User's Manual

Model DRC-70

Digital Cryogenic Thermometer

Model DRC-7C/-70C

Digital Cryogenic Controller

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SECTION I

General Information

1.1 Introduction

The following is a description of the DRC-70 cryogenic digital thermometer and DRC-7C, DRC-70C cryogenic digital thermometer/controllers. The DRC-7/70 series of instruments are designed to be used with the Model DT-500-DRC and DT-500CU-DRC-36 silicon diode sensors manufactured by Lake Shore Cryotronics, Inc.

Several different diode sensor curves are designed for use with this instrument. When ordering replacement sensors, care must be taken to assure that the correct sensor curve is specified. Multiple curves are needed so that Lake Shore can assure the customer that replacement sensors will be available at any time in the future. For details, please see Section 1.6.

1.2 Description-General

The DRC-7/70 series are comprised of completely self-contained units providing direct digital readout in kelvin temperature units and, for the controllers, temperature control by direct digital comparison between the displayed temperature, and a digital setpoint. The DRC-70 and DRC-70C display temperature to 0.1 kelvin resolution while the DRC-7C displays temperature to 1 kelvin resolution.

The specified range of operation is 4.0 to 400 K* utilizing standard DRC series sensors which have been pre-selected to provide uniform characteristics over this range. These sensors conform to the standard table (see Table 3.3) to 0.5 K or better over this temperature range. The instruments, however, are useful to 1 K although the accuracy is not guaranteed below 4 K. Pre-selection allows the DRC-7/70 series to be used with the DT-500-DRC and DT-500CU-DRC-36 sensors without adjustments of any kind. Since the standard sensors are interchangeable, the instruments may be used to read out any number of sensors with equal accuracy when selected through an appropriate switch or multiplexer.

All instruments contain a constant current source, for sensor excitation, which is preset at the factory at 10 microamps.

As a standard feature, all units are equipped with an analog output of the sensor voltage. This allows the instrument user the ability to record the sensor voltage versus time or to use a digital voltmeter to measure the sensor voltage directly. Since this output is not buffered, a high input impedance recorder or voltmeter must be used to avoid loading of the sensor. If the sensor is calibrated by the user or by Lake Shore Cryotronics, Inc., temperature may be determined to better than 10mK.

Four options are available with the DRC-7/70 series of instruments. One option is an analog signal which is proportional to temperature (DRC-L/A). This is set up to have a sensitivity of 10 mV/K but may be changed to the user's needs. Another option is a BCD output of the displayed temperature (DRC-BCD-O for DRC-70 or DRC-BCD-I/O for the DRC-7C/70C). Included with the BCD output

*If possible, temperatures above 330 K should be avoided with DRC series sensors since some of these sensors may shift their values slightly below 20 kelvin if heated above 330 kelvin.

option for the DRC-7C/70C instruments is the capability to remote program the temperature set point via a BCD signal from sources such as a computer or digital function generator. The third option is either a two position, five position, or ten position switch (DRC-SW- 2, 5, or 10) for multiple sensor readouts. The DRC-70 has the switch mounted internally while the DRC-7C/70C has the switch mounted in an external box. The fourth option is a custom cut PROM (Programmable Read Only Memory) which corresponds to the calibration curve of the customers DT-500 series sensor. A combination of calibration and custom cut PROM will increase instrument accuracy to 0.1 kelvin. Please note that any sensor may be used with this option, i.e., the customer is not restricted to the DRC series sensors.

1.3 Description-Specific

The following provides a description for the DRC-70 and DRC-7C/70C instruments.

The DRC-70 and DRC-70C provide direct temperature readout in kelvin degrees with 0.1 degree resolution. The DRC-70C controls in a properly designed system to 0.1 kelvin. The DRC-7C has 1 degree resolution and controls to 1 kelvin. Conformity to a standard DRC curve is better than 0.5 kelvin over the temperature range from 4.0 to 380 K.

The DRC-7/70 series is designed around an F8 microprocessor using a 3850/3853 configuration and associated support circuits. The DRC curve is stored in a PROM which can handle up to 32 break points. The data consists of a table of temperature, voltage and slope between each break point. These straight line segments generate the DRC curve to an accuracy of better than 0.1 kelvin over the entire temperature range (4.0 - 400 K). Sensors are selected to conform to this curve to an accuracy of better than 0.5 K over the entire range.

1.3.1 General Specifications

The following specifications for the DRC-7/70 series are applicable when used with the standard DT-500-DRC or DT-500CU-DRC-36 temperature sensors.

General:

Temperature Range:	1 to 400K (Accuracy not guaranteed below 4.0 K)
Sensor:	Silicon Diode (Model DT-500-DRC or DT-500CU-DRC-36)
Sensor Input:	4 terminal connection, constant current excitation
Sensor Excitation:	Constant current 10 microamperes
Current Regulation:	±0.01%
Input Line Voltage:	115 V or 230 V, 50 - 60 Hz, switch selectable
Operating Environment:	10 - 45°C
Circuit Design:	Integrated circuits, microprocessor controlled

Input Impedance:	Greater than 100 megohms
Weight:	5.9 Kg (13 pounds)
Dimensions:	10.7cm (4.2") high x 31.0cm (12.2") wide x 25.4cm (10.0") deep

<u>Temperature Readout</u>:

Display:	3 digits (for DRC-7C), 1.1cm (0.43") high, 7 segment, non-blinking
	4 digits (for DRC-70/70C), 1.1cm (0.43") high, 7 segment, non-blinking
Temperature Coefficient Error:	0.01 K/°C
Conformity To LSCI Standard DRC-70 Silicon Diode Table:	0.5 K (4 - 400 K)
Resolution:	1 K for DRC-7C
	0.1 K for DRC-70/70C
Response Time:	2.2 seconds to rated accuracy

<u>Outputs</u>:

Analog (Standard):	Monitor output of sensor voltage
Analog (Optional):	10mV/K at <10 ohm output impedance
Digital (Optional):	TTL compatible parallel BCD

<u>Temperature Control</u>: (For DRC-7C/70C only)

Set Point:	Digital thumbwheel selection directly in kelvin temperature units
Set Point Resolution:	1 K for DRC-7C and 0.1 K for DRC-70C
Optional Remote Set Point:	TTL compatible, parallel BCD
Controllability:	1 K (for DRC-7C) with a properly designed system
	0.1 K (for DRC-70C) with a properly designed system
Heater Output:	Standard 0 - 46 watts, 0-1A, 0 - 46 VDC
Control Mode:	Time proportional gain and reset

1.4 Major Assemblies Supplied

The DRC-7/70 series includes as standard equipment, in addition to the digital thermometer, the following:

A. Operating and Servicing Manual.

B. Five Pin Plug for Temperature Sensor Cables.

C. Three Pin Plug for Monitor of Sensor Output Voltage.

Model DT-500 series silicon diodes are not supplied as part of the DRC-7/70 instrument.

1.5 Accessory Equipment and Custom Options Available

The following accessory equipment and custom options are available from the factory. Items marked with an asterisk (*) are of a custom nature, the customer should discuss these items with a factory representative before ordering.

A. Extra Five Pin and Three Pin Connectors.

B. 19" Rack Mount.

C. DT-500-DRC and DT-500CU-DRC-36 Silicon Temperature Sensitive Diodes (Uncalibrated). (See data sheets at end of this manual for nominal operating characteristics and case styles available).

D. DT-500-DRC Silicon Temperature Sensitive Diodes (Calibrated). Standard laboratory calibration service for correlating diode output voltage with diode temperature. See sensor data sheet for additional information.

E. Custom Modification of Sensor Current Supply Value.*

F. Analog of Temperature (10mV/°K is standard).

G. TTL Compatible Parallel BCD of Temperature (Also Remote Set Point Input - Standard with BCD output for DRC-7C/70C instruments).

H. Custom Cut PROM of calibrated DT-500 diodes series.

I. Two Position, Five Position and Ten Position Switches for multiple sensor readout. (Switch is mounted internally in DRC-70 instruments (See Table 3.1) Switch is mounted in an external box for DRC-7C/70C instruments.)

1.6 Ordering of Replacement or Additional Sensors

Two different sensor configurations are available for use with the Model DRC-7/70 series instruments. These are the DT-500-DRC and the DT-500-CU-DRC-36 sensors. Their description is included in the cryogenic temperature sensing elements brochure which is included in the back of this manual (see reference numbers 8 and 14 for dimensions of these sensors).

Three curves presently exist which can be used with the DRC series instruments. The correct curve must be specified so that your instrument will have its stated accuracy. The proper curve may be determined in one of the following ways:

A. Specify the sensor serial number that is currently being used with the instrument (serial number is found on the end of the plastic box in which the sensor was received).

B. Most instruments indicate the correct curve on the serial number sticker located on the back of the instrument, e.g., DRC-70C-B-BCD-L/A. The B indicates that a B sensor must be specified, e.g., DT-500-DRC-B. The BCD-L/A indicates that both the BCD and analog of temperature option are on this instrument.

C. The third way is to open your instrument and observe the writing on PROM U13. The following table gives the correspondence between this writing and the appropriate curve:

Curve	PROM U13
0	B3
A	B4
B	B6

D. A fourth way is to measure the diode voltage for your sensor at 4.2K

DRC Curve	Sensor Voltage at 4.2 K
0	2.42 - 2.48
A	2.30 - 2.34
B	2.50 - 2.56

SECTION II

Installation

2.1 Introduction

This section contains information and instructions necessary for the installation and shipping of the model DRC-70/7C/70C Cryogenic Temperature Indicators and Controllers. Included are initial inspection instructions, power and grounding requirements, installation information and instructions for repackaging for shipment.

2.2 Initial Inspection

This instrument was electrically and mechanically inspected prior to shipment.

It should be free from mechanical damages, and in perfect working order upon receipt. To confirm this, the instrument should be inspected visually for obvious damage upon receipt and tested electrically by use to detect any concealed damage. 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 with the carrier, and/or insurance company. Please advise the company of such filings. In case of parts shortages, please advise the company. The standard Lake Shore Cryotronics warranty is given on page iv.

2.3 Power Requirements

Before connecting the power cable to the line, ensure that the line voltage selector switch (115 V or 230 V) is in the appropriate position for the line voltage to be used. Examine the power line fuse to ensure that it is appropriate for the line voltage. (115 V, 230 V = 0.4 Amp) Nominal permissible line voltage fluctuation is ±10% at 50 to 60 Hz.

Caution: Disconnect line cord before inspecting or changing line fuse.

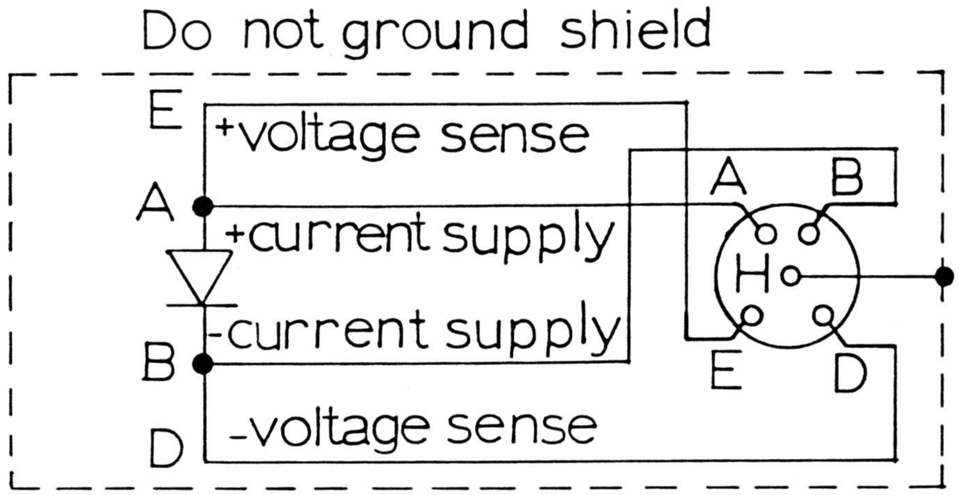
2.4 Grounding Requirements

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

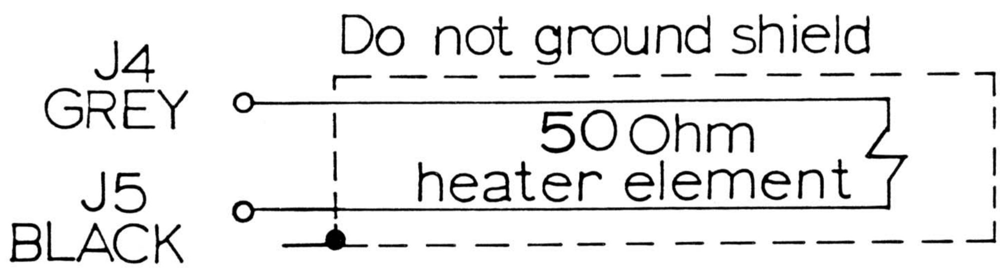
2.5 Installation

The DRC-70 Thermometer and DRC-7C/70C Thermometer/Controller are all solid state and do not generate significant heat. It may therefore be rack mounted in close proximity to other equipment in dead air spaces. The heat from such adjacent equipment should not subject the thermometer to an ambient temperature in excess of 50°C (122°F). As with any precision instrument, it should not be subjected to the shock and vibrations which usually accompany high vacuum pumping systems.

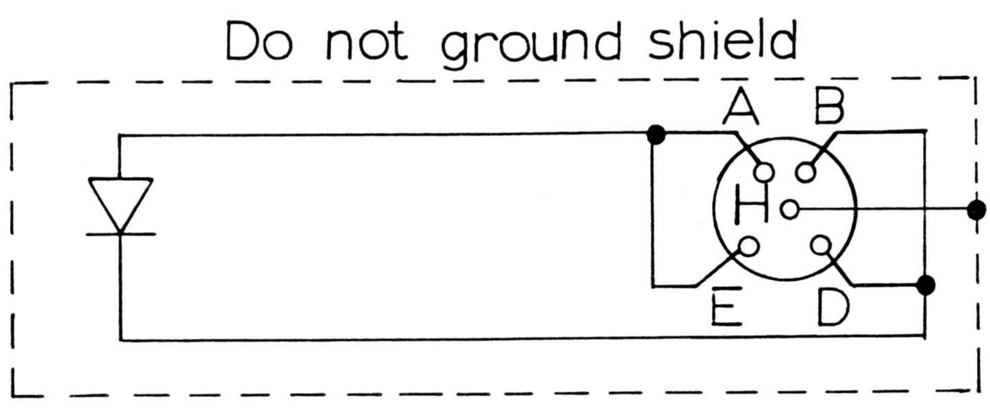
The recommended cable diagrams for the sensor diode and heater element



(A) RECOMMENDED SENSOR CABLE



(B) RECOMMENDED HEATER CABLE



(C) ALTERNATE SENSOR CABLE

FIGURE 2.1 SENSOR CABLE DIAGRAMS

(in the case of the DRC-7C/70C controllers) are shown in Figure 2.1(a) and (b). The use of a four wire diode connection is highly recommended to avoid introducing lead IR drops which will occur if the alternate two lead sensor cable connection is used. For example, for a two lead connection, every 25 ohms of cable resistance corresponds to a .1 K error above 30 kelvin. The alternate wiring scheme shown in Figure 2.1(c) may be used for the diode in less critical applications where lead resistance can be kept small. The indicated shielding connections are the recommended standard practice to avoid ground loops.

2.6 Repackaging for Shipment

Before returning an instrument to the factory for repair, please discuss the malfunction with a factory representative. He may be able to suggest several field tests which will preclude returning a satisfactory instrument to the factory when the malfunction is elsewhere. If it is indicated that the fault is in the instrument after these tests, the representative will send shipping instructions and labels for returning it.

When returning an instrument, please attach a tag securely to the instrument itself (not on the shipping carton) clearly stating:

A. Owner and Address

B. Instrument Model and Serial Number

C. Malfunction Symptoms

D. Description of External Connections and Cryostats.

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

If the original carton is not available, wrap the instrument in protective plastic wrapping material before placing in an inner container. Place shock absorbing material around all sides of the instrument to prevent damage to protruding controls. Place the inner container in a second heavy carton and seal with tape. Affix mailing labels and "FRAGILE" warnings.

SECTION III

Operating Instructions

3.1 Introduction

This section contains a description of the operating controls and their adjustment under normal operating conditions, and typical controller applications. These instructions are based upon the instrument having been installed as outlined in Section II. The diode polarity as shown in Figure 2.1(a) in particular must be correct. For the DRC-7C/70C instrument, a 50 ohm heating element is assumed to the "Heater" terminals as shown in Figure 2.1(b).

3.2 Controls, Indicators, Connectors

The operating controls, indicators and connectors on the DRC-70 and DRC-7C/70C instrument's front and rear panels are shown in Figures 3.1, 3.2, 3.3, and 3.4. The numbers with leaders to various controls in the figures are keyed to the entries in Table 3.1.

Table 3.1 - Entry Number Correlation

NO. KEY	NAME	FUNCTION
1	NO LABEL	Digital temperature display located behind filter panel. Maximum range 1-400 K.
2	NO LABEL	Ten position switch, selects sensor number from one through ten (see Section 1.5(I)).
3	POWER	A.C. line switch (ON/OFF)
4	115/230 V 50-60 Hz	A.C. line voltage selector slide switch
5	.25A S.B.	A.C. line fuse (FUI)
6	NO LABEL	Sensor input connector for sensors one through ten.
7	Remote I/O	BCD output of temperature (optional)
8	NO LABEL	A.C. line cord
9	Monitor	Analog output of sensor voltage (0-2.5 V) or optional linear analog output of temperature (0-4 V). Should be used with high input impedance recorder or voltmeter. See Section 1.5(f).
10	Sensor	Sensor input lead terminals (Pin A, I^+, Pin E, V^+, Pin B, I^-, Pin D, V^-, Pin H, Shield).
11	NO LABEL	Same as Key 1
12	NO LABEL	LED to indicate when power is applied to heater load.

NO. KEY	NAME	FUNCTION
13	Heater	Fine tuning power control. Adjusts the maximum power available from 0 to 50 watts or 0 to 20 watts dependent on switch setting on rear of instrument. Infinite resolution through use of vernier control.
14	POWER	Same as Key 3
15	NO LABEL	Digital set point. Has .1 K resolution for 70C and 1 K resolution for 7C.
16	.75ASB-115 V .4ASB-220 V	Same as Key 5
17	115/230 V 50-60 Hz	Same as Key 4
18	HI/LO	Limits maximum power to 50 watts (HI position) or 20 watts (LO position)
19	Heater	Heater element terminals
20	Remote I/O	BCD input of set point/output of temperature
21	NO LABEL	Same as Key 8
22	1.OASB	Output power fuse FU2
23	Monitor	Same as Key 9
24	Sensor	Same as Key 10

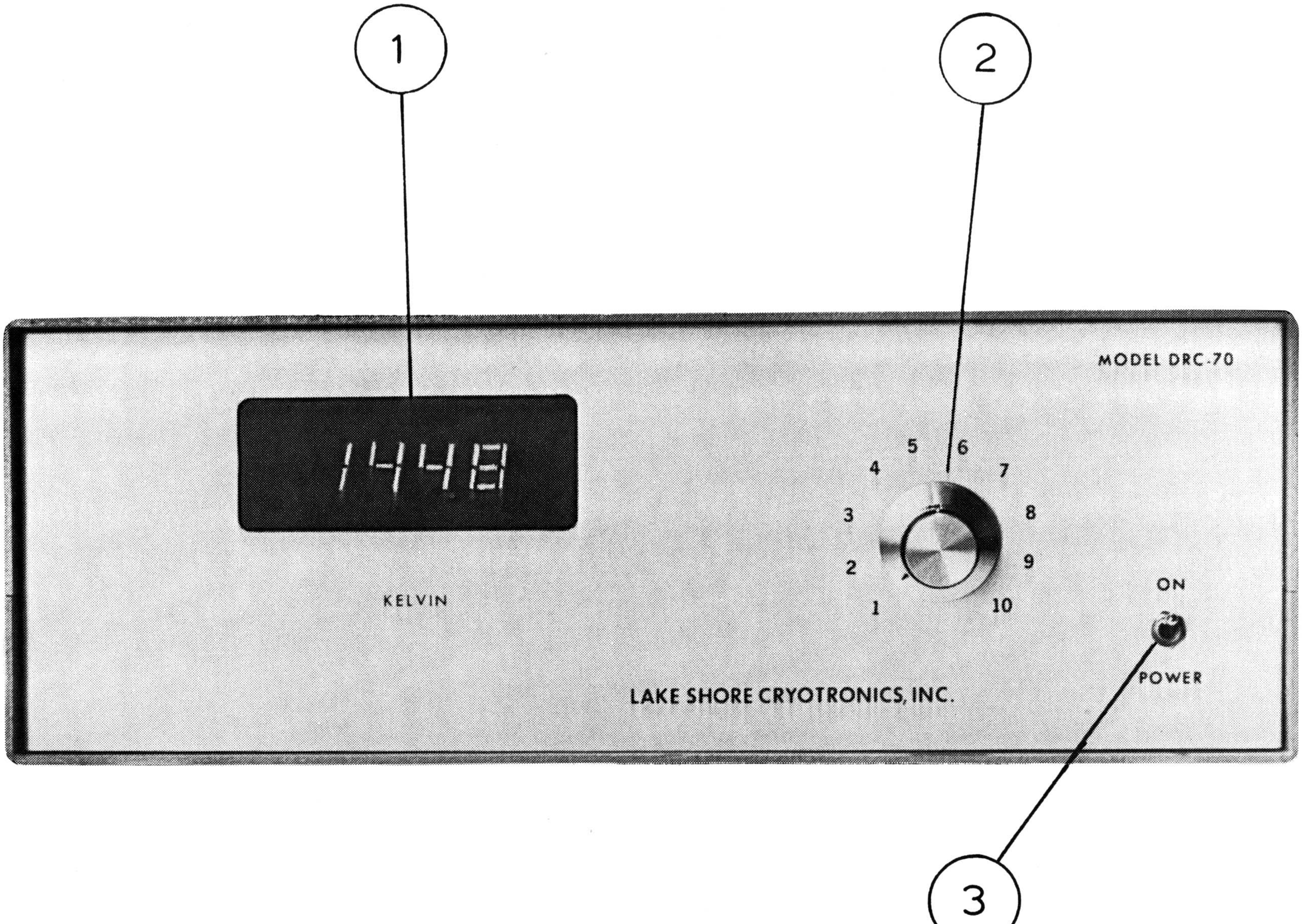


FIGURE 3.1 DRC-70 FRONT PANEL

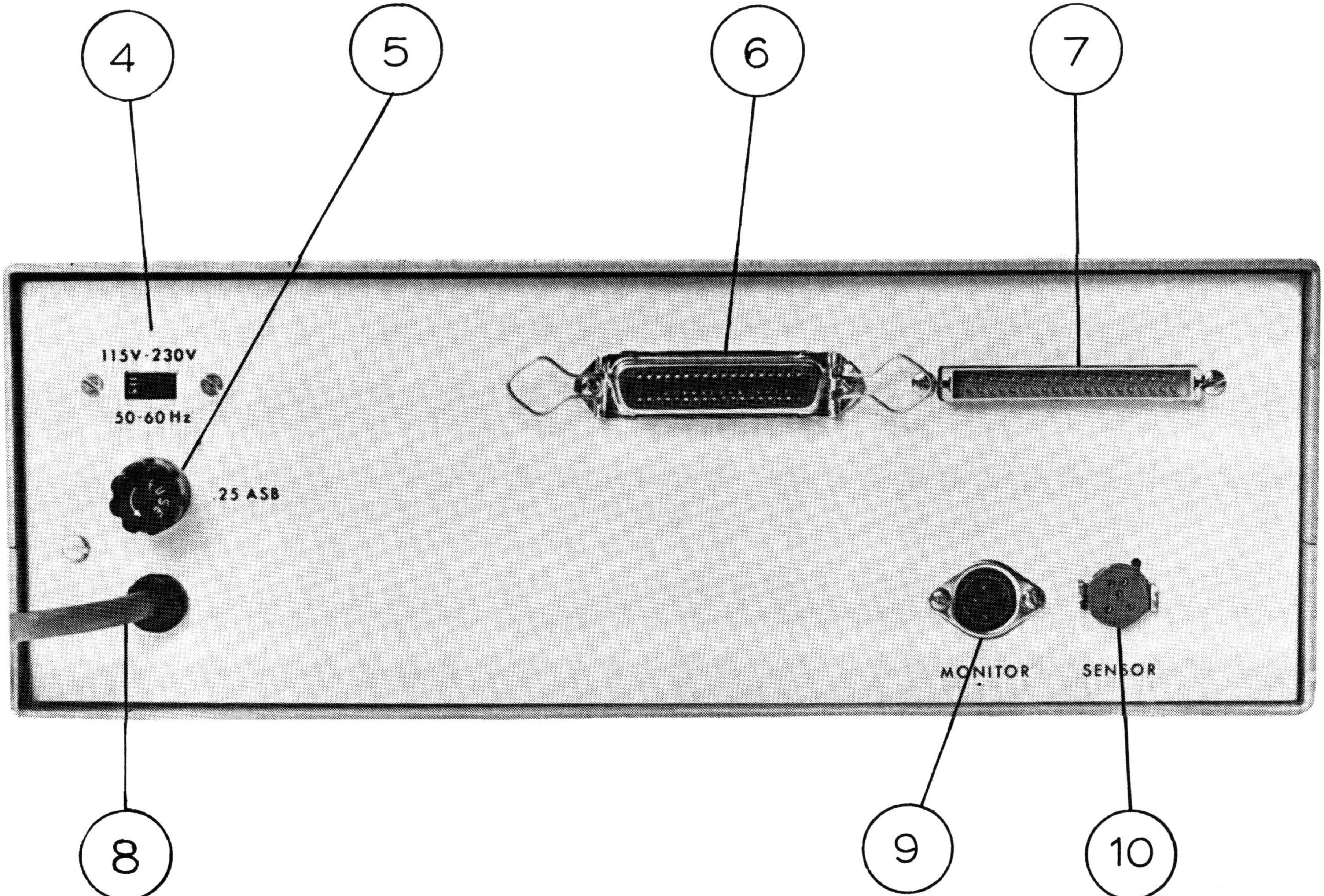


FIGURE 3.2 DRC-70 REAR PANEL

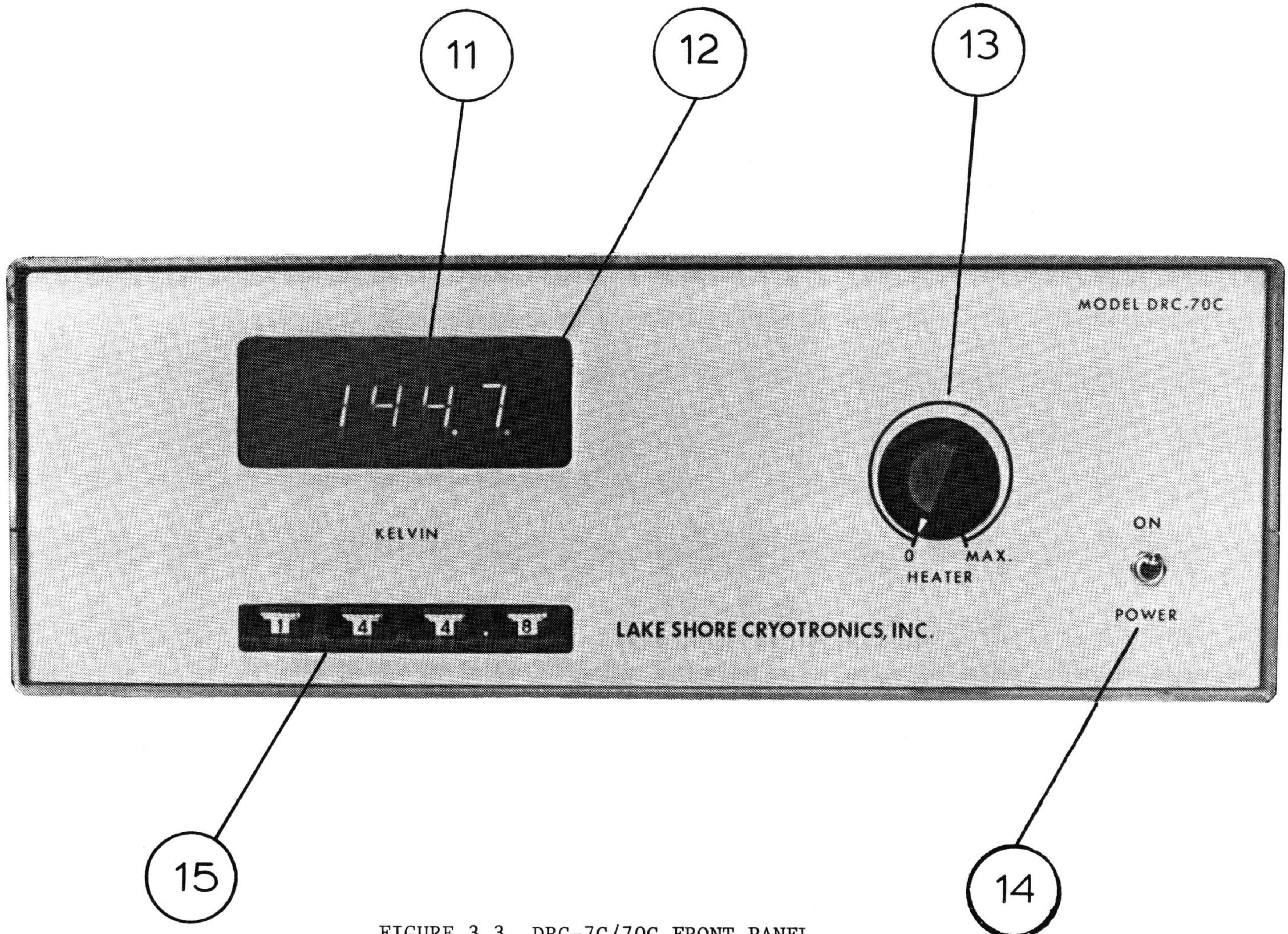


FIGURE 3.3 DRC-7C/70C FRONT PANEL

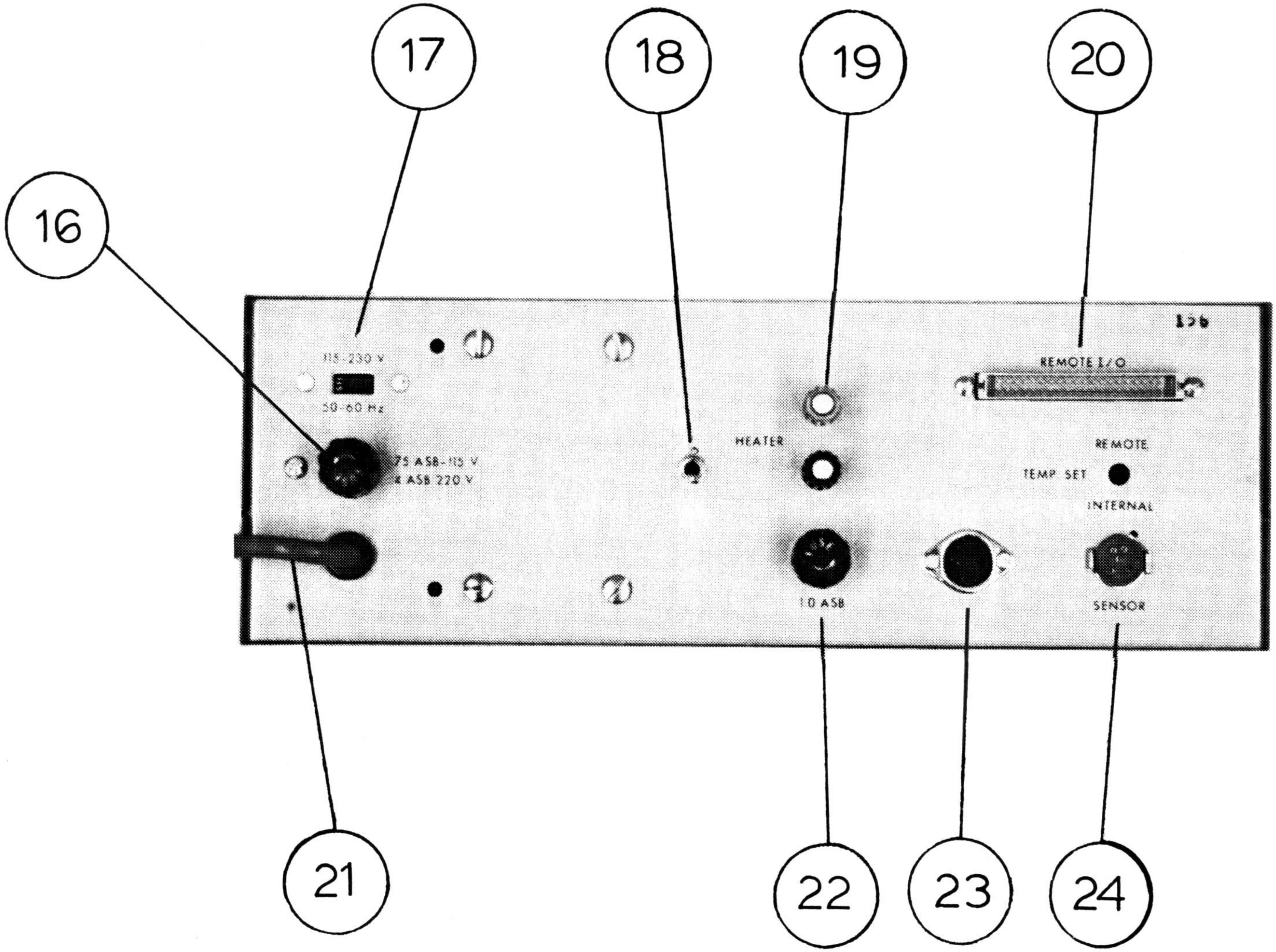


Figure 3.4 DRC-7C/70C REAR PANEL

3.3 Temperature Readout

The sensor and heater should be installed following the suggestions listed in the "Installation and Application Notes for Cryogenic Sensors" brochure in Section VIII.

Connect the sensor to the instrument following the diagram in Figure 2.1.

Turn the power switch to ON and observe that the display shows the proper temperature relative to the sample temperature.

If the diode or lead wires are shorted, the display will read one of the following:

Curve	PROM U13	Display
0	B3	431.0
A	B4	433.7
B	B6	428.0

If the display reads one of the above and blinks, the diode is connected backwards. In the case of an open lead, the display will slowly drift higher in temperature from the last voltage reading taken by the A/D converter.

The sensor and readout display should follow Table 3.3 which illustrates typical values expected of the standard DT-500-DRC or DT-500CU-DRC-36 sensors for your appropriate curve.

If the instrument or sensor does not agree with values listed in the table, within the accuracy of the system, consult sections on installation and/or section on troubleshooting to determine the cause and cure of the malfunction.

3.3.1 Remote Parallel BCD Input/Output Option

The BCD option consists of a 16 bit parallel output of temperature and, for the DRC-7C/70C controllers, a 14 bit parallel input of set point in kelvin degrees. The BCD in and out is handled through connector J3, a 40 pin 3M connector on the rear panel of the instrument (Key 7 of Figure 3.2 or Key 17 of Figure 3.4). A jumper wire is placed on the printed circuit board below I.C.'s U10 and U11 and above capacitor C21 (see Figure 6.4 - DRC-7/70 Series Components Layout). Cutting of this jumper allows the user to enable a remote set point by setting Pin-38, J1 high (see Table 3.2). Decade counters internal to the instrument provide a 1-2-4-8 code using positive logic with standard TTL levels of 0.4 volts for the low (or 0) state and 2.4 volts for the high (or 1) state under full load conditions. The drivers are sufficient to sink two standard loads, 3.2 mA, in the low state.

3.4 Standard DT-500-DRC and DT-500CU-DRC-36 Curves

The standard DT-500-DRC and DT-500CU-DRC-36 curve is presented in Table 3.3. The sensor and readout display should follow Table 3.3 which illustrates typical values expected of a standard DRC sensor to within 0.5 K. The table also includes a list of PROM sensor voltages and breakpoints used in the linearization of the DRC curve to arrive at the correct temperature readout.

3.5 Calibration of the DRC-70/7C/70C Display

The A/D (analog-to-digital converter) and current source can be calibrated in the following manner: the sensor current has been factory calibrated to 10 microamperes ±10 nanoamperes. To check the sensor current without removing the instrument cover, a precision resistor of not less than .01% tolerance should be connected to pins A and B(Figure 2.1) of the sensor socket (J2). A high input impedance volt meter connected to the precision resistor should measure a voltage equal to 10 microamperes times the value of the resistor. For example, a 100 K± .01% resistor should read 1.0000 volts within 100 microvolts. If a recalibration is needed, the voltage across the 100 K resistor can be adjusted by varying resistor R12 (see component position diagram, Figure 6.4) until correct reading is achieved.

The A/D converter has also been calibrated at the factory. To adjust the A/D converter, a voltage has to be applied across pins E and D (Figure 2.1). A variable 100 K resistor or precision voltage source in place of the diode are ideal ways to generate this voltage. If a resistor is used, it should be varied until one of the break point voltages indicated in Table 3.3 is generated. (A high impedance volt meter must be used for this adjustment). After an appropriate voltage is obtained, the display should be calibrated hy adjusting trimpot R20 until the display reads the correct temperature. If a precision voltage source is used, a break point voltage should be dialed in and the display should be calibrated as above. A break point temperature above 40 K should be used since the voltage sensitivity with temperature is lower at the higher temperatures ($\frac{dV}{dT} \approx 2.5$ mV/$_K$) than for temperatures below 30 Kelvin.

Table 3.2 gives the pin configuration for the BCD I/O option. The pins shown are for connector J1 (40 pin 3M connector on rear of instrument, Key 7 and 17).

Table 3.3 shows a table of break point data for the standard DRC curve.

Table 3.2

BCD TEMPERATURE OUTPUT - MODEL DRC - SERIES
REMOTE I/O

2 4 6 8 10 12 14 16 18 20 22 24 26 28 30 32 34 36 38 40

1 3 5 7 9 11 13 15 17 19 21 23 25 27 29 31 33 35 37 39

BCD TEMPERATURE OUTPUT		BCD TEMPERATURE INPUT	
PIN		PIN	
1	800	2	.1
3	400	4	.2
5	200	6	.4
7	100	8	.8
9	80	10	1
11	40	12	2
13	20	14	4
15	10	16	8
17	8	18	10
19	4	20	20
21	2	22	40
23	1	24	80
25	.8	26	100
27	.4	28	200
29	.2	30	Not used
31	.1	32	Not used
33	Data Valid	34	Analog Ground
35	-15v DC	36	Not used
37	+15v DC	38	Remote Control { 0 - Internal, 1 - External
39	Digital Ground	40	+ 5V

Table 3.3

DT-500-DRC (B) Voltage - Temperature Characteristic
Bias Current 10μA

T, Kelvin	Mean Sensor Voltage	PROM Sensor Voltage	
1.0	-	2.6792	BP30
1.5	2.6647	2.6648	
1.6	2.6622	2.6620	
1.7	2.6593	2.6591	
1.8	2.6562	2.6562	
1.9	2.6528	2.6534	
2.0	2.6491	2.6505	BP29
2.2	2.6410	2.6408	
2.4	2.6321	2.6310	
2.6	2.6223	2.6212	
2.8	2.6117	2.6115	
3.0	2.6005	2.6017	BP28
3.2	2.5886	2.5885	
3.4	2.5762	2.5754	
3.6	2.5633	2.5622	
3.8	2.5499	2.5491	
4.0	2.5361	2.5359	BP27
4.2	2.5220	2.5213	
4.4	2.5075	2.5066	
4.6	2.4928	2.4920	
4.8	2.4780	2.4774	
5.0	2.4631	2.4628	
5.5	2.4254	2.4262	
6.0	2.3877	2.3896	
6.5	2.3505	2.3531	
7.0	2.3142	2.3165	
7.5	2.2790	2.2799	
8.0	2.2452	2.2434	BP26
8.5	2.2127	2.2134	
9.0	2.1818	2.1835	
9.5	2.1524	2.1535	
10.0	2.1246	2.1236	BP25
11.0	2.0731	2.0741	
12.0	2.0236	2.0245	
13.0	1.9730	1.9750	BP24
14.0	1.9186	1.9156	
15.0	1.8561	1.8562	
16.0	1.7942	1.7967	BP23
17.0	1.7325	1.7298	
18.0	1.6651	1.6629	

Table 3.3

T, Kelvin	Mean Sensor Voltage	PROM Sensor Voltage	
19.0	1.5944	1.5959	BP22
20.0	1.5159	1.5155	
21.0	1.4389	1.4351	
22.0	1.3575	1.3546	BP21
23.0	1.2895	1.2951	
24.0	1.2378	1.2355	BP20
25.0	1.1955	1.2000	
26.0	1.1645	1.1645	BP19
27.0	1.1434	1.1434	BP18
28.0	1.1293	1.1288	BP17
29.0	1.1192	1.1202	
30.0	1.1115	1.1115	BP16
32.0	1.1003	1.1003	BP15
34.0	1.0923	1.0922	BP14
36.0	1.0859	1.0862	
38.0	1.0804	1.0802	BP13
40.0	1.0752	1.0754	
45.0	1.0632	1.0632	BP12
50.0	1.0515	1.0516	
55.0	1.0397	1.0399	BP11
60.0	1.0276	1.0274	
65.0	1.0151	1.0149	
70.0	1.0024	1.0024	BP10
75.0	0.98933	0.98923	
80.0	0.97610	0.97602	
85.0	0.96277	0.96281	
90.0	0.94939	0.94960	BP 9
95.0	0.93591	0.93597	
100.0	0.92238	0.92233	
105.0	0.90881	0.90869	
110.0	0.89520	0.89506	
115.0	0.88156	0.88142	
120.0	0.86788	0.86778	
125.0	0.85412	0.85414	
130.0	0.84035	0.84051	BP 8
135.0	0.82652	0.82655	
140.0	0.81265	0.81259	
145.0	0.79873	0.79864	
150.0	0.78478	0.78468	
155.0	0.77081	0.77073	

Table 3.3

T, Kelvin	Mean Sensor Voltage	PROM Sensor Voltage	
160.0	0.75680	0.75677	
165.0	0.74276	0.74281	
170.0	0.72868	0.72886	BP 7
175.0	0.71457	0.71463	
180.0	0.70041	0.70039	
185.0	0.68622	0.68616	
190.0	0.67201	0.67192	
195.0	0.65777	0.65769	
200.0	0.64353	0.64346	
205.0	0.62928	0.62922	
210.0	0.61504	0.61499	
215.0	0.60084	0.60076	
220.0	0.58672	0.58652	BP 6
225.0	0.57268	0.57275	
230.0	0.55880	0.55899	
235.0	0.54508	0.54522	
240.0	0.53152	0.53146	BP 5
245.0	0.51810	0.51814	
250.0	0.50479	0.50482	
255.0	0.49151	0.49150	
260.0	0.47818	0.47819	
265.0	0.46483	0.46487	
270.0	0.45137	0.45155	BP 4
275.0	0.43773	0.43763	
280.0	0.42388	0.42370	
285.0	0.40988	0.40977	
290.0	0.39574	0.39584	BP 3
295.0	0.38155	0.38151	
300.0	0.36729	0.36718	
305.0	0.35294	0.35284	
310.0	0.33843	0.33851	BP 2
315.0	0.32375	0.32368	
320.0	0.30893	0.30885	
325.0	0.29407	0.29401	
330.0	0.27919	0.27918	
335.0	0.26432	0.26435	
340.0	0.24943	0.24951	
345.0	0.23458	0.23468	
350.0	0.21974	0.21985	
355.0	0.20500	0.20501	
360.0	0.19037	0.19018	BP 1
365.0	0.17596	0.17619	
370.0	0.16192	0.16220	
375.0	0.14846	0.14821	BP 0
380.0	0.13597	0.13421	

SECTION IV

Theory of Operation

4.1 Introduction

This section contains the theory of operation of the DRC-7/70 series of instruments and contains a detailed description of the microprocessor temperature determination and control.

4.2 General Description

Refer to Figure 4.1, 4.2 and Figure 6.1 for the following discussion. A precision 10 microampere constant current source is used to excite the diode sensor (Model DT-500-DRC or DT-500CU-DRC-36). The voltage generated is fed into an A/D converter, where it is converted to a digital signal. The multiplexed BCD outputs of the A/D are sampled by a microprocessor.

The microprocessor is an F8 with a 3850/3853 configuration. The program for temperature conversion, and the DRC curve, which is broken up into 32 break point segments, are stored in a PROM. The microprocessor executes a program which samples the sensor voltage and, using break point voltage, temperature, and slope information, calculates the correct Kelvin temperature. The microprocessor then outputs the temperature information which is decoded and displayed by an LED display.

The microprocessor also controls the BCD output of temperature and BCD input of set point (for controllers).

For the DRC-7C/70C Thermometer/Controllers, the F8 determines if control is necessary and carries out the control by adding power or reducing power applied to a system through a heater.

4.3 Detailed Description

A detailed description of the operation of a DRC instrument is outlined in the following sections. Refer to Figures 6.1 and 6.2 for the following discussion.

4.3.1 Power Supplies

There are six different power supplies incorporated in the DRC instrument. The main power transformer, TX 1, has two split primaries for 115 or 230 volt AC operation. The slide switch, S1, selects the proper line voltage. There are three different secondaries which provide the raw voltages for the supplies.

The first secondary, which is outputed through leads 5,6 and 7 of the transformer, is rectified by CR5-8. The 5 V regulated supply that is used by the I.C.'s is formed by C7, C8 and a 5-volt positive voltage regulator, U34. A 5-volt unfiltered (but regulated) supply for the LED display is provided by C6, C9 and the 5-volt positive voltage regulator U31. The reason for splitting the 5-volt supplies is to avoid the LED display from loading down the main 5-volt supply.

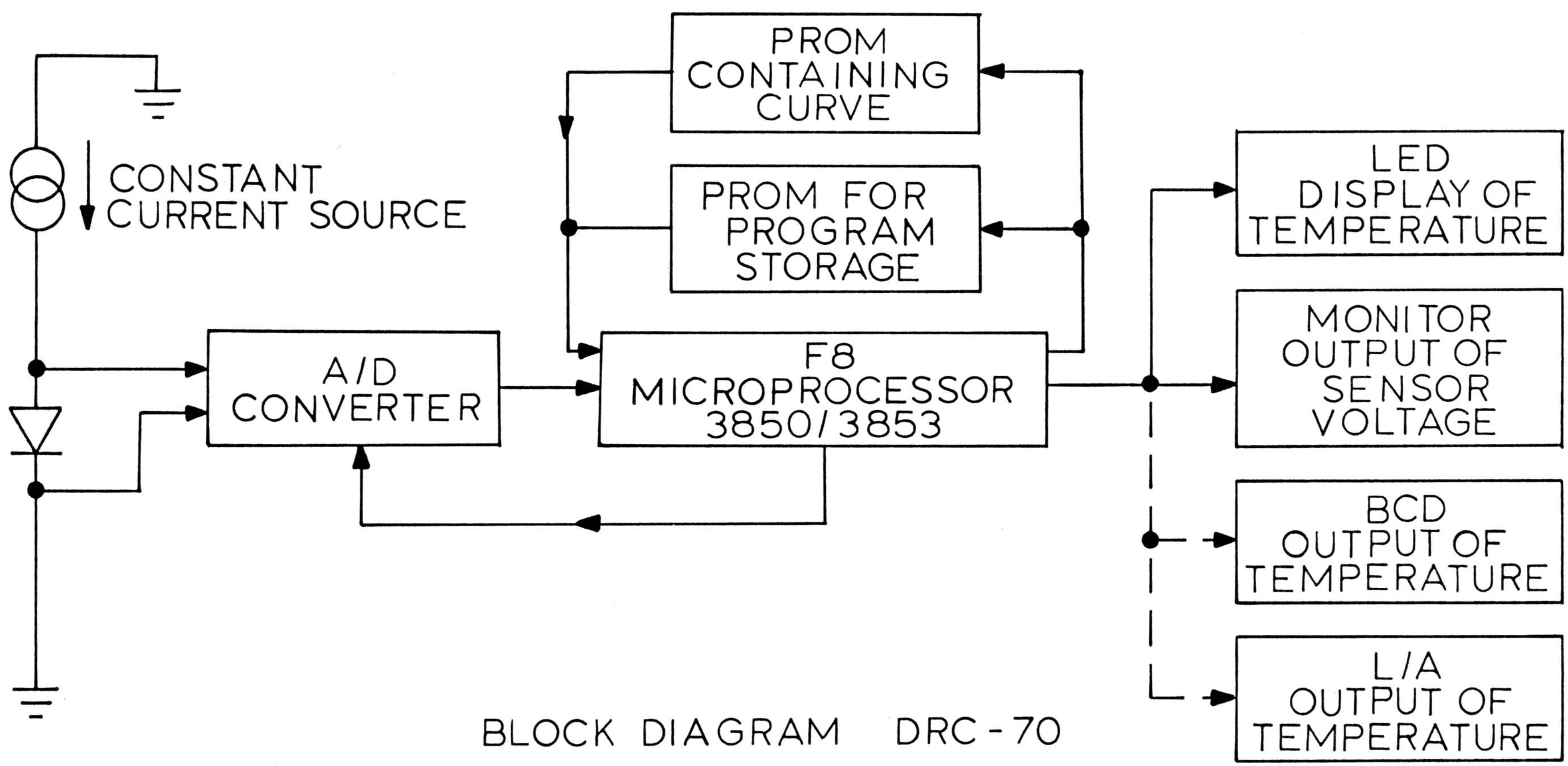


FIGURE 4.1 Block Diagram of DRC-70

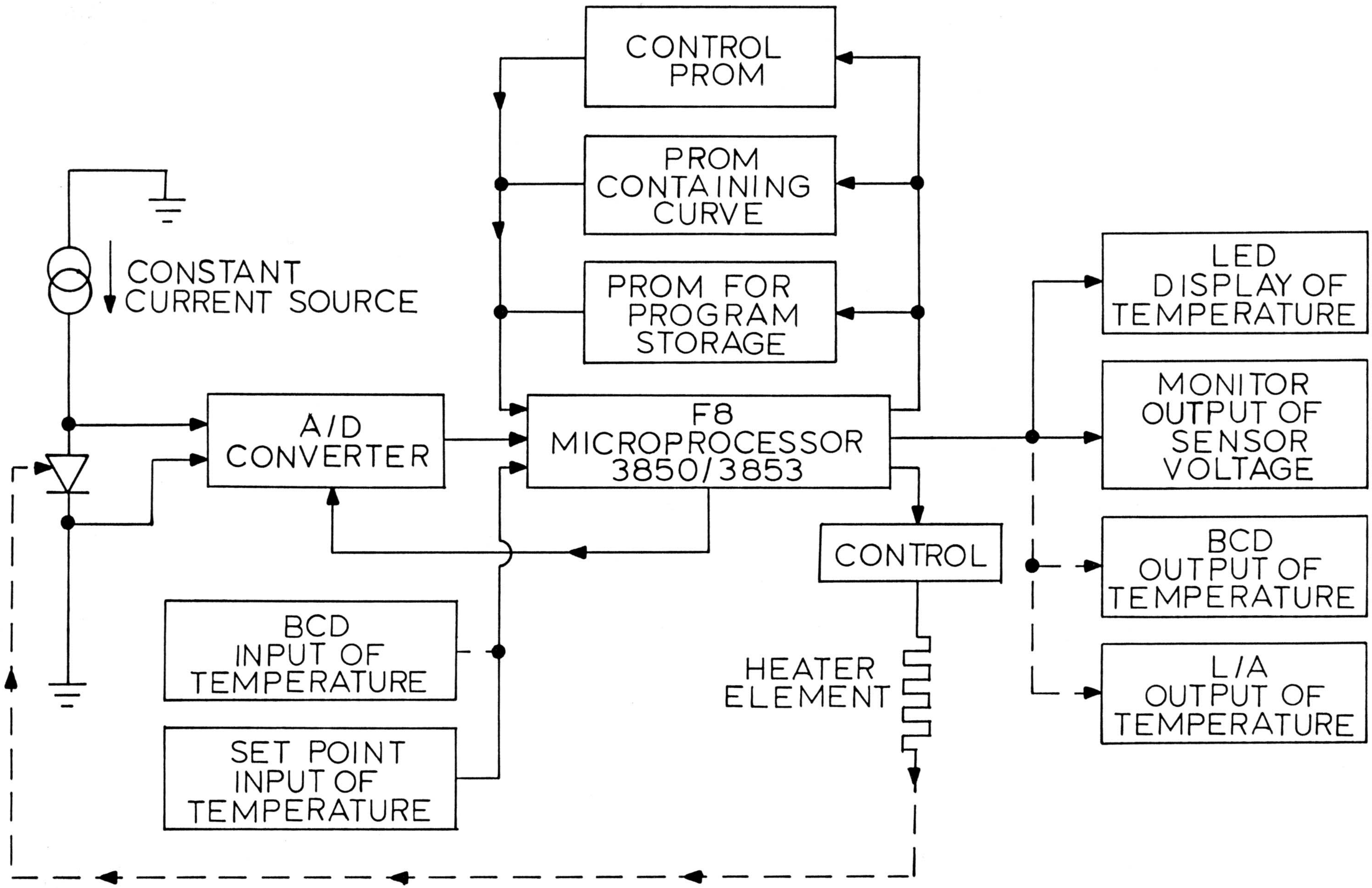


FIGURE 4.2 BLOCK DIAGRAM DRC-70C

The second secondary, through leads 8, 9, and 10, is rectified by CR1-4. A -15 volt supply is generated by C2, C5 and the negative 15 volt voltage regulator U35. This voltage is used primarily by the A/D converter. A +15 volt supply is generated by C4 and the positive 15 volt voltage regulator U33. This +15 volt supply is also used primarily by the A/D converter. A third voltage produced through this primary is a +12 volt supply generated by C1, C3, and the positive 12 volt voltage regulator U32. The +12 volt supply is used to drive the microprocessor.

The third secondary is outputed through leads 14 and 15 and is rectified by CR9-12. A floating 15 volt supply is generated by C40 and a positive 15 volt voltage regulator U36. This floating 15 volt supply is used to supply the constant current source.

4.3.2 Precision Current Source

The diode constant current supply is supplied by the precision current source U22. A reference voltage used by the current source is derived from an internal temperature stabilized precision voltage reference of 6.95 volts between pins E and C of U22. Resistors, R12A, R13, R14 and trimpot R12 vary this voltage to match the voltage generated by feedback resistor R19. Resistor R19 has been selected to generate 4.99 V (by the feedback current of 10 microamps). The trimmer resistor R12 allows for an adjustment of the reference voltage to equal this feedback voltage. The 10 microamp output current is fed through pins G and B of U22 to the sensor connector (see Figure 2.1).

4.3.3 A/D Converter

The analog-to-digital converter consists of a precision 4½ digit I.C. pair that produces a multiplexed BCD output that is accurate to ±1 count over the entire 40,000 count range. The 713A runs on a 50 K Hz clock generated by U1. This clock frequency allows for one reading every .8 seconds (since one clock pulse is required to make one count; 50,000 pulses per second would allow for 1.2 readings per second). The digital signal is outputed in a bit-paralled, byte-serial form. The A/D converter output is multiplexed by U12 and converted to a useable form for the microprocessor.

4.3.4 Microprocessor Hardware

The microcomputer used is an F8 microprocessor in a 3850/3853 configuration. The 3850 is the Central Processing Unit (CPU) and controls external support logic. The CPU has two bi-directional, 8 bit I/O ports for data transfer between the 3850 and logic external to the microprocessor. The temperature determination program and breakpoint data (plus control program) are stored in 2048-bit bipolar PROMS (256 bytes x 8 bits per byte). The CPU reads the program through the SMI.

The SMI uses external gates in the determination of which PROM is enabled to be read.

4.3.5 Software

Refer to Figure 4.3, Figure 4.4 and 4.5 as an aid in the following discussion. Figure 4.3 is a flow chart which gives the major steps of the program and their locations in memory. When the instrument is turned on, the program is reset to start from the beginning. At this point, the program initializes internal registers to be used in the program. The program inputs multiplexed A/D information when the A/D converter tells it there is fresh data ready (the program stays in a loop until the A/D signals there is information ready). Since the A/D cycles once every .8 seconds, the program takes a little under one second to run through.

After the program has read and stored the appropriate sensor voltage, it goes to the data table of 32 break point voltage, temperature, and slope relationships. The first break point (see Table 3.3) is the lowest voltage and highest temperature point with the slope being the slope of the second break point (since the first break point does not have a slope to a point above it). The program finds the correct breakpoint by checking each break point voltage to see if it is lower than the input voltage. As the break point is found, the temperature is calculated using the following equation:

$$T = (V_{BP} - V_{AD}) * S_{BP} + T_{BP}$$

where:

- T is temperature in K
- V_{BP} is break point voltage
- V_{AD} is input voltage
- S_{BP} is slope between successive break points $\left(\frac{dT}{dV}\right)$
- T_{BP} is break point temperature

The temperature is then output in a serial form to a serial-to-parallel shift register which is latched into a decoder driver to feed the digital display board. The latching of data avoids a flicker of the display while the data is changing.

If the instrument is a controller, the program continues on to determine the control function; if not, it loops back for the next A/D input.

To prepare for control, the program initiates internal interrupt levels and vectors. The set point can be input in one of two ways. One way is the BCD switches on the front of the instrument, the other is through the BCD I/O option. If the front panel switches are used, the user can dial in the control temperature directly in Kelvin degrees. If the external BCD option is used, a BCD signal (from a source such as a computer) is applied to connector J1 (see Table 3.2). In order for the instrument to accept the remote set point and disable the BCD switches, a jumper on the circuit board

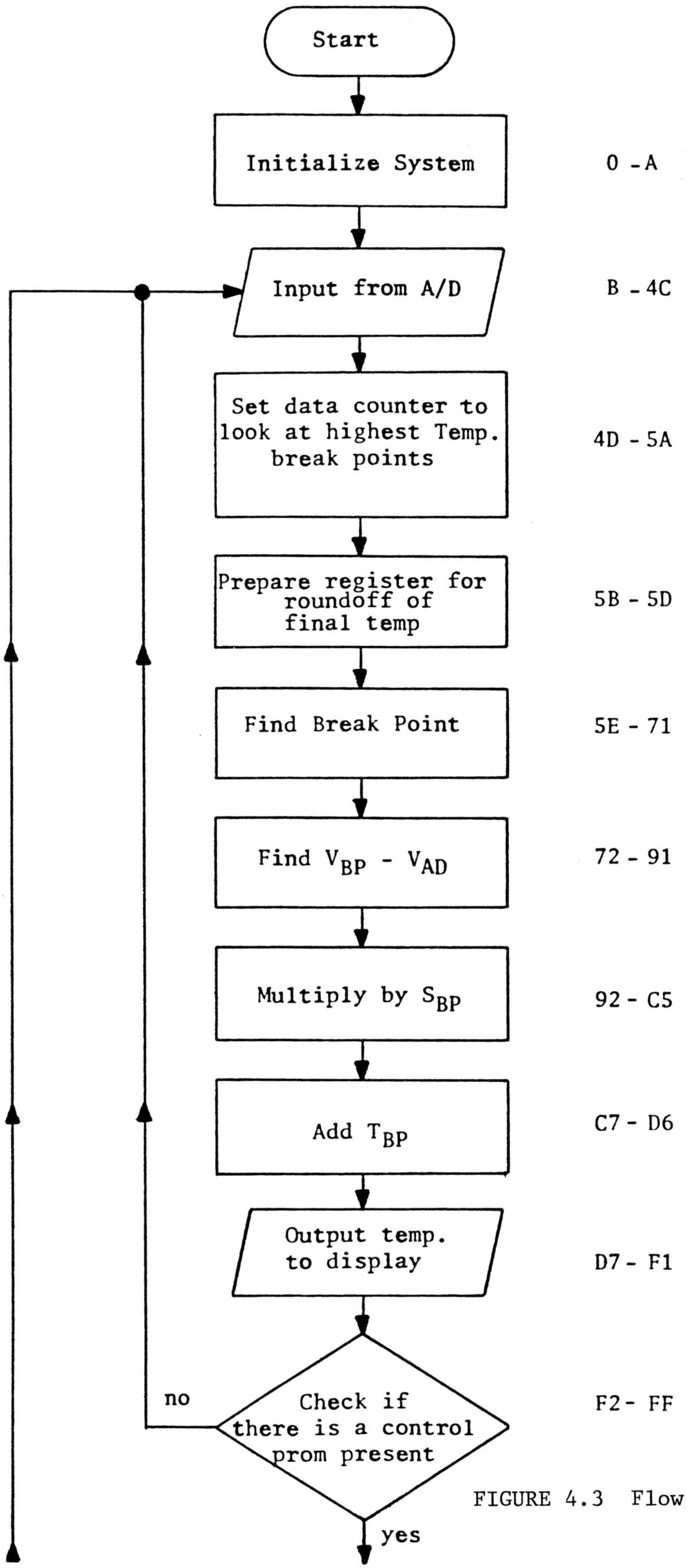


FIGURE 4.3 Flow Chart of DRC Software

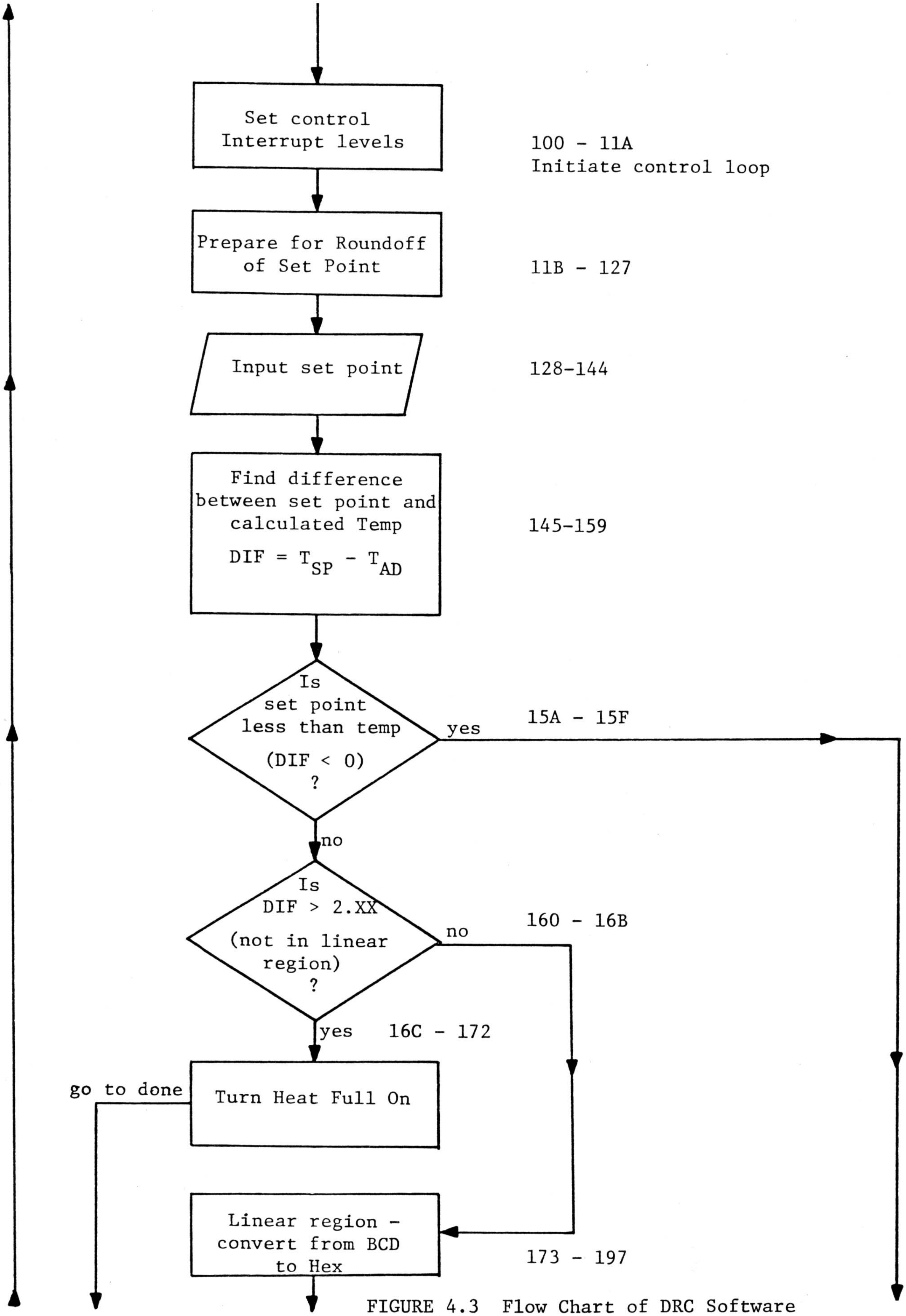


FIGURE 4.3 Flow Chart of DRC Software

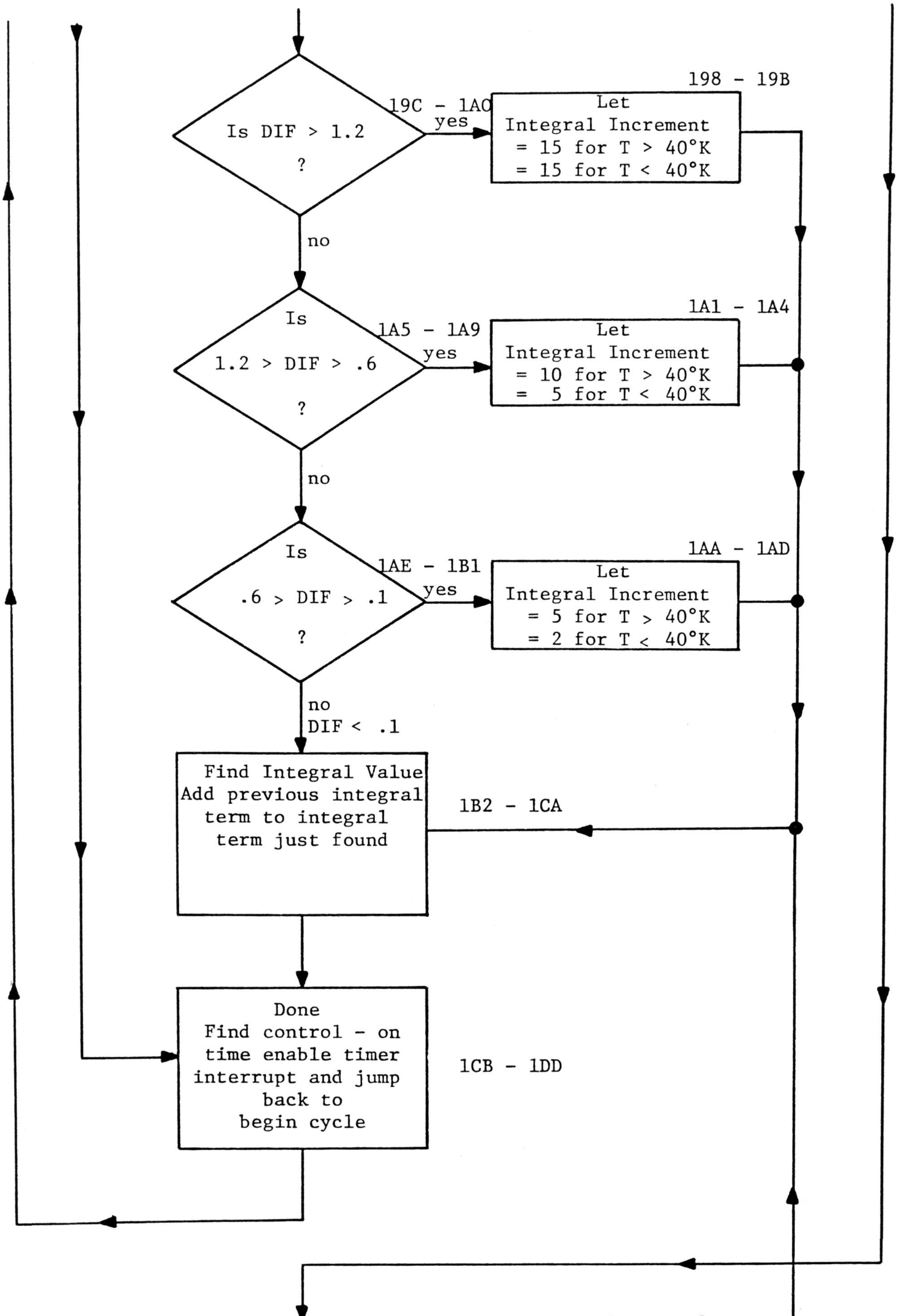


FIGURE 4.3 Flow Chart of DRC Software

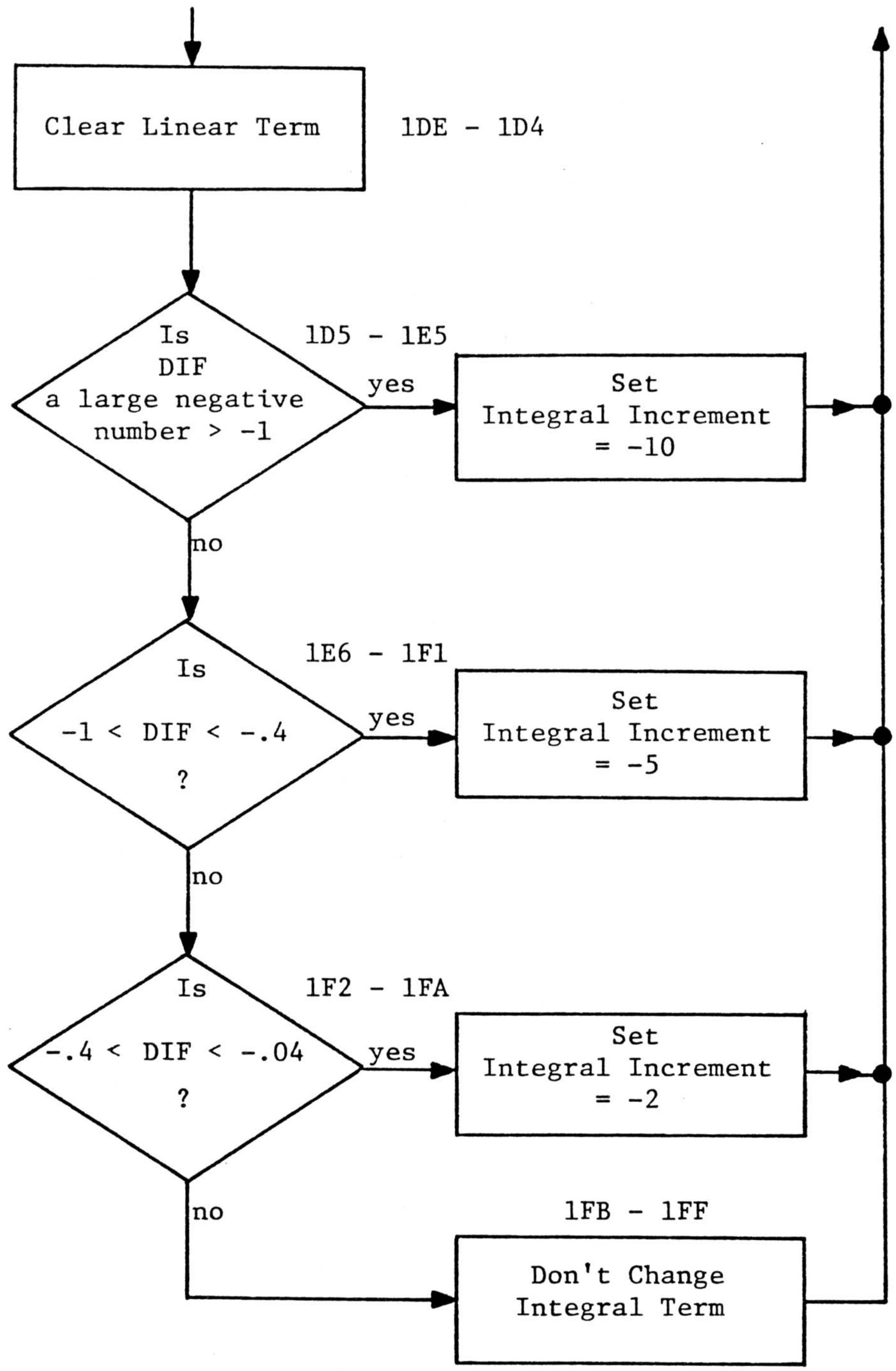


FIGURE 4.3 Flow Chart of DRC Software

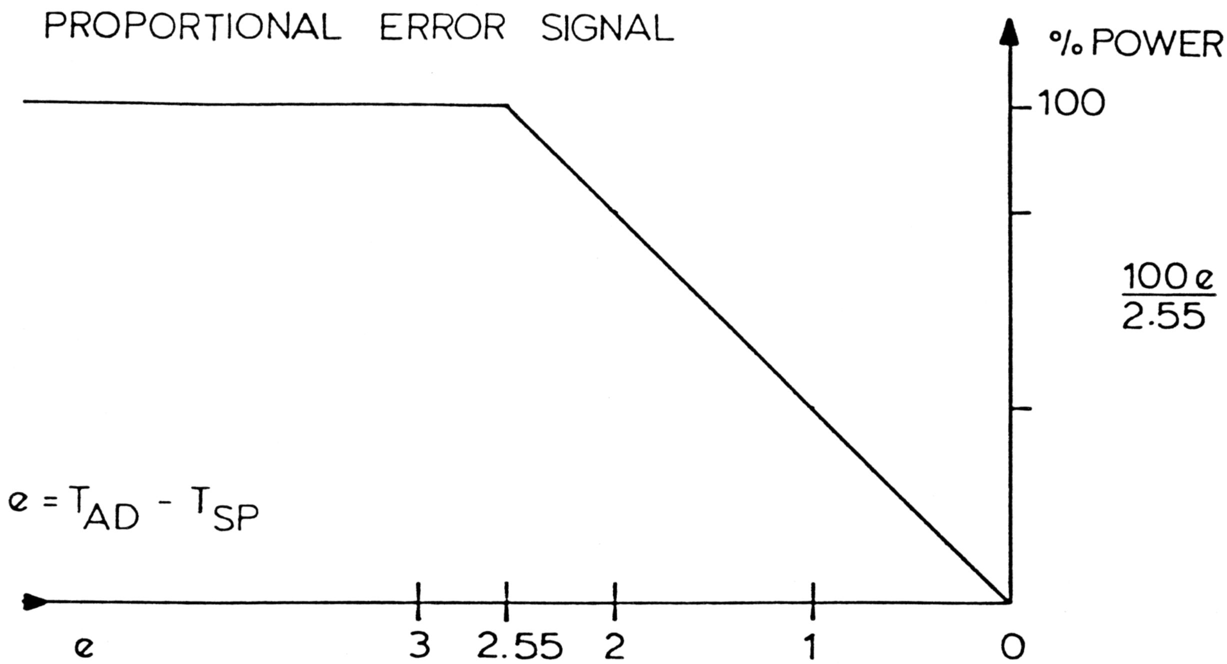


FIGURE 4.4 Control Gain Function

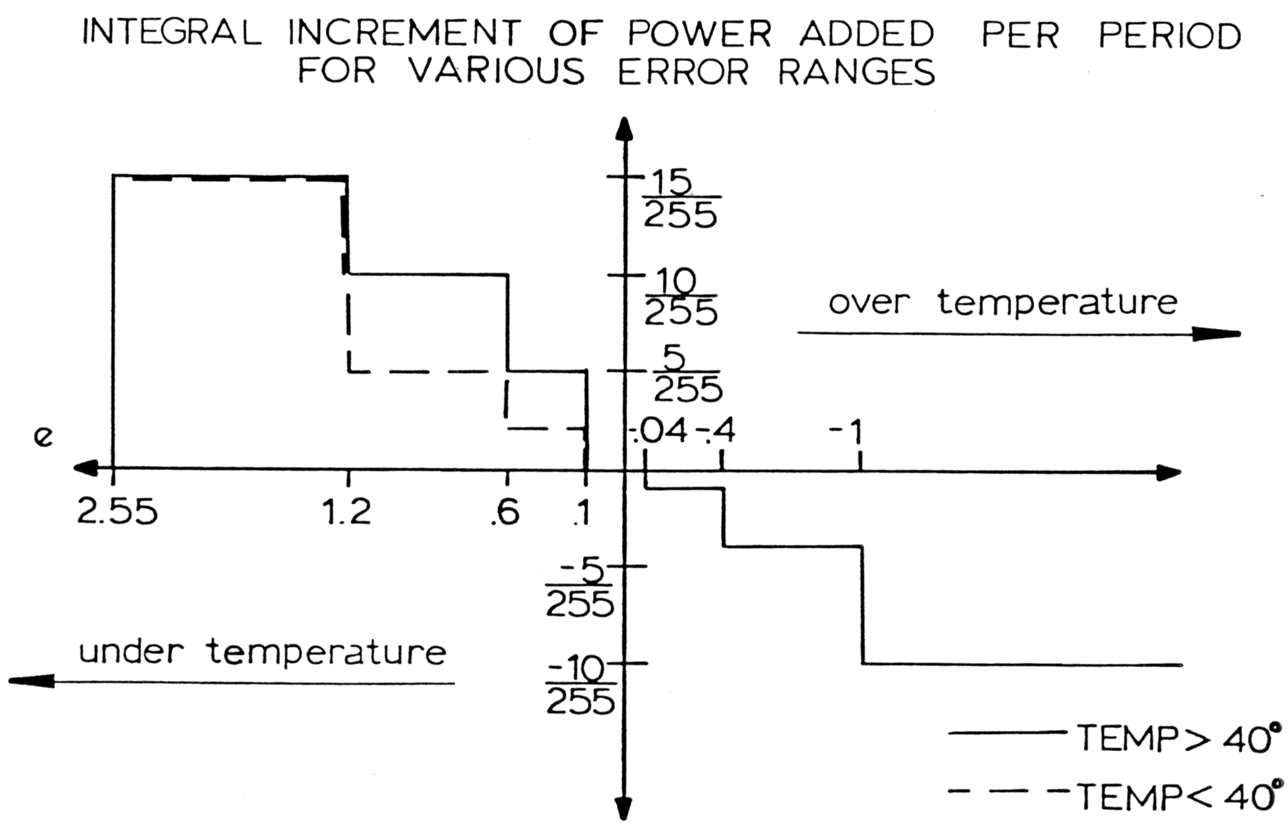


FIGURE 4.5 Control Integral Function

has to be cut and a logic high signal applied to pin 38 of J1. With the jumper in, pin 38 is held low (logic zero), so in order to enable the remote set point the jumper has to be removed.

To remove the remote-set-point-enable, remove the instrument cover and cut a jumper between U10, U11, and C21 (see Figure 6.1 and 6.4).

Once the set point has been input, an error signal is determined, with the error signal defined as:

$$\varepsilon = T_{AD} - T_{SP}$$

where: T_{AD} is calculated temperature
T_{SP} is set point temperature

The gain function for the error signal is given in Figure 4.4. The function is based on the temperature and set point. For a temperature which is more than 2.55 K below the set point, the control power is full on (or on for 100% of the cycle). From 2.55 K to 0 K, the power is reduced linearly as the error reduces. The percentage of on time is given by:

$$\% \text{ Power On} = \frac{100\ \varepsilon}{2.55}$$

For example, if the error is 1.52 °K, the control power is on 1.52/2.55 or 59% of the period.

However, if only the proportional term from Figure 4.4 was considered in the determination of the control signal, it is obvious the controller would control below the set point. Therefore, the linear term is integrated (an integral term added). Figure 4.5 shows the relationship between error signal and integral term added. In an under temperature condition, power is added while in an over temperature condition, power is taken away.

The error limit of 2.55 is chosen for two reasons. The first is the limitations of the hardware since one software instruction (or one byte) has 8 bits, the maximum decimal number that can be manipulated is 255 (or FF base 16). The second is the period of the F8 internal timer. The timer that is set for control generates an interrupt every 4 m sec. The control signal is generated by setting an external flip-flop and counting the number of interrupts until the pre-determined control count is reached. At this point, the timer shuts itself off and resets the flip-flop. Here, 255 counts that are 4 m sec apart equal just over 1 second (or just longer than the period for the program to run once). In this way, there is continuous heat on for more than 2.55 K below set point condition.

A light has been hard-wired to indicate when the power is being applied to the heater terminals. This light is a decimal point in the lower right corner of the least significant digit.

4.3.6 Digital Display Board

The digital display data Pin 1 and clock Pin 2 and ground Pin 4 are applied to the serial BCD to parallel BCD converters (U110 and U111). The four digit BCD lines are applied to four BCD 7 segment decoder drivers (U106, U107, U108, and U109). A latch signal (EL Pin 3) is applied in parallel to these decoder drivers to provide for a non-blinking display signal. The output of these converters are the 7 segment drivers to the LED digital display (U102, U103, U104, and U105).

Provisions are made to distinguish between an overrange voltage such as may occur with an open sensor lead and a shorted sensor. For the normal range of the diode sensor thermometer, the typical voltage values are 0.1 volts at 400 K and 2.5 volts at 1 K. If, however, 3 volts is exceeded, the A/D converter provides an overrange signal which in turn is applied through Pin 4 and U101 to the BCD decoder drivers to provide for a flashing light as explained in Section 3.3. The provision is also made for a zero input (as with a shorted connection) to display a temperature also outlined in Section 3.3.

A broken voltage or current lead, however, will be seen as a gradual increase in temperature with time, due to the very high input impedance of the A/D converter.

SECTION V

Troubleshooting

5.1 Introduction

This section contains the instructions for maintaining and troubleshooting the DRC-7/70 series of instruments.

5.2 Test Equipment and Accessories

A high input impedance digital voltmeter and oscilloscope, a fifty ohm, ten watt resistor to simulate a heater element (in the case of controllers) and a precision resistor connected to simulate the diode wired according to Figure 2.1 (c) are normally sufficient to test the DRC-7/70 instruments.

5.3 General Remarks

On installation, one of the major problems is an improperly connected temperature sensing diode. It is advised that other portions of the cryogenic system be tested before the instrument is troubleshooted. Some checks that could be made are:

1) Open or shorted sensor or heater leads (especially in an area of frequent disassembly).
2) Leakage paths between heater and sensor leads that induce electrical feedback in addition to thermal feedback.

If the malfunction points toward the instrument, more detailed tests should be made.

5.4 Instrument Tests

The first check to be made would be to check the input line fuse. A 3/4 Ampere, 250 V, fast-blo fuse is recommended. If the input line voltage and sensor input voltage have been checked, the following sequence should be followed:

1) Check all the power supplies for proper operation. The 5V supply for the display should be between 3.8 and 5.0 V. This is an unfiltered but regulated supply. Power supply lines are indicated on Figure 6.4. The failure of any of these six power supplies will result in your DRC instrument not operating properly.
2) Check for the waveforms at the following pins and refer to Figure 5.1 for waveforms

Table 5.1

DRC Signals and Functions

Signal	Function
a) Pin 12 of U21	Clock signal of A/D converter. Frequency should be about 150 K Hz. If not present replace U7. Also check R22 and C36A.
b) Pin 14 of U20	Integrated signal of A/D to determine the count period. The period should be about .8 seconds. If not present, check* U21 and C30.
c) Signal at R4 (closest to U16)	This is the microprocessor signal between the CPU (3850) and SMI (3853). The signal should pulse once every second. If this signal is not present, check Table 5.1, signal d), e), f). If this signal is present but does not pulse, U18 and U19 should be checked for proper operation. U18 is a quad two-input NAND gate (7400) and U19 is a hex inverter (7404). Checking logic levels of these IC's will insure proper gate operation. If both U18 and U19 are working, see Table 5.1 signals d), e), and f).
d) Pin 40 of U17	Microprocessor RC clock signal. If not present, check values and connectors for R2, R3, and C37. The frequency should be about 250 K Hz. If the capacitors and resistors are good, check to be sure that the +12 volt supply to the RC network is present.
e) Pin 1 of U17 Pin 2 of U16	Clock line from CPU (3850) to SMI (3853). If not present, microprocessor is not clocking the interface device. Replace U17.
f) Pin 2 of U17 Pin 3 of U16	Write line from CPU to SMI. If not present, replace U17.

* Note that the easiest way to check on I.C. is by direct replacement.

Table 5.1

Signal	Function
g) Pin 10, 11, 14, 15, of U12	Represents A/D bit information. Signals should be varying from low (0) state to high (1) state. All of the digit lines (D1-4) should be checked so that these lines go high at some point. These signals should also be present at the appropriate I/O port lines of U17. If signals are not present, replace U21. If signals are present, but do not appear at U17, replace U12.
h) Pin 4, 6, 8, 11 of U18	Are lines that select the appropriate PROM. If not present, check for operation of U18 (7400) as described in Table 5.1, signal c.
i) Pin 6 of U7	Should be same at Pin 12 of U21. If signal not present, check interconnections on P.C. board.

Signal paths should also be checked. If signals are present at source components and not at destination components, a printed circuit board problem requiring a repair of the printed circuit foil may be required. Continuity checks between points will turn up any unwanted open circuits in signal paths.

If the signals at the component pins outlined in Table 5.1 are present and a problem still exists, check Table 5.2 for a list of problems and solutions for the instrument.

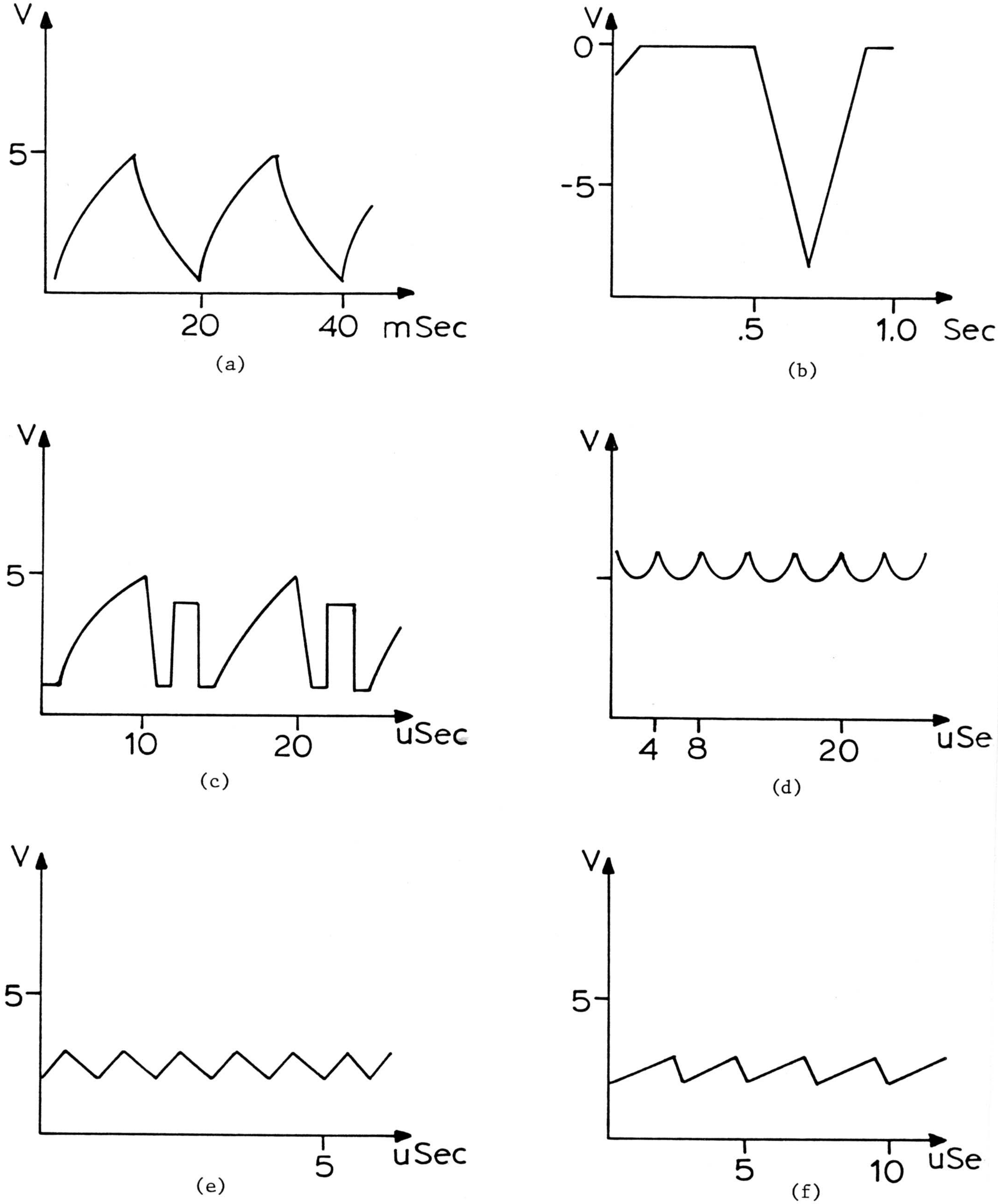
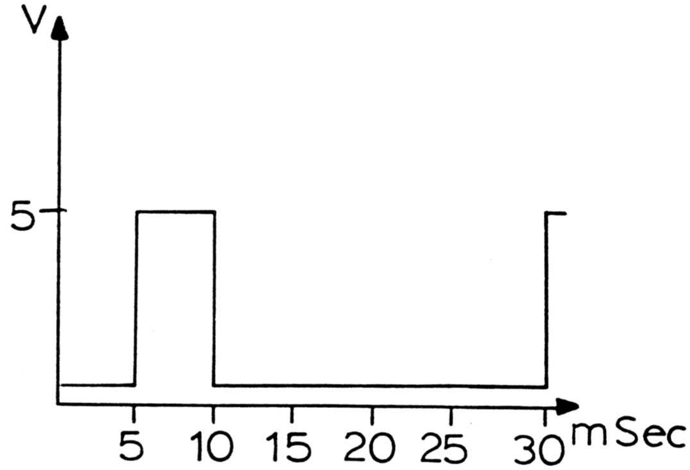
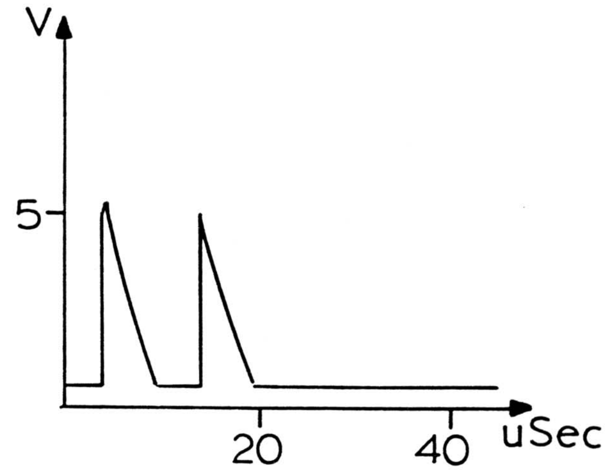


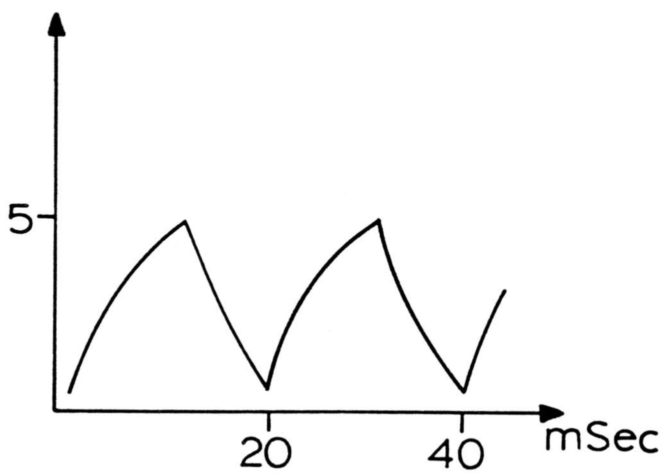
FIGURE 5.1 DRC Component Waveforms



(g)



(h)



(i)

FIGURE 5.1 DRC Component Waveforms

Table 5.2

Problem	Solution
1) Instrument blows fuses.	Check fuse size and limits. Make sure S1 is set for proper line voltage. Check for any shorts between S2 and instrument case.
2) Instrument gets excessively hot.	Check C7, and CR7-8 for proper operation. Failure of these components will result in TX1 warming up. Also check for any shorts between any of the leads of TX1.
3) A/D converter drifts.	Check period of waveform b, Table 5.1. If period is inconsistent (should be ~.8 sec), this will cause A/D converter to drift. Therefore, replace U20, and also check C30.
4) Display seems to flicker.	Check for any shorts between pins 2 and 3 going to the display board.
5) Controller does not respond to set point switches.	Check to make sure +5 V and ground go to the switches. If so, check that the proper lines on U3 and U5 are high (for example, if 100.0 were dialed in, the only line on would be the most significant digit, digit 1). If the proper lines are on and it does not respond, check and see if the control signal is present (U6 of pin 9). This should be high when control is on. If signal is present, then problem is in power board - probably U40. If signal is still not there, trace control signal back through U19 to the CPU (U17 I/O port 2). The discontinuity of the signal would be the failure of either U6, U19 or U17.
6) Power stays on all the time, no matter what set point is.	Check U44. If this power Darlington is bad, the power will stay high all the time.
7) Control does not respond and conditions 5 and 6 check out.	Problem could be in control PROM U14.

Table 5.2

Problem	Solution
8) Display does not correspond to curve at other points than the calibrated point.	The A/D converter (U21) could be losing counts. Also PROM U13 could be bad.

Other subtle problems could occur with the DRC series of instruments. If this section was not helpful in resolving the problem with the faulty DRC, a factory representative should be contacted.

SECTION VI

6.1 DRC Series Parts List and Schematics

Table 6.1
Model DRC –Series Circuit Board Components

REF. DESG.	DESCRIPTION	LAKE SHORE PART NO.
U1	Dual Retriggerable Monostable Multivibrator	74123
U2-5	Quadruple 2-line to line Data Selector/Multiplexers	74157
U6	Dual D-type Positive-edge-triggered Flip-flops with Preset and Clear	7474
U7	Hex Inverter	74C14
U8	Quadruple 2-Input Multiplexer, Inverting, Open-collector	8234
U9-10	8-bit Parallel - Out Serial Shift Register	74164
U11-12	Quadruple 2-Input Multiplexer, Inverting, Open-collector	8234
U13	2048-bit Prom (Temperature Determination Program stored)	74571
U14*	2048-bit Prom (Control Program stored)	745471
U15	2048-bit Prom (Break Point Data stored)	745471
U16	Memory Interface Unit	3853
U17	Central Processing Unit	3850
U18	Quadruple 2-Input Positive - NAND Gates	7400
U19	Hex Inverters	7404
U20-21	Precision Pair for A-D Converters	8052A/7103A
U22	10 μAmp Constant Current Source	
U31	5-volt Positive Voltage Regulator	7805CT
U32	12-volt Positive Voltage Regulator	7812CT
U33	15-volt Positive Voltage Regulator	7815CT
U34	5-volt Positive Voltage Regulator	7805CT
U35	-15 Volt Negative Voltage Regulator	7915CT
U36	15-Volt Positive Voltage Regulator	7815CT
U40-41*	Solid State Darlington Coupled Relay	4N33
U43*	PNP Silicon Switching Transistor	2N2907
U44*	8 Ampere Darlington Power Transistor	2N6045
U101	Hex Inverters	7404
U102-105	Seven Segment Indicator	hp5082-7751
U106-109	BCD-to-seven Segment LED Decoder/Driver with Latch	9374
U110-111	8-bit Parallel-Out Serial Shift Registers	74164
U201-204	Quad Latch	14042
U205-208	4-bit Presettable Up/Down Counter	4029
U209	Quad 2-Input NAND Schmitt Trigger	14093
U210	Dual D Flip-Flop	14013
U211	BCD-to-Decimal Decoder	5042-2
U212	Low Offset Monolithic JFET Input Operational Amplifier	LF355-H

* Components in DRC-7C/70C <u>only</u>

REF. DESG.	DESCRIPTION	LAKE SHORE PART NO.
R1	19.6 K ±1% ¼ W	RN60C
R2	8.25 K ±1% 1/8 W	RN55C
R3	33.2 K ±1% ¼ W	RN60C
R4-11	10 K ±5% ¼ W	
R12	5 K trimpot (current source adjust)	58PR5KSH HS
R12A	487 Ω 1% ¼ W	RN60C
R13	1.82 K 1% ¼ W	RN60D
R14	5 K 1% ¼ W	PME6019
R15	200 K 1% 1/8 W	RN55D
R16	107Ω 1% ¼ W	RN60C
R17	1180Ω 1% ¼ W	RN60C
R18	301 K 1% 1/8 W	RN55C
R19	499 K 1% ¼ W	RN60C
R19A	36.5 K 1% ¼ W	RN60C
R20	5 K trimpot (A/D Adjust)	58PR5KSH HS
R20A	146.9Ω 1% 1/8 W	RN55C
R21	121 K 1% 1/8 W	RN55C
R22	30.1 K 1% ¼ W	RN60C
R101	316Ω 1% 1/8 W	RN55C
R201	1.21 M 1% ¼ W	RN60C
R202	1.21 M 1% ¼ W	RN60C
R203	95.3 K 1% ¼ W	RN60C
R204	47.5 K 1% 1/8 W	RN55C
R205	5600Ω 1% ¼ W	RN60C
R206	Not present	RN60C
R207	1050Ω 1% ¼ W	RN60C
R208	10 K ±.5% ¼ W	
R209	10 K trimpot (scale adjust)	3005P-D72-353
R210	35 K trimpot (offset adjust)	3005P-D72-103
R25*	118Ω 1% ¼ W	RN60C
R26*	4.87 K 1% ¼ W	RN60B
R27*	22.1 K 1% ¼ W	
R28*	330Ω 1% ¼ W	RN60C
R29*	10 K Potentiometer (power adjust)	CM43055 19-4924
C1	470 MFD, 25 V, Electrolytic	
C2	470 MFD, 25 V, Electrolytic	
C3	.33 MFD, 100 V, Mylar	
C4	.33 MFD, 100 V, Mylar	
C5	.33 MFD, 100 V, Mylar	
C6	.33 MFD, 100 V, Mylar	
C7	2700 MFD, 25 VDC, Electrolytic	
C8	.33 MFD, 100 V, Mylar	
C9	.33 MFD, 100 V, Mylar	

* Components in DRC-7C/70C only

REF. DESG.	DESCRIPTION	LAKE SHORE PART NO.
C10	.1 MFD, 100 V, Mylar	
C11	.1 MFD, 100 V, Mylar	
C12	.1 MFD, 100 V, Mylar	
C13	.1 MFD, 100 V, Mylar	
C14	.1 MFD, 100 V, Mylar	
C15	.1 MFD, 100 V, Mylar	
C16	.1 MFD, 100 V, Mylar	
C17	.1 MFD, 100 V, Mylar	
C18	.1 MFD, 100 V, Mylar	
C19	.1 MFD, 100 V, Mylar	
C20	.1 MFD, 100 V, Mylar	
C21	.1 MFD, 100 V, Mylar	
C22	.1 MFD, 100 V, Mylar	
C23	.1 MFD, 100 V, Mylar	
C24	.1 MFD, 100 V, Mylar	
C25	.1 MFD, 100 V, Mylar	
C26	.1 MFD, 100 V, Mylar	
C27	.1 MFD, 100 V, Mylar	
C28	.1 MFD, 100 V, Mylar	
C28A	.1 MFD, 100 V, Mylar	
C29	330 MFD, 100 V, Polypropylene	
C30	.33 MFD, 200 V, Polypropylene	
C31	.68 MFD, 100 V, Mylar	
C32	.68 MFD, 100 V, Mylar	
C33	1.5 MFD, 10 V, Tantalum	
C34	.68 MFD, 100 V, Mylar	
C35	.33 MFD, 200 V, Polypropylene	
C36	.033 MFD, 50 V, Polypropylene	
C36A	320 MFD, 100 V, Polypropylene	
C37	180 MFD, 100 V, Polypropylene	
C40*	470 MFD, 25 V, Electrolytic	
C41	1300 MFD, 50 VDC, Electrolytic	
C101	Nominal Value, may not be present	
C102	Nominal Value, may not be present	
C103	Nominal Value, may not be present	
C104	3.3 MFD, 25 V, Tantalum	
C105	Nominal Value, may not be present	
C106	Nominal Value, may not be present	
C201	3.3 MFD, 25 V, Tantalum	
C202	100 PFD, 50 V, Mica	
C203	.22 MFD, 100 V, Polypropylene	
C204	.22 MFD, 100 V, Polypropylene	
C205	.01 MFD, 50 V, Mylar	
C206	1.5 MFD, 10 V, Tantalum	

* Components in DRC-7C/70C _only_

REF. DESG.	DESCRIPTION	LAKE SHORE PART NO.
CR1-4	Silicon Diode, 100 V, 1A	IN 4001
CR5-6	Silicon Diode, 100 V, 1A	IN 4001
CR7-8	Silicon Diode, 100 V, 3A	MR 501
CR9-12	Silicon Diode, 100 V, 1A	IN 4001
CR15-16	Silicon Diode	
CR20-23*	Silicon DIode, 100 V, 3A	MR 501
CR201	Precision Reference Diode, 6.9 V	LM 229A
FU1	Fuse Holder, 3/4A, 250 V, Fuse	Littlefuse
FU2*	Fuse Holder, 1A, 250 V, Fuse	Littlefuse
J1	40 pin, 3M connector (for BCD In/Out Option)	
J2	5 pin, Sensor Socket, Amphenol	
J3	3 pin, Monitor Socket	
J4*	Heater Binding Post	
J5*	Heater Binding Post (ground)	
S1	115/230 VAC Selector Switch	
S2	Hi/Lo Power Selector Switch	
S3*	Hi/Lo Power Selector Switch	

* Components in DRC-7C/70C <u>only</u>

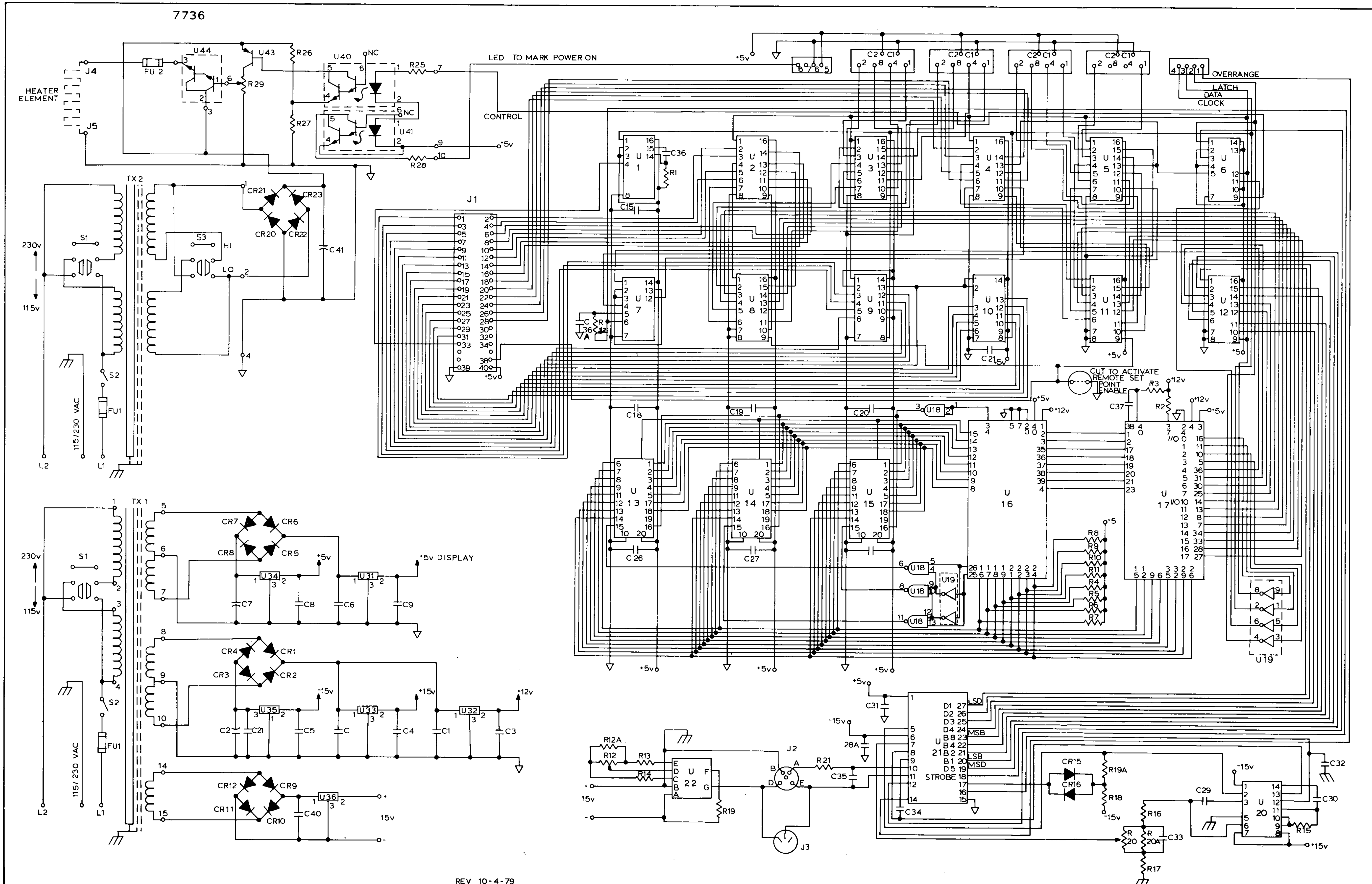


FIGURE 6.1 DRC-Circuit Schematic

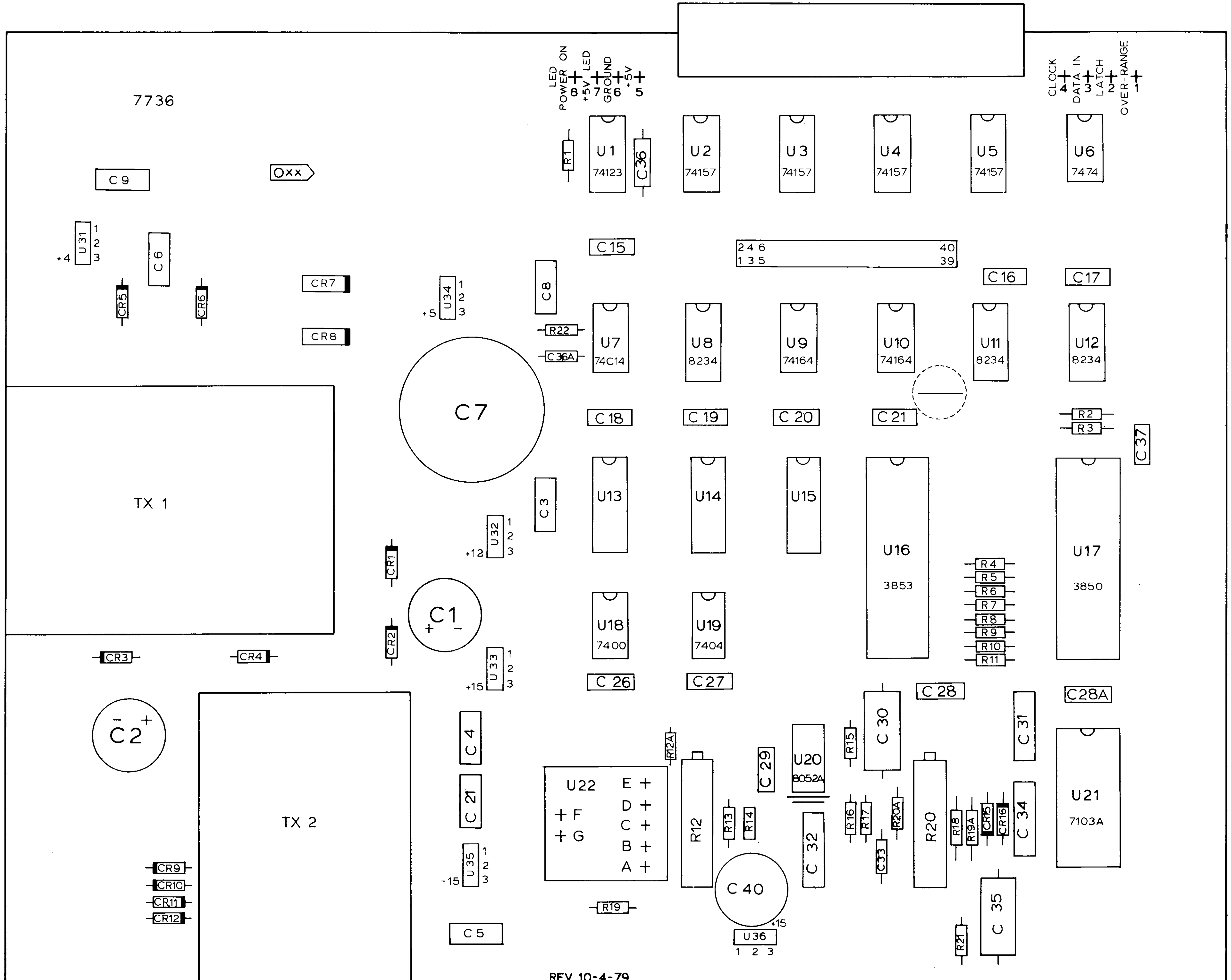


FIGURE 6.2 DRC–Component Layout

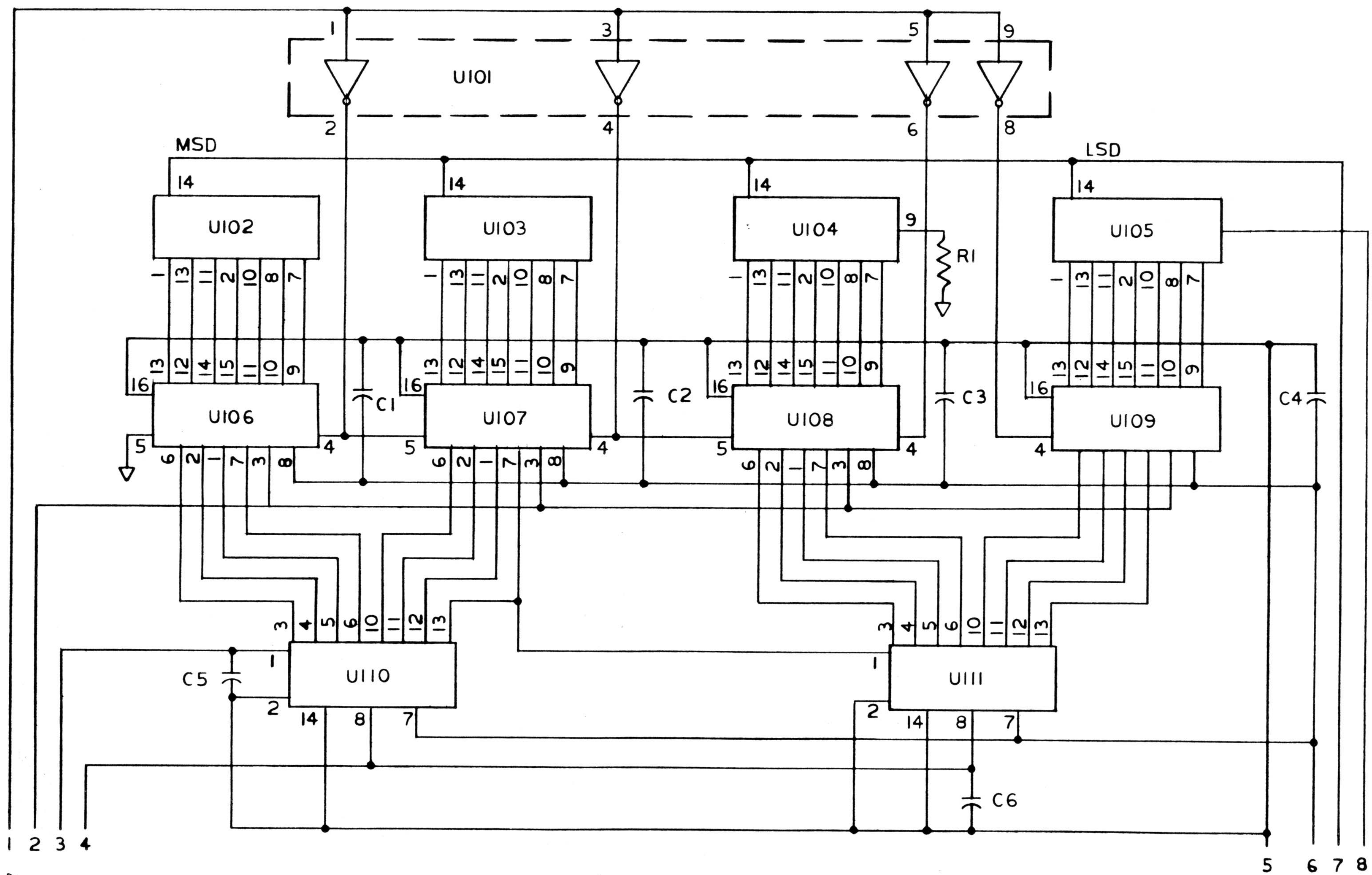


Figure 6.3 Display Board

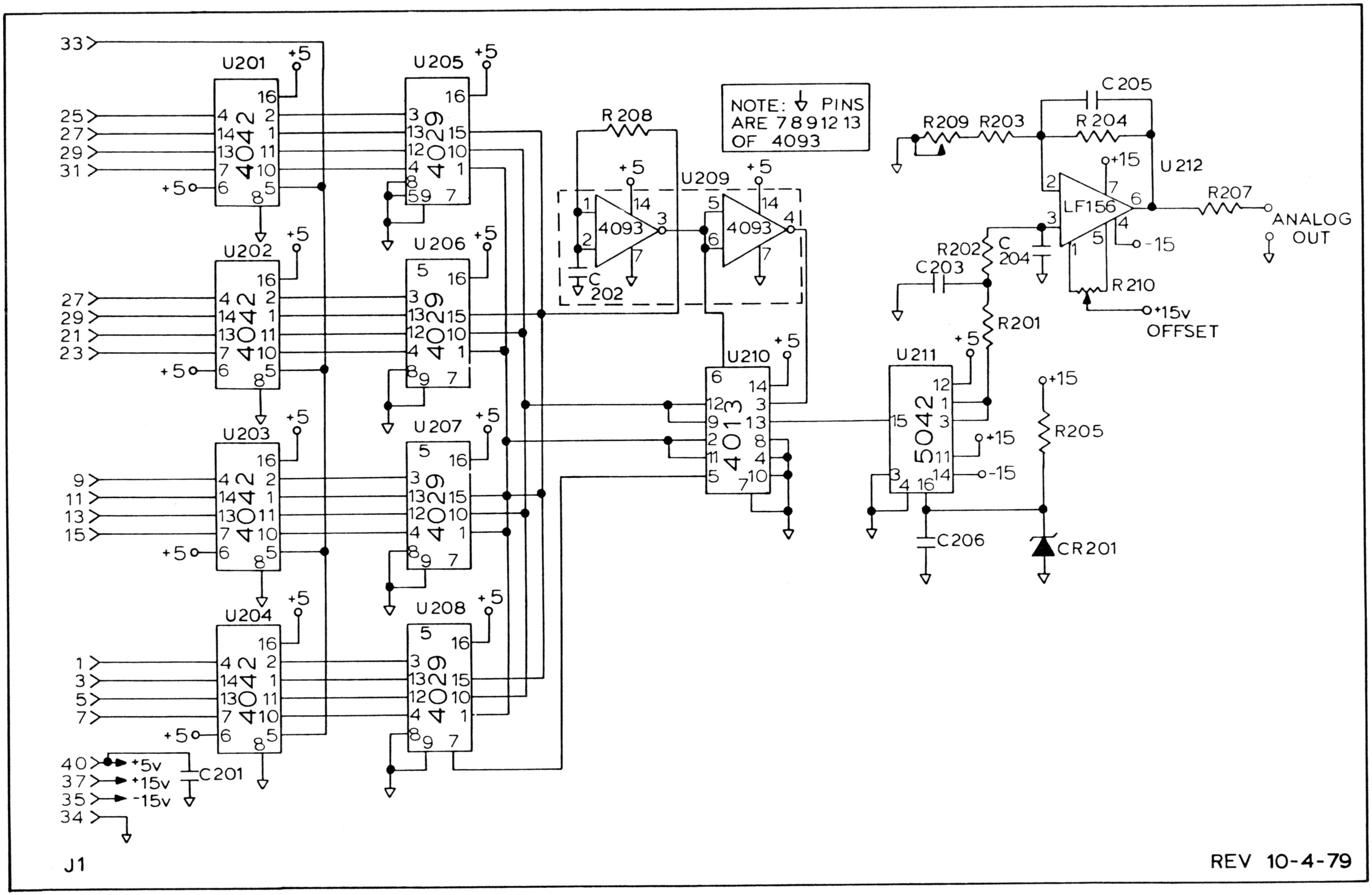


FIGURE 6.4 DRC-L/A Option Schematic

LAKE SHORE CRYOTRONICS, INC.
9631 SANDROCK RD EDEN, N. Y. 14057
716-992-3411
TELEX 91-396 CRYOTRON EDNE

INSTALLATION And APPLICATION NOTES For Cryogenic Sensors

CONTENTS:

While certain thermometers have specific characteristics which must be considered during installation, generally all thermometers have common installation constraints. Many of these general constraints and specific application and installation notes are listed below.

General:

1. Always heat-sink the temperature sensor and sensor leads when soldering or otherwise attaching the lead wires.

2. Thermal heat-sink of diode thermometry is not as critical as it is, for example, for resistance thermometers. For most resistance thermometers, construction of the sensor is such that the sensing element is both thermally and usually electrically isolated from its case (Figures 1 and 2). The result is that the main thermal input to the device is through the electrical leads. Therefore, the resistors have a tendency to read the lead temperature rather than the case temperature. To solve this problem, considerable care must be taken to properly heat-sink these leads.

   The opposite is true for diode sensors where the temperature sensing element is mounted directly on its header (case) with the cathode lead directly connected to the case (Figure 3). The positive anode lead is electrically isolated and makes electrical contact to the sensor through a short two mil gold wire. The sensor therefore measures the case temperature and thermal heat sinking of the electrical leads is of secondary importance.

   The direct thermal connection to its case for the diode thermometers results in a substantial decrease in the thermal time constant for its sensor. Due to the low heat capacity at or near 4 K, the sensor follows relatively fast temperature changes. Within this range, under appropriate conditions, it can control at better than 8 K/sec.

3. Although varnish or a heat-sink compound such as CryCon grease (see reference 5-6) may be used to heat-sink the device, somewhat more satisfactory results may be obtained if the sensor is mounted with low melting temperature solder. Woods Metal may be an appropriate choice for most applications. However, due to its super-conductive characteristics at low temperatures, it may be preferable to use a substitute. For example, 26% Sn/ 54% Bi/ 20% Cd by weight melts at 103° C. with a T_c = 3.69 K.

   Useful references which provide data on heat-sinking and heat-sinking materials are:

   1. Warren, W. H., Jr.; and Bader, W. G.: "Superconductivity Measurements in Solders Commonly Used in Low Temperature Research." Rev. of Sci. Instr. 40, p. 180 (1969).
   2. Anderson, A. C.; and Peterson, R. E.: "Selection of a Thermal Bonding Agent for Temperatures Below 1 K." Cryogenics 10, p. 430 (1970).
   3. Brown, M. A.: "A Reliable Low Thermal Resistance Bond Between Dielectrics and Metals for Use at Low Temperatures." Cryogenics 10, p. 439 (1970).
   4. Anderson, A. C.; and Rauch, R. B.: "Low-Temperature Thermal Conductivity of a Suspension of Copper Particles." Jour. App. Physics 41, p. 3648 (1970).
   5. Kreitman, M. M.: "Low Temperature Thermal Conductivity of Several Greases." Rev. of Sci. Instr. 40, p. 1562 (1969).
   6. Anderson, A. C.; Rauch, R. B.; and Kreitman, M. M.: "Another Comparison of Thermal Bonding Agents." Rev. of Sci. Instr. 41, p. 469 (1970).

7. Hust, J. G.: "Thermal Anchoring of Wires in Cryogenic Appartus." Rev. of Sci. Instr. 41, p. 622 (1970).

8. Kopp, J.; and Slack, G. A.: "Thermal Contact Problems in Low Temperature Thermocouple Thermometry." Cryogenics 11, 22 (1971).

4. Platinum sensor leads can be easily soldered to if a flux is used. Care should be taken to remove all flux after making the joint. One suitable flux is: Stay Clean Solder and Tinning Flux from the J. W. Harris Co., 433 W. 9th, Cincinnati 3, Ohio.

5. Because of the many varied installations for cryogenic temperature sensors, many are supplied without strain relief at the stem-lead interface. A strain relief, however, is recommended particularly when the sensor is not permanently installed.

   A satisfactory material is RTV silicone. This material is waterproof, dries quickly and is soft at room temperature. A small amount carefully placed at the base of the sensor leads will protect them from sharp bends and possible fracture.

6. Special care must be given in mounting sensors or thermocouples with gold leads. Gold wire will dissolve in the solder if ordinary soldering techniques are used. Extreme care must be used in soldering this lead to another lead. It is suggested that the other lead be pretinned. Then the gold lead should be wrapped around the pretinned lead and heat applied above the tinned region. As soon as the solder starts to melt, the soldering iron should be removed from the pretinned lead. A low power microscope may be of use here.

   A second equally satisfactory approach is to use pure Indium as the solder.

   In either instance great care must be taken to insure the sensor is properly heat-sinked as described above.

7. In addition to properly heat-sinking the temperature sensor and sensor leads at the site to be measured, it is most important that the lead wires be carefully lagged to the equipment surface (sometimes called thermally tempered) at regular intervals as they are brought out to room temperature. In this manner. thermal loads to both the equipment and the temperature sensor are minimized.

8. Specific care should be taken in mounting epoxy encased sensors to assure no interaction with solvents, overheating, etc. Ge-7031 varnish with its xylene solvent is particularly dangerous.

9. Always make ample allowance for thermal contractions when sizing hookup wire lead length and thus prevent possible lead fractures.

10. Because most cryogenic sensors are small and their lead wires are of negligible diameter, it is sometimes difficult to find an optimum tie-down material that will maintain strength at cryogenic temperatures and not lose its adherence. One good choice is wax impregnated dacron thread commonly known as "dental floss".

Diode Temperature Sensors:

1. Forward voltage measurements should be made at a constant current of 10 or 100 microamperes. The silicon diode can withstand 200 Volts in the reverse direction and up to five milliamperes in the forward direction. In the case of the gallium arsenide diode do not apply a current of greater than one milliampere in the forward direction or a voltage of greater than five volts in the reverse direction. Either condition can result in permanent damage to the temperature sensor.

   This dangerous condition can be generated specifically with the use of a multimeter type ohmmeter. The solution is straightforward however: For the Simpson 260 types, use the Rx100 ohm scale with a 2 K resistor in series with one lead; for Triplett 630 types, do the same with either the Rx100 or Rx1000 ohm scales. This will limit the back voltage to 1.5 volts and the forward current to less than 1 mA. - yet the forward-reverse difference can easily be seen.

2. If power input to your cryogenic system is critical, the 10 uA current should be used. The power dissipated at helium temperatures by the sensor is approximately 15 micro watts for gallium arsenide and 21 micro watts for silicon for this current. If power input is not critical, then the 100 uA current may be preferred.

3. The static impedance of the silicon diode is 210 K ohms at helium temperatures with 10 microamperes excitation current and 21 K ohms with 100 microampere excitation current. The static impedance of the gallium arsenide sensor at helium temperatures is approximately 150 K ohms at 10 microamperes and 15 K ohms at 100 microamperes, i.e., $R = V/I$.

To accurately measure the forward voltage to 100 microvolts or better, consideration must be given to the input impedance of the voltage measurement system being used. For example, a digital voltmeter with a ten megohm input impedance will have an effect on the 10 millivolt position for a current of 10 microamperes. For the 100 microampere current source, the loading effect will be seen in the one millivolt position. Therefore, for a calibrated device, readings must be taken with a very high input impedance voltage measurement system. If, however, a sensor is calibrated with a voltmeter of less than infinite impedance, as long as the same system is used, (i.e., the loading is not changed), accurate temperature measurement should be possible.

Insufficient evaluation of and attention to this feature can result in serious temperature measurement errors. For this reason, 10 megohm input impedance DPM's or DVM's at 10 uA diode excitation are not recommended. Fortunately, there is no dearth of DVM's or DPM's with the desired characteristics, i.e., 1 Volt range with 100 or 200% overrange and input in the 10^9 to 10^{10} range. Differential voltmeters are also a proper choice.

4. The dynamic impedance of the sensor is approximately 1000 ohms at 10 uA and 100 ohms at 100 uA. This is extremely fortunate since it reduces the requirements on the constant current source by nearly two orders of magnitude over that of the voltage measurement system. For example, a current source regulated to 0.1% will cause a change in the 100 microvolt position.

   The required temperature accuracy vs. the instrumentation current regulation and voltmeter resolution is:

Required Temperature Accuracy	Current Source Resolution	Voltmeter Resolution
1.0 K	5%	1 mV
.1 K	.5%	100 uV
.01 K	.05%	10 uV

5. Epoxy encased sensors should not be used in vacuum as self-heating (as a result of the epoxy acting as an insulator) can cause large temperature errors below 10 K.

6. Heat dissipation in diode thermometers can be calculated two ways, both yielding the same result. In the first case, the power dissipated is the product of the DC voltage across the diode and the DC current through the diode. In the second case, an equivalent circuit can be considered where the power is the sum of the DC current times the equivalent voltage plus the square of the DC current times the DC dynamic resistance.

7. Diode thermometer construction techniques allow a wide and diverse variety of envelope configurations. Because of this characteristic, it is important that the user assure himself that the material in the package does not affect his experiment. For example, several configurations utilize gold plated "Kovar" or "Rodar" material (nominal 50-50 Ni-Fe). This material will not effect the sensing element in a magnetic field, but its presence will certainly affect the homogenity of the field adjacent to the sensor.

8. "TO-5" headers have been designed to withstand no more than 16 inch ounces of torque.

Capacitance Temperature Sensors:

1. Capacitance sensors (Figure 4) may be connected to terminal points outside the cryostat with two unshielded insulated fine wires alongside the other wires leading to the sample area. No appreciable change in the measured capacitance arising from the leads should result, provided changes in lead capacitance due to mechanical movement are avoided. When the mechanical stability is not assured, each sensor lead should be connected to a thin coaxial cable brought out to the external terminal points, with the shield of each cable electrically **insulated from the cryostat. Two coaxial cables, one for each lead, with the shields insulated, but grounded at one end, should be used to complete the wiring.**

2. The total length of coaxial cable (internal plus external) is not critical, i.e., 100 feet is not unreasonable.

   An increasingly popular lead material is a family of ultraminiature coaxial cables. This coax has a diameter of less than .020. To prepare the ultraminiature coax for termination, the inexpensive Miller wire stripper (available at any radio supply store) is ideally suited. Care should be taken to set the opening on the wire stripper to remove just the outer two wraps of aluminized Mylar and Vylex thus exposing the drain wire and the insulated center conductor. A similar Miller wire stripper set for the appropriate opening will strip the dielectric cleanly from the center conductor.

3. These sensors may be depended upon for 1 or 2 mK stability during many hours or even days of consecutive operation, as long as a settling period of up to an hour is allowed after the device is thermally cycled (defined as a cooldown from liquid N_2 temperature or higher to some lower temperature such as 4.2 K). In its present state of development, the sensor should not be expected to reproduce to better than 0.2-0.4 K from one thermal cycle to the next. Depending on the extent and rate of cooldown, a shift in dC/dT of as much as 2% may also be observed. However, it should be recognized that none of the above constraints limits the primary function of the thermometer, viz, as a control device to hold temperature at some preset level while a magnetic field is being applied.

4. Large and erratic error signals will result from the presence of water vapor and/or ice contacting the sensor leads and lead-in cabling particularly when the sensor is used at temperatures over 200 K or when bare (unshielded) lead wires are used. Presence of the water greatly increases the loss tangent of the measuring system and hence, the capacitance readings are erroneous.

5. It should be noted that the excitation of capacitance sensors utilized in cryostats below 0.1 K will cause most resistance thermometers to self-heat and become effectively useless unless the capacitance sensor leads are fully shielded.

6. Due to a very small amount of ferro-electric phase (or interfacially-polarized phase), a large surge voltage, for example, from the measuring field will induce time-dependent dielectric phenomena which will appear as a drifting or instability in the capacitive signal of the sensor. Such effects have been observed immediately following the brief application of a five fold increase in AC sensor voltage. An example is a capacitance bridge unbalance produced by the accidental switching of the bridge range switch.

7. Excitation frequency and amplitude must not change during temperature readout or control. For example, with the recommended 50 mV rms. amplitude excitation signal held to 0.1%, and with the frequency variation less than 0.1%, temperature readout and control errors (due to these variables) can be held to 1 mK.

Resistance Thermometers:

1. These thermometers are normally used as secondary standards and should be treated in the same manner as any precision instrument. It is recommended that they not be subjected to any unnecessary shock or rough mechanical treatment.

2. Copper wires, as well as other types of wire, positioned in a thermal gradient will develop small EMF's due to inhomogenieties along the wire. These defects may be slight differences in crystal structure, may be due to work-hardening, mechanical strains, etc., which behave as small parasitic thermocouples. These EMF's change with the thermal gradient and can be a source of serious error in those temperature measurements, where sub-microvolt levels are involved. To overcome this error, it is good practice to inspect each wire by connecting each end to a suitable measuring instrument and then pull it through a liquid nitrogen bath observing the EMF readings. Any voltages greater than .1 microvolt are sufficient to cause an error in the measurement of temperature unless such effects are averaged by taking resistance readings on the thermometer with reverse polarity of the excitation current. Of course, another possibility is the use of AC measuring techniques.

3. **Lake Shore Cryotronics, Inc. resistance thermometers all use .008" dia. phosphor-bronze leads insulated with polyimide. This change from the traditional stranded teflon insulated leads facilitates thermal anchoring of the leads by eliminating the poor thermal conductivity of teflon. Lead identification is achieved by noting the location of the individual leads, relative to a reference mark on the end of the sensor as shown in Figure 2.**

4. **In reading out thermometers, it is important to use the proper measuring current. An excessively high current will cause joule (I^2R) heating, thus giving erroneous readings. The recommended measuring currents to avoid joule heating (and used by LSCI in calibrating) are as follows:**

1 to 12 ohms	- 1 mA
10 to 120 ohms	- 100 uA
100 to 1200 ohms	- 10 uA
1000 to 12,000 ohms	- 1 uA
10,000 ohms up	- 0.1 uA

Hall Generator:

1. The Hall generator is fragile. It cannot be handled the same way most other electronic components are handled. The aluminum oxide substrate is brittle and very sensitive to bending stress. Use the leads to move and locate it. Do not handle the substrate. The lead to substrate bond strength is on the order of several ounces. Avoid tension on the leads and avoid bending them close to the substrate. The leads may be bent at any angle as long as the bend is at least 1/8" away from the substrate connection.

2. The preferred mounting procedure is to locate the chip in a slot that is any depth, .003 inch wider and .010 inch longer than the substrate. Tack the leads outside the slot with Sylgard 186* or a similar substance. Don't get Sylgard

186* inside the slot. If an extreme temperature range is expected, check the coefficients of thermal expansion to be certain that the slot will always have clearance for the chip. This procedure is not recommended for installations that will be subject to any acceleration greater than 10 G.

3. Surface mounting is acceptable when necessary. The mounting surface may be any non-flexible solid with a flat, smooth (±.001") surface at least the size of the substrate. The substrate must not overhang the mounting surface. Steel, ferrite, ceramic, and glass are examples of mounting surfaces. For extended temperature ranges, choose a material with a coefficient of thermal expansion no greater than a factor of three different from that of the aluminum oxide substrate ($\cong 7\times10^{-6}$IN/IN/^{o}C). For a permanent mount, sparingly coat the mounting surface with Eastman 910 contact cement or other similar cement. The ceramic side of the substrate is visible as non-red or as opposite the Hall element. Locate the ceramic side on the clean, degreased surface and apply extremely light pressure with a foam pad until the bond is made. Wipe off the excess contact cement. Use an epoxy such as Bacon Industries FA8 or Emerson and Cuming 2850FT to form a fillet around the plate and to secure the leads. Don't get epoxy on top of the chip. If encapsulation is absolutely necessary use a light coating of Sylgard 186* or a similar soft material.

   For a non-permanent surface mount, secure the substrate against the surface with a foam padded mounting jig. The jig should apply only light pressure. Fillet the plate and secure the leads with Sylgard 186* or a similar material.

4. After the Hall generator has been mounted, check the misalignment voltage per the proper specification. A large misalignment voltage shift (100 uV or more) is a sign of Hall generator physical damage.

Vacuum Regulator Valve:

1. The 329 Valve was offered initially as a vacuum control for vacuum pumped cryostats. In this application, it is necessary to ensure that the temperature of the gas entering the valve is not lower than 175 K (-100 C). Generally, this means that the piping between the cryostat and the valve will be 2-3 feet or more.

2. For the most sensitive and stable operation, the remote sensing port should be used. This allows the valve to "see" the controlled vacuum through a static line as opposed to a line with flow.

3. If tight shut-off is necessary in the system, a separate shut-off valve should be used in series with the valve, and should be placed between the vacuum chamber and the valve.

4. A small inboard bleed from atmosphere is necessary for the proper operation of the valve. This bleed is through the small recessed screen in the end of the valve near the control handle. The most probable cause of problems with the 329 Valve is restricted flow through the screen. This part of the valve should be inspected periodically to ensure that plugging has not occurred. When flush panel mounted the shallow channel from the circumference of the valve to the bleed port ensures that sufficient air is available and no special provisions need be made in the panel.

   During normal operation, the bleed flow is approximately 1.5 SCFH through the valve and out through the vacuum pump port. There is little chance of air from the bleed entering the controlled vacuum even if the vacuum system fails as this condition will cause the bleed to be shut off completely.

Controller Heater Installation:

1. Most cryogenic temperature controllers utilize the thermal relaxation method for control. That is, heat is continually added to provide the proper balance between the payload (whose temperature is to be controlled) and the surrounding environment. Therefore, the optimum balance is best achieved with both the source of refrigeration and heat emanating from the same direction with as large an area and as even a source of each as possible.

2. The cryogenic temperature controller system including control sensor, heater, controller, lead-in wiring, etc. can all perform perfectly and the system be an abject failure, if the total system integration is not adequate. Some considerations include:

   a. The heater area should be as large as possible. For this reason, wire heaters of several feet wound on the payload are preferred to point source heaters such as carbon resistors, etc.

   b. To prevent "hunting" within a closed loop thermal control system, thermal contact between heater and load should be as close as possible. This can be accomplished by utilizing insulation materials such as formvar or bicalex. Both offer a good thermal short, with an electrical open circuit, to the load. The heater may then be appropriately cemented by Glyptal or G.E. 7031 varnish to mechanically hold and thermally anchor the heat input system to the load.

*Product of the Dow Corning Corporation

c. The controller heater output circuit sees the total heater load; e.g. heater plus lead wires. Therefore, the heater proper should be designed for as close to 100% of the heater lead-in wire-heater resistance total as possible to avoid heat leaks to the system (I^2R) from the lead-in wires and to assure proper thermal control at the heater.

d. The heater-heater lead wire combined resistance should be accurately matched to the controller. For example: a 20 ohm heater matched to a 10 ohm controller output will halve the useful heat available.

e. Control sensor preferred mounting is as near to the test specimen as practical and always between the heater and the test specimen.

f. Caution must be exercised in choosing heater wire diameter due to the possibility of exceeding the wire fusing current. This condition may be avoided by choosing a wire diameter which has a fusing current greater than the maximum deliverable current of the temperature controller.

Magnetic Field-Dependent Temperature Errors for Low Temperature Thermometers

Magnitude of relative temperature error $|\Delta T|/T$ (%) for B<

Type of Sensor	T(K)	2.5 T	8 T	14 T	Comments
Carbon-Glass Resistors	2.1	0.5	1.5	4	Behavior similar to Allen-Bradley resistors. Negative $\Delta R/R_0$ above ~60 K. Useful thermometers to 300 K. Very good reproducibility.
	4.2	0.5	3	6	
	15	<0.1	0.5	1.5	
	35	<0.1	0.5	1	
	77	<0.1	0.5	1.5	
Germanium Resistors	2.0	8	60	- -	Not recommended except at very low fields because of large and strongly orientation dependent $|\Delta T|$'s.
	4.2	5-20	30-55	60-70	
	10	4-15	25-60	60-75	
	20	3-20	15-35	50-80	
	70	3-10	15-30	25-50	
GaAs Diodes	4.2	2-3	30-50	100-250	Orientation dependent. Smaller values of $|\Delta T|/T$ apply to diode junction parallel to B. Single sensor useful from 4.2-300 K.
	10	1.5-2	25-40	75-200	
	20	0.5-1	20-30	60-150	
	40	0.2-0.3	4-6	15-30	
	80	0.1-0.2	0.5-1	2-5	
Si Diodes	4.2	75	- -	- -	More sensitive than GaAs, particularly <30 K. Strongly orientation dependent; values are given for junction parallel to B.
	10	20	30	50	
	20	4	7	10	
	30	3	4	5	
	77	0.2	0.5	0.5	
Platinum Resistors	20	20	100	250	Some orientation dependence. Useful at all B only for T ≳30 K.
	40	<1	5	10	
	80	<0.5	1	2	
Thermocouples Au + 0.07 at % Fe/ Chromel P	5	2	10	15	Table entries are errors in hot junction temperature when cold junction at 4.2 K and entire thermocouple in field B. Irreproducibilities possibly induced by handling.
	10	3	20	30	
	20	2	15	20	
	45	1	5	7	
	100	0.1	0.8	- -	
$SrTiO_3$ Capacitor	1.5	<0.05	<0.05	≤0.05	Probably "zero" magnetic field effect if proper procedures followed (see text). Useful as "transfer standard" to high fields.
	4.2	<0.05	<0.05	≤0.05	
	20	<0.05	<0.05	≤0.05	
	50	<0.05	<0.05	≤0.05	

Note: This data from "Instrumentation and Methods for Low Temperature Measurement in High Magnetic Fields". H. H. Sample and L. G. Rubin, ISA/76 Conference.

Germanium Resistor Construction

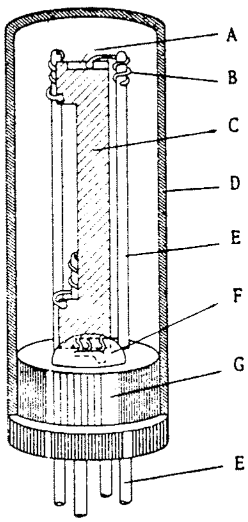


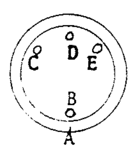
Figure 1

Approximate Mass		
Cu	.2	gm
BeO	.04	gm
Ge	.01	gm
Au	.01	gm
Ph-Bz	.05	gm

Approximate Mass		
Cu	.2	gm
BeO	.04	gm
C.G.	.01	gm
Au	.01	gm
Ph-Bz	.05	gm

A - Current injection zone
B - Gold leads (0.002" dia.)
C - Sensing element
D - Gold-plated copper enclosure
E - Phosphorus-bronze leads (0.008" dia.)
F - Epoxy heat-sink
G - Beryllium oxide base

Sensor Base



Lead Identity for Germanium & Carbon Glass

Key	Germanium	Carbon Glass
A	Index Mark	Index Mark
B	+I	+V
C	-V	-V
D	+V	+I
E	-I	-I

Carbon Glass Resistor Construction

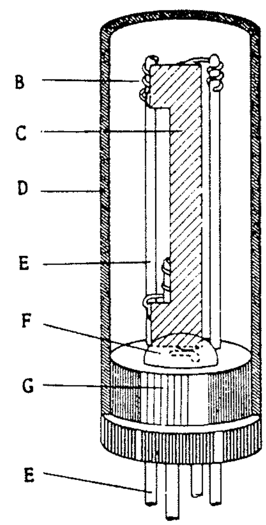
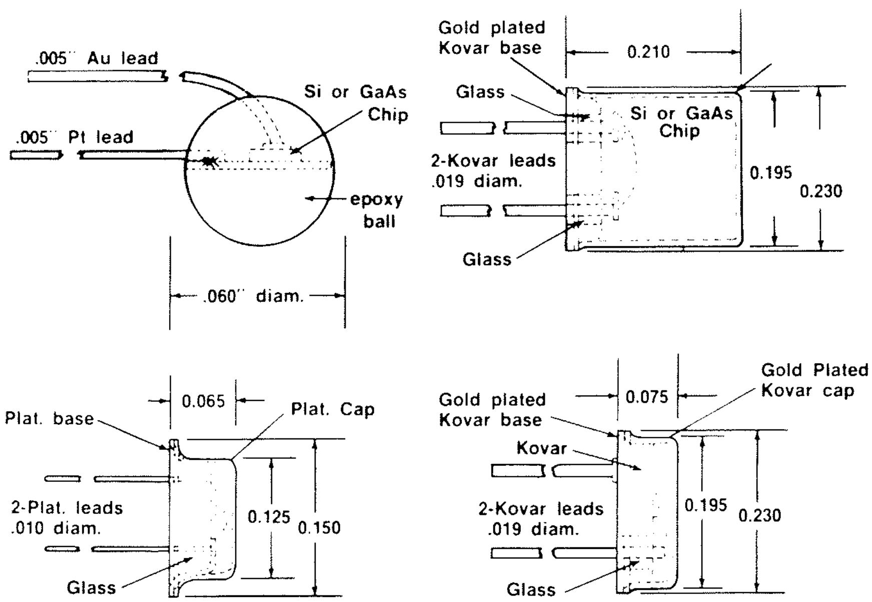
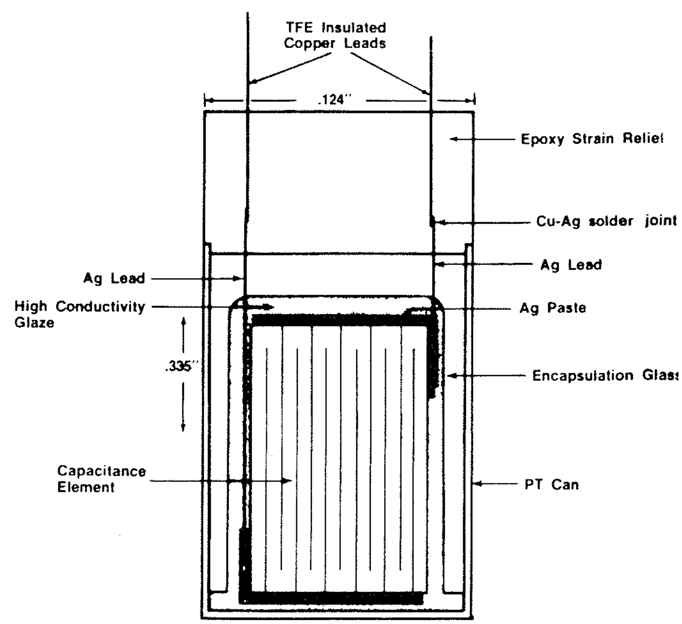


Figure 2



TYPICAL DIODE THERMOMETERS

Figure 3



Capacitance Temperature Sensor

Figure 4

Description of Operation for Model 329
Vacuum Regulator Valve: (See Fig. 6)

The Model 329 Vacuum Regulator Valve consists of a balanced poppet main valve which is sealed at one end by a sensitive lip and the other end by a rolling diaphragm. This poppet is driven by a diaphragm. The reference side of the diaphragm is gas loaded by means of two orifices in series with an absolute pressure aneroid which controls a frictionless lever and inboard bleed valving system.

Vacuum is applied to the vacuum pump port. Since the main valve is balanced, it doesn't want to move in either direction. If the poppet is open, the regulated side of the regulator will start to lower in pressure. This decrease in pressure will be sensed through the poppet, will lower the pressure under the diaphragm, and pull the valve closed. This same vacuum is applied to the dome volume through an orifice. This will lower the reference pressure (dome pressure) and cause the main valve to open. When the dome pressure gets to the set point, the aneroid expands allowing ambient air into the dome through the second orifice and maintains dome pressure at set point.

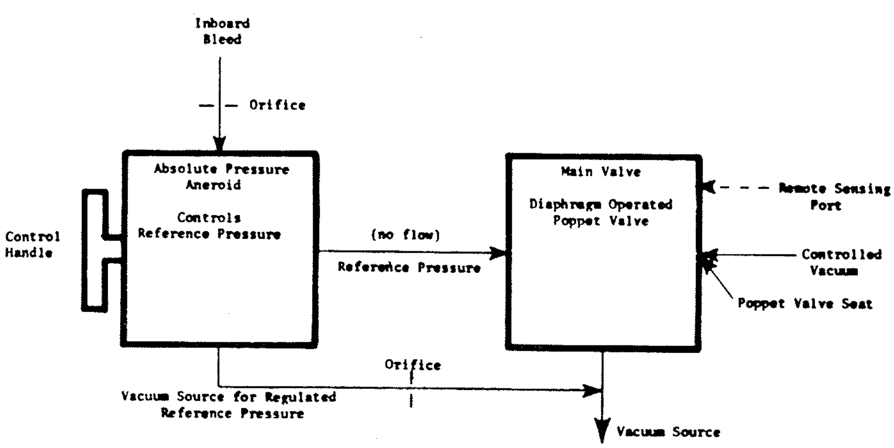


Figure 6

LHL-LHe Level Indicator Probe Installation:

1. Sensor must be mounted with leads at top.
2. Do not mount sensor in restricted areas (tubes, etc.), or cover holes.
3. Do not bend leads when cold. They are color coded: Red I+, Black I-, Blue V+, Yellow V-.
4. Do not operate in vacuum. OK at $1^{o}K$ with liquid helium present.
5. Ice formations will cause erratic operation (frozen water or gas).
6. All sensors have a ½ inch non-active portion at top and bottom.

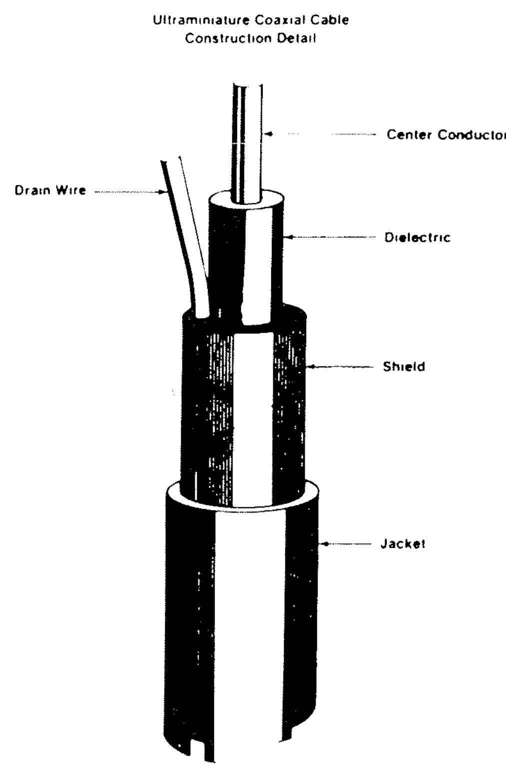
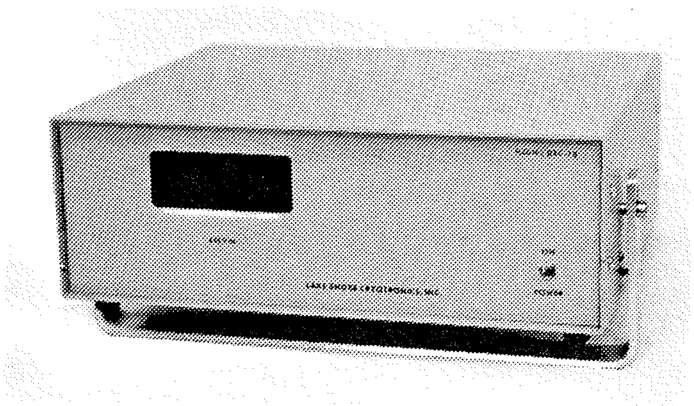


Figure 5

LAKE SHORE CRYOTRONICS, INC.
P.O. BOX 29876 • COLUMBUS, OHIO 43229 U.S.A. • (614) 846-1250
TELEX 24-5415 CRYOTRON COL

SERIES DRC
DIGITAL THERMOMETERS
Technical Specification: DRC-70

MODEL DRC-70 DIGITAL CRYOGENIC THERMOMETER



- **0.1 K Resolution**
- **1 to 400 K Range**
- **Silicon Diode Sensor (Model DT-500-DRC)**
- **Analog Output of Sensor Voltage**
- **Optional Analog Output Proportional to Temperature**
- **Optional BCD Output of Temperature**
- **Optional Multiple Sensor Input**
- **115/230 VAC**

The Model DRC-70 Digital Cryogenic Thermometer is designed to cover the range from 1 to 400 K utilizing the Lake Shore Cryotronics Model DT-500-DRC Silicon Diode Sensor.

The DRC-70 Microprocessor Controlled Circuit, combined wth the interchangeable Model DT-500-DRC sensor, allows the DRC-70 to achieve 0.5 K conformity to the standard DRC-70 Silicon Diode Table from 4 to 400 K.

An analog output equal to sensor voltage is standard, with analog output proportional to temperature or a BCD output of temperature available as options.

The thermometer is designed to connect to the sensor in a 2 or 4 wire constant current configuration.

Multiple sensor input selector switches are available to select readout of up to 10 separated sensors.

TECHNICAL SPECIFICATIONS

TEMPERATURE RANGE:	1 to 400 K	INPUT RESISTANCE:	Greater than 100 megohms
RESOLUTION: DIGITAL	0.1 kelvin	OPERATING ENVIRONMENT:	10-45°C
ANALOG	Dependent on auxiliary voltmeter	OUTPUTS: ANALOG (Standard)	Output of Sensor Voltage
SENSOR:	Silicon (Model DT-500-DRC)	ANALOG (Optional)	10 mV/K at <10 ohm output impedance
SENSOR EXCITATION:	10 microamperes constant current	DIGITAL (Optional)	TTL compatible parallel BCD
		DISPLAY:	4 digits, 1.1 cm (0.43″) high, 7 segment non-blinking
CURRENT REGULATION:	± 0.05%	RESPONSE TIME:	2.2 seconds to rated accuracy
CONFORMITY TO LSCI STANDARD DRC-70 SILICON DIODE TABLE:	0.5 K (4-400 K)	CONSTRUCTION:	Integrated circuits, microprocessor controlled
SENSOR INPUT CONNECTION:	2 or 4 wire constant current	POWER REQUIREMENTS:	115/230 VAC (switch selectable), ±10%, 50/60 Hz, (.4 AMP at 115 volts)
TEMPERATURE COEFFICIENT ERROR:	0.01 K/°C	WEIGHT:	5.9 Kg (13 pounds)
REPEATABILITY:	0.1 K	DIMENSIONS:	10.7 cm (4.2″) high x 31.0 cm (12.2″) wide x 25.4 cm (10.0″) deep

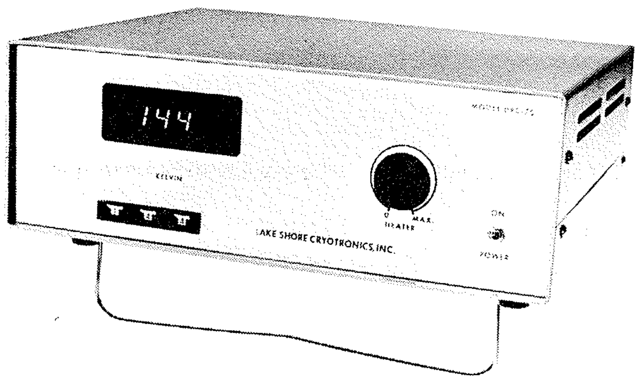
PRINTED IN U.S.A.

FEBRUARY, 1978

LAKE SHORE CRYOTRONICS, INC.
64 E. WALNUT ST. ● WESTERVILLE, OHIO 43081 ● (614) 891-2243
TELEX 24-5415 CRYOTRON WTVL

SERIES DRC
DIGITAL THERMOMETERS
Technical Specification: DRC-7C

MODEL DRC-7C DIGITAL CRYOGENIC THERMOMETER/CONTROLLER



- **1 to 400 K Range DT-500-DRC or DT-500CU-DRC-36 Sensors**
- **1 K Resolution**
- **0 to 40 Watt Heater Output**
- **Analog Output of Sensor Voltage**
- **Optional Analog Output Linear with Temperature**
- **Optional BCD Output of Temperature (includes BCD external set point capability)**
- **115/230 VAC**

As with other members of the DRC instrument family, the DRC-7C utilizes microprocessor controlled digital circuitry to achieve stable operation and long term reliability over the range from 1 to 400K. In a properly designed system the DRC-7C is capable of controlling to better than 1K.

An analog output of the silicon diode sensor voltage is standard. A linearized analog output is available as an option.

A BCD output (TTL compatible) equivalent to the display temperature is also available as an option. Included with the BCD output option is the capability to remote program the temperature set point via a BCD signal from such sources as a computer or digital function generator.

The control circuit of the DRC-7C compares the BCD equivalent of the displayed temperature to the BCD equivalent of the set point and thus generates a BCD error signal. The error signal is then processed by a time proportioned gain and reset circuit which in turn drives a DC pulse train output circuit. The amplitude of the output is continuously variable via a front panel mounted control allowing one to optimize the control for any given system and temperature region.

TECHNICAL SPECIFICATIONS

General

TEMPERATURE RANGE:	1 to 400 K
SENSOR:	Silicon Diode (Models DT-500-DRC or DT-500CU-DRC-36—ordered separately)
SENSOR INPUT:	2 or 4 terminal connection with constant current exitation
SENSOR EXCITATION:	10 microamperes
CURRENT REGULATION:	± 0.05%
CONSTRUCTION:	Integrated circuits, microprocessor controlled
VOLTAGE INPUT:	115/230 VAC (Switch Selectable) ± 10%, 50/60Hz, .4 Amp (at 115 Volts)
OPERATING ENVIRONMENT:	10-45°C
WEIGHT:	5.9 Kg (13 pounds)
DIMENSIONS:	10.7CM (4.2″) high x 31.0CM (12.2″) wide x 25.4CM (10.0″) deep

TEMPERATURE CONTROL

SET POINT:	Digital thumbwheel selection directly in kelvin temperature units
SET POINT RESOLUTION:	1K
OPTIONAL REMOTE SETPOINT:	TTL compatible, parallel BCD (Standard with BCD Output)
CONTROLLABILITY:	0.3 K with a properly designed system
HEATER OUTPUT:	Standard 0-40 watts, 0-1A, 0-40VDC
CONTROL MODE:	Time proportional gain and reset

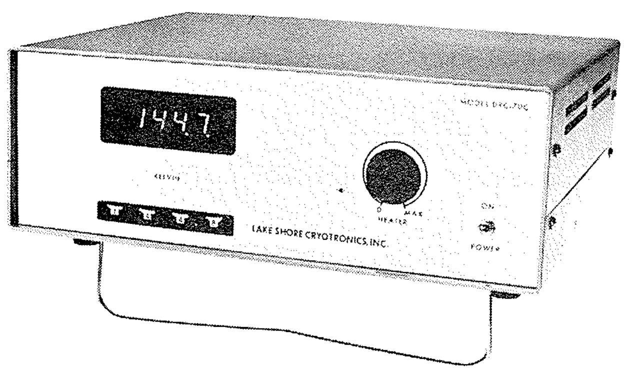
TEMPERATURE READOUT

RESOLUTION:	
DIGITAL	1 K
ANALOG	Dependent on auxiliary voltmeter
CONFORMITY TO LSCI STANDARD DRC-70 SILICON DIODE TABLE:	0.5 K from 4 to 400 K (error below 4 K may be larger)
MAXIMUM SENSOR POWER DISSIPATION:	25 uW at 4.2 K
TEMPERATURE COEFFICIENT ERROR:	0.01 K/°C
INPUT RESISTANCE:	Greater than 100 megohms
OUTPUTS: ANALOG (Standard)	Output of sensor voltage
ANALOG (Optional)	10 mV/K at < 10 ohms output impedance
DIGITAL (Optional)	TTL compatible parallel BCD
DISPLAY:	4 digits, 1.1CM (0.43") high, 7 segment non-blinking
RESPONSE TIME:	2.2 seconds to rated accuracy

Lake Shore Cryotronics, Inc.
64 E. Walnut St., Westerville, Ohio 43081
(614) 891-2243 • Telex: 24-5415 • Cryotron WTVL

SERIES DRC
DIGITAL THERMOMETERS
Technical Specification: DRC-70C

MODEL DRC-70C DIGITAL CRYOGENIC THERMOMETER/CONTROLLER



- **1 to 400 K Range with DT-500-DRC or DT-500CU-DRC-36 Sensors**
- **0.1 K Resolution**
- **0 to 40 Watt Heater Output**
- **Analog Output of Sensor Voltage**
- **Optional Analog Output Linear with Temperature**
- **Optional BCD Output of Temperature (includes external BCD set point capability)**
- **115/230 VAC**

The Model DRC-70C goes a step beyond the Model DRC-7C and provides 0.1 K readout and set point resolution with controllability of 0.1 K in a properly designed system.

As with other members of the DRC instrument family, the DRC-70C utilizes microprocessor controlled digital circuitry to achieve stable operation and long term reliability over the range from 1 to 400 K. An analog output of the silicon diode sensor voltage is standard. A linearized analog output is available as an option.

A BCD (TTL compatible) output equivalent to the display temperature is also available as an option.

Included with the BCD output option is the capability to remote program the temperature set point via a BCD signal from sources such as a computer or digital function generator.

The control circuit of the DRC-70C compares the BCD equivalent of the displayed temperature to the BCD equivalent of the set point and thus generates a BCD error signal. The error signal is then processed by a time proportioned gain and reset circuit which in turn drives a DC pulse train output circuit. The amplitude of the output is continuously variable via a front panel mounted control allowing one to optimize control for any given system and temperature region.

TECHNICAL SPECIFICATIONS

General

TEMPERATURE RANGE:	1 to 400 K
SENSOR:	Silicon Diode (Models DT-500-DRC or DT-500CU-DRC-36—ordered separately)
SENSOR INPUT:	2 or 4 terminal connection with constant current exitation
SENSOR EXCITATION:	10 microamperes
CURRENT REGULATION:	± 0.05%
CONSTRUCTION:	Integrated circuits, microprocessor controlled
VOLTAGE INPUT:	115/230 VAC (Switch Selectable) ± 10%, 50/60Hz, .4 Amp (at 115 Volts)
OPERATING ENVIRONMENT:	10-45°C
WEIGHT:	5.9 Kg (13 pounds)
DIMENSIONS:	10.7CM (4.2″) high x 31.0CM (12.2″) wide x 25.4CM (10.0″) deep

TEMPERATURE CONTROL

SET POINT:	Digital thumbwheel selection directly in kelvin temperature units
SET POINT RESOLUTION:	0.1 K
OPTIONAL REMOTE SET POINT:	TTL compatible, parallel BCD (Standard with BCD Output)
CONTROLLABILITY:	0.1 K with a properly designed system
HEATER OUTPUT:	Standard 0-40 watts, 0-1A, 0-40VDC
CONTROL MODE:	Time proportional gain and reset

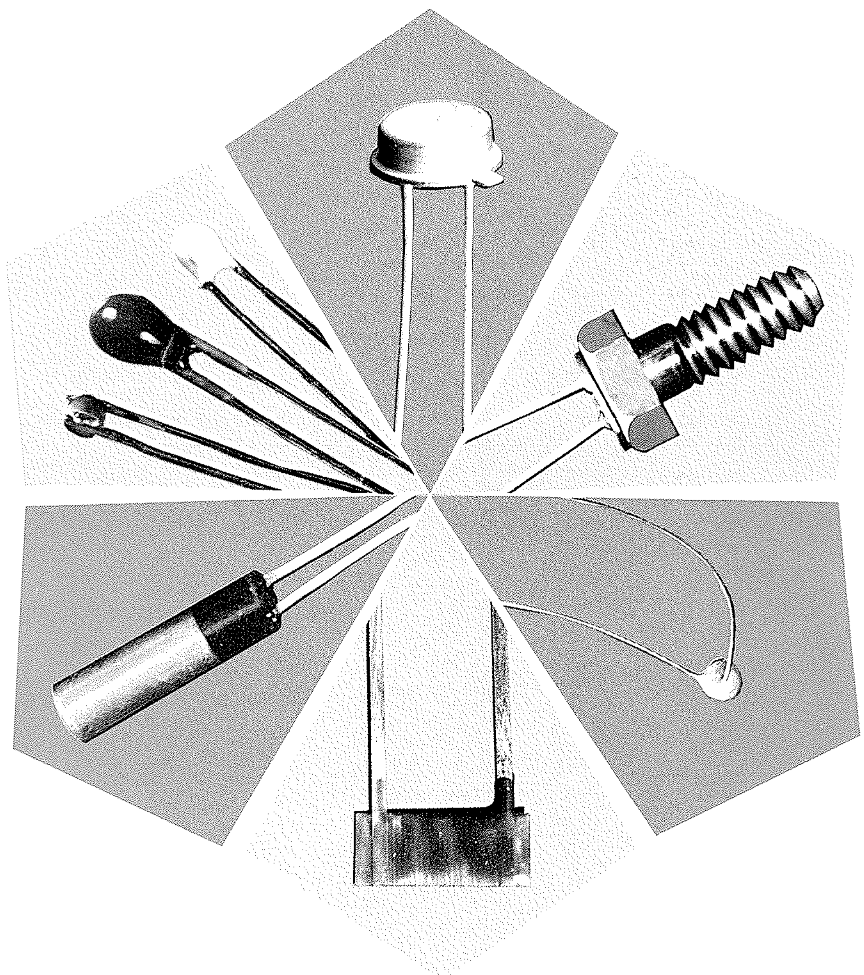
TEMPERATURE READOUT

RESOLUTION:	
ANALOG	Dependent on auxiliary voltmeter
DIGITAL	0.1 kelvin
CONFORMITY TO LSCI STANDARD DRC-70 SILICON DIODE TABLE:	0.5 K from 4 to 400 K (error below 4 K may be larger)
MAXIMUM SENSOR POWER DISSIPATION:	25 uW at 4.2 K
TEMPERATURE COEFFICIENT ERROR:	0.01 K/°C
INPUT RESISTANCE:	Greater than 100 megohms
OUTPUTS: ANALOG (Standard)	Output of sensor voltage
ANALOG (Optional)	10 mV/K at $<$ 10 ohms output impedance
DIGITAL (Optional)	TTL compatible parallel BCD
DISPLAY:	4 digits, 1.1CM (0.43″) high, 7 segment non-blinking
RESPONSE TIME:	2.2 seconds to rated accuracy

CRYOGENIC TEMPERATURE SENSING ELEMENTS

FROM

LAKE SHORE CRYOTRONICS, INC.



CAPACITANCE TEMPERATURE SENSORS

CS-400
- Strontium Titanate
- Unaffected by Magnetic Fields
- .005 K to 400 K

DIODE TEMPERATURE SENSORS

TG-100
- Gallium Arsenide
- 1 K to 400 K Full Range
- Useful in Modest Magnetic Fields

DT-500
- Silicon
- 1 K to 400 K Full Range
- Highest Sensitivity
- Interchangeable

RESISTANCE SENSORS

CGR
- Carbon Glass
- 1 K to 300 K
- Monotonic Temperature Response
- Useful in Magnetic Fields

GR-200
- Germanium
- Repeatability
- <.030 K to 100 K
- Secondary Standard

LR-700
- Copper
- 70 K to 475 K
- Essentially Linear with Temp. Coeff. .43%/K

MISCELLANEOUS
- Rhodium-Iron Resistor
- Platinum Resistor
- Nickel Resistor

Sensor Type	Available Configuration (See Pages 6 and 7)	Sensing Element Material	Heat Dissipation (at 4.2K and recommended operating current)	Useful Temperature Range	Output Signal or Nominal Value at 4.2k	Sensitivity	Inter-changeability
Diode Thermometry							
TG-100	1, 3, 4, 5, 6, 7, 8, 9	Gallium Arsenide	15 uW at 10 uA	1 K to 400 K	1.45 V at 4.2 K / 0.7 V at 295 K	0.6 mV/K at 4.2 K / at 77 K 2.75 mV/K; See Fig. 2, 4	N.A.
DT-500	1, 2, 4, 5, 6, 7, 8, 9	Silicon	25 uW at 10 uA	1 K to 400 K	2.4 V at 4.2 K / 0.4 V at 295 K	50 mV/K at 4.2 K / at 77 K 2.75 mV/K; See Fig. 1, 4	±0.1 K @ 4.2 K ±1K @ 77 K ±1K @ 300 K (see remarks)
Capacitance Thermometry							
CS-400	11, 12, 13	Strontium Titanate	< 10^{-12} W at 1 K Hz and 50 mv excitation	<10 mk to 60 K / 70 K to 400 K	3 nF to 40 nF; See Fig. 3	250 pF/K at 4.2 K / at 4.2 K 160 pF/K (-FP only); See Fig. 3	N.A.
Resistance Thermometry							
CGR-1	10	Carbon Glass	CGR-1 (2000) 0.2 uW 10 uA / .1 uW 3.0 uA CGR-1 (10,000)	0.3K to 100K (300K)	250 ohm 1000 ohm 2000 ohm 5000 ohm 10,000 ohm	See Figures 4, 5, 7	Consult Factory
GR-200	10	Germanium	GR-200-1000 0.1 uW at 10 uA	< 0.03 K to 100 K with several Elements	30 ohm 100 ohm 1000 ohm	See Figures 4, 5, 7	Limited, with Bridge Techniques
LR-700	14	Copper	N.A.	70 K to 475 K	2340 ohms at 273.2 K (O°C)	10 Ω/K	Yes, with Current Adjustment
RF-800		Rhodium with 0.5 atomic % Iron		2 K to 300 K	20, 47, or 100 ohms at 273.2 K (O°C)	90 uV/K at 4.2 K and 500 uA	No
	Data sheet available on request	Platinum Nickel					

ASK FOR BULLETIN "CRYOGENIC INSTRUMENTATION"

Thermal Response (at 4.2K) (Configuration Dependent)	Repeatability (at 4.2K)	Magnetic Field Effect (Data taken ⊥ to field at 5 Tesla and 4.2K)	Reliability (Typical cycling life 300K to 4.2K)	Suggested Temperature or Signal Read Out Accuracy	REMARKS	Sensor Type
						Diode Thermometry
100 K/sec	100 uV	0.7 K See Fig. 6	200 to 300 Cycles Nominally	100 uV	Useful in modest magnetic fields	**TG-100**
100 K/sec	50 uV	2.4 K See Fig. 6	Excellent	100 uV	Sensors of same config.can be matched at LHe, LN_2 and room temperature. If quantites to be matched exceed 5, discuss applicaton with factory	**DT-500**
						Capacitance Thermometry
100 K/sec		No Effect See Fig. 6	Excellent	±3 pF	Unaffected by magnetic fields to 18 T. Recommended for control purposes Request detailed information from factory	**CS-400**
						Resistance Thermometry
	≤ 0.5 mK at 4.2 K	< 0.05K See Fig. 6	Excellent	± 0.002 K at 4.2 K	Useful in Magnetic Fields Large useful range, essentially no piezo-resistance, monotonic R vs T and dR/dT curves. 250 ohm 0.3 - 4.2k 1000 ohm 1.5 -100K (300K) 2000 ohm 2 - 100K (300K) 5000 ohm 2.5 - 100K (300K) 10,000 ohm 3-100K (300K)	**CGR**
	0.5 mK at 4.2 K	Not Recommended	Excellent	± 0.002 K at 4.2 K For R=1000Ω at 4.2 K	Recognized secondary standard 30 ohm 0.010 - 1.5k (4.2k) 100 ohm 0.3 - 4.2K 1000 ohm 1.5 - 40K (100K)	**GR-200**
N.A.	N.A.	N.A.	Excellent	0.1 K or better	Essentially linear in response over most of the useful temperature range	**LR-700**
	0.3 mK at 4.2 K	— 0.3 K	Excellent	0.008 K or better	Model RF-802-Perf. is a perforated can version for gas or liquid use. Request detailed information from factory	**RF-800**
					Data sheet available on request	

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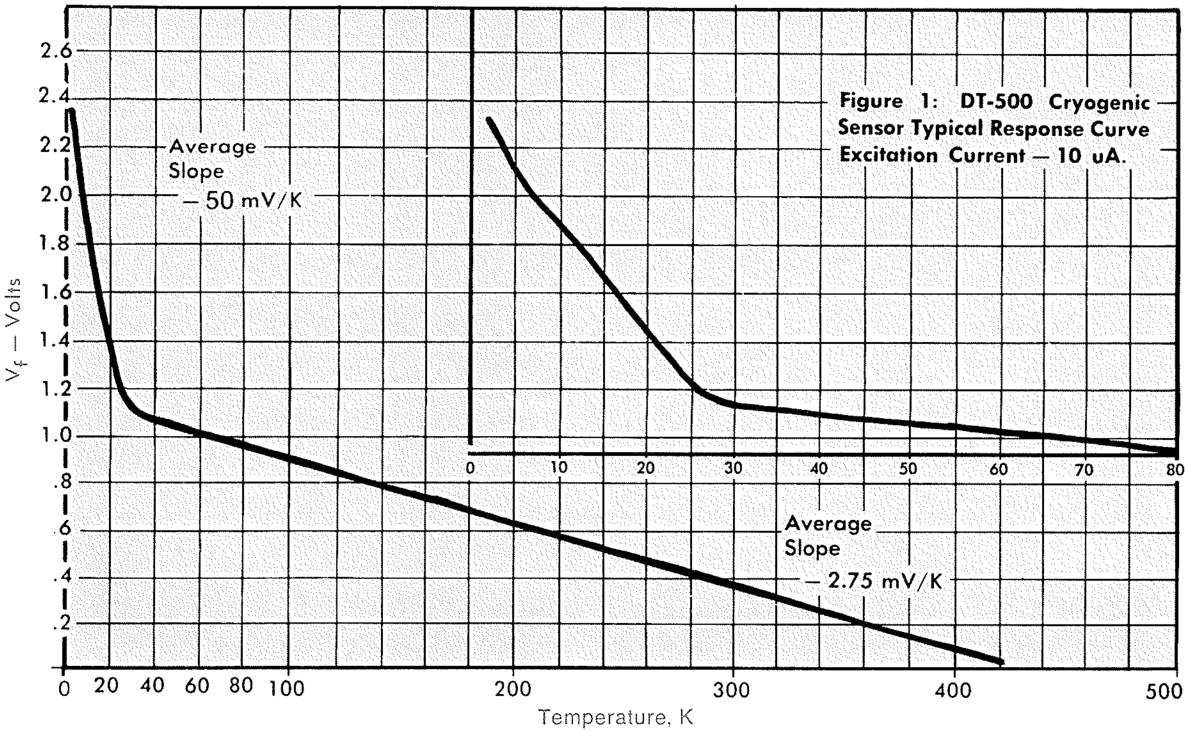


Figure 1 Detailed Response of DT-500 Silicon Diode Temperature Sensor

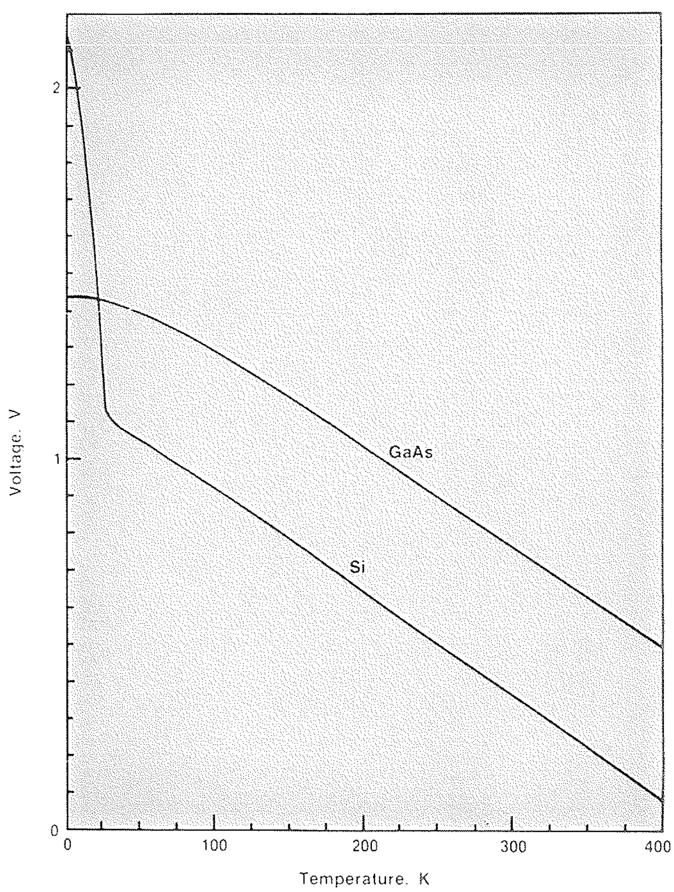


Figure 2

Comparison of typical forward voltage versus temperature characteristics for the gallium arsenide (GaAs) and silicon (Si) diode thermometers.

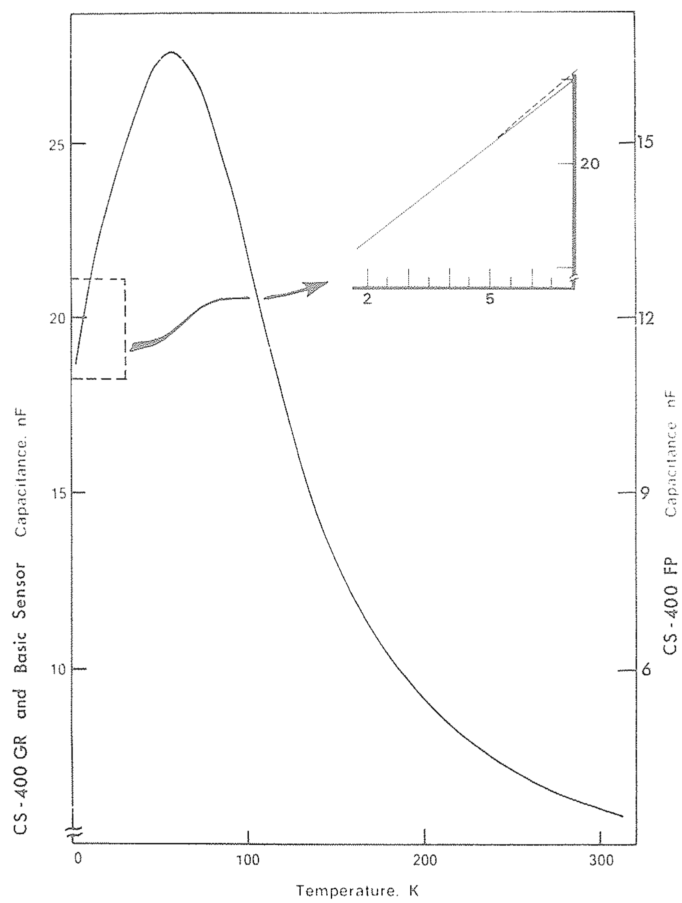


Figure 3

Typical capacitance temperature characteristics for $SrTiO_3$ capacitance thermometers.

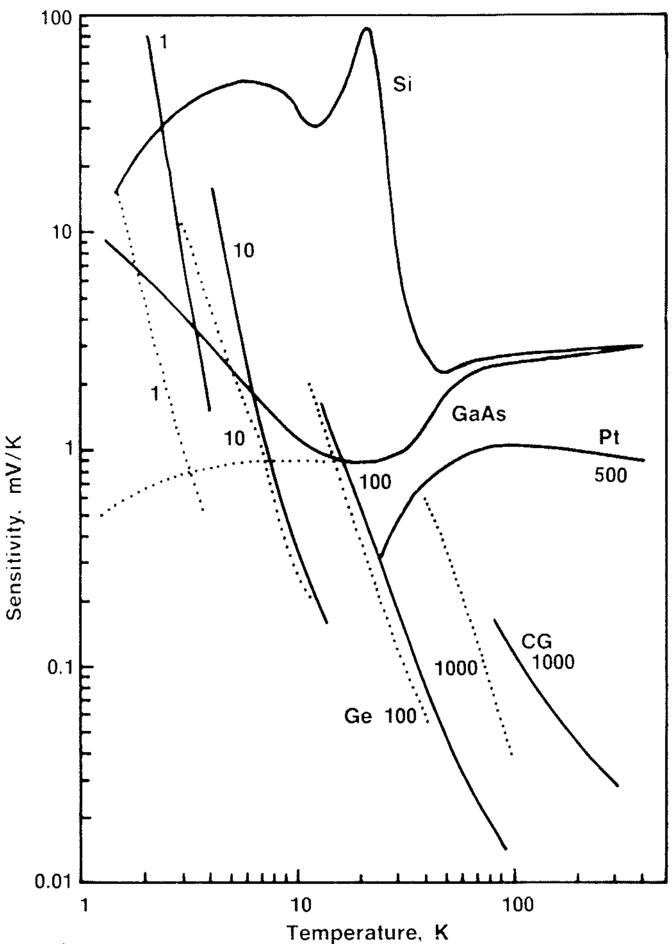


Figure 4

Temperature sensitivity of voltage (dV/dT) as a function of temperature for silicon (Si) and gallium arsenide (GaAs) diode (solid and dotted line) thermometers and carbon glass (CG) (solid line), germanium (Ge) (dotted line), and platinum (Pt) (R_0= 470 ohms) resistors. Numbers for resistors indicate current in microamperes. Diode thermometer data is at 10 microamperes.

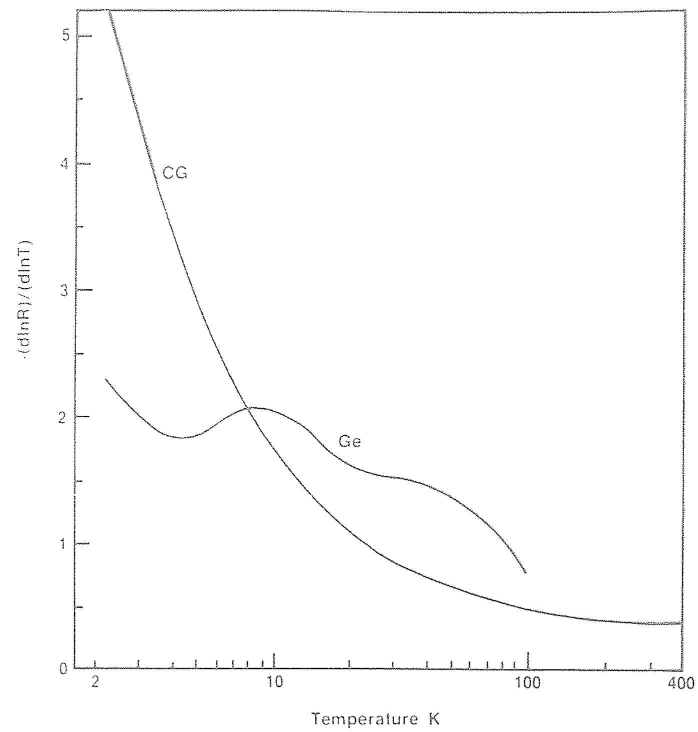


Figure 5

Relative sensitivity data (d ln R)/(d ln T) versus temperature for carbon glass (CG) and germanium (Ge) resistors.

Magnetic Field-T	2.5	5	10	15
TG-100 GaAs	-.2K	-.7K	-2.3K	N.R.*
DT-500 Silicon	-1.4K	-2.4K	N.R.*	N.R.*
CS-400 $SrTiO_3$	0	0	0	0
CGR Carbon Glass	−.015K	−.045K	−.14K	−.23K
GR-200 Germanium	-1.25K	N.R.*	N.R.*	N.R.*

Figure 6

Typical Magnetic Field Induced Temperature Errors at Selected Field Levels at 4.2 K.

*N.R. — Not Recommended

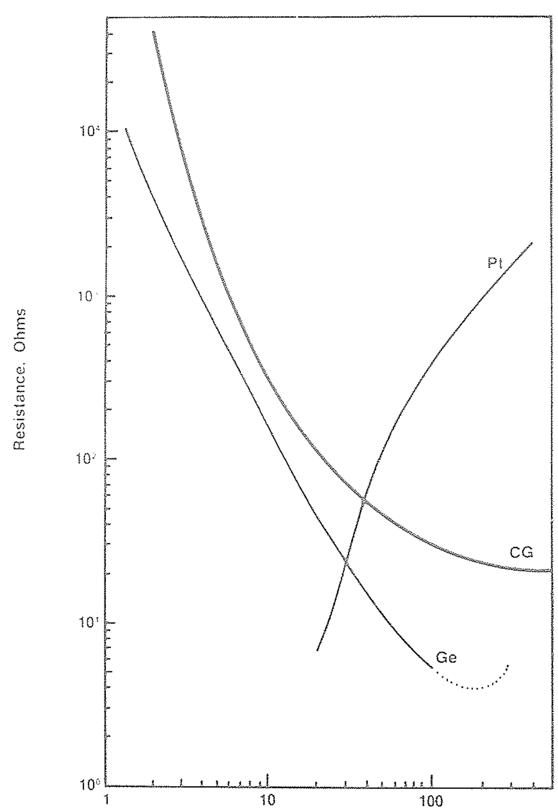
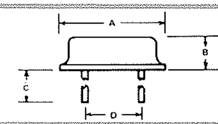
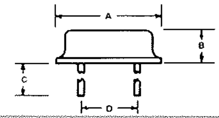
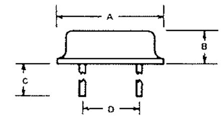
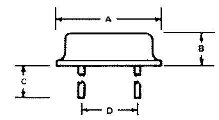
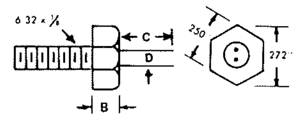
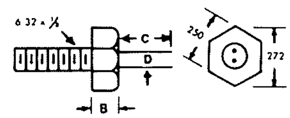
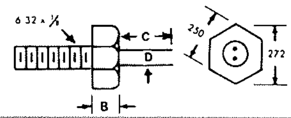
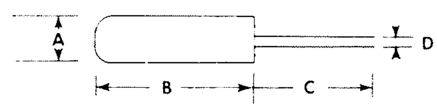
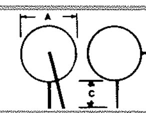
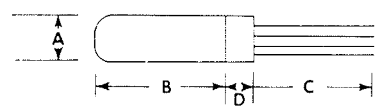
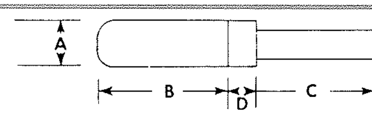
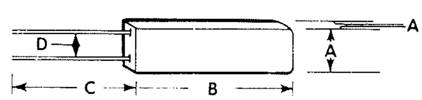
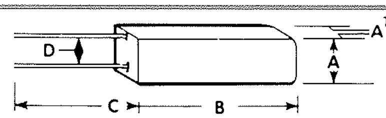
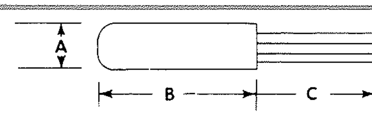


Figure 7

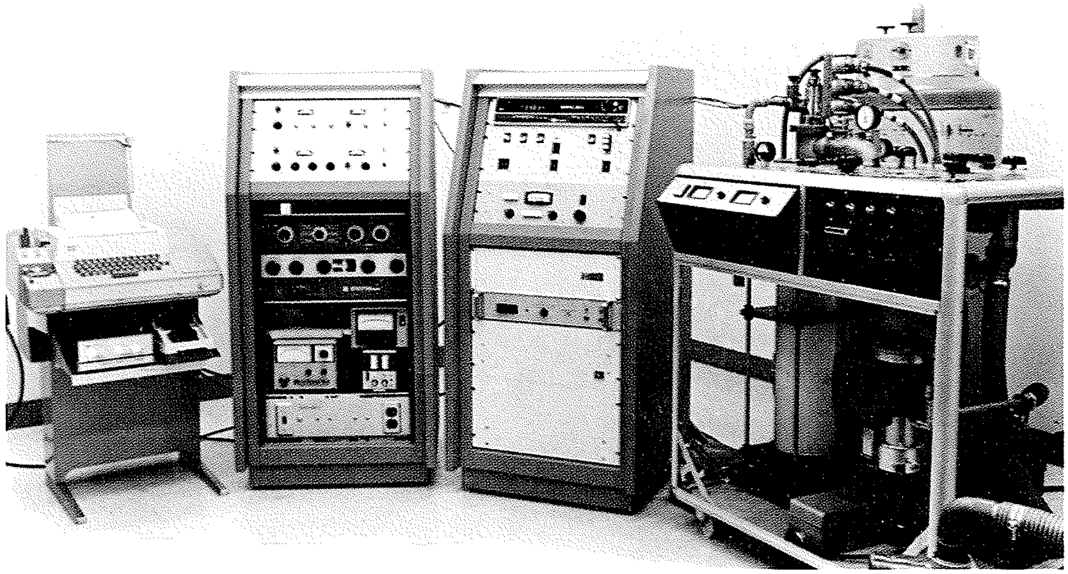
Resistance-temperature characteristics of the germanium (Ge), platinum (Pt) (R_0=1380 ohms), and carbon glass (CG) resistors.

SENSOR SERIES DESIGNATION	REF. NO.	LEAD IDENT. AND ISOLATION	CONFIGURATION
TG-100K **DT-500K** DT-500K-DE	1	Cathode is at case potential Tab index is anode	
DT-500KL DT-500KL-DE	2	Both leads isolated Tab index is anode	
TG-100KL	3	Both leads isolated Tab index is anode	
TG-100P **DT-500P**	4	Cathode is at case potential anode is shorter lead	
TG-100K-T05 **DT-500K-T05** DT-500K-T05-DE	5	Cathode is at case potential Tab index is anode	
TG-100KL-T05 **DT-500KL-T05** DT-500KL-T05-DE	6	Both leads isolated Tab index is anode	
TG-100P-T05 **TG-100P-T05/I** **DT-500P-T05** **DT-500P-T05/I**	7	Standard version Same as Ref #4 /I designates both leads isolated	
TG-100P-GR **TG-100P-GR/I** **DT-500P-GR** **DT-500P-GR/I** DT-500P-GR-MIN /I DT-500P-GR-ULTRA /I	8	Standard version Same as Ref #4 — /I designates both leads isolated Short lead — Anode	
TG-100FP **DT-500FP** DT-500FP-MIN	9	Gold lead—anode Plat lead—cathode Min. short lead – Anode	
CGR-1, **GR-200**	10	White: +I Yellow: +V Green: −V Black: −I	
CS-400-GR	11	Interchangeable — Leads have no polarity	
CS-400FP	12	Interchangeable — Leads have no polarity	
CS-400 Basic	13	Interchangeable — Leads have no polarity	
LR-700GR	14	Pairs are interchangeable — see instructions with sensor	

OTHER CONFIGURATIONS ENGINEERED ON REQUEST

DIMENSIONS: INCHES MM. A	B	C	D	LEADS	LEAD DIAM.	WEIGHT	ENCAPSULATION MATERIALS	REMARKS
.23 5.8	.08 2	1.5 38	.10 2.5	2, Gold Plated Ni-Fe 3-DE	.019 .5	.3 gr.	Gold Plated Kovar TO-46 Package	Thermal transfer thru body of unit one lead grounded DE-Dual Element w/ Common Cathodes
.23 5.8	.08 2	1.5 38	.07 1.8	2, Gold Plated Ni-Fe 3-DE	.019 .5	.3 gr.	Gold Plated Kovar TO-46 Package	Both leads isolated from case DE-Dual Element w/ Common anodes
.23 5.8	.21 5.3	1.5 38	.07 1.8	2, Gold Plated Ni-Fe	.019 .5	.5 gr.	Gold Plated Kovar TO-18 Package	Both leads isolated from case
.15 3.8	.065 1.65	1.0 25.4	.06 1.5	2, Plat.— 10% Ir	.01 .25	.18 gr.	Platinum & Glass	No ferromagnetic materials are utilized in the construction of these sensors
—	.09 2.3	1.5 38	.10 2.5	2, Gold Plated Ni-Fe 3-DE	.019 .5	1.24 gr.	Gold Plated Kovar TO-46 base set in a 6-32 x 3/8″ copper alloy hex head cap screw	TG-100K or DT-500K set into the top of a copper alloy hex head cap screw DE-Dual Element w/ Common Cathodes
—	.09 2.3	1.5 38	.07 1.8	2, Gold Plated Ni-Fe 3-DE	.019 .5	1.24 gr.	Gold Plated Kovar TO-46 base set in a 6-32 x 3/8″ copper alloy hex head cap screw	TG-100KL or DT-500KL set into the top of a copper alloy hex head cap screw DE-Dual Element w/ Common anodes
—	.09 2.3	1.0 25.4	.06 1.5	2, Plat.— 10% Ir	.01 .25	1.24 gr.	Platinum and glass header set in a a 6-32 x 3/8″ copper alloy hex head cap screw	TG-100P or DT-500P set into the top of a copper alloy hex head cap screw DE-Dual Element w/ Common Cathodes
.125 3.18 Min. .06 1.5 Ultra .04 1.0	.35 8.9 Min. } .16 Ultra } 4.1	1.0 25.4	.06 1.5 Min. } .01 Ultra } .254	2, Plat.— 10% Ir	.01 .25 Min. } .005 Ultra } .13	.42 gr. Min. 45 mg. Ultra 35 mg.	Platinum and glass header set into a gold plated copper cylinder Min. & Ultra — Platinum, Brass, & Epoxy	TG-100P or DT-500P set into a gold plated copper cylinder except Min. & Ultra
.05 1.27 Min. .030 .76	—	1.5 38	—	1 gold, 1 plat.— 10% Ir Min. 2-pt. 10% Ir	Anode .002 .05 Cathode .005 .13 2 - .005/.13	25 mg. Min. 17 mg.	Platinum, Gold and Epoxy Min. — Platinum & Epoxy	No ferromagnetic materials are utilized in the construction of these sensors
.125 3.18	.335 8.5	6 152	.1 2.5	4 Copper	32 AWG teflon insulated	.3 gr.	Platinum and glass header set into a gold plated copper cylinder & an epoxy lead strain relief	Sensor has ^4He in can to act as a heat transfer medium. ^3He and other gases are avail. for GR-200
.125 3.18	.335 8.5	6 152	.1 2.5	2, Copper	32 AWG	.55 gr.	Platinum, Glass and Epoxy	Sensor can is completely filled with sensor element and glass.
A=.107 2.7 A[1]=.044 1.1	.340 8.6	1.0 25.4	.06 1.5	2, Silver	.008 .2	.1 gr.	Glass	No ferromagnetic materials are utilized in the construction of CS-400 sensors
A=.098 2.5 A[1]=.093 2.4	.340 8.6	1.0 25.4 1.5 38	.06 1.5	2 Silver	.008 .2	.15 gr.	Glass	This is unencapsulated CS-400 GR element
.12 3.0	.320 8.1	2 51	—	4 Copper	32 AWG	.6 gr.	Gold plated copper can and high temperature epoxy	Leads are polyimide insulated

CALIBRATION SERVICE



The equipment shown is utilized for temperature calibrations from 1.3 to 400 K. Other available equipment includes a ^{3}He cryostat for .3 to 1.5 K calibrations and a dilution refrigerator for lower temperatures.

Standard calibrations are supplied according to the following table unless otherwise specified:

Temperature	Maximum Interval	Temperature	Maximum Interval
0.3 to 1.3 K	0.05 K	30 to 40 K	2.0 K
1.3 to 2.0 K	0.1 K	40 to 80 K	5.0 K
2.0 to 3.0 K	0.2 K	80 to 400 K	10.0 K
3.0 to 4.2 K	0.4 K		
5.0 to 30 K	1.0 K		

Computer printouts are provided where applicable.

All diode and resistor calibrations are performed with a 4 wire potentiometric configuration. Capacitance temperature sensors are calibrated with a 3 wire bridge configuration.

Resistor calibration currents are selected to produce a potential difference between 1 and 15 mV for the desired temperature. Diodes are calibrated with a 10 uA excitation current. Capacitors are calibrated with a 50 mV rms. excitation signal at 5 kilohertz.

Note: Consult factory for special printouts

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