8229 Scanner Conversion Option schematic, replaceable parts list and illustrated component layout. Refer to the manual for ordering information.

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REPLACEABLE PARTS LIST - MODEL 8229 SCANNER CONVERSION OPTION

ITEM NO	LSCI Part Number	Qty	Description	MFR	MFR PART NO
K1-5	105-321	5	RELAY,DPST,DRY REED	COTO	CR-3402-05-91
K6-10	105-322	5	RELAY,DPST,DRYREED	COTO	CR-7102-05-1010
MP1	106-250	1	CONNECTOR KIT	AML	57-30240
P2	106-142	1	6 POST LOCKING RA HDR	MOLX	2420-09075-1061
P3	106-424	1	26 PIN RA HEADER	TBA	609-2602MR
U1	104-524	1	IC, PORT EXPANDER	INT	P8255A-5
U2,3	104-210	2	IC, OC HEX INVERTER		7406

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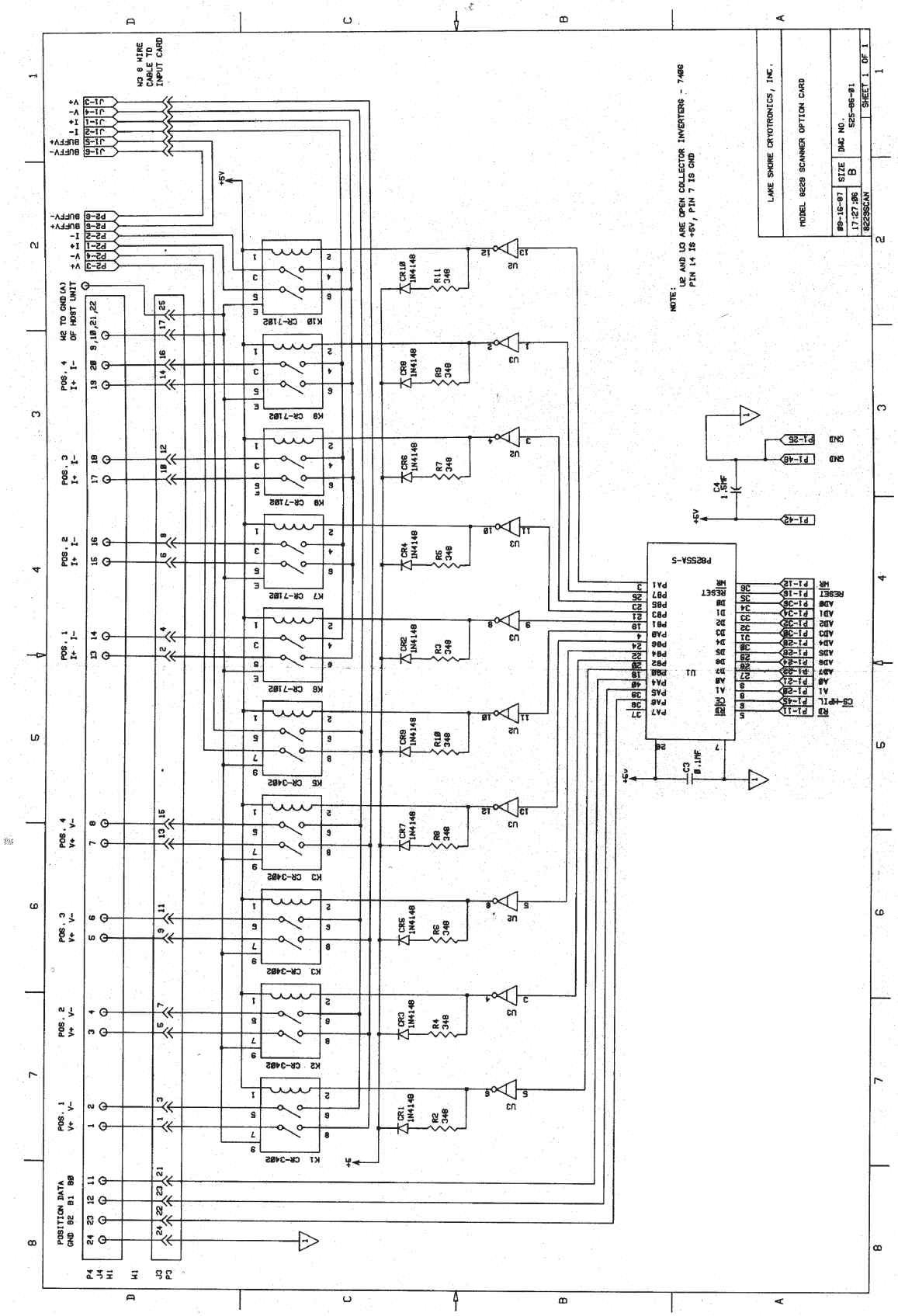


Figure 8 229-1. Model 8229 Scanner Conversion Option

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APPENDIX A - Standard Diode Voltage-Temperature Characteristics

TEMP(K)	D CURVE BP#	D CURVE VOLTAGE	E1 CURVE BP#	E1 CURVE VOLTAGE	DT-470 CURVE 10 BP#	DT-470 CURVE 10 VOLTAGE
1.4		2.5984	30	2.6591	29	1.69808
1.5		2.5958		2.6567		1.69674
1.6		2.5932		2.6542		1.69521
1.7		2.5906		2.6518		1.69355
1.8		2.5880		2.6494		1.69177
1.9		2.5854		2.6470		1.68987
2.0	30	2.5828	29	2.6446	28	1.68912
2.2		2.5735		2.6355		1.68352
2.4		2.5643		2.6265		1.67880
2.6		2.5551		2.6175		1.67376
2.8		2.5458		2.6084		1.66845
3.0	29	2.5366	28	2.5994		1.66292
3.2		2.5226		2.5868		1.65721
3.4		2.5086		2.5742		1.65134
3.6		2.4946		2.5616		1.64529
3.8		2.4807		2.5490	27	1.64112
4.0		2.4667	27	2.5364		1.63263
4.2		2.4527		2.5221		1.62602
4.4		2.4387		2.5077		1.61920
4.6		2.4247		2.4934		1.61220
4.8		2.4108		2.4791		1.60506
5.0		2.3968		2.4648		1.59782
5.5		2.3618		2.4290		
6.0		2.3269		2.3932		1.56027
6.5		2.2919		2.3574		1.54097
7.0		2.2570		2.3216		1.52166
7.5		2.2220		2.2858		1.50272
8.0		2.1871		2.2500		1.48443
8.5		2.1521		2.2142		1.46700
9.0	28	2.1172	26	2.1784	26	1.44850
9.5		2.0909		2.1516		1.43488
10.0		2.0646		2.1247		1.42013
11.0		2.0119		2.0708		1.39287
12.0		1.9592		2.0170	25	1.36687
13.0	27	1.9066	25	1.9632		1.34530
14.0		1.8338		1.9011		1.32412
15.0	26	1.7610		1.8390		1.30422
16.0		1.6984		1.7769		1.28527
17.0	25	1.6359		1.7148		1.26702
18.0		1.5646	24	1.6527		1.24928
19.0		1.4932		1.5724		1.23184
20.0		1.4219		1.4922	23	1.21555
21.0	24	1.3505		1.4120		1.19645
22.0		1.3006	23	1.3317		1.17705
23.0	23	1.2507		1.2837		1.15558
24.0		1.2114	22	1.2357	22	1.13598
25.0	22	1.1720	21	1.1877	21	1.12463

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26.0	21	1.1486	20	1.1559	20	1.11896
27.0	20	1.1308	19	1.1365	19	1.11517
28.0	19	1.1190	18	1.1239	18	1.11202
29.0	18	1.1116	17	1.1150		1.10945
30.0	17	1.1058	16	1.1080		1.10702
31.0					17	1.10465
32.0	16	1.0970	15	1.0981		1.10263
34.0	15	1.0902	14	1.0909		1.09864
36.0		1.0850	13	1.0848	16	1.09477
38.0		1.0798		1.0797		1.09131
40.0	14	1.0746	12	1.0746		1.08781
44.0					15	1.08105
45.0		1.0633		1.0630		
50.0		1.0520		1.0515		1.07053
55.0	13	1.0407		1.0399		
60.0		1.0287	11	1.0284	14	1.05277
65.0		1.0166		1.0159		1.04353
70.0	12	1.0046		1.0035		1.03425
75.0		.99172	10	0.9911		1.02482
77.35				0.9849		
77.4					13	1.02044
80.0		.97890		0.9780		1.01525
85.0		.96609		0.9649		1.00552
90.0	11	.95327		0.9518		.99565
95.0		.93987		0.9388	12	.98574
100.0		.92647	9	0.9257		.97550
105.0		.91307		0.9122		.96524
110.0		.89966		0.8988		.95487
115.0		.88626		0.8853	11	.94455
120.0		.87286		0.8718		.93383
125.0		.85946		0.8584		.92317
130.0	10	.84606	8	0.8449		.91243
135.0		.83228		0.8311		.90161
140.0		.81850		0.8173	10	.89082
145.0		.80472		0.8035		.87976
150.0		.79094		0.7896		.86873
155.0		.77716		0.7758		.85764
160.0		.76338		0.7620		.84650
165.0		.74961		0.7482	9	.83541
170.0	9	.73582	7	0.7344		.82404
175.0		.72170		0.7202		.81274
180.0		.70757		0.7060		.80138
185.0		.69344		0.6918		.78999
190.0		.67931		0.6777		.77855
195.0		.66518		0.6635	8	.76717
200.0		.65105		0.6493		.75554
205.0		.63693		0.6351		.74398
210.0		.62280		0.6210		.73238
215.0		.60867		0.6068		.72075
220.0	8	.59455	6	0.5926		.70908
225.0		.58080		0.5789		.69737
230.0		.56707		0.5651	7	.68580

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235.0		.55334		0.5514		.67387
240.0	7	.53960	5	0.5377		.66208
245.0		.52649		0.5246		.65026
250.0		.51337		0.5115		.63841
255.0		.50026		0.4984		.62654
260.0		.48714		0.4853		.61465
265.0	6	.47403	4	0.4722		.60273
270.0		.46057		0.4588		.59080
275.0		.44711		0.4454		.57886
280.0		.43365		0.4320	6	.56707
285.0	5	.42019	3	0.4186		.55492
290.0		.40613		0.4045		.54294
295.0		.39208		0.3904		.53093
300.0		.37802		0.3763		.51892
305.0	4	.36397	2	0.3622		.50689
310.0		.34940		0.3476		.49484
315.0		.33482		0.3330		.48278
320.0		.32025		0.3184		.47069
325.0		.30568		0.3038		.45858
330.0		.29111	1	0.2893		.44647
335.0		.27654				.43435
340.0		.26197			5	.42238
345.0	3	.24739				.41003
350.0		.23325				.39783
355.0		.21911				.38561
360.0		.20497				.37337
365.0	2	.19083				.36110
370.0		.17774				.34881
375.0		.16464				.33650
380.0	1	.15155				.32416
385.0					4	.31180
390.0						.29958
395.0						.28700
400.0						.27456
405.0						.26211
410.0						.24963
415.0						.23714
420.0						.22463
425.0						.21212
430.0						.19961
435.0					3	.18696
440.0						.17464
445.0						.16221
450.0						.14985
455.0						.13759
460.0					2	.12536
465.0						.11356
470.0						.10191
475.0					1	.09032

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APPENDIX A - DIN Standard Curve for 100 ohm Platinum Sensors

28	30.0	3.82000
27	32.0	4.23481
	34.0	4.68000
26	36.0	5.14601
	38.0	5.65000
25	40.0	6.17000
24	42.0	6.72621
	44.0	7.31000
23	46.0	7.90899
	48.0	8.57000
	50.0	9.24000
22	52.0	9.92364
	54.0	10.66000
	56.0	11.41000
21	58.0	12.17995
	60.0	12.99000
20	65.0	15.01541
	70.0	17.11000
19	75.0	19.22302
	80.0	21.36000
18	85.0	23.52499
	90.0	25.67000
	95.0	27.82000
	100.0	29.95000
17	105.0	32.08087
	110.0	34.16000
	115.0	36.25000
	120.0	38.34000
	125.0	40.42000
	130.0	42.49000
	135.0	44.57000
16	140.0	46.64758
	145.0	48.69000
	150.0	50.75000
	155.0	52.80000
	160.0	54.84000
	165.0	56.88000
	170.0	58.92000
15	175.0	60.96840
	180.0	62.98000
	185.0	65.00000
	190.0	67.01000
	195.0	69.02000
	200.0	71.03000
	205.0	73.03000
14	210.0	75.04385
	215.0	77.02000
	220.0	79.00000
	225.0	80.98000
	230.0	82.96000
	235.0	84.94000
	240.0	86.92000
	245.0	88.90000
	250.0	90.88000
	255.0	92.86000

	260.0	94.83000
	265.0	96.80000
13	270.0	98.78433
	275.0	100.72000
	280.0	102.67000
	285.0	104.62000
	290.0	106.57000
	295.0	108.51000
	300.0	110.45000
	305.0	112.39000
	310.0	114.32000
12	315.0	116.27003
	320.0	118.19000
	325.0	120.11000
	330.0	122.03000
	335.0	123.95000
	340.0	125.86000
	345.0	127.78000
	350.0	129.69000
11	355.0	131.61563
	360.0	133.50000
	365.0	155.40000
	370.0	137.31000
	375.0	139.20000
	380.0	141.09000
	385.0	142.98000
	390.0	144.87000
	395.0	146.76000
10	400.0	148.65215
	405.0	150.51000
	410.0	152.39000
	415.0	154.26000
	420.0	156.14000
	425.0	158.01000
	430.0	159.87000
	435.0	161.73000
	440.0	163.59000
9	445.0	165.46573
	450.0	167.30000
	455.0	169.15000
	460.0	171.00000
	465.0	172.84000
	470.0	174.68000
	475.0	176.52000
	480.0	178.36000
	485.0	180.19000
8	490.0	182.03545
	495.0	183.85000
	500.0	185.67000
	505.0	187.49000
	510.0	189.32000
	515.0	191.13000
	520.0	192.94000
	525.0	194.75000
	530.0	196.56000

7	535.0	198.38649
	540.0	200.17000
	545.0	201.96000
	550.0	203.75000
	555.0	205.54000
	560.0	207.33000
	565.0	209.12000
	570.0	210.91000
	575.0	212.69000
	580.0	214.46000
6	585.0	216.25553
	590.0	218.01000
	595.0	219.78000
	600.0	221.55000
	605.0	223.31000
	610.0	225.07000
	615.0	226.83000
	620.0	228.59000
	625.0	230.34000
5	630.0	232.10593
	635.0	233.84000
	640.0	235.57000
	645.0	237.31000
	650.0	239.06000
	655.0	240.79000
	660.0	242.52000
	665.0	244.25000
	670.0	245.97000
4	675.0	247.71350
	680.0	249.42000
	685.0	251.14000
	690.0	252.85000
	695.0	254.56000
	700.0	256.27000
	705.0	257.97000
	710.0	259.68000
3	715.0	261.39092
	720.0	263.07000
	725.0	264.77000
	730.0	266.46000
	735.0	268.14000
	740.0	269.83000
	745.0	271.51000
	750.0	273.19000
	755.0	274.87000
2	760.0	276.56633
	765.0	278.22000
	770.0	279.88000
	775.0	281.55000
	780.0	283.21000
	785.0	284.87000
	790.0	286.53000
	795.0	288.18000
1	800.0	289.83000

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A P P E N D I X B

Sensor Curve 18 Character Information Line
Reserved Character Definitions

Each Sensor Curve has an 18 character information line. Some of the characters are reserved for specific operations. The definitions are as follows:

Character	Description
1	Curve type: (L) - Unit performs Lagrangian calculations on the data. Any other character - Unit performs Straight - Line interpolation on the data.
2	Temperature Range (Setpoint Limit): (0) - Up to 324.9 K. (1) - Up to 374.9 K. (2) - Up to 474.9 K. (3) - Up to 799.9 K. (4) - Up to 999.9 K.
3	Sensor type (used for front panel curve entry here alphanumerics cannot be entered with the standard numeric keypad): (0) - DT-470 Series Silicon Diode Sensors (1) - DT-500 Silicon Diode Sensors (2) - TG-100/TG-200GaAs and GaA/As (3) - 100 Ohm Platinum Resistance Thermometers (PRT's) (4) - 1000 Ohm Platinum Resistance Thermometers (PRT's) (5) - Rhodium-Iron Resistance Sensors (6) - Germanium Resistance Sensors (7) - Carbon-Glass Resistance Sensors (8) - Capacitance Sensors (9) - Reserved (for Thermocouples)

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Character	Description
13 thru 18	Stored in the Sensor Curve Information Table (typically where the sensor serial number is stored in Precision Options). The sensor serial number formats are as follows (where # is used to indicate a 0-9 numeric): Sensor Type — Format 0 — D##### 1 — D##### 2 — #### 3 — P#### 4 — P#### 5 — #### 6 — ##### 7 — C#### 8 — #### 9 — No S/N

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A P P E N D I X C

DRC-91C Error Code Summary

The error codes for the DRC-91C are separated into categories. The Err0x codes are for mainframe error conditions, the Err1x codes are for Input Card error conditions. If an Err0x, or an OL or Err2x error occurs for an input selected as the control input, the heater range is taken to OFF and must be reset following correction of the fault condition. The following is a summary of the error codes.

Error Code	Possible Cause/Corrective Action
Err01	The unit encountered an unwriteable NOVRAM data location. When this error occurs, the unit displays the error, stores it in the WS data location and halts operation. The NOVRAM initialization sequence should be performed to try to correct the problem. If the error code still exists, the NOVRAM needs to be replaced.
Err02	The unit performs a NOVRAM check on power-up. If the unit detects a NOVRAM data error (or if the interface XR&I* function was performed) the unit displays the error, stores it in the WS data location and waits for the NOVRAM initialization sequence to be performed.Repeated Err02 conditions could signal a failure by the NOVRAM to retain data and it should be replaced.
Err09	The REMOTE SENSOR ID for the unit allows for an input range of 00 (00000 on bits B4 thru B0 of the ID) to 1F (11111 on bits B4 thru B0). The 1F input is reversed for a REMOTE SENSOR ID error condition (the Position Data Adaptor uses this code to indicate that more than one Sensor Scanner is active to the unit). When the error, stores it in the WS data location and continues to monitor the REMOTE SENSOR ID until the fault is corrected.
Err10	8223 RS-232C Interface Parity Error. The error may be caused by problems with the signal lines or incorrectly specified parity. The error, and any of the other DRC91-RS errors, is transmitted when the unit is asked to output and is cleared following the first transmission after the error.

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Error Code	Possible Cause/Corrective Action
Err11	8223 RS-232C Interface Overrun Error. The error is caused by the unit's main processor not reading the input character before the next one becomes available. The overrun character(s) are lost.
Err12	8223 RS-232C Interface Framing Error. The error may be caused by signal line transients or incorrectly specified stop bits or character length.
Err13	8223 RS-232C Interface Input Buffer Overrun Error. The error occurs when more than 256 characters are input to the FIFO buffer of the unit. Any characters received after the 256th character are lost.
OL	Input Overload. When an input signal which exceeds the maximum allowed for that input is applied the error occurs. When the error occurs, the displays OL if it is the DISPLAY SENSOR input and stores OL in either the WS and/or WC data locations.
Err20	8217C/8218C Input Card Error. The 8217C and 8218C Input Cards have an EEPROM that stores the calibration constants used to set the sensor current and determine the resulting voltage accurately. When the card detects an error in the EEPROM storage it tries to correct it. If it cannot correct the error,it transmits the Err20 code to the main processor and resets the sensor current to the lowest value to avoid any potential sensor damage. The unit displays the error,stores it in the WS data location and halts operation. The Input Card calibration procedure should be preformed to try to correct the problem. If the error code still exists, the Input Card EEPROM needs to be replaced.

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Error Code	Possible Cause/Corrective Action
Err25	Unrecognized A Input Card type. The 92xx Series cards and "Smart" (microprocessor controlled) Input Cards tell the main processor what card type they transmitted, the error could be caused by the Input Card not being present or if the card had a selection switch de-selected (for example, if it were not pressed correctly or came out of detent in shipping). When the error occurs, the unit displays dashes (-----) if it is the DISPLAY SENSOR input and continues operation until the fault is corrected. The error is stored in the WI A Input data location and is displayed when the LOCAL key is pressed to determine the Input Card type.
Err26	Unrecognized B Input Card type. Operation is the same for Err25 except the error is stored in the WI B Input data location.
Err27	Incorrect A Input Card polarity. The 92xx Series Input Cards determine the input signal polarity doesn't match the temperature coefficient of the sensor type selected, there is either an error in the sensor wiring an open circuit or a fault on the Input Card. When the error occurs, the unit displays the error if it is the DISPLAY SENSOR input and continues operation until the fault is corrected. The error is stored in the WI A Input data location and is displayed when the LOCAL key is pressed to determine the Input Card type.
Err28	Incorrect B Input Card polarity. Operation is the same as for Err27 except the error is stored in the WI B Input data location.

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APPLICATION NOTES

This appendix includes the following Lake Shore documentation:

1. Fundamentals For Usage Of Cryogenic Temperature Controllers – Application Note .....Page 1
2. Standard Curve 10 – Technical Data .....Page 8
3. DT-470 Series Temperature Sensors Installation and Operation – Application Note.....Page 10
4. Measurement System Induced Errors In Diode Thermometry – Article Reprint.....Page 14

FUNDAMENTALS FOR USAGE OF CRYOGENIC TEMPERATURE CONTROLLERS

by

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I INTRODUCTION

Cryogenic temperature controllers have been available for years, but users often have an incomplete understanding of their operating principles and of the closed-loop interactions between the controller and the controlled low temperature environment. The object of this primer is to address this problem by presenting some fundamental and practical concepts of control at low temperatures. The so-called "three-mode" or "PID" controller, utilizing Proportional (gain), Integral (reset), and Derivative (rate) functions, will be discussed and examples given of its operation and adjustment. While the emphasis will be placed on analog control systems, the advantages and disadvantages of digital versus analog control will also be presented.

II CHARACTERISTICS OF CRYOGENIC TEMPERATURE CONTROL SYSTEMS

The adjective "cryogenic" as applied to temperature control systems defines a set of conditions that distinguishes such systems from those for which the great majority of applications exist, i.e., industrial processes in which temperatures are above—and often well above—room temperature. There are at least five factors which crucially affect temperature control performance when one compares a cryogenic system with that existing inside a furnace, for example:

1. The values of heat capacity (lower, C_p, and thermal conductivity (often higher, κ, are such that much shorter thermal time constants ($\tau \alpha C_p/\kappa$) are the rule at low temperatures.
2. The temperature sensor used in a furnace is almost always one of a variety of thermocouples with sensitivities in the 10-100uV/°C range. In the cryogenic regime, resistance thermometers (both metallic and semi-conductive), diode, and capacitance thermometers provide from one to three order-of-magnitude higher sensitivity.
3. The heat input for furnaces is almost always derived from a line frequency source, and is controlled by relays, variable transformers, saturable reactors, or SCRs. Experiments performed in a cryostat usually involve low level signals, and hence require a low noise background. For that reason, ripple-free direct current, usually controlled by a series transistor bank, should be used to power the heater.
4. As one traverses the cryogenic regime from the liquid helium range up towards room temperature, there can be quite large *variations* in both the thermal time constants and thermometer sensitivities.
5. In the case of the furnace in which the load does not experience large endo- or exothermic reactions, the heat input required to maintain a set point temperature is approximately constant. This is because the heat loss through a fixed thermal conductance to the room temperature environment outside the furnace is also constant. However, there are cryogenic systems where the low temperature environment provided by, e.g., a surrounding cryogen such as a liquid helium or liquid nitrogen bath, may vary drastically as the level of the cryogen changes. In addition, the thermal conductance to the outside world is highly dependent on the gas pressure (vacuum) maintained in the cryostat. The resulting variations in "cooling power" will cause the heat input requirements to be anything *but* constant. A few cryogenic systems employ a controller cooling loop, but this type of system will not be discussed.

Most of the difficulties in cryogenic control applications are associated with factors 4 and 5, where changes in parameters are involved.

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III PROPORTIONAL CONTROL

The block diagram in Figure 1 shows a systems in which only proportional control is being used. In this system, the desired control temperature setting (set point) is being compared to the sensor signal and the difference, or error signal (including polarity), is amplified within the controller. When the sensor temperature corresponds to the set point temperature (in voltage for a diode or resistance for a resistor), the sensor signal will be equal to, but opposite in polarity to the set point signal and the error signal will be zero. In older instruments, the set point is normally calibrated in millivolts or volts or resistance, corresponding to the sensor output signal. Most modern controllers have stored within them the appropriate voltage-temperature or resistance-temperature sensor characteristic so that the set point can be calibrated directly in temperature. However, as discussed in Section VII, this convenience feature can compromise the resolution and accuracy of the controller.

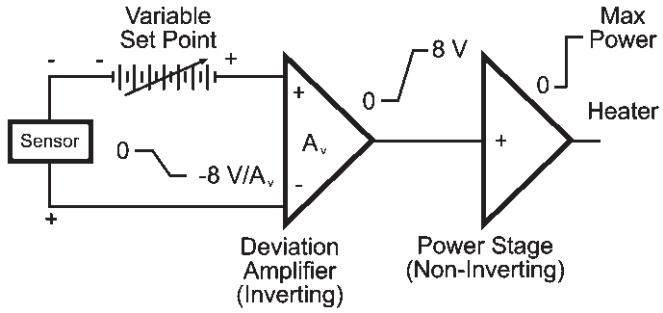


FIGURE 1. Block diagram of Cryogenic Temperature Controller. A_v is amplifier voltage gain.

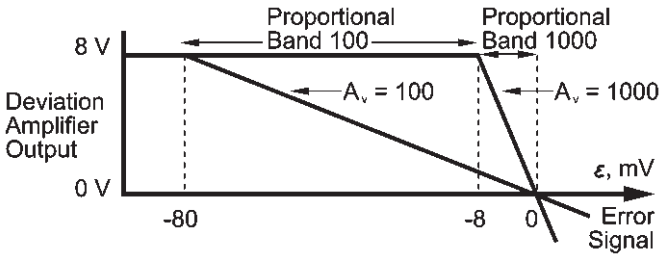


FIGURE 2. Output plot of the deviation amplifier showing Proportional Bands for gain settings of 100 and 1000. For the DRC-82C, the maximum available gain is 1000.

The output of the controller is dc power to a resistive heater, the output magnitude of which depends on the size and sign of the error signal, as well as on the gain of the deviation amplifier and the output power supply. Since the controller's power output state tracks the deviation amplifier output, it is evident that the power output is proportional to the magnitude of the error signal. In process control nomenclature, this response is described in terms of "proportional control".

Let us examine the behavior of the sensor signal—set point—deviation circuit in a modern cryogenic controller, the Lake Shore Cryotronics Model DRC-82C. In figure 2, the amplifier output (deviation gain times error) is plotted against the error signal for two amplifier gains: A_v = 100 and A_v = 1000. "Gain" in this closed loop system refers not to the power gain, as in an audio amplifier, but is related to the maximum amount of error signal allowed before the controller is directed to produce full output power. The DRC-82C requires a 0 to 8 volt signal from the deviation amplifier to drive the power output stage from zero-to-maximum. In Figure 2, For Av = 1000, there is a narrow band of error signals (0 to -8 mV) within which the proportional action occurs. This "proportional band" expands tenfold for A_v = 100, and so on for lower gains; obviously, gain and proportional band are inversely related. Proportional band is expressed as a percentage of full scale range.

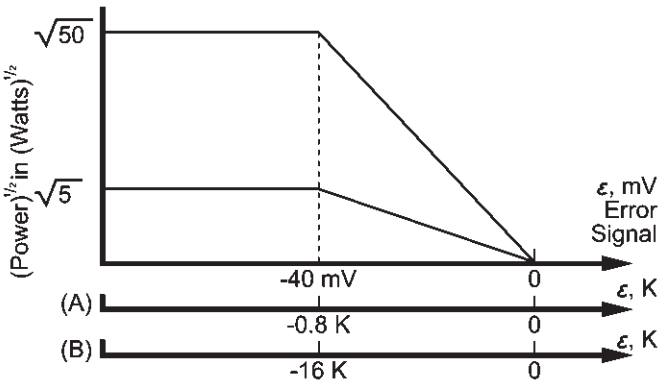


FIGURE 3. Output Power versus error signal in voltage or equivalent temperature of sensor for two different power settings: (A) corresponds to a sensor sensitivity of -50 mV/K; (B) corresponds to a sensor sensitivity of -2.5 mV/K. Note that the curves are linear in voltage, *not* power.

Note that the proportional band in mV can be converted to temperature in kelvins if the sensitivity of the sensor in mV/K is known. As an example, suppose the sensor producing the error signal in Figure 2 had a sensitivity of 1 mV/K and the set point full scale range was 100 mV = 100 K. The proportional band would then be 8% (or 8 K) and 80% (or 80 K) for A_v = 1000 and 100, respectively. In cryogenic applications, this terminology is less significant; gain, which is multiplicative, is usually more useful, since it is more easily understood by the user.

The power output stage of a cryogenic controller may or may not have variable gain associated with it. If the controller has several output power stage ranged for example, 5, covering 5 orders of magnitude in power) as does the DRC-82C, then the controller output into a 50 ohm load and with a gain of 200 for 5 watts and 50 watts would have the response shown in figure 3. Note that the *overall* voltage and power gain of the controller is modified by changing the output power settings.

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To illustrate the effect of the sensor, in more detail, consider the idealized curve (Figure 4) for a Lake Shore silicon diode which has a nominal sensitivity of -50 mV/K below 30 kelvin and -2.5 mV/K above 30 kelvin. Figure 3 illustrates the effect of converting the voltage error signal (horizontal axis) to its equivalent temperature error for the two sensitivity regions of the silicon diode sensor. These curves introduce the concept of loop gain dP/dT (watts/kelvin), which includes the gain of the sensor as well as that of the deviation amplifier and power output stage. As the transition in temperature from above 30 kelvin to below 30 kelvin is made, the loop gain is increased by a factor of 20 because of the increased sensitivity of the silicon diode thermometer. Because of noise and thermal phase lag, the deviation amplifier gain will normally have to be reduced by the same factor so that the loop gain remains relatively constant.

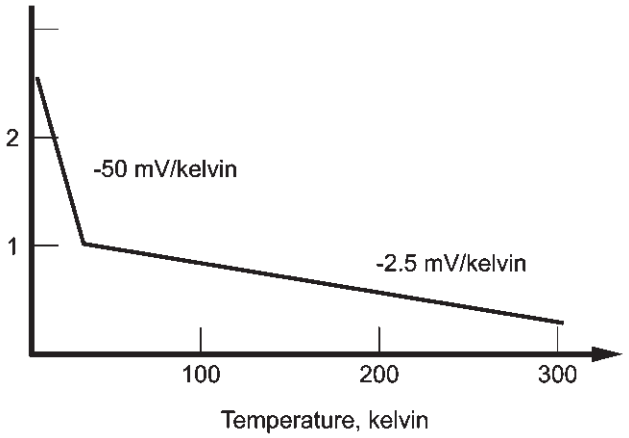


FIGURE 4. Idealized curve for Lake Shore Cryotronics, Inc. DT-500 Series silicon diode temperature sensors.

In order to maintain any desired temperature above that of the cryogen in a cryogenic system, of course some level of heater power must be supplied by the controller. We have seen in Figures 2 and 3 that a non-zero temperature error signal is necessary to produce an output, and that the magnitude of the error—or temperature *offset*— is a function of the power output level and the loop gain. Let us demonstrate the nature of the offset, also called droop, with an example.

Assume that a system sample block (the mass whose temperature is to be controlled) has a finite heat capacity, but that its thermal conductivity is infinite, as is the thermal conductance between the block and the sensor and heater. The result will be that the temperature within the block will be isothermal, no matter at what rate the block is heated or cooled. For the following discussion, ignore any noise associated with the system and assume that to control at 20 kelvin, the heating power required is 0.2 watts. Assume also that 50 watts of heater power is available, reducible in five steps of one decade each. Figure 5 shows the control offset for an amplifier gain of 100 and three output power settings which will deliver enough power to the system to balance the cooling power.

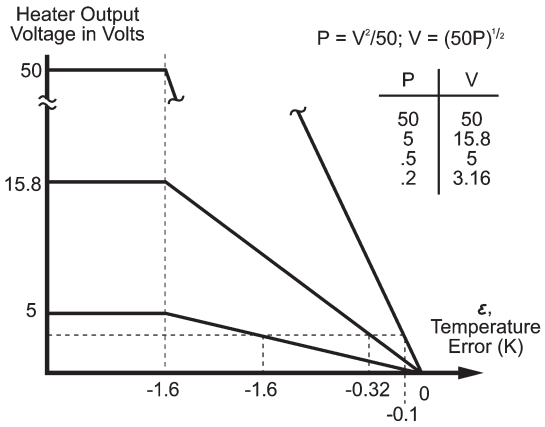


FIGURE 5. Effect of output power setting on offset for a proportional controller *only*.

The temperature offsets for a power level of 0.2 watts at 20 kelvin are easily calculated from Figures 2 and 4 for the three maximum power settings: 0.1 K for a 50 watt setting, 0.32 for a 5 watt setting, and 1.0 for the 0.5 watt setting. As expected, the temperature offsets become smaller as the loop gain increases. However, there are limits to this approach as we move from the idealized example to a real system.

The Real World

Unfortunately, the thermal conductivity within a system is not infinite, and both it and the heat capacity may vary by several orders of magnitude between 1 K and 300 K. Also, the controller, the sensor, the sensor leads, and the block may all have electrical noise. This noise is amplified by the controller; for a high enough amplifier gain setting, the output of the controller will become unstable and oscillate. In addition, the placement of the sensor with respect to the heater and the sensor construction and mounting itself introduce thermal lags. This is due to the finite thermal conductivity of the block and the thermal resistances between the heater, sensor and the block. These thermal lags introduce a phase shift between the controller output and the sensor, which will reduce even further the gain at which the system will be stable.

Therefore, the thermal block design is extremely important in the proper performance of any cryogenic system. No controller can make up for poor thermal design of the system, nor can good design overcome the inherent limiting properties of the materials and sensor packages which are currently available.

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Since the thermal conductivity of cryogenic materials is finite, good practice dictates that the controller power output be the same order of magnitude as the cooling power. If, for example, the cooling power is 0.2 watt, and 50 watts is available, a change in set point to a higher temperature outside the proportional band of the controller will dump 50 watts into the system block. Due to the thermal lag of the block, etc., a large temperature overshoot may occur, with the system stabilizing only after several oscillations. This thermal lag can easily be observed since the sensor temperature will continue to rise long after the output from the controller has been reduced to zero. The obvious way to reduce this effect is to limit the heater power to the system to, for example, 0.5 watts. This can readily be done with a controller such as the DRC-82C which has multiple maximum output power settings. The overshoot will therefore be smaller when the set point is changed and the system will stabilize much faster although the rate of temperature rise will be less. Because changing the power output setting affects the loop gain (dP/dT), it may be necessary to readjust the deviation amplifier gain (controller gain setting) for optimum control. It is normally good practice to determine the power requirements for one's system prior to or during the first experimental run. Some system manufacturers may have that information available and may possibly supply a power load curve with the system.

Two other aspects of temperature control should be mentioned. First, ON-Off controllers are frequently encountered at room temperature and above. As the name implies, such systems have only two states: power on when the temperature is below the set point, and off when it is above. The proportional controller with excessive loop gain approximates this mode. Although ON-OFF controllers perform adequately with large furnaces, for example, they are generally unsatisfactory for cryogenic applications, because of the relatively short thermal time constants encountered at low temperatures.

Secondly, some controllers, such as the DRC-82C, have a manually adjustable power output control. This control can be used in either of two modes: (1) open loop, with a manual adjust of heater power *in place of* the signal from the deviation amplifier and (2) automatic, where the adjustment is *in addition to* the controller's closed loop signal. Mode 1 is extremely helpful in set up procedures and in subsequently determining the power levels associated with the desired temperatures. In Mode 2, one can reduce and sometimes eliminate temperature offset by providing the required power without the need for a large error signal to drive the output stage. This latter method has a name—manual reset—and serves as an introduction to the next section on reset control.

IV PROPORTIONAL (GAIN) PLUS INTEGRAL (RESET) TEMPERATURE CONTROL

The manual reset adjustment described above varies markedly with the temperature set point and with the often changing heater power demands of the system. Thus, it is normally neither convenient nor desirable to have to resort to such a means of eliminating temperature droop (offset). Instead, suppose a circuit could be added to the loop that would: (1) sense that there is a steady state offset signal within the proportional band; (2) make a bit-by-bit addition to the power output, proportional to the magnitude of the offset; and (3) continue the corrective action until the offset is reset to zero. The practical realization of this circuit is an integrator inserted between the deviation amplifier and the power stage. The origin of the interchangeable terms "integral" control and (automatic) "reset" is evident.

How does a proportional-plus-integral controller behave in a cryogenic system?

First, in the idealized case, let us again assume an infinite thermal conductivity, which results in zero thermal resistance between the sensor and the heater. The reset integrator continues to integrate until the error signal reaches zero, which stops the integral action, but keeps its output at the level corresponding to that needed by the power stage to overcome the droop. This output is now the only drive to the power stage since the proportional error signal has been forced to zero. No overshoot will occur since zero thermal resistance eliminates the thermal lag which is the cause of overshoot. The zero thermal time constant also means that *any* amount of reset will eventually force the system to zero error.

Before we switch the discussion back to real systems, let us deal with the nomenclature and units involved in integral control. Automatic reset action can be expressed in terms of a time constant (minutes) or its inverse, reset rate (repeats per minute). The reset time constant is the time required—measured in minutes—for the reset circuit to integrate to full output with an input signal which is *constant* and equal to the proportional band error signal. The amount of reset action can also be measured in "repeats per minute", or the number of times which the integrator can integrate between zero and full output in a time period of one minute for the constant proportional band error signal. Thus, if the time constant were, say, two minutes, this is the same as saying that the reset circuitry repeats the proportional action in two minutes, or ½ repeats per minute.

The term "reset windup" refers to a condition occurring in reset controller when an offset persists for a sufficiently long time. The integration of the error, with time, will cause the integrator to saturate or "windup" at maximum output and remain so until the control point is traversed. By the time this has happened, a large overshoot may have occurred. This problem can be prevented by disabling the reset action when controller response goes outside the proportional band. A controller such as the DRC-82C accomplishes this with an anti-reset windup (or reset inhibit) circuit.

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The Real World Revisited

Since a real cryogenic system has non-zero thermal resistance, the value of the reset is important in setup of the controller. The amount of reset desired is dependent on: (1) the time required for the control sensor to reach equilibrium once it enters the proportional band; and (2) the amount of output signal required from the reset action to overcome the cooling power of the cryogenic system. For example, assume that 50% output is required and the time to reach equilibrium is 3 seconds (.05 minutes). Therefore the repeats per minute is 10 and the time constant is 0.1 minutes. In actuality, this is not easy to determine without a few tries. Almost always, however, the time constant increases with increasing temperature so that if one is operating over a broad temperature range, finding the appropriate time constants for the two extremes will bracket the appropriate time constants within that temperature range. Once the correct time constant has been selected, the system should settle to its control set point within two or three time constants. If significant overshoot is still occurring, the system design should be carefully reviewed.

V ADDING DERIVATIVE (RATE) TO THE TEMPERATURE CONTROL LOOP

If there is still an overshoot of the control temperature during transient changes of the set point within one's system, it can be significantly reduced by the addition of a third control function to the controller, called rate or derivative control.

Normally, overshoot can be attributed to one of two causes: (1) the application of much more power than is required to maintain the system at its desired set point; or (2) the result of the thermal response relationships between the cooling power, the heating power, and the control sensor. The best solution to the first possibility is to reduce the available power as discussed previously. The second problem normally occurs with a large thermal mass, where response is slow and overshoot due to the thermal inertia of the system can be quite large. This overshoot is caused by the time lag between a change in output power and the control sensor sensing this change. In very large non-cryogenic systems this time lag can be 10-30 minutes. In cryogenic systems, it is usually less than a minute, even near room temperature. Consequently, placement of the control sensor with respect to the heater is extremely important in the design of a cryogenic system, as is the placement of both the heater and sensor with respect to the cooling power.

Rate action can be achieved by means of a differentiator circuit which provides a signal proportional to the *rate* of temperature change, and which is subtracted from the proportional output signal. This reduces the effective overall amplifier gain driving the output power stage. The reduced gain effectively increases the proportional band of the controller. This slows down the rate of temperature rise and therefore allows more time for the block to stabilize. Consequently, the overshoot is substantially reduced or eliminated, depending on the magnitude of the thermal problem, as is indicated in Figure 6.

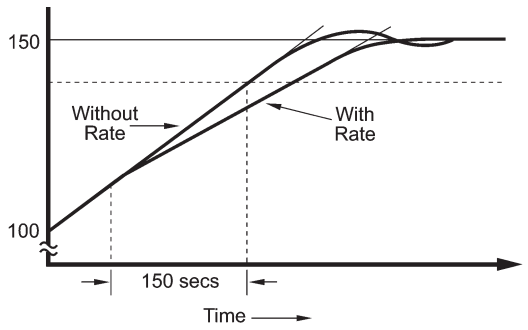


FIGURE 6. The effect of adding Rate to the control circuit to dynamically widen the proportional band and reduce the overshoot which would occur in its absence.

The addition of rate is necessary only because of inherent thermal problems which cannot be substantially eliminated by improvements in thermal design. Also note that rate is effective only during the transition from one set point to another. Near or at the set point, rate has a destabilizing influence. It should therefore be normal practice to turn off the rate control when near the control point.

The differentiator circuit should precede the reset integrator in the circuit so that the deviation and derivative signals acting on the integrator input will be just sufficient to create the proper reset value by the time the temperature reaches set point. In some cases, it is important for the rate circuit to precede the deviation amplifier as well, i.e., immediately following the sensor input. This would then prevent the rate circuit from operating on *changes* in the set point, such as in temperature seep applications. Fortunately, most sweeping is done slowly enough so as to be unaffected by typical rate time constants.

To determine the rate control setting (in seconds) for a system, an abrupt increase in power is applied to the system while in equilibrium. The time delay is then observed to the start of the resulting temperature increase as indicated by the control sensor. This delay corresponds to the value to be set on the rate control.

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VI SENSOR CONSIDERATIONS

Sensor Gain Revisited: Since a controller will amplify input noise as well as sensor signal, it becomes important to consider sensor performance when designing a complete system. The Lake Shore DT-500 Series Sensors have a voltage-temperature characteristic which lend themselves to cryogenic temperature control use because of their high sensitivity at low temperatures (Figure 3). Coupled with this sensitivity is an extremely low noise-level which results, in part, from assembly techniques used for all DT-500 Sensors which comply with the relevant portions of MIL STD 750C. It is therefore possible to obtain short-term control at low temperatures which can approach 0.1 mK in specially designed systems such as the Lake Shore calibration facility. Even above 30 K, where the sensitivity is reduced by a factor of 20, short-term controllability is better than 2 mK.

With diodes, there is no need for a sensor pre-amplifier, which would precede the set point control and deviation amplifier. However, in the case of resistance thermometers, including both semiconductor and metal types, a pre-amplifier becomes necessary. In a dc measurement system, such as is used in the DRC-82C, it is sometimes possible to obtain temperature control stability with resistance thermometers superior to that obtainable with diodes. This requires a highly stable and adjustable constant current source in addition to a pre-amplifier designed for very low noise and drift. The choice of sensor is not at all obvious; it depends on many factors besides sensitivity, including sensor size, time response, power dissipation, magnetic field dependence and temperature range. In the less common case of cryogenic thermocouples, the very low sensitivity (10uV/K) requires quite large pre-amplifier gains and a stable reference junction arrangement. Thermocouples are sometimes used when sensor size or time response are more important than temperature stability and accuracy. At cryogenic temperatures, thermocouple accuracy does not approach that of a semiconductor diode or resistance thermometer when either are properly installed.

VII ANALOG VERSUS DIGITAL CONTROL

In this day of computers, designing digital instrumentation with a microprocessor is definitely in vogue. In a digital control system, the sensor voltage is digitized by an analog-to-digital (AD) converter. The digitized temperature is then compared to the digital set point within the microprocessor and by means of an appropriate algorithm, the average power to the heater is adjusted.

A converter with a 14 bit resolution (1 part in 16,384) enables the microprocessor to determine the temperature to approximately 4 mK at 4.2 kelvin using the diode sensor of Figure 2. In a system which is inherently stable, the control temperature stability can be no better than the temperature resolution of the AD converter (4 mK for this example). Cost-effective AD converters with such resolution have sampling times in the half-second range. In the world of ovens, furnaces, and other large industrial processes which operate above room temperature, stable control can be maintained by digital systems updating temperature only once or twice a second. This is for the same reason that ON-OFF controllers are successful in these cases: the large thermal time constants of the controlled environments.

However, as discussed in Section II, the time constants are much shorter in cryogenic systems, so much so that temperature can, and frequently does, change at a rate which exceeds the sampling frequency of a typical digital cryogenic controller (approximately 2 Hz). A good example is a mechanical refrigerator based on the Gifford-McMahon cycle. At 10 kelvin and below, these refrigerators, unloaded, often have a peak-to-peak variation in temperature which exceeds 1 kelvin at a nominal 3 Hz frequency. That variation represents an inherent disadvantage which is difficult for the all-digital system to overcome since the sampling rate is lower than the frequency of the temperature variation. The Sampling Theorem of Electrical Engineering implies that no sampled data control system can be stable unless it is sampled at a rate which exceeds at least twice the highest frequency variation within the system.

Some designers of all-digital controllers for cryogenic temperatures appear to have overlooked this sampling rate problem. There are also examples of digital controller which fail to achieve optimum performance because of the design of their output stage: heater power is varied on a cyclical time-proportioning ON-OFF basis. This often introduces noise within the system which may interfere with the cryogenic experiment.

An advantage that the microprocessor and its read-only memory provides for users of digital controllers is that of a direct reading (in temperature) set point and sensor readout. However, as noted in Section III, this feature may exact a price. In the real world, there is always an error due to lack of perfect conformity between the *true* sensor voltage- (or resistance-) temperature characteristic and the value actually stored in memory. This error will depend on the degree of non-linearity of the characteristic and on the amount of storage available. It is seldom cost-effective to keep the conformity error as small as the useful resolution of the controller system. Thus, in the 14-bit system referred to earlier in this section, its 4 mK resolution would be swamped by, e.g., a conformity-limited 100 mK. Fortunately, in a controller such as the DRC-82C, the user can select either a temperature *or* voltage (resistance) set point and readout.

The choice between analog and digital controllers turns out to be not a choice at all but an optimum combination of the best features of each. True analog control provides a heater output that is a continuous function of the sensor signal, and so eliminates the sampled data problem. This analog control may be combined with digital circuitry for readout of sensors and power output, for setting the PID control parameters and for deriving the set point signal. This approach is used in most of the Lake Shore Cryotronics, Inc. controllers.

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For Further Reading

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2. A series on "process Control" published in the journal, Measurement & Control, Part 3, "On/Off and Proportional Control", September 1984, pp. 165-170; Part 4, "Reset and Rate Control", October 1984, pp. 133-145; Part 5, "Selecting the Mode of Control", December 1984, pp. 132-136. Some of this material has appeared in "Principles of Temperature Control", available from Gulton Industries, West Division. Unlike reference 1, the discussion is not related to cryogenics but temperature control system principles are briefly and clearly explained.
3. C. L. Pomernacki, "Micro Computer-Based Controller for Temperature Programming the Direct Inlet Probe of a High Resolution Mass Spectrometer", Review of Scientific Instruments, *48* (1977), pp. 1420-1427.
4. W. M. Cash, E. E. Stansbury, C. F. Moore, and C. R. Brooks, "Application of a Digital Computer to Data Acquisition and Shield Temperature Control of a High-Temperature Adiabatic Calorimeter", Review of Scientific Instruments, *52* (1981), pp. 895-901.
5. R. B. Strem. B. K. Das, and S. C. Greer, "Digital Temperature Control and Measurement System", Review of Scientific Instruments, 52 (1981), pp. 1705-1708.

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Standard Curve 10

Standard Curve 10: Measurement Current = 10 µA ±0.05%

T (K)	Voltage	dV/dT (mV/K)	T (K)	Voltage	dV/dT (mV/K)	T (K)	Voltage	dV/dT (mV/K)
1.40	1.69812	–13.1	16.0	1.28527	–18.6	95.0	0.98564	–2.02
1.60	1.69521	–15.9	16.5	1.27607	–18.2	100.0	0.97550	–2.04
1.80	1.69177	–18.4	17.0	1.26702	–18.0	110.0	0.95487	–2.08
2.00	1.68786	–20.7	17.5	1.25810	–17.7	120.0	0.93383	–2.12
2.20	1.68352	–22.7	18.0	1.24928	–17.6	130.0	0.91243	–2.16
2.40	1.67880	–24.4	18.5	1.24053	–17.4	140.0	0.89072	–2.19
2.60	1.67376	–25.9	19.0	1.23184	–17.4	150.0	0.86873	–2.21
2.80	1.66845	–27.1	19.5	1.22314	–17.4	160.0	0.84650	–2.24
3.00	1.66292	–28.1	20.0	1.21440	–17.6	170.0	0.82404	–2.26
3.20	1.65721	–29.0	21.0	1.19645	–18.5	180.0	0.80138	–2.28
3.40	1.65134	–29.8	22.0	1.17705	–20.6	190.0	0.77855	–2.29
3.60	1.64529	–30.7	23.0	1.15558	–21.7	200.0	0.75554	–2.31
3.80	1.63905	–31.6	24.0	1.13598	–15.9	210.0	0.73238	–2.32
4.00	1.63263	–32.7	25.0	1.12463	–7.72	220.0	0.70908	–2.34
4.20	1.62602	–33.6	26.0	1.11896	–4.34	230.0	0.68564	–2.35
4.40	1.61920	–34.6	27.0	1.11517	–3.34	240.0	0.66208	–2.36
4.60	1.61220	–35.4	28.0	1.11212	–2.82	250.0	0.63841	–2.37
4.80	1.60506	–36.0	29.0	1.10945	–2.53	260.0	0.61465	–2.38
5.00	1.59782	–36.5	30.0	1.10702	–2.34	270.0	0.59080	–2.39
5.50	1.57928	–37.6	32.0	1.10263	–2.08	280.0	0.56690	–2.39
6.00	1.56027	–38.4	34.0	1.09864	–1.92	290.0	0.54294	–2.40
6.50	1.54097	–38.7	36.0	1.09490	–1.83	300.0	0.51892	–2.40
7.00	1.52166	–38.4	38.0	1.09131	–1.77	310.0	0.49484	–2.41
7.50	1.50272	–37.3	40.0	1.08781	–1.74	320.0	0.47069	–2.42
8.00	1.48443	–35.8	42.0	1.08436	–1.72	330.0	0.44647	–2.42
8.50	1.46700	–34.0	44.0	1.08093	–1.72	340.0	0.42221	–2.43
9.00	1.45048	–32.1	46.0	1.07748	–1.73	350.0	0.39783	–2.44
9.50	1.43488	–30.3	48.0	1.07402	–1.74	360.0	0.37337	–2.45
10.0	1.42013	–28.7	50.0	1.07053	–1.75	370.0	0.34881	–2.46
10.5	1.40615	–27.2	52.0	1.06700	–1.77	380.0	0.32416	–2.47
11.0	1.39287	–25.9	54.0	1.06346	–1.78	390.0	0.29941	–2.48
11.5	1.38021	–24.8	56.0	1.05988	–1.79	400.0	0.27456	–2.49
12.0	1.36809	–23.7	58.0	1.05629	–1.80	410.0	0.24963	–2.50
12.5	1.35647	–22.8	60.0	1.05267	–1.81	420.0	0.22463	–2.50
13.0	1.34530	–21.9	65.0	1.04353	–1.84	430.0	0.19961	–2.50
13.5	1.33453	–21.2	70.0	1.03425	–1.87	440.0	0.17464	–2.49
14.0	1.32412	–20.5	75.0	1.02482	–1.91	450.0	0.14985	–2.46
14.5	1.31403	–19.9	80.0	1.01525	–1.93	460.0	0.12547	–2.41
15.0	1.30422	–19.4	85.0	1.00552	–1.96	470.0	0.10191	–2.30
15.5	1.29464	–18.9	90.0	0.99565	–1.99	475.0	0.09062	–2.22

Lighter numbers indicate truncated portion of Standard Curve 10 corresponding to the reduced temperature range of DT-471 diode sensors. The 1.4 – 325 K portion of Curve 10 is applicable to the DT-450 miniature silicon diode sensor.

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POLYNOMIAL REPRESENTATION

Curve 10 can be expressed by a polynomial equation based on the Chebychev polynomials. Four separate ranges are required to accurately describe the curve. Table 1 lists the parameters for these ranges. The polynomials represent Curve 10 on the preceding page with RMS deviations of 10 mK. The Chebychev equation is:

$$T(x) = \sum_{i=0}^{n} a_i t_i(x) \qquad (1)$$

where T(x) = temperature in kelvin, $t_i(x)$ = a Chebychev polynomial, and a_i = the Chebychev coefficient. The parameter x is a normalized variable given by:

$$x = \frac{(V - VL) - (VU - V)}{(VU - VL)} \qquad (2)$$

where V = voltage and VL & VU = lower and upper limit of the voltage over the fit range. The Chebychev polynomials can be generated from the recursion relation:

$$t_{i+1}(x) = 2xt_i(x) - t_{i-1}(x)$$
$$t_0(x) = 1, t_1(x) = x \qquad (3)$$

Alternately, these polynomials are given by:

$$t_i(x) = \cos\left[i \times \arccos(x)\right] \qquad (4)$$

The use of Chebychev polynomials is no more complicated than the use of the regular power series and they offer significant advantages in the actual fitting process. The first step is to transform the measured voltage into the normalized variable using Equation 2. Equation 1 is then used in combination with equations 3 and 4 to calculate the temperature. Programs 1 and 2 provide sample BASIC subroutines which will take the voltage and return the temperature T calculated from Chebychev fits. The subroutines assume the values VL and VU have been input along with the degree of the fit. The Chebychev coefficients are also assumed to be in any array A(0), A(1),..., A(i_{degree}).

An interesting property of the Chebychev fits is evident in the form of the Chebychev polynomial given in Equation 4. No term in Equation 1 will be greater than the absolute value of the coefficient. This property makes it easy to determine the contribution of each term to the temperature calculation and where to truncate the series if full accuracy is not required.

```
FUNCTION Chebychev (Z as double)as double
REM Evaluation of Chebychev series
  X=((Z-ZL)-(ZU-Z))/(ZU-ZL)
  Tc(0)=1
  Tc(1)=X
  T=A(0)+A(1)*X
  FOR I=2 to Ubound(A())
     Tc(I)=2*X*Tc(I-1)-Tc(I-2)
     T=T+A(I)*Tc(I)
  NEXT I
  Chebychev=T
END FUNCTION
```

Program 1. BASIC subroutine for evaluating the temperature *T* from the Chebychev series using Equations (1) and (3). An array T_c (i_{degree}) should be dimensioned. See text for details.

```
FUNCTION Chebychev (Z as double)as double
REM Evaluation of Chebychev series
    X=((Z-ZL)-(ZU-Z))/(ZU-ZL)
    T=0
    FOR I=0 to Ubound(A())
       T=T+A(I)*COS(I*ARCCOS(X))
    NEXT I
    Chebychev=T
END FUNCTION
```

NOTE: $\arccos(X) = \frac{\pi}{2} - \arctan\left[\frac{X}{\sqrt{1-X^2}}\right]$

Program 2. BASIC subroutine for evaluating the temperature *T* from the Chebychev series using Equations (1) and (4). Double precision calculations are recommended.

Table 1. Chebychev Fit Coefficients

2.0 K to 12.0 K	12.0 K to 24.5 K	24.5 K to 100.0 K	100 K to 475 K
VL = 1.32412	VL = 1.32412	VL = 1.32412	VL = 1.32412
VU = 1.69812	VU = 1.69812	VU = 1.69812	VU = 1.69812
A(0) = 7.556358	A(0) = 17.304227	A(0) = 71.818025	A(0) = 287.756797
A(1) = -5.917261	A(1) = -7.894688	A(1) = -53.799888	A(1) = -194.144823
A(2) = 0.237238	A(2) = 0.453442	A(2) = 1.669931	A(2) = -3.837903
A(3) = -0.334636	A(3) = 0.002243	A(3) = 2.314228	A(3) = -1.318325
A(4) = -0.058642	A(4) = 0.158036	A(4) = 1.566635	A(4) = -0.109120
A(5) = -0.019929	A(5) = -0.193093	A(5) = 0.723026	A(5) = -0.393265
A(6) = -0.020715	A(6) = 0.155717	A(6) = -0.149503	A(6) = 0.146911
A(7) = -0.014814	A(7) = -0.085185	A(7) = 0.046876	A(7) = -0.111192
A(8) = -0.008789	A(8) = 0.078550	A(8) = -0.388555	A(8) = 0.028877
A(9) = -0.008554	A(9) = -0.018312	A(9) = 0.056889	A(9) = -0.029286
A(10) = 0.039255	A(10) = -0.116823	A(10) = 0.015619	
		A(11) = 0.058580	

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DT-470 SERIES TEMPERATURE SENSORS INSTALLATION AND OPERATION

There are three aspects of using a temperature sensor which are critical to its optimum performance. The first involves the proper electrical and thermal installation of the connecting leads which run to the sensor, while the second aspect is the actual mounting of the sensor to the sample assembly. The final concern is the measurement electronics used for reading and recording temperature data from the sensor.

CONNECTING LEADS

Although the majority of the DT-470 series sensors are two lead devices, measurements should preferably be made using a four wire configuration to avoid all uncertainties associated with the lead resistance. This is done by using four connecting leads to the device and connecting the V+ and I+ leads to the anode and the V- and I- leads to the cathode as shown in Figure 1. The exact point at which the connecting leads are soldered to the device leads results in negligible temperature measurement uncertainties.

In a two wire measurement configuration, the voltage connections (point A in Figure 1) are made near or at the current source so only two leads are actually connected to the device. Some loss in accuracy can be expected since the voltage measured at the voltmeter is the sum of the diode voltage and the voltage drop across the connecting leads. The exact temperature uncertainty will depend on the temperature range and lead resistance. For a 10 ohm lead resistance, the diode voltage will be offset by 0.1 mV which gives a negligible temperature error at liquid helium temperature but a 50mK error near liquid nitrogen temperature. Note the DI and CY adapter can be used only in a two wire configuration.

An excessive heat flow through the connecting leads to any temperature sensor can create a situation where the active sensing element (for the DT-470 this is the diode chip) is at a different temperature than the sample to which the sensor is mounted. This is then reflected as a real temperature offset between what is measured and the true sample temperature. Such temperature errors can be eliminated by proper selection and installation of the connecting leads.

In order to minimize any heat flow through the leads, the leads should be of small diameter and low thermal conductivity. Phosphor-bronze or manganin wire is commonly used in sizes 32 or 36 AWG. These wires have a fairly poor thermal conductivity yet the resistivities are not so large as to create any problems in four wire measurements.

Lead wires should also be thermally anchored at several temperatures between room temperature and cryogenic temperatures to guarantee that heat is not being conducted through the leads to the sensor. A final thermal anchor at the sample itself is a good practice to assure thermal equilibrium between the sample and temperature sensor. Note that the CU, CY, BO, and DI mounting adapters serve as their own sample thermal anchor.

If the connecting leads have only a thin insulation such as Formvar or other varnish type coating, a simple thermal anchor cn be made by winding the wires around a copper post or other thermal mass and bonding them in place with a thin layer of GE 7031 varnish. There are a variety of other ways in which thermal anchors can be fabricated and a number of guidelines which may be found in detail in the references given below.

SENSOR MOUNTING

General Comments

Before installing the DT-470 sensor, identify which lead is the anode and which lead is the cathode by referring to the accompanying device drawings. Be sure that the lead identification remains clear even after installation of the sensor, and record the serial number and location.

The procedure used to solder the connecting leads to the sensor leads is not very critical and there is very little danger in overheating the sensor, If for some reason the leads have to be cut short, they should be heat sunk with a copper clip or needle-nose pliers before soldering. Standard rosin core electronic solder (m.p. - 180 C) is suitable for most applications. Applications involving the use of the SD package up to 200° C will require a higher melting point solder. A 90% Pb 10% Sn solder has been used quite successfully with a rosin flux.

For all adapters except the CY, CU, and DI, the leads are a gold-plated Kovar. Prolonged soldering times may cause the solder to creep up the gold plated leads as the solder and gold alloy. This is not detrimental to the device performance.

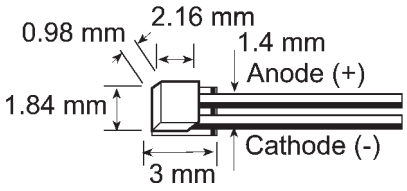
When installing the sensor, make sure there are no shorts or leakage resistance between the leads or between the leads and ground. GE-7031 varnish or epoxy may soften varnish-type insulations so that high resistance shunts appear between wires if sufficient time for curing is not allowed. Teflon spaghetti tubing is useful for sliding over bare leads when the possibility of shorting exists. Also, avoid putting stress on the device leads and allow for the contractions that occur during cooling which could fracture a solder joint or lead if installed under tension at room temperature.

The DT-470 sensor is designed for easy removal for recalibration checks or replacement and the following discussions for each of the adapters are geared in this direction. If semi-permanent mountings are desired, the use of Stycast epoxy can replace the use of Apieson N Grease. In all cases, the mounting of the sensor should be periodically inspected to verify that good thermal contact to the mounting surface is maintained.

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DT-470-SD

The SD version is the basic package for the DT-470 sensor line from which all other configurations are made using the appropriate adapter. The base of the device has a gold metallized surface and is the largest flat surface on the sensor. The base is electrically isolated from the sensing element and leads, and all thermal contact to the sensor must be made through the base. A thin braze joint around the sides of the SD package is electrically connected to the sensing element. Contact to the sides with any electrically conductive material must be avoided. When viewed with the base down and with leads towards the observer, the positive lead (anode) is on the right.



For a removable mount, the Sd sensor can be3 held against the mounting surface with the CO adapter (see below) or similar clamping mechanism. Any method of clamping the sensor must avoid excessive pressure and should be designed so that thermal contractions or expansions do not loosen contact with the sensor. For uses restricted to below 325 K, a thin layer of Apiezon N Grease should be used between the sensor and sample to enhance the thermal contact.

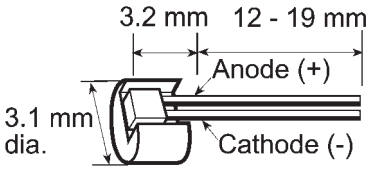
The SD package can also be bonded with an epoxy such as Stycast. The sensor should be pressed firmly against the surface during curing to assure a thin epoxy layer and good thermal contact. The device may be removed in the future by using the appropriate epoxy stripper.

The SD adpater can be soldered using a rosin flux (non-corrosive) if extreme care is exercised. First, tin the base of the sensor using a low wattage, temperature controlled soldering iron which will not exceed 200° C. Use only a minimal amount of solder. Tin the surface to which the sensor is to bonded and again avoid an excessive thickness of solder. Clean both the sensor and mounting surface of any residual flux. Next, re-heat the mounting surface to the melting point of the solder, press the device into position and allow the sensor to warm to the melting point of the solder. After both tinned surfaces have flowed together, remove the heat source and let the sample and sensor cool. Under no circumstance should the sensor be heated above 200° C and the solder must be limited to only the base of the sensor. Excess solder running up the sides of the SD package can create shorts. Repeated mounting and demounting of a soldered sensor may eventually cause wetting deterioration and ruin the thermal contact to the sensing element, although the nickel buffer layer should minimize these problems.

CAUTION: The preferred method for mounting the SD sensor is either the CO adapter or bonding with epoxy. Lake Shore Cryotronics, Inc. will not warranty replace any device damaged by a user-designed clamp or damaged through solder mounting.

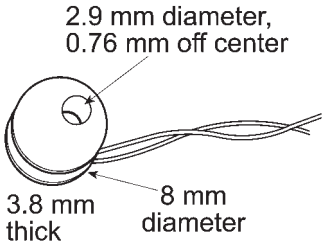
DT-470-LR

The gold-plated copper LR adapter is designed for insertion into a 1/8 inch diameter hole. A thin layer of Apiezon N Grease should be applied to the copper adapter before insertion. This eases installation at room temperature and enhances the thermal contact.

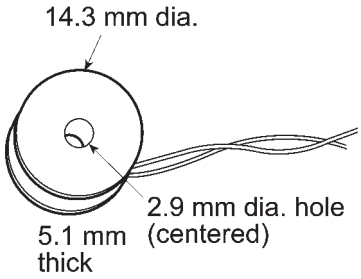


DT-470-CU / DT-470-DI / DT-470-CY

The gold-plated copper CU, DI, and CY adapters serve as both sensor and thermal anchor assembly. These adapters mount to a flat surface with a 4-40 brass screw. Avoid over-tightening the screw; use only enough force to firmly hold the sensor in place. A brass screw is recommended as the differential thermal contraction between the adapter and the screw causes the mounting assembly to tighten as opposed to loosen when the system cools. Apply a thin layer of Apiezon N Grease to enhance thermal contact between the adapter and mounting surface.



DT-470-CU / DT-470-DI

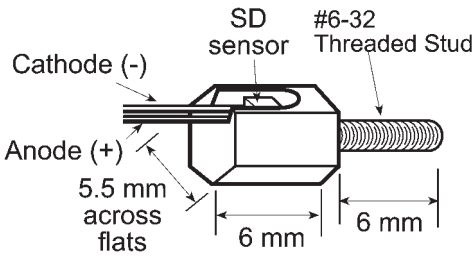


DT-470-CY

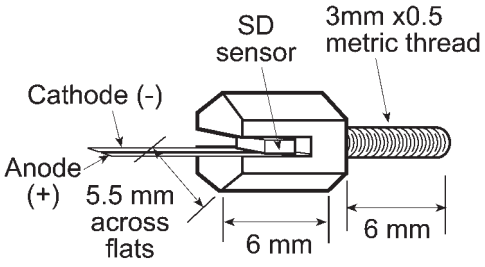
The CU adapter has four color-coded leads: Red (I-), Green (V-), Clear (V+), and Blue)I+). The CY adapter has two color-coded leads: Yellow (+) and Green (-). The green lead on the DI adapter is the cathode.

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DT-470-ET / DT-470-MT



DT-470-ET

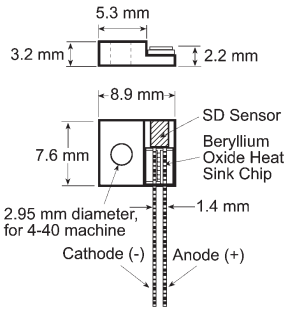


DT-470-MT

Both adapters are gold-plated copper hex head bolts with the SD package mounted in a slot on the adapter head. The ET adapter screws into a ¼ inch deep, 6-32 threaded hole while the MT adapter screws into a 6 mm deep, 3x0.5 mm threaded hole. Before assembly the threads should be lightly greased with Apiezon N Grease Do not over-tighten since the threads are copper and can be easily sheared. Finger tight should be sufficient.

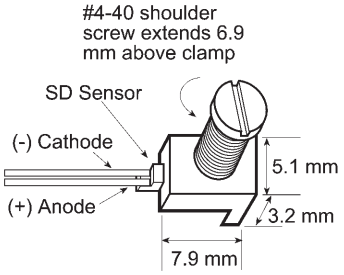
DT-470-BO

The BO adapter should be mounted in the same manner as the CU. The BO adapter contains its own thermal anchor and is an epoxy free assembly.



DT-470-CO

The CO adapter is a spring-loaded clamp to attach the DT-470-SD package to a flat surface. It maintains pressure on the SD package as the temperature varies. First, remove the hold down cap which holds the three piece CO assembly together. The CO assembly should appear as shown in the accompanying drawings. Bolt the assembly into a 4-40 threaded hole. The stop on the brass screw should rest against the mounting surface and it also prevents over-compressing the spring. Lift the edge of the clip using a small pliers or screw driver. Slide the SD package into place underneath the clip and gently lower the clip onto the lid of the SD package. Note that a slot is cut underneath the clip to accept the SD package. Refer to the drawing for details. If the device is to be used only below 325 K, apply a layer of Apiezon N Grease between the SD package and mounting surface to enhance thermal contact.



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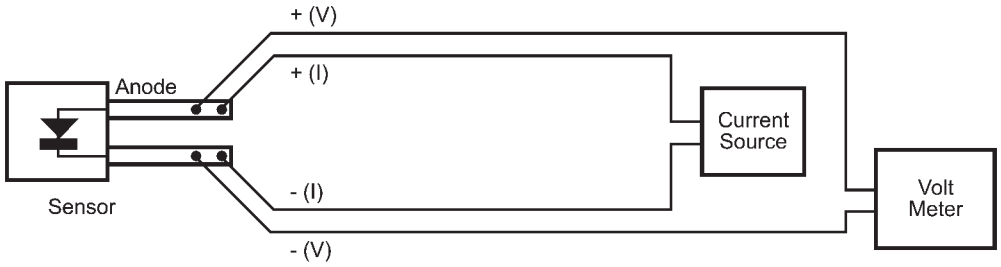


FIGURE 1. Four-Wire Configuration for DT-470 Installation

SENSOR OPERATION

Temperature controllers and thermometer instrumentation manufactured by Lake Shore Cryotronics are designed to be directly compatible with the DT-470 sensor to give optimum performance and accuracy together with direct temperature readouts. Simply follow the instructions provided with the instrument concerning sensor connection and instrument operation. If a user-supplied current source, voltmeter, or other instrumentation are going to used with the DT-470 sensor, special attention should be given to the following details.

The DT-470 is designed to operate at a constant current of 10 microamperes while the voltage variation with temperature is monitored. Therefore, the accuracy of the temperature measurement depends directly onf the specifications of the current source and the voltmeter. A current source operating at the level of 10 ±0.01 microamperes (±0.1%) gives a nominal temperature uncertainty of 10 millikelvin (0.01 K) which is probably suitable for most applications The voltmeter resolution required can be estimated from the sensitivity (dV/Dt) of the DT-470:

Temperature (K)	Sensitivity (mV/K)
305	2.4
77	1.9
4.2	33

Multiplying the above sensitivity by the desired temperature resolution in kelvin will give the required voltage resolution in millivolts.

The static impedance of the DT-470 sensor operating at a 10 microampere current is on the order of 100,000ohms. Therefore, the input impedance of the voltmeter must be significantly larger than this to avoid measurement errors. Voltmeters with input impedances of greater than 109 or 1010 ohms should be used.

Good quality instrumentation must be used and all instrumentation and wiring should be properly grounded and shielded. Temperature measurement errors will result if there is excessive AC noise or ripple in the circuitry. Further details can be found in the article by Krause and Dodrill given in the references.

NOTE: All materials mentioned which are used in sensor installation are available from Lake Shore Cryotronics, Inc.

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Krause, J. K. and Dodrill, B. C. (1986). Measurement System Induced Errors in Diode Thermometry. Review of Scientific Instruments 57 (4), 661-665. (Available on request from Lake Shore Cryotronics, Inc.)

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MEASUREMENT SYSTEM INDUCED ERRORS IN DIODE THERMOMETRY

by John K. Krause and Brad C. Dodrill

Diode temperature sensors are capable of being used at the accuracy level of a few hundredths of a kelvin. However, in order to achieve this performance, proper measurement techniques must be used. Poorly shielded or improperly grounded measurement systems can introduce ac noise which will create an apparent shift in the dc voltage reading across a diode sensor. This results in a temperature measurement error which may approach several tenths of a kelvin. The presence of the ac noise in question is not obvious during normal usage and several quick tests are outlined to verify whether or not a noise problem exists. Experimental data and derivations from theoretical *p-n* junction characteristics are given which correlate the ac noise level with possible voltage/temperature measurement errors. These results can be used in estimating the accuracy and performance of a temperature measurement system. Several of the more common problems which introduce noise into diode circuitry are described.

INTRODUCTION

Current technological uses of temperature sensors require better calibration accuracies and better device performance than ever before. However, the assurance of an accurate temperature measurement does not stop with simply the sensor specifications. Just as critical is the instrumentation used with the sensor and the manner in which the instrumentation is used. This paper concentrates on identifying, verifying, and eliminating an often overlooked instrumentation or system-induced error in the use of diode temperature sensors.

I. PROBLEM DEFINITION

Semiconductor diode temperature sensors have been in use for over 20 years and, with the advantages they offer over resistance sensors or thermocouples for many applications, their popularity continues to increase. Diodes are operated at a constant current, typically 1, 10, or 100 µA, while the voltage variation with temperature (V[T]) is monitored. The diode sensor has a useful temperature range from above room temperature to as low as 1 K, with reproducibilities to better than ±50 mK. Figure 1 shows the voltage variation with temperature for a typical silicon diode temperature sensor.

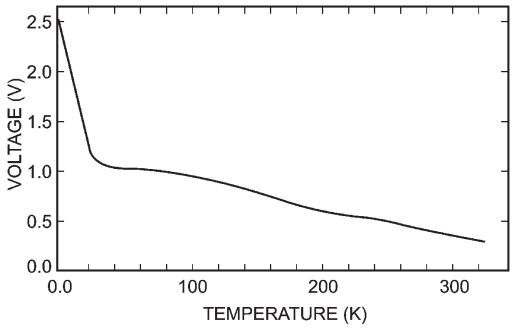


FIGURE 1. Voltage-temperature curve for a typical silicon diode temperature sensor at a constant current of 10 µA.

An error arises in diode thermometry if the excitation current is not a true dc current but has an ac component superimposed on the dc. Although the ac component can be due to a poorly designed current supply, a more common source of the ac is noise induced in the measurement circuit. This noise can be introduced through improper shielding, improper electrical grounds, or ground loops. Currently available voltmeters have sufficient normal-mode rejection capabilities in their dc measurement modes that these noise effects can go completely unnoticed if they are not explicitly checked. The equivalent temperature error which may be caused by this problem is typically a few tenths of a kelvin, although an extreme case with a 4 K error has been observed.

The effect of the ac noise appears as a shift in the dc voltage measurement due to the nonlinear current/voltage characteristics of the diode. An illustration of this effect is shown in Fig. 2 where an exaggerated IV curve is given. An induced ac noise current superimposed on the dc operating current (I_{dc}) is shown along the current axis. The resulting voltage seen by the voltmeter is shown along the voltage axis. The nonlinear IV characteristics of the diode have caused a distortion in the ac voltage signal making it asymmetrical with respect to the voltage reading corresponding to I_{dc}. When a voltmeter operating in a dc voltage mode reads this signal, the signal is processed (by integrating, filtering, etc.) to give an average dc voltage reading which will be lower than expected. The apparent temperature measurement will then be too high. Note that this voltage offset is due to induced currents in the total measuring system and is not simply a voltage pickup by the diode itself. An ac voltage superimposed symmetrically about the dc operating voltage of the diode would not cause a dc voltage offset.

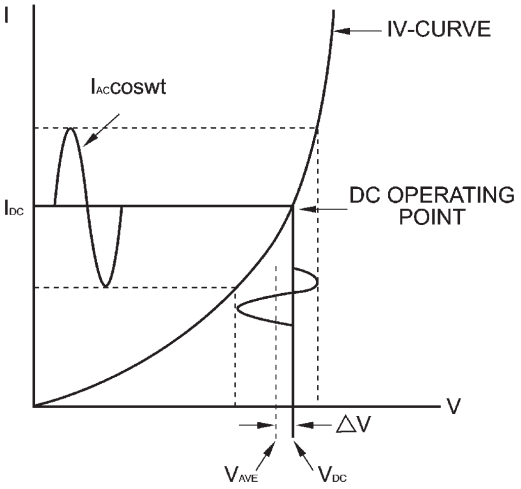


FIGURE 2. IV curve for a silicon diode sensor showing effect of an induced ac current superimposed on the dc operating current I_{dc}. The expected dc operating voltage is V_{dc}, which is shifted from the average voltage V_{ave} indicated by the voltmeter in a dc measurement mode.

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There are two simple techniques which can be used to test whether these errors might be present in a measuring system. The first is to connect a capacitor (about 10 µF) in parallel with the diode to act as a shunt for any ac noise currents. The capacitor must have low leakage current so as not to alter the dc current through the diode. The capacitor may also alter the time response of the measurement system, so allow sufficient time for the capacitor to charge and for the system to equilibrate. If the dc voltage reading across the diode increases with the addition of the capacitor, there are probably ac noise currents present. The second method simply involves measuring the ac voltage signal across the diode. Although an oscilloscope is often the logical choice for looking at ac signals, many do not have the sensitivity required and they often introduce unwanted grounds into the system and compound the problem. Most testing can be performed with the same digital voltmeter used to measure the dc voltage by simply selecting the ac voltage function. There should be no ac voltage across the diode. If there is, the data presented in the following sections can be used to estimate the potential error in the temperature measurement.

II. EXPERIMENTAL

In order to quantify the effects of induced currents on silicon diode temperature sensors, the circuit of Fig. 3 was used to superimpose an ac current on the dc operating current. The dc current source was battery powered with currents selectable from < 1 µA to > 1 mA.. The signal generator could be varied in both amplitude and frequency. All voltage measurements were made with a Hewlett-Packard 3456A voltmeter in either the dc voltage mode or the ac (rms) voltage mode. The dc measurements were taken with an integration time of 10 power line cycles without using the filtering options available on the voltmeter. The average of several readings was taken to reduce the measurement uncertainty. An oscilloscope was also used to double-check and monitor signal frequency, shape, and distortion, but the oscilloscope was removed from the circuit when actual data were recorded.

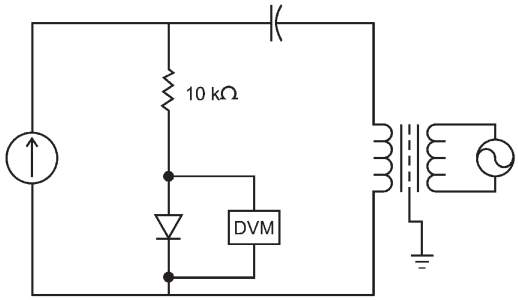


FIGURE 3. Measurement circuit schematic diagram.

Data were recorded at the three dc current values of 1, 10, and 100 µA with the temperature stabilized at 305, 77, or 4.2 K. At each temperature and dc current value, the dc voltage and the ac voltage across the diode were recorded as the amplitude and frequency of the signal generator were varied. The dc voltage reading across the 10 kΩ standard resistor was also monitored to verify that the dc component of the current remained constant to within 0.05%. In addition, the IV characteristic of the diode was measured at each temperature from 0.1 to 150 µA.

Although detailed measurements were taken on only one diode, other diodes were randomly selected and spot checked at all three temperatures and frequencies to verify consistency with the measured data. The diodes tested were of the DT-500 series of Lake Shore Cryotronics, Inc. and have been in production long enough to have a substantial reliability and calibration history.

III. RESULTS AND DISCUSSION

The data were analyzed by calculating a voltage offset ΔV. This offset is defined as the difference between the dc voltage reading across the diode when operated with an ac + dc current and the dc voltage reading when operated with a pure dc current (see Fig. 2). At first glance, the logical choice seems to be to examine the variation of this offset as a function of the ac current amplitude. However, the ac (rms) voltage across the diode was chosen instead for two reasons, the first of which is purely practical. In many circumstances, the ac voltage measurement can be made without any modifications to existing measurement systems, so laboratory checks can be quickly taken and compared directly to the data presented here to give an estimate of potential temperature errors. Second, in the calculations using the model presented below, one unknown parameter could be eliminated from the calculations by using the voltage across the diode instead of the current.

Figures 4 and 5 give the offset voltage as a function of the ac (rms) voltage across the diode for dc currents of 1, 10, and 100 µA with the ac current modulation at 60 Hz. The equivalent temperature error corresponding to the dc offset voltage is indicated along the right edge of the figure. Figures 6 and 7 give similar plots but at a fixed 10 µA dc current with the ac current modulation at 60, 1000, and 20,000 Hz. The magnitude of the dc offset voltages is consistent with what has been observed in measurement systems when corrective action has been taken to eliminate noise problems. Special note should be taken of the dc current independence in Fig. 4 and the frequency independence in Figs. 6 and 7. The data taken at 305 K have not been shown as the results are qualitatively very similar to the 77 K measurements and can be adequately described by the mathematical model which is presented below.

One surprising aspect of the data acquisition was how well the signal processing in the voltmeter could hide even high ac levels in the dc measurement modes. For example, operating at 10 µA dc and 77 K with a rms noise level of 6 mV gives a dc voltage offset of about 1.5 mV, which is about a 0.6 K temperature error. When reading the voltage signal using the filtering and integrating capabilities of the HP 3456A, the dc voltage reading is stable to better than ±0.02 mV (8 mK).

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This stability gives a deceptive view of exactly how accurate the temperature measurement really is and emphasizes the importance of checking all aspects of a measuring system.

The measured offset voltages shown in Figs. 4 and 6 can be understood by using the well-known result from *p-n* junction theory:

$$I = I_s [\exp(eV / nkT) - 1] \qquad (1)$$

where **I** = the forward current through the junction, $\mathbf{I_s}$ = the reverse saturation current, **e** = the electron charge, **V** = the voltage across the junction, **k** = Boltzmann's constant, and **T** = the absolute temperature. **n** is a parameter depending on the location of the generation and recombination of the electrons and holes and typically has a value between 1 and 2. This expression for the IV characteristics of a *p-n* junction is valid from approximately 40 K to above 300 K for the silicon diodes discussed here. Below 40 K, a new conduction mechanism becomes dominant, suggesting the influence of impurity conduction, carrier freezeout, increased ohmic behavior of the bulk material, and *p-i-n* diode type behavior.[1-6]

The only adjustable parameter in Eq. 1 which is necessary for the present analysis is the parameter **n**. This parameter can be determined quite easily from the IV characteristics of the silicon diode temperature sensor. The parameter $\mathbf{I_s}$ is eliminated by normalizing the IV curve to an arbitrarily chosen point on the curve. The value of n = 1.8 was found to give a relatively good fit to the IV data for both 305 and 77 K and has been assumed in the present discussion.7 Equation (1) can now be solved for V(I):

$$V(I) = (nkT / e)\ln(I / I_s + 1) \qquad (2)$$

Substituting a dc current with an ac modulation, $I_{dc} + I_{ac} \cos\omega t$, the average voltage read by the voltmeter in the dc voltage mode can be calculated from:

$$\overline{V} = \frac{1}{T}\int_0^T V(I_{dc} + I_{ac}\cos\omega t)dt \qquad (3)$$

where T = the period of integration of the voltmeter or approximately $2\pi/\omega$. Implied in this derivation is the assumption that ω is sufficiently small so that effects from diode capacitance (on the order of picofarads) can be ignored.

On carrying out the integration of Eq. (3) and subtracting $V(I_{dc})$, the dc offset voltage is:

$$\Delta V = \overline{V} - V(I_{dc}) = \frac{nkT}{e}\ln\left[\frac{1}{2}\left(1+\sqrt{1-2\left(\frac{eV_{rms}}{nkT}\right)^2}\right)\right] \qquad (4)$$

where $I_{ac} \le I_{dc} + I_s$. If a small signal (linear) model is used, the rms voltage across the diode can be easily related to I_{ac}:

$$V_{rms} = \frac{I_{ac}}{\sqrt{2}}\left(\frac{dV}{dI}\right)\Bigg|_{I=I_{dc}} = \frac{1}{\sqrt{2}}\left(\frac{nkT}{e}\right)\left(\frac{I_{ac}}{I_{dc}+I_s}\right) \qquad (5)$$

Evaluation of Eq. (5) and substitution back into (4) yields:

$$\Delta V = \frac{nkT}{e}\ln\left[\frac{1}{2}\left(1+\sqrt{1-2\left(\frac{eV_{rms}}{nkT}\right)^2}\right)\right] \qquad (6)$$

where $2(eV_{rms} / nkT)^2 \le 1$ for a physical solution. Equation (6) predicts an offset voltage which is independent of both frequency and dc operating current and is shown plotted in Fig. 4 by the solid line. The agreement with the experimental measurements is quite good, verifying the overall picture as to the effect of induced currents on diode temperature sensors. The results recorded at 305 K are described equally well by Eq. (6).

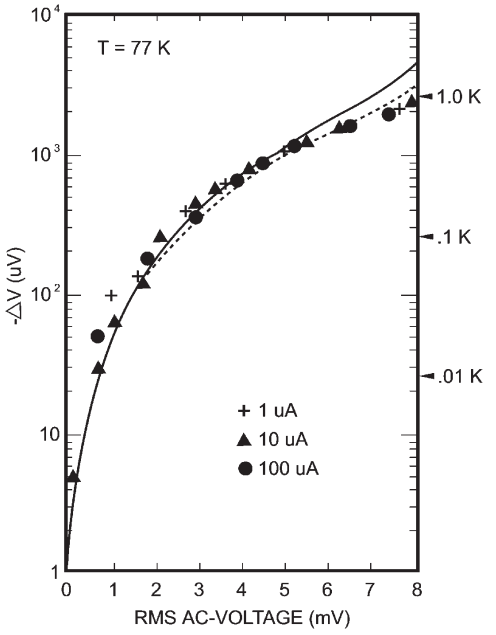


FIGURE 4. DC offset voltage as a function of rms ac voltage across a silicon diode temperature sensor operating at 77 K. The symbols represent data recorded at three different dc operating currents with a 60 Hz signal superimposed. The solid curve gives small signal model results while the dashed curve represents the extended calculations. Equivalent temperature errors are indicated along the right edge.

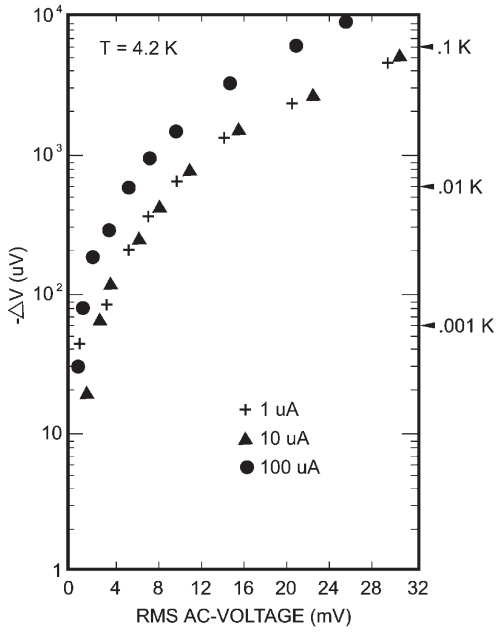


FIGURE 5. DC offset voltage as a function of rms ac voltage across a silicon diode temperature sensor operating at 4.2 K. The symbols represent data recorded at three different dc operating currents with a 60 Hz signal superimposed. Equivalent temperature errors are indicated along the right edge.

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The utilization of the small signal model has the advantage of being analytically simple. However, the model does not contain the nonlinearity inherent in the forward biased IV characteristics of a *p-n* junction. In an attempt to retain the non linear characteristics, $V(I_{dc} + I_{ac} \cos\omega t)$ was expanded in a Fourier series. The first term (constant term) is just the average dc voltage in Eq. (3) and is not seen by the voltmeter operating in an ac measurement mode. The remaining terms in the Fourier series can then be used to calculate the rms voltage which will be read by the voltmeter:

$$V_{rms}^2 = \frac{1}{T}\int_0^T \left[\sum_{n=1}^{\infty} a_n \cos n\omega t + \sum_{m=1}^{\infty} b_m \sin m\omega t \right]^2 dt \qquad (7)$$

where $\mathbf{a_n}$ and $\mathbf{b_m}$ are the Fourier coefficients. In order to evaluate the Fourier coefficients, V(I) was expanded in a power series around I_{dc}. Sufficient terms were maintained in both the power series expansion and in Eq. (7) to give a second-order correction to Eq. (5):

$$V_{rms} = \frac{1}{\sqrt{2}}\left(\frac{nkT}{e}\right)\left(\frac{I_{ac}}{I_{dc}+I_s}\right)\left(1+\frac{5}{16}\frac{I_{ac}^2}{(I_{dc}+I_s)^2}\right)^{1/2} \qquad (8)$$

Substitution of this result into Eq. (4) gives the 77 K offset voltages shown in Fig. 4 by the dashed line. Slightly better agreement with the experimental data is seen at the higher rms voltages. At 305 K, the two calculation methods are in even better agreement and a plot similar to Fig. 4 would show no difference. The details of the extended calculation have not been given as the mathematics is somewhat tedious, and the slight discrepancies between the small signal model and the extended model do not justify the added complexity. For all practical purposes, Eq. (6) can be reliably used above 40 K.

The physics of a p-n junction at 4.2 K is not clearly understood and attempts to correlate the present data by modeling low-temperature IV characteristic of a diode failed. If the diode does take on a p-i-n type behavior, the different curves shown in Fig. 5 for 1, 10, and 100 μA can possibly be understood in terms of the additional current-dependent terms in the IV curve.6 Another explanation for the significant offset voltage at 100 μA could be self-heating in the diode. If the diode is operated at too high a power level, the diode has a tendency to warm slightly above the surrounding environment. This will have the effect of distorting the IV curve in the direction of lower voltages at higher currents. This distortion will then increase the offset voltage. At 4.2 K, self-Heating usually becomes a problem as the current approaches 100 μA.

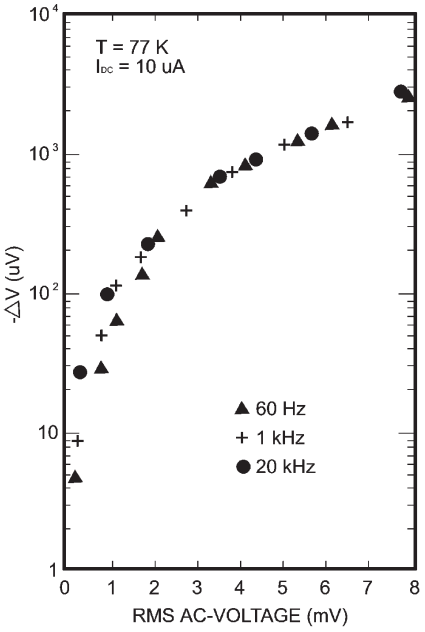


FIGURE 6. DC offset voltage as a function of rms ac voltage across a silicon diode temperature sensor operating at 77 K. The symbols represent data recorded at a 10 μA dc current with the ac current modulation at 60, 1000, and 20,000 Hz.

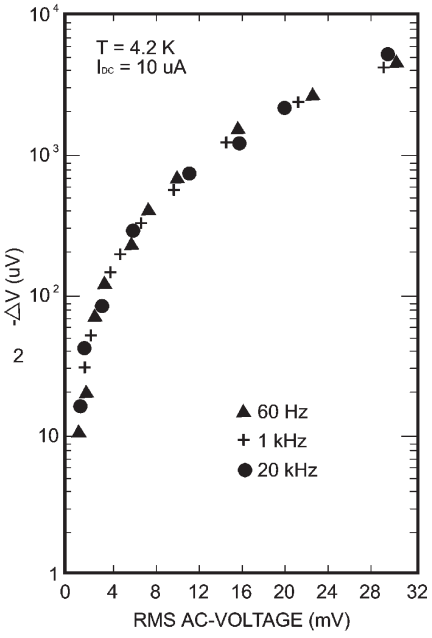


FIGURE 7. DC offset voltage as a function of rms ac voltage across a silicon diode temperature sensor operating at 77 K. The symbols represent data recorded at a 10 μA dc current with the ac current modulation at 60, 1000, and 20,000 Hz.

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IV. CONCLUDING REMARKS

Noise in any measurement circuit is undesirable and should be eliminated to as great an extent as possible. The first step is to electrically shield all instrumentation and wiring and use proper grounding techniques.[8] Secondly, the diode measurement circuit should have a single circuit ground which is generally made at the voltmeter and which then requires a floating current source. The installation of the diode and its connecting leads should be done carefully to avoid introducing any unwanted circuit ground connections such as an electrical short to a cryostat.

As a last resort, a "quick fix" can be used to eliminate much of the dc offset voltage with some degradation in the diode circuit performance. A good quality capacitor (low leakage) can be placed across the diode to shunt the induced ac currents similar to the test procedure used for identifying a noise problem. This is most easily done by connecting the capacitor across the input to the voltmeter. The size of the capacitor needed will depend on the frequency of the noise (generally related to the power line frequency of 60 Hz) and the dynamic impedance of the diode (on the order of a few thousand ohms at a 10 μA operating current). A capacitor in the range of 10 to 20 μF should reduce most noise effects to an acceptable level. However, because the capacitor increases the time constant in the circuit, a sluggish response should be expected. In switching operations, 30 seconds or more may be required for the circuit to stabilize. This "quick fix" is not meant as a substitute for proper measurement techniques, but in certain circumstances it may be useful.

Note added in proof. The capacitance values given above are for the elimination of the effects of low-frequency noise such as 60 Hz. If high-frequency noise is a problem, an additional capacitor of lower capacitance value may be needed. The reason for this is because larger capacitors often have an associated inductance which limits their usefulness as a high-frequency shunt.

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