USER'S MANUAL

Model DRC-93C

Temperature Controller

Obsolete Notice:

This manual describes an obsolete Lake Shore product. This manual is a copy from our archives and may not exactly match your instrument. Lake Shore assumes no responsibility for this manual matching your exact hardware revision or operational procedures. Lake Shore is not responsible for any repairs made to the instrument based on information from this manual.

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SERIAL NUMBER ______________

MB SOFTWARE ______________

DB SOFTWARE ______________

I N S T R U C T I O N   M A N U A L

M O D E L   D R C - 9 3 C
T E M P E R A T U R E   C O N T R O L L E R

Input Card Configuration

		Input A	Input B
9210-3	Standard 3 volt Configuration	☐	☐
-6	6 Volt Diode Configuration	☐	☐
9215-15	Standard 15 Nanofarad Capacitance Input	☐	☐
-150	150 Nanofarad Configuration	☐	☐
9220-3	Standard 3 volt Configuration	☐	☐
-6	6 Volt Configuration	☐	☐
-P2	100 ohm platinum conversion module	☐	☐
-P3	1000 ohm platinum conversion module	☐	☐
-R1	27 ohm Rh-Fe conversion module	☐	☐
9305	Thermocouple Input Card	☐	☐
9317C	Ultra-low (0.3K) Germanium input Card	☐	☐
9318C	Germanium/Carbon Glass Input Card	☐	☐
	No Input Card	☐	☐

8223 RS-232C Interface ☐

8225 Analog Output Interface (0-10 volt) ☐

8229 Scanner Input Option ☐

9126 High Resolution Set Point ☐

Precision Option(s)

8001 ☐ 8002 ☐

Output Power Option

W60 ☐

This manual applies directly to instruments with Serial Number 17000 and higher.

WARRANTY

Lake Shore Cryotronics, Inc., the manufacturer, warrants this product to the owner for a period of 12 months from the date of shipment. During the warranty period, under authorized return of instruments or component parts to Lake Shore freight prepaid, the company will repair, or at its option replace, any part found to be defective in material or workmanship, without charge to the Owner for parts, service labor or associated customary shipping cost. Replacement or repaired parts will be warranted for only the unexpired portion of the original warranty.

All products are thoroughly tested and calibrated to published specifications prior to shipment. Calibration Certifications are offered for six month periods only. Where such documentation must be updated, a re-certification service is offered by Lake Shore Cryotronics, Inc. at a reasonable cost.

LIMITATION OF WARRANTY

This warranty does not apply to defects resulting from improper or inadequate maintenance, unauthorized modification or misuse, operation outside of the environmental specifications for any product or part or buyer-supplied software or interfacing.

THIS WARRANTY IS IN LIEU OF ANY OTHER WARRANTIES, EXPRESSED OR IMPLIED, INCLUDING MERCHANTABILITY OR FITNESS FOR A PARTICULAR PURPOSE, WHICH ARE EXPRESSLY EXCLUDED. THE OWNER AGREES THAT LAKE SHORE'S LIABILITY WITH RESPECT TO THIS PRODUCT SHALL BE SET FORTH IN THIS WARRANTY, AND INCIDENTAL OR CONSEQUENTIAL DAMAGES ARE EXPRESSLY EXCLUDED.

CERTIFICATION

Lake Shore Cryotronics, Inc. certifies that this product has been inspected and tested in accordance with its published specifications and that this product met its published specifications at the time of shipment.

The accuracy and calibration of this product at the time of shipment are traceable to the United States National Bureau of Standards.

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SECTION I

GENERAL INFORMATION

1.1 INTRODUCTION

The information contained in this operations manual pertains to the installation, operation, remote programming, options and accessories for the Lake Shore Cryotronics, Inc. Model DRC-93C Temperature Controller. This manual also contains troubleshooting and calibration procedures, schematics, component layouts and replaceable parts lists.

This section contains general information for the Lake Shore Cryotronics, Inc. DRC-93C Temperature Controller. Included is an instrument description, specifications, instrument identification, option and accessory information.

1.2 DESCRIPTION

The DRC-93C Temperature Controller is a microprocessor based instrument which provides true analog control. It is capable of scanning multiple sensor inputs and displaying temperature with up to 5 digits of resolution in K, ^{O}C or ^{O}F or sensor units (volts, ohms or nanofarads) to five digits.

The DRC-93C can be used with either 1 or 2 input cards. When two input cards are used, these cards can be different to allow two separate types of sensors to be used with the controller.

The dual sensor input with the optional 8229 Scanner Conversion Card expand the input capability of the DRC-93C to up to 6 input sensors. Depending on the input option selected, the DRC-93C handles silicon (9210-3 or 9220-3) or the patented Gallium-Aluminum-Arsenide (9210-6 or 9220-6) diodes, platinum or rhodium-iron resistors (9220 series), germanium or carbon glass resistors (9317C, 9318C), or capacitance sensors (9215).

With or without the 8229 Scanner Card, the DRC-93C can be set to scan automatically with an individual dwell time of 1 to 99 seconds per channel or stepped to any available input and held there. Setting the dwell time to zero causes a particular channel to be skipped. If all dwell times are zero, the instrument stays on the channel selected.

The DRC-93C gives a direct reading in temperature when used with any DT-470 Series Temperature Sensor. All DT-470 Sensors follow the same temperature response curve. Four bands of tracking accuracy are available. Refer to DT-470 technical data for details.

Diode sensor voltages are digitized to a resolution of 100 microvolts with full scale dependent on input card configuration. The temperature display has a resolution capability of 0.01 kelvin above 100 kelvin and 0.001 kelvin below 100 kelvin.

For greater precision individual sensor calibrations can be accommodated with the 8001 Precision Calibration Option which programs the instrument with calibration data for a specific Sensor. The algorithm within the instrument interpolates between data points to an interpolation accuracy which exceeds 0.01K over the entire temperature range of the Precision Option. The 16 bit analog-to-digital converter is accurate to plus or minus the least significant bit, which for the 470 series sensor results in an uncertainty of 1mK below 28K and 45mK above 40K with a transitional region between these two temperatures. Therefore, at temperatures below 28K, the overall system accuracy, the sum of the instrument accuracy (11mK) and that of the calibration itself (Lake Shore calibrations are typically better than 20mK within this region) is ± 30mK. Above 28K, system accuracy gradually moderates to a typical value of ±75mK above 40K. See the Lake Shore Low Temperature Calibration Service brochure for additional discussion of calibration accuracy.

The Model DRC-93C can also be used with the 9220 input card which handles both diodes and positive temperature coefficient metallic resistors., i.e., platinum or rhodium-iron resistors. The DIN curve is standard within the instrument and is called up automatically unless a positive temperature coefficient precision option curve is selected for that input. The accuracy of the reading is dictated by the sensor and its conformity to the DIN curve. The tolerance on these devices is given on the technical data sheet for the Lake Shore PLATINUM RTD's. The combined accuracy of the instrument and a calibrated resistor with a precision option is on the order of 40mK over the useful range of the sensor (above 40K for the platinum). Note that a precision option is required for a rhodium-iron to read correctly in temperature.

The Model DRC-93C with the 9318C germanium/carbon-glass input card results in the most accurate system below 50K in temperature. For both sensors, a precision option is required to read in temperature. Near 4K, the overall accuracy of the system, including the calibration accuracy, the software interpolation accuracy and the calculation of the resistance results in an overall accuracy on the order of 10mK.

These input option cards are easily installed by the user; thus, units can be changed or upgraded to satisfy changing requirements.

The ample memory space provided in the DRC-93C allows several response curves to be stored in the instrument. Depending on the complexity of the curves, up to 25 can be programmed into the unit. The active curve is selected either from the front panel or over the remote interface.

The data for calibrated sensors can be stored in the instrument as an 8001 Precision Option or by the customer via the front panel or remote interfaces. These curves can contain up to 99 sensor temperature data points. With the standard precision option format of 31 data points and an 18 character information line, up to twenty curves can be stored.

Although data points are stored as a table, the interpolation algorithm used results in the equivalent of a high order Chebychev polynomial calculation in the converting of the input voltage (or resistance) to temperature. This is done by means of a proprietary algorithm developed at Lake Shore Cryotronics.

An averaging algorithm can be selected to average up to ten temperature readings. This mode eliminates noise within the system analogous to averaging with a digital voltmeter. This averaging mode can be disabled from the front panel or over the remote interface for a given input if the customer prefers not to average readings.

The control set point is also displayed on the front panel and can be set from the front panel. The set point automatically takes on the units selected for the control sensor. In the units mode the set point can be set to five digits with the range of defined by the control sensor input card. The standard set point temperature can be set to 0.1 degree. This temperature is converted to an equivalent voltage with a resolution of 100 microvolts out of 3 volts full scale. The optional High Resolution Set point expands the set point resolution to 0.01 degrees 100 and 0.001 degrees below 100. The equivalent voltage is expanded to 25 microvolts out of 3 volts full scale. This results in a settability of approximately 0.01 kelvin above 40K and 0.001 kelvin below 28K for the DT-470 series sensors.

The control section of the DRC-93C provides three-term temperature control. Proportional (GAIN), integral (RESET) and derivative (RATE) are individually set with a range from 0.1 to 99 resulting in a 990 to 1 range.

Heater power output of the DRC-93C Temperature Controller is a maximum of 50 watts when a 50 ohm heater is used. A digital bar graph on the front panel displays the output as a percentage of output range selected. Thus, the user can conveniently monitor power applied to his system. To accommodate systems which require lower heater power, the maximum output can be attenuated in four steps of a decade each. Three resistance ranges are available; 0-25, 25-35 and 35-50 ohms.

The desired range is selected by a slide switch on the rear panel. The power must be off for this selection, since the transformer output is shorted momentarily by changing the setting.

The maximum power can also be limited by using the rheostat on the rear panel. Power can be reduced on the MAX scale to any value between MAX and a reduction of a factor of ten in power.

When greater output power is required, the optional W60 output stage can provide 60 watts into a 25 ohm load.

An IEEE-488 interface is standard in the DRC-93C. This interface can be used to remotely control all front-panel functions. When two input cards are used, data from both inputs is available via the interface.

1.3 SPECIFICATIONS

Instrument specifications are listed in Table 1.1. These specifications are the performance standards or limits against which the instrument is tested.

1.4 OPTIONS

The options for the DRC-93C Controller are listed in Section VII.

Three option ports are designed into the DRC-93C. The options are field installable by the user.

822x-series options can be factory installed in the DRC-93C or field-installed at a later time. The 8223 RS-232C Interface Option operates similar to the IEEE-488 interface. With the display in temperature units, the Model 8225 Analog Output option is available to provide a linearized analog output of 10mV/K independent of the display temperature units chosen. If the display is in sensor units, the output for diodes is 1V/V; for 100 ohm platinum, 10mV/ohm; for 1000 ohm platinum, 1mV/ohm; for rhodium-iron, 100mv/ohm; and for capacitance units, 100mV/nF and 10mV/nF. Since the 9317C and 9318C vary over such a large range of resistance, use of the 8225 with these two input cads is limitd to 10mV/K. The Model 8229 Scanner Option provides four additional channels of sensor input to the "A" input. The A input is channel A with the additional inputs designated 1-4 with the selection indicated on the display.

Table 1.1. Specifications, Model DRC-93C Temperature Controller

Input Characteristics:

Inputs: Two Sensor Inputs, A and B. The 8229 Scanner Conversion Option provides for four additional channels of Sensor Input. Display sensor can be selected from front panel or interface, or display can be set to scan between sensor inputs. Dwell time per channel can be set independently from 0 (skip) to 99 seconds. Input characteristics are a function of Sensor Input Option Installed. The DRC-93C can accommodate two input options which allows the A input and the B input to each be assigned their own input card. This allows concurrent use of different sensor types, dependent on the user's application.

Sensors: Ordered Separately. DRC-93C will handle all types of diodes; germanium, carbon glass, carbon, etc. negative temperature coefficient resistors; thermistors; platinum, rhodium-iron, etc. metallic resistors as well as capacitance thermometers with proper choice of input option cards. See the Lake Shore Cryotronics, Inc. Sensor catalog for details on the above Sensors.

Display Readout:

Display: 5-digit LED Display of Sensor reading in Sensor Units (Volts, Ohms or Nanofarads) or temperature in K, ^{O}C, or ^{O}F shown with annunciators.

Resolution: Display resolution is 0.001K below 100K, 0.01K above 100K (0.0001K below 10K for 9317C Resistance Sensor Input Card). Resolution can be user-limited to 1K, 0.1K or 0.01K. Same resolution considerations apply for °C and °F. Changes made by front panel keys or over interface.

Temperature Accuracy: Dependent on Sensor Input Card and Sensor. See Input Options available.

Temperature Range: Dependent of Sensor Input Card and Sensor.

Temperature Control:

Set Point: Keypad selection as a numeric value, as a step change from prior value, or incrementally via up/down counter. All keypad operations can be duplicated with optional interfaces.

Set Point Resolution: Selection in kelvin, celsius, fahrenheit or Sensor Units. Temperature to 0.1 in corresponding units; in Sensor Units, 0.1mV in voltage, 0.01 ohms but limited to five digits in resistance and 0.001 nanofarads out of 15 nanofarads (0.01 nanofarads out of 150 nanofarads for second scale) in capacitance. May also be set over the interface.

Typical Controllability: Dependent on Sensor, its temperature and the resultant Sensor "gain", i.e., sensitivity. Typically better than 1mK in a properly designed system below 30K and 5mK above 30K using a

Diode Sensor. But, for example, a thermistor, due to its large sensitivity, may result in a controllability approaching 0.5mK above 200K over a narrow temperature range in certain systems and a germanium below 10K may control to 0.1mK in another system.

Control Modes: Proportional (GAIN), integral (RESET) and derivative (RATE). Set numerically (0.0 to 99. of internally established range) or incremented via front-panel keypad. Continuous two-digit display of each mode. Manual Mode allows 0 to 100% of available heater power to be selected via keypad. Auto and Manual modes can be used concurrently. All keypad operations can be duplicated thru interfaces.

Heater output: Up to 50 watts (1A,50V) standard. Five output ranges can be selected either from front-panel or interface and provide approximate decade step reductions of maximum power output. Optional 60 watt output available. Rear panel maximum current limit for MAX scale.

Heater output Monitor: BAR display continuously shows heater current or power output as a percentage of range with a resolution of 1%.

Control Sensor: Either Sensor Input (selected from front panel or remote interfaces).

General:

Sensor Voltage Monitor: For 9210 Option, buffered output of each diode sensor voltage. For 9220 Option diode configurations (-3,-6) give buffered output of diode sensor; for -6 configuration, buffer is 0.458 times sensor voltage; for 9220 Option positive temperature coefficient configurations (-P2, -P3, -R1), buffer is sensor voltage output times -10. For 9215, signal is proportional to capacitance value; for 9317C or 9318C, monitor not of use.

Response time (electronics): Less than 1 second to rated accuracy for non-Lagrangian calculations. Lagrangian curves result in update times between one and two seconds. Three readings on channel change or range change to reach rated accuracy.

IEEE-488 Interface: Allows remote control of set-point, gain, rate, reset, units and heater power range. Provides output of display in units chosen, units and all front panel functions (except power on/off). Allows input of curve data for calibrated sensors and internal ramping programs.

Dimensions, Weight: 432mm wide x 102mm high x 330mm deep (17in. x 4in. x 13in.) Style L, full-rack package. Net weight 8kg (17 lb.).

Power: 90-110, 105-125, or 210-250 VAC (selected via rear panel with instrument off), 50 or 60 Hz, 75 watts.

Accessories Supplied: Mating connector for sensor/monitor connector, instruction manual.

SECTION II

INSTALLATION

2.1 INTRODUCTION

This Section contains information and instructions pertaining to instrument set-up. Included are inspection procedures, power and grounding requirements, environmental information, bench and rack mounting instructions, a description of interface connections, and repackaging instructions.

2.2 INITIAL INSPECTION

This instrument was electrically, mechanically and functionally inspected prior to shipment. It should be free from mechanical damage, and in perfect working order upon receipt. To confirm this, the instrument should be visually inspected for damage and tested electrically to detect any concealed damage upon receipt. Be sure to inventory all components supplied before discarding any shipping materials. If there is damage to the instrument in transit, be sure to file appropriate claims promptly with the carrier, and/or insurance company. Please advise Lake Shore Cryotronics, Inc. of such filings. In case of parts shortages, advise LSCI immediately. LSCI can not be responsible for any missing parts unless notified within 60 days of shipment. The standard Lake Shore Cryotronics Warranty is given on the first page of this manual.

2.3 PREPARATION FOR USE

2.3.1 Power Requirements

The Model DRC-93C requires a power source of 100, 120, 220 or 240 VAC (+5%, -10%), 50 to 60 Hz single phase.

CAUTION

> Verify that the AC Line Voltage Selection Wheel (Figure 3-2,Key 1) located on the rear panel of the Model DRC-93C is set to the AC voltage to be used (Table 2-1) and that the proper fuse is installed before inserting the power cord and turning on the instrument.

2.3.2 Power Cord

A three-prong detachable power cord for 120 VAC operation which mates with the rear panel UL/IEC/ICEE standard plug is included with the instrument.

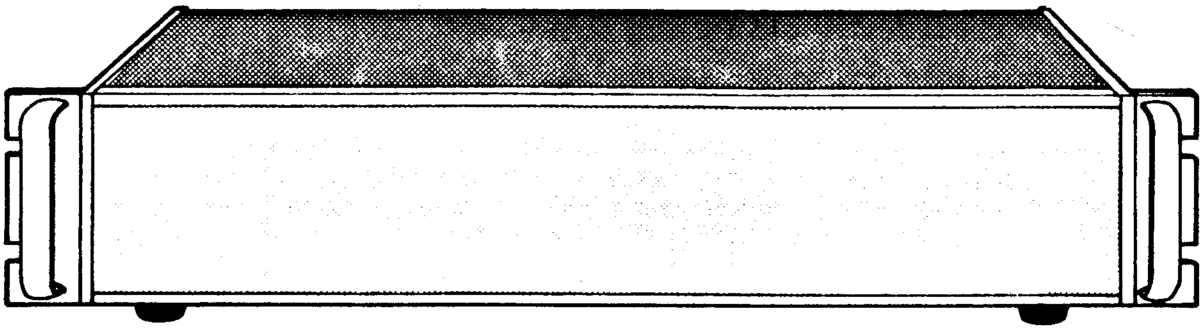
2.3.3 Grounding Requirements

To protect operating personnel, the National Electrical Manufacturer's Association (NEMA) recommends, and some local codes require, instrument cabinets be grounded. This instrument is equipped with a three-conductor power cable which, when plugged into an appropriate receptacle, grounds the instrument.

Table 2-1. Line Voltage Selection

Line Voltage (Volts)	Operating Range (Volts)	Fuse (A)
100	90-105	2 - SB
120	108-126	2 - SB
220	198-231	1 - SB
240	216-252	1 - SB

Figure 2-1. Typical Rack Configuration



2.3.4 Bench Use

The DRC-93C is shipped with plastic "feet" and a tilt stand installed and is ready for use as a bench instrument. The front of the instrument may be elevated for convenient operation and viewing by extending the tilt stand.

2.3.5 Rack Mounting

The DRC-93C can be installed in a standard 19 inch instrument rack by using the optional RM-3F or RM-3F-H rack mounting kit. A typical RM-3F-H kit installation is shown in Figure 2-1.

2.3.6 Sensor Input Connections

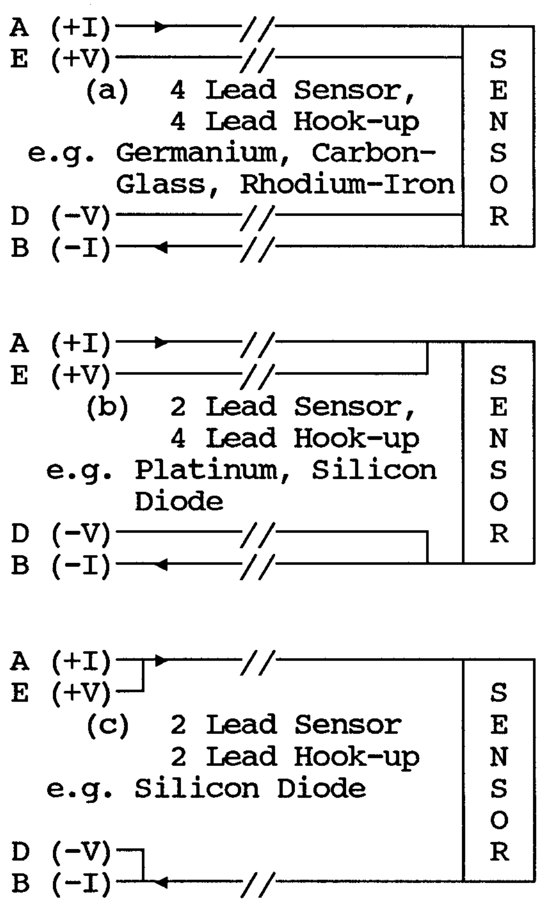
The DRC-93C has two rear panel 5-pin input connectors for sensors. The lead connection definition for the sensor(s) is given in Table 2-2 and is shown in Figure 2-2.

Table 2-2. INPUT Connections for J1 Input A and J2 Input B

Terminal	Description
A	+ Current Out
B	- Current Return
D	- Voltage Sense
E	+ Voltage Sense
H	Shield

The use of a four lead connection arrangement (a) is required for a four lead sensor.

Figure 2-2. Sensor Connections



The use of a four wire connection (Figure 2-2a and b) is highly recommended for resistive elements to avoid introducing IR drops in the voltage sensing pair which translates into a temperature measurement error.

An alternate two line wiring method (Terminals A and E shorted together, B and D shorted) may be used for the DT-470 and TG-120 series diodes in less critical applications where lead resistance is small and small readout errors can be tolerated (c). Measurement errors due to lead resistance for a two lead hook-up can be calculated using; $\delta T = IR/[dV/dT]$ where I is 10 microamperes, R is the total lead resistance; dV/dT is the diode sensitivity and δT is the measurement error. For example, R = 250 ohms with dV/dT = 2.5 millivolts/kelvin results in a temperature error of 1 kelvin. Two wire connections are not recommended for other sensor types.

The Lake Shore Cryotronics, Inc. QUAD-LEAD™ 36 Gauge Cryogenic wire is ideal for connections to the sensor since the four leads are run together and color-coded. The wire is Phosphor Bronze with a Formvar insulation and Butryral bonding between the four leads. Color coding is red, green, clear and blue on the four leads which makes it extremely easy to determine one wire from another.

2.3.7 J3 Sensor Output MONITORS

Buffered voltage outputs for both Sensor Input A and B are available on the J3 connector on the back panel of the instrument. The voltage from the Model 8225 Analog Output Option is present on this connector also. The connector pin assignments are given in Table 2-3.

Table 2-3. J3 MONITORS Connections

Terminal	Description
A	Voltage Output (Input A)
B	Voltage Output (Input B)
C	10 mV/K Analog Output
D	Ground for Analog Output
E	Setpoint Output
F	Ground (A,B,Setpoint)
H	(Optional Shield)

2.3.9 Heater Power

The heater output leads should be electrically isolated from the sensor(s) ground(s) to preclude the possibility of any of the heater current affecting the sensor input signal. The heater leads should not run coincident with the sensor leads due to the possibility of capacitive pick-up between the two sets of leads. If they are in close proximity, they should be wound so as to cross the sensor leads at ninety degrees if at all possible.

The heater output is a current drive and does not have to be fused. The DRC-93C is designed to power a 50 ohm heater for maximum heater output. If a smaller resistance is used, the maximum heater power corresponds to the heater resistance, i.e., 10 ohms yields 10 watts. A larger heater can also be used. Since the compliance voltage is 50 volts; a 100 ohm heater will allow a maximum power output of 25 watts $[(50)^2/100]$.

A slide switch on the back panel sets the available output power dependent on the value of the heater resistance. This slide switch **must only** be changed with the instrument turned **off** since it shorts the windings of the output transformer between positions. The setting range of the switch should coincide with the heater resistance to minimize power dissipated within the DRC-93C. Three setting ranges are available: 10-25, 25-35 and 35 to 50 ohms.

An optional output power stage (W60) of 60 watts is available for the DRC-93C. The W60 is rated at 1.5 amperes at approximately 43 volts (into 25 ohm load).

A 50 ohm, 50 watt (1/4" dia. x 1" long) cartridge heater is available as well as a 25 ohm, 25 watt (3/8" dia. x 1" long) cartridge heater.

A 30 gauge stranded copper lead wire (ND-30) is recommended for connecting to the heater.

2.3.9.1 MAX HEATER POWER Limit

Make sure that the MAX HEATER POWER limit potentiometer is turned fully clockwise during the setup of the instrument so that full power is available on the MAX power scale, if desired.

2.3.9.2 Current or Power Output Display

The HEATER % meter can be set to read either % of output power or % of output current. The internal DIP switch setting (switch 1) controls whether the meter reads in % current (closed) or % power (open). The DRC-93C is shipped to read in % power.

2.4 REMOTE SENSOR ID Connector

The REMOTE SENSOR ID connector, J5, on the rear panel receives POSITION DATA from a Model 8084 or 8085 Sensor Scanner or a Model SW-10A Ten-Sensor Selector Switch. The REMOTE SENSOR ID Interconnecting Cable and REMOTE SENSOR ID connector assignments are given in Table 2-4.

Table 2-4. REMOTE SENSOR ID Connector Assignments

REMOTE SENSOR ID Connector Pin	Function
10	Bit 0 (B0-LSB)
8	Bit 1 (B1)
6	Bit 2 (B2)
4	Bit 3 (B3)
14	Bit 4 (B4-MSB)
12	Digital Ground

The POSITION DATA is the binary representation of the remote position. Table 2-4 gives the POSITION DATA binary combinations and equivalent hexadecimal remote position. The remote position input can be used to select specific sensor curve tables stored in the DRC-93C. The correlation between remote position and sensor curve is given in Section III.

2.5 IEEE-488 INTERFACE Connector

The IEEE-488 Connector on the back of the DRC-93C is in full compliance with the IEEE Standard 488-1978. The connector has metric threaded mounting studs, visually indicated by the color black. Metric threaded cable lockscrews (also black) must be used to secure an IEEE-488 interface cable to the instrument. Model 8072 IEEE-488 Interconnect Cables (one meter long) are available from Lake Shore.

2.6 Options

2.6.1 8223 RS-232C Interface. Provides remote operation of the same parameters as the IEEE-488. The RS-232C interface option is described in Section VII of this manual including connections.

2.6.2 8225 Analog Output. Provides analog output proportional to kelvin temperature f display sensor (10mV/K) at <10 ohms output resistance. The 8225 Analog Output is described in Section VII of this manual.

2.6.3 8229 Scanner Input Option. Adds four additional channels to the "A" input. Scans up to six sensors with programmable dwell times. The 8229 Scanner Option is described in Section III and Section VII of this manual.

2.6.4 The High Resolution Set Point expands the set point resolution to 0.01 kelvin above 100K and 0.001 kelvin below 100K. The equivalent voltage is expanded to 25 microvolts out of 3 volts full scale. This results is a setability of approximately 0.01 kelvin above 40K and 0.001 kelvin below 28K for the DT-470 series sensors.

2.6.5 8001 Precision Option. Custom programming of specific Sensor calibration curve(s) at factory. Provides highest degree of readout accuracy.

2.6.6 The W60 Output Option will deliver 60 watts at 1.5 amperes at approximately 43 volts into a 25 ohm load. This is a factory installed option.

2.7 ENVIRONMENTAL REQUIREMENTS

WARNING

To prevent electrical fire or shock hazards, do not expose the instrument to rain or excess moisture.

2.7.1 Operating Temperature

In order to meet and maintain the specifications in Table 1-1, the DRC-93C should be operated at an ambient temperature range of 23°C ± 5°C. The unit may be operated outside the range of 15-35°C with less accuracy.

2.7.2 Humidity/Altitude

The DRC-93C is for laboratory use and no humidity or altitude specifications have been determined for this unit.

2.8 REPACKAGING FOR SHIPMENT

If the Model DRC-93C appears to be operating incorrectly, refer to the Troubleshooting Guide in Section 5.7. If the tests indicate that there is a fault with the instrument, contact Lake Shore or a factory representative for a returned Goods Authorization (RGA) number before returning the instrument.

When returning an instrument for service, photocopy and complete the Service Form found at the beginning of Appendix A. The form must be filled in to ensure efficient solution of the problem. The following information must be provided before Lake Shore will attempt any repair.

1. Instrument Model and Serial #s
2. User's Name, Company, Address, and Phone Number
3. Malfunction Symptoms
4. Description of system
5. Returned Goods Authorization No.

If the original carton is available, repack the instrument in a plastic bag, place it in the carton using original spacers to protect protruding controls. Seal the carton with strong paper or nylon tape. Affix shipping labels and "FRAGILE" warnings.

If the original carton is not available, pack the instrument similar to the above procedure, being careful to use spacers or suitable packing material on all sides of the instrument.

SECTION III

OPERATING INSTRUCTIONS

3.1 INTRODUCTION

This section contains information and instructions concerning the operation of the Model DRC-93C Temperature Controller. Included is a description of the front and rear panel controls and indicators.

3.2 INSTRUMENT CONFIGURATION

3.2.1 Input Card Configurations

The Model DRC-93C can be used with either one or two input cards. The input cards available for use with the DRC-93C are summarized in Section I. The input cards available allow the 93C to be used with almost any type of cryogenic sensor. Input cards can be mixed, allowing two different sensor types to be used with the DRC-93C.

3.2.2 Single Input Card

When only one input card is present within the unit, it occupies the INPUT CARD #1 slot of the DRC-93C mainframe and is connected to the Sensor A input of the controller. Only one sensor can be used with the controller under these conditions.

3.2.3 Dual Input Cards

When two input cards are present in the unit, the input card that occupies the INPUT CARD #1 slot is routed to the Sensor A input and the input card that occupies the INPUT CARD #2 slot is routed to the Sensor B input. Consequently, both sensors are energized at all times.

The second input card allows the instrument to mix sensor types, e.g., both a diode thermometer and a resistance thermometer can be used on the two inputs. Another possibility with the 9318C and 9220 Options would be the presence of a GR-200A Series Germanium Sensor as well as a PT-100 Series Platinum Resistance Sensor. Both inputs are updated independently, which allows them both to be displayed or queried under IEEE-488 or RS-232C control. The addition of an optional 8229 Sensor Scanner Card adds capability for 4 additional inputs to the A channel resulting in up to 5 sensors of the same type being allowed using the A input card.

3.2.4 Old Version Input Cards

The 8210, 8211 diode input cards can be used in the 93C as well as the 8219 series resistance input card. The installation of these cards is covered in Section 7-3 of this manual. Note that there are Dip Switch settings on the main board which must be set in order for these older cards to work properly.

3.3 CURVE ENTRY

The DRC-93C allows the user to enter his own sensor calibration via the front panel or over the remote interface. Section 3.9.3 discusses curve entry via the front panel and Section IV covers entry over the IEEE-488 or RS-232C interfaces. The curve is stored in a battery back-up non-volatile RAM (NOVRAM) which can be read and written an unlimited number of times. The number of data points stored per curve can be between 2 and 97; two being the lower limit which defines a straight line.

3.4 PRECISION OPTIONS

3.4.1 The Model 8000 Precision Option

There are three types of Precision Options available for the DRC-93C. The Model 8000 Precision Option generates the data table from a Lake Shore calibrated sensor. The upper limit of data points is again 97, with a typical calibration ranging between 30 and 40 points, depending on sensor type and temperature range for the calibration. The data and accuracy of the fit is supplied to the user as a separate document. This information can then be entered by the user via the front panel or over the computer interface.

3.4.2 The Model 8001 Precision Option

Lake Shore can also generate custom sensor response curves from the individual sensor calibrations as indicated above and store them in the DRC-93C via the 8001 Precision Option prior to shipment. The data and accuracy of the fit is then supplied to the user in an Appendix of this manual.

3.4.3 The Model 8002-05 Precision Option

The 8002 Precision Option is used when the customer already owns a DRC-93C and wants new sensor calibration data stored in the instrument. LSCI stores the calibration data in a PROM chip and sends the programmed chip to the customer. The PROM is then installed in the DRC-93C by the customer.

Note that additional calibrations can be added to the instrument at a later time by specifying with the sensor calibration at time of order, the serial number of the instrument and with which input the sensor will be associated if remote operation is used.

3.5 CONTROL FUNDAMENTALS

An application note entitled "Fundamentals for Usage of Cryogenic Temperature Controllers" is included as an appendix in this manual and should be read in detail if you are not familiar with cryogenic temperature controllers.

3.6 CONTROLS AND INDICATORS

Figures 3-1 and 3-2 identify the DRC-93C displays, annunciators, controls, and connectors. The identification of each item is keyed to the appropriate figure.

FRONT PANEL DESCRIPTION

3.7 POWER ON

Before connecting AC power to the DRC-93C, make sure the rear panel voltage selector is set to correspond to the available power line voltage. Be certain the correct fuse is installed in the instrument.

3.7.1 Power Up Sequence

Immediately on POWER ON the DRC-93C runs through a power up sequence as follows:

1. Light Test

All digits, annunciators, and the bar graph turn on to test the lights.

The TEMPERATURE Block indicates ·+8.8.8.8.8. in both the upper, lower and setpoint windows. The CONTROL Block indicates 8.8. in the GAIN, RATE, and RESET windows. The

HEATER POWER Bar Graph indicates 100%. The UPPER and LOWER DISPLAY SENSORS have ·8. The indicators for the six sets of UNITS for both the Upper and Lower displays are displayed to the far left of the front panel. The control (CTRL) annunciators are between the SENSOR annunciators. The RANGE from OFF to MAX annunciators are below the Bar graph and the LOCAL, REMOTE, PROG (programming) and INT (internal program) to the far right of the front panel.

2. Instrument Name and IEEE Address

Next the unit displays LSCI in the Upper Display, -93C- in the Setpoint Display and the IEEE-488 interface address in the Lower Display. For a factory set IEEE address of 12 the display would indicate Add12. This address can obviously be changed by the user and verification of that change is always given on power-up. <u>Note that this address is only read by the instrument on power-up.</u>

3. Input Card Configuration

The unit then displays the input cards associated with the inputs on the upper and the lower displays.

4. Normal Operation

The unit then goes into normal operation.

3.7.2 Power-up Status

A provision has been made to store parameter changes in the DRC-93C memory (NOVRAM). The sample and control units, as well as the curve numbers and scan dwell times can be stored as power-up settings. When enabled, any time the parameter is changed, either in the LOCAL or REMOTE mode, the NOVRAM is updated. The internal DIP switch setting (switch 2) controls whether or not the settings are updated. The updating is enabled (switch 2 on) at the factory prior to shipment.

3.7.3 Blue Legend Keys

At the beginning of an operation, if one of the grey keys of the keypad with Blue Legends (also labelled 0-9, and .) is pressed, the function described by the blue legend is immediately displayed or carried out. These functions are SENSOR, UNITS, CURVE#, RSLTN, FILTER, CONTROL, DEV, MATH, MAX, MIN, MAXDEV.

The CURVE#, RSLTN, FILTER, DEV, MATH, MAX, MIN, and MAXDEV keys must be held down in order to observe the quantity continuously. For example, if the RSLTN (resolution) key is pressed, the display will immediately show the resolution assigned to the Upper and Lower Displays. When the key is let up, operation will return to normal operation with the displays showing temperature, voltage, etc.

The CONTROL, SENSOR, UNITS, CURVE#, RSLTN, FILTER, DEV, and MATH keys provide operations that can be changed by the user. The ▴▴ (up) and ▾▾ (down) keys are used in conjunction with these Blue Legend keys to alter the quantity with the ▴▴ key referring to the Upper Display and the ▾▾ key referring to the Lower Displays. In order to change one of these quantities it is necessary to hold the Blue Legend key down while hitting the ▴▴ (up) key or ▾▾ (down) key. The ▴▴ key will change the entry of the Upper display and the ▾▾ key will change the Lower display.

Figure 3-1. DRC-93C Temperature Controller Front Panel

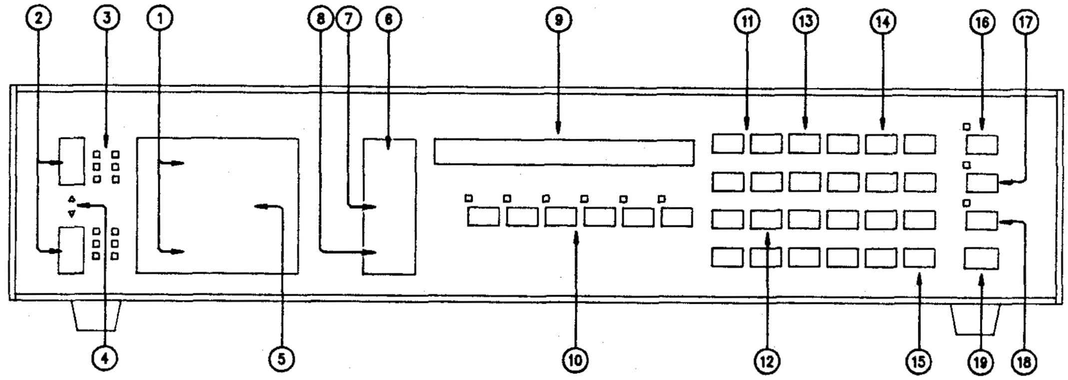


Figure 3-1. Model DRC-93C Temperature Controller Front Panel Description

Upper and Lower Displays

1. Sensor reading in temperature (Kelvin, Celsius, or Fahrenheit), or sensor units (Voltage, Resistance, Capacitance).
2. Sensor No. (A, b, 1, 2, 3, 4).
3. Annunciators indicating units of Sensor (K, F, C, Ω, V, N).

Set Point

4. CTRL (control) Arrow Annunciator indicating whether the sensor in the Upper or Lower Display is the control sensor.
5. Display of Set Point in temperature (kelvin, celsius, or fahrenheit), or sensor units (voltage, resistance or capacitance) in the units of the Control Sensor (as indicated by CTRL Arrow).

Control Display

6. GAIN (proportional) display.
7. RATE (derivative) display.
8. RESET (integral) display.
9. HEATER CURRENT or HEATER POWER Bar Graph in percent of full scale.
10. Full Scale selection of HEATER CURRENT or HEATER POWER for four orders of magnitude. Includes power OFF position.

Keyboard

11. Control Data input keys (Gain, Rate, Reset, Setpoint, and Manual Heater).
12. ▲▲ (Up) and ▼▼ (Down) keys.
13. PROG (Programming), ↑-↓ (SCAN and Sign), TIME, and POINT # keys.
14. Decimal Keypad with Blue Legend functions of SENSOR, CURVE#, FILTER, MATH, UNITS, RSLTN (ReSoLuTioN), DEV (DEViation), CONTROL, MAX (MAXimum), MIN (MINimum), and MAXDEV (MAXimum DEViation)
15. CLEAR and ENTER functions for use with keypad 0, 1, 2, 3, 4, 5, 6, 7, 8, 9, decimal point and ↑-↓ minus sign.
16. Return-to-LOCAL key with annunciator.
17. REMOTE key with annunciator.
18. INT (INTernal Program) Key with annunciator.
19. POWER ON-OFF switch

3.7.4 Black Legend Keys

When one of the Black Legend keys (GAIN, RATE, RESET, SETPOINT, MANUAL HEATER, TIME, or POINT#) is pressed it is not to be held down released immediately.

The quantity described by the key will begin to flash indicating that it can be changed.

The keypad (0-9 and .) is then used to enter the new value. Negative quantities are preceded by the minus ↑-↓ key. The ENTER key completes the operation and inserts the new value. The CLEAR key will cancel the entry and return the instrument to normal operation.

When the ▲▲ (up) and ▼▼ (down) keys are used after selecting a Black Legend key the ▲▲ key will increment and the ▼▼ key decrement the quantity. Detailed operation of these keys will be discussed in the sections dealing with the specific Black Legend functions.

SUMMARY: THE KEYPAD (0-9 AND .) ARE ONLY THE NUMBERS 0-9 AND DECIMAL POINT WHEN A DISPLAY (SETPOINT, GAIN, RATE, RESET, OR MANUAL HEATER POWER) IS FLASHING. OTHERWISE THE KEYS WILL CARRY OUT THE FUNCTION DESCRIBED BY THE BLUE LEGEND. THE ENTER AND CLEAR KEY ARE ONLY EFFECTIVE WHEN A QUANTITY IS FLASHING. THE ▲ KEY AND ▼ KEY ARE USED IN CONJUNCTION WITH BLUE LEGEND KEYS TO CHANGE THE QUANTITY BEING REQUESTED.

3.8 TEMPERATURE BLOCK

The TEMPERATURE block consists of the Upper Display, Setpoint Display and the Lower Display. The Upper and Lower Displays each have

1. SENSOR Number
2. ↑-↓ (SCAN) indicator in the upper left hand corner of the SENSOR Number
3. Units (K, C, F, V, Ω, N)
4. A 5 digit display with sign
5. An indicator in the upper left hand corner of the sign to signal FILTER ON.

A Control arrow (CTRL) to the far left of the TEMPERATURE block points to the Controlling Sensor.

The Setpoint Display is discussed in Section 3.10 with the CONTROL Block.

3.8.1 Sample and Control Sensor Inputs

The choice of which input is associated with the Control Sensor or the Sample Sensor is determined by the CONTROL key of the keypad and indicated by the CTRL annunciator arrow. If the CTRL Arrow points up then the Upper Display with its associated SENSOR Number and UNITS are the Control sensor. The Lower Display is then the Sample Sensor with its associated SENSOR number and UNITS. Similarly, if the CTRL Arrow points down then the Lower Display and its associated SENSOR and UNITS is the Control Sensor and the Upper Display is the Sample Sensor.

3.8.2 Upper and Lower SENSOR Number

The selection of A or B inputs for the Upper Display is changed by holding in the SENSOR key and pressing the ▲▲ (Up) key.

The selection of A or B inputs for the Lower Display is changed by holding in the SENSOR key and pressing the ▼▼ (Down) Key.

The A input is distinguished by a uppercase letter A in the Sensor window and the B input by a lowercase b in the Sensor window.

While the SENSOR key is held down, the Upper and Lower Displays will show the card types being used by the displayed sensor. The GAIN, RATE, and RESET windows are blank.

They are used to indicate REMOTE POSITION DATA when an External Scanner (Models 8084 or 8085) are attached (see Section 3.9.2).

When the 8229 Scanner Conversion Option is not present the display toggles between the A and B input cards.

3.8.3 8229 Scanner Input Option

With the addition of the Model 8229 Scanner Input Option, four more inputs are added to the A channel input. These additional inputs are designated 1, 2, 3, and 4 in the SENSOR window.

With the scanner conversion option present, the SENSOR key and ▲▲ (Up) key increments the Upper Display inputs in the sequence A-1-2-3-4-b-A etc. Similarly for the Lower Display with the SENSOR key and ▼▼ (Down) key.

The 8229 Scanner Input Option is covered in Section VII.

3.8.4 SCAN Function

The SCAN function allows the instrument to step between the two inputs with a scan rate independently set between 0 (Skip) and 99 seconds for each input. Setting a dwell time to zero automatically skips the channel <u>only</u> when in the SCAN mode. If the scanner option is present, inputs (1-4) are included in the SCAN function and each has its own dwell time which is set independently.

3.8.5 The SCAN Dwell Time

The dwell time for the Sensor inputs associated with the Upper and Lower Display can be displayed by pressing the ↑-↓ key down for more than one second. The display will read dt-00 for a dwell time of 0 seconds. If it is desired to change the dwell shown in the upper display, the user continues to hold down the SCAN key and presses the ▲▲ key. Both keys can then be released. The dwell in the Upper Display will flash indicating that it can be changed by the keypad (0-9) and entered into the instrument with the ENTER key. Hitting the CLEAR key before the ENTER key will cancel the entry and return the instrument to normal operation.

To change the dwell shown in the Lower Display is the same except that the SCAN and ▼▼ keys are employed.

When the dwell is being changed, in addition to using the keypad (0-9) there are two other methods to modify the dwell displayed. The first method is to increment the dwell with the ▲▲ key and decrement it with the ▼▼ key. When the desired dwell is displayed hitting the ENTER key will store that dwell in the instrument and return to normal operation. The second method in which the entry can be changed is by using the keypad to enter an amount which is to be added or subtracted from the previous value. Hitting the ▲▲ key will add the amount and the ▼▼ key will subtract the amount. The two methods can be used at will. The ENTER key will enter the final value into the instrument or the CLEAR key will cancel the operation at any time.

3.8.6 Upper and Lower Display Units

3.8.6.1 Units Select

The units of the Upper Display is changed by holding down the UNITS key and pressing the ▲▲ (Up) key until the units desired are obtained. Each time the ▲▲ key is pressed the units of the Upper Display cycle clockwise. The units which do not pertain to the input card selected are automatically skipped, i.e., only one of the sensor units (V, Ω, or nF) is possible depending on which sensor input card is present within the instrument. Similarly the units of the Lower Display are changed by holding down the UNITS key and pressing the ▾▾ (Down) key.

For any input card <u>except</u> the 9215, the DRC-93C will read temperature regardless of whether a curve is stored within the instrument which corresponds to the temperature sensor being interrogated. For diodes, germanium, carbon glass, and all other negative temperature dependence sensors; the default curve is Curve 00 which is the D curve for the DT-500-DRC sensors. For a positive temperature dependence temperature sensor such as platinum and rhodium-iron, the default curve is Curve 03 which is the standard 3750 DIN curve for platinum. This default will only occur <u>if</u> a curve of opposite temperature dependence has been inadvertently selected by the user. In the case of the 9215 card, temperature units are not allowed due to the inability of this sensor to hold a calibration upon cycling.

3.8.6.2 Sensor Units Mode

3.8.6.2.1 Voltage Units

The voltage mode is allowed for the 9210-3 and -6 configurations, the 9220-3 and -6 configurations as well as the older version 8210 and 8211 cards. In the voltage mode, the <u>display</u> has a resolution of 0.1 millivolt with the full scale range dependent on the input card (2.9999 volts for the -3 configurations and the 8210 card and 6.5535 volts for the -6 configurations and the 8211 input card). The actual Input Card resolution is 0.05 millivolts and 0.1 millivolts, respectively. If a voltage exceeding full scale is applied to the displayed input an overload condition is present and is indicated by OL on the display.

3.8.6.2.2 Resistance Units

The Resistance mode is allowed for the 9317C, 9318C, and the 9220-P2,-P3, and -R1 configurations as well as the older 8219-P2, the 8219-P3 and 8219-R1 cards. The display range and resolution for the 9317C is 0.000 to 9999.9 ohms; the 9318C is 0.000 to 99999 ohms. Note that the resistance automatically ranges from --.--- to ---.-- to ----.- to ----- as the resistance increases in value. If the input resistance exceeds the resistance range for the card, an overload condition is present and is indicated by OL on the display.

The display ranges and resolutions for the 9220-P2 (and 8219-P2), 9220-P3 (and 8219-P3) and 9220-R1 (and 8219-R1) are 0.00 to 299.99 ohms, 0.0 to 2999.9 and 0.000 to 99.999 ohms respectively. Again, if a resistance exceeding full scale is applied to the input, OL is indicated on the display.

3.8.6.2.3 Capacitance Units

The capacitance mode is allowed for the 9215 Input Card which can be configured in the -15 or -150 configurations. The display range is 0.000 to 30.000 or 150.00 nanofarads, respectively. An input in excess of the configured maximum is indicated by OL on the display.

3.8.7 Display Resolution

The Model DRC-93C allows the user to set his display resolution over the range from 1 kelvin to 1 millikelvin (0.1 millikelvin for the 9317C input card). The temperature is rounded to the least significant digit of the resolution range selected. Since the temperature display resolution is dependent on both the sensor units (voltage, resistance or capacitance) resolution of the Input Card as well as the sensor sensitivity, temperature resolution is greatly dependent on the sensor. Refer to Table 3-1 for a representative summary of "system" resolution, (sensor plus instrument) versus sensor sensitivity.

3.8.7.1 Temperature Display Resolution Set

To examine the resolution of the Upper and Lower Display hold in the RSLTN key. The displays will read one of the following:

---. , ---.- , ---.-- , --.--- , -.----

If it is desired to change the resolution then while holding down the RSLTN key hit the ▲▲ key to cycle the resolution in the Upper Display through those shown until the desired resolution is obtained. When the keys are released the new resolution is entered in the DRC-93C. Similarly, holding in the RSLTN key and hitting the ▼▼ key will change the resolution in the Lower Display.

Changing the display resolution fixes the resolution transmitted over the computer interface as well but does not change the resolution of the "system". Display resolution can also be different for each input card, i.e., A and B. Also note, that the chosen resolution will only be displayed when "appropriate". In other words, only five digits can be displayed.

In the temperature mode, the chosen input is displayed in the selected scale (K, °C or °F) with a maximum display capability of 0.01 degrees above 100 kelvin, to 0.001 degrees between 1 and 100 kelvin and in the case of the 9317C resistance card to 0.0001 kelvin (0.1 millikelvin) below 1 kelvin. Please note that this is display capability and <u>neither</u> system resolution <u>nor</u> necessarily accuracy of the reading. Also note that if the sensitivity of the sensor is too low to support this resolution, i.e., one bit corresponds to greater than the above resolution, some temperatures may be skipped. This will be true for a silicon diode sensor between 30 kelvin and 100 kelvin where the sensitivity is approximately 2.5 millivolts per kelvin and the voltage resolution is 0.046 millivolts. For this case, the resulting temperature resolution is 0.046/2.5 = 0.018 kelvin. However, below 30 kelvin the silicon diode sensitivity is approximately 25 millivolts per kelvin which results in an approximate resolution of 0.002 kelvin (0.046/25).

TABLE 3-1. System Resolution Versus Sensor Sensitivity

Sensor Sensitivity	Maximum Temperature Resolution (in kelvin)		Sensor Sensitivity	Maximum Temperature Resolution (in kelvin)
Voltage Mode	9210/9220		Resistance Mode	9317C/9318C
mV/K	-3^1	-6^1	$(1/R)(dR/dT)$, K^{-1}	9220-P2,-P3,-R1^2
0.1	0.5	1.	0.001	0.1 to 0.01
1.0	0.05	0.1	0.01	0.01 to 0.001
10.0	0.005	0.01	0.1	0.001 to 0.0001
100.0	0.0005	0.001	1.	0.0001 to 0.00001

Note 1. The input resolution is 0.05 millivolts for the 9210/9220-3 and is 0.1 millivolts for the 9210/9220-6.

Note 2. This assumes an ability to resolve between 1 part in 10^4 and 1 part in 10^5, where $\Delta T = (\Delta R/R)/[(1/R)(dR/dT)]$ and $(\Delta R/R)$ varies between 10^{-4} and 10^{-5}.

3.8.8 Filtering the A and B Inputs

An averaging algorithm within the instrument is available which averages up to ten readings. This reading mode eliminates noise within the cryogenic system analogous to averaging within a digital voltmeter. This function can be examined and selected or deselected by the FILTER key and the ▲▲ key and ▼▼ key.

When the FILTER key is pressed, the words On (filter on) and OFF (filter off) are presented in the Upper and Lower Displays. To toggle the filter of the input of the Sensor shown in the upper display hold down the FILTER key and press the ▲▲ key. Similarly holding the FILTER key and pressing the ▼▼ key toggles the filter of the input of the Sensor shown in the Lower Display from On to OFF.

In operation, an indicator will appear in the upper left hand corner of the sign digit in the Upper and/or Lower Displays to flag "Filter-on" for that input.

If the averaging algorithm is used, displayed temperature is the average of between 1 and ten readings depending on the temperature variation. If an abrupt change in temperature is observed, averaging is disabled and the last calculated reading is displayed. As the disturbance is reduced in value, the averaging gradually increases until a total of ten readings are considered.

3.8.9 Math Functions

The DRC-93C has three built-in Math Functions to retain the maximum and minimum temperatures as well as the maximum deviation from the setpoint for the Sensor in the Upper Display and the Sensor in the Lower Display.

The three keys MAX, MIN, and MAXDEV on the keypad (digits 9, 6, and 3 respectively) allow the user to observe the MAXimum and MINimum temperature, and MAXimum DEViation from the Setpoint. When one of these keys is depressed, the Upper and Lower Displays will contain the selected Math Function.

These Math Functions are enabled using the MATH key (decimal point on the keypad) and the ▲▲ key or ▼▼ key. In combination with the MATH key, the CLEAR key restarts the process.

When the MATH key is depressed, the Upper display shows "OFF" or "On". When "OFF" is displayed, the Math Functions are inhibited. When "On" is displayed, the Math Functions are enabled. To change from "OFF" to "On" and vice versa, hold the MATH key down and hit the ▲▲ key or ▼▼ key to toggle between "On" and "OFF". When the MATH key is released, operation returns to normal.
If the "On" was left in the Upper Display when the MATH key was released, then the instrument will begin calculating the Math Functions.

If "OFF" was left in the Upper Display when the MATH key was released, then the instrument freezes the contents of the Math Functions. The MAX, MIN, and MAXDEV keys can be used to observe the last readings of the Math Functions.

If it is desired to restart the calculation of the Math Functions, the MATH key is held down and the CLEAR key hit, the Lower Display will show the word "CLEAr" to indicate that the registers holding the Maximum, Minimum and Maximum Deviation have been zeroed. If the Math Functions were enabled ("On") then new Math Functions will be computed. Once the Math Functions have been cleared and enabled ("On"), changing the Sample or Control units will result in inconsistant values being stored in the Math Function registers. The new Math Functions can be observed at any time by depressing and holding in the appropriate key (MAX, MIN, or MAXDEV).

3.9 SENSOR CURVE SELECTION

3.9.1 Standard and Precision Option Curves

The standard curves are given in Table 3-2. The Precision Option Curves are given in Table 3-3.

Table 3-2. Standard Curve Information

Curve No.	Temperature Range(K)	Description
00	1 - 324.9	DRC-D
01	1 - 324.9	DRC-E1
02	1 - 324.9	CRV 10
03	14 - 799.9	DIN-PT
04	1 - 474.9	CRV 10
05		RESVRD

3.9.1.1 The Precision Option

For Lake Shore stored Precision Option, a proprietary algorithm is used to fit the calibration data to within a few millikelvin over the entire temperature range.

The Precision Option Table shown in Table 3-3 gives the standard curves as well as any Precision Options which are factory installed including their address and the number of data points associated with each curve. This Table should be updated for the instrument if additional curves are added at a later time.

Up to 25 Precision Option Curves can be stored in the DRC-93C with an average of 31 lines per curve. A Precision Option Curve can have up to 97 points with two additional end points automatically put into the curve table by the DRC-93C software.

3.9.1.2 Display of Accessed Curve Number

To determine which curve is being used press and hold the CURVE# key. The displays will show the letters "CU" for Curve Number followed by a curve number in each display.

Table 3-3. Sensor Curve Table Information - Precision Option Table

Curve	#Lines	Address	Description
00	31	1D40	DRC-D
01	31	1DF0	DRC-E1
02	31	1EA0	CRV 10
03	31	1F50	DIN-PT
04	31	2000	CRV 10
05	31	20B0	RESVRD
06			
07			
08			
09			
10			
11			
12			
13			
14			
15			
16			
17			
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21			
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27			
28			
29			
30			
31			

For Example, by holding down the CURVE# key the Displays might look as follows:

SENSOR	DISPLAY	
Upper Display	A	CU-02
Lower Display	b	CU-06

The CU-02 in the Upper Display indicates that the Sensor using the Upper Display is calculating the temperature with the data of Curve #02. Curve #02 from Table 3-2 is the CRV 10 for the DT-470 Series Sensors. The CU-06 in the Lower display indicates that the Precision Option is installed and the DRC-93C is calculating the temperature with the data stored in Curve #6.

Since the DRC-93C knows which type of input card is present for each input (assuming that two input cards were installed), it will not, for example, allow the selection of the platinum curve (Curve #03) for a diode input card. If Curve #03 is selected, the DRC-93C will default to the lowest curve number with the correct temperature coefficient, in this case, curve #00. For the case of a platinum input card and no Precision Option curves present, the DRC-93C will select Curve #03, regardless of the curve selected using the CURVE# key.

3.9.1.3 Addition of 8229 Scanner Option

Adding the 8229 Scanner to Input A adds four more Inputs 1, 2, 3, and 4. Each of these inputs has its own curve assigned using the CURVE# key.

3.9.1.4 Changing the Curve used by a Sensor (No External Scanners)

With the CURVE# key held in, pressing the ▴▴ (up) key allow the user to change the curve # used by the Upper Display Sensor. When the CURVE# key is let up, the instrument will return to normal operation with the new curve being selected for calculation by the Sensor associated with the Upper Display. Similarly, the CURVE# key and the ▾▾ (down) key change the curve # for the sensor associated with the Lower Display.

3.9.2 External Scanner Model 8085

Up to three 8085 Scanners can be daisy-chained together to give 30 remote positions for either the A input or the B input of the DRC-93C.

In order for the instrument to select the correct curve for the sensors connected to an 8084 or 8085 Scanner it is necessary for the user to make a connection between the REMOTE POSITION DATA Connector of the Scanner to the DRC-93C REMOTE SENSOR ID Connector. In this way the DRC-93C will have the data regarding which position the scanner is in and thus which external sensor is being examined. The data on the REMOTE SENSOR ID Connector will be called the REMOTE POSITION DATA.

The user must provide the DRC-93C the information which relates the REMOTE POSITION DATA to the Curve Number. This information is stored within the DRC-93C in its Correlation Table (See Table 3-4).

In addition, the user must enable the DRC-93C to use the REMOTE POSITION DATA. This is done by using the CURVE#, REM, ▴▴, and ▾▾ keys as described in the next section.

3.9.2.1 Selection of the REMOTE POSITION DATA

To allow the REMOTE POSITION DATA to determine the curve selection, the user does the following:

1. Press the CURVE# key and hold it down. The Curve # associated with the Upper and Lower Displays will be given and the GAIN, RATE, and RESET blanked.

2. While holding in the CURVE# key, press the REM (REMote) key. Release the CURVE# key.

3. Now press the ▲▲ (Up) key to toggle the Upper Display External curve selection. The REMOTE POSITION DATA will appear in the GAIN windows to indicate that the REMOTE POSITION DATA will be used for curve selection by the Upper Display Sensor. Hitting the ▲▲ key again will blank the GAIN window indicating that the REMOTE POSITION DATA will not be used. The operation is the same for the ▼▼ key except that the Lower Display Sensor and RESET window are involved.

4. When the desired condition is reached, release all keys.

3.9.2.2 The Correlation Table

The CURVE# key will show that the External Scanner has been selected by indicating the REMOTE POSITION DATA in the GAIN window for the Upper and in the RESET window for the Lower Display. The instrument uses the REMOTE POSITION DATA (the signal applied to the REMOTE SENSOR ID Connector from the Scanner) in conjunction with the Correlation Table of Table 3-4 to obtain the Curve Number.

If the REMOTE POSITION DATA is zero, then instrument uses the same Curve Number assigned to the input without the Scanner. When there is an 8229 Scanner Option present, there are 5 Curve Number assignments for Input A---one each for A0, A1, A2, A3, and A4.

If the REMOTE POSITION DATA is non-zero, then the Curve Number is selected from the row of the Correlation Table corresponding to the value of the REMOTE POSITION DATA. When there is an 8229 Scanner Option present, there is only one Curve Number assignment for Input A---A0, A1, A2, A3, and A4 all use the Curve Number from the A column of the correlation table.

3.9.2.3 Modifying the Correlation Table from the Front Panel

The DRC-93C is shipped from the factory with curve 02 stored in all positions of the Correlation Table.

The Correlation Table is modified by using the CURVE# and ▲▲ key and ▼▼ key as follows.

1. Use the procedure described in the previous section to put the instrument in the External Scanner mode.

2. Apply a signal on the REMOTE SENSOR ID Connector to indicate a position number, the REMOTE POSITION DATA. This can be done by attaching a Scanner and selecting a position.

3. Select the Curve Number desired for that position from the front panel as described in section 3.9.1.4. The GAIN or RESET window must have the REMOTE POSITION DATA to show that the function is enabled.

4. When the ENTER key is pressed, the Curve Number will be stored in the Correlation Table in the Position indicated by the REMOTE POSITION DATA in the GAIN window if the Curve in the Upper Display was altered or in the RESET window if the Curve# in the Lower Display was altered.

Table 3-4. Correlation Table for Curve # from REMOTE POSITION DATA

REMOTE POSITION DATA	Curve# for Input A		Curve# for Input B	
01	A01	_______	B01	_______
02	A02	_______	B02	_______
03	A03	_______	B03	_______
04	A04	_______	B04	_______
05	A05	_______	B05	_______
06	A06	_______	B06	_______
07	A07	_______	B07	_______
08	A08	_______	B08	_______
09	A09	_______	B09	_______
10	A0A	_______	B0A	_______
11	A0B	_______	B0B	_______
12	A0C	_______	B0C	_______
13	A0D	_______	B0D	_______
14	A0E	_______	B0E	_______
15	A0F	_______	B0F	_______
16	A10	_______	B10	_______
17	A11	_______	B11	_______
18	A12	_______	B12	_______
19	A13	_______	B13	_______
20	A14	_______	B14	_______
21	A15	_______	B15	_______
22	A16	_______	B16	_______
23	A17	_______	B17	_______
24	A18	_______	B18	_______
25	A19	_______	B19	_______
26	A1A	_______	B1A	_______
27	A1B	_______	B1B	_______
28	A1C	_______	B1C	_______
29	A1D	_______	B1D	_______
30	A1E	_______	B1E	_______
31	A1F	ERR09	B1F	ERR09

3.9.3 Programming Curves from the Front Panel

This section describes how the user can enter his own sensor calibration via the front panel. Section IV covers entry over the IEEE-488 or RS-232C interfaces. The curve is stored in a battery back-up non-volatile RAM (NOVRAM) which can be read and written an unlimited number of times. The number of data points stored per curve can be between 2 and 99; two being the lower limit which defines a straight line.

3.9.3.1 Accessing Stored Curve Data

In order to access stored curve data hit the PROG (Programming) key. The PROG indicator will turn on and flash. Next hit the CURVE# key. The PROG indicator will stop flashing and turn on. The Upper and Lower Displays will blank and the Setpoint Display will contain 00-00 with the second zero from the left flashing. The Upper Display UNITS will show K for kelvin and the Lower Display UNITS V for volts.

NOTE: At any time, if it is desired to exit from the Curve Programming routine hit the PROG key. Operation will return to normal. The CLEAR key is used to clear a number partially entered but not desired.

IF A KEY IS NOT HIT FOR A PERIOD OF 20 SECONDS, THE INSTRUMENT WILL ABORT THE CURVE PROGRAMMING ROUTINE AND RETURN TO NORMAL OPERATION.

The flashing quantity in the Setpoint Display is the Curve # to be examined. The other quantity is used to hold the number of points in the Curve Data of the selected Curve.

Using the keypad (0-9) type in the Curve# to be examined followed by the ENTER key. The CLEAR key may be used if there is an error in typing the curve #. Also the keypad can be used until the correct Curve # is displayed. For example if 30 shows in the display and the 2 key is hit, the 3 of the 30 will disappear and the 2 show up in the units digit to give 02. Hitting the ENTER key will cause the instrument to accept the entry and to search for Curve #02. Since Curve #02 is present (it is a Standard Curve--see Table 3-2), the instrument will find the curve and then show

0.0
02-31
6.5536

in the displays. The 02 in the Setpoint Display is the Curve# and the 31 indicates that there are 31 lines (or points) in the curve data. Points are numbered from 1 to the total number of points---here 31.

The 0.0 in the Upper Display is the temperature in kelvin for point #31 and the 6.5536 the sensor voltage of point #31 (at 0.0 K).

NOTE: A Standard Curve cannot be edited, but the standard curve data can be examined.

To examine Point#12 first hit the POINT# key. The Point# in the Setpoint Display will begin to flash. Enter 12 using the keypad followed by the ENTER key. The displays will read

115.0
02-12
0.9445

to indicate that Point# 12 of Curve#02 is 0.9445 volt at 115.0 K.

At any time that the POINT# key is appropriate, the ▲ key and ▼ key can be used to examine the next higher numbered point and lower numbered point respectively. If the ▲ key was pressed after point# 12 was displayed in the example given above, the display would change to

95.0
02-13
0.9857

The ▲ key and ▼ key do not operate when the instrument is requesting a Curve#, temperature, or voltage.

To exit the Curve Programming routine hit the PROG key.

3.9.3.2 Entering New Curves

The user should know what Curve# is available for new data by keeping accurate records and updating Table 3-3 as curves are added. If an error is made in record keeping, the instrument will catch it since 00 number of points indicates an available set of data storage.

It is suggested that the curve data be put in ascending Raw Units order prior to the curve entry session. The data must be in ascending units order. The temperature will follow the temperature coefficient of the curve being entered. The temperature will be in decreasing order for a negative temperature coefficient curve and increasing for a positive temperature coefficient curve.

Let us say that we wish to enter a new set of curve data into an available slot at Curve#21. From normal operation, the user presses the PROG key followed by the CURVE# key to enter the Curve Programming routine. Pressing the 2, 1 and ENTER keys tell the instrument to find Curve#21 and will indicate that it is available by showing 00 number of points. The displays will read as follows:

21-00

The dashes indicate there is no data present for curve number 21. No entries will flash. At this time, one of four keys can be selected; PROG, CURVE#, or POINT#.

The PROG key will abort the curve programming and return the instrument to normal operation.

Pressing the CURVE# key will cause the Curve# portion of the Setpoint Display to flash allowing the user to select another curve.

Pressing the POINT# key will cause the point # entry in the Setpoint Display to begin flashing and the Upper and Lower displays to be cleared. The keypad (0-9) is used to enter a point# to be inserted. Type 01 and press the ENTER key. Now the Upper and Lower displays will go to 0.0 and the Upper display will begin flashing. Use the keypad to enter the temperature of the point in kelvin. The decimal point can be used, but the resolution will be limited to ---.- . If the entry is begun but not as desired, the CLEAR key can be used to clear the display to restart.

The first and last points entered are determined by the temperature coefficient of the curve being entered. For a negative temperature coefficient (N) curve the first data point (#01) is 499.9K and 0.0000 volts. For a positive temperature coefficient (P) curve the first data point is 0.0K and 0.0000 volts.

The quantity is accepted for the temperature when the ENTER key is pressed.

NOTE: You cannot use the ▲ key or ▼ key when entering curve data. Only the keypad (0-9,and .) and the CLEAR key are active.

After the temperature is entered, the Lower Display will begin to flash. The keypad is used to enter the Raw Units Data for the point as described in Table 4-14. The entry is accepted when the ENTER key is pressed.

Another point can be added by pressing the POINT# key. After the curve has been entered, the last data point to enter is 0.0K and 6.5536 volts for N type and 999.9K and 6.5536 volts for P type curves.

NOTE: Failure to enter the correct curve end points will result in unpredictable results.

Pressing the PROG key will return operation to normal with the curve being entered into the memory of the instrument and available through an assignment as described in section 3.9.1.

3.9.3.3 Editing Existing Curve Data

Curve data can be modified using the same procedure described in the previous section. The difference is that the temperature and voltage (raw data) will be shown in the Upper and Lower displays respectively after the POINT# has been selected. If it is not desired to edit the point, then simply enter another point# using the POINT# key or press the PROG key to return to normal operation.

Following the editing of a data point, the unit compares the temperature and voltage entered against the existing curve to see if either match and existing point. The point is matched first in temperature, then voltage. If a match occurs, the point is edited to reflect the change. If no match occurs, the unit inserts the new point into the curve in the correct increasing Raw Units order.

3.9.3.4 Summary of Curve Programming from the Front Panel

1. The Curve Programming routine is entered by pressing the PROG key followed by the CURVE# key. The PROG light will remain on while in the routine and turnoff when operation returns to normal.

2. The displays have the following format during curve programming.

Upper Display:	Temperature in K
Setpoint Display:	Curve# - Point#
Lower Display:	Raw Units Data

3. The Upper and Lower SENSOR windows are blank. The Upper UNITS show "K" and the Lower UNITS "V" to indicate Raw Units Data (see Table 4-19).

4. When no digits are flashing, the Curve# is accessed using the CURVE# key and the POINT# by the POINT# key.

5. The keypad (0-9) is used to enter a quantity after it begins to flash. The decimal point can be used with Temperature or Raw Units Data but not with Curve# or Point#.

6. The PROG key always returns operation to normal operation.

7. The CLEAR key clears the display if pressed after an entry is begun.

8. The instrument will return to normal operation if no key is pressed for 20 seconds.

3.10 SETPOINT and CONTROL BLOCK

Parameters entered using a blue key with a black legend (SETPOINT, GAIN, RATE, RESET, and MANUAL HEATER) require the use of the ENTER key. When one of these keys is pressed and released, the least significant digit or digits will flash to indicate that the parameter can be entered. The quantity can be entered in three ways.

NOTE: IN ALL CASES, pressing the CLEAR key will result in the old value being inserted and the operation completed. Pressing the ENTER key enters the quantity in the appropriate display into the DRC-93C.

1. Enter the digits via the keyboard. The ↑-↓ minus sign can be used with the Setpoint and must preced the digits. The decimal point can be entered as desired. The operation is completed with the ENTER key or cancelled with the CLEAR key.

2. Increment the quantity using the ▲▲ key or decrement the quantity with the ▼▼ key. The operation is completed with the ENTER key or cancelled with the CLEAR key.

3. The quantity can be incremented or decremented by any amount as follows. Enter the digits of the increment or decrement desired via the keyboard. The decimal point can be entered as desired. Pressing the ▲▲ key will add the quantity and the ▼▼ key will subtract the quantity. The operation is completed with the ENTER key or cancelled with the CLEAR key.

Methods 2 and 3 can be used together in any combination. This same procedure is also used to enter the dwell except that the minus sign and decimal point are not permitted. (See section 3.8.5).

3.10.1 SETPOINT

To change the Setpoint, press the SETPOINT key an then use methods 1, 2, and/or 3 described above.

If in degrees celsius or degrees fahrenheit, the (-) key can be used to change the sign of the setpoint.

3.10.2 GAIN

Variable gain (proportional) allows adjustment of overall controller gain over a range from 0.1 to 99.

To change the Gain, press the GAIN key and use methods 1, 2, and/or 3 described above.

3.10.3 RATE

Adjusts rate time constant of differentiator. Effectively sets time constant between 1 and 990 seconds.

These are displayed as 0.1 to 99 which means that the displayed number is multiplied by ten to get the rate in seconds. For a discussion of beats per second and time constants, see the Application Note enclosed as an Appendix to this manual.

To change the Rate, press the RATE key and use methods 1, 2, and/or 3 described above.

3.10.4 RESET

Adjusts reset (integral) time constant of integrator. Effectively sets time constant between 1 second and 990 seconds. These are displayed as 0.1 to 99.

To change the RESET, press the RESET key and use methods 1, 2, and/or 3 described above.

3.10.5 MANUAL HEATER POWER

The DRC-93C provides a feature in which the heater power can be set manually. The Manual Heater Power value is indicated on the Bar Graph by a blinking segment at the percent at which it is set.

To change the Manual Heater Power, press the MANUAL HEATER key and use methods 1, 2, and/or 3 described above. If the decimal number 5 is entered, the Bar Graph will blink the segment at 5%. If a zero is entered immediately after the 5 (thus entering 50) the Bar Graph will blink the segment at 50%. The CLEAR key cancels anything entered and returns the instrument to normal operation. The ENTER key inserts the new Manual Heater Power and then returns to normal operation.

3.11 HEATER POWER

3.11.1 HEATER %.

The Bar Graph displays the magnitude of the heater power in percent of full scale. Full scale is defined as the product of the maximum heater current of one ampere squared times the heater resistance times the range setting. The DRC-93C Temperature Controller is shipped from the factory with the Bar Graph indicating power. If the user prefers, he can change this to a current reading by turning on switch 1 of the eight station dip switch located at the rear center of the main board.

3.11.2 The HEATER POWER RANGE

The heater power range setting is determined by the keys directly below the HEATER POWER Bar Graph. MAX corresponds to a 10^0 or 1 multiplier, while -1, -2, -3 and -4 corresponds to a 10^{-1}, 10^{-2}, 10^{-3} and 10^{-4} multiplier respectively. The OFF key turns off the output power independent of the setpoint and the control parameters.

NOTE: The DRC-93C is equipped with a current limit vernier on the rear panel which can limit the output current on the MAX scale between 0.33 and 1 ampere, dependent on setting. If the instrument will not deliver full power, this vernier may be set wrong or the load resistance may be too large and the unit is compliance voltage limited.

NOTE: If a SETPOINT, GAIN, RATE, RESET, MANUAL HEATER POWER or HEATER POWER RANGE is entered too quickly, the unit may not update the parameter properly. The instrument Display and Main Boards verify entered parameters each update cycle. Changing a parameter more than once in an update cycle may result in inconsistant parameters being entered.

Figure 3-2. DRC-93C Temperature Controller Rear Panel

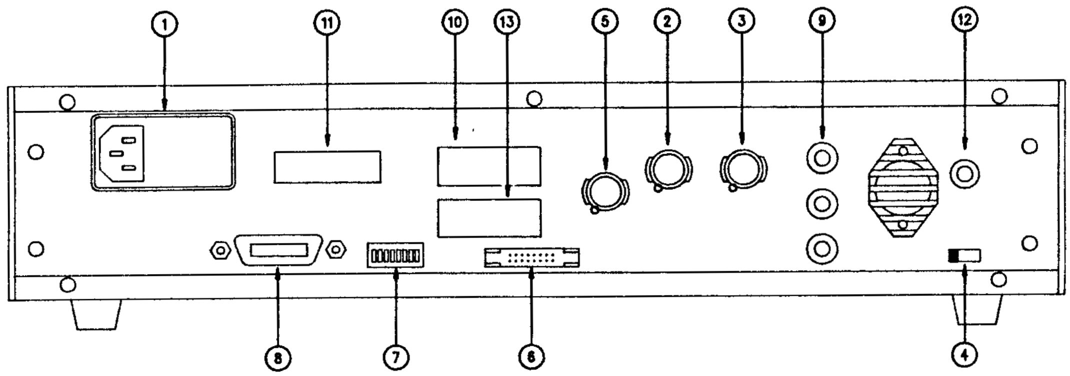


Figure 3-2. Model DRC-93C Temperature Controller Rear Panel Description

1. Line cord receptacle with fuse and voltage selection
2. Sensor INPUT A connector (J1)
3. Sensor INPUT B connector (J2)
4. HEATER RESISTANCE selector switch
5. Monitors output of Sensor INPUT A and Sensor INPUT B buffered voltages and 8225 linear analog output option (J3)
6. REMOTE SENSOR ID (J5) - Connects to POSITION DATA of Models 8084 or 8085 Scanner (optional)
7. IEEE-488 address switch
8. IEEE-488 connector (J4)
9. Heater Power output terminals (J6, J7, J8)
10. Optional interface access plate (J9) (8229 Scanner Option)
11. Optional interface access plate (J10) (8223 RS-232C Option)
12. MAX HEATER POWER Limit
13. Optional connector access plate (J11)

3.12 LOCAL/REMOTE BLOCK

3.12.1 LOCAL.

The LOCAL key is used to return the instrument from remote control by the IEEE-488 BUS or the RS-232C optional interface to front-panel control.

3.12.2 REMOTE

The REMOTE key is used to place the controller under remote control and to disable the front panel. When the REMOTE key is pressed for more than one second, the display shows the IEEE-488 address of the instrument.

REAR PANEL DESCRIPTION

3.13 REMOTE SENSOR ID

The REMOTE SENSOR ID connector is connected to the REMOTE POSITION DATA output of a Model 8084 or Model 8085 Sensor Scanner or a Model SW-10A ten-position switch. This input is called the REMOTE POSITION DATA and allows the user to automatically call up different curves for different sensor/channel positions when the instrument is used with either remote switch (see Section 3.9.2). The Parallel input data format is given in Table 3-5. The user may supply to the REMOTE SENSOR ID his own parallel BCD 5 volt signal referred to the DIGITAL GROUND on pin 12.

3.14 HEATER CURRENT LIMIT

The DRC-93C Temperature Controller has a current drive output with a maximum current rating of one ampere unless the optional 1.5 ampere output (W60) was ordered, or the current-limiting vernier has been set at a lower value.

With the current-limiting vernier on the back of the instrument, the output current on the MAX scale can be limited anywhere between 1 ampere and the maximum current for the 10^{-1} scale (330 mA). This allows the user to limit the maximum power to between 50 watts and 5 watts, dependent on his requirements.

Table 3-5. Pin Assignments for the J5 REMOTE SENSOR ID Connector

J5 CONNECTOR Pin Assignments

15	13	11	9	7	5	3	**1**
16	**14**	**12**	**10**	**8**	**6**	**4**	**2**

ONLY BOLD PINS USED

J5	Function
1	+5
2	RESERVED
4	Bit 3
6	Bit 2
8	Bit 1
10	Bit 0 (LSB)
12	DIGITAL GROUND
14	Bit 4 (MSB)
16	RESERVED

SECTION IV

REMOTE OPERATION

4-1. IEEE-488 INTERFACE

The IEEE-488 INTERFACE is an instrumentation bus with hardware and programming standards designed to simplify instrument interfacing. The IEEE-488 INTERFACE of the DRC-93C fully complies with the IEEE-488-1978 standard and incorporates the functional, electrical and mechanical specifications of the standard. It also follows the supplement to that standard titled "Code and Format Conventions for use with IEEE Standard 488-1978". This section contains general bus information, Model DRC-93C interface capabilities, addressing and the programming instructions that control the DRC-93C functions.

4.2 GENERAL IEEE SPECIFICATIONS AND OPERATION

The following discussion covers the general operation of the IEEE-488 interface. For a more detailed description of signal level and interaction, refer to the IEEE Standard 488-1978 publication "IEEE Standard Digital Interface for Programmable Instrumentation".

All instruments on the interface bus must be able to perform one or more of the interface functions of TALKER, LISTENER, or BUS CONTROLLER. A TALKER transmits data onto the bus to other devices. A LISTENER receives data from other devices through the bus. The BUS CONTROLLER designates to the devices on the bus which function to perform.

The DRC-93C performs the functions of TALKER and LISTENER but cannot be a BUS CONTROLLER. The BUS CONTROLLER is your Digital Computer which tells the DRC-93C which functions to perform.

The interface works on a party line basis with all devices on the bus connected in parallel. All the active circuitry of the bus is contained within the individual devices with the cable connecting all the devices in parallel to allow the transfer of data between all devices on the bus.

The following discussion of the signal lines on the bus are for general information. Your digital computer handles these lines through its circuitry and software. The user need never concern himself with these lines or signals, however, knowledge of their purpose will help one to understand the operation of the Interface.

There are 16 signal lines contained on the bus:

1. 8 Data Lines
2. 3 Transfer Control Lines
3. 5 General Interface Management Lines

The data lines consist of 8 signal lines that carry data in a bit parallel, byte serial format. These lines carry universal commands, addresses, program data, measurement data and status to all the devices on the bus.

The three Transfer Control lines and the five Interface Management lines are asserted low which means that they carry out their function when pulled low. When the voltage on one of these lines is high then the line is not asserted and the function is inhibited. The General Interface Management Lines IFC (Interface Clear), ATN (Attention), REN (Remote Enable), EOI (End or Identify) and the SRQ (Service request) manage the bus and control the orderly flow of commands on the bus. The IFC, ATN, and REN management lines are issued only by the BUS CONTROLLER.

The IFC (Interface Clear) management line is pulled low by the BUS CONTROLLER to clear the interface.

The ATN (Attention) line is the management line used by the BUS CONTROLLER to get the attention of the devices on the bus. The BUS CONTROLLER does this by pulling the ATN line low and sending talk or listen addresses on the DATA lines. When the ATN line is low, all devices listen to the DATA lines. When the ATN line goes high, then the devices addressed to send or receive data (for example, the DRC-93C) perform their functions while all others ignore the DATA lines.

The REN (Remote Enable) management line is pulled low by the BUS CONTROLLER to enable a device (the DRC-93C) to perform the functions of TALKER or LISTENER.

The EOI (End or Identify) management line is pulled low by the BUS CONTROLLER or a TALKER (the DRC-93C) to indicate the end of a multiple byte transfer sequence. Also the EOI line along with the ATN line are pulled low by the BUS CONTROLLER to execute a polling sequence.

The SRQ (Service Request) management line is pulled low by a device (for example, the DRC-93C) to signal the BUS CONTROLLER that a process is completed, a limit, overload or error encountered. In some cases this means that service is required.

Transfer of the information on the data lines is accomplished through the use of the three signal lines: DAV (Data Valid), NRFD (Not Ready for Data) and NDAC (Not Data Accepted). Signals on these lines operate in an interlocking hand-shake mode. The two signal lines, NRFD and NDAC, are each connected in a logical AND to all devices connected to the bus.

The DAV line is pulled low by the TALKER after it places its data on the DATA lines. This tells the LISTENERS that information on the DATA lines is valid. A LISTENER holds the NRFD line low to indicate it is not ready. Since these lines are connected in a logical AND to all other devices, then the NRFD line will not go high until all of the devices are ready.

The NDAC line is pulled low by a LISTENER while it is receiving the DATA and lets it go high when the DATA is captured. Since the NDAC lines of all devices are connected in a logical AND, the NDAC line will not go high until all devices have received the DATA.

4.3 INTERFACE CAPABILITIES

The IEEE-488 Interface capabilities of the Model DRC-93C are listed in Table 4-1 as well as in mnemonic format on the instrument's rear panel.

Table 4-1. Interface Functions.

Mnemonic	Interface Function Name
SH1	Source Handshake Capability
AH1	Acceptor Handshake Capability
T5	Basic TALKER, serial poll capability, Talk only,Unaddressed to Talk if addressed to Listen
L4	Basic LISTENER, Unaddressed to Listen if addressed to Talk
SR1	Service Request capability
RL1	Complete Remote/Local capablty
PP0	No Parallel Poll capability
DC1	Full Device Clear capability
DT0	No Device Trigger capability
C0	No System Controller capablty
E1	Open Collector Electronics

4.4 DRC-93C IEEE-488 ADDRESS SWITCH

The IEEE-488 Address Switch is located on the instrument's rear panel (see Figure 3-2, Key No. 7). Refer to Figure 4-1 for the following discussion.

4.4.1 Terminating Characters (delimiters)

Switch 1 (*) is used to define the instrument's terminating characters (delimiters). The OPEN (0) position selects the ASCII characters CR and LF (Carriage Return and Line Feed) as the terminating characters for input and output data. For the output data from the DRC-93C back to the computer over the Bus, the EOI line is set by the DRC-93C with the output of the Line Feed (LF). This setting (0) for switch 1 is the setting for all Hewlett-Packard computers.

When Switch 1 (*) is CLOSED (1), a variable terminating character format may be selected for the input and output data. In this configuration the power-up (default) terminating characters are LF and CR with the EOI line being set with the output of the Carriage Return (CR). However, the two terminating characters can be changed via input data to the DRC-93C as detailed in Table 4-6. If the terminating characters are changed by the user, these are only in effect until the instrument is turned off.

4.4.2 TALKER and/or LISTENER Configuration

Since the DRC-93C is both a TALKER and a LISTENER, normally switches two and three should both be OPEN (0). These switches are usually of use when one instrument is a TALKER and another instrument is a LISTENER and they are to share the same address.

Figure 4-1. IEEE-488 Address Switch for the DRC-93C

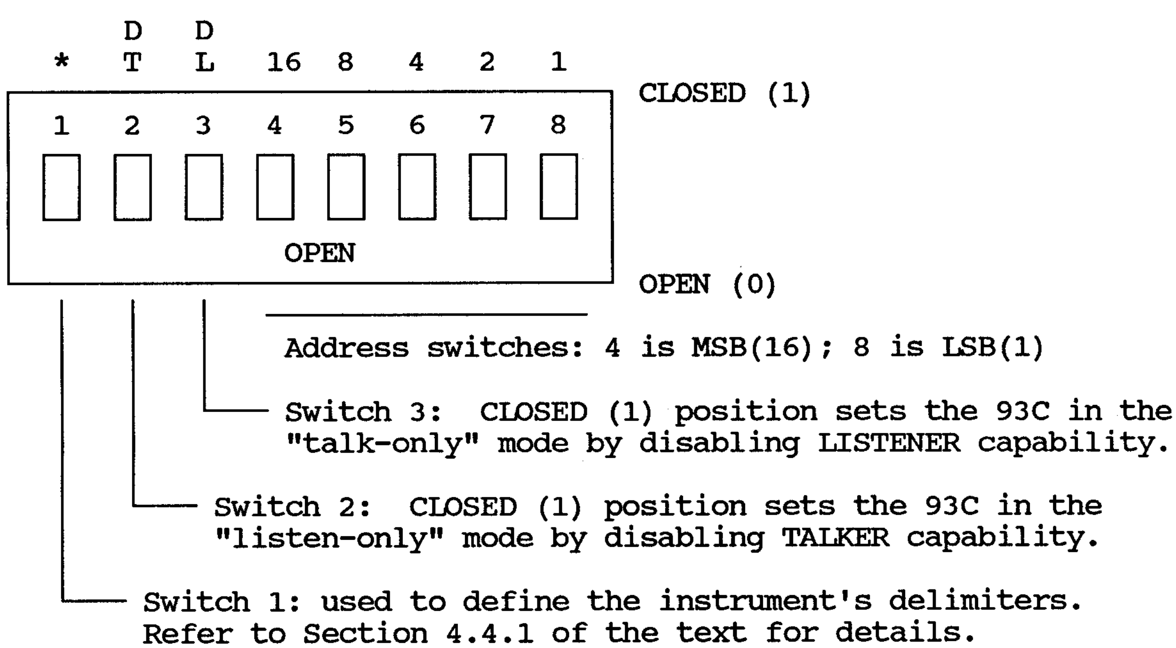


Table 4-2. Allowable Address Codes for the DRC-93C (Factory preset address is decimal 12)

ASCII Code Character		Bit 2*	Bit 3	Address Switches 4	5	6	7	8	5-bit Decimal Code
Listen	Talk	B7	B6	B5	B4	B3	B2	B1	
SP	@	0	0	0	0	0	0	0	00
!	A	0	0	0	0	0	0	1	01
"	B	0	0	0	0	0	1	0	02
#	C	0	0	0	0	0	1	1	03
$	D	0	0	0	0	1	0	0	04
%	E	0	0	0	0	1	0	1	05
&	F	0	0	0	0	1	1	0	06
'	G	0	0	0	0	1	1	1	07
(	H	0	0	0	1	0	0	0	08
)	I	0	0	0	1	0	0	1	09
*	J	0	0	0	1	0	1	0	10
+	K	0	0	0	1	0	1	1	11
,	L	0	0	0	1	1	0	0	12
-	M	0	0	0	1	1	0	1	13
.	N	0	0	0	1	1	1	0	14
/	O	0	0	0	1	1	1	1	15
0	P	0	0	1	0	0	0	0	16
1	Q	0	0	1	0	0	0	1	17
2	R	0	0	1	0	0	1	0	18
3	S	0	0	1	0	0	1	1	19
4	T	0	0	1	0	1	0	0	20
5	U	0	0	1	0	1	0	1	21
6	V	0	0	1	0	1	1	0	22
7	W	0	0	1	0	1	1	1	23
8	X	0	0	1	1	0	0	0	24
9	Y	0	0	1	1	0	0	1	25
:	Z	0	0	1	1	0	1	0	26
;	[	0	0	1	1	0	1	1	27
<	\	0	0	1	1	1	0	0	28
=	]	0	0	1	1	1	0	1	29
>	~	0	0	1	1	1	1	0	30

Factory preset address

* Only the first five bits of the binary code are listed. These bits are the same for the TALK and LISTEN address. The sixth and seventh bits (BUS CONTROLLER originated) determine whether the instrument is being addressed to TALK or LISTEN.

Function	Bit 2	Bit 3
TALK	1	0
LISTEN	0	1

4.4.3 The IEEE-488 INTERFACE bus address for the DRC-93C is set by switches 4 through 8 which are reserved for the address selection. Switch 4 is the most significant bit (MSB[=16]) and 8 is the least significant bit (LSB[=1]).

The factory preset address of this instrument is 12 (see Table 4-2). Address switch numbers 5 and 6 should be CLOSED (1) which will result in the Address Switch having a setting of 00001100 or 10001100 dependent on the requirements for the delimiters.

4.5 IEEE-488 BUS COMMANDS

4.5.1 The Uniline Command

A Uniline Command (Message) is a command which results in a single signal line being asserted. The DRC-93C recognizes two of these messages from the BUS CONTROLLER, REN and IFC (See Table 4-3). When the BUS CONTROLLER executes the appropriate software code the effect is to pull the corresponding Interface Management line low. For example, when the software command REMOTE712 is executed by the HP86 digital computer, the management line REN is pulled low and the listen address 12 issued to signal the instrument having address 12 (DRC-93C) to go into the remote mode.

The SRQ is a uniline command asserted by the DRC-93C when it wishes to signal the BUS CONTROLLER. The BUS CONTROLLER will in turn use the Addressed command SPE (Serial Poll Enable) described below to interrogate the DRC-93C about the reason or reasons for the communication.

4.5.2 The Universal Commands

The Universal Commands shown in Table 4-3 are those multiline commands that address all devices on the bus. A multiline command involves a group of signal lines. All devices equipped to implement such commands will do so simultaneously when the command is transmitted. As with all multiline commands, these commands are transmitted with ATN line asserted (low). There are two Universal commands recognized by the DRC-93C, Local Lockout and Device Clear.

LLO (Local LOckout) - LLO is sent to instruments to lock out (prevent the use of) their front panel controls.

DCL (Device CLear) - DCL is used to return the DRC-93C to the power-up conditions.

4.5.3 The Addressed Commands

The Addressed Commands shown in Table 4-3 are multiline commands that must include the DRC-93C listen address before it will respond to the command in question. Note that only the addressed device will respond to these commands. The DRC-93C recognizes three of the Addressed commands; SDC (Selective Device Clear), GTL (Go To Local), and SPE (Serial Poll Enable).

SDC (Selective Device Clear) - The SDC command performs essentially the same function as the DCL command except that only the addressed device responds. Generally, instruments return to their power-up default conditions when responding to the SDC command.

GTL (Go To Local) - The GTL command is used to remove instruments from the remote mode. With some instruments, GTL also unlocks front panel controls if they were previously locked out with the LLO command.

SPE (Serial Poll Enable), SPD (Serial Poll Disable) - Serial polling is used to obtain the SRQ Status Register. The Status Register contains important operational information from the unit requesting service. The SPD command ends the polling sequence.

4.5.4 The Unaddress Commands

The Unaddress Commands in Table 4-3 are used by the BUS CONTROLLER to remove any TALKERS or LISTENERS from the bus. The ATN line is asserted (low) when these commands are asserted.

UNL (Unlisten) - LISTENERS are placed in the listener idle state by the UNL command.

UNT (Untalk) - Previous TALKERS will be placed in the TALKER idle state by the UNT command.

Table 4-3 summarizes the IEEE-488 Bus Commands acknowledged by the DRC-93C.

4.5.5 Device-Dependent Commands

The DRC-93C supports a variety of device-dependent commands to allow the user to program the instrument remotely from a digital computer and to transfer measurements to the computer. These commands are sent from the computer (BUS CONTROLLER) to the DRC-93C as one or more ASCII characters that tell the device to perform a specific function. For example, the command sequence F0K sent by the BUS CONTROLLER to the DRC-93C is used to select kelvin as the set point units. The IEEE-488 bus actually treats these commands as data in that ATN is high when these device-dependent commands are transmitted.

4.5.6 TALKER and LISTENER Status

For the DRC-93C to be a LISTENER, it has to be in REMOTE and can be returned to LOCAL with the M0 (device-dependent) command or GTL (addressed) command as desired. For most, but not all computers, the DRC-93C as a TALKER does not have to be placed in REMOTE operation, but can remain under LOCAL control. This allows the user to collect data while maintaining front panel control. The HP computers will allow this mode of operation. If your computer automatically places the DRC-93C in remote and keeps it in remote after the transmission is over, sending the additional command M0 after the request for data will return the DRC-93C to LOCAL.

Table 4-3. IEEE-488 Bus Commands

Message Mnemonic	HP9825A Command	HP86 Command	IEEE-488 Bus Format
Uniline Commands			
Remote/REN	rem712	REMOTE712	?U*
Interface Clear/IFC			(IFC)
Universal Commands			
Local Lock Out/LLO	llo7	LOCAL LOCKOUT 7	?U(LLO)
Device Clear/DCL	clr7	CLEAR7	?U(DCL)
Addressed Command			
Selected Device Clear/SDC	clr712	CLEAR712	?U,(SDC)
Go to Local/GTL	lcl712	LOCAL712	?U,(GTL)
Serial Poll Enable/SPE	rds(712)→S	S=SPOLL(712)	?U,(SPE)
Unaddress Commands			
Unlisten/UNL			?
Untalk/UNT			-

* U is the controller (computer) Talk Address (Address 21)

4.6 PROGRAMMING INSTRUCTIONS

The following discussion references the DRC-93C at address 12. The allowable address codes are given in Table 4-2. Therefore, its Talk ASCII Code is "L" and its LISTENER ASCII Code is "," (comma). The controller referred to in the following discussion is the BUS CONTROLLER and is normally a digital computer. It should not be confused with the temperature controller on the bus (DRC-93C). Set the IEEE Address of the DRC-93C to 12 by making Switches 5 and 6 CLOSED (1), 4, 7 and 8 (OPEN) (0) and make sure Switch 1 is OPEN (0) to select (CR)(LF) as the terminating characters. Note that this should be done prior to turning on the instrument since the DRC-93C updates the IEEE address on power-up <u>only</u>. Confirm that the address selected is correct by holding in the REMOTE button for longer than one second and observe the IEEE address on the front panel display as follows:

LSCI
93C
Add12

4.6.1 Commands and Requests

The device-dependent commands to program the DRC-93C are given in Table 4-4. The 93C must be addressed as a "LISTENER" to receive any instruction or string of instructions from the Command list.

The DRC-93C input data format does not require a set number or set sequence of Commands to implement proper instrument set-up. These Commands are processed only after the terminators [TERM1][TERM2] are sent across the bus. The listing and explanation of the 93C commands are summarized in Table 4-4. There are commands for Interface Setup, Instrument Setup, Control Setup, Scanner Setup, Status Register and restoring Executable Programs.

The Output Statement Requests are sent by the BUS CONTROLLER to the DRC-93C to tell the 93C what data to output when data output is requested. These requests are listed in Table 4-5 and the data formats are described in detail in the following tables as well as the adjoining text associated with those tables.

4.7 INSTRUMENT SETUP COMMANDS AND REQUESTS

4.7.1 EOI Status - The ZN_1 Command

When EOI (end or identify) is enabled ("Z0"; Table 4-6), the EOI line is set active concurrent with the last byte of a transfer. Use of EOI identifies the last byte allowing for variable length data transmissions. EOI can be disabled ("Z1"; Table 4-6).

4.7.2 Interface Mode - The MN_1 Command

4.7.2.1 Local - This message ["M0"; Table 4-6] clears the remote operation of the DRC-93C and enables front panel operation. Pressing the front panel LOCAL button also sets the instrument to local, provided the button has not been disabled by the Local Lockout Message (see Section 4.7.2.3).

See Section 4.5.6 for a discussion of the DRC-93C under local operation while acting as a TALKER.

4.7.2.2 Remote - The DRC-93C is in the local front panel mode when first turned on. A remote message ["M1"; see Table 4-6] allows the 93C to be controlled over the IEEE-488 interface. In Remote, the front panel controls are disabled (except the LOCAL button) and are then controllable over the IEEE Bus. The instrument's initial set up is determined by the front panel settings at the time when the instrument is placed into Remote. The DRC-93C may also be placed into remote by pressing the REMOTE button on the front panel or addressed to talk by the BUS CONTROLLER.

Table 4-4. DRC-93C Command Summary of Instrument Setup

Summary of Input Command Formats. Choices of the commands are:		
Table		Interface Setup Commands
4-6	ZN_1	Selects EOI status
	MN_1	Selects Remote Interface Mode
	TN_1	Changes terminating Characters
	C	"Clear" Command
Table		Instrument Setup Commands
4-7	$F0C_1$	Select Control Units
	$F1C_1$	Select Sample Units
	$F2CC_1N_1$	Select Control (Setpoint) Sensor
	$F2SC_1N_1$	Select Sample Sensor
	$F3CN_1$	Select the Control (Setpoint) Resolution
	$F3SN_1$	Select the Sample Resolution
	F4CON, F4COFF	Select the control Sensor Deviation ON or OFF
	F4SON, F4SOFF	Select the Sample Deviation ON or OFF
	F5ON, F5OFF and F5CLR	Select the MATH Function ON, OFF or CLeaRed
	$NC_1N_1N_2N_3$	Assign Curve Number for Input Channel selected
Table		Control Setup Commands
4-9	S,etc	Set Point Input
4-10	PN_1N_2,etc.	Proportional (GAIN)
	IN_1N_2,etc.	Integral (RESET)
	DN_1N_2,etc.	Derivative (RATE)
	RN_1	Heater Range
	HN_1N_2	Manual Heater %
Table		Scanner Setup and Selection Commands
4-11	$YAN_1N_2N_3$ or $YB0N_2N_3$	Set the Scanner channel dwell time
	YS	Enable the (S)CAN function.
	YH	Disable, or (H)old, the SCAN.
Table		Status Register Mask Command
4-13	QC_1C_2	Set the Status Register mask
Table		Restoring Executable Programs Command
4-14	$EN_1N_2C_1$-C_{60}	Transmit (Restore) Program Step # N_1N_2 data

4.7.2.3 Local Lockout - This message ["M2"; Table 4-6] disables the DRC-93C's Local Front Panel controls, including the LOCAL button. The message is in effect until the message is cleared over the Bus or power is cycled.

Many IBM PC IEEE-488 cards automatically place addressed instruments into Local Lockout. To be able to place the DRC-93C into Remote without Local Lockout the user may need to reconfigure his IEEE-488 card.

4.7.3 Terminating Characters - The TN_1 Command

Terminating characters ["T0", "T1", "T2" and "T3"; Table 4-6] are used to indicate the end of a record. Record terminators are used when the unit has completed its message transfer. Switch 1 of the IEEE address defines the terminator status. If switch 1 is OPEN (0) the terminator status is defined as "T0" [(CR)(LF)] and terminator status can not be changed over the interface. When switch 1 is CLOSED (1) the terminator status is defined as "T1" [(LF))(CR)] and the status can be changed using the "T0", "T1", "T2" or "T3" commands.

4.7.4 Clear

The (C)lear Message [see Table 4-4] sets the DRC-93C to the turn-on state. This action is similiar to turning the instrument OFF and then turning it back ON, except that it occurs in milliseconds, rather than seconds and the DRC-93C does not go through the power-up display sequence.

Table 4-5. DRC-93C Summary of Output Requests

Table	Request	Output
4-6	W2 WI	Interface Status Input and Option Card Data
4-7	WD	Sample, Control,A and B Input Information
4-9	WP	Set Point Data
4-10	W3	Control Data (Gain, Reset, etc.)
4-11	WY	Scan Data
4-13	WQ	Service Request Data
4-14	WEN_1N_2	Program Step # N_1N_2 Data
4-15	WS WC WO WM	Sample Sensor Data Control Sensor Data Sample & Control Sensors, Setpoint Data MAX, MIN and MAXDEV Data

Table 4-6. DRC-93C Interface Setup Commands and Request Status

Command	Functional Description
ZN_1[a]	Selects IEEE EOI status. Forms of the command are Z0 and Z1. <u>When N_1 is:</u> <u>EOI Status is</u>: 0 EOI line is set/accepted on last character input or output. 1 EOI line is not set on last character output or acknowledged on input.
MN_1	Selects Remote Interface mode. Forms of the command are M0, M1 and M2. <u>When N_1 is:</u> <u>Mode is</u>: 0 Local 1 Remote 2 Remote with Local Lockout
TN_1	Changes terminating characters (when IEEE Address Switch #1 is CLOSED [1]). Forms of the command are T0, T1, T2 and T3. <u>When N_1 is:</u> <u>Terminators are</u>:[b] 0 (CR)(END[c] ^ LF) [also with Switch OPEN] 1 (LF)(END ^ CR) [default, unless changed] 2 (END ^ LF) 3 (END ^ DAB[d])
C	"Clear" command, returns unit to power up state (Restart).

****

Request	Functional Description
W2	Interface Status - ZN_1,MN_2,TN_3 8 Characters plus up to 2 Terminators where: ZN_1 is EOI status MN_2 is Mode status TN_3 is Terminator status
WI	Input and Option Card Data[e] $A-C_1C_2C_3C_4C_5C_6C_7,B-C_8C_9C_{10}C_{11}C_{12}C_{13}C_{14},$ $1-C_{15}C_{16}C_{17}C_{18},2-C_{19}C_{20}C_{21}C_{22},3-C_{23}C_{24}C_{25}C_{26}$ 40 Characters plus up to 2 Terminators where: C_1-C_7 is the A Input Card. C_8-C_{14} is the B Input Card. $C_{15}-C_{18}$ is the Option 1 Present. $C_{19}-C_{22}$ is the Option 2 Present. $C_{23}-C_{26}$ is the Option 3 Present.

a) N_i corresponds to a numeric value (0 - 9)
b) The AND symbol (^) is used to indicate messages sent concurrently.
c) END = EOI; d) DAB = last data byte
e) C_i corresponds to an alphanumeric (0 - F)

4.7.5 The "W2" Data String

For the case of W2, the data string would have the following format:

Z0,M2,T1[TERM1][TERM2]

where the Z0, M2 and T1 are defined in Table 4-6.

4.7.6 The "WI" Data String

This Data String gives the input cards present (9210, 9220, 9215, 9317C or 9318C) in Input A and B, and if the analog option, interface option or scanner is present. A typical data string would be:

A-9220-P2,B-9318C ,1-8225,2-8223, 3-8229

which indicates 9220 card configured as a 100 ohm platinum input for Input A; a germanium/carbon glass input for Input B; a linear analog option in Option Slot 1; a RS-232C option in Option Slot 2 and a Scanner Card option in Option Slot 3.

4.8 SELECTION OF QUANTITIES FOR THE CONTROL AND SAMPLE DISPLAYS-UNITS, SENSORS, RESOLUTIONS, AND DEVIATION (TABLE 4-7)

4.8.1 Units for Control Display and Setpoint - The F0C_1 Command

The F0C_1 command set the temperature or sensor units for the control display and for the setpoint. Sensor units (volts, ohms or nano-farads) are selected automatically by the input card type. Consequently, the command for selecting sensor units for control is F0S. Temperature units are selected with the same command with K, C, or F substituted for S.

Note that only one choice of sensor units (volts, ohms, or nanofarads) is available which is dependent on the input card type selected.

4.8.2 Units for Sample Display-The F1C_1 Command

The sample units may be set independently by the command F1C_1. The commands for selecting sensor units are F1K, F1C, F1F and F1S.

4.8.3 Control Sensor Selection-The F2CC_1N_1 Command

The sensor to be selected for the control display can be changed by the F2CC_1N_1 command. The quantity C_1N_1 is A0, A1, A2, A3, A4, or B0. Examples: F2CA0, F2CB0, F2CA4.

4.8.4 Sample Sensor Selection - The F2SC_1N_1 Command

The sensor to be selected for the sample display can be changed by the F2SC_1N_1 command. The quantity C_1N_1 is A0, A1, A2, A3, A4, or B0. Examples: F2SA0, F2SB0, F2SA4. **Caution** is advised when using this command **if** the control sensor is not on Channel B since this command may then be switching the control sensor.

4.8.5 Resolution for the Control and Sample - The F3CN_1 and F3SN_1 Commands

The resolution for the control and sample displays can be set independently with the F3CN_1 and F3SN_1 commands, respectively. The quantity N_1 is a number 0 thru 4 where

0	for a resolution of	xxx.
1	for a resolution of	xxx.x
2	for a resolution of	xxx.xx
3	for a resolution of	xx.xxx
4	for a resolution of	x.xxxx

Examples:

F3C1 for a resolution of xxx.x on the Control Sensor Display

F3S3 for a resolution of xx.xxx on the Sample Sensor Display

4.8.6 Selection of Deviation for Control and Sample - The F4CON, F4COFF, F4SON and F4SOFF Commands
Deviation output instead of magnitude and sign output can be selected for the sample and control displays independently using the F4CON, F4COFF, F4SON and F4SOFF commands.

4.8.7 Selection of MATH Functions ON, OFF and CLEAR - The F5ON, F5OFF and F5CLR Commands

The MATH function can be turned on, off or cleared using the F5ON, F5OFF and F5CLR commands.

4.8.8 Sensor Curve # Selection - The $NC_1N_1N_2N_3$ Command

The Curve Number to be selected for the inputs can be changed by the $NC_1N_1N_2N_3$ command. The quantity C_1N_1 is the input A0, A1, A2, A3, A4, or B0. The quantity N_2N_3 is the curve number from 00 thru 30. Examples: NA000, NA006, NA405, NB002, etc.

4.8.9 The A and B Sensor ID Information - The AC_1C_2 and BC_1C_2 Commands

The purpose of this command is to select Filtering of the A or B input, whether the Remote Position Data is used to establish the curve numbers, the Temperature Coefficient sign for the 9215 card, and whether or not thermal correction is desired on the 9317C/9318C cards.

Table 4-8 defines C_1 and C_2 in the AC_1C_2 and BC_1C_2 commands. C_1 defines whether the Remote Position Data should be used to select the Curve Number. C_2 defines whether the thermal correction is on or off on the 9317C/9318C cards, filtering on or off, and the sign of the temperature coefficient with a 9215 Capacitance Card.

A02 - Enable digital filtering to be used to determine display value.

A10 - Enables the REMOTE SENSOR ID. If the remote position data is 0, then the sensor curve reverts to the curve in A00 (or B00) rather than being selected from the REMOTE SENSOR ID Table.

A12 - Enable digital filtering in addition to the A10 description.

4.8.10 The "WD" Data String

An example of the data received when requesting Sample, Control, A and B information using the WD command is as follows

A0,K,3,N,B0,K,2,N,00,A00,02,00,00,
00,00,B02,04

The above string indicates that the Sample Sensor is A0, sample units are kelvin, sample resolution is 3 (xx.xxx) and the sample form is normal; the Control Sensor is B0, control units are in kelvin, control resolution is 2 (xxx.x) and control form is normal; the remote position is off; the SENSOR A ID indicating that the Digital Filtering is Off and the REMOTE SENSOR ID is off; the curve being used for INPUT A0 is 2 and A1, A2, and A3 are using curve 0; the SENSOR B ID indicates that Digital Filtering for this channel is On and the curve assigned is 4.

Both channels are using the DT-470 "Curve 10", the difference is that INPUT A is set for an upper limit of 325K and INPUT B is set with an upper limit of 475K.

4.9 THE CONTROL COMMANDS

4.9.1 The Set Point Value - The S Command

The set point is sent from the controller to the DRC-93C in a free field format of which examples are given in Table 4-9. Note that the sign only has to be present if negative celsius or fahrenheit settings are desired. Although

Table 4-7. DRC-93C Command Summary for Instrument Setup

Command	Functional Description
Selection of Units, Sensors, Resolution, and Deviation	
$F0C_1$	Function 0 - Select Control (Setpoint) Units. Forms of the command are F0K (kelvin), F0C (celsius), F0F (fahrenheit), and F0S for Sensor Units in volts, ohms or nanofarads.
$F1C_1$	Function 1 - Select Sample Units. Forms of the command are F1K (kelvin), F1C (celsius), F1F (fahrenheit), and F1S for Sensor Units in volts, ohms or nanofarads.
$F2CC_1N_1$	Function 2C - Select Control (Setpoint) Sensor. Forms of the command are F2CA0, F2CA1*, F2CA2*, F2CA3*, F2CA4* and F2CB (or F2CB0). * With 8229 Scanner Card Only.
$F2SC_1N_1$	Function 2S - Select Sample Sensor. Forms of the command are F2SA0, F2SA1*, F2SA2*, F2SA3*, F2SA4* and F2SB (or F2SB0). * With 8229 Scanner Card Only.
$F3CN_1$	Function 3C - Select the Control (Setpoint) Resolution. N_1 is 0 (xxx.), 1 (xxx.x), 2 (xxx.xx), 3 (xx.xxx) or 4 (x.xxxx). Forms of the command are F3C0, F3C1, F3C2, F3C3 and F3C4.
$F3SN_1$	Function 3S - Select the Sample Resolution. N_1 is 0 (xxx.), 1 (xxx.x), 2 (xxx.xx), 3 (xx.xxx) or 4 (x.xxxx). Forms of the command are F3S0, F3S1, F3S2, F3S3 and F3S4.
F4CON F4COFF	Function 4C - Select the Control Sensor Deviation ON or OFF.
F4SON F4SOFF	Function 4S - Select the Sample Sensor Deviation ON or OFF.
F5ON F5OFF F5CLR	Function F5 - Select the MATH Function on, off or cleared.
$NC_1N_1N_2N_3$	Function N assigns Curve Number to Input Channel. Forms of the command are NA000 thru NA031 (NA431 with Scanner Card) and NB000 thru NB031.
AC_1C_2 or BC_1C_2	Input A ID and B ID. C_1C_2 are 00 thru 1F. Forms of the command are A00 thru AFF. C_1 ranges between 0 and F. If C_2 is between 0 and 7, then C_1 selects the Sensor Curve number 00(0) thru 15(F). If C_2 is between 8 and F, then C_1 corresponds to a Remote Position between 0 and F.

Table 4-7 Cont'd. DRC-93C Request Summary for Instrument Setup

****

Request	Output of Instrument Variables
WD	Sample, Control, A and B Input Information $C_1C_2,C_3,N_1,C_4,C_5C_6,C_7,N_2,C_8,C_9C_{10},AC_{11}C_{12},$ $N_3N_4,N_5N_6,N_7N_8,N_9N_{10},N_{11}N_{12},BC_{13}C_{14},N_{13}N_{14}$ 46 characters plus up to 2 terminators where: C_1C_2 is the Sample Sensor A0, A1, A2, A3, A4 or B0. C_3 is the Sample Units K, C, F, V, N or R. N_1 is the Sample Resolution 0 (xxx) through 4 (x.xxxx) C_4 is the Sample Form - N for normal,D for Deviation C_5C_6 is the Control Sensor A0, A1, A2, A3, A4 or B0. C_7 is the Control Units (K, C, F, V, N or R). N_2 is the Control Resolution 0 (xxx) through 4 (x.xxxx) C_8 is the Control Form - N for normal, D for Deviation C_9C_{10} is the Remote Position (00 through 1F). $C_{11}C_{12}$ is the A ID (00 through 1F). N_3N_4 is the A0 curve number (00 through 30). N_5N_6 is the A1 curve number (00 through 30). N_7N_8 is the A2 curve number (00 through 30). N_9N_{10} is the A3 curve number (00 through 30). $N_{11}N_{12}$ is the A4 curve number (00 through 30). $C_{13}C_{14}$ is the B ID (00 through 1F). $N_{13}N_{14}$ is the B Curve Number (00 through 30).

Table 4-8. C_1 and C_2 in A ID and B ID, the SENSOR ID's

```
 _____C2_____  _____C1_____
 1  2  3  4    4  3  2  1    4 is MSB, 1 is LSB
 1  2  4  8    8  4  2  1    Binary Weighting
 ↑  ↑  ↑  ↑— Remote Position (On), Curve # (Off) Bit
 |  |  └──── Thermal Correction
 |  └─────── Digital Filtering
 └────────── Thermal Correction or Ice-Point Compensation
```

C_1	C_2			
Curve # or Remote Position	Select Curve # (0) or Remote Position (8)	9317C/9218C Card Thermal Correction	Digital Filtering	9215 Card Temperature Coefficient
0 to F	0 or 8	OFF (0)	OFF (0)	+ (0)
"	1 or 9	OFF (0)	OFF (0)	- (1)
"	2 or A	OFF (0)	ON (2)	+ (0)
"	3 or B	OFF (0)	ON (2)	- (1)
"	4 or C	ON (4)	OFF (0)	+ (0)
"	5 or D	ON (4)	OFF (0)	- (1)
"	6 or E	ON (4)	ON (2)	+ (0)
"	7 or F	ON (4)	ON (2)	- (1)

input range may be above the values possible for the various sensors, the set point is limited by the input card present as shown in the table. Note that the temperature limit can be different for the DT-470 depending on whether curve 02 (324.9K) or curve number 04 (474.9K) has been selected. If a number above the limitation for the card is entered, the set point is set to the upper temperature limit. Also note that an S sent by itself to the 93C sets the set point to 0 kelvin (or its equivalent in the units chosen) which will result in shutting down the heater output stage of the temperature controller.

Table 4-9. DRC-93C Command/Request Summary for Setpoint Setup

Command	Functional Description
S or SN_1 or $SN_1.N_2$ or SN_1N_2 or $SN_1N_2.N_3$ or $SN_1N_2N_3.N_4$ or $SN_1.N_2N_3$ etc. or ( )SN_1 or ( )$SN_1.N_2$ or ( )SN_1N_2 or ( )$SN_1N_2.N_3$ etc.	Set Point Input. The decimal point is "FREE FIELD" and its allowable position depends on the control units. Limits are Units — Range K — 0 through 999.9 C,F — -999.9 through 999.9 V — 0.0000 through 9.9999 R — 0 through 99999 N — 0 through 99.999 or 999.99 The Set Point is limited based on input card and Sensor. Lower limit is 0 K (-273.1 °C or -459.6 °F).

Input Card	Sensor Type	Upper Set Point Limit K	°C	°F	Sensor Units
9210/20-3	DT-470, DT-500	324.9	51.7	125.1	2.9999 volt
9210/20-6	TG-100,TG-120	"	"	"	6.5535 volt
9317C	Germanium/Carbon Glass	"	"	"	9999.9 ohms
9318C	Germanium/Carbon Glass	"	"	"	99999 ohms
9215-15	CS-400,CS-501	N/A	N/A	N/A	29.999 nF
9215-150	CS-401,CS-501	N/A	N/A	N/A	149.99 nF
9210/20-3	DT-470	474.9	201.7	395.1	2.9999 volt
9220-P2	PT-100 Series	999.9	526.7	980.1	299.99 ohms
9220-P3	PT-1000 Series	"	"	"	2999.9 ohms
9220-R1	Rhodium-iron	"	"	"	99.999 ohms

****

Request	Output of Instrument Data
WP	Set Point Data – ( )$N_{11}N_{12}N_{13}$(.)$N_{14}N_{15}$( ) 8 Characters plus up to 2 terminators where the N_{11}-N_{15} variations are the same as for W0 (see Table 4-15).

Note: Although limitations on the range of the set point are set within the software when in temperature units; these limits are not possible for sensor units due to the different characteristics for each sensor.

Since the set point is soft, the transition from REMOTE to LOCAL does not result in a change in the set point.

4.9.2 The "WP" Request Data String

This request is a subset of the "W0" command; the "WP" command giving the set point value by itself.

4.9.3 Setting the GAIN (Proportional) - The P Command

The gain is a multiplier between 0.1 and 99., a range of 990, i.e., 99./0.1 = 990. A gain of 0.0 is not allowed. The format is free field with examples of the command being P.1, P0.1, P9, P9., P9.0, P99, P99., etc.

The string P987.12 will be interpreted as P87, i.e., the first valid combination will be retained. A P transmitted by itself is equivalent to P0 or P0.0 and sets the gain to 0.1.

4.9.4 Setting the RESET (Integral) - The I Command

The reset is set from 0.1 through 99 (1 to 990) seconds. Like the gain command, it is free field with the same characteristics and format. A setting of 0.0 turns the reset off.

4.9.5 Setting the RATE (Derivative) - The D Command

The rate is also set in seconds/10 (from 0.1 to 99). It handles its input format exactly the same as both gain and reset commands. A setting of 0.0 turns the rate off.

4.9.6 Heater Range - The R Command

The heater range can be changed over the bus with the RN_1 command. R6 and up are equivalent to the R0 command (see Table 4-10).

4.9.7 % Manual Heater Power - The H Command

The Per Cent Manual Heater Power can be set between 00 and 99 with this command. Total power can be greater or less than this setting, dependent on control settings and actual control sensor temperature.

4.9.8 The "W3" Data String

The settings for the gain, rate, reset, manual heater power, heater range as well as the instantaneous % of Heater Power can be transmitted from the DRC-93C with the "W3" command.

The command "SPIDR" or any combination without a value following the letter sets the chosen parameters to 0, e.g., "SP" sets the set point and gain to 0.

4.10 THE SCANNER INPUT CARD

4.10.1 SCAN Programming Instructions

NOTE: The YA, YB (Table 4-11) and Y2S (Table 4-7) commands should be issued when the SCAN mode is Holding. Changing a SCAN time or Scanner Channel while the unit is actively scanning may cause unpredictable results.

4.10.2 Setting the Dwell Time - The $YAN_1N_2N_3$ and $YB0N_2N_3$ Commands

The time spent on a given scanner channel can be varied between 0 and 99 seconds by setting the dwell time for that channel. This can be done over the IEEE-488 Bus with these commands or from the front panel. Setting the dwell time to 0 skips that channel.

Table 4-10. DRC-93C Command/Request Summary for the Control Parameters

Command	Functional Description
	Setting of all other Control Parameters
$PN_1.N_2$ or PN_1N_2	Proportional (GAIN). N_1N_2 is 0.1 through 99. Examples the command are P, P0, P0.0 and P99.
$IN_1.N_2$ or IN_1N_2	Integral (RESET). N_1N_2 is 0.0 (OFF) through 99. (three characters including the decimal point). Forms of the command are I0 (I0.0) through I99.
$DN_1.N_2$ or DN_1N_2	Derivative (RATE). N_1N_2 is 0.0 (OFF) through 99. (three characters including the decimal point). Forms of the command are D0 (D0.0) through D99.
RN_1	Heater Range. N_1 is 0 through 5. Forms of the command are R0 through R5. N_1 — Range — Heater Current 0 — OFF — 0 1 — -4 — 10 mA 2 — -3 — 33 mA 3 — -2 — 100 mA 4 — -1 — 330 mA 5 — MAX — 1 A
HN_1N_2	% Manual Heater Power. 00 to 99 % of Heater Range

****

Request	Functional Description
W3	Control Parameters $N_1N_2N_3,N_4N_5N_6,N_7N_8N_9,N_{10},N_{11}N_{12}N_{13},N1_4N_{15}$ 20 characters plus up to 2 terminators where: $N_1N_2N_3$ is the Gain Value $N_4N_5N_6$ is the Rate Value $N_7N_8N_9$ is the Reset Value N_{10} is the Heater Range $N_{11}N_{12}N_{13}$ is the % of Heater Power or Current out. $N1_4N_{15}$ is the % of Manual Heater Power or Current Out

4.10.3 Enabling the Scan Function - The YS Command

Upon sending the YS command from the BUS CONTROLLER, the DRC-93C starts its scan of the inputs from the channel input which it is currently on. The scan sequence is A, 1(A1), 2(A2), 3(A3),4(A4), A, etc. with any channel whose dwell time is set to zero being skipped.

It is strongly recommended that the control channel be the B channel when the scanner is used. If it is not, it will be changed if a scanner card is present, since one current source is associated with the A0-A4 inputs.

Table 4-11. DRC-93C Command/Request Summary for Scanner

Command	Functional Description
$YAN_1N_2N_3$ or $YB0N_2N_3$ (After YH cmmd)	Set the AN_1 (A0 - A4) or B0 Scanner channel dwell time time to N_2N_3 seconds. N_2N_3 is 00 to 99 seconds. Forms are YA000 thru YA099, YA100 thru YA199, etc.
YS	Enable the (S)CAN function.
YH	Disable, or (H)old, the SCAN.

****

Request	Functional Description
WY	Scan Information $C_1,C_2C_3,C_4C_5,C_6C_7,C_8C_9,C_{10}C_{11},C_{12}C_{13},C_{14}C_{15}$ 22 characters plus up to 2 terminators where: C_1 is the SCAN status, (H)olding or (S)canning. C_2C_3-$C_{12}C_{13}$ is the A0 - A4 and B0 dwell times in seconds. $C_{14}C_{15}$ is the SCAN position A0, A1, A2, A3 or A4.

a) C_i corresponds to an alphanumeric

4.10.4 Holding the Scan Function - The YH Command

The Scan can be stopped any time over the IEEE-488 Bus by sending out the YH command. The scanner should be in hold when any of the other scanner commands are sent to the scanner.

4.10.5 The "WY" Data String

This request includes whether the instrument is scanning or holding, the channel dwell information and the scan position.

4.11 THE SERVICE REQUEST, STATUS REGISTER, STATUS REPORTS, AND THE STATUS REGISTER MASK

As mentioned earlier, a Service Request can be initiated by the DRC-93C to indicate a function has been performed, or a limit, overload or error has been encountered. The DRC-93C does this by pulling its SRQ (Service Request) management line low. The BUS CONTROLLER uses the serial poll (SPOLL) to obtain the contents of the register in the DRC-93C called the Status Register.

The DRC-93C Status Register is a single byte of data from the DRC-93C containing five bits called the Status Reports. These Status Reports indicate when certain processes are complete, whether the channel was changed, or a limit, overload or error encountered. The Status Register Mask is provided so that the Status Request interrupt and undesired Status Reports can be inhibited.

Reading the Status Register resets the Status Register to all zeros so that only new status reports will be registered by the DRC-93C. Thus, through the SRQ management line and the Status Register, the DRC-93C is able to signal Status Reports on five conditions immediately to the BUS CONTROLLER.

It is possible to disable the DRC-93C SRQ line thereby preventing the

DRC-93C from interrupting the BUS CONTROLLER. However, the BUS CONTROLLER can still read the Status Register to determine appropriate instrument conditions.

4.11.1 The Service Request

The Service Request Message is independent of all other IEEE-488 activity and is sent on a single line called the SRQ line. When the Service Request is sent and more than one instrument on the Bus has the capability to send this message, the BUS CONTROLLER must decide which instrument is sending the request. This is done by conducting a "Serial Poll" of the instruments on the Bus. The instrument polled responds by sending a Status Register. The Status Register indicates whether the device has requested service and if so, for what reason.

Once the reading on a given channel becomes stable (or valid), a service request is issued by the DRC-93C provided that Bit 6 in the Status Register Mask is set (See 4.11.2.5). With the SRQ bit of the Status Register mask disabled, no SRQ interrupt by the DRC-93C will be generated, however, the BUS CONTROLLER can still read the Status Register to determine appropriate instrument conditions.

4.11.2 The Status Register and Status Reports

The DRC-93C Status Register is a single byte of data from the DRC-93C containing five bits called the Status Reports which give information indicating which process is complete, whether the channel was changed, or a limit, overload or error encountered.

The Status Register can be read at any time by means of a Serial Poll Enable command.
Reading the Status Register resets the Status Register to all zeros so that only new status reports will be registered by the DRC-93C. Executing the Q command (Section 4.11.3) also resets the Status Register to all zeros. Reading the Status Register resets all of its bits to zero.

4.11.2.1 Status Reports 0 and 1 - Display and Control Data Ready. Bit 0 of the Status Register is set when a valid Display data reading is available. Bit 1 of the Status Register is set when a valid Control data reading is available. If the Service Request is enabled, either one of these being set will cause the DRC-93C to pull the SRQ management low to signal the BUS CONTROLLER. These bit(s) are reset to zero upon reading the Status Register on response to a serial poll or if the reading is no longer valid.

These functions can be inhibited by turning their corresponding bits in the Status Register mask off.

4.11.2.2 Status Report 2 - The Control Channel Limit. When the control sensor reading gets within the chosen limit from the set point, bit 2 is set in the Status Register. If the Service Request is enabled this bit being set will cause the DRC-93C to pull the SRQ management low to signal the BUS CONTROLLER. As with all of the Status Reports, this bit is reset to zero upon reading the Status Register. The bit will not revert to zero if the control sensor difference from the set point later exceeds the limit selected.

The control channel limit is entered using the Q command. (See Section 4.11.3.2).

This function can be inhibited by turning off bit 2 in the Status Register mask.

4.11.2.3 Status Report 3 - Display Sensor Channel Change. Bit 3 of the

Status Register is set when a channel change occurs for the Display. If the Service Request is enabled this bit being set will cause the DRC-93C to pull the SRQ management low to signal the BUS CONTROLLER. This Status Register bit is reset to zero upon reading the Status Register.

This function can be inhibited by turning off the bit 3 in the Status Register Mask.

4.11.2.4 Status Report 5 - Overload Error Indicator. If the display has an overload condition on any selected channel or an error occurs, then bit 5 of the Status Register is set and a Service Request is issued if enabled. This Status Register bit is reset to zero upon reading the Status Register.

This function can be inhibited by turning bit 5 off in the Status Register Mask.

4.11.2.5 When operating without the Service Request it is still possible for the BUS CONTROLLER to read the Status Register. The Service Request is inhibited by turning off the SRQ bit (bit 6) in the Status Register Mask.

However, it must be understood that certain bits in the Status Register are continually changing. The Status Reports for the Overload/Error, Display Data Ready, and Control Data Ready are continuously updated to reflect current instrument status. The Channel Change and Control Channel Limit once encountered are latched (set to 1) and remain latched until the Status Register is read.

4.11.3 The Status Register Mask - The QC_1C_2 Command

The Status Reports listed above may not be desired or perhaps only a few are of interest. The Status Register Mask is provided to allow the user to select whether he wants a given Status Report or not. The various bits of the Status Register Mask enable the various Status Reports. The bits in the Status Register Mask have the same bit position as the bits in the Status Register.

Only those bits which are allowed by the Status Register Mask Command are potentially changeable in the Status Register. Note that the corresponding bit in the Status Register Mask determines whether its counterpart in the Status Register can change.

The Status Register Mask is shown in Figure 4-2. It consists of 8 bits, one bit (bit 6) which determines whether the DRC-93C is to report via the SRQ line and five bits to determine which Status Reports to make. Bit 6 is the SRQ (Service Request) bit and if set allows the DRC-93C to send out a Service Request on the SRQ IEEE-488 line. If the SRQ bit is not set (off) then the DRC-93C is inhibited from producing a Service Request. The Status Register can still be read by the BUS CONTROLLER to examine the Status Reports, but the BUS CONTROLLER will not be interrupted by the Service Request. Five of the other seven bits select which of the five Status Reports to make. If one of these five bits is set (on), the DRC-93C will update the corresponding Status Report bit in the Status Register. Then if the SRQ bit (bit 6) of the Status Register Mask is set, the DRC-93C will send out a Service Request on the SRQ IEEE-488 line. By means of a serial poll enable (SPE), the BUS CONTROLLER determines that the DRC-93C has sent out a service request and then reads the Status Register. Reading the Status Register resets the Status Register to all zeros. Executing the Q command also resets the Status Register to all zeros. The Status Register Mask command is the ASCII letter Q followed by two alphanumerics representing the most significant four bits and the least significant four bits, respectively. Note that the controller can be programmed for more than one set of conditions simultaneously. To enable the Service Request, Bit 6 must be a 1.

4.11.3.1 Status Register Mask Bits 0 and 1 - Sample and Control Data Ready Enables. If either Bit 0 or Bit 1 of the Status Register Mask is set (1), then for that data, the corresponding bit in the Status Register is set when a valid data reading is available.

4.11.3.2 Status Register Mask Bit 2- The Control Channel Limit Enable. If the control channel limit (Figure 4-2, Bit 2) is selected, the limit <u>must</u> follow the Q command and is in a free field format. Examples are xxx.x, .x, x.x, xx.x, x., xx., etc. If Bit 2 of the Mask is set (1), then when the control sensor reading gets within the chosen limit from the set point, the corresponding bit is set in the Status Register.

4.11.3.3 Status Register Mask Bit 3- Sample Sensor Channel Change Enable If the Sensor Channel Change (Bit 3) is selected, then bit 3 in the Status Register is set when a channel change occurs.

4.11.3.4 Status Register Mask Bit 5 - Overload/Error Indicator Enable. If the Overload/Error Indicator Enable Bit (5) is set, then if the display has an overload condition on any channel or an error occurs, the corresponding bit on the Status Register is set and a Service Request is issued if the SRQ bit of the mask is a 1. The user can check which overload or error was detected by sending the Output Data Statement W0 (See Section 4.14.2 and Table 4-15).

For example, in Figure 4-2, Q21 will allow the setting of the Overload/Error Indicator and Sample Data Ready bits in the Status Register, but will not send an Service Request if either condition is met. Q61 however will allow either of these bits to be set and when either is set, an Service Request will be issued by the DRC-93C over the IEEE-488 Bus. This Service Request will remain on the Bus until either a Serial Poll is initiated or the cause of the setting of the SRQ is eliminated.

The Status Register mask and control channel limit is part of the power-up save settings like the set point and units. It is updated on power-up to the last settings with internal switch 2 set. On power up the Status Register mask is set to 00 and the control channel limit to 000.0 if switch 2 is off.

4.11.3.5 Examples for setting Mask

Example #1 - Q61 - Sample Data Ready with the Service Request bit (SRQ) on. - With the SRQ bit of the Status Register mask enabled, the DRC-93C SRQ interrupt will be generated. The BUS CONTROLLER can read the Status Register to determine appropriate instrument conditions. In this case bits 1 is continuously updated to reflect current instrument status of the Sample Data Ready. Q61 also results in a service request if an OVERLOAD/ERROR is indicated.

Example #2 - Q2F000.1 - All Status Reports with the SRQ bit off. - With the SRQ bit of the Status Register mask disabled, no SRQ interrupt by the DRC-93C will be generated, however, the BUS CONTROLLER can still read the Status Register and this command will give all five Status Reports.

Example #3 - Q06000.1 - Enable the Control Data Ready and Control Channel Limit with a band of 0.1 about the control point.

Figure 4-2. DRC-93C Status Register Mask and Status Register Format

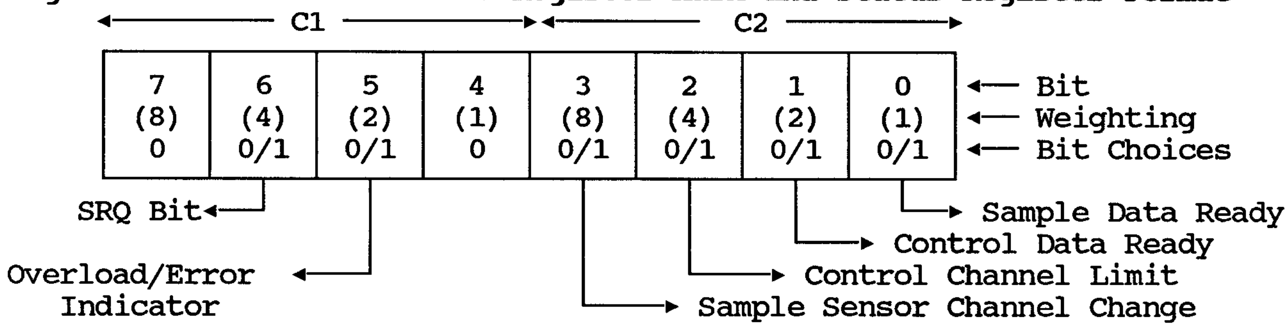


Table 4-12. Commands to Fix the Status Register Mask

QC_1C_2	Not Used	SRQ Bit	Overload /Error Indicator	Not Used	Sample Channel Change	Control Data Limit	Control Data Ready	Sample Data Ready
Bit	3	2	1	0	3	2	1	0
Q2F			On		On	On	On	On
Q40		On						
Q41		On						On
Q42		On					On	
Q43		On					On	On
Q44		On				On		
Q45		On				On		On
Q46		On				On	On	
Q47		On				On	On	On
Q48		On			On			
Q49		On			On			On
Q4A		On			On		On	
Q4B		On			On		On	On
Q4C		On			On	On		
Q4D		On			On	On		On
Q4E		On			On	On	On	
Q4F		On			On	On	On	On
Q60		On	On					
Q61		On	On					On
.		.	.		.	.	.	.
.		.	.		.	.	.	.
Q6E		On	On		On	On	On	
Q6F		On	On		On	On	On	On

Note: On means 1. Those entries left blank are OFF (0).

Table 4-13. DRC-93C Command/Request Summary for Status Register Mask

Command	Functional Description
$QC_1C_2{}^e$	The Status Register mask is set using the Q command. Forms of the command are $Q0C_2$, $Q2C_2$, $Q4C_2$, $Q6C_2$ and QC_10, QC_11, QC_12, QC_13, QC_14, QC_15, QC_16, QC_17. When C_1 is: — Status Register Mask is: 0 — Service Request OFF;Error/Overload Indicator Request OFF 2 or 6 — Error/Overload Indicator Request ON 4 or 6 — Service Request is ON; When C_2 is: — Status Register Mask Status is: 0 — Sample Data, Control Data and Limit OFF 1, 3, 5 or 7 — Sample Data Service Request is ON 2, 3, 6 or 7 — Control Data Service Request is ON 4, 5, 6 or 7 — Control Channel Limit SRQ is ON

****

Request	Output of Instrument Setup
WQ	SRQ Mask Data - $C_1C_2,N_1N_2N_3.N_4$ 8 Characters plus up to 2 terminators where: C_1C_2 is the SRQ Mask Byte $N_1N_2N_3.N_4$ is the control channel limit band

4.11.3.6 Status Register Mask at Power Up. The Status Register Mask is saved at power-down, provided switch 2 of the internal 8 switch package is on.

4.11.4 The "WQ" Data String

This command gives the Status Register Mask and control channel limit information.

4.12 SAVING AND RESTORING EXECUTABLE (INTERNAL) PROGRAMS

4.12.1 Requesting a Program Step for Saving - The WEN_1N_2 Command

The WEN_1N_2 command requests the Program Step # N_1N_2 from the 93C. The data of the Program Step will be in the next output transmitted from the instrument. The Data consists of the the Program Step # in ASCII followed by sixty characters. These characters are to be stored by the user for later transmission back to the instrument by the EN_1N_2 command described below. Examples of this command and the EN_1N_2 command are given in section 4.12.3.

4.12.2 Transmitting a Program Step to the 93C - The $EN_1N_2C_1$-C_{60} Command

The E command requests that Program Step # N_1N_2 and its data (C_1 thru C_{60}) be sent to the 93C. The form is $EN_1N_2C_1$-C_{60}. The data must have been previously received from the instrument using the WEN_1N_2 command and stored for transmission back to the instrument using this command. Examples of the E command in conjunction with the WEN_1N_2 command are given below.

Table 4-14. DRC-93C Command/Request Summary for Program Step

Command	Functional Description
$EN_1N_2C_1-C_{60}$	Transmit (Restore) Program Step # N_1N_2 data (C_1-C_{60}) to the 93C

****

Request	Functional Description
WEN_1N_2	Request the Program Step # N_1N_2 for Saving $N_1N_2C_1-C_{60}$ 62 Characters plus up to 2 terminators where: N_1N_2 is the Program Step Number $C1-C_{60}$ are the sixty characters of Program Step # N_1N_2

4.12.3 Examples of Saving and Restoring Executable (Internal) Program Steps

4.12.3.1 Program to Request and Store Program Step # 1 thru 10 using the HP86B

The following program for the HP86B requests and get Program Steps #01 thru #10 and stores the data in a file called "PROGRAM1" on afloppy with volume label "93C". To initialize an unused floppy in slot 0 for this purpose the command INITIALIZE "93C", "D700" can be executed.

```
10 REM "STORE"
20 REM PROGRAM TO READ AND STORE AN INTERNAL PROGRAM
30 REM SET IEEE ADDRESS TO 12
40 ADDRESS SWITCH 1 OPEN (0) TO GET (CR)(LF)
50 DIM A$[62],N1$[1],N2[1]
60 REM CREATE "PROGRAM1.93C" ,99,32         ! ONLY USE FIRST TIME TO CREATE FILE
70 ASSIGN# 1 TO "PROGRAM1.93C"              ! OPEN THE FILE
80 FOR I=1 TO 10                            ! FOR PROGRAM STEPS #01 THRU #10
90 IF I<10 THEN GOTO 140
100 I$=VAL$(I)
110 N1$=I$[1,1]
120 N2$=I$[2,2]
130 GOTO 160
140 N1$="0"
150 N2$=VAL$(1)
160 OUTPUT 712;"WE";N1$;N2$ ! SEND THE WE COMMAND REQUESTING PROGRAM STEP I
170 ENTER 712; A$                           ! GET PROGRAM STEP I
180 DISP A$                                 ! DISPLAY ON THE SCREEN
190 PRINT# 1; A$                            ! SAVE PROGRAM STEP I IN THE FILE
200 NEXT I
210 ASSIGN# 1 TO *                          ! CLOSE THE FILE
220 END
```

4.12.3.2 Program to Restore Program Step # 1 thru 10 using the HP86B

*The following program for the HP86B restores Program Steps #01 thru #10 from a file called "PROGRAM1" previously stored a floppy with the volume label "93C".

```
10 REM "RESTORE"
20 REM PROGRAM TO RESTORE THE INTERNAL PROGRAM AND PRINT ON THE SCREEN
30 DIM A$[62],N1$[1],N2$[1]
40 REM "PROGRAM1.93C" WAS CREATED AND WRITTEN BY PROGRAM STORE
50 ASSIGN# 1 TO "PROGRAM1.93C"      ! OPEN THE FILE
60 FOR I=1 TO 10                    ! PROGRAM STEP #01 TO #10
70 READ# 1 ; A$                     ! GET PROGRAM STEP I FROM THE FILE
80 OUTPUT 712 ;"E"; A$              ! SEND PROGRAM STEP I
90 DISP A$                          ! DISPLAY THE PROGRAM STEP ON THE SCREEN
100 WAIT 200                        ! WAIT 200 MILLISECONDS
110 NEXT I
120 ASSIGN# 1 TO *                  ! CLOSE THE FILE
130 END
```

4.12.3.3 National Instruments GWBASIC and BASICA IBM Example of WEN_1N_2 Request

This program will store Programs Step # 1 thru 10 in File "PROGRAM1" on Disk A: using GWBASIC or BASICA and the National Instruments GPIP-PC2 IEEE-488 Card for the IBM PC and compatibles.

```
10  CLEAR   ,60969  ' BASIC DECLARATIONS
20  IBINIT1 = 60969 ' This number is different for each computer
30  IBINIT2 = IBINIT1 + 3
40  BLOAD "bib.m",IBINIT1
50  CALL IBINIT1(IBFIND,IBTRG,IBCLR,IBPCT,IBSIC,IBLOC,IBPPC,IBBNA,IBONL,
IBRSC,IBSRE,IBRSV,IPPAD,IBSAD,IBIST,IBDMA,IBEOS,IBTMO,IBEOT,IBRDF,IBWRTF)
60 CALL IBINT2(IBGTS,IBCAC,IBWAIT,IBPOKE,IBWRT,IBWRTA,IBCMD,IBCMDA,IBRD,IBRDA,
IBSTOP,IBRPP,IBRSP,IBDIAG,IBXTRC,IBRDI,IBWRTI,IBRDIA,IBWRTIA,IBSTA%,IBER-
R%,IBCNT%)
70  TEMP$="93C"         '93C is IEEE address label set up when running IBCONF
80  CALL IBFIND(TEMP$,TEMP%)                'Required command to address 93C
90  OPEN "A:PROGRAM1" FOR OUTPUT AS #1      'Open file to store data
100 FOR I=1 TO 10                           'Program Steps #01 TO #10
110 IF I<10 THEN GOTO 150
120 N1$=MID$(STR$(I),2,1)
140 GOTO 160
150 N1$="0"
160 N2$=RIGHT$(STR$(I),1)
170 B$="WE"+N1$+N2$                         'Assemble command
180 B$=B$+CHR$(13)+CHR$(10)                 'Add CR and LF to command
190 CALL IBWRT(TEMP%,B$)                    'Send request to 93C
200 CALL IBRD(TEMP%,A$)                     'Get data from 93C
210 PRINT A$                        'Display received information on screen
220 PRINT# 1;A$                             'Save in file "A:PROGRAM1"
230 NEXT I
240 CLOSE 1
250 END
```

4.12.3.4 National Instruments GWBASIC and BASICA IBM Example of E Command

This program will restore Programs Step # 1 thru 10 previously stored in file "PROGRAM1" on Disk A: using GWBASIC or BASICA and the National Instruments GPIP-PC2 IEEE-488 Card for the IBM PC and compatibles.

```
10  CLEAR   ,60969              'BASIC DECLARATIONS
20  IBINIT1 = 60969             'This number is different for each computer
30  IBINIT2 = IBINIT1 + 3
40  BLOAD "bib.m",IBINIT1
50  CALL IBINIT1(IBFIND,IBTRG,IBCLR,IBPCT,IBSIC,IBLOC,IBPPC,IBBNA,IBONL,
IBRSC,IBSRE,IBRSV,IPPAD,IBSAD,IBIST,IBDMA,IBEOS,IBTMO,IBEOT,IBRDF,IBWRTF)
60  CALL IBINT2(IBGTS,IBCAC,IBWAIT,IBPOKE,IBWRT,IBWRTA,IBCMD,IBCMDA,
IBRD,IBRDA,IBSTOP,IBRPP,IBRSP,IBDIAG,IBXTRC,IBRDI,IBWRTI,IBRDIA,IBWRTIA,
IBSTA%,IBERR%,IBCNT%)
70  TEMP$="93C"  '93C is IEEE address label set up when running IBCONF
80  CALL IBFIND(TEMP$,TEMP%)              'Required command to address 93C
90  OPEN "A:PROGRAM1" FOR INPUT AS #1     'Open file to get data
100 FOR I=1 TO 10                         'Program Steps #01 TO #10
110 INPUT#1,C$
120 B$="E"+ $                             'Assemble command
130 B$=B$+CHR$(13)+CHR$(10)               'Add CR and LF to command
140 CALL IBWRT(TEMP%,B$)                  'Send data to 93C
150 FOR Z=1 TO 1000
160 NEXT Z
170 NEXT I
180 CLOSE 1
190 END
```

4.12.3.5 National Instruments QUICK BASIC IBM Example of WEN_1N_2 Request

```
'   Quick Basic 3.0 Example #2
'   THIS PROGRAM WAS WRITTEN FOR THE NATIONAL INSTRUMENTS GPIP-PC2
'   IEEE-488 CARD FOR IBM PC AND COMPATIBLES
'
'   This program will store Programs Step # 1 thru 10 in File "PROGRAM1"
'   on Disk A:
'
        COMMON SHARED IBSTA%, IBERR%, IBCNT%
        TEMP$="dev12"                      '93C
        CALL IBFIND(TEMP$,TEMP%)           'Required to address instrument
        OPEN "A:PROGRAM1" FOR OUTPUT AS #1 'Open file to store data
        FOR I=1 TO 10                      'Program Steps #01 Thru #10
        IF I<10 THEN
               N1$="0"
               N2$=LTRIM$(RTRIM$(STR$(I)))
        ELSE
               N$=RTRIM$(LTRIM$(STR$(I)))
               N1$=LEFT$(N$,1)
               N2$=RIGHT$(N$,2)
               N2$=RIGHT$(STR$(I),1)
          END IF
```



```
B$="WE"+N1$+N2$              'Assemble command
B$=B$+CHR$(13)+CHR$(10)      'Add CR and LF to command
CALL IBWRT(TEMP%,B$)         'Request Program Step I
CALL IBRD(TEMP%,A$)          'Get Program Step I
PRINT A$                    'Display received information on screen
PRINT #1,A$                  'Save on disk in file PROGRAM1
NEXT I
CLOSE 1                      'Close the file
END
```

4.12.3.6 National Instruments QUICK BASIC IBM Example of E Command

```
'   Quick Basic 3.0 Example #3
'   THIS PROGRAM WAS WRITTEN FOR THE NATIONAL INSTRUMENTS GPIP-PC2
'   IEEE-488 CARD FOR IBM PC AND COMPATIBLES

'   This program will restore Programs Step # 1 thru 10 from File "PROGRAM1"
'   on Disk A:

           COMMON SHARED IBSTA%, IBERR%, IBCNT%

           TEMP$="dev12"                       '93C
           CALL IBFIND(TEMP$,TEMP%)            'address instrument
           OPEN "A:PROGRAM1" FOR INPUT AS #1   'Open file with data
           FOR I=1 TO 10                       'Program steps #01 Thru #10
           INPUT #1,C$                        'Get data from file "PROGRAM1"
           B$="E"+C$                           'Assemble command
           B$=B$+CHR$(13)+CHR$(10)             'Add CR and LF to command
           CALL IBWRT(TEMP%,B$)                'Send command to instrument
           FOR Z=1 TO 1000: NEXT Z
           NEXT I
           CLOSE 1                             'Close the file
           END
```

4.13 COMMAND OPERATIONS

The following example in HP Basic sets the set point to 123.4 K, the gain to 45, the reset (integral) to 30, the rate (derivative) to 25, the heater range to 10^{-1} and the output statement sent to be W3.

```
OUTPUT  712 ; "S123.4P45I30D25R4W3"
  |     |           |
  |     |           └── Data
  |     └─ 12 = 93C preset address
  |      7 = IEEE-488 card address
  └─  Output Data Command
```

If the user were to monitor the IEEE-488 Bus when the computer sent its command string over the Bus, the following IEEE-488 Format would be observed.

? L , S123.4P45I30D25R4W3(CR)(LF)

The Universal Unlisten Command (?) is sent so that no other instruments on the Bus will eavesdrop on the Bus and assume that the data being sent is for their attention. The DRC-93C's Talk Address (L) is sent to unaddress any existing TALKER. Note that the BUS CONTROLLER could have designated another instrument as the TALKER. Therefore, to keep the format consistent, it must send a Talk Address even when the DRC-93C is going to be that TALKER. The Listen Address (,) must be sent to tell which instrument on the Bus is to receive the Data String. Note that [TERM1][TERM2] have been indicated to be CR LF (carriage return, line feed); these are the correct terminators for the HP computer example.

Note that the string "P45I30P40" would result in a gain of 40 and an integral value of 30, i.e., only the last value sent over the bus for that command will be entered after the appropriate terminators have been sent over the bus.

4.14 OUTPUT DATA STATEMENTS

The DRC-93C's Output Requests for Data Statements are summarized in Table 4-5.

The DRC-93C will always respond when asked to talk with the last command sent to it, i.e., if W0 is sent once then the 93C will always output the W0 information whenever it is asked to talk as long as it has not received another output data statement.

4.14.1 The "WS", "WC" and "WP" Data Strings

These three commands are subsets of the "W0" command; the "WS" command giving the Sample Sensor reading, the "WC" command the control sensor reading while the "WP" command results in the set point value.

4.14.2 The "W0" Data String

The following example in HP Basic illustrate the commands associated with obtaining output data from the DRC-93C. The addition of the M0 command returns the instrument to front panel control where it stays even when data is requested from the 93C by the HP computer.

```
10   DIM A$ [19]
20   OUTPUT 712; "W0M0"
30   ENTER  712; A$
```

The following information is sent across the bus in the IEEE-488 format as a result of the above software commands.

Request sent:
? U , W 0 M 0 (CR)(LF)
Data returned:

```
? 5 L +123.45K,+123.42,+123.40K
| | |          |            (CR)(LF)
| | |          └─ Data returned
| | └─ 93C's Talk Address
| └─ BUS CONTROLLER's Listen Add
└─ Universal Unlisten Command
```

The data above indicates that the

display temperature is 123.45K and that the set point is 123.40K.

Table 4-15. DRC-93C Output Data Statements

Request	Output of Instrument Data
WS	Sample Sensor Data - ( )$N_1N_2N_3$(.)N_4N_5( ) 8 Characters plus up to 2 Terminators where the N_1-N_5 variations are the same as for WO (see below).
WC	Control Sensor Data - ( )$N_6N_7N_8$(.)N_9N_{10}( ) 8 Characters plus up to 2 terminators where the N_6-N_{10} variations are the same as for WO (see below).
WP	Set Point Data - ( )$N_{11}N_{12}N_{13}$(.)$N_{14}N_{15}$( ) 8 Characters plus up to 2 terminators where the N_{11}-N_{15} variations are the same as for WO (see below).
WO	Sample (WS), Control Sensor (WC) and Set Point (WP) Data ( )$N_1N_2N_3$(.)N_4N_5( ),( )$N_6N_7N_8$(.)N_9N_{10}( ),( )$N_{11}N_{12}N_{13}$(.)$N_{14}N_{15}$() 26 characters plus up to 2 terminators where: (.) may vary in position dependent on units and temperature. ( )N_1-N_5( ) is the Sign, Display Sensor reading and units. ( )N_6-N_{10}( ) is the Sign, Control Sensor reading and units. ( )N_{11}-N_{15}( ) is the Sign, Set Point and units. Examples of the Display reading are (±)$N_1N_2N_3$(.)N_4N_5(F), (±)$N_1N_2N_3$(.)N_4N_5(C), ( )$N_1N_2N_3$(.)N_4N_5(R) or ( )N_1(.)$N_2N_3N_4N_5$(V) Note that all are "free field" where the units are K, C, F, V or R and the sign ( ) may be (±) for the ° and °C scales.
WM	Display Math Data C_1,( )$N_1N_2N_3$(.)N_4N_5(),()$N_6N_7N_8$(.)N_9N_{10}( ), ( )$N_{11}N_{12}N_{13}$(.)$N_{14}N_{15}$( ),C_2,( )$N_{16}N_{17}N_{18}$(.)$N_{19}N_{20}$( ), ( )$N_{21}N_{22}N_{23}$(.)$N_{24}N_{25}$( ),( )$N_{26}N_{27}N_{28}$(.)$N_{29}N_{30}$( ) 57 characters plus up to 2 terminators where: (.) may vary in position dependent on units and temperature. C_1 is 0 if the MATH Function is off and 1 if on ( )N_1-N_5( ) is the Sign, MAX Sample Sensor reading and units. ( )N_6-N_{10}( )is the Sign, MIN Sample Sensor reading and units. ( )N_{11}-N_{15}( ) is the Sign, MAXDEV Sample Sensor reading and units. C_2 is 0 if the MATH Function is off and 1 if on ( )N_{16}-N_{20}( ) is the Sign, MAX Control Sensor reading and units. ( )N_{21}-N_{25}( ) is the Sign, MIN Control Sensor reading and units. ( )N_{26}-N_{30}( ) is the Sign, MAXDEV Control Sensor reading and units.

4.15 SAMPLE PROGRAMMING

4.15.1 HP86B Keyboard Interactive Program

The following program for the HP86B is an interactive program with the keyboard of the computer. For example, when the user sees the prompt on the screen and types in a valid DRC-93C command such as "W0", the program will result in the display of the DRC-93C response on the screen.

```
10  REM Set IEEE Address to 12
20  REM Address Switch 1 OPEN(0) to get (CR)(LF)
30  REM This program allows the user to communicate with the 93C,
interactively from the computer keyboard
40  DIM A$[100]              ! Must be increased for curve information
50  INPUT B$                 ! INPUT KEYBOARD COMMAND
60  OUTPUT 712 ;B$           ! SEND COMMAND TO 93C
70  ENTER 712 ; A$           ! RECEIVE ANSWER FROM 93C
80  DISP A$                  ! DISPLAY ANSWER
90  GOTO 50
100 END
```

4.15.2 National Instruments GWBASIC or BASICA IBM Example

The following is the same program written for the National Instruments GPIP-PC2 IEEE-488 Card for IBM PCs and Compatibles using Quick Basic 3.0.

```
10  CLEAR   ,60969 ! BASIC DECLARATIONS
20  IBINIT1 = 60969 ! This number is different for each computer
30  IBINIT2 = IBINIT1 + 3
40  BLOAD "bib.m",IBINIT1
50  CALL IBINIT1(IBFIND,IBTRG,IBCLR,IBPCT,IBSIC,IBLOC,IBPPC,IBBNA,IBONL,
IBRSC,IBSRE,IBRSV,IPPAD,IBSAD,IBIST,IBDMA,IBEOS,IBTMO,IBEOT,IBRDF,IBWRTF)
60  CALL IBINT2(IBGTS,IBCAC,IBWAIT,IBPOKE,IBWRT,IBWRTA,IBCMD,IBCMDA,IBRD-
,IBRDA,IBSTOP,IBRPP,IBRSP,IBDIAG,IBXTRC,IBRDI,IBWRTI,IBRDIA,IBWRTIA,
IBSTA%,IBERR%,IBCNT%)
70  TEMP$="93C" ! 93C is IEEE address label set up when running IBCONF
80  CALL IBFIND(TEMP$,TEMP%) ! Required command to address 93C
90  A$=SPACE$(255)    ! 255 largest data transfer allowed by IBM format
100 INPUT B$                   ! Entered from keyboard while running
110 B$=B$+CHR$(13)+CHR$(10)    ! Add CR and LF to command
120 CALL IBWRT(TEMP%,B$)       ! Send command to 93C
130 CALL IBRD(TEMP%,A$)        ! ENTER from 93C (SEE NOTE BELOW)
140 PRINT A$                   ! Display received information on screen
150 A$=SPACE$(255)             ! Clear A$
160 GOTO 110
170 END
180 REM  The 93C will return data requested, but if the command input
does
190 REM  not request new information, the 93C will give the information
last requested.
```


4.15.3 National Instruments QUICK BASIC IBM Example

```
'   IEEE-488 TEST PROGRAM   Quick Basic 3.0 Example
'   THIS PROGRAM WAS WRITTEN FOR THE NATIONAL INSTRUMENTS GPIP-PC2
'   IEEE-488 CARD FOR IBM PC AND COMPATIBLES

'   This program will allow the user to communicate with Lake Shore's
'   instruments, interactively from the keyboard of an IBM compatible
'   computer which has a National Instruments GPIB-PC2 installed.

    common shared IBSTA%, IBERR%, IBCNT%

    print "Input number for the type of instrument---820,93C,82C, or 93C
    print "0=820"
    print "2=82C"
    print "1=93C"
    print "3=93C"
    input I$
    if I$="0" then TEMP$="dev20" 'default address for 820
    if I$="1" then TEMP$="dev12" 'default address for 93C,etc.
    if I$="2" then TEMP$="dev12"
    if I$="3" then TEMP$="dev12"
                                 'set up when running IBCONF
    call IBFIND(TEMP$,TEMP%)     'Required command to address instrument
    A$=space$( 750)

Loop1: input B$                  'Entered from keyboard while running
    B$=B$+chr$(13)+chr$(10)      'Add CR and LF to command
    call IBWRT(TEMP%,B$)         'Send command to instrument
    call IBRD(TEMP%,A$)          'ENTER from instrument (SEE NOTE BELOW)
    print A$                     'Display received information on screen
    A$=space$(750)               'Clear A$
    goto Loop1

    end

'   Lake Shore Cryotronics instruments will return the data requested,
'   but if the command input to the instrument does not request any
'   information the instrument will respond with the information last
'   requested.
```

4.15.4 HP86B Bus Commands Program

The following program is for the HP86B and exercises the various bus commands.

```
10 REM Set IEEE Address to 12
20 REM Address Switch 1 OPEN (0) to get (CR)(LF)
30 DIM A$[42]                       ! For longest string
40 OUTPUT 712;"W0"                  ! Note W0
50 ENTER 712;A$                     ! Ask for string W0
60 DISP "W0 = ";A$                  ! Display string W0
70 DISP "Display Sensor =";A$[1,8]  ! Display Sensor reading
80 DISP "Control Sensor =";A$[10,17] ! Display Control Sensor Reading
90 DISP "Set Point =";A$[19,26]     ! Display Set Point Reading
```

```
100 DISP                                ! Space a Line
110 OUTPUT 712;"W1"                     ! A and B Input information
120 ENTER 712;A$                        ! Ask for string W1
130 DISP "W1 = ";A$                     ! Display string W1
140 DISP                                ! Space a Line
150 OUTPUT 712;"W2"                     ! Interface Status
160 ENTER 712;A$                        ! Ask for string W2
170 DISP "W2 = ";A$                     ! Display string W2
180 DISP                                ! Space a Line
190 OUTPUT 712;"W3"                     ! Control Data (Gain, Reset, etc.)
200 ENTER 712;A$                        ! Ask for string W3
210 DISP "W3 = ";A$                     ! Display string W3
220 DISP "Gain =";A$[1,3]               ! Display Gain setting
230 DISP "Rate =";A$[5,7]               ! Display Rate setting
240 DISP "Reset =";A$[9,11]             ! Display Reset setting
250 DISP "Heater Range =";A$[13]        ! Heater Range
260 DISP "% Power =";A$[15,17]          ! % Power
270 DISP                                ! Space a Line
280 OUTPUT 712;"WS"                     ! Set for WS
290 ENTER 712;A$                        ! Ask for string WS
300 DISP "WS = ";A$                     ! Display Sensor Reading
310 DISP                                ! Space a Line
320 OUTPUT 712;"WC"                     ! Set for WC
330 ENTER 712;A$                        ! Ask for string WC
340 DISP "WC = ";A$                     ! Display Control Sensor Reading
350 DISP                                ! Space a Line
360 OUTPUT 712;"WP"                     ! Set for WP
370 ENTER 712;A$                        ! Ask for set point data
380 DISP "WP = ";A$                     ! Display string WP
390 DISP                                ! Space a Line
400 OUTPUT 712;"WY"                     ! Set for WY
410 ENTER 712;A$                        ! Ask for Scan Information
420 DISP "WY = ";A$                     ! Display Scan Information
430 DISP                                ! Space a Line
440 OUTPUT 712;"WI"                     ! Set for WI
450 ENTER 712;A$                        ! Ask Input Cards and Options
460 DISP "WI = ";A$                     ! Display string WI
470 END
```

4.16 SENSOR CURVE PROGRAMMING INSTRUCTIONS

The commands which will either output, input, edit or erase a Sensor Curve are given in Table 4-16. In addition, the commands to assign or change assignments of the various curves to the Sensor ID tables (both A and B) are given in Table 4-16.

4.16.1 The XDT Command

This command from the BUS CONTROLLER tells the DRC-93C that when it is asked to output data, that data should be the output of the standard Sensor Curves stored, Precision Option Curves stored and the format associated with the REMOTE SENSOR ID Remote Position to Sensor Curve assignments as given in Table 4-17. This output is defined as the Sensor Curve Information Table (SCIT). As can be seen from the output shown on this page, the instrument is shipped with all remote positions calling up Standard Curve 02.

The information lines for Sensor Curves 05 through 31 will only be present if these curves are actually present either as user generated curves or as Precision Option curves. The Information Table is output as **one very long character string**.

The following program is for the HP86B and is an example of the XDT output (SCIT) for a unit with only Standard Curves 00 thru 05 present.

```
10 REM Program to Output SCIT
20 DIM FILETABLE$[321]
30 OUTPUT 712;"XDT"     !Ask for
40 ENTER 712;FILETABLE$ !Input SCIT
50 DISP FILETABLE$[1,16]!Bytes Free
60 DISP FILETABLE$[17,38] !Next Loc
70 DISP FILETABLE$[39,56] !Curve 00
80 DISP FILETABLE$[57,74] !Curve 01
90 DISP FILETABLE$[75,92] !Curve 02
100 DISP FILETABLE$[93,110]!Curve
03
110 DISP FILETABLE$[111,128]!Curve
04
110 DISP FILETABLE$[129,152] !A00
120 DISP FILETABLE$[153,176]
130 DISP FILETABLE$[177,200]
140 DISP FILETABLE$[201,224]
!Thru A1F
150 DISP FILETABLE$[225,248] !B00
160 DISP FILETABLE$[249,272]
170 DISP FILETABLE$[273,296]
180 DISP FILETABLE$[297,319]
!thru B1F
190 END
```

Note that the last character to be displayed is number 319 since the Terminators (CR)(LF) have to be input but not displayed. This program results in the following output of the Sensor Curve Information Table.

```
3584 BYTES FREE,
0200 IS NEXT LOCATION,
00,31,1D40,DRC-D ,
01,31,1DF0,DRC-E1,
02,31,1EA0,CRV 10,
03,31,1F50,DIN-PT,
04,31,2000,CRV 10,
05,31,20B0,RESVRD,
02,02,02,02,02,02,02,02,
02,02,02,02,02,02,02,02,
02,02,02,02,02,02,02,02,
02,02,02,02,02,02,02,02,
02,02,02,02,02,02,02,02,
02,02,02,02,02,02,02,02,
02,02,02,02,02,02,02,02,
02,02,02,02,02,02,02,02
```

4.16.2 The XDN$_1$N$_2$ Command

The XDN$_1$N$_2$ command is used to output a particular Sensor Curve (rather than all the curves stored within the instrument as in the XDA command) with N$_1$N$_2$ being the curve number 00 thru 31. The format of the Sensor Curve output is given in Table 4-18. The information is output as **one very long character string**. The following program is for the HP86B and is an example of the XDN$_1$N$_2$ to output Sensor Curve 00.

```
10 REM Program to output Curve
Table
20 DIM Curve$[462]
30 OUTPUT 720;"XD00"
40 ENTER 720;Curve$
50 REM Display Curve #, Title,
Temperature
60 REM Coefficient and Number of
Breakpoints 70 DISP Curve$[1,27]
80 REM Display voltage and temp
data points
90 I=28
100 DISP Curve$[I,I+41] ! Voltage;
Temp.
110 IF I=447 THEN 140 ! I=477 for
D.Pnt 31
120 I=I+42
130 GOTO 100
140 DISP Curve$ [448,460]
150 END
```

Table 4-16. Sensor Curve Commands and Description

Commands	Output of Information Table, Sensor Curve or All Curves
XDT	Output the Sensor Curve Information Table. Refer to Table 4-17 for the format of the output.
XDN_1N_2	Output Sensor Curve number N_1N_2 where N_1N_2 is from 00 to 31. Refer to Table 4-18 for the format of the Sensor Curve output.
XDA	Output the Sensor Curve Information Table (XDT) and all the Sensor Curves stored in the unit. Refer to Table 4-17 for format of the Information Table output and Table 4-18 for format of the Sensor Curve output.
	Curve Input, Curve Edit and Curve Erasure
XCN_1N_2, $C_1....C_{18}$, X.XXXXX,TTT.T, ... *	Sensor Curve Input. N_1N_2 is Sensor Curve number from 06 to 31. Immediately after Sensor Curve cmmnd XCN_1N_2 a comma is required. Up to 18 characters can be input as a curve description. When all 18 characters are input, the last 6 are used in the Sensor Curve table (in the 8000 Series Precision Option curves these 6 characters are used to indicate the sensor serial no.) The 18 characters must be immediately followed by a comma. The data is input in units/temperature pairs with the units in the form of Voltage, R_{equiv} or LogR. Data points <u>**must**</u> be entered in ascending units order. The * character terminates the Sensor Curve input.
XEN_1N_2, X.XXXXX,TTT.T*	Edit Sensor Curve N_1N_2. The point is either inserted in its proper position in the curve or it is added to the curve as a new data point.
XKN_1N_2*	Erases (kills) Sensor Curve N_1N_2 and repacks all curve data (Standard Curves 00 thru 05 cannot be erased).
XR&I*	Command sent five times will delete all Precision Options and any curves stored in unit by user.
	Assignment of Curve # to Position # in Correlation Tables
$XAC_1C_2=N_1N_2$* $XBC_1C_2=N_1N_2$*	Assign the Input A or Input B Remote Position C_1C_2 to Sensor Curve number N_1N_2. C_1C_2 is the Remote Position 00 thru 1F. N_1N_2 is the Sensor Curve number 00 thru 31 This Command modifies the Remote Position to Sensor Curve Correlation Table 3-3 (and XDT output data).

NOTE: The * added to the end of the XAC_1C_2, XBC_1C_2, XCN_1N_2, XEN_1N_2 and XK commands is required for the command to operate properly. Due to the length of some of the data strings, appropriate computer time outs must be allowed when performing these functions. If a hardware problem is detected in modifying one of the NOVRAM locations, an **Err01** error will be displayed and instrument operation is halted. An **Err02** error is displayed if the unit detects a NOVRAM hardware problem.

Table 4-17. Sensor Curve Information Table Output Format

Command	Output
XDT	$N_1N_2N_3N_4$(BYTES FREE)(,) $H_1H_2H_3H_4$(IS NEXT LOCATION)(,) (00)(,)(31)(,)(1D40)(,)(DRC-D)(,) (01)(,)(31)(,)(1DF0)(,)(DRC-E1)(,) (02)(,)(31)(,)(1EA0)(,)(CRV 10)(,) (03)(,)(31)(,)(1F50)(,)(DIN PT)(,) (04)(,)(31)(,)(2000)(,)(CRV 10)(,) (05)(,)(31)(,)(20B0)(,)(RESVRD)(,) . (31)(,)......................(,) C_1C_2(,)C_1C_2(,)C_1C_2(,)C_1C_2(,)C_1C_2(,)C_1C_2(,)C_1C_2(,)C_1C_2(,) C_1C_2(,)C_1C_2(,)C_1C_2(,)C_1C_2(,)C_1C_2(,)C_1C_2(,)C_1C_2(,)C_1C_2(,) C_1C_2(,)C_1C_2(,)C_1C_2(,)C_1C_2(,)C_1C_2(,)C_1C_2(,)C_1C_2(,)C_1C_2(,) C_1C_2(,)C_1C_2(,)C_1C_2(,)C_1C_2(,)C_1C_2(,)C_1C_2(,)C_1C_2(,)C_1C_2(,) C_1C_2(,)C_1C_2(,)C_1C_2(,)C_1C_2(,)C_1C_2(,)C_1C_2(,)C_1C_2(,)C_1C_2(,) C_1C_2(,)C_1C_2(,)C_1C_2(,)C_1C_2(,)C_1C_2(,)C_1C_2(,)C_1C_2(,)C_1C_2(,) C_1C_2(,)C_1C_2(,)C_1C_2(,)C_1C_2(,)C_1C_2(,)C_1C_2(,)C_1C_2(,)C_1C_2(,) C_1C_2(,)C_1C_2(,)C_1C_2(,)C_1C_2(,)C_1C_2(,)C_1C_2(,)C_1C_2(,)C_1C_2 [TERM1][TERM2] A minimum of 321 Characters (when only the 6 Standard Curves are present) and a maximum of 805 Characters (when all 32 Curves are present) plus up to 2 Terminators where: $N_1N_2N_3N_4$ is the decimal number of curve locations available (BYTES FREE). $H_1H_2H_3H_4$ is the Hex address the next curve will start at. C_1C_2 is the Sensor Curve assigned to Remote Position A00 through A1F and B00 through B1F.

Table 4-18. XDN_1N_2 Sensor Curve Output Format

Command	Output
XDN_1N_2	N_1N_2(,) C_1..........C_{18}(,)C_{19}(,)N_3N_4(,) (X.XXXXX)(,)(TTT.T)(,) . (X.XXXXX)(,)(TTT.T) A minimum of 54 Characters (for a curve with the minimum of 2 data points) and a maximum of 1412 Characters (for a curve the maximum of 97 data points) plus up to 2 Terminators where: N_1N_2 is the Sensor Curve number 00 thru 31. C_1-C_{18} is the 18 Character Information line. C_{19} is the Temperature Coefficient, P or N. N_3N_4 is the number of data points 00 thru 99. X.XXXXX is the Voltage, Equivalent V or Log R. TTT.T is the Temperature to 0.1 only.

Note that the last character to be displayed is number 460 since the Terminators (CR)(LF) have to be input but not displayed. This results in the following display.

```
00,     STANDARD DRC-D ,N,31,
0.00000,499.9,0.19083,365.0.0.24739,345.0,
0.36397,305.0,0.42019,285.0,0.47403,265.0,
0.53960,240.0,0.59455,220.0,0.73582,170.0,
0.84606,130.0,0.95327,090.0,1.00460,070.0,
1.04070,055.0,1.07460,040.0,1.09020,034.0,
1.09700,032.0,1.10580,030.0,1.11160,029.0,
1.11900,028.0,1.13080,027.0,1.14860,026.0,
1.07200,025.0,1.25070,023.0,1.35050,021.0,
1.63590,017.0,1.76100,015.0,1.90660,013.0,
2.11720,009.0,2.53660,003.0,2.59840,001.4,
6.55360,000.0
```

The N indicates that the silicon diode is a negative temperature coefficient device. For the platinum curve (03), which is a positive temperature coefficient device, a P will appear in that position.

4.16.3 The XDA Command

The XDA command asks for the output of the Sensor Curve Information Table as well as **all** the Sensor Curves stored in the unit. When the command XDA is used, the 93C will output the Information Table formatted as in Table 4-17 followed by a comma (in place of the Terminators) followed by each Sensor Curve in ascending order with a comma between each Sensor Curve (in place of the Terminators) as in Table 4-18 until all the curves have been output followed by the Terminators. The information is output as **one very long character string**.

4.16.4 The XCN_1N_2 Command

The XCN_1N_2 command is the most powerful curve command in the 93C. It allows for the remote input of Sensor Curves. The Sensor Curves that can be input using the XC command are 06 thru 31 (note that the first five curves 00 thru 04 are the Standard Curves with Curve 05 reserved). The format for the XC command is given in Table 4-16. The format for the XC command **must** be followed for the curve entry to be successful. Following the XCN_1N_2 (where N_1N_2 is between 06 and 31) is a comma. Then up to 18 characters can be entered as a curve information line. At least one character is required and any more than 18 characters are ignored. If 18 characters are input, the last 6 are used in the Sensor Curve Information Table as a capsule description of the curve (in the 8000 Series Precision Option curves these 6 characters are used to indicate the sensor serial number). The 18 characters must be immediately followed by a comma. The data points are then input in the form X.XXXXX, comma, TTT.T. The X.XXXXX input is in Voltage or LogR. Refer to Table 4-19 for the conversion of the raw units information into the format required for the XC command. The unit automatically fills in leading and trailing zeroes in the data point. A data point entered as ...,0.8,70,... would be converted by the unit into

...,0.80000,070.0,... . The data points **must be entered in ascending units order**. After all the data points are entered the (*) character terminates the Sensor Curve input.

Following the input of the (*) to indicate to the unit that the there are no more data points, it determines and stores whether the curve is a positive or negative temperature coefficient curve. Based on temperature coefficient, the unit then stores the curve end points. For a negative temperature coefficient curve the first end point is 0.00000,499.9 and the last end point is 6.55360,000.0. For a positive temperature coefficient curve the first end point is 0.00000,000.0 and the last end point is 6.55360,999.9. Therefore, the minimum number of data points which the user can input for a curve is 1 (which would result in a 3 data point curve) and the maximum number of data points is 97 (which would result in a 99 point curve). The XC information **must be output to the unit as one very long character string**.

The first character of the 18 character management string indicates the type of breakpoints to be entered. If the character is an "L", then the unit performs Lagrangian calculations on the data. If the character is anything else, the unit performs Straight-Line interpolation on the data. See Appendix B for a description of the difference between the two. In addition, sensor type and temperature range is included in this 18 characters as well.

Curves 06 thru 31 are stored in Non-Volatile RAM (NOVRAM) where the first 0200 hex bytes are reserved for file management. There are 3584 bytes free for the storage of curves. If the curve stored has 31 data points, it will take up 177 bytes. For this length curve, up to 20 curves can be stored in the unit. Refer to Appendix B for additional information on curve entry and how the curves are generated.

4.16.5 The XEN_1N_2 Command

The command XEN_1N_2,X.XXXXX,TTT.T* either adds a point to or edits the N_1N_2 curve (provided that this curve is present). The * terminates the data point input. If either the units or temperature information matches one of the data points in the curve the curve data point edited to match the XE data point If the information does not match any of the data points for the curve, the unit inserts the point in its proper position in the table.

4.16.6 The XKN_1N_2* Command

The command XKN_1N_2* erases all the data associated with curve number N_1N_2 and repacks the remaining curves stored within the NOVRAM. Standard Curves 00 thru 05 are stored in a Prom and are not erasable by this command.

4.16.7 The XAC_1C_2=N_1N_2* and XBC_1C_2=N_1N_2* Commands

The XA an XB commands allows Table 3-4 which defines the correlation between the Remote Position and Sensor Curves for the REMOTE SENSOR ID. Note-that this correlation exists for both inputs and normally only one input would select the REMOTE SENSOR ID position data. Once this data has been changed, it would be good practice to read out the changed table by means of the XDT command and update Table 3-4. C_1C_2 is the hex Remote Position, 00 thru 1F, and N_1N_2 is the decimal curve number 00 thru 31.

Table 4-19. Conversion of Raw Units Data for the XC Command

Input Card	Units	Conversion
9210/20-3 9210/20-6	Voltage	Input range is 0.00000 to 6.55350 volts. No conversion is necessary.
9215	Capacitance	No conversion to temperature is allowed
9317C 9318C	Resistance	Input range is 1 to 10^4 Ω for the 9317C, 1 to 10^5 Ω for the 9318C. Input must be in Log R where 1 Ω would look like 0.00000 and 10^5 Ω would look like 5.00000.
9220-P2	Resistance	Input range is 0.00 to 299.99 ohms. 0.00 ohms looks like 0.00000 and 299.99 ohms looks like 2.99990 (0.01 times R).
9220-P3	Resistance	Input range is 0.0 to 2999.9 ohms. 0.0 ohms looks like 0.00000 and 2999.9 ohms looks like 2.99990 (0.001 times R).
9220-R1	Resistance	Input range is 0.00 to 100.00 ohms. 0.00 ohms looks like 0.00000 and 100.00 ohms looks like 3.00000 (0.03 times R).

SECTION V

MAINTENANCE

5.1 INTRODUCTION

This section contains information necessary to maintain the Model DRC-93C. General maintenance, fuse replacement, line voltage selection and performance testing is contained in this section.

5.2 GENERAL MAINTENANCE

Clean the DRC-93C periodically to remove dust, grease and other contaminants. Use the following procedure:

1. Clean the front and back panels and case with a soft cloth dampened with a mild detergent and water solution.

Note: **DO NOT** use aromatic hydrocarbons or chlorinated solvents to clean the DRC-93C. They may react with the plastic materials used in the unit or the silk screen printing on the back panel.

2. Clean the surface of the printed circuit boards (PCB) using clean, dry air at low pressure. If grease is encountered, spray with Freon T.F. degreaser and remove grime with dry, low-pressure air.

5.3 FUSE REPLACEMENT

The line fuse is accessible from the rear of the DRC-93C. Use the following procedure to check and/or replace the fuse:

WARNING

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

1. Set the POWER switch to OFF and disconnect the power cord from the unit. The fuse compartment is located just to the right of the power connector.
2. Open the fuse compartment by prying open the cover with a small screw driver.
3. Remove the lower fuse holder by sliding it out of its position with the aid of the small screw driver.

CAUTION

For continued protection against fire hazard, replace only with the same type and rating of fuse as specified for the line for the line voltage selected.

4. Replace the fuse per Table 2-1.
5. Replace fuse holder, close fuse compartment and connect power cord.

5.4 LINE VOLTAGE SELECTION

The rear-panel, three-pronged line power connector permits the DRC-93C to be connected to 100, 120, 220, or 240 VAC line voltages. Use the following procedure to change the line voltage:

WARNING

> To prevent shock hazard, turn off the instrument and disconnect it from AC line power and all test equipment before changing the line voltage selection.

1. Pull fuse compartment cover using the procedure found in Section 5.3.
2. Remove voltage selector wheel and insert with the proper voltage facing out. Note that the wheel can only be inserted with the writing read from the left.
3. Install the proper fuse as outlined in Section 5.3.

5.5 OPERATIONAL CHECKS

5.5.1 Test Connector

A test connector for the rear panel J1 INPUT A or J2 INPUT B connector to simulate a diode sensor input is required for operational checks of the DRC-93C. The test connector can be made by taking one of the plugs supplied with the DRC-93C and configuring a resistor to simulate the temperature sensor in the two wire configuration as described in Section 2.3.6. The test resistors specified in Table 5-1 are used in the operational checks.

5.5.2 Operational Test Procedure

The operational test procedure is designed to verify the overall operation of the DRC-93C and can be used as a periodic maintenance check. The following equipment is used in the test.

1. Digital Voltmeter - 4½ digit resolution or better.
2. Test Connector - fabricated per Section 5.5.1.

Complete the following set-up procedure for this test:

1. Plug the connector into INPUT A.
2. Connect the DVM across the test resistor of Input A.
3. Connect the DRC-93C to line power and turn the unit ON. Verify that the DRC-93C initializes to the proper POWER-ON state as defined in Section 3.7.

The following procedure is used to test the overall DRC-93C operation.

Note: The unit should be allowed a one-hour warm-up time to achieve rated specifications.

5.5.3 Current Source Check

The DVM across the test resistor should read as follows:

9210/20-3	1.0000V $\pm$ 100μV
9210/20-6	1.0000V $\pm$ 100μV
9220-P2	0.10000V $\pm$ 10μV
9220-P3	0.10000V $\pm$ 10μV
9220-R1	0.03000V $\pm$ 10μV
9317C	N/A
9318C	N/A

5.5.4 Monitor Voltage

The voltage across the sensor or test resistor is also available on the monitor plug. The connections are given in Section II of this manual. The monitor voltage will be equal to the sensor voltage for 3 volt (-3) diode inputs and all platinum (-P2, -P3) and rhodium iron (-R1) inputs. If the input is a GaAlAs Diode (-6) input then the monitor voltage will be 0.458 times the sensor voltage. This test is not applicable for the 9215, 9305, 9317C or 9318C input cards.

5.5.5 Temperature Display

5.5.5.1 Determine Input Type - The first step to check the instrument's display and operation is to determine the type of sensor input.

a. The type of input option card(s) installed in the DRC-93C is located on the front page of every DRC-93C manual.

b. The DRC-93C displays the type of input card(s) installed in the A and B inputs sequentially when the instrument is powered on. Possibilities are 9210-3, 9210-6, 9215-30, 9215-150, 9220-3, 9220-6, 9220-P2, 9220-P3, 9220-R1, 9305, 9317C or 9318C.

c. The type of input can also be displayed by holding down the SENSOR key.

5.5.5.2 Check units display- Verify that the A units can be changed by holding in the UNITS key and using the ▲▲ or the ▼▼ to scroll through the sequence K, C, F, V, K, etc. (Note: the unit goes to V for a diode configuration 9210-3, -6 or 9220-3, -6) or Ω for a resistance card configuration (9220-P2, -P3, -R1 or 9317C/ 9318C Input card).

5.5.5.3 Check sensor units reading Next, check to see if the instrument is reading the correct sensor units (volts, ohms or nanofarads) value for the appropriate test resistor or capacitor from Table 5.1. The reading should match the value given in the Display in Sensor Units column of Table 5-1. The allowable error is provided in the Input A/D Accuracy column.

5.5.5.4 Check temperature reading- Confirm that the temperature in kelvin displayed corresponds to the selected curve number.

a. Check the Sensor Curve Table (Table 3-2 or below) to determine the curve number that selects the standard curve or precision option that is needed. A 9215 card will not read temperature. The 9317C/9318C will not read accurately in temperature unless a precision option is present.

b. Select the curve as described in Section 3-9.

Curve No.	Switch 45678	Temperature Displayed,K	Curve
00	00000	71.79	DRC-D
01	00001	71.42	DRC-E1
02	00010	87.77	CRV 10
03	00011	273.1	DIN-PT
04	00100	87.77	CRV 10

5.5.5.5 Check Input B - Change the connector from J1 INPUT A to J2 INPUT B. Repeat the above process by verifying the current source and the A/D settings for this input as well as the units change.

5.5.6 Heater Output Test

5.5.6.1 Heater Output Conditions- The heater should output power when the setpoint temperature is above the display temperature, as long as the heater is on and a gain value has been entered. If the sensor is a diode, the voltage across the device will change inversely with temperature. Therefore the higher the voltage the lower the temperature. For Platinum sensors the resistance increases as the temperature increases. Germanium and carbon glass sensors are negative temperature coefficient resistance sensors which vary several orders of magnitude in resistance with temperature.

5.5.6.2 Test Setup - Test the heater by placing an appropriate test resistor (see Table 1) into the control sensor input, and place a 10 ohm (at least 10 watts) up to 50 ohm (at least 50 watts) resistor across the heater terminals.

5.5.6.3. The Heater Display - The heater display is shipped from the factory reading the percent of power out. If the heater is 10 ohms then at 100 percent output current, the heater will have 1 amp through it and 10 volts across it. If the heater bar graph is reading 50% then the instrument is delivering 5 watts (0.707 amps and 7.07 volts) to the 10 ohm load. If the unit is reading in current a reading of 50 will mean 2.5 watts (0.5 amps and 5 volts). The heater display can be changed from power to current by switching internal dip switch S4-1.

5.5.7 Checking Gain, Reset and Rate

Check the operation of the Gain, Rate and Reset as follows:

1. Place a dummy load into the selected sensor input.
   a. 50K to 100K for a diode.
   b. Short V^+ to V^- for 9317C or 9318C Input Card.
   c. 10nF capacitor for 9215 Input Card.

2. Place a 10 ohm, 10 watt (or greater) resistance load on the heater terminals.

3. Set the Display Units to Sensor Units, i.e., volts, ohms or nanofarads.
   a. If 9210-3/20-3 enter a volt age 0.01 volts less than the display.
   b. If 9317C or 9318C, enter a resistance of 1 ohm for the set point.
   c. If 9215 enter 11nF set point.

5.5.7.1. Gain - Enter a gain value. The heater display should now indicate that power is being delivered to the heater. The amount of power is a scaled factor of the error signal times the gain ([Sensor voltage - Setpoint voltage] * Gain). If the setpoint temperature is increased or the gain is increased the output power will increase.

Keep the LO lead of the DVM at TP1 and move the HI lead to TP29. Turn off the GAIN, RATE and RESET by entering a value of 0.0 for each. The DVM will now read approximately 0.0 volts. Change the GAIN to 1.0 and the DVM will read approximately 0.1 volts which is the error 0f 0.01 times the gain of 10. Change the GAIN to 10 and the DVM will read approximately 1 volt. Setting the GAIN to 99 will result in a reading of approximately 7.2 volts.

5.5.7.2 Reset - Set up the controller as instructed in step 5.5.6.1. Enter a gain and setpoint value that results in less than full power to the load. If a Reset value is now entered, the instrument will try to integrate out the error. With a test resistor in the control sensor input and a fixed setpoint, the error signal will be constant. With a constant error the Reset will continue to increase the analog output control signal until the heater display reads 100 percent. If the heater output increases to approximately 100 percent for these conditions the reset circuit is operating.

To check the RESET circuit in more detail use the same set point and a GAIN of 10. Move the HI lead of the DVM to TP30 and enter a RESET of 1.0. The reading on the DVM should gradually integrate to approximately 7.2 volts. The time required will depend on the amount of reset with time required being the shortest for higher settings. Next, turn the reset off and make sure that the reading returns to 0.0 volts.

5.5.7.3 Rate - The operation of the Rate can not be observed without measuring voltages in the unit.

To check the RATE move the DVM HI lead to TP31, keep the GAIN at 10, turn the RESET off (0.0) and enter a RATE to 99. The DVM should read 0.0 volts. Quickly change the set point value from approximately equal to the display value to a value 20% higher in equivalent kelvin temperature, e.g. from 1.00 volts to 0.80 volts. The DVM should show a positive transient whose peak value will lie between 0.1 and 7 volts depending on the rate at which you change the set point, the amount of gain, the speed at which you change the voltage as well as when the reading is read by the DVM. For the change from .80 to 1.00 the reading will be negative in value.

The GAIN, RATE and RESET values are summed together before the heater drive circuit with the GAIN being multiplied by two in signal strength before summation. The sum of the three terms can be measured at TP28 ANA OUT.

5.5.8 Checking the Heater Ranges

5.5.8.1 Standard 50 Watt output - Set up the unit so that 100 percent is output to the heater load. At full power out on the Max scale 1 amp should be through the resistor, as long as the resistor is 50 ohms or less. The heater circuit has a compliance voltage limit of 50 volts, so a resistor larger than 50 ohms will limit the current to 50 divided by the load's Resistance. If the next lower range (-1) is selected then the heater will put 0.33 amperes through the resistor at 100 percent. The -2 range will output 0.10 amperes at full scale output. At the -3 range the output will be 0.033 amperes full scale and at the -4 range the output will be 0.001 amperes

5.5.8.2 W60 Watt Option - If the unit has a W60 output option the Max scale has a 1.55 amp, 40 volt limit. If a 25 ohm resistor is used the controller will supply 60 watts to the load. If a 100 ohm resistor is used on the Max scale the unit will output 40 volts at 0.4 amps or 16 watts. The lower ranges are scaled as explained in 5.5.7.1 above except the voltage limit is 43 volts.

NOTE: The values given above are nominal values. If they are slightly off it should not effect operation since the heater circuit is part of a feedback loop.

5.6 CALIBRATION

The adjustments and test points referred to in this section are labeled on the instrument calibration cover. Remove the two top panel screws and slide the top cover off to gain access to the adjustments and test points.

Note: The unit should be allowed a one-hour warm-up time to achieve rated specifications. This calibration procedure is for a DRC-93C with standard diode A and B inputs. For other configurations, refer to Section VII for the specific Input Card present in the unit.

5.6.1 Input Card Calibration

Calibrate each input card as specified in Section VII for that card.

5.6.2 Set Point Voltage Calibration

Calibrate the Set Point Voltage as follows:

1. Remove the instrument cover.

2. Calibrate with the Control Switch selecting either a 9210 or 9220 Input Card and the -3 configuration. If the DRC-93C does not contain one of these input cards, calibrate the set point by following the procedure described with that Input Card.

3. To calibrate the Set Point voltage with a 9210 or 9220 card, connect the LO lead of your DVM to TP1 and the HI lead to TP25 SP V.

4. Enter a set point of 0.0000V and adjust the potentiometer labeled SP ZERO ADJ until the DVM reads 0.0000 volts.

5. Enter a set point of 2.7000V and adjust the potentiometer labeled SP SPAN ADJ until the DVM reads -2.7000 volts.

6. Repeat the two settings until the values are constant.

5.6.4 Calibration of Power Output

If the heater output is not the standard 50 watts for the DRC-93C, the optional power output installed should be indicated on the front page of this manual.

1. Verify that the back panel HEATER RESISTANCE switch is on 10-25 and use a load resistor between 10 and 25 ohms with a wattage rating equivalent to its resistance. The W60 output requires a load between 10 and 25 ohms with a wattage rated 1.5 times the resistance value.

   Set a set point and gain value which results in full scale output on the MAX Heater Range scale.

2. With full power across the load resistor on the -1 scale, place the DVM LO probe in TP19 PWR V+ and the DVM HI probe in TP21 and adjust PWR V+ until the DVM reads 1.000 volts. There now should be one ampere through the load (1.5 amperes in the case of the W60). The heater can now be turned off.

3. Place the DVM LO into TP15 PWR V- and the DVM HI into TP17 HTR V+ and adjust PWR V- ADJ until the DVM reads 1.0000 volts.

4. Place the DVM LO into TP20 PWR LO and the DVM HI into TP16 VREF and adjust PWR VREF until the DVM reads 1.0000 volts.

5. Repeat 3 and 4 until they do not change.

Note: TP 24 CNT V is the control voltage. For the 9210/20-3 it is the voltage across the sensor; for the 9210/20-6 it is 0.45 times the voltage across the sensor. TP 25 is the set point voltage and is of opposite sign from TP 24. These two voltages algebraically sum to the error signal.

5.7 TROUBLESHOOTING

Information on troubleshooting the Model DRC-93C controller is contained in this Section.

5.7.1 Sensor Current

If the sensor current is not within specifications (Section 5.5.3) then adjust the current trimpot on the input card (Section VII).

5.7.1 Monitor Voltage, Display Voltage or Resistance

The display reading in volts or resistance should match the monitor reading and the voltage across the sensor, except for the 9215, 9305, 9317C and 9318C input cards and the -6 configuration. If the readings do not match then the input card should be calibrated. If the monitor reading is incorrect and can not be adjusted then the following IC's may need to be replaced.

"Old" Input cards

1. 8210, 8211 cards - replace U5
2. 8219, 8220 cards - replace U5. If that does not solve the problem then replace U4.

"New" Input Cards

1. 9210, 9220 cards - replace U5
2. For the 9318C, the monitor voltage should be approximately ±10mV. If it is not between 5-16mV then U16, U13 or U10 could be bad. For the 9317C the monitor voltage should be approximately a factor of ten lower. The same three IC's are involved.

If the monitor voltage is incorrect, the input card may control at an offset or not at all.

If the sensor voltage matches the monitor voltage and the display voltage is incorrect then the A/D needs to be calibrated.

5.7.2 Units Display is correct but temperature reading is incorrect

If the units display matches the voltage or resistance value of the sensor, but the temperature display is incorrect then check the curve selected. This can be accomplished by holding down the CURVE# button or by reading the selected curve over the interface using the W1 command.

If the correct curve is selected, but the display in temperature is still incorrect, then check the data in the curve. This can be done over the IEEE by using the test program and the XDN_1N_2 command.

5.7.3 The Heater Circuit

If the DRC-93C does not have output power check to see that U13 on Figure 93C-1C (the LM317HVK) is tightly screwed into its heat sink. It is on standoffs near the fan in the left rear of the unit.

Configure the DRC-93C as in Section 5.5.6.2. Verify that there is heater current going to the load resistor.

Next, measure the analog out signal to be sure the PID circuits are operating correctly. The analog out signal can be measured at TP28 (Gnd at TP1). If this is a positive value that varies from 0-7.3 volts as the gain setpoint, or reset values are changed then the circuit is probably operating correctly. Now measure the voltage across from TP19 to TP21. The voltage should vary from 0 to 1 volt as the analog out signal varies from 0 to 7.3 volts. As the gain or manual heater is increased the analog signal will increase and the voltage between TP19 and TP21 will in-crease. If the voltage stays at 0 Volts then U45 or U46 is probably bad as long as the raw V+(TP21 to TP6) is close to 28 volts for the 10-25 Ohm Heater Range (37 and 53 volts for the 25-35 and 35-50 Ohm Heater Ranges respectively). The V+ can be checked by measuring approximately 28V from TP21 to TP1. The V+ value is 50 Volts if a W50 watt option is installed in a DRC-91C or if the resistor setting is 50 ohms on the DRC-93C. If a W60 Watt option is installed the V+ voltage should be approximately 44 volts.

NOTE: DO NOT CHANGE the Heater Range switch when the unit is on. Changing this switch with the unit on WILL DAMAGE the unit.

If the Voltage from TP19 to TP21 is correct, and there is no heater power on any range than U47 or U48 are probably bad and both should be replaced. Before it is decided that U47 and U48 are bad be sure the relays K4-K8 are working. If they can be heard clicking as they are turned off and on, then they are probably operating properly. They are turned off and on by selecting different heater ranges.

Table 5-1: Input Card Characteristics

Sensor Input	Sensor Type	Temp Range and Units Range	Sensor Current	Input A/D Resolution	Input A/D Accuracy	Test Resistor	Display in Sensor Units	Standard Curves	Display with Std Curves (K)
8210 9210-3 9220-3	Si Diodes	1.4 to 475K 0-2.9999V	10μA	0.05mV	±0.1mV	100kΩ 0.01%	1.0000V	DRC-D (00) DRC-E1(01) CRV 10(02) CRV 10(04)	71.79 71.42 87.77 87.77
9210-6 9220-6	GaAlAs Diodes	1.4 to 325K 0-6.5535V	10μA	0.1mV	±0.2mV	100kΩ 0.01%	1.0000V	no std crv see note 3	
8219-P2 9220-P2	100Ω Pt RTD	14 to 800K 0-299.99Ω	1mA	0.005Ω	±0.01Ω	100Ω 0.01%	100.0Ω	Din 43760 (03)	273.1
8219-P3 9220-P3	1000Ω Pt RTD	14 to 800K 0-2999.9Ω	0.1mA	0.05Ω	±0.1Ω	1000Ω 0.01%	1000Ω	Din 43760 (03)	273.1
8219-R1 9220-R1	RhFe RTDs	14 to 800K 0-99.999Ω	3mA	0.003Ω	±0.01Ω	10Ω 0.01%	10.00Ω	no std crv see note 3	
9317C	Ge CGR	0.3 to 100K see note 1 1.4 to 325K 1 to 10,000Ω	see note 2	1 in 10^4	±0.1% fr 10-1000Ω ±0.5% fr 1k-100kΩ	100Ω 0.01%	100.00Ω	no std crv see note 3	
9318C	Ge CGR	1.4 to 100K see note 1	see note 2	1 in 10^4	±0.05%fr 10-10kΩ ±0.25%fr 10k-100k	100Ω 0.01%	100.00Ω	no std crv see note 3	

Note 1: The lower temperature limit is dependent upon resistance-temperature characteristic of sensor used.
Note 2: 0.1μA to 1.0mA. Sensor voltage pinned at 1mV (9317C) or 10mV (9318C).
Note 3: To read correctly in temperature these input cards must be used with calibrated sensors and the 8001 precision option.
Note 4: 9317C and 9318C will read to 1 ohm full scale with reduced accuracy.

REPLACEABLE PARTS LIST - DRC-93C MAIN BOARD

ITEM NO	LSCI Part Number	Qty	Description	MFR	MFR PART NO
C1	101-275	1	CAP,ELECT,9500MF,15V	MEP	3188BA952U015AMA1
C2,6,10 7,13,16 18,20, 26,28	101-225	10	CAP,ELECT,470MF,35V	PAN	ECEAIVV471S
C23	101-238	1	CAP,ELECT,2100MF,75V	MEP	3186BA212U075AMA1
C40,42 46,50	101-034	4	CAP,PP,1MF,100V	FDYNE	MPP2X-1.0-100-10
CR2-6, 11	102-008	6	BRIDGE RECTIFIER	GI	W02M
CR7-10 26-29	102-003	8	DIODE RECTIFIER	MOT	MR501
CR12,13	102-001	2	DIODE RECTIFIER	MOT	1N4006
CR19	102-058	1	DIODE, ZENER 24V	MOT	1N4749A
CR20	102-053	1	DIODE, ZENER 5.1V	MOT	1N751A
J4	106-310	1	CONNECTOR (IEEE)	AML	57-92245-12
J5	106-412	1	CONNECTOR (REMOTE ID)	TBAN	609-1602M
JA1,2	106-146	2	CONNECTOR (TX1 TO MB)	MOL	2630-09-74-1091
JC1,2	106-139	2	CONNECTOR (TX2 TO MB)	MOL	2630-09-74-1041
JF	106-143	1	CONNECTOR (BP TO MB)	MOL	2630-09-74-1061
JG,JH	106-129	4	CONNECTOR POSTS	SAMT	TSW-120-04-06
K1,2	106-321	2	RELAY,DPST,DRY REED	COTO	CR-3402-05-91
K3-K7	105-302	5	DRY REED RELAY, 20 W	EAC	B1A5AH
K8	105-304	1	DRY REED RELAY, 50 W	EAC	P1A5A
Q1	102-072	1	TRANSISTOR, PNP	MOT	2N3906
R35,36	113-063	2	RES,PREC,100K,.01% MATCHED PAIR	LSCI	
R63	103-209	1	RES,MTF,30.1 ,1/4W,1%		
R64	103-495	1	RES,MTF,9.84 ,1/4W,1%		
R65	103-540	1	RES,MTF,2.92 , 1 W,1%		
R66	103-586	1	RES,MTF,3.5 , 3 W,1%		
R67	103-583	1	RES,MTF,1.25 , 3 W,1%		
R76	103-675	1	RES,WWD,587 , 5 W,1%		
S1	105-014	1	POWER SWITCH (2 POLE)	ITT	F-01-2UEE/NE15-1B
S3,5,7	105-408	3	DIP SWITCH 8 POS	GYH	76SB08
SL0-3	106-229	4	CONNECTOR (25/50)	BRDY	PWBH25DBF1F
SL4-6	106-227	3	CONNECTOR (18/36)	BRDY	PWBH18DBS1B
U2,10	102-011	2	REGULATOR, +5V	MOT	MC7805ACT
U3	102-021	1	REGULATOR, -5V		7905CT
U4,7 11,12 14	102-014	5	REGULATOR, +15V		7815CT
U5,8,15	102-024	3	REGULATOR, -15V		7915CT
U6	102-012	1	REGULATOR, +8V		7808CT
U9	102-022	1	REGULATOR, -8V		7908CT
U13	102-036	1	REGULATOR, ADJ, 1.2-57V	NAT	LM317HVK-STEEL
U16	104-712	1	IC, IEEE CHIP	TI	TMS9914ANL
U17	104-710	1	IC, IEEE SUPPORT CHIP	TI	SN75160AN
U18	104-711	1	IC, IEEE SUPPORT CHIP	TI	SN75161AN
U19,20	104-529	2	IC, PORT EXPANDER	INT	82C55A-5
U21	104-310	1	IC, 8 BIT MULTIPLEXER	NAT	81LS95
U22	104-419	1	IC, 16 BIT D/A CONVERTER	BB	DAC703BH-5
U23	104-061	1	IC, DISPLAY DRIVER	NAT	MM5480N
U24-27	104-408	3	IC, 10 BIT D/A CONVERTER	ISL	AD7533JN
U28	104-076	1	IC, DUAL SPDT ANL SWITCH	HAR	HI5043-5
U29,30 32	104-088	3	IC, QUAD OP AMP	TSC	TSC914A
U31	104-162	1	IC, DISPLAY DRIVER	NAT	MM5451N
U33-37 43	104-355	6	IC, OPTOCOUPLER	GI	740L6000
U38	104-356	1	IC, OPTOCOUPLER	GI	740L6010
U39	104-453	1	IC, 8 BIT A/D CONVERTER	NAT	ADC0831CCN
U40,41	104-210	2	IC, HEX INVERTER, O.C.		7406
U42,44	104-010	2	IC,LIN,F/V OR V/F	NAT	LM331N
U45	104-022	1	IC, OP AMP, JFET INPUT	NAT	LF356N
U46	102-104	1	POWER MOSFET, 90V N-CH	SPTX	VN0109N5
U47	104-068	1	IC, OP AMP, DUAL MC1741	MOT	1458PI
U48	102-095	1	POWER MOSFET, 100V P-CH	IR	IRF9130
W1		1	CABLE (MB TO U1)	LSCI	
XU13	106-571	1	SOCKET, TO-3	AUG	M8080-1G40

REPLACEABLE PARTS LIST - DRC-93C

ITEM NO	LSCI Part Number	Qty	Description	MFR	MFR PART NO
MP3	113-131	1	CONNECTOR KIT consisting of	LSCI	113-131
	106-010	2	5 PIN PLUG - MATE TO J3:	AML	126-127
	106-012	1	7 PIN PLUG - MATE TO J5:	AML	126-195
	106-414	2	16 PIN IDC SOCKET	TBA	609-1630
	106-415	2	16 PIN STRAIN RELIEF	TBA	609-1631SP
	107-017	1	RMA INSERTS	LSCI	107-017
	115-006	1	POWER CORD		
	110-014	1	FUSE: 1.0A SB (115 VAC)	BUS	MDL-1
			0.5A SB (230 VAC)	BUS	MDL 1/2
H6	105-671	10	KEY TOP - BLUE	LSCI	105-671
H7	105-676	4	KEY TOP - LIGHT GREY	LSCI	105-676
H8	105-677	19	KEY TOP - MEDIUM GREY	LSCI	105-677
F1	106-028	1	AC LINE CORD PLUG/FUSE HOLDER/LINE VLTG SLCTR	SFR	FN372-6/22
JF	106-140	3	CNNCTR (J3 ON RB TO MB)	MOL	2139-09-50-3061
	110-150	18	CONNECTOR TERMINALS	MOL	2878-08-50-0116
J1/2	106-011	2	CONNECTOR 5 PIN SOCKET	AML	126-218
J3	106-013	1	CONNECTOR 7 PIN SOCKET	AML	126-198
J6	106-002	1	HEATER HI OUT - GRAY	EFJ	111-0113-001
J7	106-001	2	HEATER LO OUT - BLACK	EFJ	111-0103-001
J8			HEATER GND - BLACK		
R68	103-765	1	POT,20 OHM,10%,LIN TAPER	CLAR	LSCI-765
U48	102-095	1	POWER MOSFET, 100V P-CH	IR	IRF9130
XU48	106-571	1	SOCKET,TO-3	AUG	M8080-1G40
TX1	109-019	1	INPUT TRANSFORMER	LSCI	C696-114
TX2	109-021	1	OUTPUT TRANSFORMER	LSCI	C696-115
B1	107-180	1	FAN ASSEMBLY	LSCI	107-180

REPLACEABLE PARTS LIST - DRC-93C DISPLAY AND DISPLAY DRIVER BOARDS

ITEM NO	LSCI Part Number	Qty	Description	MFR	MFR PART NO
J1,2,4	106-151	3	CONNECTOR(HEADER ON DB)	ALP	TDB24SG
J3	106-150	1	CONNECTOR(HEADER ON DB)	ALP	TDB10SG
S1-33	105-651	33	SWITCH	ALPS	KEF10901
C1	101-132	1	CAP,TANT,1.5MF,10V	SPRG	150D155X9010A2
C14	101-137	1	CAP,TANT,10MF,35V	SPRG	119D106X0035DB1
C17	101-144	1	CAP,TANT,33MF,25V	SPRG	196D336X9025PE-14
CR1-3	102-062	3	DIODE,SIL,SWITCHING		1N459A
J1-2,4	106-153	3	CONNECTOR(SOCKET ON DDB)	AMP	1-103183
J3	106-152	1	CONNECTOR(SOCKET ON DDB)	AMP	103183-4
Q1-10	102-072	10	TRANSISTOR, SIGNAL PNP		2N3906
U2,16	104-526	2	IC, KEYBOARD INTERFACE	INT	P8279-5
U3,11	104-277	2	IC, 4-16 LINE DECODER		74HC154
U8	104-522	1	IC, I/O EXPANDER	INT	P8243
U12	104-270	1	IC, 4-10 LINE DECODER		74145
U15,24	104-120	2	IC, 3-8 LINE DECODER		74HC138
U17	104-654	1	IC, 2K NOVRAM W/CLOCK	MOS	MK48T08B-25
U18	104-661	1	IC, EPROM	MOS	27C256
U19	104-528	1	IC, 8 BIT LATCH	INT	82C82
U20	104-511	1	IC, MICROPROCESSOR	INT	P80C31BH
U23	104-653	1	IC, NOVRAM	DAL	DS1225Y

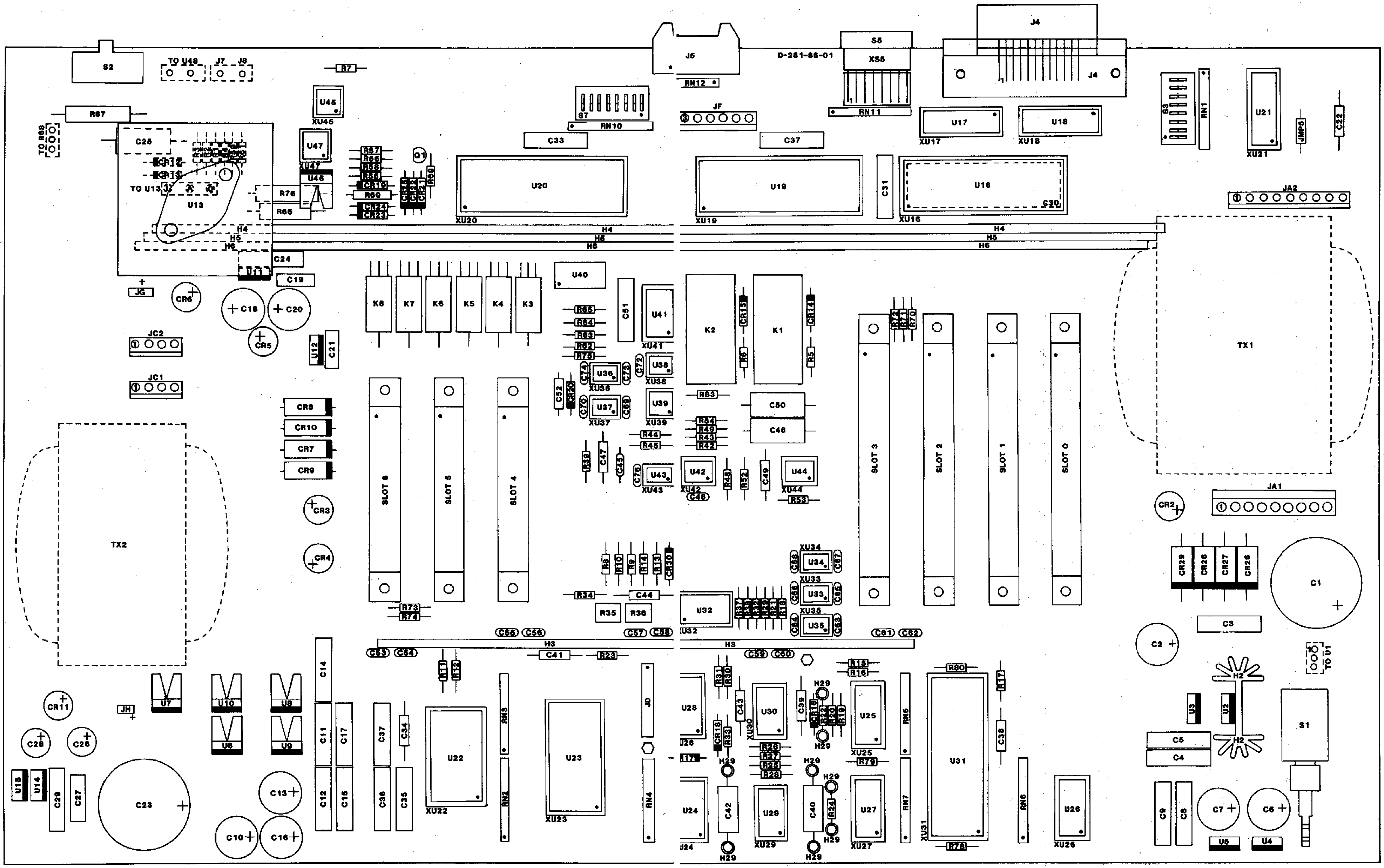


Figure 93C-1a. Component Layout - DRC-93C Main Board

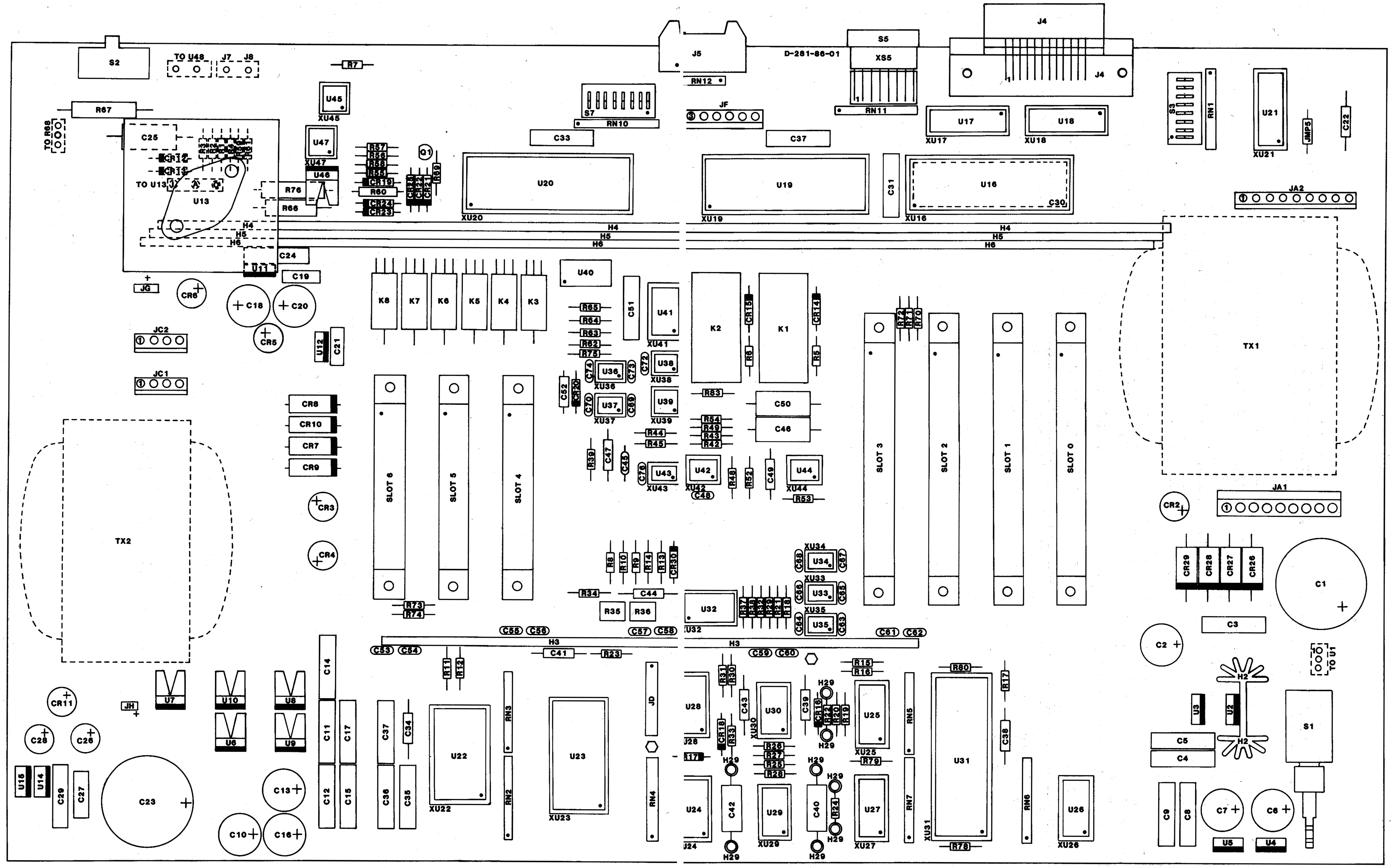


Figure 93C-1a. Component Layout - DRC-93C Main Board

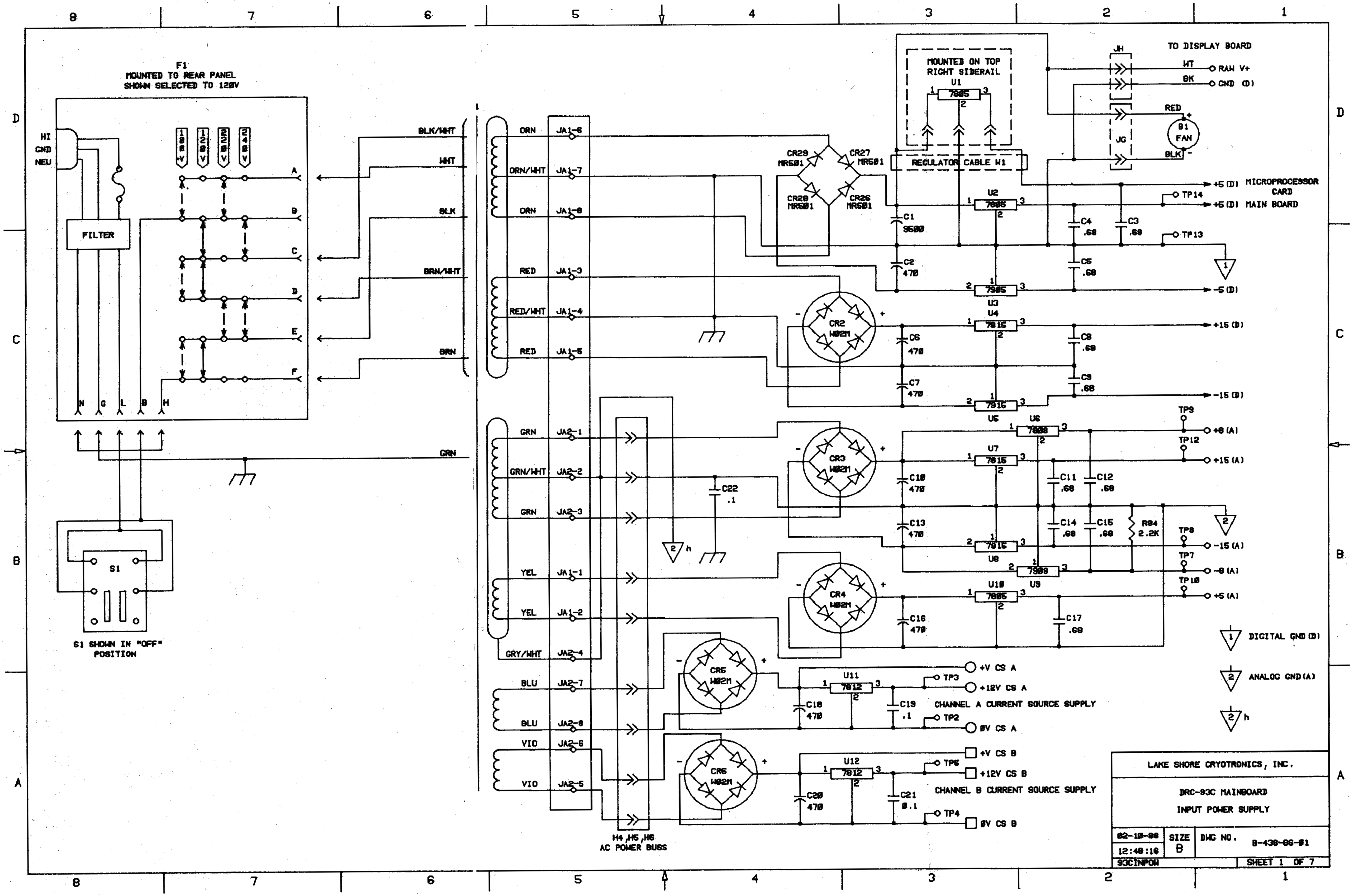


Figure 93C-1b. Schematic - DRC-93C Main Board #1 (Input Power Supply)

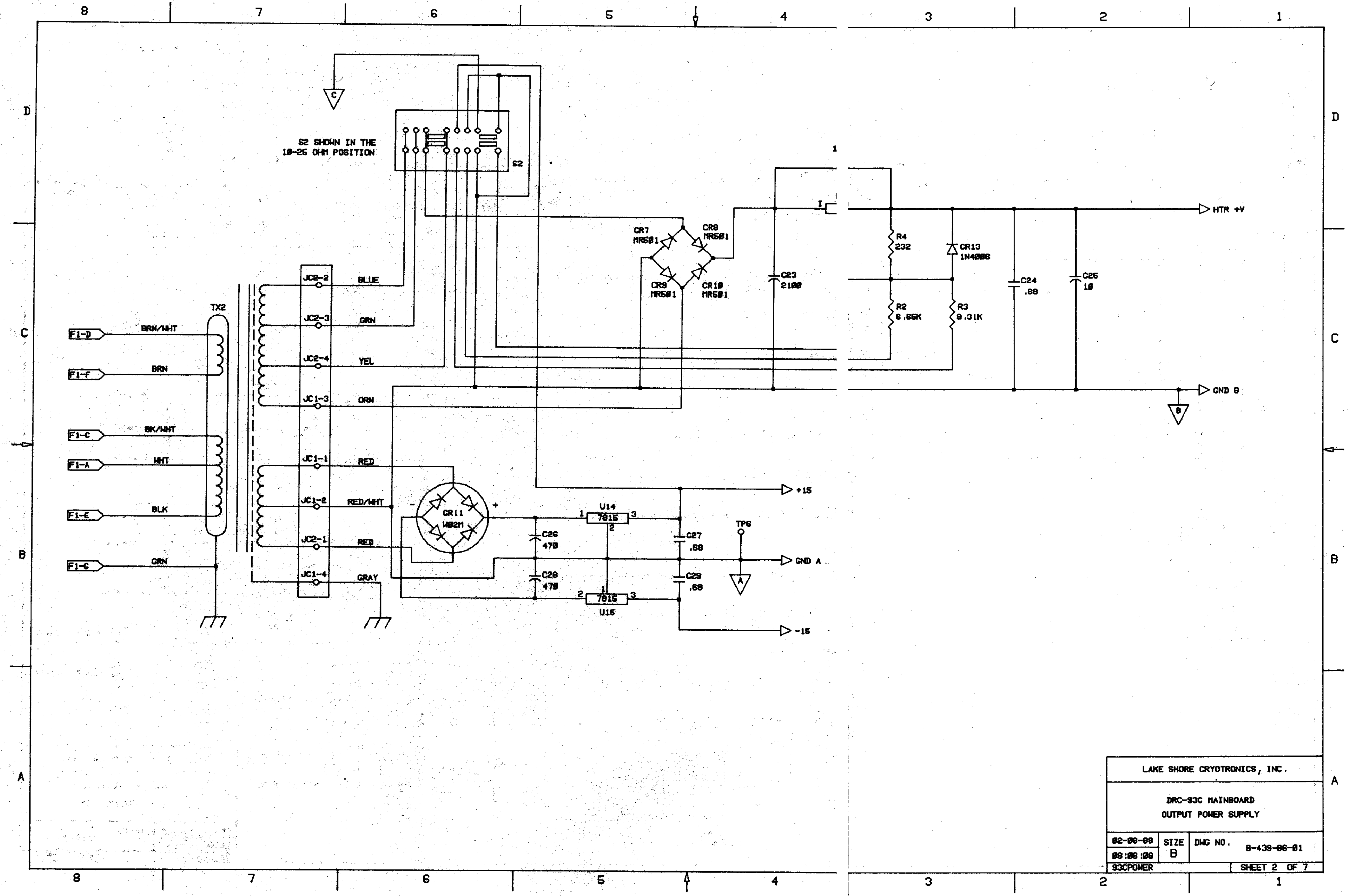


Figure 93C-1c. Schematic - DRC-93C Main Board #2 (Output Power Supply)

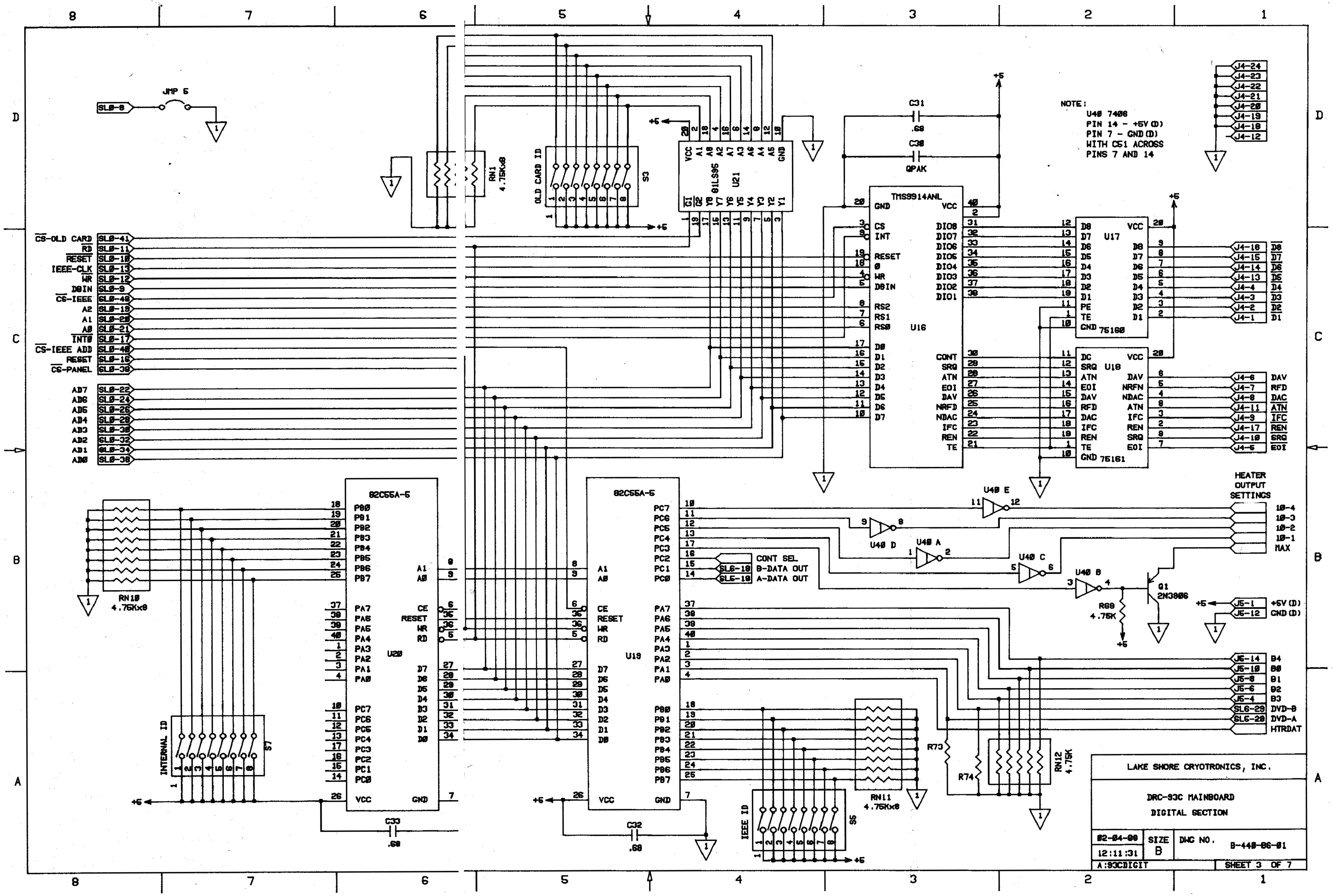


Figure 93C-1d. Schematic – DRC-93C Main Board #3 (Digital Section)

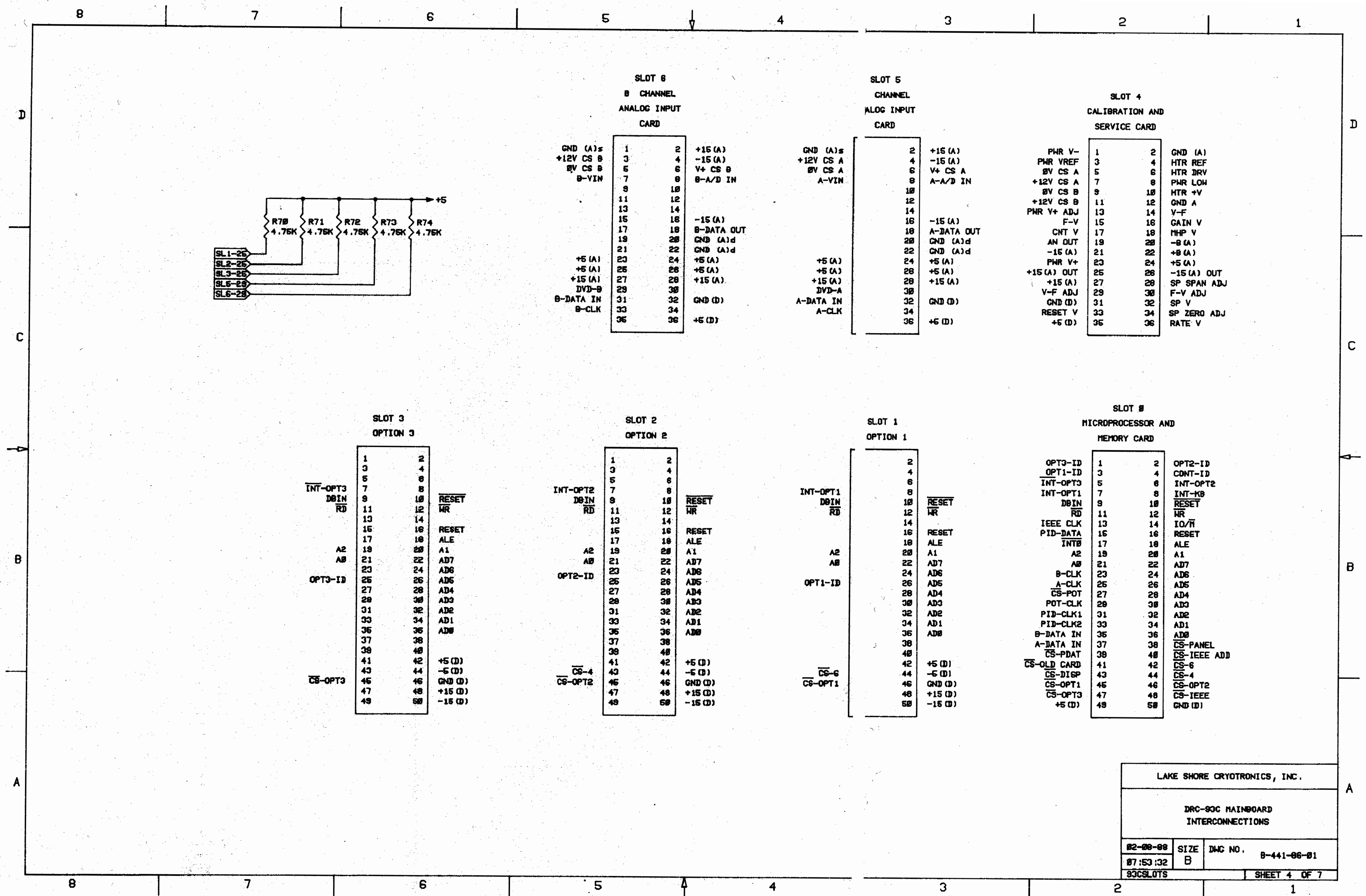


Figure 93C-1e. Schematic - DRC-93C Main Board #4 (Interconnections)

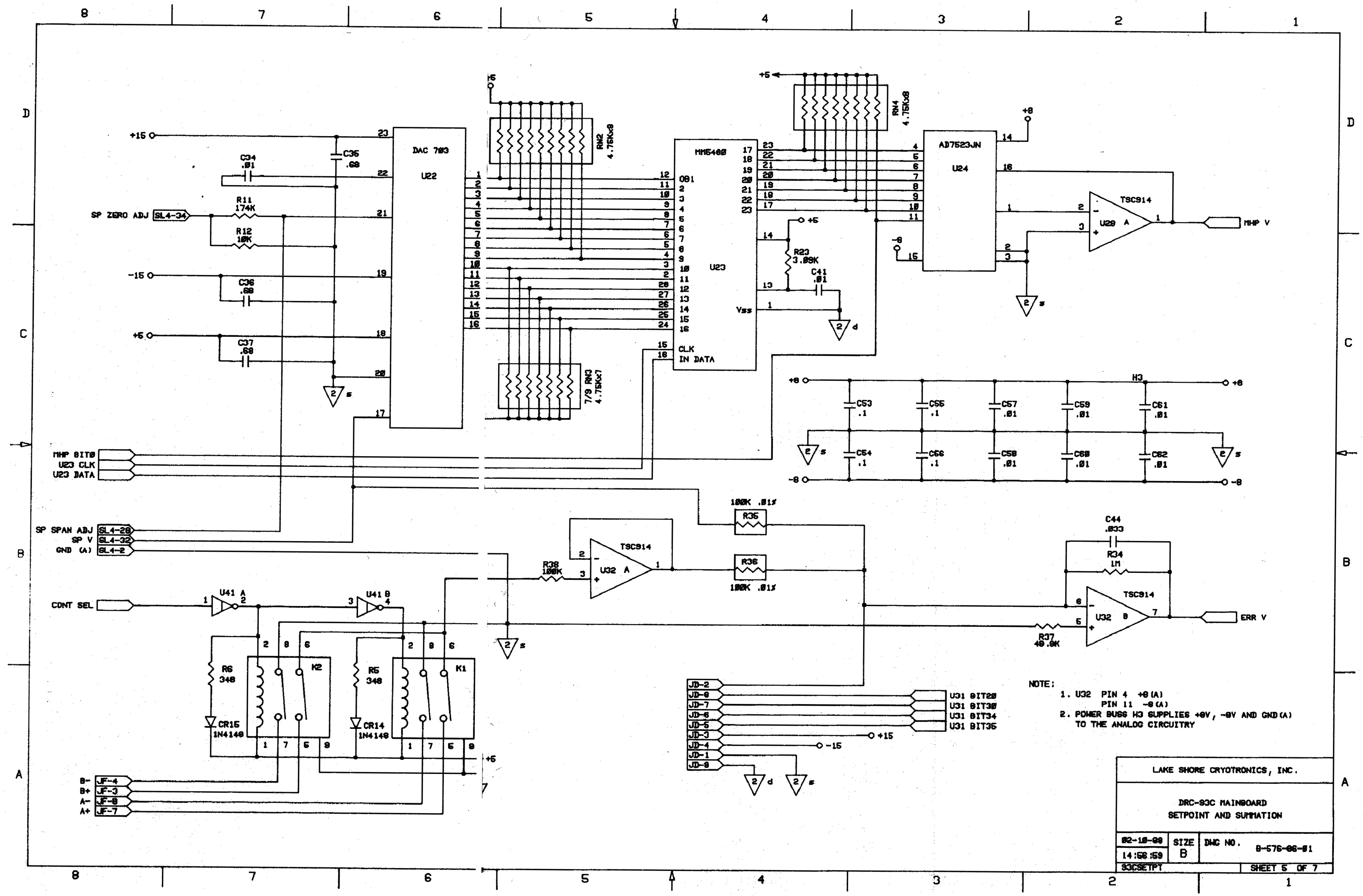


Figure 93C-1f. Schematic - DRC-93C Main Board #5 (Setpoint and Summation)

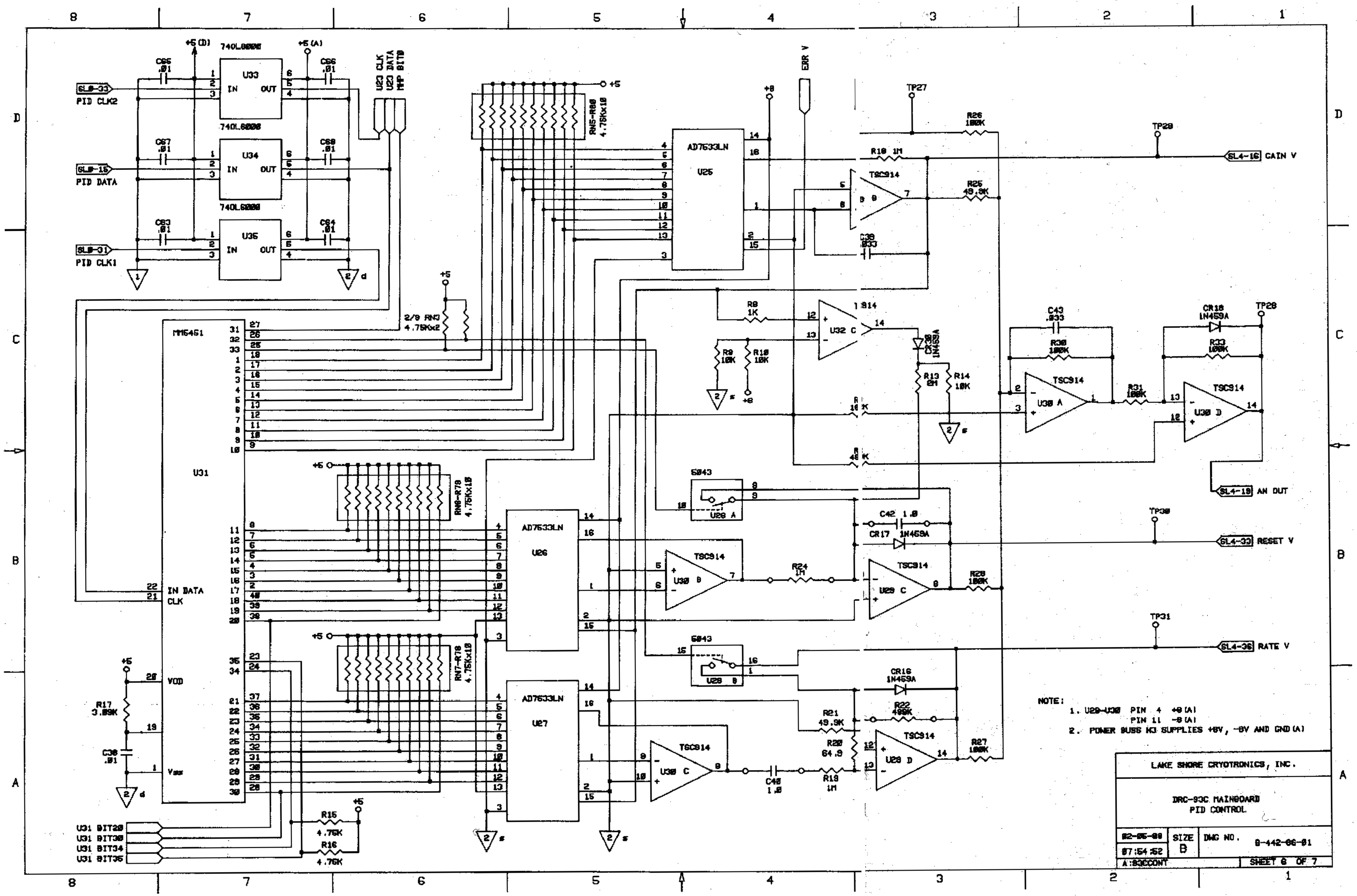


Figure 93C-1g. Schematic – DRC-93C Main Board #6 (PID Control)

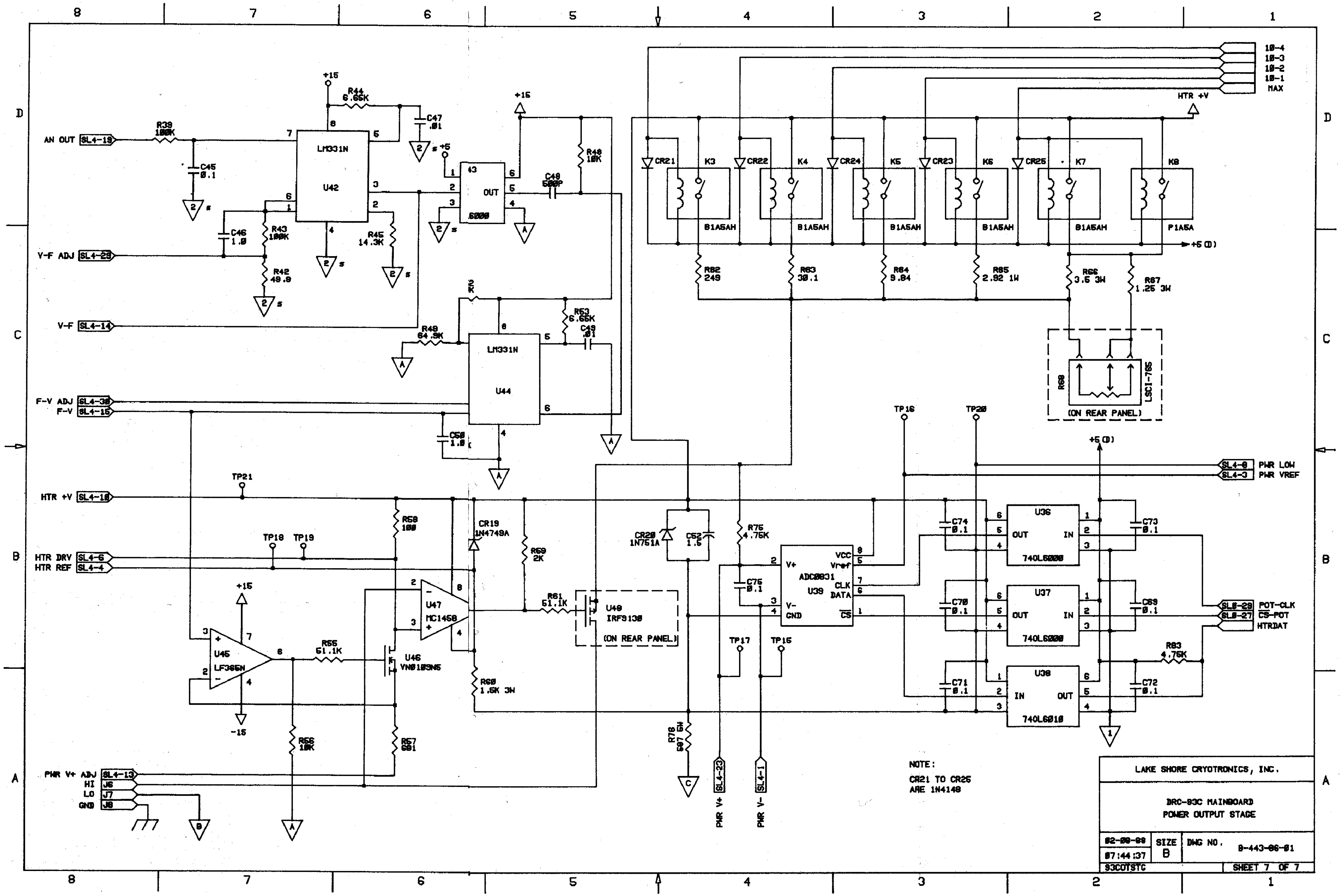


Figure 93C-1h. Schematic - DRC-93C Main Board #7 (Output Stage)

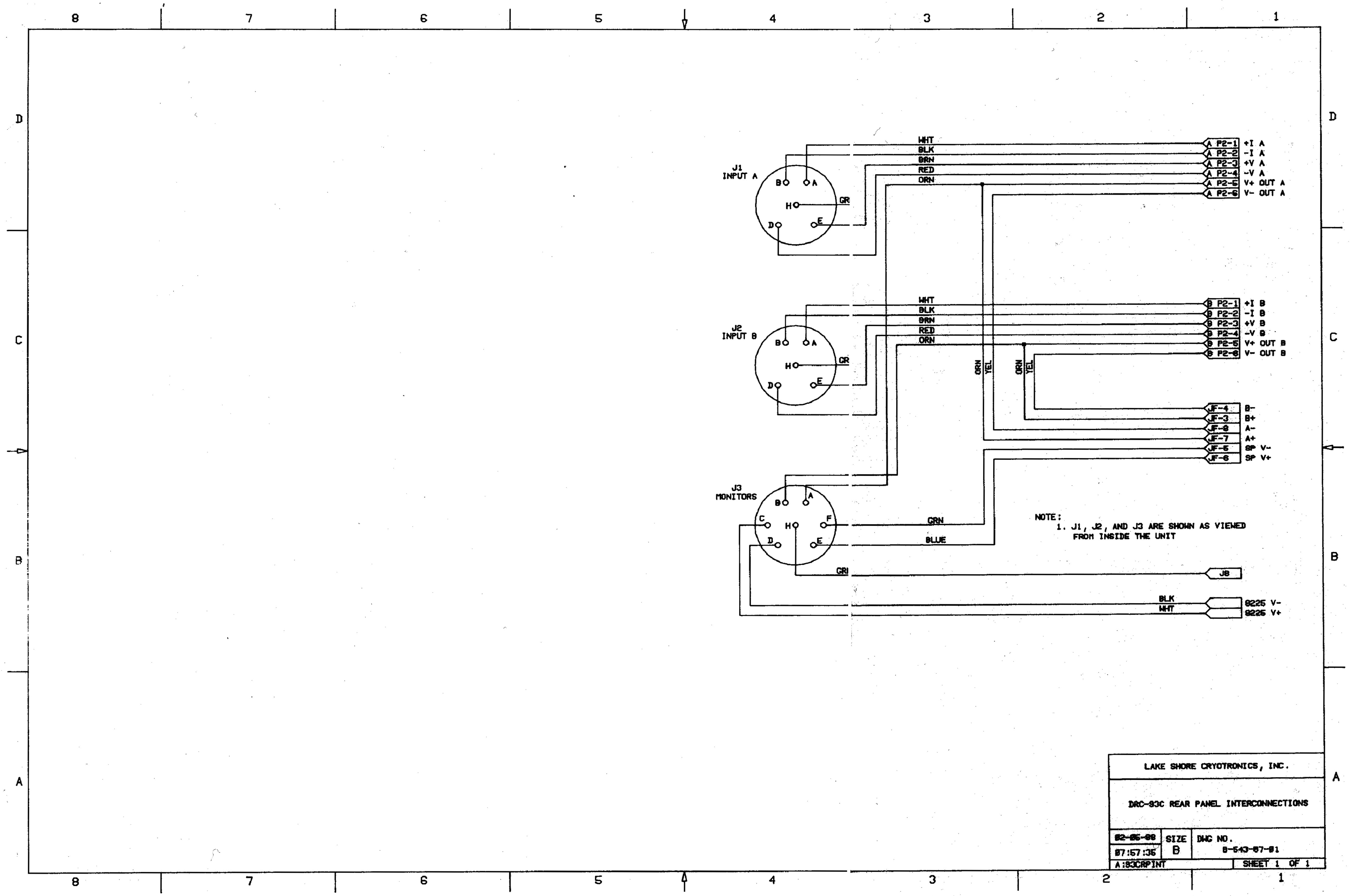


Figure 93C-1i. Schematic - DRC-93C Main Board #8 (Rear Panel Interconnectio

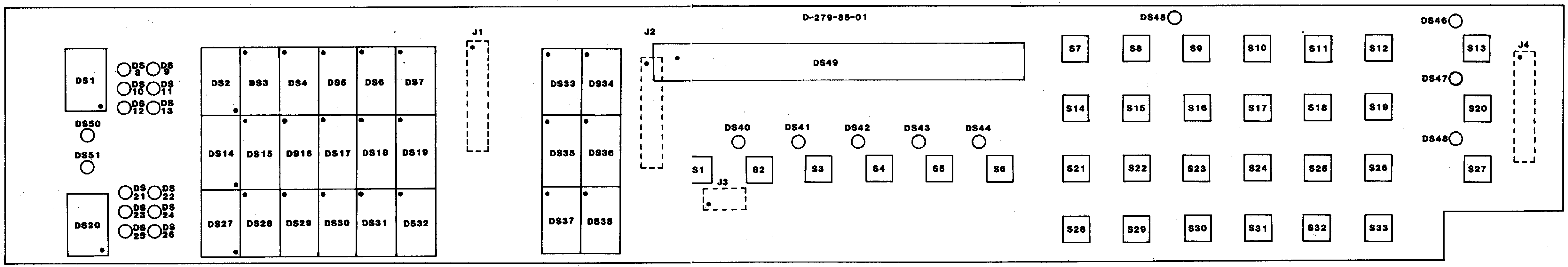


Figure 93C-2a. Component Layout - DRC-93C Display Board

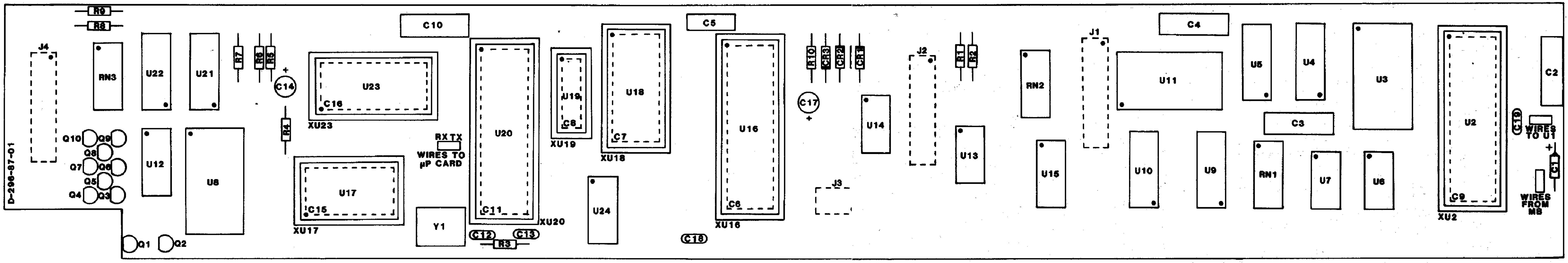


Figure 93C-2b. Component Layout - DRC-93C Display Driver Board

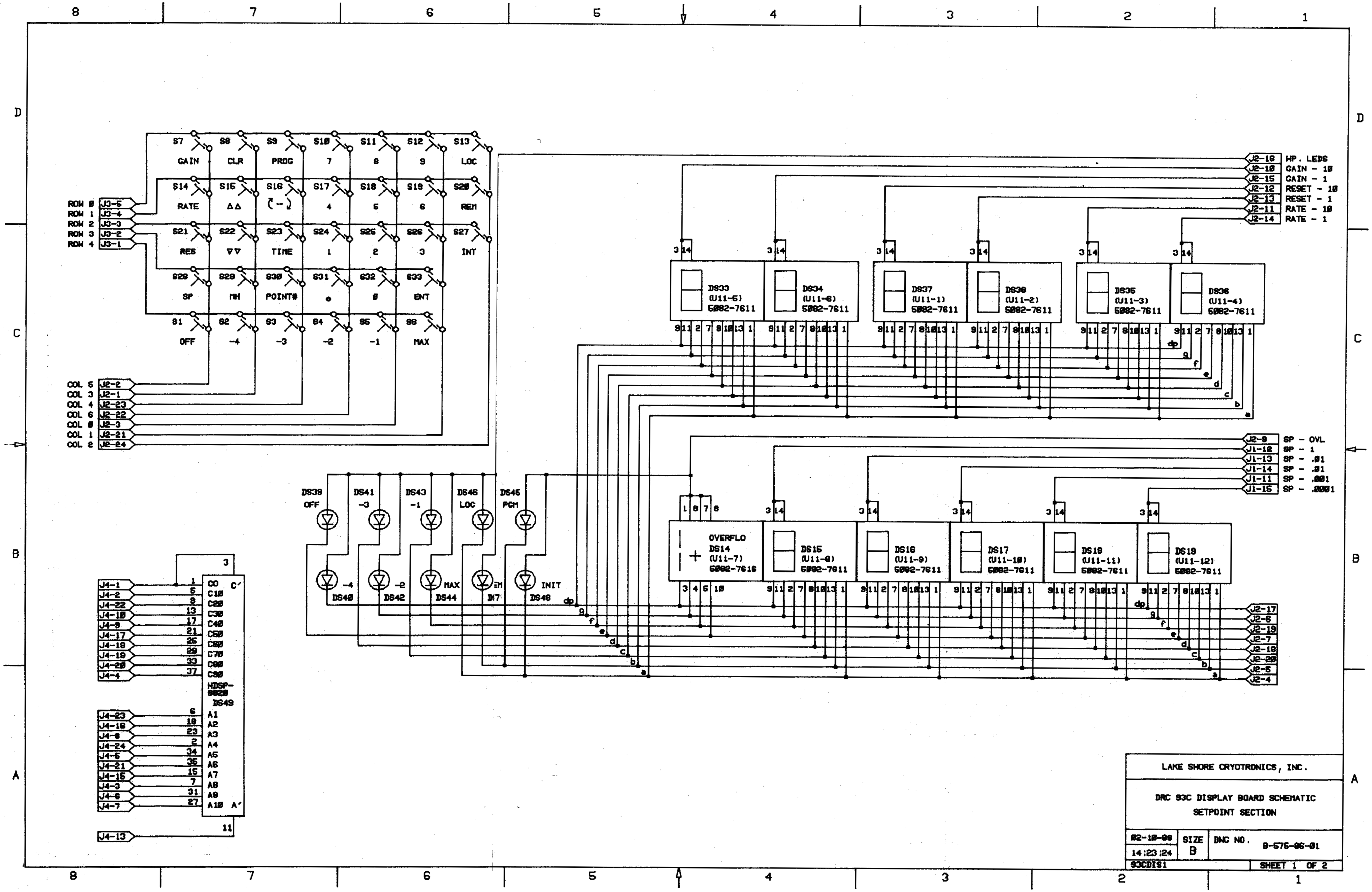


Figure 93C-2c. Schematic - DRC-93C Display Board #1 (Setpoint Section)

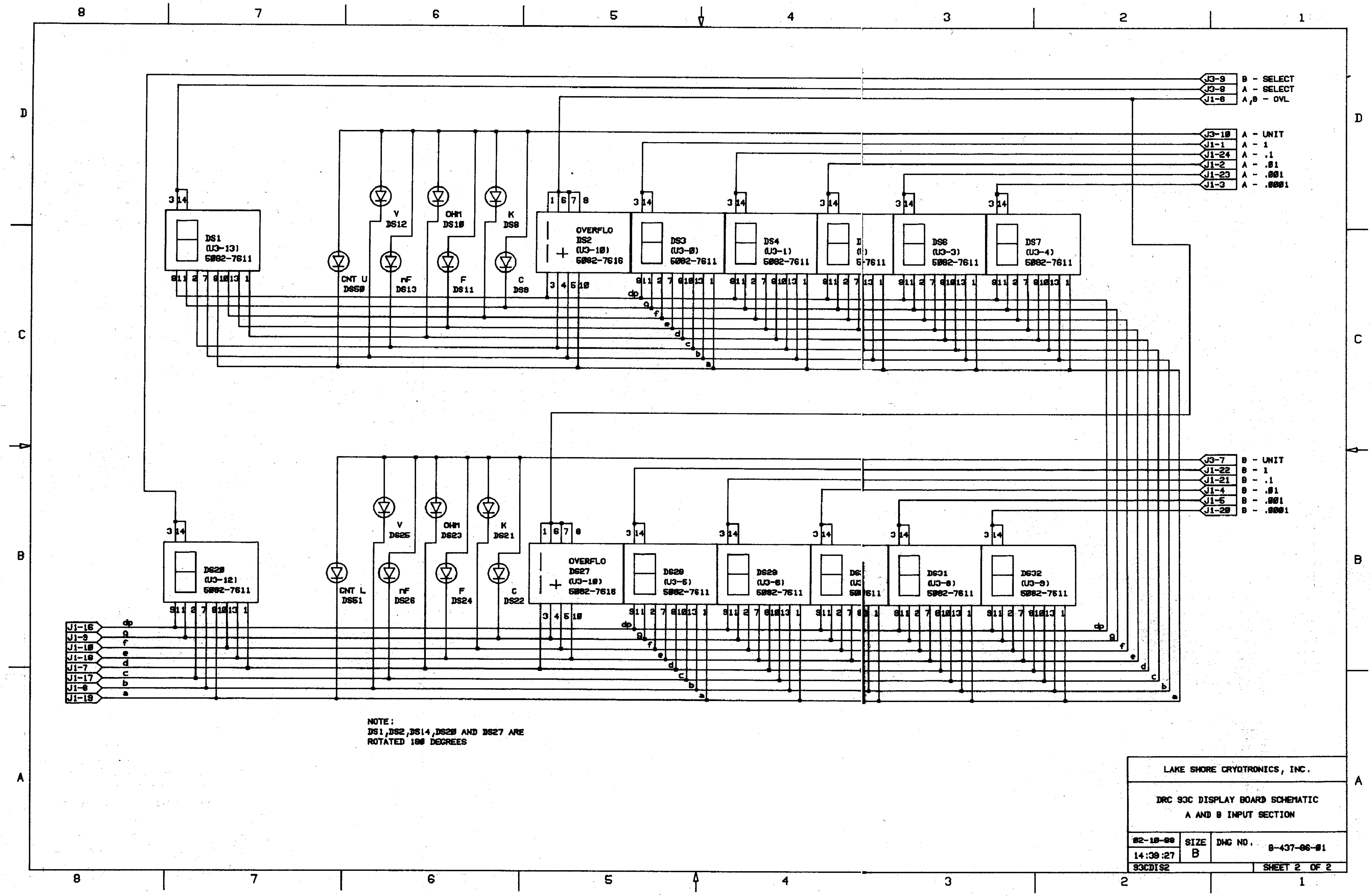


Figure 93C-2d. Schematic - DRC-93C Display Board #2 (Input Display Section)

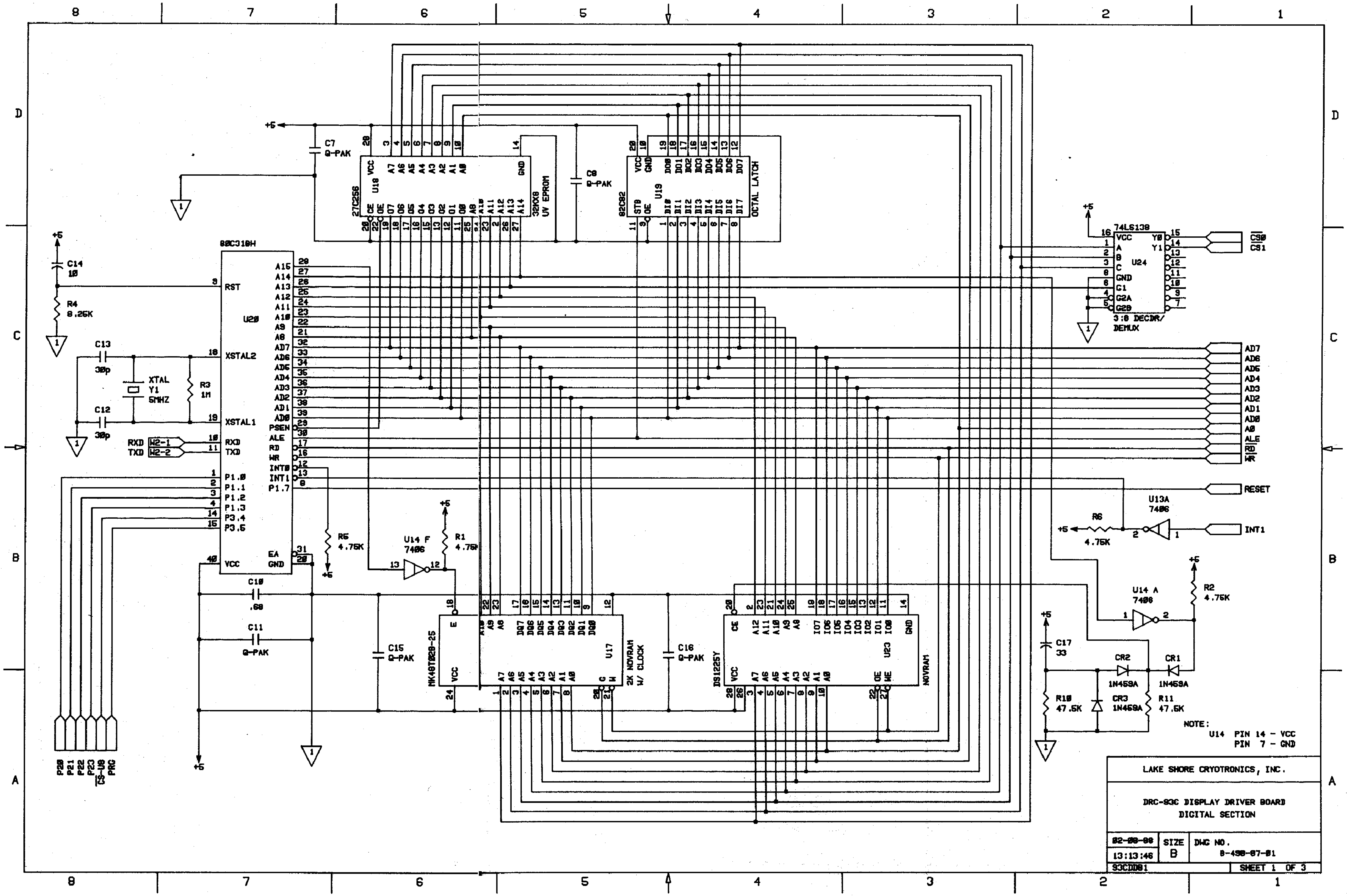


Figure 93C-2e. Schematic - DRC-93C Display Driver Board #1 (Digital Section)

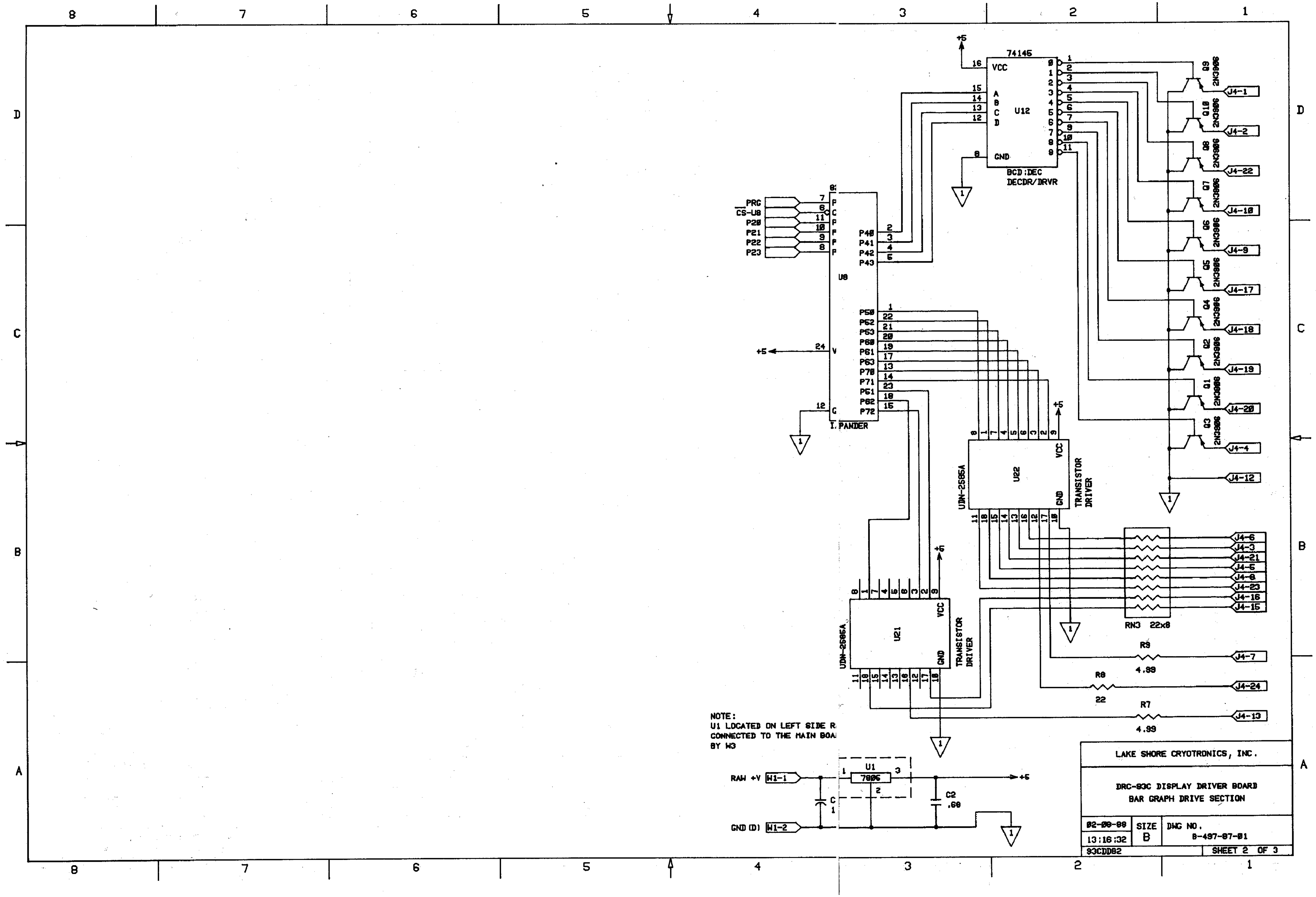


Figure 93C-2f. Schematic - DRC-93C Display Driver Board #2 (Bar Graph Drive S

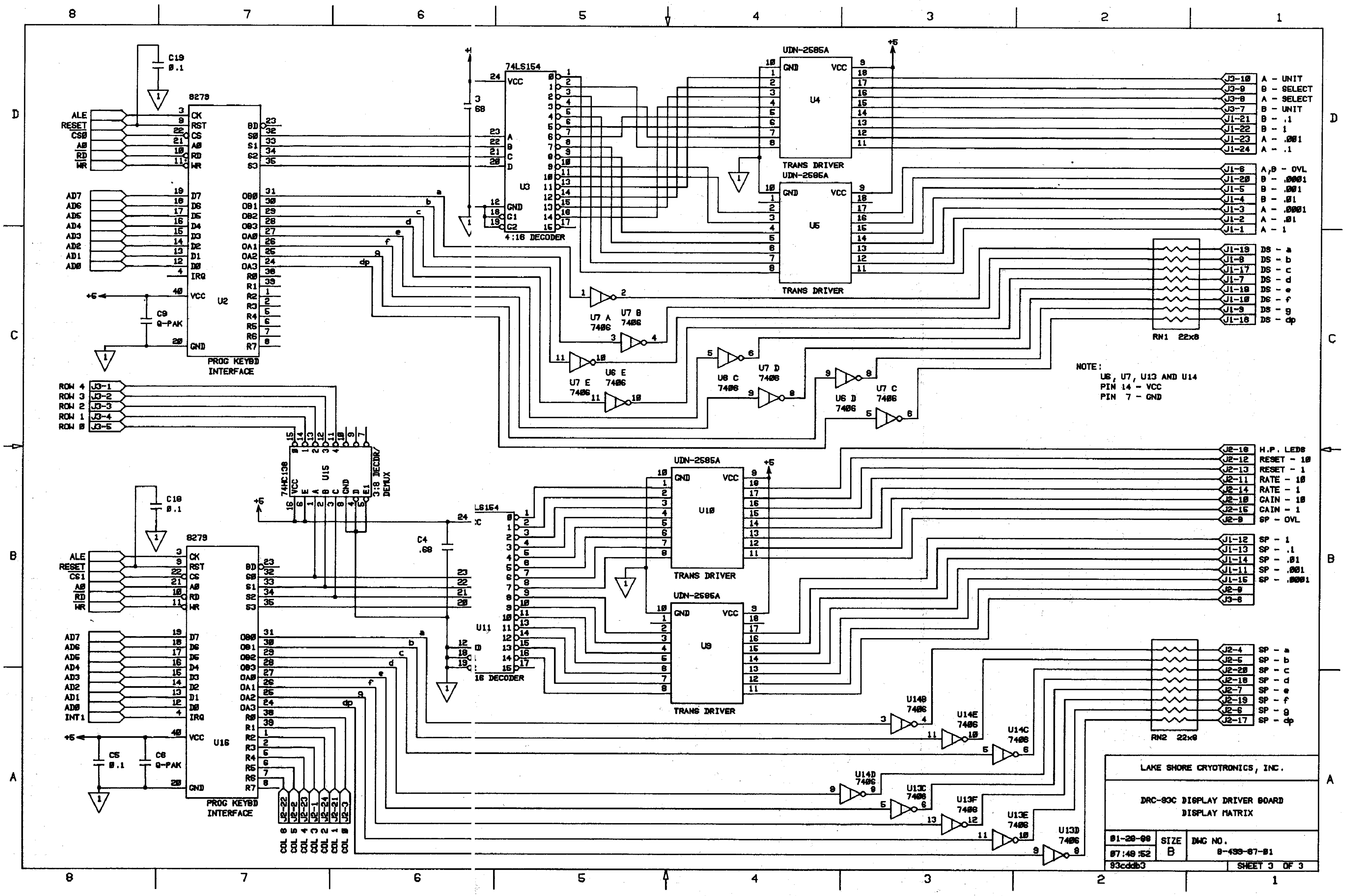
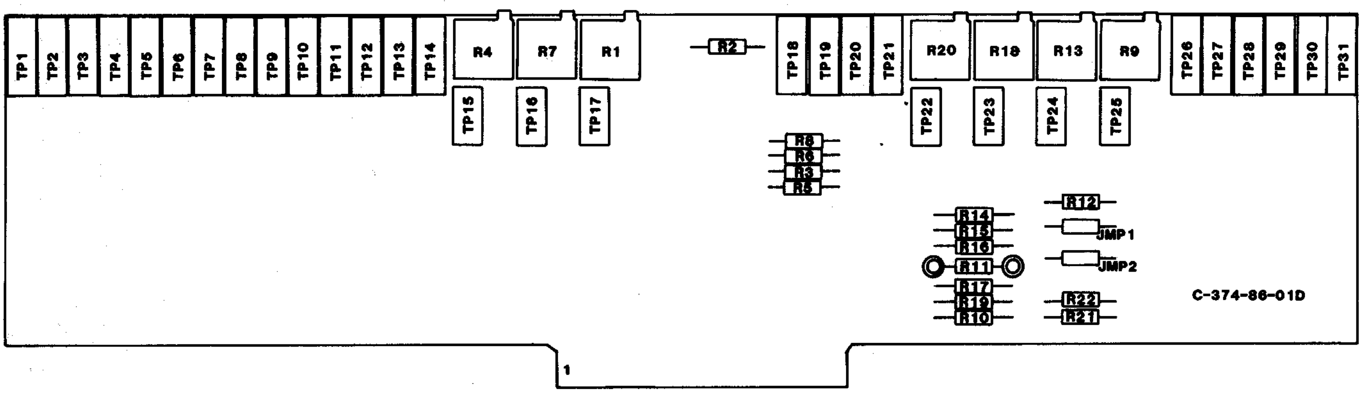


Figure 93C-2g. Schematic - DRC-93C Display Driver Board #3 (Display Matrix)


TP1
TP2
TP3
TP4
TP5
TP6
TP7
TP8
TP9
TP10
TP11
TP12
TP13
TP14
R4
R7
R1
R2
TP18
TP19
TP20
TP21
R20
R18
R13
R9
TP26
TP27
TP28
TP29
TP30
TP31
TP15
TP16
TP17
TP22
TP23
TP24
TP25
R8
R6
R3
R5
R12
R14
R15
R16
JMP1
R11
JMP2
R17
R19
R10
R22
R21
C-374-86-01D
1

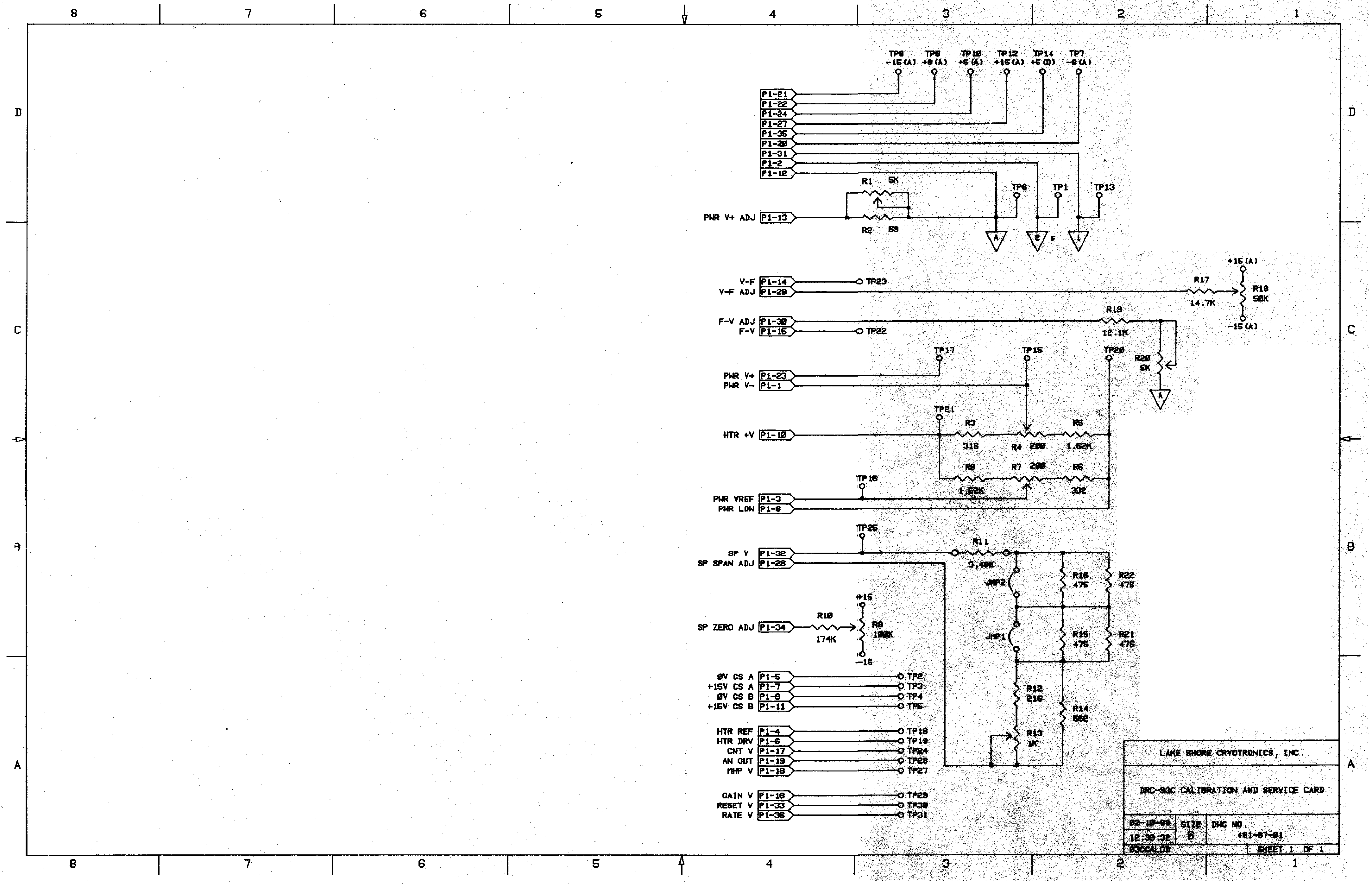
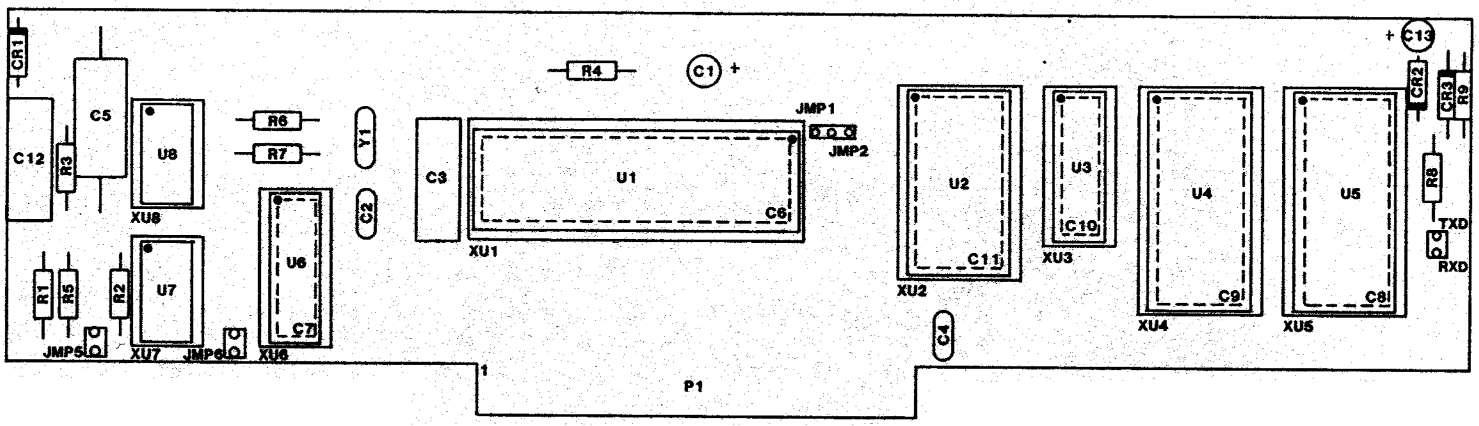


Figure 93C-3. Schematic and Component Layout - DRC-93C Calibration and Service Card



REPLACEABLE PARTS LIST - A9 MICROPROCESSOR CARD

ITEM NO	LSCI Part Number	Qty	Description	MFR	MFR PART NO
C1	101-137	1	CAP,TANT,10MF,10V	SPRG	119D106X0035DB1
C2	101-059	1	CAP,MICA,10PF,500V	CDE	CD15CD100D03
C5	101-018	1	CAP,.047MF,POLY,600V	CDE	WMF6S47
C13	101-144	1	CAP,TANT,33MF,25V	SPRG	199D336X0025EA2
U1	104-511	1	IC,MICROPROCESSOR	INT	P80C31
U2	104-125	1	IC,4-16 LINE DECODER		74HC154
U3	104-528	1	IC,8 BIT LATCH		P82C82
U4	104-661	1	IC,EPROM (PROGRAM)		27C256
U5	104-653	1	IC 8KX8 NOVRAM	DAL	DS1225Y
U6	104-310	1	IC,8 BIT MULTIPLEXER	NAT	DM81LS95
U7	104-210	1	IC,O.C. HEX INVERTER		7406
U8	104-207	1	IC,HEX INVERTER		74LS04
Y1	103-990	1	CRYSTAL,5.000 MHZ	MTRON	MP1 5.000 MHZ

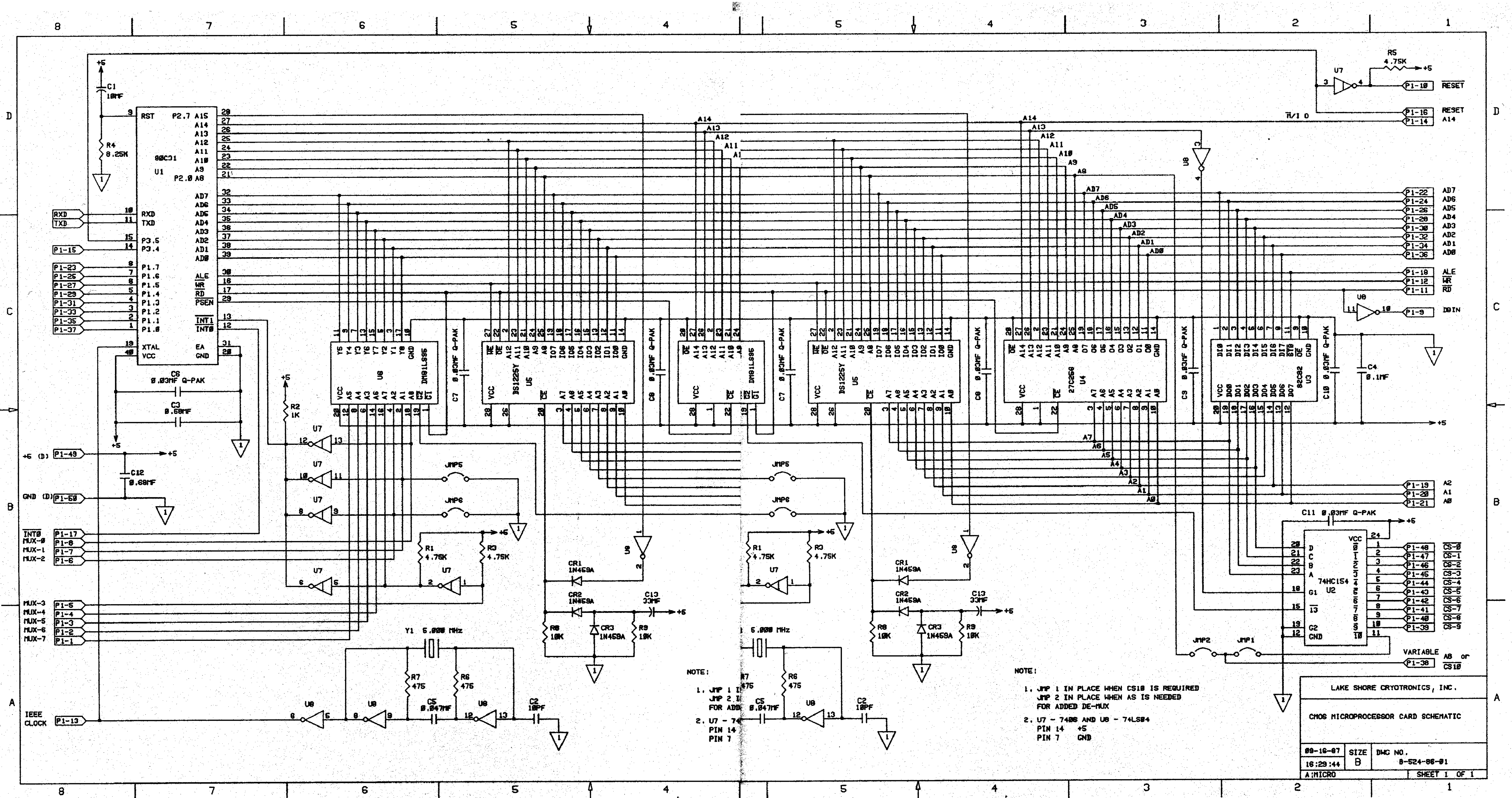


Figure 053. Microprocessor Card

SECTION VI

PROGRAMMING INSTRUCTIONS

6.1 INTRODUCTION

This section contains information and instructions concerning the Internal Program feature of the Model DRC-93C Temperature Controller. The feature permits simple ramp and Dwell (or Soak) as well as elaborate sequences including ramping the setpoint up and down and ramping of the gain, rate and reset.

The DRC-93C is capable of automatically executing internally stored programs. The programs are entered into the instrument from the front panel. The programs are permanently stored in a nonvolatile memory permitting their execution even though the instrument has been turned off and on, unplugged and moved. The instrument comes from the factory with a repertoire of example stored programs which ramp-and-soak, etc. These programs allow the user to quickly learn the contents of this chapter and many can be used directly with minor modification of the setpoint and control parameters.

6.2 PROGRAM STEPS AND SIZE

The Program Steps of the internal programming feature are very powerful. A single Program Step contains information to enable the instrument to ramp the setpoint to a given value with control parameters selected for that ramping function. A single Program Step is all that is necessary to provide a soak with all parameters desired.

A simple ramp and soak requires only two Program Steps---one to ramp and one to soak.

There are provisions for 99 Program Steps. Since typical programs are three to four Programs Steps in length, this provides storage for many programs.

The Programmer Specifications are summarized in Table 6-1.

Table 6-1 Programmer Summary

Number of Stored Programs - limited by a total of 99 steps; for example, 49 Ramp and Dwells

Steps per Program - Up to 99

Programming Commands - 8 different commands

Ramp Formats - Total of 3; ramp setpoint up, ramp Setpoint Down, and ramp setpoint, gain, rate and reset to a final value

Ramp Time - 0 to 30 days; specified in days, hours, minutes and seconds

Repeat Cycles - 99 per step; can be multiplied by using additional steps

6.3 PROGRAM STEP FORMAT

Each Program Step contains the Step #, Command and JUMP VECTOR, REPEAT COUNT or RAMP COUNT as well as a full description as indicated by the front panel. These are listed below.

1. Sample and Control Sensors
2. Sample and Control Units
3. Sample and Control Resolutions
4. Setpoint
5. Gain, Rate, and Reset
6. Manual Heater Power
7. Heater Range
8. Program Timer
9. Filtering on/off

TABLE 6-2 PROGRAMMING COMMANDS

0 **Null**	**Step #.0.REPEAT COUNT. Does nothing** but enter a REPEAT COUNT into the REPEAT COUNTER associated with Command 2 and move to the next Program Step #. No front panel parameters can be changed with the Null Command. This command is used in conjunction with Command 2 (Dwell) to establish a do loop. The REPEAT COUNT number establishes the number of times a given set of operations will be repeated.
1 **Dwell**	**Step #.1.JUMP VECTOR. Dwell (Soak)** for the time given (set with Time key) with the front panel parameters set in the program step format. After this dwell time jump to the Program Step # specified by the JUMP VECTOR.
2 **Dwell**	**Step #.2.JUMP VECTOR. Dwell (Soak) with Conditional Jump.** Same as Programming Command 1 except that when the Dwell is completed, the REPEAT COUNTER (set by Command 0) is decremented. If the value of the REPEAT COUNTER is non-zero, operation continues at the Program Step specified by the JUMP VECTOR. If the REPEAT COUNTER is zero then operation continues at the next Program Step #.
3 **Ramp Up**	**Step #.3.RAMP COUNT. Ramp the Setpoint Up.** The setpoint is incremented by the value given in the setpoint display of that Program Step (set with SETPOINT key). The setpoint is incremented the number of times specified by the RAMP COUNT given in the last two digits of the Upper Display. The time for each increment is specified by the timer in the Program Step (set with TIME key). After ramping the specified number of times given by the RAMP COUNT, operation continues at the next Program Step #. All other parameters change to the displayed values on entering this command during program operation at the beginning of the ramp. This command is normally used for rapid warmup where ramp times exceed 0.1K/second (6K/minute).
4 **Ramp Down**	**Step #.4.RAMP COUNT. Ramp the Setpoint Down.** Same as Program Command 3 except that the setpoint is ramped down, that is, the setpoint is decremented by the quantity specified in the setpoint display. After ramping the specified number of times given by the RAMP COUNT, operation continues at the next Program Step #. This command is normally used for rapid cooldown where ramp times exceed 0.1K/second (6K/minute).
5 **Ramp**	**Step #.5.JUMP VECTOR. Ramp Setpoint, Gain, Rate and Reset Up or Down.** The Setpoint, Gain, Rate, and Reset are ramped in this Command. The setpoint is incremented or decremented in its least significant bit at a rate given in the timer of the Program Step. The setpoint begins at the value given in the previous Program Step and increments or decrements to the value specified in this Program Step. Similarly, the gain, rate and reset are decremented or incremented as required to ramp from the value given in the previously executed Program Step to the value specified in this Program Step. After ramping the specified amount, operation continues at the Program Step # indicated by the JUMP VECTOR.
8 **Jump**	**Step #.8.JUMP VECTOR. Jump to the Program Step specified by the JUMP VECTOR.** The previous parameters are used and those in the Program Step are ignored.
9 **Exit**	**Step #.9.00. Exit the Internal program** resuming normal operation with the front panel values given in this command.

6.4 SUMMARY OF COMMANDS

The Program Commands are summarized in Table 6-2. When the temperature has been stabilized at the Setpoint, the Dwell command is essentially a Soak command.

6.5 INTERNAL PROGRAM ENTRY

This section discusses the procedure for entering an internal program.

A short description of the sequence is as follows. Additional information is described in the Sections listed in parenthesis.

1. Press the PROGram key. The PROGram indicator will flash on and off (Section 6.5.1).

2. Press the INTernal key. The PROGram indicator will stop flashing and turn on as will the INTernal indicator (Section 6.5.1).

3. The Program Step is selected using the POINT# key (Section 6.5.2).

4. The command and JUMP VECTOR (REPEAT COUNT) are entered (Section 6.5.3).

5. The setpoint, gain, rate, reset, heater range, manual heater power, units, etc. are selected (Section 6.5.4 and 6.5.5).

6. The Timer value is selected (Section 6.5.6).

7. The SCAN key is pressed to store the Program Step (section 6.5.7).

8. Stages 3. through 7. are repeated to enter more Program Steps.

9. After all steps of the program are entered, the PROGram key is pressed to exit the programming mode. The PROGram indicator turns off and normal operation will resume (Section 6.5.8).

6.5.1 Starting the Program Edit Mode

NOTE: There must be a valid input present when editing a program. The DRC-93C incorporates fault protection that will automatically force the HEATER RANGE to the OFF state on an input overload (OL) condition.

To enter or modify a program in the DRC-93C, the operation must be started with the PROGram key. Next press the INTernal key and it is now possible to create or edit a program. The Program Edit Mode is depicted by having both the PROGram and INTernal annunciator lights lit.

6.5.2 Program Step Selection

Upon entering the Program Edit Mode, the display will always enter at Program Step 01.

The Temperature and Setpoint Blocks will show the contents of the first Program Step (#01) as (for example)

```
01.2.02
00 - 00
20 - 00
```

The upper display shows the Program Step # (01), the Program command (2) and the JUMP VECTOR (02) which tells the program which Program Step # will next be executed.

The Setpoint Display contains the Days and Hours and the Lower Display the Minutes and Seconds of Program Step #01.

If another Program Step is desired, the user presses the POINT# key, the point # desired followed by the

ENTER key. The new Program Step # and information is then displayed.

At any time that the POINT# key is appropriate, the ▲ key or ▼ key can be used to select the next higher or lower Program Step # respectively. The ▲ key and ▼ key do not operate in any other case for any other purpose except to increment or decrement the Program Step # at a time when it could be entered using the POINT# key.

After the desired Program Step # has been selected and displayed, the user can enter or modify (as required) the Command, the JUMP VECTOR, REPEAT COUNT or RAMP COUNT), Sensor#, Units, Setpoint, Gain, Rate, Reset, Manual Heater Power, Heater Range, and Timer.

6.5.3 Entering the Program Command and JUMP VECTOR, REPEAT COUNT or RAMP COUNT.

When a Step# is selected, the command position will flash. If a number is entered, then the command will change to that number. When the desired number is displayed press the ENTER key. Then the JUMP VECTOR, REPEAT COUNT or RAMP COUNT position will flash. If it is correct press the ENTER key. If not, then enter the new value with the keypad followed by the ENTER key.

At this point the setpoint, gain, etc. may be changed.

6.5.4 Entering the Setpoint, Gain, Rate and Reset

The Setpoint, Gain, Rate, Reset, and Manual Heater Power for the Program Step are changed as described in Chapter 3. For example, to change the Setpoint, press the SETPOINT key followed by the keypad digits, ▲ key or ▼ key as desired. Pressing the ENTER key stores the result. Note that for Commands 3 and 4 the entry into the Setpoint is an **incremental value** whereas for all others it is an actual Setpoint.

6.5.5 Entering Other Parameters

In addition, the sensor units, resolution, filtering of either display, Manual Heater Power and Heater Range can be changed for any POINT #.

6.5.6 Entering the Timer Value

The Time (Timer) displayed is changed using the TIME key. Pressing the TIME key causes the Days entry to flash. The keypad is used to enter the Days. After the Days desired is shown, the user presses the ENTER key. The Days will stop flashing and the Hours will flash. The Hours, Minutes and Seconds are entered in the same way. The time value should be non-zero for commands 1, 2, 3, 4 and 5.

6.5.7 Entering the Program Step into Memory

Once all parameters of a step are as desired, pressing the SCAN (↑-↓) key will enter that program step into memory. If the SCAN key is **not** pressed, the program step is not stored and subsequent request for the program step will produce the old configuration.

6.5.8 Ending or Aborting the Programming Mode

If it is desired to end or abort the operation at any time (except when the setpoint, gain, rate, reset, manual heater power, or time is in the progress of being entered), press the PROG key. The PROG indicator will turn off and operation will return to normal.

6.6 RUNNING THE PROGRAM

To begin execution of the internal program, the user does the following.

1. Press the INTernal key. The INTernal indicator will begin to blink on and off.

2. Select the Program Step using the POINT# key followed by the ENTER key.

3. If another Program Step is desired, repeat step 2. The ▲ key or ▼ key can be used to examine the next higher or lower Program Step # respectively.

4. If it is desired to return to normal operation thus aborting the programming setup, press the INTernal key. The INTernal indicator will turn off and normal operation will resume.

5. Press the SCAN key to begin execution of the program beginning at the Program Step selected in part 2. The INTernal indicator will turn on and stay on showing that the instrument is in the programming mode.

6. The only keys active while a program is being executed are the CLEAR key and the TIME key. Pressing the CLEAR key causes execution of the program to cease and operation to be returned to normal. Pressing the TIME key causes the elapsed time in a particular cycle to be displayed.

7. To exit from the programming mode, press the CLEAR key. The INT indicator will turn off. It is also possible to exit the program by using command 9.

6.7 CLEARING All INTERNAL PROGRAM MEMORY

ALL internal program memory can be cleared of program material from the front panel. The procedure is as follows.

1. Press the PROGRAM key.

2. Press and hold the CLEAR key for approximately 15 seconds until the PROG indicator goes off. **ALL** program steps will be cleared and front panel operation restored.

6.8 EXAMPLES

6.8.1 Example #1 - Ramp and Soak

In Figure 6-1 is shown a graph of a simple ramp from 40K to 100K in a period of 30 minutes and a soak (dwell) of 1 hour.

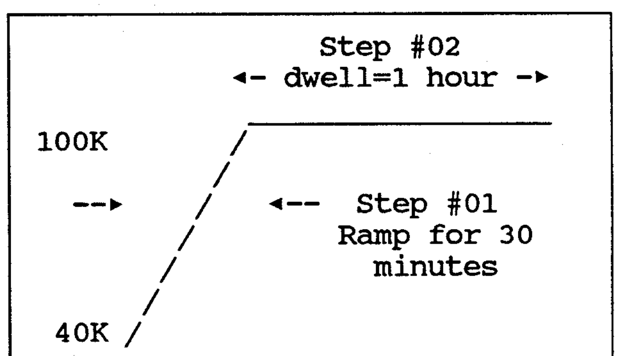


Figure 6.1 Simple Ramp and Soak

It is assumed that the system has stabilized at 40K prior to execution of the program.

Step #01 and #02 will be used for the program. Step #01 will ramp and Step #02 will dwell. It is assumed that the system can follow the setpoint in the time provided.

Step #01 will look as follows.

STEP #01

Step#.Command.RAMP COUNT	01.3.60
Days - Hours	00 - 00
Minutes - Seconds	00 - 30
Setpoint	1.0
Gain	20
Rate	0
Reset	10

The command selected is 3 for Setpoint ramp up. The RAMP COUNT is 60. The setpoint will ramp up by the amount specified in the Step #01 setpoint display every 30 seconds for 60 times.

The setpoint of step #01 will be set to 1K to indicate 1K step up every 30 seconds for a total of 60 steps or 60K in 30 minutes (1800 seconds).

The gain, rate, and reset will remain constant during the ramp as specified in Step #01.

The soak is covered by Step #02 as follows.

STEP #02

Step#.Command.JUMP VECTOR	02.1.03
Days - Hours	00 - 01
Minutes - Seconds	00 - 00
Setpoint	100.0
Gain	10
Rate	0
Reset	5

If it is desired to shut down the controller after the one hour soak, step 3 will be as follows:

STEP #03

Step#.Command.---------	03.9.00
Days - Hours	00 - 00
Minutes - Seconds	00 - 00
Setpoint	0.0
Gain	0
Rate	0
Reset	0
Heater Power	OFF

Note that the Setpoint, gain, rate, reset, etc. are part of command 9 and will be installed as the parameters when normal operation resumes. Setting the setpoint to 0 will remove power to the system as will setting the Gain to 0 or setting the Heater Power to 0.

6.8.2 Example #2 - Ramp and Soak

The ramp and soak of Figure 6.1 will be accomplished in this example with command 5 ramping. It will be necessary to fix the setpoint at 40K prior to the ramp. Here it will be set to dwell for 10 minutes. The entire process is shown in Figure 6.2. Steps #4, #5, and #6 are used.

```
                       Step #06
                  <-- dwell=1 hour -->
                 _________________________
 100K           /
               /
   -->        /      <--  Step #05
             /             Ramp for 30
            /                minutes
           /
40K_______/
->        <-- Step #4,Dwell 10 minutes
```

Figure 6.2 Example #2

Step #04 will look as follows.

Step #04

Step#.Command.JUMPVECTOR	04.1.05
Days - Hours	00 - 00
Minutes - Seconds	10 - 00
Setpoint	40.0
Gain	10
Rate	0
Reset	10

Step #05 will look as follows.

STEP #05

Step#.Command.JUMP VECTOR	05.5.06
Days - Hours	00 - 00
Minutes - Seconds	00 - 03
Setpoint	100.0
Gain	10
Rate	0
Reset	5

The command selected is 5 for Setpoint ramp. The JUMP VECTOR is 06 so that operation after the ramp goes to Step #06. The setpoint of step #05 will be set to 100K to indicate where the ramping will end. Note that even if the time were selected incorrectly, the ramping would still end at 100K. It is necessary to select the timer increment per tenth to arrive at the 100K in the 30 minutes.

From 40K to 100K is 600 tenths. It will require 600 increments of 3 seconds each to end up at 100K in 30 minutes (1800 seconds). Thus the setpoint will ramp up by 0.1K every 3 seconds up to 100K and will reach 100K in 30 minutes.

The reset will ramp from the value given in Step #04 to those specified in Step #05.

The soak is covered by Step #06 as follows.

STEP #06

Step#.Command.JUMP VECTOR	06.1.03
Days - Hours	00 - 01
Minutes - Seconds	00 - 00
Setpoint	100.0
Gain	10
Rate	0
Reset	5

After the soak, the next Program Step will be Step #03 which has a Command 9 and is explained at the end of Example #1.

6.8.3 Example #3 - Repeated Setpoint Ramp Up, Soak, and Ramp Down with Gain Ramping

The ramp up, soak, and ramp down shown in Figure 6.3 will be repeated indefinitely in this example. The first part of the example is identical to that given in Example #2 except that the gain will be ramped up from 10 to 20 and held at 20 for the 100K soak (See Figure 6.4). Steps #07, #08, and #09 and #10 will be dedicated to this example.

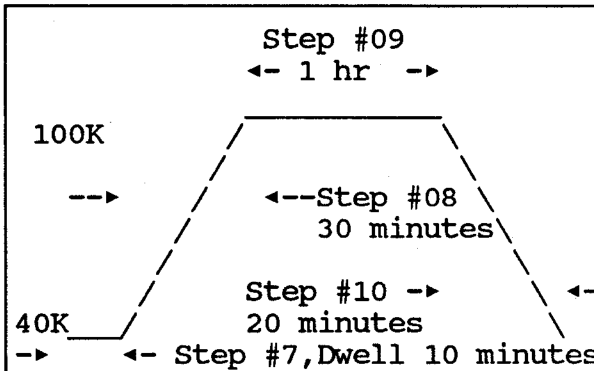


Figure 6.3 Example #3-Setpoint

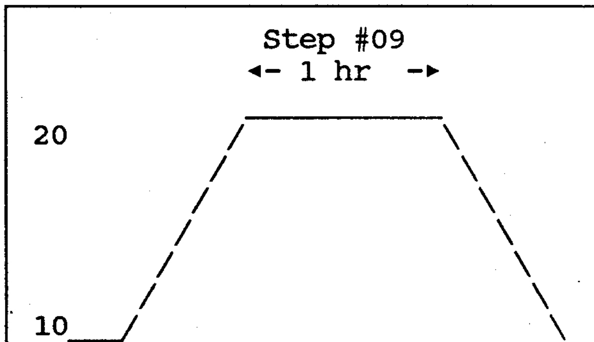


Figure 6.4 Example #3-Gain

Step #07 and #08 are identical to Steps #04 and #05 of Example #2 and are repeated here.

STEP #07

Step#.Command.JUMP VECTOR	07.1.08
Days - Hours	00 - 00
Minutes - Seconds	10 - 00
Setpoint	40.0
Gain	10
Rate	0
Reset	10

STEP #08

Step#.Command.JUMP VECTOR	08.5.09
Days - Hours	00 - 00
Minutes - Seconds	00 - 03
Setpoint	100.0
Gain	20
Rate	0
Reset	5

The soak is covered by Step #09 is the same as Step #06 of Example #2 except that the JUMP VECTOR is to Step #10.

STEP #09

Step#.Command.JUMP VECTOR	09.1.10
Days - Hours	00 - 01
Minutes - Seconds	00 - 00
Setpoint	100.0
Gain	20
Rate	0
Reset	5

After the soak, the next Program Step will be Step #10 which is to ramp down.

STEP #10

Step#.Command.JUMP VECTOR	10.5.07
Days - Hours	00 - 00
Minutes - Seconds	00 - 01
Setpoint	40.0
Gain	10
Rate	0
Reset	10

The JUMP VECTOR of Step #10 is to Step #07. In this way the entire sequence is repeated until the operator presses the CLEAR key to terminate the program mode.

The command for Step #10 is 5 for Setpoint ramping. The setpoint of step #05 will be set to 40K to indicate where the ramping will end. Note that even if the time were selected incorrectly, the ramping would still end at 40K. It is necessary to select the timer increment per tenth to arrive at the 40K in the 10 minutes.

From 40K to 100K is 600 tenths. It will require 600 increments of 1 seconds each to end up at 40K in 10 minutes (600 seconds).

The gain will ramp up during Step #08 and ramp down during Step #10.

6.8.4 Example #4 - Repeat of Example 3 with a Limit of 10 Cycles

STEP #11

Step#.Command.REPEAT COUNT 11.0.10

STEP #12

Step#.Command.JUMP VECTOR	12.2.14
Days - Hours	00 - 00
Minutes - Seconds	10 - 00
Setpoint	40.0
Gain	10
Rate	0
Reset	10

STEP #13

Step#.Command.JUMP VECTOR 13.8.17

STEP #14

Step#.Command.JUMP VECTOR	14.5.15
Days - Hours	00 - 00
Minutes - Seconds	00 - 03
Setpoint	100.0
Gain	20
Rate	0
Reset	5

STEP #15

Step#.Command.JUMP VECTOR	15.1.16
Days - Hours	00 - 01
Minutes - Seconds	00 - 00
Setpoint	100.0
Gain	20
Rate	0
Reset	5

STEP #16

Step#.Command.JUMP VECTOR	16.5.12
Days - Hours	00 - 00
Minutes - Seconds	00 - 01
Setpoint	40.0
Gain	10
Rate	0
Reset	10

STEP #17

Step#.Command.00	17.9.00
Setpoint	40.0
Gain	10
Rate	0
Reset	10

SECTION VII

ACCESSORIES, INPUT CARDS AND OPTIONS

TABLE OF CONTENTS

7.1 INTRODUCTION

This section contains information concerning the Accessories, Input Cards and Options for use with the DRC-93C Temperature Controller. Each Accessory, Input Card and Option is listed by part number in the Table on page 7-1.

7.2 ACCESSORIES

7.2.1 RM-3F Rack Mounting Kit

The DRC-93C can be rack mounted in a standard 19 inch instrument rack by using the RM-3F Rack Mounting Kit. The RM-3F mounts one controller in a height of 3.5 inches. Use the following procedure to install the RM-3F Kit.

1. Remove the two blue rack mount access covers, if present, from the front-side corners of the unit to be rack mounted. This is easily done by sliding the cover up as far as possible and using a blade screwdriver on the bottom edge to remove it from its position.

2. If the -H (handles) option was added, mount the handles onto the rack ears.

3. Attach the rack ears on opposite sides of the unit.

7.2.2 Cables

7.2.2.1 8072 IEEE-488 Interface Cable - The 8072 IEEE-488 Interface cable is one meter long and is equipped with double-ended connectors so it may be interconnected in serial or star patterns common in IEEE-488 instrument configurations.

7.2.2.2 8271-04 Scanner Sensor Cable - The 8271-04 Scanner Sensor cable for the 8229 Scanner Card is 3 meters long and brings out leads for the four additional input sensors provided by the 8229 Option. The cable's mechanical and electrical specifications are included with the cable.

7.2.2.3 8271-21 Sensor/Heater Cable - The 8271-21 Sensor/Heater Cable is a six pair individually shielded cable with two five pin miniature hexagonal plugs which mate with the SENSOR A and SENSOR B connectors on the back panel of the DRC-93C Temperature Controller. In addition to the sensor connectors, it has a dual banana plug for heater output and a single banana plug for heater output shield.

The cable's mechanical and electrical specifications are included with the cable.

7.2.2.4 8271-22 Sensor/Heater /Output Cable - The 8271-22 Sensor/Heater/Output Cable consists of two discrete cables. The first is a six pair individually shielded cable with two five pin miniature hexagonal plugs which mate with the SENSOR A and SENSOR B connectors on the back panel of the DRC-93C Temperature Controller. In addition to the sensor connectors, it has a dual banana plug for heater output and a single banana plug for heater output shield. The second cable is a three pair overall shielded cable for the Monitors Outputs.

The cable's mechanical and electrical specifications are included with the cable.

7.2.3 Cartridge Heaters

7.2.3.1 50 Ohm Cartridge Heater- This cartridge heater is 1/4" in diameter by 1" in length and is rated at 50 watts.

7.2.3.2 25 Ohm Cartridge Heater - This cartridge heater is 3/8" in diameter by 1" in length and is rated at 25 watts.

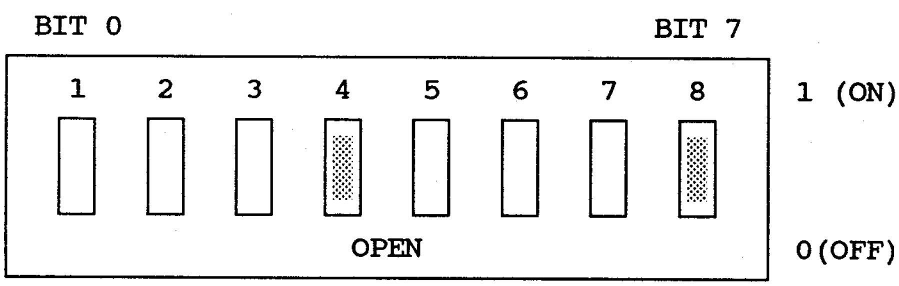
7.3 Installation of Input Cards from a DRC-81C or DRC-82C

Input cards from the DRC-81C or DRC-82C can be used in the DRC-93C. The DRC-93C will recognize these cards if the dip switch settings are set correctly. This Dip Switch is located in the rear right hand corner of the main board below the AC input connector.

WARNING

> To prevent shock hazard, turn off the instrument and disconnect it from the AC line power before changing the Input Card switch settings.

"OLD" INPUT CARD DIP SWITCH DEFINITIONS



1	2	3	4	5	6	7	8	A INPUT CARD	B INPUT CARD
0	0	0	X	0	0	0	X	NEW CARD (NON 8210,8211 OR 8219)	
0	0	1	X	0	0	0	X	8210	NEW CARD
0	1	0	X	0	0	0	X	8211	NEW CARD
1	0	0	X	0	0	0	X	8219-P2	NEW CARD
1	0	1	X	0	0	0	X	8219-P3	NEW CARD
1	1	0	X	0	0	0	X	8219-R1	NEW CARD
1	1	1	X	0	0	0	X	EMPTY	NEW CARD
0	0	0	X	0	0	1	X	NEW CARD	8210
0	0	0	X	0	1	0	X	NEW CARD	8211
0	0	0	X	1	0	0	X	NEW CARD	8219-P2
0	0	0	X	1	0	1	X	NEW CARD	8219-P3
0	0	0	X	1	1	0	X	NEW CARD	8219-R1
0	0	0	X	1	1	1	X	NEW CARD	EMPTY
ALSO COMBINATIONS OF A AND B									

X DON'T CARE - SWITCHES 4 AND 8 ARE RESERVED

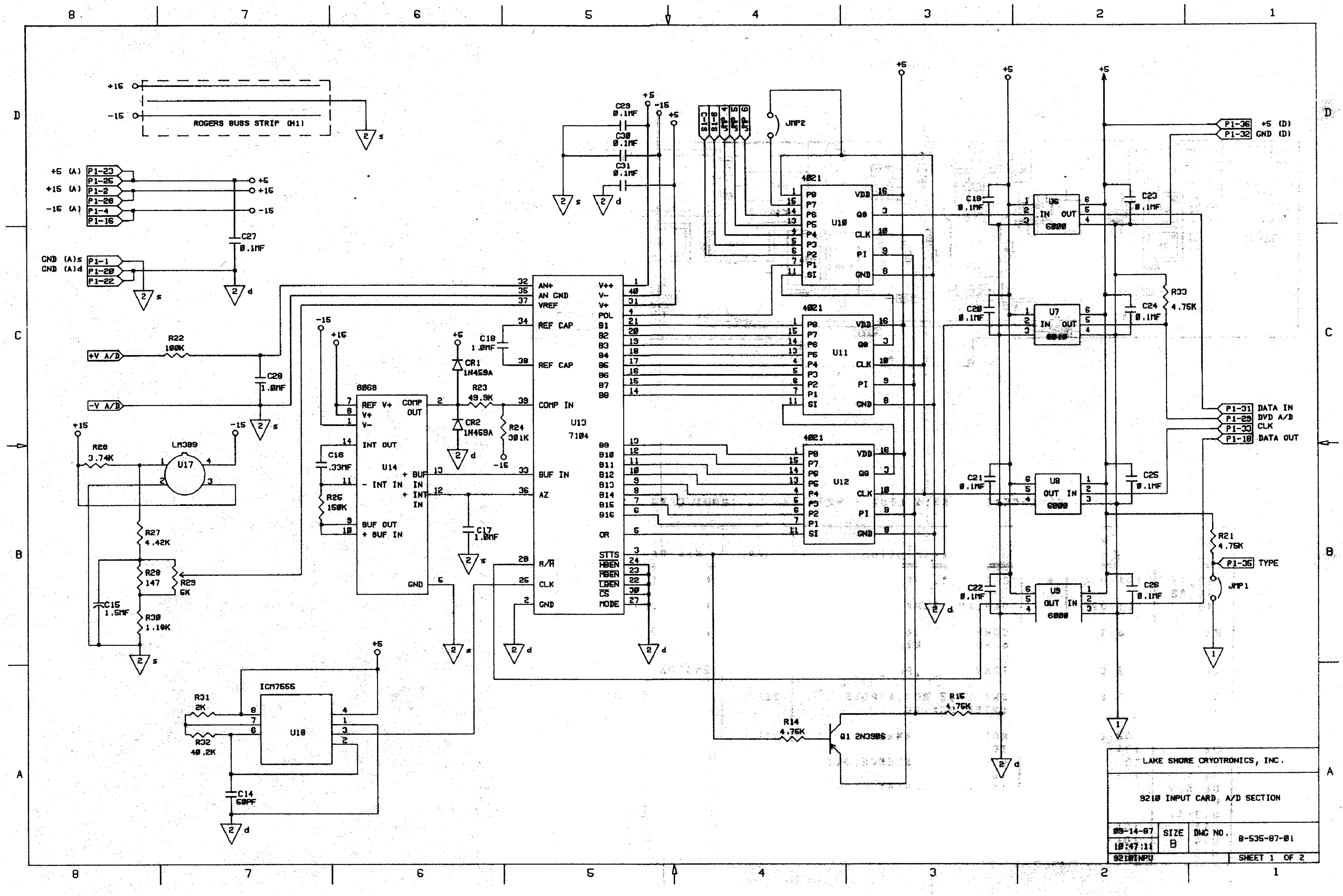
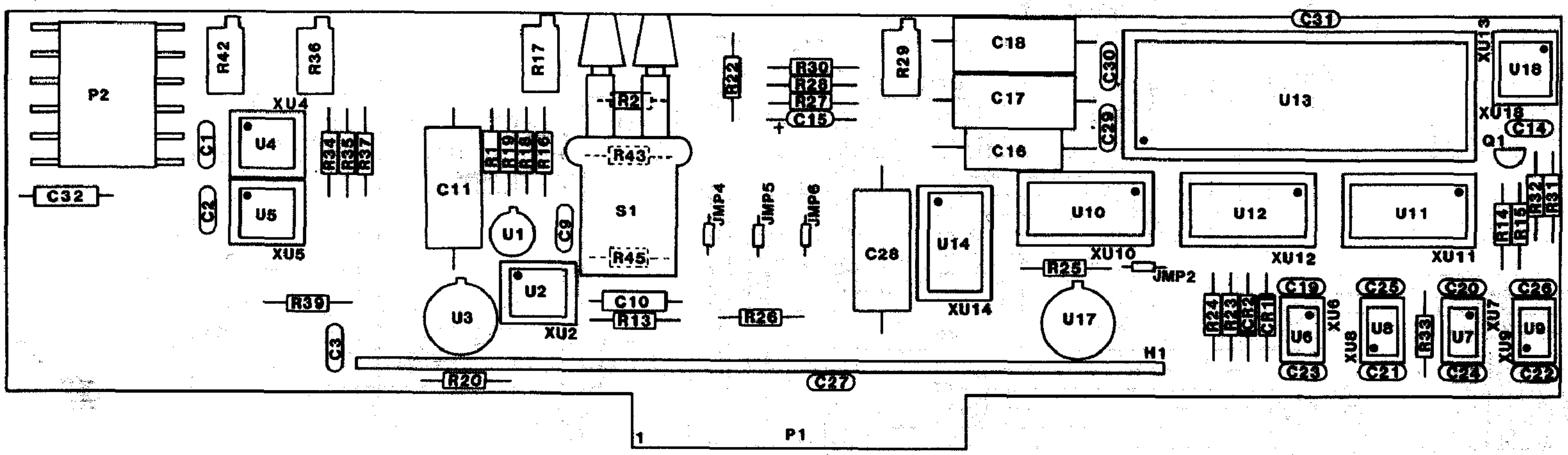
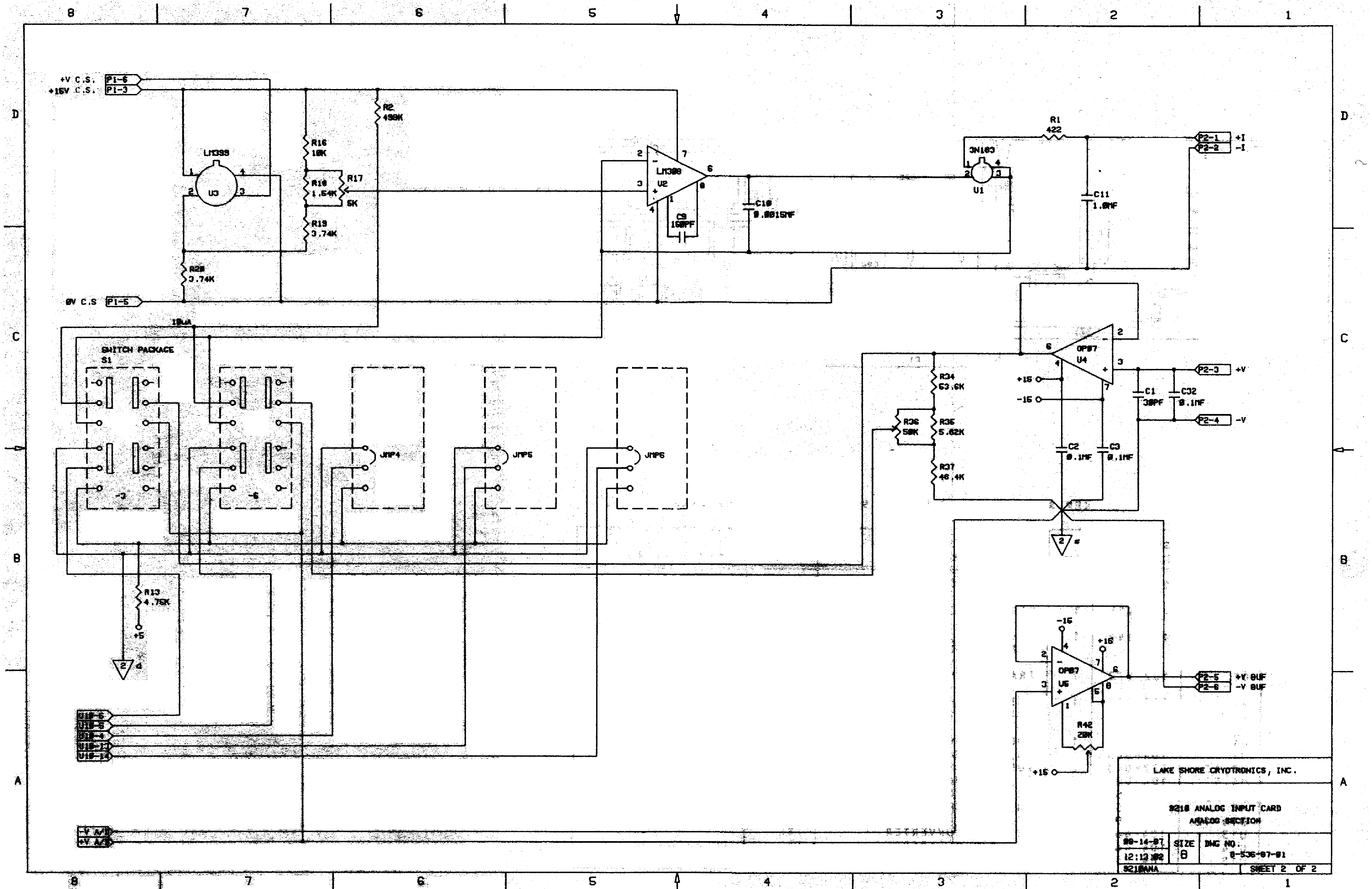


Figure 9210-1. Model 9210 Diode Input Card

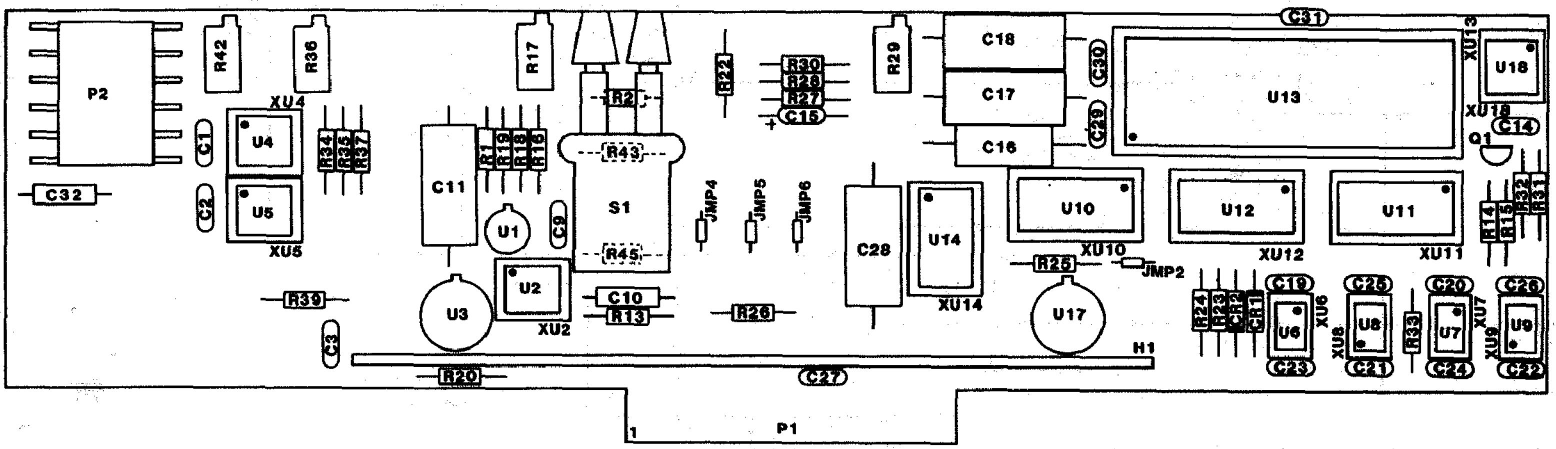


REPLACEABLE PARTS LIST - 9210 ANALOG INPUT CARD

ITEM NO	LSCI Part Number	Qty	Description	MFR	MFR PART NO
C11,17 18,28	101-034	4	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	104-001	2	IC, OP AMP	PMI	OP07E
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
U18	104-051	1	IC, TIMER	ISL	ICM7555IPA



+V C.S. P1-6
+15V C.S. P1-3
0V C.S P1-5
LM339 U3
R2 499K
R16 10K
R18 1.54K
R17 5K
R19 3.74K
R20 3.74K
10uA
LM308 U2
C9 150PF
C10 0.0015MF
3N163 U1
R1 422
C11 1.0MF
P2-1 +I
P2-2 -I
SWITCH PACKAGE S1
-3
-6
JMP4
JMP5
JMP6
R13 4.75K
+5
OP07 U4
R34 53.6K
R35 5.62K
R36 50K
R37 46.4K
+15
-15
C1 30PF
C32 0.1MF
C2 0.1MF
C3 0.1MF
P2-3 +V
P2-4 -V
OP07 U5
R42 20K
P2-5 +V BUF
P2-6 -V BUF
U10-6
U10-5
U10-4
U10-11
U10-14
-V A/D
+V A/D
LAKE SHORE CRYOTRONICS, INC.
9210 ANALOG INPUT CARD
ANALOG SECTION
08-14-87
12:13:02
SIZE B
DWG NO. B-536-07-01
9210ANA
SHEET 2 OF 2



REPLACEABLE PARTS LIST - 9210 ANALOG INPUT CARD

ITEM NO	LSCI Part Number	Qty	Description	MFR	MFR PART NO
C11,17 18,28	101-034	4	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	104-001	2	IC, OP AMP	PMI	OP07E
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
U18	104-051	1	IC, TIMER	ISL	ICM7555IPA

9210 DIODE INPUT CARD OPTION

9210.1 INTRODUCTION

This section contains information pertaining to the Model 9210 Diode Input Card. Included is a description, specifications, installation, operation and maintenance information.

9210.2 DESCRIPTION

The Model 9210 Diode Input Card is designed to be installed in a DRC-91C or DRC-93C to convert either the Input A or Input B (or both with two options) to accommodate diode sensors with a voltage output of up to 3.0000 volts (9210-3 configuration). The 9210-3 is used with Lake Shore DT-500-DRC or DT-470 Series Sensors. Calibrated DT-500 or DT-470 Series Sensors can be accommodated with an 8000 Series Precision Option.

The 9210-6 configuration will accommodate diode sensors (TG-120 series) with voltages between 0 and 6.5535 volts. A calibrated sensor and 8001 Precision Option is required for the DRC-91C/93C to read accurately in temperature. 9210-3 can be converted to 9210-6 configuration by switch on the 9210 Diode Input Option Card. This configuration will also read DT-470 and DT-500 series sensors but with reduced resolution and accuracy. See Table 9210-1.

9210.3 SPECIFICATIONS

Specifications for the Model 9210 Diode Input Card are given in Table 9210-1. The card can be configured by the user as either a 3 volt (9210-3) or a 6 volt (9210-6) card.

Table 9210-1. 9210 Diode Card

Sensor (ordered separately): DT-470 series, DT-500 series and TG-120 series from LSCI as well as any other diode sensor. See Lake Shore Diode Sensor brochures.

Temperature Range: Dependent on Diode Sensor. See Sensor brochure.

Sensor Excitation: DC current source. 10 microamperes ($\pm$0.005%). AC current noise less than 0.01% of DC current.- Compliance voltage - 7 volts minimum

Maximum Sensor Power Dissipation 20 microwatts @ 4.2K for DT-470 Series. 25 microwatts @ 4.2K for DT-500 Series. Dissipation under other conditions is a product of Sensor Excitation Current and developed sensor voltage.

9210-3:
Input Voltage Range: 0 to 3 V
Resolution: 0.05 millivolts
Accuracy: 0.1 millivolts
Display Resolution: 5 digits. Displays 0.0000 to 2.9999 volts. Equivalent temperature accuracy is a function of sensor type, sensitivity and curve specification or Precision Option.

9210-6:
Input Voltage Range: 0-6.5535V
Resolution: 0.1 millivolts
Accuracy: 0.2 millivolts
Display Resolution: 5 digits. displays 0.0000 to 6.5535 volts. equivalent temperature accuracy is a function of sensor type and sensitivity. Precision Option required for TG-120 Sensors.

9210.4 INSTALLATION

The 9210 can be installed in the 91C/93C as either Input A or Input B (or both with two options). The 9210 is factory installed if ordered with a DRC-91C/93C Temperature Controller or can be field installed at a later date. If field installation is required, use the following procedure.

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 the Input Card the 9210 will occupy.

WARNING

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

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

3. If an Input Card must be removed, disconnect the wiring harness mating connector by lifting the locking tab on the Input Card connector and gently pulling on the body of the wiring harness mating connector.

4. Plug the new 9210 Input Card into the A Input Card Slot 5 or the B Input Card Slot 6 with the component side to the left of the unit as viewed from the front. Connect the wiring harness mating connector to the 9210 making sure that the wiring harness locking tab is seated over the extended edge of the wiring harness mating connector. Verify that the wiring harness is in place correctly by noting that the "A" or "B" on the harness mating connector is facing up (if it is not, review the harness installation again). Thread the wiring harness along the rear edge of the unit and slip it into the harness strain relief on the rear panel.

5. Install the calibration cover by reversing procedure 2.

6. Install the top panel.

9210.5 OPERATION

The Model 9210-3 Diode Configuration provides the 10 microampere excitation current to the sensor. The resulting sensor voltage is digitized by a 16 bit A/D converter with a resolution of 50 microvolts and a full scale input voltage of 3.0000 volts (100 microvolts and 6.5535 volts for the 9210-6 configuration). The digitized value is converted to a serial data string and transferred to the main microprocessor using optical isolation. The sensor voltage is also buffered and transferred to the rear panel MONITORS connector for external monitoring as well as for control selection. For the 9210-3 configuration, it is multiplied by 1, for the 9210-6 configuration it is multiplied by 0.457771 (3.0000/6.5535).

9210.6 CALIBRATION

The 9210 was calibrated to specification in the configuration specified prior to shipment. If recalibration is needed, refer to the following procedure. The following equipment is used to calibrate the 9210 Diode Input Card:

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

2. Precision Standard Resistor - 100 kilohms with a tolerance of ±0.01% or better.

3. Precision Voltage Source - capable of supplying a voltage with an accuracy and resolution of 100 microvolts out of 10 volts or better.

The unit should be allowed a one hour warm-up time to achieve rated specifications. Use the following procedure to calibrate the 9210 Diode Input Card.

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

2. **Set 10μA Current** - Connect the precision resistor across the A (+I) and B (-I) pins of the five pin input connector for the input the 9210 occupies. Connect the DVM plus lead to the +I pin and the minus lead to the -I pin. Adjust the trimpot marked 10μA on the calibration cover for the appropriate Input Card until the voltage across the resistor is 1.0000 ± 0.0001 volts.

3. **Calibrate the Buffered Sensor Output Signal.** Connect the DVM plus lead to the +V Buffered Sensor Output Signal pin for the appropriate Input Card and the minus lead to the -V pin on the MONITORS connector. Connect the precision voltage source across the E (+V) and D (-V) pins of the five pin input connector for the appropriate input. Set the standard to 1.5000 volts and adjust the trimpot marked B on the calibration cover until the DVM reads as close to 1.5000 volts as possible for the 9210-3 configuration and adjust the value to 0.68666 volts for the 9210-6 configuration.

4. **Calibrate the A/D Converter.** Verify that the Display selects the desired Input Card and that the units selected are V. Set the standard to 1.5000 volts for the 9210-3 and adjust the trimpot marked **A/D** until the display reads 1.5000 V. Check linearity by inputting 2.0000 and 1.0000 volts and verify that the unit displays those settings within ± 0.0001 volts (5.0000 and 1.0000 volts for the 9210-6). If this specification is not met, check the Technical Service Guide for further instructions.

5. Install the top cover panel.

9210.7 SENSOR CURVE INFORMATION

Sensor Curve data for use with the 9210 Diode Input Card must be put in table form consisting of voltage and temperature points with the voltage in ascending voltage order. Refer to Section 4 of this manual for a discussion of how the data must be formatted for entry into the unit over the remote interfaces and to Appendix B for a discussion of Precision Option curves and examples of curves that would be used with the 9210.

9210.8 REPLACEABLE PARTS

Included in this section is Figure 9210-1. It includes the Model 9210 Diode Input Schematics, replaceable parts list and illustrated component layout. Refer to the manual for ordering information.

9215 CAPACITANCE INPUT CARD OPTION

9215.1 INTRODUCTION

This section contains information pertaining to the Model 9215-15/9215-150 Capacitance Input Card Configurations. Specifications, installation and operating instructions, a description of the principle of operation, and maintenance information are included. Section 9215.3 describes some characteristics of Capacitance sensors.

9215.2 DESCRIPTION AND SPECIFICATIONS

The Model 9215 Capacitance Input Card is designed to be installed in a DRC-91C or DRC-93C to convert either Input A or Input B to accommodate Capacitance sensors. When used to control temperature in magnetic fields the capacitance sensor is superior to other sensors since the displacement current in a capacitor is magnetic field independent. Accurate temperature reading requires the use of another type of sensor in zero magnetic field. This accurate sensor can be placed in the other Input Slot of the DRC-91C/DRC-93C.

The 9215-15 configuration is used with Capacitance sensors with a maximum of 30 nanofarads (for example, Lake Shore CS-401 Series Sensors).

The 9215-150 configuration will accommodate Capacitance sensors of up to 150 nanofarads (for example, Lake Shore CS-501 Series).

The card can be configured by the user as either a 15 nanofard (9215-15) or a 150 nanofarad (9215-150) card by switches on the card.

Specifications for the Model 9215 Capacitance Input Card Configurations are given in Table 9215-1.

Table 9215-1. Specifications of the Capacitance Input Card

Display Resolution: 5 digits.

Display Units: Capacitance in nanofarads.

Temperature Accuracy:
A function of sensor sensitivity. See Table 9215-2. Unit supports capacitance only.

Sign of Temperature Coefficient:
User Selectable by Switch on on DRC-91C, Keys on DRC-93C or via Computer Interface.

Magnetic Field Sensitivity:
< ±0.15% for B < 19 Tesla and T > 4.2K. See Section 9215.3.

9215-15:
Sensor Excitation: 5 kilohertz charging current.
Capacitance Range: 0 to 15 nF, 0-30 nF with reduced accuracy.
Sensor (ordered separately):
CS-401 Series from LSCI or or other Capacitance Sensor.
Resolution: 0.001 nF
Accuracy: ±0.25% of Full Scale
Range: 0.000 to 29.999 nF
Analog Output Signal: 0.1 times capacitance (nF) in volts

9215-150:
Sensor Excitation: 1 kilohertz charging current.
Capacitance Range: 0 to 150 nF
Sensor (ordered separately):
CS-501 Series from LSCI or other Capacitance Sensor.
Resolution: 0.01 nF
Accuracy: ±0.25% of Full Scale
Range: 0.00 to 149.99 nF
Analog Output Signal: 0.02 times capacitance (nF) in volts.

Table 9215-2 Typical Temperature Ranges and Sensitivities

Sensor Type	T (K)	C (nf)	dC/dT (pf/K)
CS-401GR-A[1] (1184)	4.2	1.7609	20.77
	20.0	2.0347	15.30
	60.0	2.4227	2.42
	80.0	2.3544	- 9.14
	140.0	1.4847	-12.91
	200.0	0.9445	- 5.95
	295.0	0.6307	- 1.83
CS-401GR-B[1] (1186)	4.2	5.3155	65.22
	20.0	6.1118	44.63
	60.0	7.2357	7.38
	80.0	7.0525	-25.61
	140.0	4.5379	-38.46
	200.0	2.9062	-18.10
	270.0	2.1054	- 7.07
	295.0	1.9492	- 5.55
CS-401LG-B[1]	---[3]	------	-------
CS-401LG-C[1] (1248)	4.2	11.1972	137.
	20.0	12.9423	94.8
	60.0	15.3912	21.2
	80.0	14.9303	-60.7
	140.0	9.3561	-81.3
	200.0	5.9762	-37.1
	270.0	4.3180	-14.0
	295.0	3.9989	-12.2
CS-501[2] (10002)	4.4	6.5884	30.74
	20.0	7.1334	37.61
	60.0	9.0452	56.19
	80.0	10.1940	57.52
	140.0	14.0355	82.44
	200.0	21.7233	197.4
	270.0	91.0746	4025.
	295.0	130.140	-1226.

Notes:

1. 9215-15 configuration.
2. 9215-150 configuration.
3. No Calibration Data Available

9215.3 NOTES ON CS-501 CAPACITANCE SENSORS

9215.3.1 Short-Term Stability

The capacitance sensor provides very stable temperature control over long periods of time. However, since an operational "aging" phenomenon exists some care must be exercised in their use. The short-term (minutes to hours) capacitance/temperature drift is initiated by a thermal perturbation of the sensor.

In order to minimize this short-term drift, it is recommended that approximately one hour be allowed for the sensor to stabilize after the initial cooldown. The short-term drift is then on the order of a few tenths of millikelvin/minute at 4.2K, several millikelvin/minute at 77K and one millikelvin/minute at 305K. For temperatures less than 290K the short-term drift is such that the equivalent temperature will decrease with time and for temperatures above 290K will increase with time.

9215.3.2 Thermal Cycling and Reproducibility

Thermal cycling of capacitance sensors can produce variations in capacitance/temperature values equivalent to several tenths of a degree over the short term (days). Thermal cycling over the long term (weeks) can result in variations that exceed a degree. These variations are always such that the equivalent temperature increases with time and with increased cycling. The reduced capacitance C(T)/C(4.2K) for T<290K is stable to within ±0.5K on the average. Also these variations do not create instabilities and do not impair the sensors primary function as a control device in magnetic fields. They also are not seen within a temperature cycle.

9215.3.3 Magnetic Field Dependency

Magnetic field sensitivity is less than ±0.15 % at 4.2K and less that ±0.05 % between 77K and 305K for fields up to 18.7 Tesla.

9215.3.4 Frequency Dependence

For frequencies between 1 and 5 kilohertz the frequency sensitivity is as follows:

-0.18K/kilohertz at 4.2K

-1K/kilohertz at 77K

+0.06K/kilohertz at 305K

9215.4 INSTALLATION

The 9215 can be installed in the DRC-91C/93C as either Input A or Input B. The card is factory installed if ordered with a DRC-91C/93C Temperature Controller or can be field installed at a later date. If field installation is required, use the following procedure.

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 the Card will occupy.

WARNING

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

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 J11 blank cover plate to the interface opening and remove the plate. (Note: some early DRC-91Cs do not have the J11 opening. Use the J9 8229 Scanner option opening. If an 8229 is present move the 8229 to the J10 RS-232 slot.

3. If an Input Card must be removed, disconnect the wiring harness mating connector by lifting the locking tab on the Input Card connector and gently pulling on the body of the wiring harness mating connector.

4. Plug the new Input Card into the A Input Card Slot 5 or the B Input Card Slot 6 with the component side to the left of the unit as viewed from the front. Connect the wiring harness mating connector to the card making sure that the wiring harness locking tab is seated over the extended edge of the wiring harness mating connector. Verify that the wiring harness is in place correctly by noting that the "A" or "B" on the harness mating connector is facing up (if it is not, review the harness installation again). Thread the wiring harness along the rear edge of the unit and slip it into the harness strain relief on the rear panel. Thread the 9215 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.

NOTE: Be sure that the card is centered in the slot. The harness will have a tendency to push the card forward and may in some instances cause the card and instrument to not behave properly.

5. Position the 9215 connector plate in the appropriate opening and secure it in place using the screws provided.

6. Install the calibration cover by reversing procedure 2.

7. Select either the 9215-15 or 9215-150 configuration by pressing the appropriate pushbutton switch.

8. Install the top panel.

9215.5 SENSOR CONNECTIONS

The 9215 connector plate supplies two independent dual isolated BNC connectors for the sensor connections. A four lead measurement is used to minimize the effect of series resistance on the capacitance measurement. Since the capacitance sensor is non-polarized, one pair should be used for the current connections and the other pair for the voltage connections. The pin contact of the connector is + and the socket -.

9215.6 SELECTION OF THE SIGN OF THE TEMPERATURE COEFFICIENT

The temperature coefficient of some Capacitance Sensors can be positive or negative depending on the temperature range. The 9215 Card produces a voltage proportional to the Capacitance which is sent to the control circuitry of the DRC-91C/93C to be compared to a user selected setpoint. For control to operate properly, the sign of the voltage must reflect the temperature coefficient of the sensor. It is necessary for the user to determine which range the sensor is in and to inform the controller of the sign of the temperature coefficient. This is accomplished on the DRC-91C by a switch (switch 1 of the SENSOR ID) on its rear panel and on the DRC-93C by a sequence of key strokes from its front panel. Also the Sign of the temperature coefficient can be entered via the computer interface using the AC_1C_2 or BC_1C_2 command.

9215.6.1 Selection of Temperature Coefficient Sign on the DRC-91C

The sign to be used on the Temperature Coefficient of the capacitance is selected using Switch 1 of the appropriate SENSOR ID located on the rear panel of the DRC-91C.

When Switch 1 of the SENSOR ID is **closed** the Temperature Coefficient is Positive. When Switch 1 of the SENSOR ID is **open**, the Temperature Coefficient is Negative.

9215.6.2 Selection of Temperature Coefficient Sign on the DRC-93C

When a 9215 Capacitance Input Card is installed, pressing the SENSOR key will display for the appropriate channel either ±15-15 or ±15-50; the -15 for the 9215-15 configuration or -50 for the 9215-150 configuration. The (±) sign indicates whether the Temperature Coefficient is positive or negative. The plus (+) means that the Temperature Coefficient is positive. The minus (-) means that the Temperature Coefficient is negative.

Select the Temperature Coefficient sign from the front panel by using a combination of the SENSOR key, SCAN (↑↓) key and the ▴▴ key and ▾▾ key as follows:

1. Press and hold the SENSOR key.
2. While holding down the SENSOR key, press the SCAN (↑↓) key. You may now let up on the SENSOR key.
3. To change the sign if in the upper display hit the ▴▴ key while still holding down the SCAN (↑↓) key. Similarly, to change the sign if in the lower display hit the ▾▾ key while still holding down the SCAN (↑↓) key.
4. Now let up on the ▴▴ key (or ▾▾ key) and then the SCAN (↑↓) key.

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

9215.6.3 Selection of the Sign of the Temperature Coefficient via the Computer Interface

To select the sign of the temperature coefficient via the IEEE interface, check the AC_1C_2 and BC_1C_2 commands in the instrument manual.

9215.7 PRINCIPLE OF OPERATION

The 9215-15 configuration provides a charging current switched at a frequency of 5 kilohertz. The frequency is precisely controlled by a crystal oscillator. The operation of the 9215-150 is identical except that the frequency is 1 kilohertz. The charging current produces a sawtooth voltage waveform with a peak-to-peak voltage of about 7 volts. Another voltage of precise amplitude is generated which has a duty cycle dependent on the charging time of the capacitor. This waveform is averaged and filtered to produce a positive DC voltage proportional to the capacitance. This DC voltage is sent to a 16 bit A/D converter on the card. The A/D converter has a resolution of 50 microvolts and a full scale input voltage of 3.0000 volts. With the 9215-15 Configuration the 3.0000 volts corresponds to a capacitance of 30 nanofarads; and on the 9215-150 configuration to 150 nanofarads. The digitized value is converted to a serial data string and transferred to the main microprocessor using optical isolation.

A relay on the Card configures the sensor voltage as negative or positive based on the temperature coefficient sign selected by the user (Section 9215.5). That voltage is buffered and transferred to the rear panel MONITORS connector for external monitoring as well as to the main board control circuitry.

9215.8 CALIBRATION

The 9215 was calibrated to specification prior to shipment. The card meets specification for operation either in the 9215-15 or 9215-150 configuration by simply pressing the switches located on the card. This Section provides information to permit recalibration if needed.

NOTE: Calibration for zero capacitance may be required to meet accuracy specifications if your sensor lead capacitance or stray capacitance is excessive.

The following equipment is used to calibrate the 9215 Capacitance Input Card:

1. Digital Voltmeter/Multimeter (DVM) - 4½ digit resolution or better.
2. Precision Standard Capacitors - 10 nanofarad and 100 nanofarad with tolerance of ±0.1% or better.
3. Precision Voltage Source - capable of supplying a voltage with an accuracy and resolution of 100 microvolts out of 10 volts or better.

The unit should be allowed a one hour warm-up time to achieve rated specifications. To begin remove the three top panel screws and slide the panel off. The procedure is divided into three parts as follows.

1. Calibration of the A/D Converter.
2. Zero calibration.
3. Span Calibration.

The zero and span calibration is done with the instrument and system wiring configured as it will be used. This will provide optimum accuracy because lead and stray capacitance will be taken into account.

9215.8.1 A/D Calibration

1. Locate DIP switch package S1A-Switch 2. Under normal operation this switch is CLOSED(1). Change this switch to the OPEN(0) position.
2. Connect the DVM plus lead to the +V Buffered Sensor Output Signal pin for the appropriate Input Card and the minus lead to the -V pin on the MONITORS connector. Connect the precision voltage source across the E (+V) and D (-V) pins of the five pin input connector for the input corresponding to the Capacitance Card.
3. Set the standard to 1.5000 volts.
4. Verify that the Display indicates the Capacitance Input Card.
5. Adjust the trimpot marked **A/D** until the display reads 15.000nF for the 9215-15 or 75.00nF for the 9215-150. Check linearity by inputting 2.0000 and 1.0000

volts and verify that the unit displays 20.000 and 10.000nF within ±0.001nF for the 9215-15 or 100.0 and 50.0nF within ±0.01nF for the 9215-150.

6. Return S1A - Switch 2 to the CLOSED(1) position.

9215.8.2 Zero Calibration

1. Be sure that the leads are in the configuration which will be used in your system. Detach the capacitance sensor.

2. Verify that the Display indicates the Capacitance Input Card.

3. Adjust the trimpot marked **ZERO** so that the display reads 0.000 on the 9215-15 or 0.00 on the 9215-150.

9215.8.3 Span Calibration

1. Be sure that the leads are in the configuration which will be used in your system. Attach the standard capacitor in place of the capacitance sensor.

2. Verify that the Display indicates the Capacitance Input Card.

3. Adjust the trimpot marked **SPAN** so that the display reads the value of the standard capacitor.

9215.9 REPLACEABLE PARTS

Included in this section is Figure 9215-1. It includes the Model 9215 Capacitance Input Schematics, replaceable parts list and illustrated component layout. Refer to the manual for ordering information.

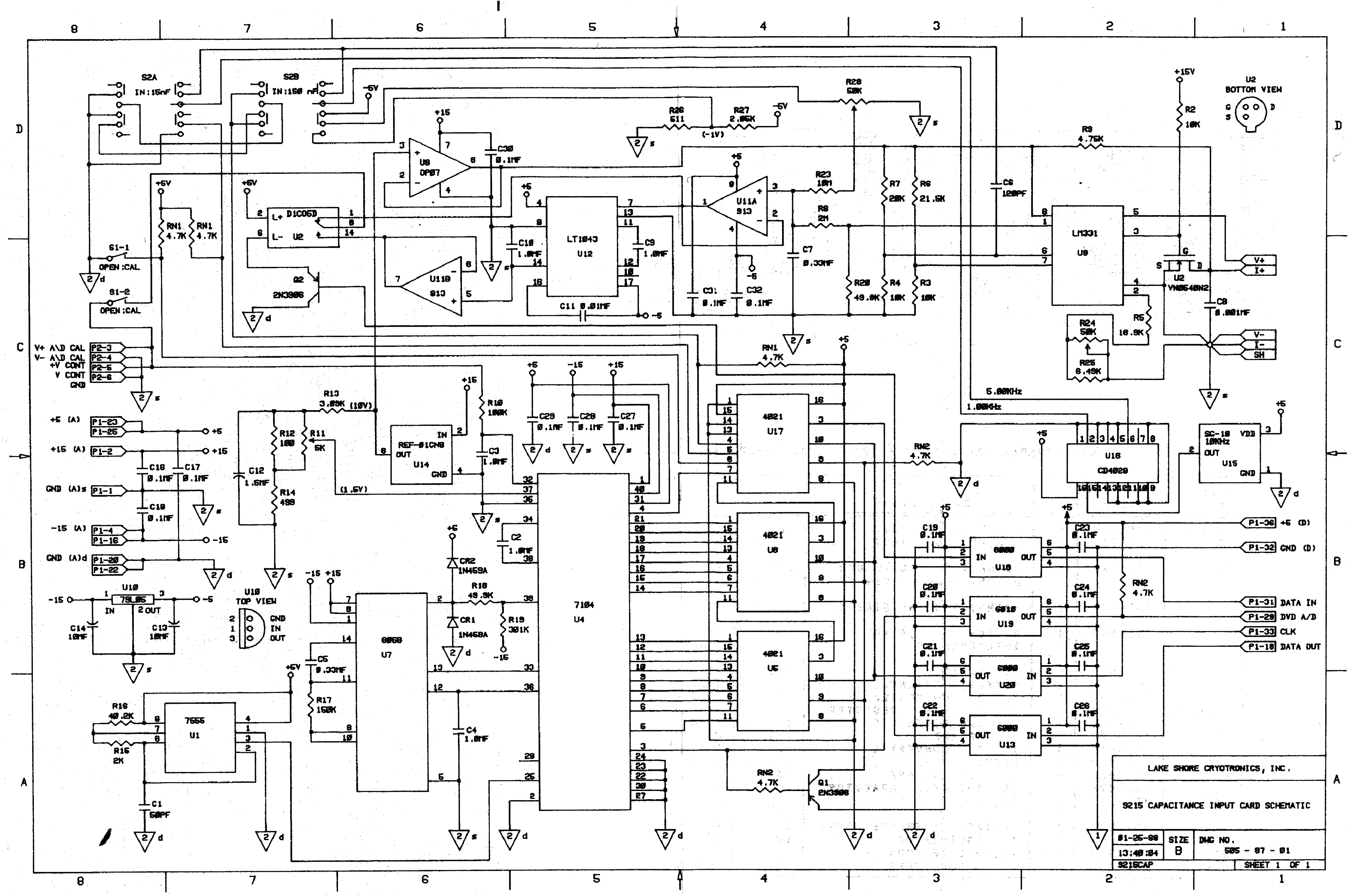
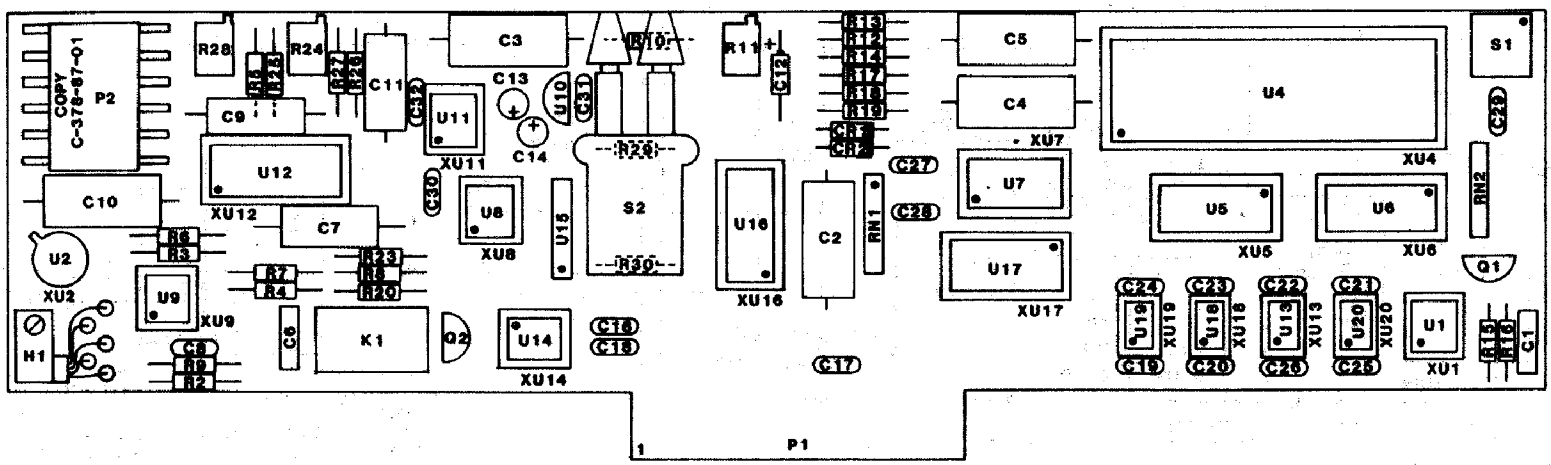


Figure 9215-1. Model 9215 Capacitance Input Card



REPLACEABLE PARTS LIST - 9215 CAPACITANCE INPUT CARD

ITEM NO	LSCI Part Number	Qty	Description	MFR	MFR PART NO
C2,3,4	101-034	3	CAP,PP,1.0MF,100V	FDYNE	MPP2X-1.0-100-10
C5	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	2	TRANSISTOR,PNP,SIGNAL		2N3906
S1	105-649	1	SWITCH,2 POS,4 POLE INTERLOCKING	EGC	2XMTA7.5(NONE) 4UGRP
U1	104-051	1	IC, TIMER	ISL	ICM7555IPA
U2	102-075	1	MOSFET,N CHANNEL		VN0535N2
U4	104-461	1	IC, A/D CONVERTER	ISL	ICL7104-16CPL
U5,6,17	104-099	3	IC, P-S SHIFT REGISTER		CD4021BCN
U7	104-460	1	IC, A/D REFERENCE	ISL	ICL8068ACPD
U8	104-001	1	IC, OP AMP	PMI	OP07E
U9	104-010	1	IC, F/V CONVERTER	NAT	LM331N
U10	102-020	1	REGULATOR,-5	MOT	79L05
U11	104-087	1	IC, DUAL OP AMP	TDYN	TSC913A
U12	104-078	1	IC, SWITCHED CAPACITOR	LT	LT1043CN
U13,18,20	104-355	3	IC, OPTOCOUPLER	GI	740L6000
U14	102-037	1	VOLTAGE REFERENCE, 10V	LT	REF-01EN8
U15	104-054	1	IC, OSCILLATOR	EPS	SG-10-10KA
U16	104-101	1	IC, DECADE COUNTER		4029CBN
U19	104-356	1	IC, OPTOCOUPLER	GI	740L6010

9220 USER CONFIGURABLE INPUT CARD OPTION

9220.1 INTRODUCTION

This section contains information pertaining to the Model 9220 Diode and Platinum User Configurable Input Card. Included is a description, specifications, installation, operation and maintenance information.

9220.2 DESCRIPTION

The Model 9220 Diode and Platinum Input Card is designed to be installed in a DRC-91C or DRC-93C to convert either the Input A or Input B (or both with two options) to accommodate either diode or positive temperature coefficient sensors such as platinum or rhodium-iron.

The 9220-3 configuration is equivalent to the 9210-3 configuration described earlier. The 9220-6 configuration is equivalent to the 9210-6 configuration.

The 9220-P2 converts either Input A or B (or both with two options) to accommodate 100 ohm platinum RTD's which conform to DIN 43760 tolerances ± 0.1K, have an interchangeability of 0.1% at 0°C and a temperature coefficient of 0.00385/°C from 0 to 100°C. This card may also be configured as a 9220-P3 (1000 ohm platinum) or 9220-R1 (rhodium-iron) input card.

9220.3 SPECIFICATIONS

Specifications for the Model 9220 User Configurable Input Card are given in Table 9220-1 of this manual. The card can be configured as a 9220-3 or 9220-6 diode card, a 9220-P2 or 9220-P3 platinum card or a 9220-R1 rhodium-iron input card.

Table 9220-1. 9220 Configurable Input Card

9220-3: See 9210-3 specifications.

9220-6: See 9210-6 specifications.

Sensor (ordered separately):
Platinum RTD sensor. PT-100 series or any other 100 ohm or 1000 ohm platinum sensor.
27 ohm rhodium-iron sensor.
See Lake Shore Sensor brochures.

Temperature Range: Dependent on Sensor. See Sensor brochure.

RTD Sensor Power Dissipation: Depends on Sensor Resistance. Dissipation is the product of sensor excitation current squared and the Sensor resistance.

9220-P2: 100 ohm platinum
Current Excitation: 1mA(±0.005%)
Resistance Range: 0.00-299.99Ω.
Resolution: 0.005 ohms
Accuracy: 0.01 ohms
Display Resolution: 5 digits. Displays 0.00 to 299.99 ohms.*

9220-P3: 1000 ohm platinum
Current Excitation: 0.1mA(±0.005%)
Resistance Range: 0.0 to 2999.9 Ω.
Resolution: 0.05 ohm
Accuracy: 0.1 ohm
Display Resolution: 5 digits. Displays 0.0 to 2999.9 ohms.*

9220-R1: 27 ohm platinum
Current Excitation: 3 mA(±0.005%)
Resistance Range: 0.000 to 99.999Ω
Resolution: 0.003 ohm
Accuracy: 0.003 ohm
Display Resolution: 5 digits. Displays 0.000 to 99.999 ohms.*

*Equivalent temperature accuracy is a function of sensor type, sensitivity and Precision Option.

9220.4 INSTALLATION

The 9220 can be installed in the 91C/93C as either Input A or Input B (or both with two options). The 9220 is factory installed if ordered with a 91C or 93C 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 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 on the calibration cover the position of the Input Card the 9220 will occupy.
2. Remove the four screws that secure the calibration cover to its clips and remove the cover.
3. If an Input Card must be removed, disconnect the wiring harness mating connector by lifting the locking tab on the Input Card connector and gently pulling on the body of the wiring harness mating connector.
4. Plug the new 9220 Input Card into the A Input Card Slot 4 or the B Input Card Slot 5 with the component side to the left of the unit as viewed from the front. Connect the wiring harness mating connector to the 9220 making sure that the wiring harness locking tab is seated over the extended edge of the wiring harness mating connector. Verify that the wiring harness is in place correctly by noting that the "A" or "B" on the harness mating connector is facing up (if it is not, review the harness installation again). Thread the wiring harness along the rear edge of the unit and slip it into the harness strain relief on the rear panel.
5. Install the calibration cover by reversing procedure 2.
6. Install the top panel.

9220.5 OPERATION

The 9220-3 and 9220-6 configurations are equivalent to the 9210-3 and 9210-6 configurations in terms of operation.

The Model 9220-P2 Configuration provides the 1 milliampere excitation current to the platinum sensor (the 9220-P3 supplies 0.1 milliampere and the 9220-R1 supplies 3 milliamperes). The resulting sensor voltage is amplified by a factor of -10 (negative 10) and digitized by a 16 bit A/D converter with a resolution of better than 100 microvolts out of 3.0000 volts full scale. The digitized value is converted to a serial data string and transferred to the main microprocessor using optical isolation. The amplified (-10) sensor voltage is transferred to the J3 MONITORS connector for external monitoring.

9220.6 CALIBRATION

The 9220 was calibrated to specification prior to shipment. If recalibration is needed, refer to the following procedure. The following equipment is used to calibrate the 9220 Input Card:

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

2. Precision Standard Resistor - 1 kilohms for 9220-P3 or 100 ohms for 9220-P2 and 9220-R1 with a tolerance of +/- 0.01% or better.

3. Precision Voltage Source - capable of supplying a voltage with an accuracy and resolution of 10 microvolts out of 1 volt or better.

The unit should be allowed a one hour warm-up time to achieve rated specifications.

Refer to the 9210 section for the calibration procedure for the 9220-3 and 9220-6 configurations.

Use the following procedure to calibrate the 9220-P2, -P3 and -R1 Configurations.

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

2. **Set 100 μA, 1mA, 3mA Current-** Connect the appropriate precision resistor across the A (+I) and B (-I) pins of the five pin input connector for the input (J1 or J2) the 9220 occupies. Connect the DVM plus lead to the +I pin and the minus lead to the -I pin. Adjust the trimpot marked **1mA** (for -P2) on the calibration cover (**100μA** for -P3, **3mA** for -R1) for the appropriate Input Card until the voltage across the resistor is equal to the sensor current times the resistance ± the tolerance of the resistor.

3. **Calibrate the Input -10 Amplifier** -Connect the DVM plus and minus leads to the + V and -V Sensor Output Signal pins for the appropriate Input Card of the J3 MONITORS connector. Connect the precision voltage source across the E(+V) and D(-V) of J1 INPUT A or J2 INPUT B for the appropriate input and set the standard to 0.0000 volts. Adjust the trimpot marked **AMP Z** on the calibration cover until the DVM reads as close to 0 volts as possible. Set the standard to 0.2500 volts and adjust the trimpot marked **AMP S** on the calibration cover until the voltage reads -2.5000 volts.

4. **Calibrate the A/D Converter-** Verify that the Display Sensor is the desired Input Card and that the units are ohms. Set the standard to 0.2700 volts and adjust the trimpot marked **A/D** until the display reads 270.00 ohms (for the 9220-P3 an input of 0.2700 volts results in a display of 2700.0 ohms and for the 9220-R1 an input of 0.2700 volts results in a display of 81.00 ohms). Check linearity by inputting 0.2000 and 0.1000 volts and verify that the unit displays 200.00 and 100.00 ohms within +/- 0.01 ohms (or equivalent for the 9220-P3 and 9220-R1).

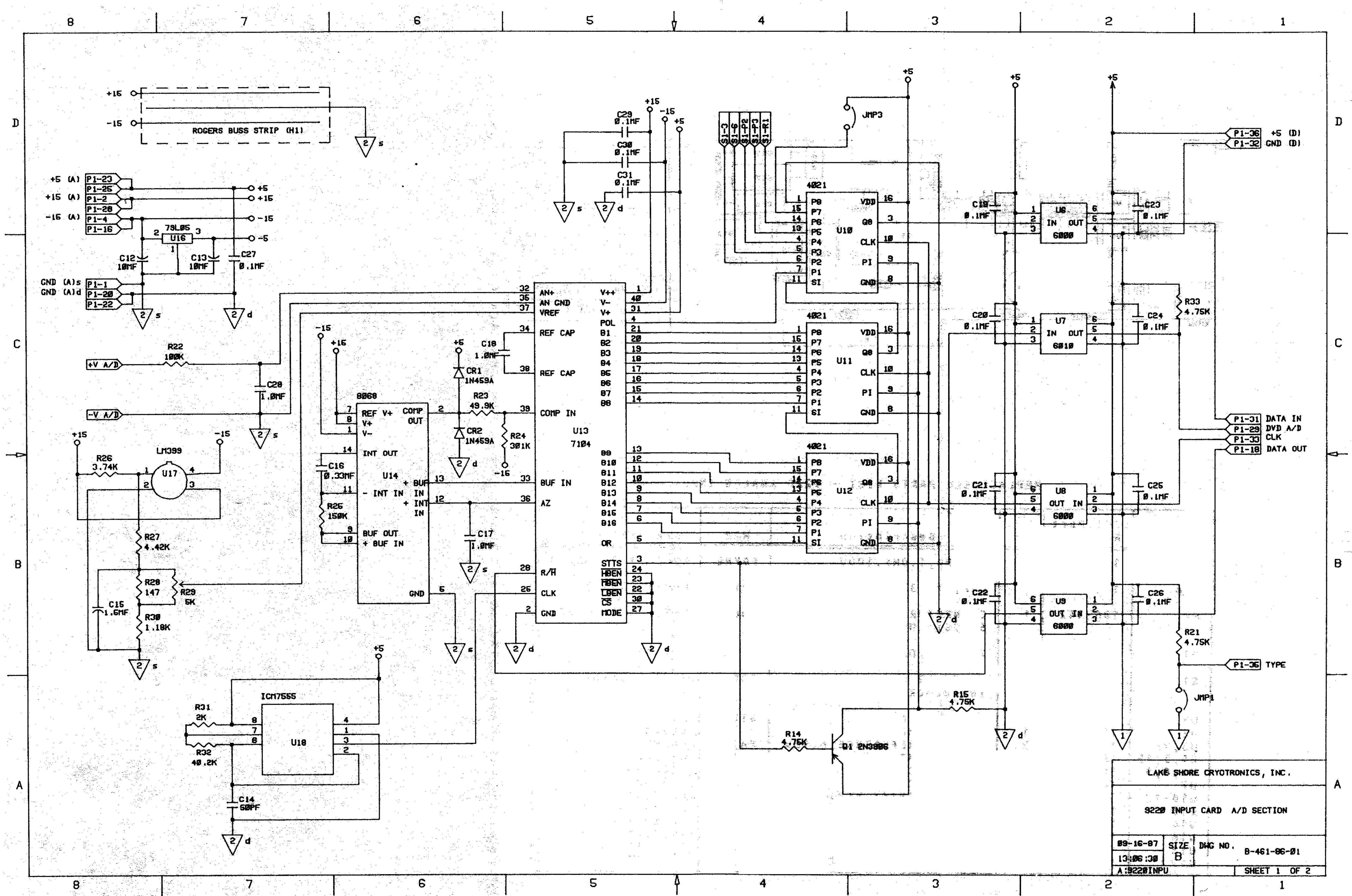
5. Install the top panel.

9220.7 SENSOR CURVE INFORMATION

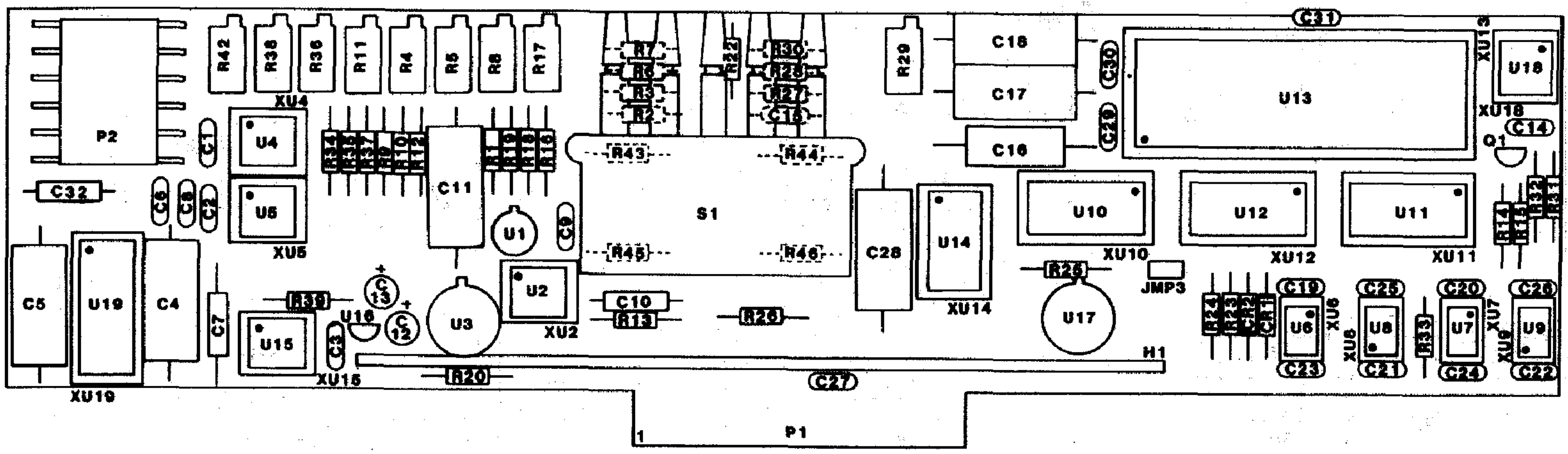
Sensor Curve data for use with the 9220 RTD Configurations must be put in table form consisting of voltage and temperature points with the voltage in ascending voltage order. Since the 9220 raw data would be in resistance form, it must be converted prior to entering. Refer to Section 4 of this manual for a discussion of how the data must be converted and formatted for entry into the unit over the remote interface and to Appendix B for a discussion of Precision Option curves and examples of curves that would be used with the 9220.

9220.8 REPLACEABLE PARTS

Included in this section is Figure 9220-1. It includes the Model 9220 input schematics, replaceable parts list and illustrated component layout. Refer to the manual for ordering information.

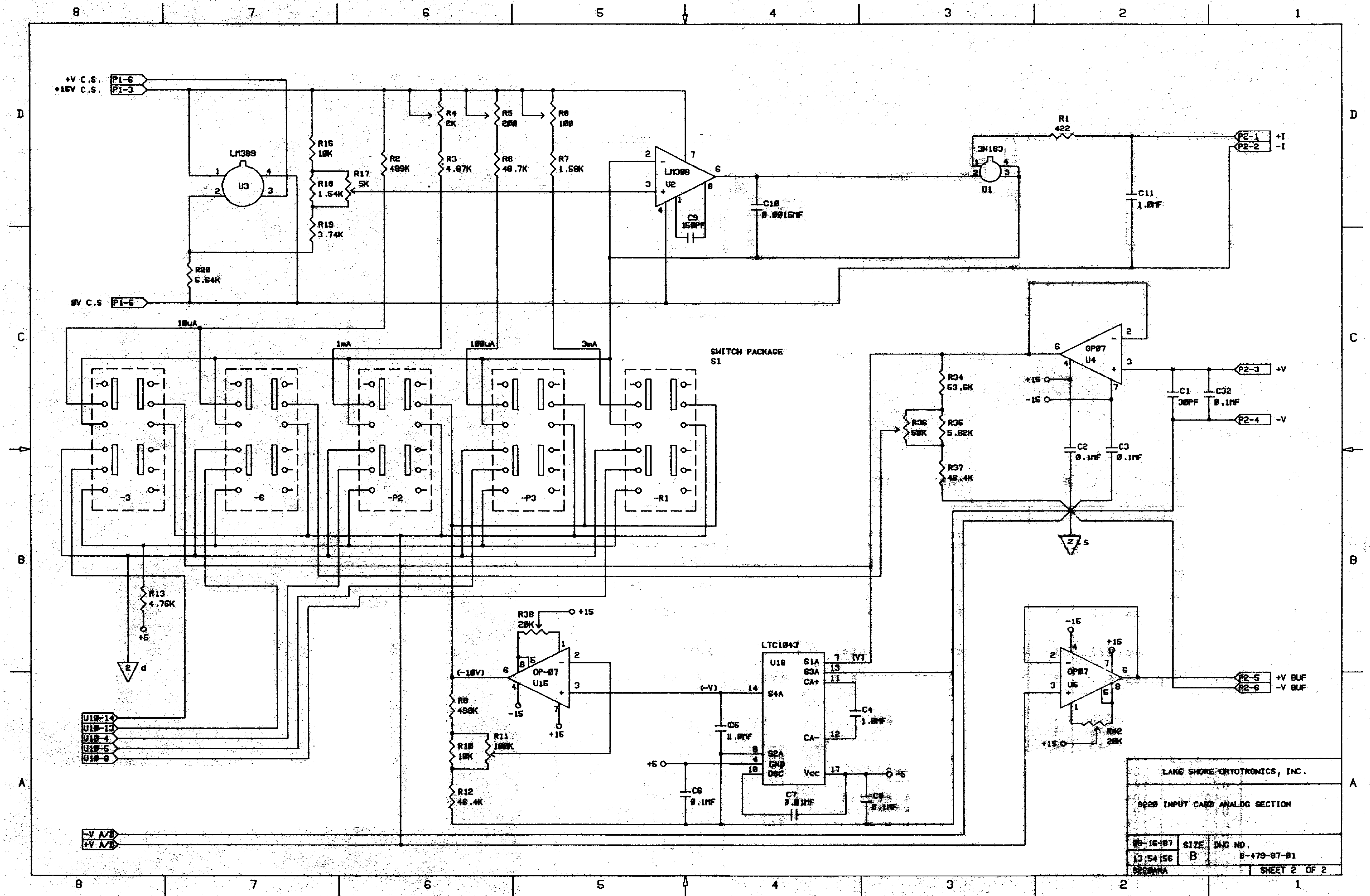


Model 9220-1. Model 9220 User Configurable Input Card

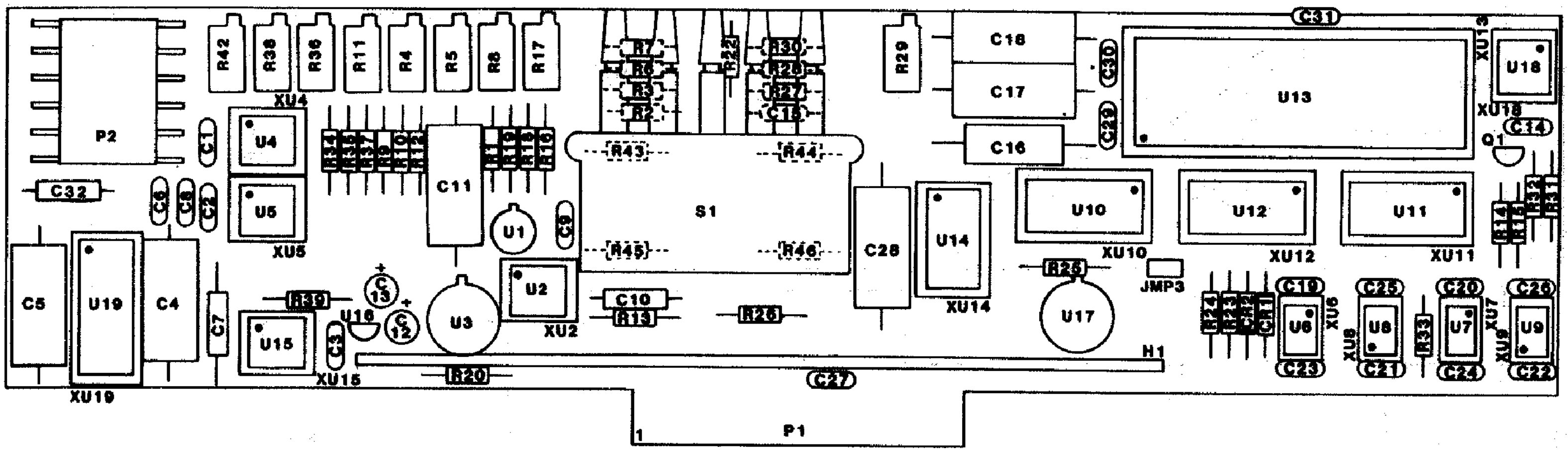


REPLACEABLE PARTS LIST - 9220 ANALOG INPUT CARD

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



+V C.S. P1-6
+15V C.S. P1-3
0V C.S P1-5
LM399
U3
R16 10K
R18 1.54K
R17 5K
R19 3.74K
R20 5.64K
R2 499K
R4 2K
R3 4.87K
R5 200
R6 40.7K
R8 100
R7 1.50K
LM308
U2
C9 150PF
C10 0.0015MF
R1 422
3N163
U1
C11 1.0MF
P2-1 +I
P2-2 -I
10uA
1mA
100uA
3mA
SWITCH PACKAGE S1
-3
-6
-P2
-P3
-R1
OP07
U4
R34 53.6K
R36 50K
R35 5.62K
R37 46.4K
C2 0.1MF
C3 0.1MF
C1 30PF
C32 0.1MF
P2-3 +V
P2-4 -V
R13 4.75K
R38 20K
OP-07
U15
(-10V)
R9 499K
R10 10K
R11 100K
R12 46.4K
LTC1043
U10
S1A
S3A
CA+
S4A
CA-
S2A
GND
OSC
Vcc
C4 1.0MF
C5 1.0MF
C6 0.1MF
C7 0.01MF
C8 0.1MF
OP07
U5
R42 20K
P2-5 +V BUF
P2-6 -V BUF
U10-14
U10-13
U10-4
U10-5
U10-6
-V A/D
+V A/D
LAKE SHORE CRYOTRONICS, INC.
9220 INPUT CARD ANALOG SECTION
09-16-87
13:54:56
9220ANA
SIZE B
DWG NO. B-479-87-01
SHEET 2 OF 2



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

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.

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.

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

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

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 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.

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.

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))

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

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 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

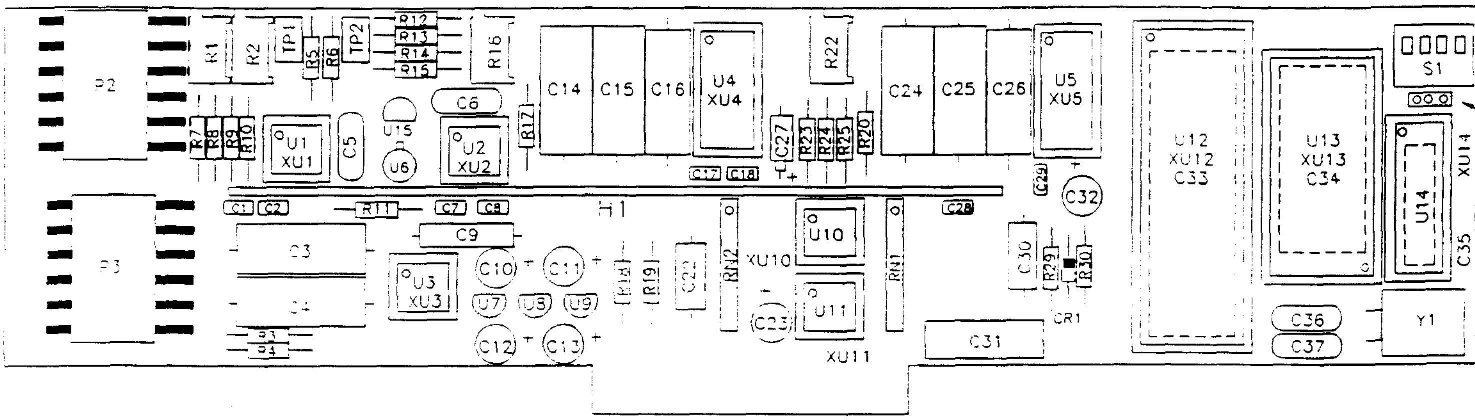
Included in this section is Figure 9305-1 showing the Model 9305 Thermocouple Input Card Schematic, Replaceable Parts List and illustrated Component Layout. Also included is Figure 9305-2 showing the 9305 Terminal Block Schematic, Replaceable Parts List and Component Layout.

Table 9305-4. 9305 Thermocouple Curves

Breakpoint Number	Chromel vs. Au-0.03 at.% Fe Temp(K)	Chromel vs. Au-0.03 at.% Fe V_{TC}(mV)	Chromel vs. Au-0.07 at.% Fe Temp(K)	Chromel vs. Au-0.07 at.% Fe 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

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

Breakpoint Number	Chromel vs. Constantan E Temp(K)	V_{TC}(mV)	Chromel vs. Alumel K Temp(K)	V_{TC}(mV)	Copper vs. Constantan T 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



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	76PS804
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

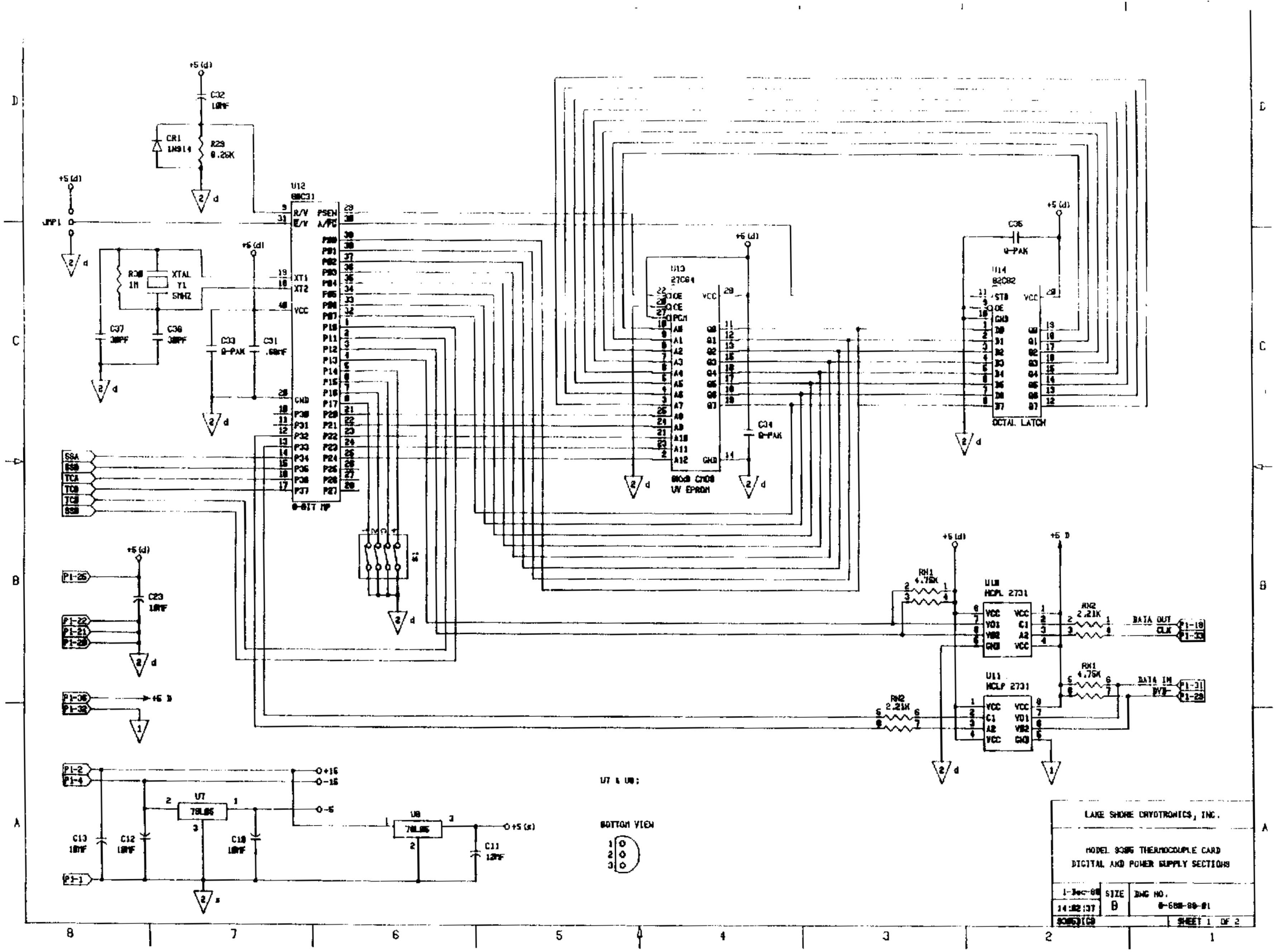
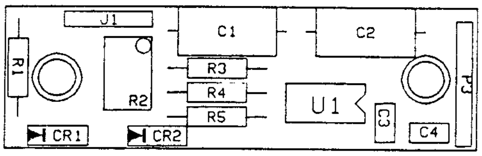


Figure 9305-1. Model 9305 Thermocouple In(Card



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

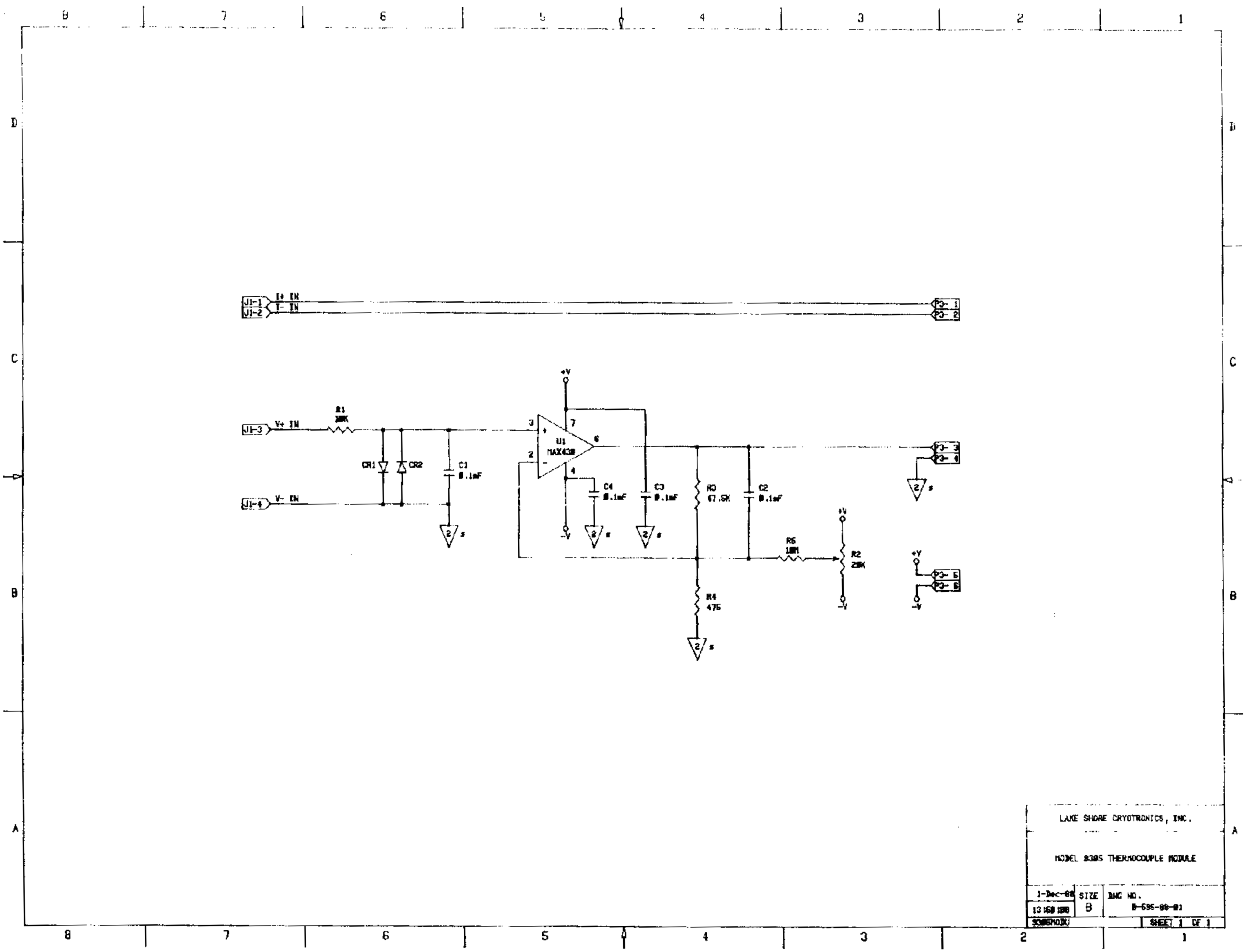


Figure 9305-3. Mo[illegible] 9305 Thermocouple Input Card Module

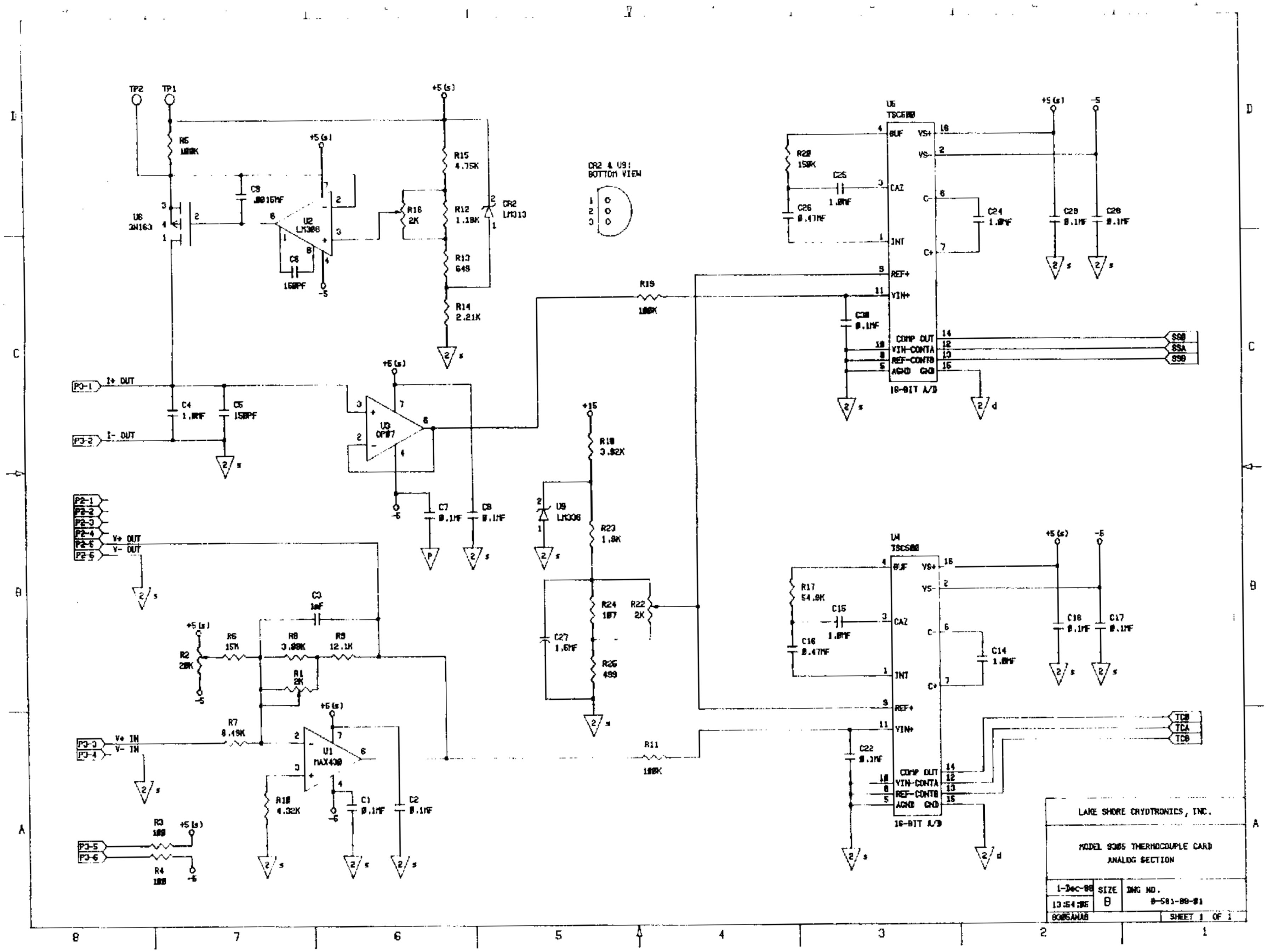


Figure 9305-2. Model 9305 Thermocouple Input Card

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.

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.

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.

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 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.

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 <u>only</u> and make the units <u>Ω</u>. 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 <u>all</u> 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.

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.

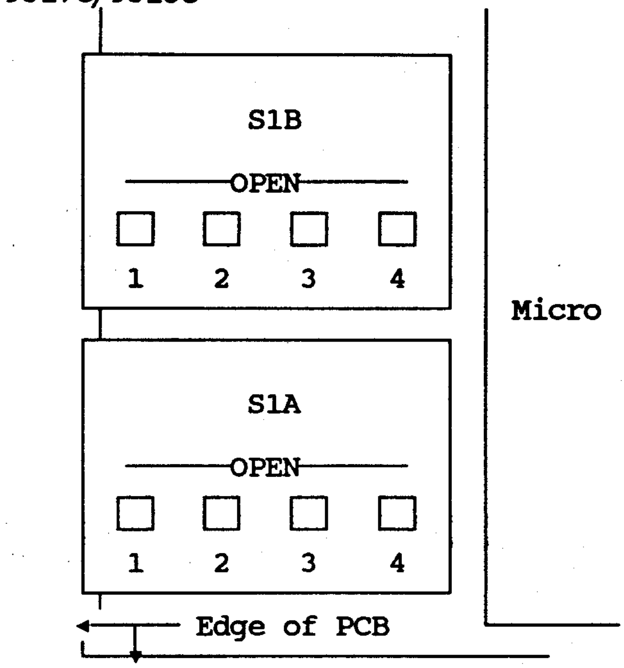
9. **Current Range 4, Value 60-** Finally substitute the 1 ohm (9317C) or 10 ohm (9318C) resistor for the previous resistor and enable the last switch, CAL 1. The display will indicate **460.** for approximately 30 seconds and then a **0.** indicating that the calibration of the card is complete. Disable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

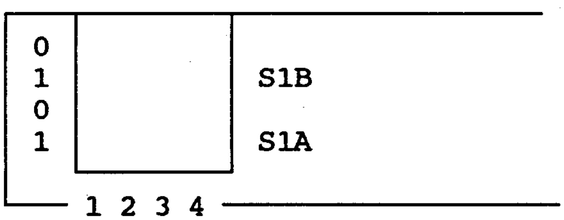
11. Replace the calibration cover and then the top cover.

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.

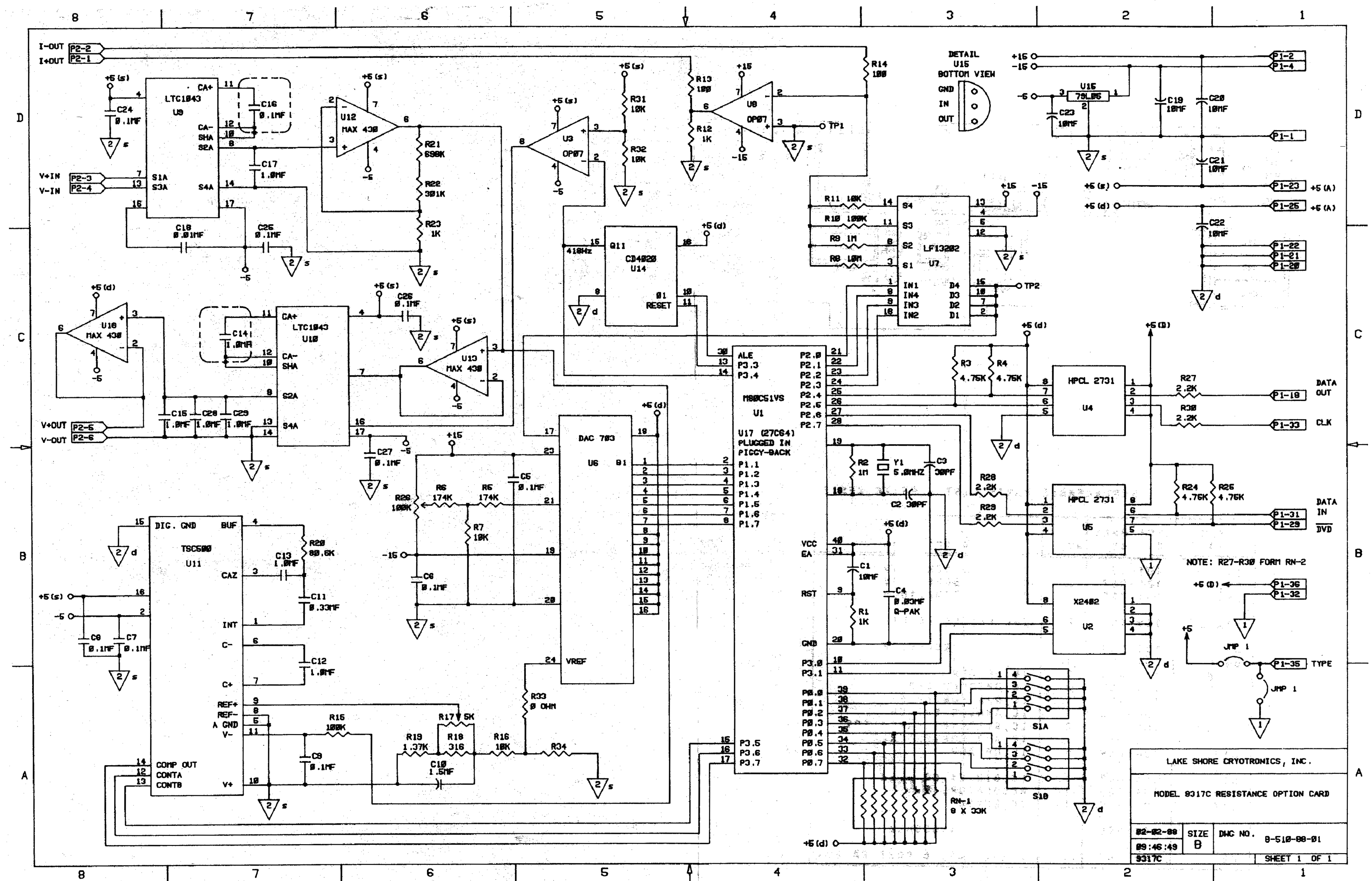
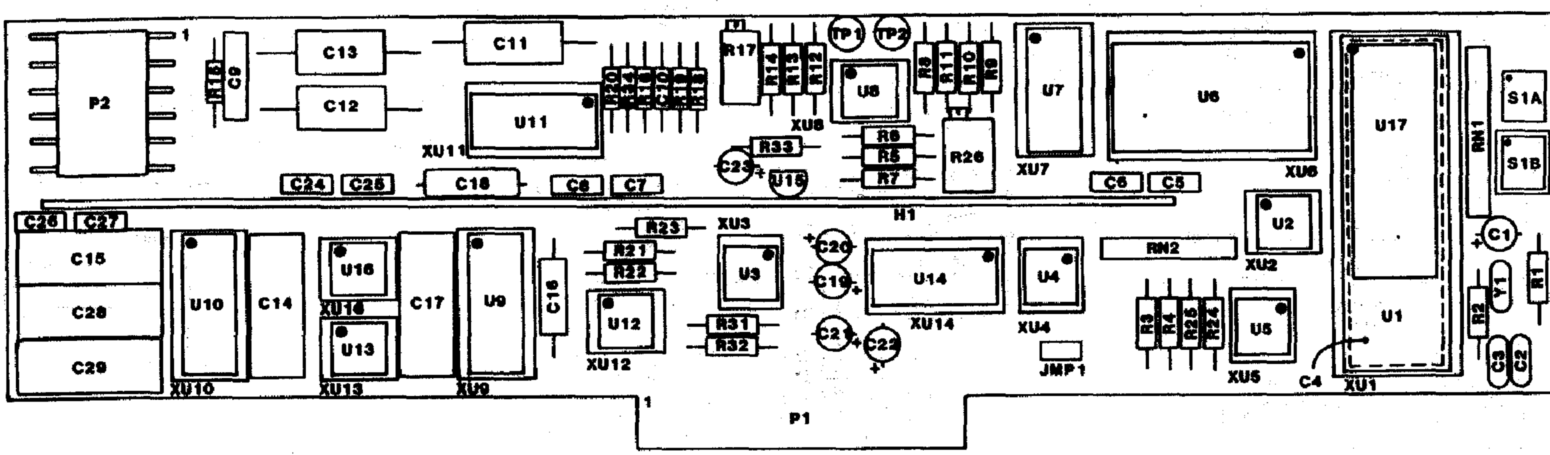


Figure 9317C-1. Model 9317C Resistance Input Card



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	

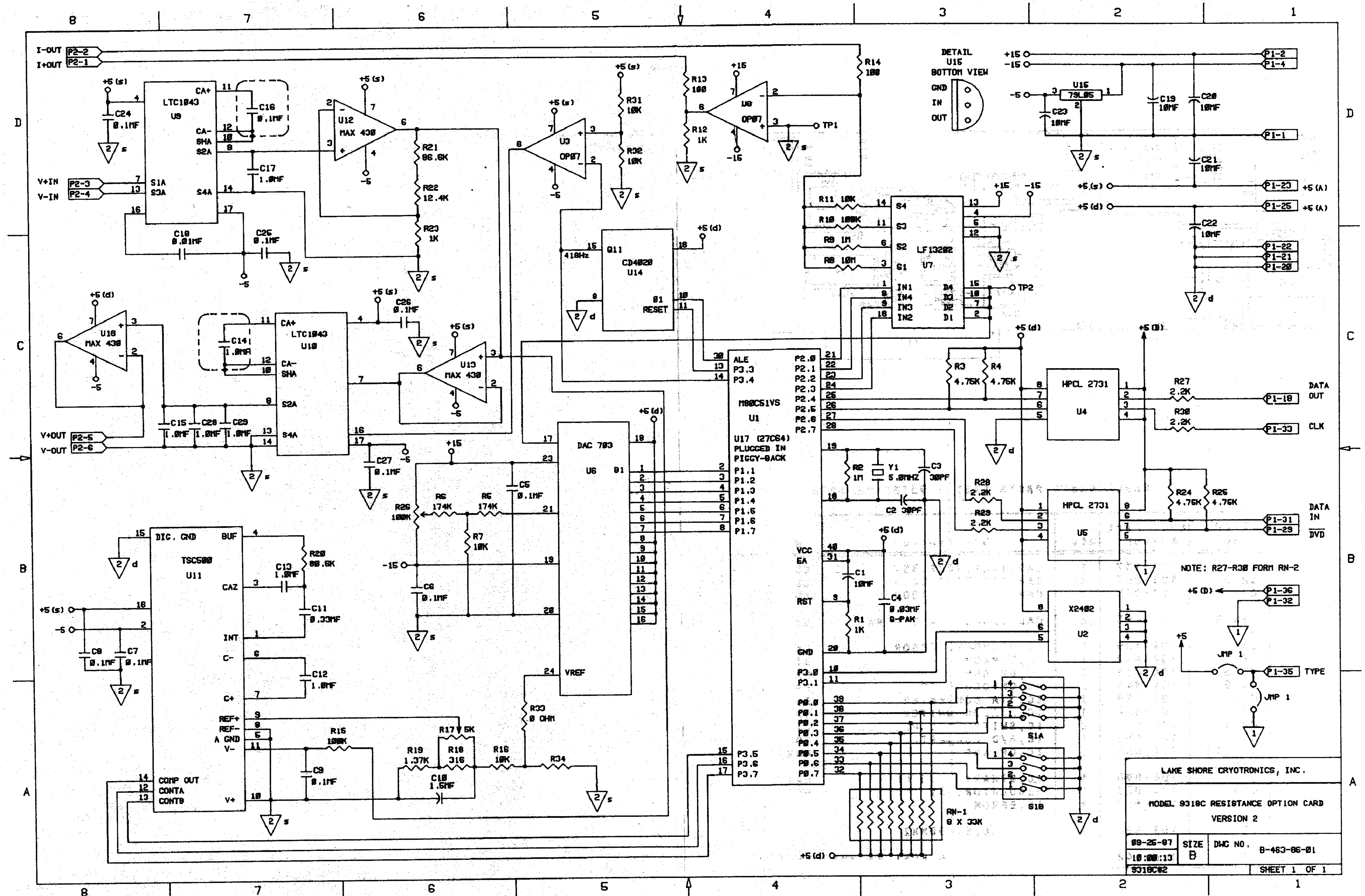
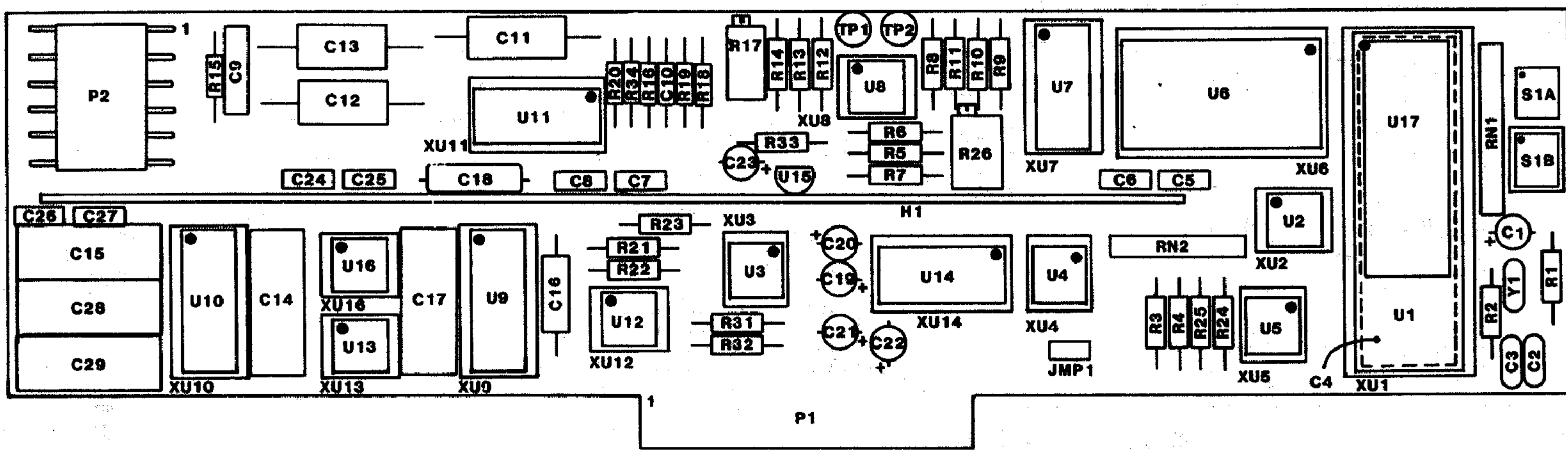


Figure 9318C-1. Model 9318C Resistance Input Card



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	

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.

Figure 8223-2. Word Structure

↓Stop Bit(s)

	LSB						MSB		

Start Bit↑ ——— Character 7 Bits ——— ↑Parity Bit (optional)

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.

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.

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:

S24.5P40I20D25R2<u>W0</u>

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

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.

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

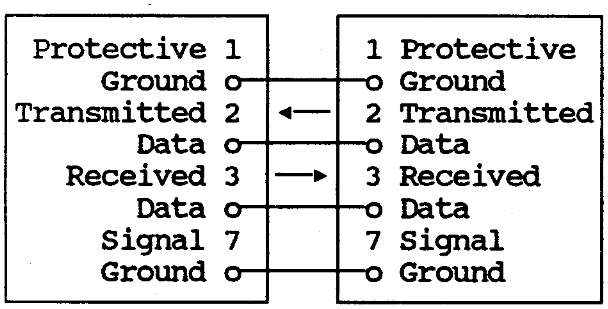
1. Interface select code = 10
2. Baud rate = 300 Baud
3. Autohandshake = Off
4. Character Length = 7 bits
5. Parity = Odd
6. Stop bits = 1
7. Cable Option = Standard (25 pin socket)

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

Connection to HP-86B



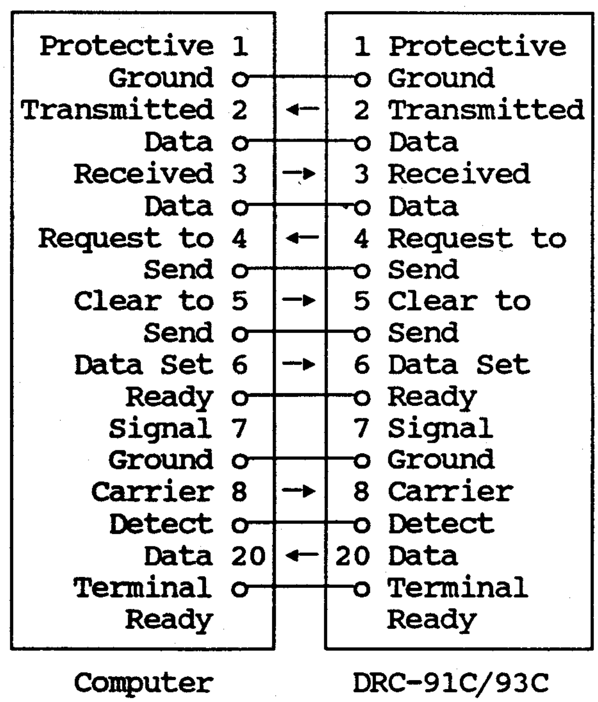
The following program will input a command from the keyboard and output it to the 8223. The program will then input the specified 8223's response, display it and return for another command.

```
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



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

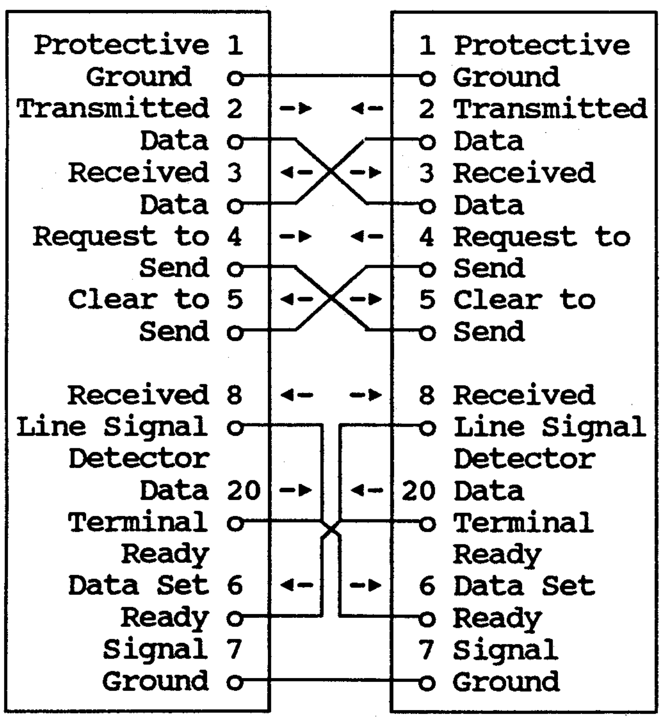
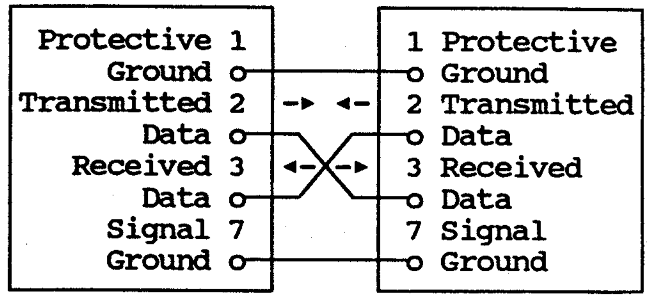


Figure 8223-6. General Serial Interface Interconnection for Half Duplex without Handshake



*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.

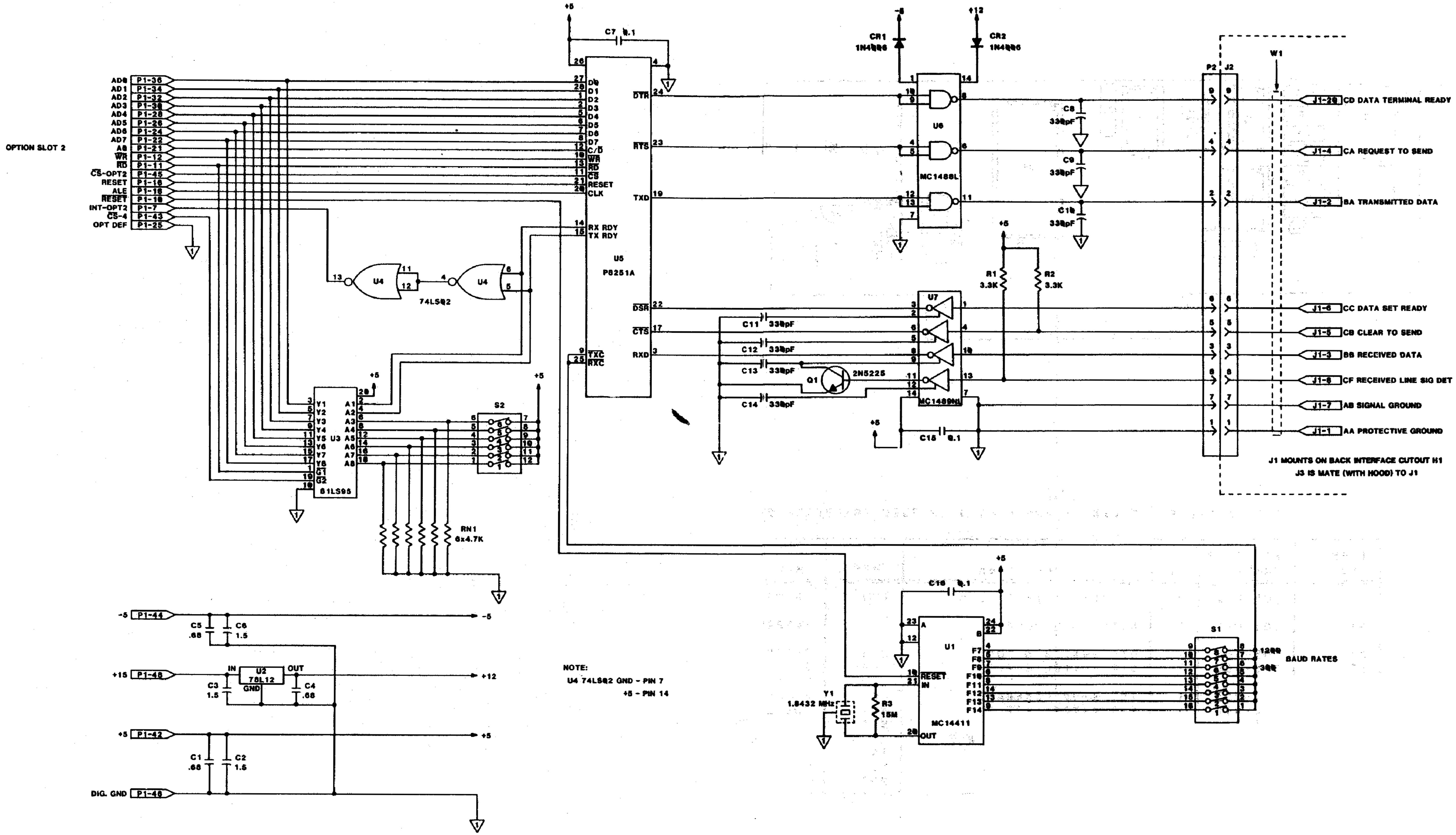
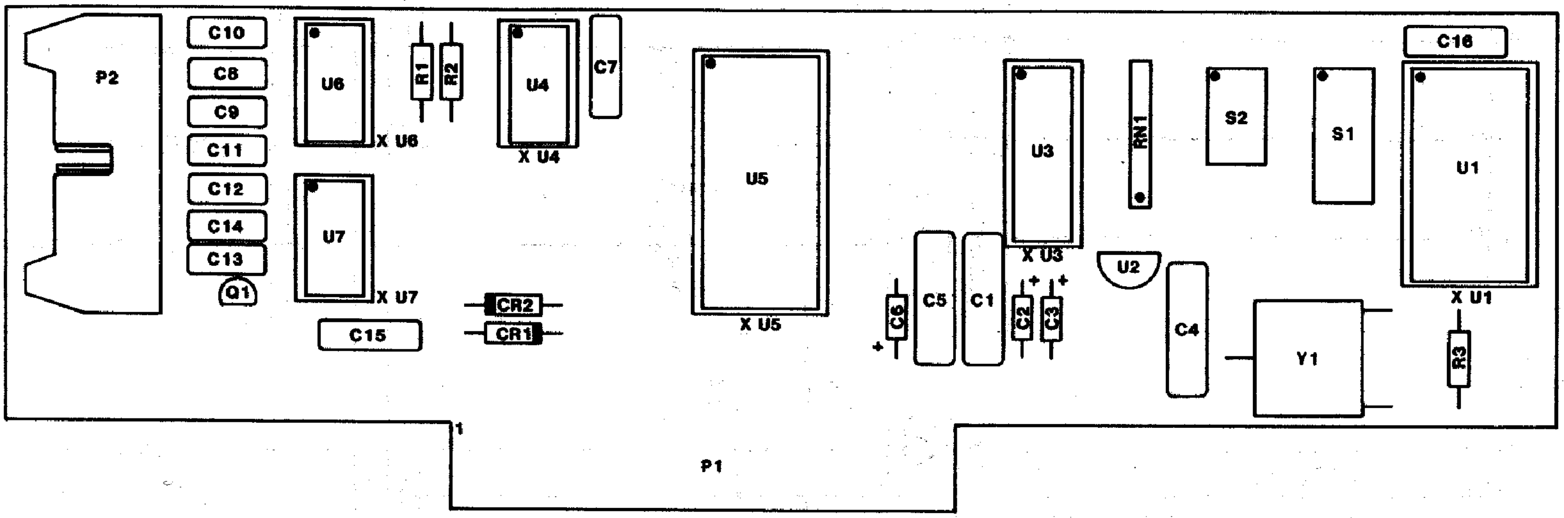


Figure 8223-1. Model 8223 RS-232C Interface Option



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

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.

> **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.

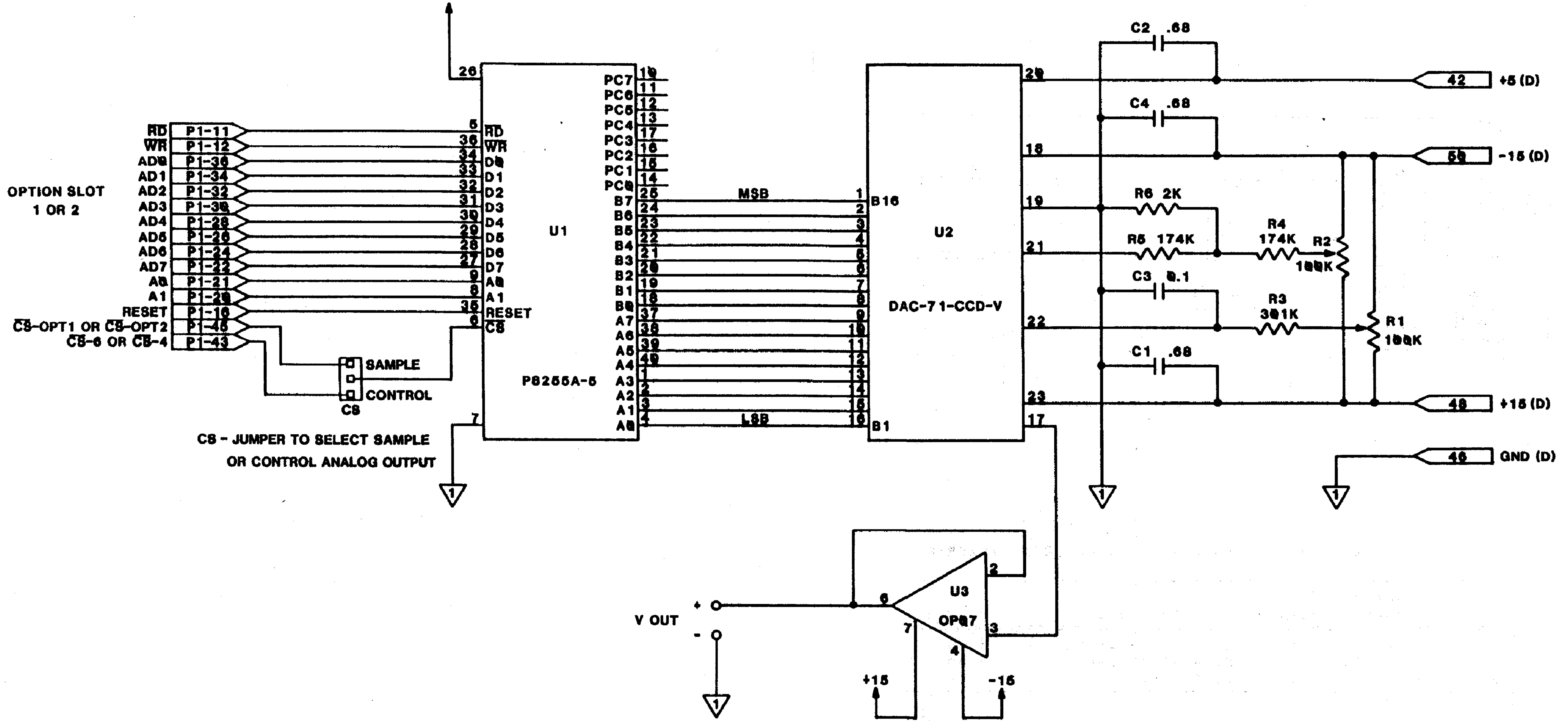
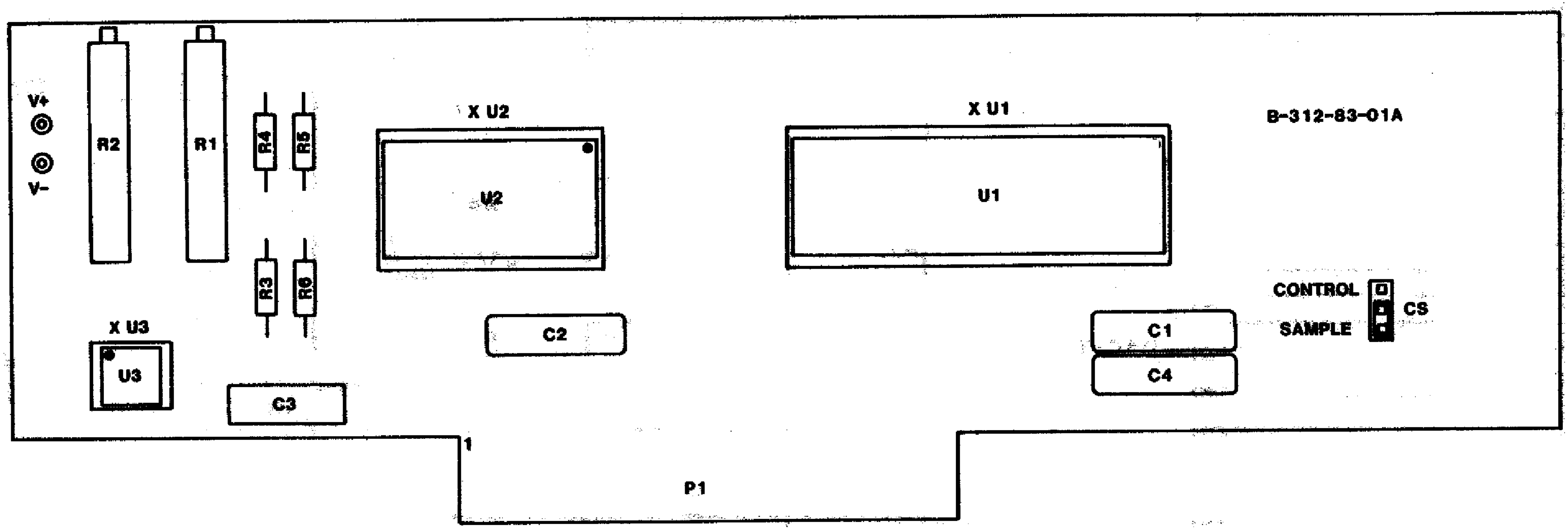


Figure 8225-1. Model 8225 Analog Output Option



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

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.

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

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.

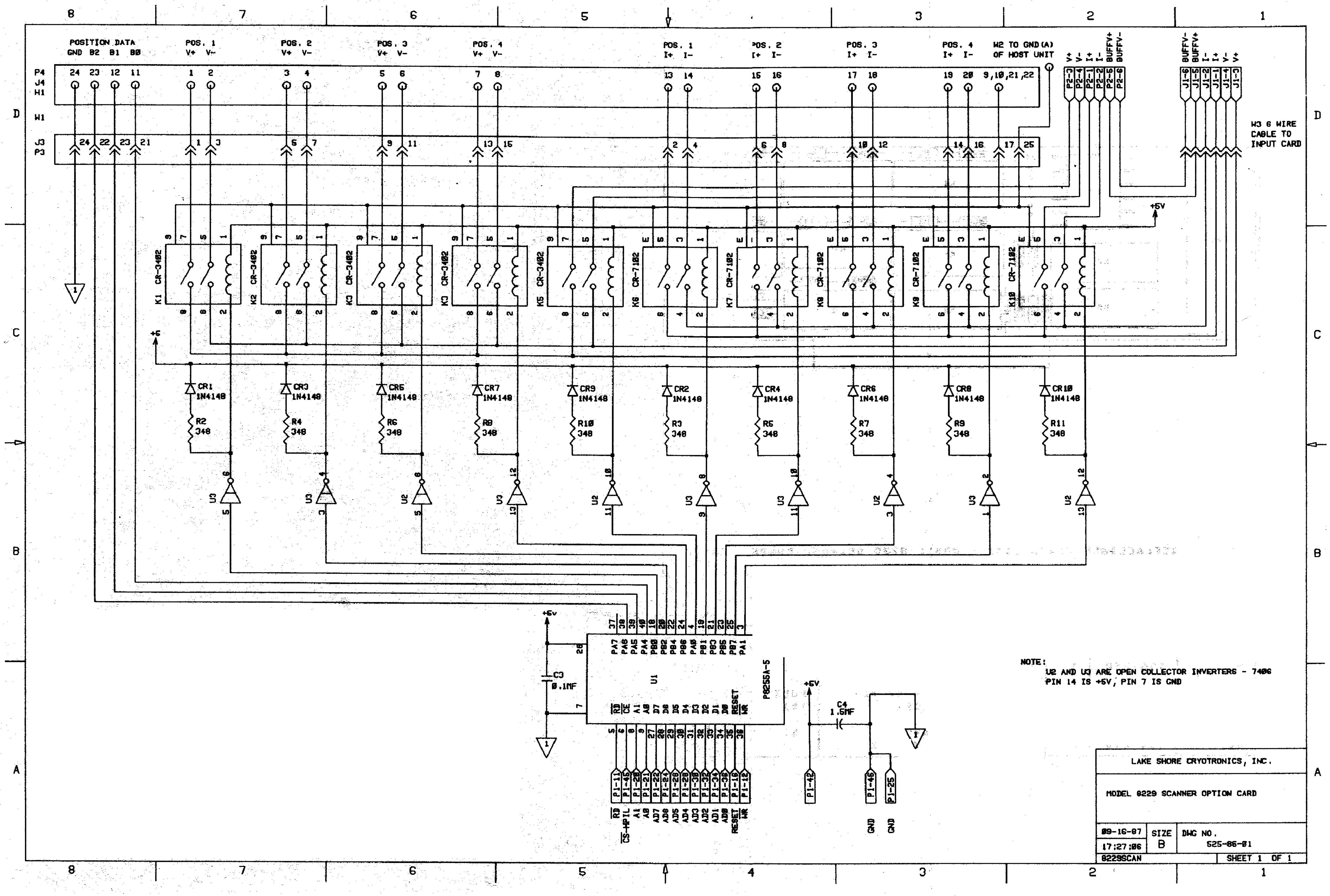
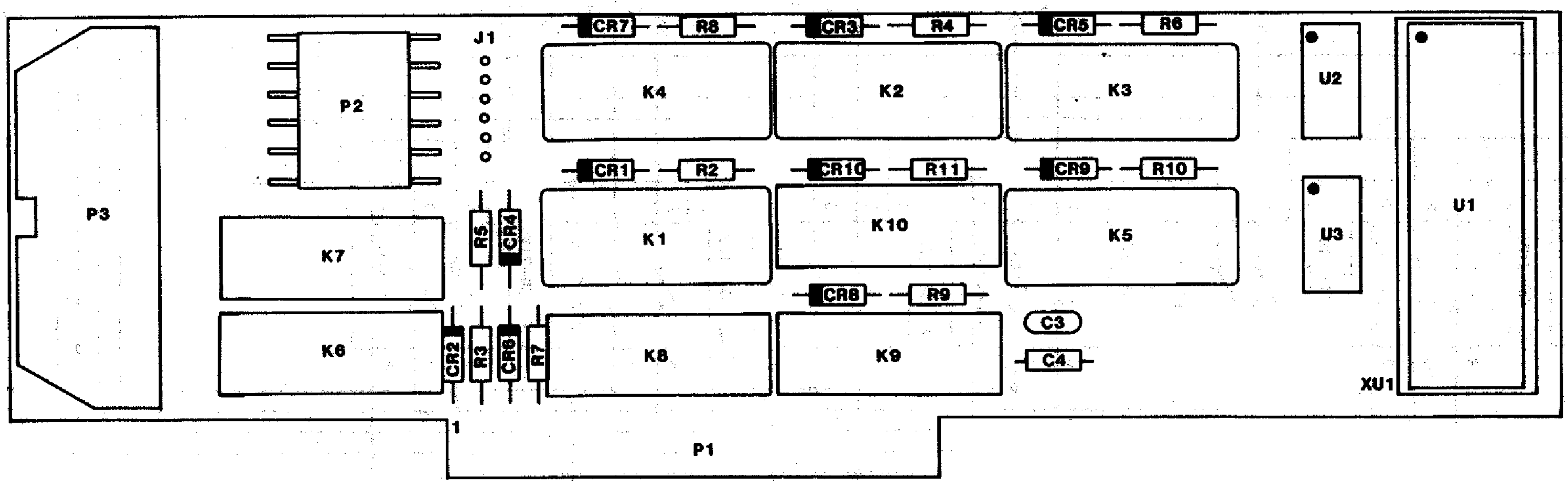


Figure 8229-1. Model 8229 Scanner Conversion Option



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

APPENDIX A - Standard Diode Voltage-Temperature Characteristics

TEMP(K)	D CURVE		E1 CURVE		DT-470 CURVE 10	
	BP#	VOLTAGE	BP#	VOLTAGE	BP#	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

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

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

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

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)

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): <u>Sensor Type</u> — <u>Format</u> 0 — D##### 1 — D##### 2 — #### 3 — P#### 4 — P#### 5 — #### 6 — ##### 7 — C#### 8 — #### 9 — No S/N

A P P E N D I X   C

DRC-93C Error Code Summary

The error codes for the DRC-93C 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.

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.

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.

APPLICATION NOTES

This appendix includes the following Lake Shore documentation:

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 ($\tau \propto C_p/\kappa$) 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.

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.

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.

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.

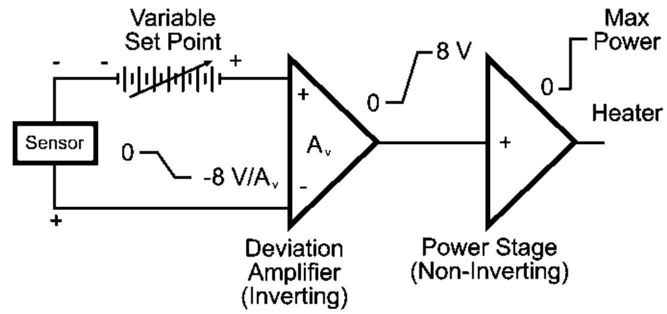


FIGURE 1. Block diagram of Cryogenic Temperature Controller. A_v is amplifier voltage gain.

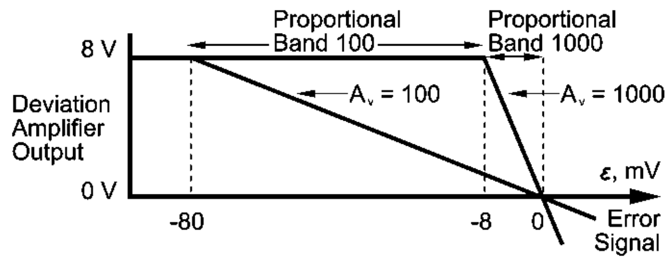


FIGURE 2. Output plot of the deviation amplifier showing Proportional Bands for gain settings of 100 and 1000. For the DRC-82C, the maximum available gain is 1000.

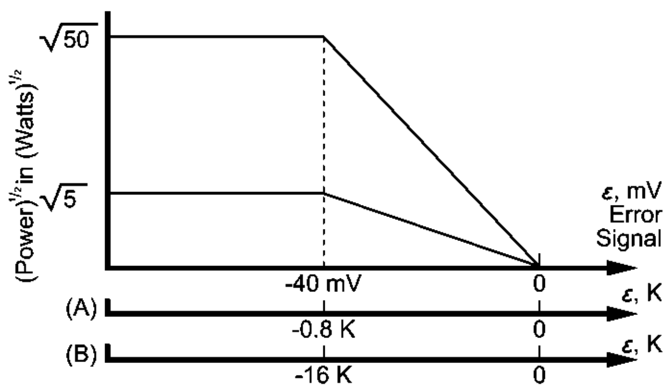


FIGURE 3. Output Power versus error signal in voltage or equivalent temperature of sensor for two different power settings: (A) corresponds to a sensor sensitivity of -50 mV/K; (B) corresponds to a sensor sensitivity of -2.5 mV/K. Note that the curves are linear in voltage, *not* power.

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.

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.

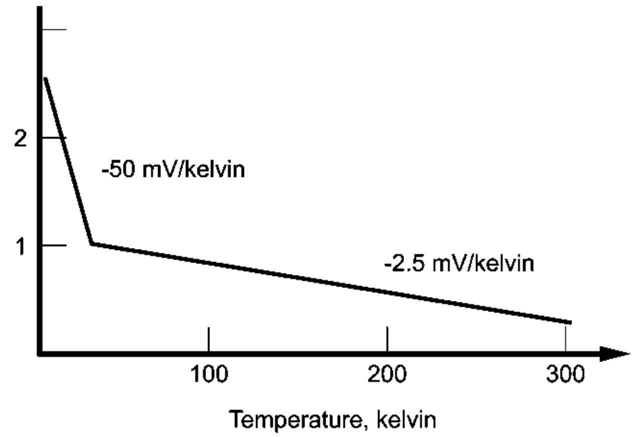


FIGURE 4. Idealized curve for Lake Shore Cryotronics, Inc. DT-500 Series silicon diode temperature sensors.

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.

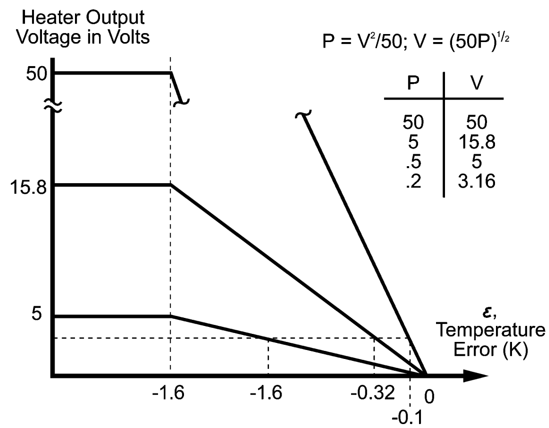


FIGURE 5. Effect of output power setting on offset for a proportional controller *only*.

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.

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.

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.

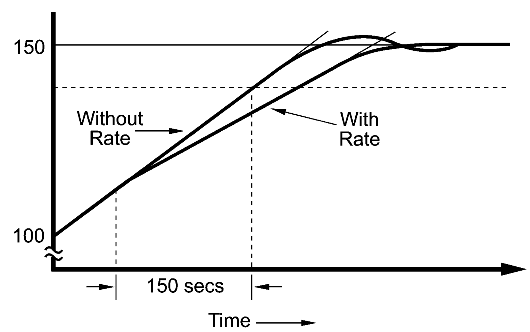


FIGURE 6. The effect of adding Rate to the control circuit to dynamically widen the proportional band and reduce the overshoot which would occur in its absence.

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.

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.

For Further Reading

1. E. M. Forgan, "On the Use of Temperature Controllers in Cryogenics". Cryogenics 14 (1974), pp. 207-214. This is a cogent discussion of the interaction between the electrical and thermal response times in a typical *cryogenic* control system. The mathematical analyses are straightforward and relatively easy to follow.
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.

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.

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:

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

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:

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

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:

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

Alternately, these polynomials are given by:

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

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	

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.

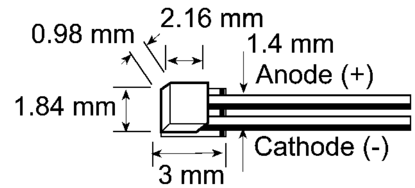
For all adapters except the CY, CU, and DI, the leads are a gold-plated Kovar. Prolonged soldering times may cause the solder to creep up the gold plated leads as the solder and gold alloy. This is not detrimental to the device performance.

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.

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.

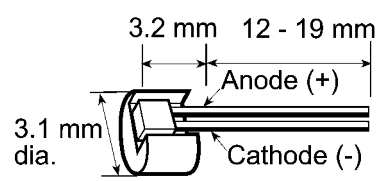
The SD package can also be bonded with an epoxy such as Stycast. The sensor should be pressed firmly against the surface during curing to assure a thin epoxy layer and good thermal contact. The device may be removed in the future by using the appropriate epoxy stripper.

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.

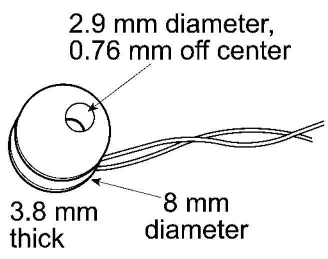
DT-470-LR

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.

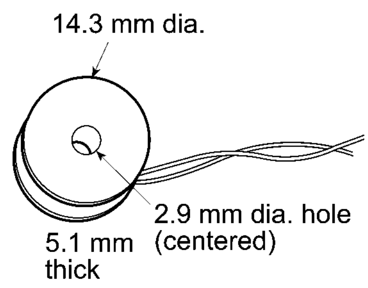


DT-470-CU / DT-470-DI / DT-470-CY

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.



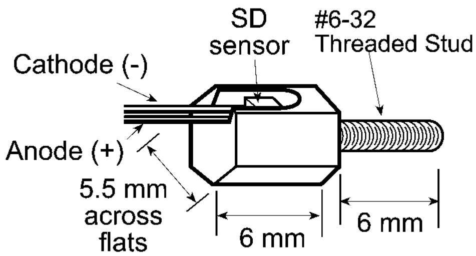
DT-470-CU / DT-470-DI



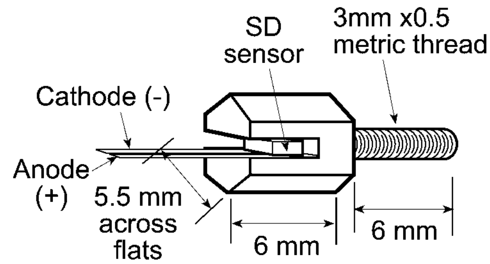
DT-470-CY

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.

DT-470-ET / DT-470-MT



DT-470-ET

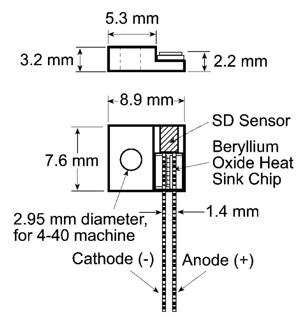


DT-470-MT

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.

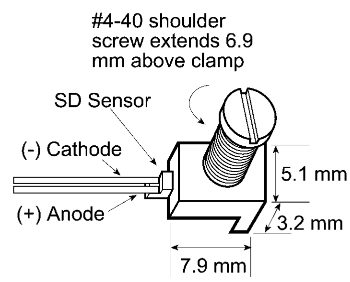
DT-470-BO

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.



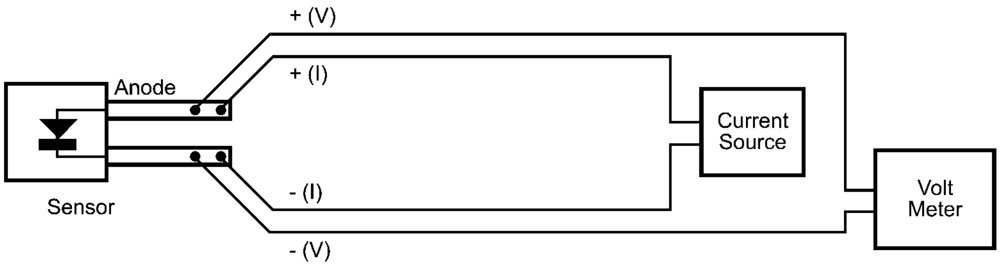


FIGURE 1. Four-Wire Configuration for DT-470 Installation

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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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.

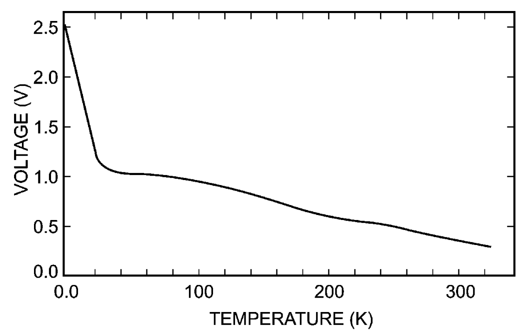

FIGURE 1. Voltage-temperature curve for a typical silicon diode temperature sensor at a constant current of 10 μA.

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.

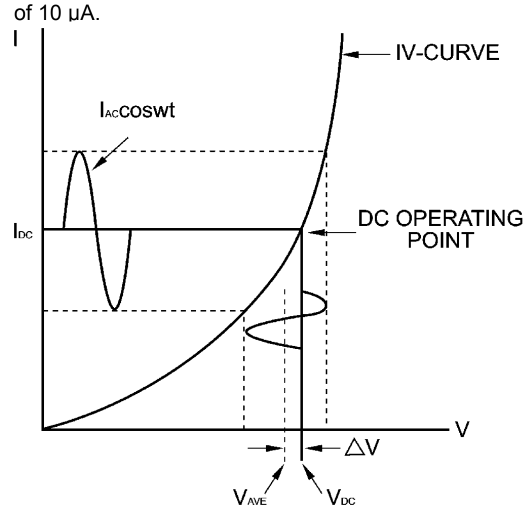

FIGURE 2. IV curve for a silicon diode sensor showing effect of an induced ac current superimposed on the dc operating current I_{dc}. The expected dc operating voltage is V_{dc}, which is shifted from the average voltage V_{ave} indicated by the voltmeter in a dc measurement mode.

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.

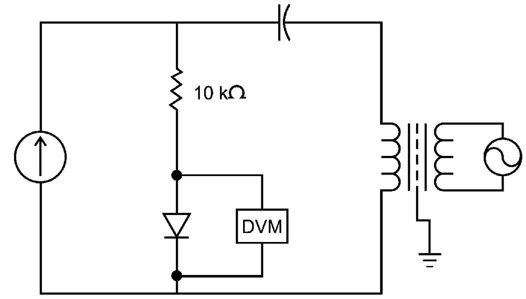

FIGURE 3. Measurement circuit schematic diagram.

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).

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).

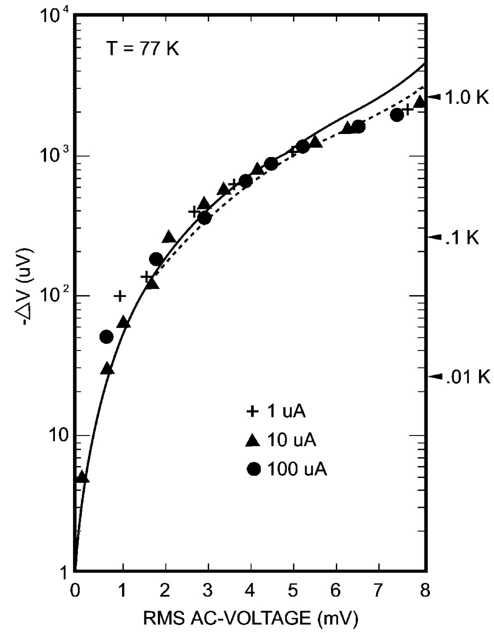

FIGURE 4. DC offset voltage as a function of rms ac voltage across a silicon diode temperature sensor operating at 77 K. The symbols represent data recorded at three different dc operating currents with a 60 Hz signal superimposed. The solid curve gives small signal model results while the dashed curve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

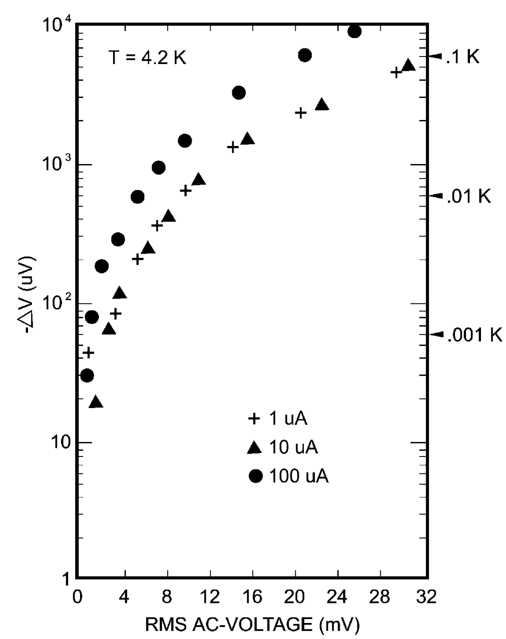

FIGURE 5. DC offset voltage as a function of rms ac voltage across a silicon diode temperature sensor operating at 4.2 K. The symbols represent data recorded at three different dc operating currents with a 60 Hz signal superimposed. Equivalent temperature errors are indicated along the right edge.

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):

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

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.

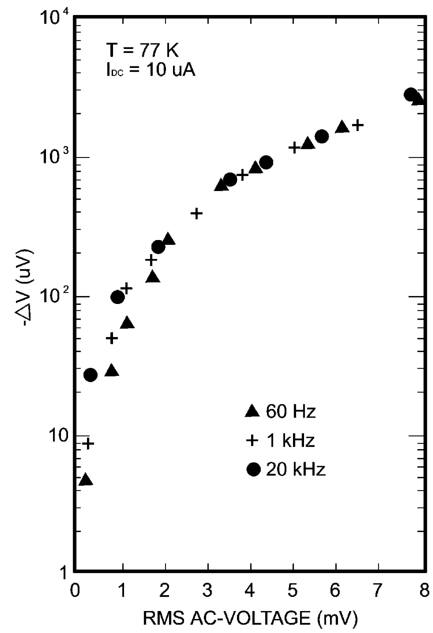

FIGURE 6. DC offset voltage as a function of rms ac voltage across a silicon diode temperature sensor operating at 77 K. The symbols represent data recorded at a 10 µA dc current with the ac current modulation at 60, 1000, and 20,000 Hz.

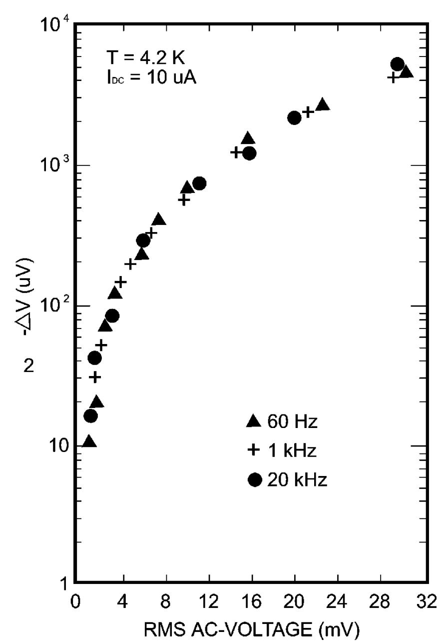

FIGURE 7. DC offset voltage as a function of rms ac voltage across a silicon diode temperature sensor operating at 77 K. The symbols represent data recorded at a 10 µA dc current with the ac current modulation at 60, 1000, and 20,000 Hz.

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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