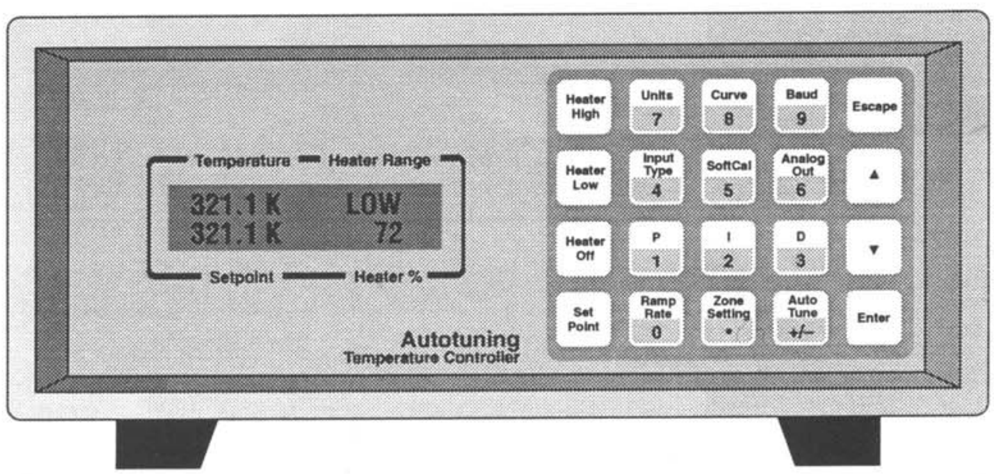
CYC321-01, CYC322-02, and CYC324-03

Cryogenic Temperature Controller



OMEGA®
An OMEGA Technologies Company

Operator's Manual

TABLE OF CONTENTS

TABLE OF CONTENTS (Cont'd)

TABLE OF CONTENTS (Cont'd)

TABLE OF CONTENTS (Cont'd)

CHAPTER 1

INTRODUCTION

1.0 GENERAL

This chapter provides an introduction to the CYC3211/CYC3212/CYC3214 Autotuning Temperature Controller. The Autotuning Temperature Controller is a microprocessor-based instrument with digital control of a variable current output. The controller features include the following:

- Three Models available
  - Silicon Diode — CYC3211
  - Platinum Resistor 100 Ω — CYC3212
  - Thermocouple — CYC3214
- Thermometry
  - Single Sensor Input
  - Differential Input Allows Four-Lead Sensor Measurement
  - Nonvolatile Memory Space to Store One Precision Calibration Option Curve
  - Nonvolatile Memory Space to Store One SoftCal Curve
- Five Tuning Modes
  - Autotuning P
  - Autotuning PI
  - Autotuning PID
  - Manual
  - Zone (Ten Temperature Zones)
- Control
  - Control Stability to ±0.1 K
  - Three Term PID Control Loop
  - 25 Watt Heater Power with Two Ranges
  - Setpoint Ramping
- Interface
  - Backlit 2 Row by 16 Character LCD for High Visibility
  - Display of Sensor Temperature in K, °C, or sensor units in volts, ohms
  - Serial Interface (RS-232C Electrical Format)
  - Analog Output Corresponding to Temperature

Proceed to Chapter 2 to become familiar with the installation instructions. Operation is described in Chapter 3. Remote operation is covered in Chapter 4. Service and calibration procedures are provided in Chapter 5. Options and accessories are detailed in Chapter 6. For reference, various appendices are included. Finally, an alphabetical index is included at the end of the manual.

1.1 DESCRIPTION

The microcontroller-based autotuning temperature controller provides a simple answer to basic control needs. There are three models: the CYC3211 for Silicon Diode Temperature Sensors, the CYC3212 for Platinum Resistors, and the CYC3214 for Thermocouples.

The controller displays the temperature in K, °C or sensor units in volts (V), millivolts (mV), or ohms (Ω). The 2 x 16 LCD simultaneously displays temperature, setpoint, heater range, and heater % current.

Precision thermometry is the most basic building block of any digital controller and is necessary for stable, accurate control. Careful analog design provides the controller with stable and repeatable measurements. A differential input allows for a four-lead measurement of the sensor signal. A high resolution A/D converter digitizes the signal for use in thermometry, control, and autotuning.

The control software in the controller compares the measured value of the control sensor to the desired control setpoint and acts with three term (PID) function to minimize the difference. Control parameters can be entered in any one of five tuning modes: Autotuning P, Autotuning PI, Autotuning PID, Manual, and Zone.

Autotuning represents the OMEGA's commitment to bringing convenience and performance to the cryogenic measurement and control market. Autotuning utilizes information gathered during setpoint changes to automatically optimize the control parameters.

The controller allows the user to program up to 10 custom temperature zones where the controller will automatically use pre-programmed PID settings and heater range.

The ramping feature permits the user to set the rate that the setpoint increases or decreases when the setpoint is changed. If this feature is combined with the zone feature, the user could do a ramp through all 10 zones from ≈2 K to room temperature by only changing the setpoint. The controller will change the PID and heater range settings as the temperature setpoint passes through the different zones.

Two heater ranges, with the high providing 25 watts and the low 2.5 watts, accommodate a variety of cryogenic cooling systems. The power output of the controller is a quiet, variable dc current to ensure as little noise coupling as possible between the heater and experiment.

The Serial Interface provides remote access to data from the controller and allows setting of most front panel functions.

The thermometry accuracy can be enhanced by using a OMEGA calibrated sensor and ATP-8000 Precision Calibration Option, or by the use of SoftCal.

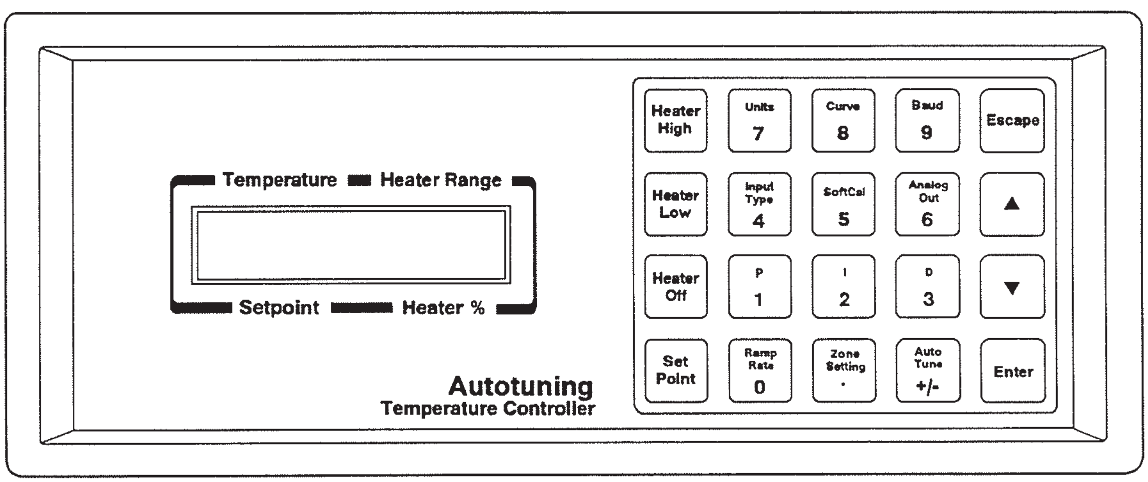


Figure 1-1. Temperature Controller Front Panel

Table 1-1. Electronic Information for Various Sensors and Temperature Ranges

Model No.	CYC3211	CYC3212	CYC3214*
Sensor Type	Silicon diode	100 Ω Platinum RTD	Thermocouple
Sensor Temp Coefficient	Negative	Positive	Positive
Sensor Units	Volts (V)	Ohms (Ω)	Millivolts (mV)
Controller Temp. Range	1.4 – 475 K †	14 K – 800 K	–273 – 1000 °C †
Input Range	0 – 2.5 V	0 – 300 Ω	±45 mV
Sensor Excitation	10 µA ±0.05% constant current	500 µA ±0.01% constant current	N/A
The following specifications reflect operational characteristics with the specified OMEGA Sensor.			
Example OMEGA Sensor	Silicon Diode (CY7)	Pt 100 RTD (PT 100 R669)	OMEGA Thermocouple (TFAU.07FE)
Sensor Temp. Range	1.4 - 475 K	30 - 800 K	1.4 - 325 K
Standard Sensor Curve	Curve 10	DIN 43760	NBS generated
Typical Sensor Sensitivity	–30 mV/K at 4.2 K –1.9 mV/K at 77 K –2.4 mV/K at 300 K –2.2 mV/K at 475 K	0.19 Ω/K at 30 K 0.42 Ω/K at 77 K 0.39 Ω/K at 300 K 0.33 Ω/K at 800 K	16 µV/K at 4.2 K 20 µV/K at 300 K
Measurement Resolution			
Sensor Units	0.04 mV	5 mΩ	1.5 µV
Temperature Equivalence	1.3 mK at 4.2 K 21 mK at 77 K 16 mK at 300 K 18 mK at 475 K	26 mK at 30 K 12 mK at 77 K 13 mK at 300 K 15 mK at 800 K	90 mK at 4.2 K 75 mK at 300 K
Sensor Unit Display Resolution	0.1 mV to 1 mV	0.01 Ω to 0.1 Ω	2 µV
Measurement Accuracy	±0.2 mV ±0.02% RDG	±20 mΩ ±0.05% RDG	±4 µV ±0.05% RDG
Measurement Temp. Coefficient			
Sensor Units (%RDG/°C)	±0.01%	±0.01%	±0.018%
Temperature Equivalence	±8 mK/C° at 4.2 K ±77 mK/°C at 77 K ±33 mK/°C at 300 K ±9 mK/°C at 475 K	±33 mK/°C at 4.2 K ±22 mK/°C at 77 K ±64 mK/°C at 300 K ±171 mK/°C at 800 K	±200 mK/°C at 30 K ±110 mK/°C at 300 K
Setpoint Display Resolution in Sensor Units	0.1 mV to 1 mV	0.01 Ω to 0.1 Ω	2 µV

* Thermocouple data are for uncompensated inputs.
† Dependent on sensor type.

Table 1-2. Specifications

Thermometry:	
Number of Inputs:	One
Sensor Types:	CYC3211 – Silicon Diode CYC3212 – Platinum RTD CYC3214 – Thermocouple
Accuracy:	Based on Model and Sensor Type (Refer to Table 1-1)
Update Rate:	1 second
Precision Curve Storage:	One 97 point curve entered via Serial Interface
SoftCal:	Entered in voltage or temperature
Control:	
Control Type:	Digital, three term PID with Autotuning
Automatic Control Mode:	P, PI, or PID control, user selectable
Manual Control Mode:	Gain (**P**roportional) 1-999, Reset (**I**ntegral) 1-999 sec., and Rate (**D**erivative) 0 - 200%
Control Stability:	Better than ±0.1 K in a properly designed system for diode and platinum sensors
Setpoint Resolution:	0.1 K or °C
Heater Output Type:	Analog dc Current Source
Heater Setting Resolution:	15 bit
Heater Ranges:	25 W, 2.5 W
Max Power To Heater:	25 W
Max Current To Heater:	1 A
Heater Output Compliance:	25 V
Heater Load:	25 Ω, 25 W required for full power
Heater Noise:	0.005% of full scale power
Ramp Rate:	0.1 to 99.9 K/min
Analog Output:	
Default Settings:	
Range:	0 to 10 volts at 1 mA max
Default Output:	10 mV/K, 0 - 10 V, 0 - 1000 K
Resolution:	1.22 mV, 0.122 K
Accuracy:	±0.04% of full scale output + measurement accuracy
Programmable Settings:	
Range:	0 V = user defined minimum temperature in kelvin 10 V = user defined maximum temperature in kelvin Minimum temperature resolution is 0.1 K
Front Panel:	
Display:	2 row by 16 character LCD
Display Units:	Temperature in K or °C. Sensor units in volts (CYC3211), ohms (CYC3212), or millivolts (CYC3214)
Temperature Resolution:	0.1 K or °C
Sensor Units Resolution:	5 digits
Keypad:	Numeric keypad
Interface:	
Serial Interface:	300 or 1200 baud, RJ-11 connector (RS-232C electrical standard)

Table 1-2. Specifications (Continued)

General:	
Ambient Temperature Range:	20 to 30 °C (68 °F to 86 °F), or with reduced accuracy in range 15 °C to 35 °C (59 °F to 95 °F)
Power Requirements:	90 – 110, 105 – 125, or 210 – 250 VAC, 50 or 60 Hz; 65 watts
Size:	217 mm wide x 90 mm high x 317 mm deep (8.5" x 3.5" 12.5"), half-rack package
Weight:	2.7 kilograms (6 pounds)

1.2 CONTROL FUNDAMENTALS AND AUTOTUNE

The controller has several features which aid in temperature control of a cryogenic system. These include standard built-in curves along with the ability to store a single 97 point curve, Serial Interface, a differential input allowing true four-wire sensor readings, 2 row by 16 character LCD for high visibility, 25 Watt DC current output with short circuit protection of the output, and digital filtering. These and other features are discussed in detail throughout this manual.

The Autotuning algorithm determines the settings of controller gain (**P**roportional), reset (**I**ntegral), and rate (**D**erivative) by observing the time response of the system upon changes in setpoint under either P, PI, or PID control.

Since this is a digital system, there are inherent limitations associated with digital control and Autotuning. First, there is the limitation that any control system is inherently unstable if the sampling rate (frequency) is not greater than twice the system bandwidth (inverse of system time constant). This is known as the Nyquist criterion. With the current technology used in this controller, i.e., sampling frequency, etc., digital control is possible for cryogenic system with time constants near or greater than one second. Fortunately, most cryogenic systems which operate above 1 kelvin will have time constants that meet this criteria.

The Autotuning function requires that the system time response be measured as a result of a change in temperature setpoint. In order to get meaningful data for determining the PID parameters, several points on this response curve must be measured. Consequently, for cryogenic systems where step responses are less than ≈5 seconds (where the number of measured points is small), correct determination of the PID parameters is difficult and better temperature control will normally be achieved by manual selection of gain and reset (rate will not normally be required). Fortunately, fast cryogenic systems are not difficult to tune manually.

For slower systems with longer time constants (which can be very difficult to tune manually), Autotuning can obtain enough information on a step change to characterize the system and determine proper values of gain, reset, and rate.

There may be other conditions where you will prefer to stay with manual settings. For example, when a closed cycle refrigerator has very little mass on its second stage and is near its bottom temperature, attempts at Autotuning may give poor results for control settings due to the large inherent temperature fluctuations associated with the cooling cycle. Adding mass to the second stage smoothes out these fluctuations, but lengthens cooldown time.

OMEGA has simplified the input of the rate time constant in this controller to correspond to a percentage of the reset time constant, i.e., 0 to 200%. Consequently, if you are in the manual mode and you set RATE at 100%, on any change in RESET, the controller will automatically calculate the RESET time constant (999/RESET) and set the RATE time constant at 1/8 of the RESET time constant. This is one-half the conventional Zeigler-Nichols setting for rate and results in a smaller overshoot of a given setpoint. Therefore, once RATE is set as a percent, you do not have to worry about updating its value with setpoint changes resulting in new PI settings. Obviously, if you prefer less RATE, set the rate setting at something less than 100%. Remember, however, in many cryogenic systems, rate will not be required anyway, and is consequently set at 0%.

An application note titled *Fundamentals for Usage of Cryogenic Temperature Controllers* is included with Appendix D. This application note should be read in detail if you are not familiar with cryogenic temperature controllers.

1.3 PRECISION CALIBRATION OPTIONS

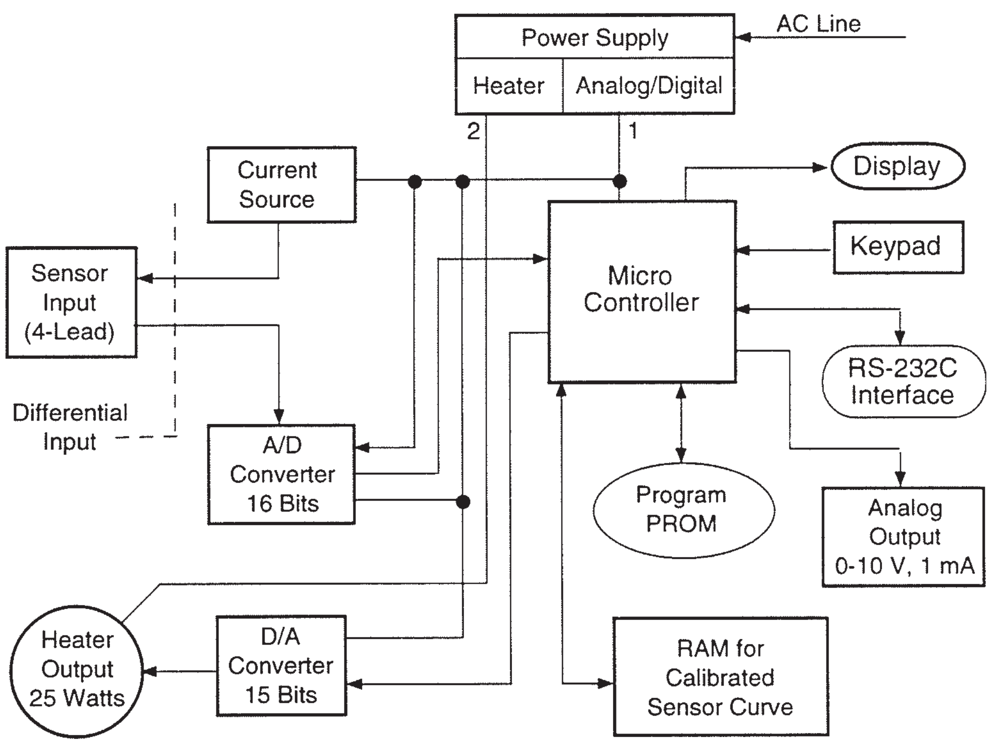
The Precision Calibration Option allows the user to convert calibrated sensor data into breakpoint pairs readable by the controller program. The Precision Calibration Option is available in two forms:

--- The ATP-8000 loads the breakpoint pairs on a floppy disk in ASCII format for Customer downloading.
--- The ATP-8002-05 is a NOVRAM that is installed in the field.

The Precision Calibration Option improves the specified accuracy to 0.1K or better over a given calibration range for Silicon Diode Sensors. Accuracy for other sensors depends on the sensor type and calibration range.

A copy of the break point information containing sensor type, sensor serial number, maximum allowable error, break point number, voltage (or resistance), temperature and temperature error is supplied. A second sheet containing only the break point temperatures and voltages is also supplied.

The Precision Calibration Option Table is a piecewise linear interpolation based on the sensor calibration. Optimum break points are determined by an iterative procedure using weighted linear least squares defined by either a maximum number of break points allowed or a maximum allowable error. The break point voltages are the values from the least squares linear equations and will therefore differ from the calibration data. Differences between voltages from the input table and the break point voltage are converted to a corresponding error in temperature by dividing the voltage difference by the sensitivity. Temperature errors by this method will be considerably less than by linear interpolation between calibration data points.



Grounds 1 and 2 represent separate isolated power supplies.
Ground 1 is connected to Earth.

Figure 1-2. Block Diagram

1.4 SAFETY SUMMARY

The following general safety precautions must be observed during all phases of operation, service, and repair of this instrument. Failure to comply with these precautions or with specific warnings elsewhere in this manual violates safety standards of design, manufacture, and intended use of the instrument. OMEGA assumes no liability for Customer failure to comply with these requirements.

Ground The Instrument
To minimize shock hazard, the instrument chassis and cabinet must be connected to an electrical ground. The instrument is equipped with a three-conductor ac power cable. The power cable must either be plugged into an approved three-contact electrical outlet or used with a three-contact adapter with the grounding wire (green) firmly connected to an electrical ground (safety ground) at the power outlet. The power jack and mating plug of the power cable meet Underwriters Laboratories (UL) and International Electrotechnical Commission (IEC) safety standards.

Do Not Operate In An Explosive Atmosphere
Do not operate the instrument in the presence of flammable gases or fumes. Operation of any electrical instrument in such an environment constitutes a definite safety hazard.

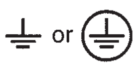
Keep Away From Live Circuits
Operating personnel must not remove instrument covers. Component replacement and internal adjustments must be made by qualified maintenance personnel. Do not replace components with power cable connected. To avoid injuries, always disconnect power and discharge circuits before touching them.

Do Not Substitute Parts Or Modify Instrument
Because of the danger of introducing additional hazards, do not install substitute parts or perform any unauthorized modification to the instrument. Return the instrument to OMEGA for service and repair to ensure that safety features are maintained.

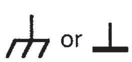
1.5 SAFETY SYMBOLS

 Product will be marked with this symbol in order to protect against damage to the instrument.

 Indicates dangerous voltage (terminals fed by voltage over 1000 volts must be so marked).

 Protective conductor terminal. For protection against electrical shock in case of a fault. Used with field wiring terminals to indicate the terminal which must be connected to ground before operating equipment.

 Low-noise or noiseless, clean ground (earth) terminal. Used for a signal common, as well as providing protection against electrical shock in case of a fault. A terminal marked with this symbol must be connected to ground in the manner described in the installation (operating) manual, and before operating equipment.

 Frame or chassis terminal. A connection to the frame (chassis) of the equipment which normally includes all exposed metal structures.

 Alternating current (power line).

 Direct current (power line).

 Alternating or direct current (power line).

This Page Intentionally Left Blank

CHAPTER 2

INSTALLATION

2.0 GENERAL

This chapter provides general installation instructions for the Autotuning Temperature Controller.

Inspection and unpacking instructions are provided in Section 2.1.

Repackaging for shipment instructions are provided on the inside back cover.

Rear panel controls are described in Section 2.3.

Environmental requirements are detailed in Section 2.4.

Grounding and shielding requirements are discussed in Section 2.5.

Sensor input settings are detailed in Section 2.6.

Sensor installation recommendations are detailed in Section 2.7.

Sensor curve selection is detailed in Section 2.8.

The Precision Calibration Option is discussed in Section 2.9.

Heater setup is detailed in Section 2.10.

Rack mounting is discussed in Section 2.11.

The power up sequence, configuration, and errors are provided in Section 2.12.

2.1 INSPECTION AND UNPACKING

Remove the Packing List and verify that you have received all equipment, including the following (quantities in parentheses):

CYC3211 or CYC3212 or CYC3214 controller (1)
Operator's Manual (1)

If you have any questions about the shipment, please call the OMEGA Customer Service Department. When you receive the shipment, inspect the container and equipment for signs of damage. Note any evidence of rough handling in transit. Immediately report any damage to the shipping agent.

NOTE

The carrier will not honor damage claims unless all shipping material is saved for inspection. After examining and removing contents, save packing material and carton in the event reshipment is necessary.

2.2 REPACKAGING FOR SHIPMENT

If it is necessary to return the CYC3211, CYC3212, CYC3214, sensor, or accessories for repair or replacement, contact OMEGA Engineering, Inc. (refer to the Inside Back Cover for details).

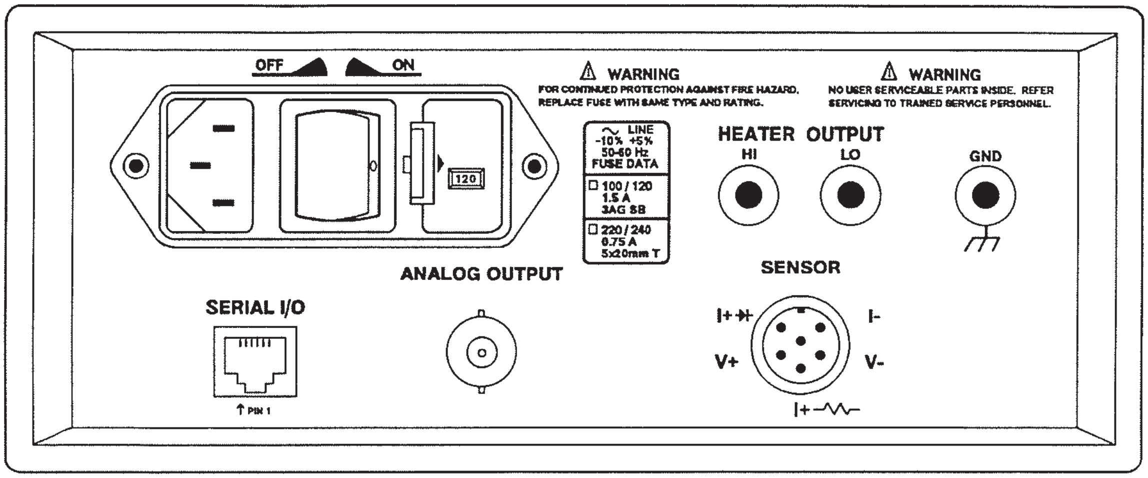


Figure 2-1. Typical Rear Panel

2.3 DEFINITION OF REAR PANEL CONNECTIONS

This section provides a description of the CYC3211/CYC3212/CYC3214 rear panel connections. The rear panel consists of the power and fuse assembly, Serial I/O Connector, Analog Output Connector, Sensor Input Connector, and Heater Output Connector.

CAUTION

- Verify that the ac Line Voltage shown in the window on the fuse drawer corresponds to that marked on the rear panel, and that both these settings are appropriate for the intended ac power input. Also remove and verify the proper fuse is installed before inserting the power cord and turning on the instrument.
- Always turn off the instrument before making any rear panel connections. This is especially critical when making sensor to instrument connections.

Power and Fuse Assembly. The power and fuse assembly is the primary entry and control point for ac power to the unit. The assembly consists of two parts: power line jack and the fuse drawer. The line cord is connected to the power line jack. Power to the unit is controlled by the power switch located on the rear panel. Press the right side of the switch for On (I) and the left side for Off (O). The fuse drawer contains a 1.5 A 3AG Slow Blow fuse for 100-120 Vac or a 0.75 A 5x20mm T fuse for 220-240 Vac. Refer to Section 5.2 for changing power settings and fuse rating.

Serial I/O Connector. The Serial I/O (Input/Output) Connector accepts a standard RJ-11 telephone connector. To connect to the User's computer, the optional CYD200-C RJ-11 to RJ-11 14-foot Cable, CYD200-D RJ-11 to DB-25 Adapter, and CYD200-DB9 RJ-11 to DE-9 Adapter are available as accessories from OMEGA. Refer to Chapter 4 for setup and Serial I/O commands. Refer to Chapter 6 for further information on the serial accessories.

Analog Output BNC Connector. The analog output is available on one Bayonet Nut Connector (BNC). The signal is on the center conductor while the outer casing is for ground. In the default setting, the analog output provides a 0 to 10 volt output corresponding to 0 to 1000 K (10 mV/K). The user can also redefine the scaling of this output. Refer to Chapter 3 for further information.

Sensor Input Connector. A sensor input connector is provided for attaching temperature sensor to the unit. Always turn off the instrument before connecting the sensor. Refer to Section 2.6 for further information on setting up the sensor input.

Heater Connectors. Banana jacks provide HI, LO, and GND heater connections (25 Ω, 25 W Heater recommended). Refer to Section 2.10 for further information on heater connection setup.

2.4 ENVIRONMENTAL REQUIREMENTS

The controller is intended for laboratory use. In order to meet and maintain specifications, the controller should be operated at an ambient temperature range of 20 to 30 °C (68 to 86 °F). The unit may be operated within the range of 15 to 35 °C (59 to 95 °F) with reduced accuracy.

WARNING

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

2.5 GROUNDING AND SHIELDING

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

Grounding and shielding of signal lines are major concerns when setting up any precision instrument or system. The controller allows 4-wire measurement of diode voltage and resistance. To prevent inaccurate measurements, diode and resistive sensor leads must be isolated from earth ground. Thermocouple sensors, however, may be grounded. Shield sensor cables whenever possible. Attach the shields to the shield pin provided in the connector. Do not attach the shield at the sensor end.

The heater output is isolated from earth ground. To prevent heater noise coupling into the measurement, do not allow the heater output to contact earth ground. Earth ground (GND) is provided on the rear panel for shielding purposes only.

Digital logic in the controller is tied directly to earth ground for interface communications. The sensor lines and digital communication lines should be separated whenever possible to prevent excess noise in the measurement.

2.6 SENSOR INPUT SETTINGS

The sensor input type is established at the factory before shipping. Sensor input type is configured by setting DIP switches S1 and S2 on the main PCB inside the unit. If you wish to check the DIP switch settings, the configurations are as follows.

DIP Switch S1 *

	Silicon Diode (CYC3211)	Platinum (CYC3212)	Thermocouple (CYC3214)
S1-1	Closed	Open	Open
S1-2	Open	Closed	Open
S1-3	Open	Open	Closed
S1-4	Open	Open	Closed

DIP Switch S2 *

	Silicon Diode (CYC3211)	Platinum (CYC3212)	Thermocouple (CYC3214)
S2-1	Closed	Open	Open
S2-2	Open	Closed	Open
S2-3	Open	Open	Closed
S2-4	Open	Open	Closed

* *To change sensor input type, DIP switches on S1 and S2 must be switched identically.*

To change the DIP Switch settings, refer to Section 5.7. The controller must be recalibrated when switched between sensor input types.

Diode and Platinum connections are defined in Section 2.6.1.

Thermocouple connections are described in Section 2.6.2.

Thermocouple compensation is discussed in Section 2.6.3.

2.7 SENSOR INSTALLATION

Abbreviated sensor installation recommendations for the CYC3211/CYC3212/CYC3214 are included in this section. Please refer to Manual number M808 normally supplied with the silicon diode sensor. The following are general recommendations on sensor installation:

1. Do not ground the sensor.
2. Shield the leads and connect the shield wire to SHIELD on the screw terminal connector only. Do not connect shield at the other end of the cable.
3. Keep leads as short as possible.
4. Using CYW4 special low thermal conductivity extension wire is strongly recommended.
5. Lead wires should be thermally anchored.

Sensor installation is provided in two parts. Diode (CYC3211) and Platinum (CYC3212) sensor connections are detailed in Section 2.7.1. Thermocouple (CYC3214) sensor connections are detailed in Section 2.7.2. Finally, sensor input error messages are described in Section 2.7.3.

2.7.1 Diode (CYC3211) and Platinum (CYC3212) Connections

The controller has a rear panel 6-pin input connector for silicon diode (CYC3211) or platinum resistance (CYC3212) sensors. The lead connections are defined in Table 2-1.

Table 2-1. Diode or Platinum Input Connections

Terminal	Description
1	– Current
2	– Voltage
3	+ Current 500 μA (platinum)
4	+ Voltage
5	+ Current 10 μA (diodes)
6	Shield

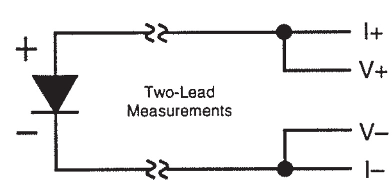
Section 2.7.1.1 discusses two-lead versus four-lead measurements. Section 2.7.1.2 discusses connecting leads. Sensor mounting is covered in Section 2.7.1.3. Finally, Section 2.7.1.4 describes the effect of measurement errors due to AC noise.

2.7.1.1 Two-Lead Versus Four-Lead Measurements

The use of a four-lead connection is highly recommended for two lead resistive elements and diodes to avoid introducing current/resistive (IR) drops in the voltage sensing pair which translates into a temperature measurement error. In the two lead measurement scheme, the leads used to measure the sensor voltage are also the current carrying leads. The resultant voltage measured at the instrument is the sum of the temperature sensor voltage and the IR voltage drop within the two current leads. Since in a cryogenic environment, the flow of heat down the leads can be of critical concern, normally wire of small diameter and significant resistance per foot is preferred to minimize this heat flow. Consequently, a voltage drop within the leads can be present.

1. Two-Lead Measurements

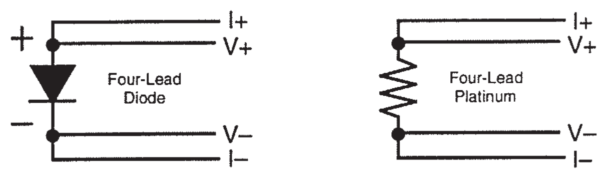
Sometimes system constraints dictate the use of two-lead measurements. Connect the positive terminals (V+ and I+) together and the negative terminals (V– and I–) together at the instrument, then run two leads to the sensor.



Some loss in accuracy can be expected since the voltage measured at the voltmeter becomes the sum of the sensor voltage and the voltage drop across the connecting leads. The exact measurement error will depend on sensor sensitivity and variations resulting from changing temperature. For example, a 10 Ω lead resistance will result in a 0.1 mV voltage error. The resultant temperature error at liquid helium temperature is only 3 mK, but, because of the diode's lower sensitivity (dV/dT) at higher temperatures, it becomes 10 mK at liquid nitrogen temperature.

2. **Four-Lead Measurements**

All sensors, including both two-lead and four-lead devices, can be measured in a four-lead configuration to eliminate the effects of lead resistance. The exact point at which the connecting leads are soldered to the two-lead sensor normally results in a negligible temperature uncertainty.



The four-lead measurement configuration should always be used with Series Pt-100 Platinum Sensors being attached to the CYC3212.

2.7.1.2 Connecting Leads To The Sensor

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

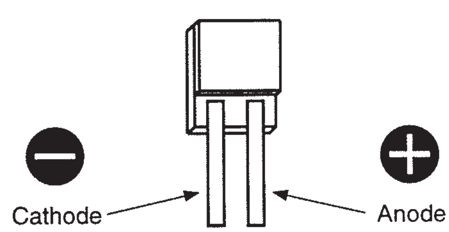
In order to minimize any heat flow through the leads, the leads should be of small diameter and low thermal conductivity. Phosphor-bronze or Manganin wire is commonly used in sizes 32 or 36 AWG. These wires have a fairly low thermal conductivity yet the electrical resistivities are not so large as to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

Lead wires should also be thermally anchored at several temperatures between room temperature and cryogenic temperatures to guarantee that heat is not being conducted through the leads to the sensor.

2.7.1.3 Sensor Mounting

Before installing a diode sensor, identify which lead is the anode and which is the cathode. When viewed with the base down and with the leads towards the observer, the positive lead (anode) is on the right and the negative lead (cathode) is on the left. The CY7-SD7 silicon diode sensor lead configuration is shown below. For other sensors, read the accompanying literature or consult the manufacturer to ensure positive identification of sensor leads. Be sure the lead identification remains clear even after installation of the sensor. It is also a good idea to record the serial number and location of the sensor.

CY7-SD7
Diode Sensor Leads



On the CY7-SD7, the base is the largest flat surface. It is sapphire with gold metallization over a nickel buffer layer. The base is electrically isolated from the sensing element and leads, and all thermal contact to the sensor should be made through the base. A thin braze joint around the sides of the package is electrically connected to the sensing element. Contact to the sides with any electrically conductive material must be avoided.

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

For temporary mounting in cold temperature applications, a thin layer of CYAG Grease may be used between the sensor and sample to enhance the thermal contact under slight pressure. The preferred method for mounting the CY7-SD7 sensor is the OMEGA CY7-CO.

CAUTION

OMEGA will not warranty replace any device damaged by a user-designed clamp or damaged by solder mounting.

If semi-permanent mountings are desired, the use of OB-CY20 epoxy can replace the use of CYAG Grease. (Note: Do not apply epoxy over the CY7-SD7 package—stress on the sensor can cause shifts in the readings.) In all cases, the mounting of the sensor should be periodically inspected to verify that good thermal contact to the mounting surface is maintained.

For the CYC3212, Series Pt-100 Platinum Sensors follow the same procedures for diode type sensors. The difference is Platinum sensors have no lead polarity and some of the materials used at cold temperatures will not tolerate the high temperature range of the Platinum sensor.

2.7.1.4 Measurement Errors Due To ac Noise

Poorly shielded leads or improperly grounded measurement systems can introduce ac noise into the sensor leads. For diode sensors, the effect of the ac noise appears as a shift in the dc voltage measurement due to the non-linear current/voltage characteristics of the diode. When this occurs, the dc voltage measured will be too low and the corresponding temperature indication will be high. The resulting measurement error can approach several tenths of a kelvin.

For Series Pt-100 Platinum Sensors, the noise will not cause a dc shift, but it can still degrade the accuracy of the measurement. To determine if this is a problem in your measurement system, perform either of the two following procedures.

1. Place a capacitor across the diode to shunt the induced ac currents. The size of the capacitor will depend on the frequency of the noise. If the noise is related to the power line frequency, use a 10 microfarad capacitor. If ac-coupled digital noise is suspected (digital circuits or interfaces), then use a capacitor between 0.1 to 1 microfarad. In either case, if the resultant dc voltage measured is observed to increase, there is induced noise in your measurement system.
2. Measure the ac voltage across the diode with an ac voltmeter or oscilloscope. Note that most voltmeters will not have the frequency response to measure noise associated with digital circuits or interfaces (which operate in the MHz range). A thorough discussion of this potential problem, and the magnitude of error which may result, is given in the paper "Measurement System-Induced Errors In Diode Thermometry," J.K. Krause and B.C. Dodrill, Rev. Sci. Instr. 57 (4), 661, April, 1986; which is in Appendix D.

The potential for this type of error can be greatly reduced by connecting twisted leads (pairs) between the controller and the diode sensors when an AC noise environment exists. We recommend the use of CYW4 Cryogenic Wire, which features phosphor bronze wire, 32 or 36 AWG [twisted at 3.15 twists per centimeter (8 twists per inch)]. Wire is available from OMEGA. Refer to OMEGA's Temperature Catalog.

2.7.2 Thermocouple (CYC3214) Connections

The thermocouple input has a thermal block for connecting thermocouple wires. The positive and negative terminals correspond to V+ and V– and should match the polarity of the thermocouple used. Be sure to tighten the screw terminals carefully. Loose connections will result in unstable readings and control. For additional information on thermocouple operation, refer to Section 3.5.

2.7.2.1 Thermocouple Compensation

The thermocouple input has a thermal block for connecting thermocouple wires and for temperature compensation. The thermocouple response curve tables within the instrument are normalized to the ice point of water. Consequently, accurate readings can be obtained by one of two methods. An ice bath with a reference junction can be used with the internal room temperature compensation turned OFF. The more convenient method is to eliminate the reference junction with its associated ice bath and use the internal electronic room temperature compensation by turning the internal compensation ON.

2.7.2.2 Thermocouple Wire Types at Cryogenic Temperatures

The following are recommended thermocouple wire types that may be used at cryogenic temperatures. For more information on thermocouples or other sensors, refer to OMEGA's Temperature Catalog.

CHROMEGA® - Gold/Iron (0.07%)

Consists of Gold (Au) doped with 0.07 atomic percent Iron (Fe) as the negative thermoelement and a Ni-Cr alloy (CHROMEGA®) as the positive thermoelement. This thermocouple is widely used in cryogenic applications due to its relatively high thermoelectric sensitivity (>15mV/K above 10K).

Type E

(CHROMEGA®-Constantan) Has the highest sensitivity among the three standard thermocouple types typically used at low temperatures - Types E, K and T (8.5mV/K at 20K). The best choice for temperatures down to 40K. CHROMEGA® is the positive thermoelement.

Type K

(CHROMEGA®-ALOMEGA®) Has about one half the sensitivity of Type E at 20K (Type K = 4.1mV/K). Recommended for continuous use in inert atmospheres. CHROMEGA® is the positive thermoelement.

Type T

(Copper-Constantan) For use in vacuum, as well as oxidizing, reducing or inert environments down to 90K. The copper element has high thermal conductivity, making this thermocouple the least usable for cyrogenic applications. Sensitivity at 20K (4.6mV/K) is similar to Type K. Copper is the positive thermoelement.

2.7.3 Sensor Input Error Messages

If an input signal from the sensor exceeding full scale is applied to the input leads, an overload condition is present and is indicated by "OL" on the display, as shown below.

```
OL
```

If no signal or a signal of the wrong polarity is present at the input leads, a Zero Error is indicated by "Er27" on the display, as shown below.

```
Er27
```

2.8 SENSOR CURVE SELECTION

In order for the instrument to provide accurate temperature readings, it is necessary to select the response curve that matches the sensor being used. To determine which curve is selected, press the Curve key. The default curve for the CYC3211 is DT-470 Curve 10, being the second selection in the curve list built into the unit (refer to Table 2-2). This display is shown below.

```
Select With ▲ ▼
Curve:02:DT-470
```

The default curve for the CYC3212 is Curve DIN-PT, being the third selection in the curve list built into the unit (refer to Table 2-2). This display is shown below.

```
Select With ▲ ▼
Curve:03:PT DIN
```

The default curve for the CYC3214 is Curve AuFe07%, being the sixth selection in the curve list built into the unit (refer to Table 2-2). This display is shown below.

```
Select With ▲ ▼
Curve:06:AuFe07%
```

To change the curve, press the Curve key, then press either the ▲ (up) or ▼ (down) key to increment or decrement through the available curve selections. The curve numbers available are 0 through 12. To accept a new curve number, press the Enter key, or press the Escape key to cancel. The standard curves, with their curve number and temperature range, are given in Table 2-2. If a curve with the wrong temperature coefficient slope is selected, the controller will default to the lowest order curve of the correct type.

Table 2-2. Sensor Curves

Curve No.	Number of Lines	Range (K)	Abbreviation	Description
00	31	1 – 325	DRC D	DRC Curve D
01	31	1 – 325	DRC E1	DRC Curve E1
02	31	1 – 325	DT-470	Sensors Curve 10
03	31	14 – 800	Plat.	Platinum DIN Curve
04	88	2 - 475	DT-470 *	Sensors Curve 10
05	31			Reserved
06	31	1.4 – 325 *	AuFe07%	AuFe 0.07% vs. Chromel
07	31	4 – 325 *	AuFe03%	AuFe 0.03% vs. Chromel
08	31	3 – 850 *	Type E	Type E
09	31	3 – 1272 * †	Type K	Type K
10	31	3 – 670 *	Type T	Type T
11			User	User Curve or Precision Option
12			SoftCal	SoftCal Curve

* Values are for thermocouples with compensation. Uncompensated, the thermocouple can use the full ±45 mV range.
† Display reading is limited to 999.9 in K. For higher readings, change units to °C.

Sensor curves available with the controller include D Curve, E1 Curve, Curve 10, Platinum Curve (DIN 43760), various thermocouple curves, and a factory installed Precision Calibration Option for a calibrated sensor.

D and E1 Curve. D-Curve (Domestic) and E1-Curve (Export).

Curve 10. The OMEGA CY7 silicon diodes follow the same standard temperature response Curve 10. Consequently, all of the sensors in this series can be routinely interchanged with one another. Curve 10 is programmed into all OMEGA Temperature Controllers, Digital Thermometers, and Temperature Transmitters. CY7 silicon diode sensors are offered in five bands of tracking accuracy, enabling sensors to be selected on the basis of both technical performance and budgetary requirements.

Platinum Curve. Users of the CYC3212 have the option of the standard platinum curve, or the precision option. The standard platinum curve, which is detailed in Appendix C, conforms to DIN 43760:1980; IEC 751:1983; and 1904:1984.

Thermocouple Curves. The curve selected should match the type of thermocouple being used.

User Curve. In addition to the standard curves, the controller provides space for one user-defined curve. Space for this user curve is provided as Curve Number 11 in the controller (refer to Table 2-2). This curve can be a custom curve developed by the Customer, a Precision Calibration Option Curve purchased from OMEGA (refer to Section 2.9), or a curve purchased from another vendor. The user defined curve can have up to 97 points plus two end points. The points can be loaded into the controller using the serial interface, or if the Precision Calibration Option Curve is purchased from OMEGA, the curve can be entered at the factory. Chapter 5 of this manual describes user curve entry using the serial interface.

SoftCal Curve. If the SoftCal feature of the controller is used, the resulting SoftCal curve is stored in curve location number 12. Refer to Table 2-2 and Section 3.2.6 to use SoftCal.

2.9 PRECISION CALIBRATION OPTION

The Precision Calibration Option is the easiest way to combine the additional performance of an OMEGA-calibrated sensor with the controller. The Precision Calibration Option is a read-only memory chip (PROM) with specific sensor calibration stored on it. The Precision Calibration Option improves combined sensor/instrument accuracy to within ±0.25 K or better over the calibrated temperature range of the sensor.

There are three types of precision options available for the controller. The ATP-8000 Precision Calibration Option generates the data table from an OMEGA calibrated sensor. The maximum number of data points is 99. A typical calibration precision option ranges between 30 and 40 points depending on the sensor type and temperature range of the calibration. The data and accuracy of the fit is supplied to the user as a separate document. This information can be entered by the user over the serial interface.

The Model 8002 Precision Calibration Option is used when the customer already owns a controller and wants the additional sensor calibration stored in the instrument. OMEGA stores the calibration data in a NOVRAM and sends the programmed IC to the customer. The IC is then installed in the instrument by the customer. The user should be prepared to supply the serial number at the time of order.

2.10 HEATER SETUP

The heater output of the controller is brought out the back panel as a Dual Banana Jack. A mating connector is supplied. Current is driven from the HEATER (HI) connection to the HEATER (LO) connection. A resistive heater load of 25 Ω, 25 W should be connected between these two points.

The heater output is a 1 A on High range, 0.31 A on Low range, and does not have to be fused. The controller is designed to power a 25 Ω heater for maximum heater output. A larger heater resistance may also be used but will result in a lower maximum power output. For example, the output compliance voltage is 25 volts so that a 100 Ω heater resistance allows a maximum power output of 6.25 watts $[(25V)^2/100\Omega]$.

If the heater load drops below ≈21 Ω, the output current will limit to prevent the instrument from overheating. The maximum output current will drop with the heater resistance when the resistance is below 21 Ω. The heater output is isolated from earth ground. To prevent heater noise coupling into the measurement, do not allow the heater output to contact earth ground. For example, if the heater load is 20 Ω, the maximum output current is ≈0.90 A. If the heater output is shorted, the maximum output current is ≈0.30 A.

NOTE

- The front panel Heater % display is calculated, not measured. If heater resistance is not 25 Ω, the display may not indicate actual heater output.
- The heater output is isolated from earth ground. To prevent heater noise coupling into the measurement, do not allow the heater output to contact earth ground. Earth ground is provided on the back panel for shielding purposes only.
- If the heater leads must be close to the sensor leads, wind (twist) them in such a manner that they cross each other at ninety degrees.

Within a cryostat, 30 gauge stranded copper lead wire is recommended for connection to the heater. The heater leads should not run coincident with the sensor leads due to the possibility of capacitive pick-up between the two sets of leads. If the heater leads must be close to the sensor leads, wind (twist) them in such a manner that they cross at ninety degrees.

2.11 POWER UP

The power up paragraph consists of a power up sequence in Section 2.8.1. Power up (PUP) Configuration is defined in Section 2.8.2. Power up errors are explained in Section 2.8.3.

2.11.1 Power Up Sequence

The following power up sequence occurs at power up.

1. The first display gives the name of the unit.

```
Autotuning Temp.
   Controller
```

2. Next, the unit displays the current RS-232C Baud rate setting. The default setting is 300 Baud.

```
Baud Rate:   300
```

3. The temperature sensor input type is then displayed. The type of sensor depends on the model of the instrument. A CYC3211 will display the following message.

```
Input Type:
Silicon Diode
```

A CYC3212 will display the following message.

```
Input Type:
Plat. Resistor
```

A CYC3214 will display the following message.

```
Input Type:
Thermocouple
```

4. The controller then goes into normal operation showing the Temperature and Heater Range (High, Low, or Off) setting on the first line and the Setpoint and Heater % power on the second line. Refer to Chapter 3 for operation.

2.11.2 Power Up (PUP) Configuration

A provision has been made to store a Power Up (PUP) configuration for the controller. This ensures that it will power up to a user-defined state after power down. Parameters including heater range, setpoint, gain, reset, units, and curve number are stored in non-volatile memory and preserved even when the line cord is disconnected.

To view PUP status, press and hold the Enter key for ≈5 seconds. You will see the following display.

```
Select With ▲ ▼
PUP: →On  Off
```

"On" indicates that the power up settings will change when settings on the instrument are made via the front panel or over the remote interface. "On" is the default PUP condition.

"Off" indicates that updates to the power up memory are disabled and the instrument will power up in the configuration it was in when the power up feature was turned off.

2.11.3 Power Up Errors

On power up, the controller does a check of the internal memory. There are two potential error messages. The first is usually recoverable, the second is not. The first error display is shown below.

```
RAMnotRecog.Er#2
Escape to Init.
```

This indicates than an attempt to read the internal non-volatile RAM for the Model ID was unsuccessful. In some situations, this error can be corrected by the user by initializing the controller memory. There are three methods that can be used to reinitialize the instrument: (1) Press the Escape key when the error message is being displayed, (2) hold the Escape key down when the instrument is off and then turning the instrument on, or (3) holding the Escape key down for more than 5 seconds. Wait until a message is given before releasing the key.

The second error display is shown below.

```
RAM Rd/Wr    Er#1
Escape to Retry.
```

This error message indicates that an attempt to write and then read the internal non-volatile RAM was unsuccessful. This error is not correctable by the user. Consult OMEGA.

This Page Intentionally Left Blank

CHAPTER 3
OPERATION

3.0 GENERAL

This chapter describes the Temperature Controller operation.
A definition of front panel controls is provided in Section 3.1.
Thermometry related functions are described in Section 3.2.
Control functions are described in Section 3.3.
Interface and miscellaneous functions are described in Section 3.4.
Thermocouple controller operation (CYC3214 only) is described in Section 3.5.

3.1 DEFINITION OF FRONT PANEL CONTROLS

This section provides a description of the front panel controls on the controller. The front panel consists of two major sections: a description of the 20 front panel buttons in Section 3.1.1, and a description of the 2 row by 16 character LCD in Section 3.1.2.

3.1.1 Front Panel Keypad Definitions

The buttons on the front panel are defined as follows. Note the following are abbreviated descriptions of each button. A more detailed description of each function is provided in subsequent paragraphs.

Heater High Turns the heater on high – 25 Watts (maximum). Refer to Section 3.3.1.

Heater Low Turns the heater on low – 2.5 Watts (maximum). Refer to Section 3.3.1.

Heater Off Turns the heater off. Refer to Section 3.3.1.

Set Point Permits the user to adjust the temperature setpoint. Refer to Section 3.3.2.

Units Sets the controller to display temperature units in degrees kelvin (K) or Celsius (C), or sensor units in volts (V), millivolts (mV), or ohms (Ω), depending on Model number. Refer to Section 3.2.2.

Input Type Displays the currently selected sensor input type. Refer to Section 3.2.1. This is a display only. To change the sensor input, refer to Section 5.7. (The controller must be recalibrated after changing the input type.) This button also has two press and hold functions: Thermocouple Compensation and Display Filter. Refer to Sections 3.2.3 and 3.2.4 respectively.

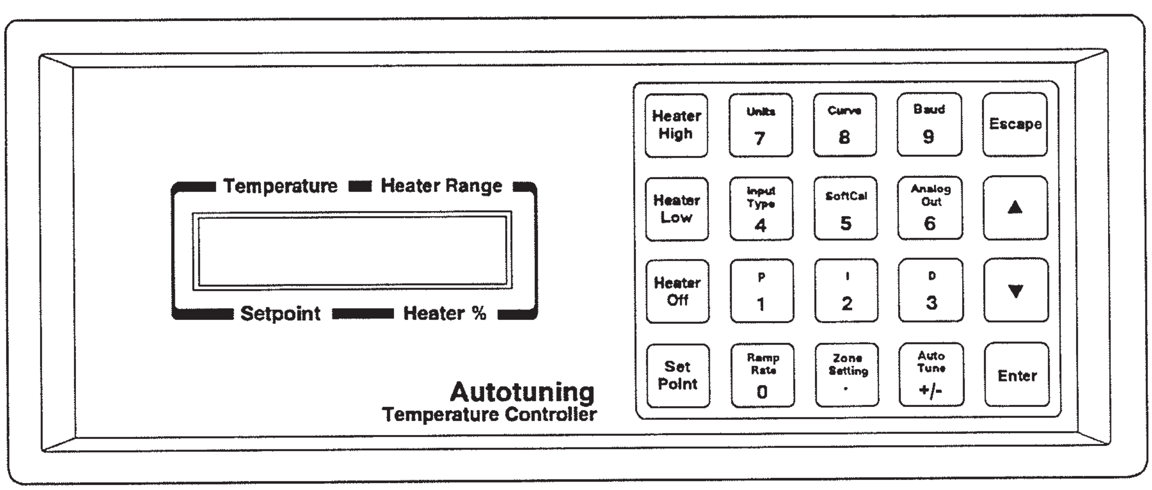


Figure 3-1. Front Panel

Ramp Rate Allows the user to set the rate at which the temperature setpoint increases or decreases when the user changes the setpoint value. Refer to Section 3.3.3.

Curve Used to select the sensor response curve. Refer to Section 3.2.5.

SoftCal Permits the user to improve the accuracy of the silicon diode sensor by setting up a special modification to the Standard Curve 10. Refer to Section 3.2.6.

Zone Setting The user is able to enter up to 10 temperature zones where the controller will automatically use preprogrammed PID settings and Heater Ranges. Refer to Section 3.3.6.

Baud If the Serial Interface is being used, the Baud Rate of the controller may be selected from 300 or 1200 by pressing this button. Refer to Section 3.4.1.

Analog Out Use this button to set the scaling of the analog output. The default is 0 to 10 volts corresponding to 0 to 1000 K. A user defined output scaling can also be specified. Refer to Section 3.4.2.

AutoTune The controller has the capability of automatically setting P, PI, or PID values. Refer to Section 3.3.4.

P For manual adjustment of controller gain (**P**roportional). Refer to Section 3.3.5.1.

I For manual adjustment of reset (**I**ntegral). Refer to Section 3.3.5.2.

D For manual adjustment of rate (**D**erivative). Refer to Section 3.3.5.3.

Escape The **Escape** button is used to terminate a function without making changes to the existing settings. Pressing and holding the **Escape** button for ≈5 seconds resets the controller, returning most parameters to factory default values. Refer to Section 3.4.3.

▲ The up triangle (**▲**) serves two functions. The first is to toggle between various settings shown in the display. The second is to increment a numerical display.

▼ The down triangle (**▼**) serves two functions. The first is to toggle between various settings shown in the display. The second is to decrement a numerical display.

Enter The **Enter** button is used to accept changes made in the field display. Press and hold the **Enter** button to gain access to the Power Up (PUP) configuration setup display. Refer to Section 3.4.4.

3.1.2 Two Row by Sixteen Character Liquid Crystal Display (LCD)

In normal operation, the two row by sixteen character display provides a temperature reading and heater status on the top row and the current temperature setpoint and heater output status on the bottom row. Other information is displayed when using the various functions on the keypad. Each character is comprised of a 5 by 7 dot matrix. See Figure 3-2.

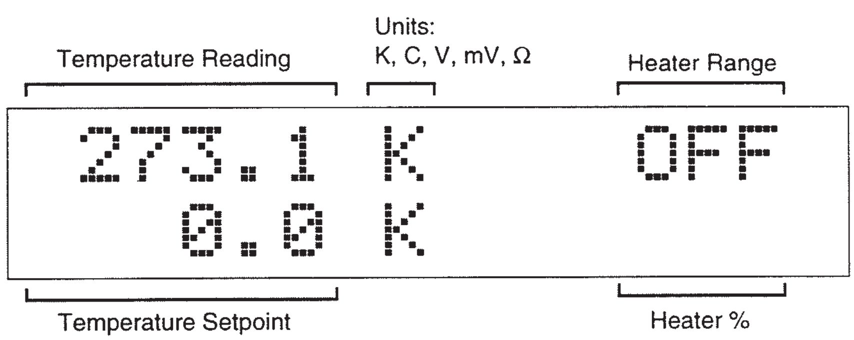


Figure 3-2. Definition of 2 by 16 Display

3.2 THERMOMETRY FUNCTIONS

The following front panel keyboard function are related to the thermometry or temperature control aspects of the controller.

Function	Section
Input Type	3.2.1
Units	3.2.2
Temp. Compensation	3.2.3
Display Filter	3.2.4
Curve	3.2.5
SoftCal	3.2.6

3.2.1 Input Type

The **Input Type** button has been included to permit the user ascertain the internal DIP switch setting configuration that determines the type of sensor input. When first configured at the factory, the Model number will correspond the type of sensor to be used with the controller. The CYC3211 will display the following message.

```
Input Type:
Silicon Diode
```

The CYC3212 will display the following message.

```
Input Type:
Plat. Resistor
```

The CYC3214 will display the following message.

```
Input Type:
Thermocouple
```

The Input Type display is for information only; no user changes are available. The display will remain visible for 3 seconds and then will return to the normal display.

In addition to showing input sensor type, pressing and holding the **Input Type** button on a also has the function of turning the Display Filter on or off. Refer to Section 3.2.4. For thermocouple units only, the extra Input Type display is Temperature Compensation. Refer to Section 3.2.3.

3.2.2 Units

The **Units** button gives a slightly different display depending on the sensor input and model number. All three models permit selection of temperature displays in degrees kelvin (K) or Celsius (C). The difference is in the selection of sensor output. For the silicon diode used with the CYC3211, the additional units selection is Volts (V). Refer to Section 3.2.2.1. For the platinum resistor used with the CYC3212, the additional units selection is ohms (Ω). Refer to Section 3.2.2.2. For the thermocouple used with the CYC3214, the additional units selection is millivolts (mV). Refer to Section 3.2.2.3. Units in K is the default for all models.

3.2.2.1 Units for Silicon Diode Input (CYC3211)

To select the display units for a silicon diode input (CYC3211), press the **Units** button.

```
Select With ▲ ▼
Units:→K   C   V
```

Use the ▲, ▼, or **Units** button to cycle the selector arrow (→) between choices. The available selections are K (kelvin), C (Celsius), and V (Volts). Display in K is the default value. Press **Enter** to accept the new units or **Escape** to return the normal display and retain the old setting.

NOTE

If the display is set to read in V (Volts) and Ramp Rate or Zone Setting are selected, the controller will request the user to return the display to K or C before proceeding.

3.2.2.2 Units for Platinum Resistor Input (CYC3212)

To select the display units for a platinum resistor input (CYC3212), press the **Units** button.

```
Select With ▲ ▼
Units:→K   C   Ω
```

Use the ▲, ▼, or **Units** button to cycle the selector arrow (→) between choices. The available selections are K (kelvin), C (Celsius), and Ω (ohms). Display in K is the default value. To Press **Enter** to accept the new units or **Escape** to return the normal display and retain the old setting.

NOTE

If the display is set to read in Ω (ohms) and Ramp Rate or Zone Setting are selected, the controller will request the user to return the display to K or C before proceeding.

3.2.2.3 Units for Thermocouple Input (CYC3214)

To select the display units for a thermocouple input (CYC3214), press the **Units** button.

```
Select With ▲ ▼
Units:→K   C   mV
```

Use the ▲, ▼, or **Units** button to cycle the selector arrow (→) between choices. The available selections are K (kelvin), C (Celsius), and mV (millivolts). Display in K is the default value. To Press **Enter** to accept the new units or **Escape** to return the normal display and retain the old setting.

NOTE

If the display is set to read in mV (millivolts) and Ramp Rate or Zone Setting are selected, the controller will request the user to return the display to K before proceeding.

3.2.3 Thermocouple Temperature Compensation (CYC3214 Only)

For thermocouple sensors only (CYC3214), the temperature compensation display is shown after the Input Type display has timed out (≈3 seconds). The display appears as follows:

```
Select With ▲ ▼
TempComp: On→Off
```

Use either the ▲, ▼, or **Input Type** button to cycle the selector arrow (→) between choices. The available selections are On and Off, with Off being the default. Press **Enter** to turn temperature compensation on or **Escape** to return the normal display and retain the old setting.

3.2.4 Display Filter

The filter function reads 8 sequential temperature readings and displays the average. It is used to quiet the display, making it more readable when the sensor is exposed to fluctuating conditions. Filter affect the display only and does *not* affect any other control functions. Filter has the effect of slowing the display, and therefore should not be used when ramping. To turn the filter on, press and hold the **Input Type** button (for ≈5 seconds) until you see the following display.

```
Select With ▲ ▼
Filter:  On →Off
```

Use either the ▲, ▼, or **Input Type** button to cycle the selector arrow (→) between choices. The available selections are On and Off, with Off being the default. Press **Enter** to turn the filter on or **Escape** to return the normal display and retain the old setting.

3.2.5 Curve

In order for the controller to provide accurate temperature readings, it is necessary to select the response curve that matches the sensor being used. To determine which curve is selected, press the **Curve** button. The default curve for the CYC3211 is Curve 10, being the second selection in the curve list built into the unit. Refer to Table 3-1. The default display is shown below.

```
Select With ▲ ▼
Curve:02:DT-470
```

The default curve for the CYC3212 is Curve DIN-PT, being the third selection in the curve list built into the unit. Refer to Table 3-1. The default display is shown below.

```
Select With ▲ ▼
Curve:03:PT DIN
```

The default curve for the CYC3214 is Curve AuFe07%, being the sixth selection in the curve list built into the unit. Refer to Table 3-1.

The default display is shown below.

```
Select With ▲ ▼
Curve:06:AuFe07%
```

To change the curve, press the **Curve** button, then press either the ▲, ▼, or **Curve** button to increment or decrement through the available curve selections. The curve numbers available are 0 through 12. When cycling through the displays, only the curves appropriate for the specified sensor type will be displayed. To accept a new curve number, press the **Enter** button, or press the **Escape** button to cancel. The standard curves, with their curve number and temperature range, are given in Table 3-1. If a curve with the wrong temperature coefficient (slope) is selected, the controller will default to the lowest order curve of the correct type.

Table 3-1. Sensor Curves

Curve No.	Number of Lines	Range (K)	Abbreviation	Description
00	31	1 – 325	DRC D	DRC Curve D
01	31	1 – 325	DRC E1	DRC Curve E1
02	31	1 – 325	DT-470	Sensors Curve 10
03	31	14 – 800	Plat.	Platinum DIN Curve
04	88	2 - 475	DT-470 *	Sensors Curve 10
05	31			Reserved
06	31	1.4 – 325 *	AuFe07%	AuFe 0.07% vs. Chromel
07	31	4 – 325 *	AuFe03%	AuFe 0.03% vs. Chromel
08	31	3 – 850 *	Type E	Type E
09	31	3 – 1272 * †	Type K	Type K
10	31	3 – 670 *	Type T	Type T
11			User	User Curve or Precision Option
12			SoftCal	SoftCal Curve

* Values are for thermocouples with compensation. Uncompensated, the thermocouple can use the full ±45 mV range.
† Display reading is limited to 999.9 in K. For higher readings, change units to °C.

3.2.6 SoftCal

SoftCal is used to improve the accuracy of the Silicon Diode Sensor. The SoftCal feature enables the user to reduce the error between a silicon diode and the Standard Curve 10 used by the controller to convert the input voltage from the diode to a corresponding temperature. In short, SoftCal provides the means to generate inexpensive calibrations for CY7 sensors used with the controller.

The CY7 sensors incorporate remarkably uniform sensing elements that exhibit precise, monotonic, and repeatable temperature response in the range from 2 K to 475 K. Temperature characteristics are extremely stable and predictable, and exhibit excellent uniformity from device to device. As a result, these sensors can be routinely interchanged with one another. It is this diode feature that makes the use of SoftCal possible.

For the CY7 diodes, five tolerance bands of tracking accuracy are available. See Table 3-2. If better accuracy is required, SoftCal can be employed with the controller to improve the absolute accuracy of the sensor.

Table 3-2. Tolerance Table

Band Suffix (Range)	Accuracy (Tolerance)		
	2K - 100K	100K - 305K	305K - 475K
-1 (1.4 to 475K)	±0.25K	±0.5K	±1K
-2 (1.4 to 475K)	±0.5K	±1.0K	±2.0K
-3 (1.4 to 475K)	±0.5K	±1% of T	±1% of T
-4 (1.4 to 475K)	±1K	±1% of T	±1% of T
-7 (10 to 425K)	±1.5K	±1.5% of T	±1.5% of T

SoftCal can be implemented as a method by the user.

The Customer may perform the SoftCal procedure. This would involve using the controllerand the silicon diode sensor to sense either two or three sources of a stable temperature. For a 3 point SoftCal, the customer must provide stable temperatures of 4.2 K (Liquid Helium), 77.35 K (Liquid Nitrogen), and 295 K (Room Temperature). For a 2 point SoftCal, the customer must provide stable temperatures of 77.35 K and 295 K. The procedure to follow is provided in Section 3.2.6.2. User performed SoftCal has the advantage of nulling both sensor and controller inaccuracies.

The controller will create a new curve for this specific diode, which is stored as Curve 12 in the controller memory. This procedure can make an inexpensive Band 7 diode more accurate than our tightest Band 1 diode.

3.2.6.1 SoftCal Error

The calibration cannot be transferred from one sensor to another. A SoftCal calibration will compensate for some of the temperature error of the controller if an instrument is used to do the calibration. If the sensor is calibrated outside the instrument, the specified accuracy of the instrument must be added to the sensor accuracy.

SoftCal accuracy also depends on the precision of the setting points. An error in the setting temperature can actually degrade the sensor performance beyond the normal tolerance bands. For example, the boiling point of nitrogen at standard pressure is near 77.4 K. During a storm, this can change as much as 0.2 K because of the change in atmospheric pressure. These types of errors must be added to the sensor accuracy specification.

3.2.6.2 Customer Performed SoftCal

The customer may locally perform the SoftCal procedure using their own controller and silicon diode sensor. Although not as convenient as obtaining a OMEGA SoftCal, it has the advantage of nulling the error of both the sensor and the controller as a system, thereby eliminating much of the controller error. Depending on the temperature range of interest, the customer has the option of doing a 2 point or 3 point SoftCal. This example will assume a 3 point SoftCal. If only 2 points are required, then omit the steps associated with reading the voltage at 4.2 K. Requirements are a stable temperature source at three temperatures: 4.2 K (Liquid Helium), 77.35 K (Liquid Nitrogen), and <300 K (room temperature). It does not matter in which order the SoftCal data are taken.

NOTE

Allow the instrument to warm up for ≈1 hour before beginning the SoftCal procedure.

In this example, we will take our first SoftCal measurement around 4.2 K. Immerse the temperature sensor in Liquid Helium and allow the controller temperature reading to stabilize. Press the **SoftCal** button. Use either the ▲, ▼, or **SoftCal** button to cycle the selector arrow (→) to T (Temperature). You will see the following display.

```
Select With ▲ ▼
Cal: V →T  Erase
```

Press **Enter**. Use the numeric keypad to enter your actual reading (we will use 4.20 K). Be sure to enter the reading as accurately as possible. You will see the following display.

```
Enter Temp in
     +004.20 K
```

Once your observed temperature is entered, press the **Enter** button. The display will read "Processing..." for a couple of seconds, and then will return to the Enter Temperature display. If you attempt to enter a temperature that is too far out of tolerance, you will see the following message.

```
Temperature diff
too large.
```

To take the second SoftCal measurement near 77.35 K, immerse the sensor in liquid nitrogen and allow the reading to stabilize. Press the **SoftCal** button. Use either the ▲, ▼, or **SoftCal** button to cycle the selector arrow (→) to T (Temperature). Press the **Enter** button. Use the numeric keypad to enter your actual reading (we will use 77.35 K). You will see the following display.

```
Enter Temp in
     +077.35 K
```

Once your observed temperature is entered, press the **Enter** button. The display will read "Processing..." for a couple of seconds, and then will return to the Enter Temperature display.

To take the third SoftCal measurement, allow the temperature sensor to stabilize at ambient temperature. Take an independent temperature measurement of the air at the location of the temperature sensor. Press the **SoftCal** button. Use either the ▲, ▼, or **SoftCal** button to cycle the selector arrow (→) to T (Temperature). Press the **Enter** button. Use the numeric keypad to enter your room temperature measurement (we will use 295 K). You will see the following display.

```
Enter Temp in
     +295.00 K
```

Once the proper temperature is entered, press the **Enter** button. The display will read "Processing..." for a couple of seconds, and then will return to the Enter Temperature display. This completes the temperature entry procedure.

To use the newly calculated SoftCal curve, press the **Curve** button, and press either the ▲, ▼, or **Curve** button to increment or decrement until you get to Curve 12:SoftCal, as shown below.

```
Select With ▲ ▼
Curve:12:SoftCal
```

Press the **Enter** button. The controller will now use the new SoftCal curve to interpret the silicon diode sensor voltages to the corresponding temperature reading.

3.2.6.3 Entering Voltage Values from an OMEGA SoftCal Report

If an OMEGA SoftCal Report was purchased, the voltage values for the 2 or 3 point calibration can be entered and the resulting modified Standard Curve 10 stored as Curve 12 in the controller. To enter the voltages, pressing the **SoftCal** button. Use either the ▲, ▼, or **SoftCal** button to cycle the selector arrow (→) to V (Voltage). You will see the following display.

```
Select With ▲ ▼
Cal:→V   T   Erase
```

Press **Enter**. You will see the following display.

```
Select With ▲ ▼
→4.2K 77.3K 305K
```

This procedure will assume a 3 point SoftCal was obtained. The customer will now enter the 3 voltages corresponding to the temperature points on the report. (A 2 point SoftCal uses the same procedure, but skips the 4.2 K entry.) With the selector arrow (→) pointing to 4.2 K, press the **Enter** button.

NOTE

In this example, we will be using voltages taken from a sample SoftCal Report. These values are *for example only.* Since voltage values are unique to individual silicon diode sensors, the customer should substitute the values from their report when following this procedure.

For this example, the OMEGA SoftCal Report provided a reading of 1.6229 V corresponding to 4.2 K. For the controller, you must round the provided voltage to four places. Use the numeric keypad to enter the voltage. You will see the following display.

```
Enter V for 4.2K
     +1.6339 V
```

If you attempt to enter a value that is ±10° from the Standard Curve 10, you will see the following error message.

```
Voltage out of
range for 4.2K
```

A similar message will be displayed if entering an incorrect value for 77.3 K or 305 K.

Once the proper voltage value is entered, press the **Enter** button. The display will read "Processing..." for a couple of seconds, and then will return to the temperature selection display. Use the ▲, ▼, or **SoftCal** button to cycle the selector arrow (→) to 77.3 K and press the **Enter** button. Again look at the SoftCal Report and enter the voltage corresponding to 77.35 K. In this example, the report provided a value of 1.0215. You will see the following display.

```
Enter V for 77.3
     +1.0215 V
```

Once the proper voltage value is entered, press the **Enter** button. The display will read "Processing..." for a couple of seconds, and then will return to the temperature selection display. Use the ▲, ▼, or **SoftCal** button to cycle the selector arrow (→) to 305 K and press the **Enter** button. Again look at the SoftCal Report and enter the voltage corresponding to 305 K. In this example, the report provided a value of 0.5123. You will see the following display.

```
Enter V for 305K
     +0.5126 V
```

Once the proper voltage value is entered, press the **Enter** button. The display will read "Processing..." for a couple of seconds, and then will return to the temperature selection display. This completes the voltage entry procedure.

To use the newly calculated SoftCal curve, press the **Curve** button, and press either the ▲, ▼, or **Curve** button to increment or decrement until you get to Curve 12:SoftCal, as shown below.

```
Select With ▲ ▼
Curve:12:SoftCal
```

Press the **Enter** button. The controller will now use the new SoftCal curve to interpret the silicon diode sensor voltages to the corresponding temperature reading.

3.2.6.4 Erasing the SoftCal Curve

To erase an existing SoftCal curve, press the **SoftCal** button. Use the ▲, ▼, or **SoftCal** button to cycle the selector arrow (→) to Erase. You will see the following display.

```
Select With ▲ ▼
Cal: V   T →Erase
```

Press **Enter**. Use the ▲, ▼, or **SoftCal** button to cycle the selector arrow (→) to Yes. You will see the following display.

```
Select With ▲ ▼
Erase:   →Yes  No
```

Press Enter. You will briefly see the "Erasing SoftCal Values & Curve" message. The old SoftCal curve is now erased.

With regards to accuracy, there are 3 things that can be done with a temperature sensor:

Silicon Diode Temperature Sensor

Standard

Standard sensors are interchangeable within the published tolerance band. Standard Curve 10 Tolerance (Accuracy) Bands for CY7 are listed below.

Band Suffix (Range)	Accuracy (Tolerance) 2K-100K	100K-305K	305K-475K
-1 (1.4 to 475K)	±0.25K	±0.5K	±1K
-2 (1.4 to 475K)	±0.5K	±1.0K	±2.0K
-3 (1.4 to 475K)	±0.5K	±1% of T	±1% of T
-4 (1.4 to 475K)	±1K	±1% of T	±1% of T
-7 (10 to 425K)	±1.5K	±1.5% of T	±1.5% of T

To increase accuracy, the User may perform a SoftCal with his controller and sensor. Once a sensor is calibrated, the standard Curve 10 is replaced with the custom curve for that sensor.

SoftCal Calibration

An OMEGA SoftCal can only be performed on Silicon Diodes. For a 2 point SoftCal, data points are taken at 77.35 K and 305 K. For a 3 point SoftCal, data points are taken at 4.2 K, 77.35 K, and 305 K.

Typical 2 Point Accuracy

±1.0 K	2 K to <30 K
±0.25 K	30 K to <60 K
±0.15 K	60 K to <345 K
±0.25 K	345 K to <375 K
±1.0 K	375 K to 475 K

Typical 3 Point Accuracy

±0.5 K	2 K to <30 K
±0.25 K	30 K to <60 K
±0.15 K	60 K to <345 K
±0.25 K	345 K to <375 K
±1.0 K	375 K to 475 K

A voltage is taken at the 2 or 3 data points. These voltages can be entered into controllers with SoftCal capability. A calibration report is sent with the sensor.

Precision Calibration

OMEGA can do a precision calibration on most sensor types. Up to 99 separate data points can be taken, with the ability to concentrate taking data in areas of particular interest. Typical calibration accuracy for silicon diodes is listed below.

Typical Precision Cal. Accuracy

Temp.	Typical	Maximum
<10 K	12 mK	20 mK
10 K	12 mK	20 mK
20 K	15 mK	25 mK
30 K	25 mK	45 mK
50 K	30 mK	55 mK
100 K	25 mK	50 mK
300 K	25 mK	50 mK
340 K	—	100 mK
480 K	—	100 mK

A curve is fitted to these points. A very detailed report that includes:

- Raw Temperature Data
- Polynomial Fits
- Interpolation Tables

is sent with the sensor.

A Precision Option can be generated for either SoftCal or the Precision Calibration:

Precision Option - or - **User calculates break-points and manually enters data into the controller**

ATP-8000

Precision Option breakpoint pairs are loaded on a Floppy Disk in ACSII format for Customer downloading.

ATP-8002-05

Precision Option breakpoint pairs are loaded in a NOVRAM for field installation.

Figure 3-3. Sensor Calibrations and Precision Options

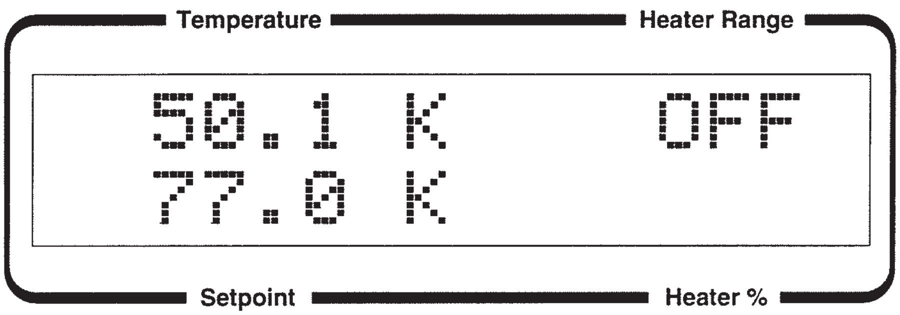
3.3 CONTROL FUNCTIONS

The following front panel keyboard function are related to the control aspects of the controller.

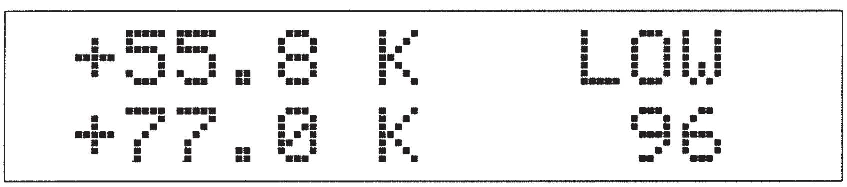
Function	Section
Heater	3.3.1
Setpoint	3.3.2
Ramp	3.3.3
Autotune	3.3.4
Manual	3.3.5
Zone	3.3.6

3.3.1 Heater High, Low, and Off

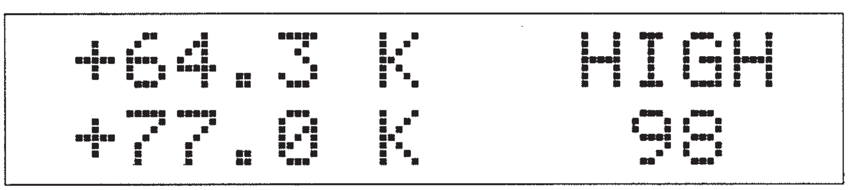
There are three buttons and two portions of the display to control and indicate heater operations. The three buttons are **Heater High**, **Heater Low**, and **Heater Off**. The two display areas are **Heater Range** in the top line and **Heater %** in the lower line. When the user presses **Heater High**, **Heater Low**, or **Heater Off**, the selection is reflected in the **Heater Range** portion of the display. The Heater Off condition is shown in the following display.



When the heater is on, **Heater %** will reflect the percentage of current being applied to the heater. The heater low output is 2.5 Watts maximum into 25 Ω. A typical **Heater Low** display is shown as follows.



The heater high output is 25 Watts maximum into 25 Ω. A typical **Heater High** display is shown as follows.



The percentage of current reflects the percentage of full scale current being applied to the heater output, and will change automatically according to control parameters.

NOTE

If the heater load drops below ≈20 Ω, the output power will reduce. However, the display may still show the Heater % reading of a 25 Ω load.

A 25 Ω load is required to get a full 25 Watt power output. Refer to Section 2.10 for heater setup and power considerations.

3.3.2 Setpoint

To change the setpoint, press the **Setpoint** button. You will see the following display.

```
Enter Setpoint:
       +077.0   K
```

Use the numeric keypad to enter a new setpoint, press **Enter** to accept the new setpoint or **Escape** to return the normal display and retain the old setting. You may also use either ▲ or ▼ to increment or decrement the display in tenths of a degree. The setpoint can be set as follows: for a CYC3211, the available selections are K (kelvin), C (Celsius), and V (Volts). For a CYC3212, the available selections are K (kelvin), C (Celsius), and Ω (ohms). For a CYC3214, the available selections are K (kelvin), C (Celsius), and mV (millivolts). Display in K is the default value for all three models.

The setpoint is limited in temperature to the range of the curve being used for control. Table 3-1 gives these limitations in kelvin for curves 00 through 04 and 06 thru 10. The setpoint resolution in temperature is 0.1 degrees.

3.3.2.1 Voltage Resolution (CYC3211 and CYC3214 Only)

Voltage mode is used for the Silicon Diode Input. In voltage mode, the display has a resolution of 0.0001 Volt (V). For thermocouple input, the display is in millivolts. The millivolt display resolution is 1 microvolt.

3.3.2.2 Resistance Resolution (CYC3212 Only)

The Resistance mode is allowed for the Platinum Resistor input configuration. The display resolution, in resistance, is 0.01 Ω below 200 Ω and 0.1 Ω above 200 Ω.

3.3.3 Ramp

The controller has a programmable ramp feature with a programmable rate. This feature allows the user to set the rate at which the temperature setpoint increases or decreases when the user changes the setpoint value. The ramp rate range is from 0.1 to 99.9 degrees per minute. Ramp will only work if the controller is reading in temperature units (K or °C). An example of ramp rate is as follows. Given a starting setpoint is 50 K, the user would see the following normal display.

```
  +50.1 K    OFF
  +50.0 K
```

In this example, the user wants to change the setpoint from 50 K to 100 K at a rate of 1 k/min. To set this up, the user begins by pressing the **Ramp Rate** button. Then press the either the ▲, ▼, or **Ramp Rate** button to cycle the selector arrow (→) between choices. The available selections are On and Off, with Off being the default. See the following display.

```
Select With ▲ ▼
Ramping:→On  Off
```

With the arrow pointing to On, pressing the **Enter** button will bring up the Enter Ramp Rate display. Using the numeric keypad, press the number 1. You should see the following display.

```
Enter Ramp Rate
      01.0   K/min
```

Press **Enter** to accept the new ramp rate. You will now return to the normal display. Now press the **Setpoint** button and use the numeric keypad to enter 100 K. You should see the following display.

```
Enter Setpoint:
     +0100.0 K
```

The normal display returns showing the old setpoint of 50 K. The display slowly begin to change to 100 K at a rate of 1 K per minute, reaching 100 K in 50 minutes. The ramp can be stopped at the current setpoint by pressing **Setpoint** and then **Enter**. To turn off the ramping feature, press the **Ramp Rate** button and use either the ▲, ▼, or **Ramp Rate** button to cycle the selector arrow (→) to no, then push **Enter**.

3.3.4 Autotune

There are five tuning modes on the controller: Auto P, Auto PI, Auto PID, Manual, and Zone. This paragraph will discuss the three Autotune modes. The Autotuning algorithm determines the proper settings for Gain (**P**roportional), Reset (**I**ntegral) and Rate (**D**erivative) by observing the time response of the system upon changes in setpoint under either P, PI or PID control.

Adaptation of an autotuning algorithm for use at cryogenic temperatures is a more complex issue than for more stable, well-behaved, high-temperature loads. For example, over its useful temperature range a single cryogenic load may exhibit thermal property variations of three orders of magnitude or greater.

The Autotuning function is initiated with a change in temperature setpoint. The controller automatically gathers data to determine optimum control parameters. No more tuning will be done until the next change in setpoint. The controller will never disturb the system. It tunes only on user setpoint changes.

System design is also a factor. Under some circumstances, very fast cryogenic systems may not provide sufficient data points on step changes to accurately predict the proper control settings. Unusually large thermal lags, caused by poor placement and mounting relative to the heater, can obstruct the correlation between the heater and the system necessary to tune properly.

For slower systems with longer time constants, which are very difficult to tune manually, Autotuning can obtain enough information on a step change to characterize the system and determine proper values for Gain, Reset, and Rate.

To put the controller in Autotune PID mode, press the **AutoTune** button, and press either the ▲, ▼, or **AutoTune** button to cycle the selector arrow (→) to Auto PID. You should see the following display.

```
Select With ▲ ▼
Tune: Auto PID
```

Press the **Enter** button. The controller is now in Autotuning PID mode. The method for setting the controller to Auto P or Auto PI modes is the same as just explained. Further information on Auto P, I, and D settings are provided in the following paragraphs.

3.3.4.1 Initial Values of PID Parameters In Autotune Mode

The initial values of the PID parameters in the Autotune mode are set when the controller is changed from Manual to either P, PI or PID control. The initial PID factory settings are 50 and 20 with the controller set for PI control.

3.3.4.2 Minimum Overshoot

The full three function PID control algorithm is designed to minimize overshoot. It uses Gain (P), Reset (I), and Rate (D) to bring the system to the control temperature as smoothly as possible. To select the PID tuning algorithm, press the **AutoTune** button.

3.3.4.3 Minimum Time To Setpoint

The two function PI control algorithm minimizes the time it takes for the system to first reach the setpoint. Some of the damping used in PID control is not present so more overshoot should be expected. To select the PI tuning algorithm, press the **AutoTune** button.

3.3.4.4 Gain Only

The third control algorithm available on the controller is Gain (P) only. No time dependent control parameters (other than digital sampling rate) will be initiated by the controller. In this mode, characteristics of the system being controlled are more apparent but there will be a temperature offset from the setpoint. To select the P tuning algorithm, press the **AutoTune** button.

3.3.5 Manual Control Settings (PID)

There are five tuning modes on the controller: Auto P, Auto PI, Auto PID, Manual, and Zone. This section will discuss the Manual mode. In manual mode, the controller will accept Gain, Reset and Rate parameters from the user to provide three term PID control. To put the controller in Manual mode, press the **AutoTune** button, and press either the ▲, ▼, or **AutoTune** button to cycle the selector arrow (→) to Manual. You should see the following display.

```
Select With ▲ ▼
Tune: Manual
```

Press the **Enter** button. The controller is now in Manual mode. Further information on setting gain (Proportional), refer to Section 3.3.5.1. Setting reset (Integral) is discussed in Section 3.3.5.2. Setting rate (Derivative) is discussed in Section 3.3.5.3. Finally, the effect of temperature on tuning parameters is discussed in Section 3.3.5.4.

3.3.5.1 Setting Gain (Proportional)

Adjustment of the gain (Proportional) part of the control function gives the controller an overall range of 000 to 999. To enter a gain value, press the **P** button. You will see the following display.

```
Enter P: 000-999
         050
```

This display shows the current Proportional setting (the default setting is 50). Use the numeric keypad to enter a new setting. Press **Enter** to accept the new Proportional setting or **Escape** to return the normal display and retain the old setting.

To experimentally determine the proper gain setting, use the following procedure. Set Autotune to Manual, then turn off both Reset (I) and Rate (D). Set in a nominal gain setting of 50. Make sure that the heater turns on; if not, increase the gain setting until the heater turns on. Let the system stabilize. Note that it will stabilize at some point below the setpoint (typically 2 to 3 K below). Keep increasing the controller gain by factors of two until the system temperature begins to oscillate. Adjust the gain for small sustained oscillations. Measure the period of these oscillations for determining the correct setting for reset. Reduce the gain by a factor of two to three until the temperature again becomes stable with time. Be sure that you allow time at each setting for the system to stabilize (if it will). For some systems and cryogenic sensors with low sensitivity, the maximum gain is required.

3.3.5.2 Setting Reset (Integral)

Adjusts the reset time constant of reset (Integral) in the control function. Effective reset time constants, between 1 and 999 seconds can be achieved by entering reset settings of 1 - 999. Reset time in seconds is (999/Value Entered). A reset of zero will make the controller proportional only. To enter a reset value, press the **I** button. You will see the following display.

```
Enter  I:  000-999
          020
```

This display shows the current Integral setting (the default setting is 20). Use the numeric keypad to enter a new setting. Press **Enter** to accept the new Proportional setting or **Escape** to return the normal display and retain the old setting. For example, if the Reset setting is 20 the reset time in seconds is approximately 50 (999/20=50).

The reset number is an industrial control term which in the controller corresponds to the number of repeats (or time constants) per 1000 seconds. The time constant is 1000 divided by this number in seconds. Consequently, a reset number setting of 20 corresponds to a time constant of 50 seconds. A system will normally take several time constants to settle into the set point, e.g. the 50 second time constant, if correct for the system being controlled, would result in a stable set point in a time frame between 5 and 10 minutes.

The oscillation period which you measured in determining the appropriate gain setting is equal to the reset time constant which is desired. Divide this number in seconds into 1000 and set the result into the RESET register. This result is the number of repeats per 1000 seconds. If the system did not oscillate at the highest gain setting, use the following procedure. Stabilize the temperature at a high gain setting. Change the set point downward by one or two degrees and observe the time that it takes for the temperature to change 60% of this excursion. Use this number as the reset time constant; divide it into 1000 and set in the result as the RESET value.

3.3.5.3 Setting Rate (Derivative)

This adjusts rate time constant of derivative (D) in the control function. Effective settings are between 0 seconds and 200% of 1/4 the reset time. In manual mode, rate is normally set at 1/4 the reset time in seconds (100%), because larger values may cause system instability. To enter a rate value, press the **D** button. You will see the following display.

```
Enter  D:  000-200
          100
```

This display shows the current Derivative setting (the default setting is 100). Use the numeric keypad to enter a new setting. Press **Enter** to accept the new Proportional setting or **Escape** to return the normal display and retain the old setting.

The rate time constant should normally be somewhere between 1/4 and 1/8 the reset time constant, if it is used at all. Consequently, you can set it between 0 and 200% of 1/4 the reset time constant. Start with settings of either 0, 50 or 100% and determine which setting gives you the type of control which you desire. Don't be surprised if for your system, the setting you prefer is 0 (OFF). Note that by using a percent of reset time constant, rate scales automatically with changes in the reset value and does not have to be revisited frequently.

3.3.5.4 Effect of Temperature on Tuning Parameters

As the temperature increases, the system gain normally increases. Consequently, if the sensor sensitivity is relatively constant, you can normally increase the controller gain with increasing temperature.

The system gain is a product of the controller gain and the sensor gain. For example, for a silicon diode at 25 K the sensor sensitivity (dV/dT) is approximately an order of magnitude larger than it is at 35 K. If the load parameters have not changed greatly, neither will the system gain. Therefore, the controller gain should be increased to compensate for the reduction in sensor sensitivity.

Concerning Reset (I) change with temperature, in a normal cryogenic system, the time response of the system slows down as the temperature increases. Consequently, as the temperature rises the time constant will become longer as well. Therefore, if you have determined a valid value of reset at a particular temperature, increasing the temperature will result in a decrease in the reset number, i.e., a longer time constant; conversely decreasing temperature will demand a shorter time constant, i.e., an increase in the reset setting.

3.3.6 Zone Setting

There are five tuning modes on the controller: Auto P, Auto PI, Auto PID, Manual, and Zone. This paragraph will discuss Zone. The controller allows the user to establish up to 10 custom temperature zones where the controller will automatically use pre-programmed PID settings and heater range. The user should configure the zones using 01 as the lowest to 10 as the highest zone in K. Make a copy of Figure 3-4 to plan your zones, then use the manual to record final zone settings.

If this feature is combined with the ramp rate feature, the user could do a ramp through all 10 zones from 1.4 K to room temperature by only changing the setpoint. The controller will automatically change the PID and heater range settings as the temperature setpoint passes through the different zones.

To setup a zone, ensure the units are set to K, then press the **Zone Setting** button. Use the numeric keypad to enter the number 1. You will see the following display.

```
Enter Zone 01-10
        01
```

Press the **Enter** button. The Enter Setpoint display will then appear. Use the numeric keypad to enter a setpoint. For this example, we will enter 77 K. You should see the following display.

```
Enter Setpoint:
    +077.0  K
```

Press the **Enter** button. The Heater Range display will then appear as follows.

```
Select With ▲ ▼
Rg:→Off Low High
```

Use the ▲ or ▼ button to cycle the selector arrow (→) through Heater Range selections of Off, Low, and High. For this example, we will select Off. Press the **Enter** button. The Gain (Proportional) display is next as follows.

```
Enter P: 000-999
       050
```

The user may select a gain setting from 000 to 999. For this example, we have entered a setting of 50. Press the **Enter** button. The Reset (Integral) display is next as follows.

```
Enter I: 000-999
       020
```

The user may select a reset setting from 000 to 999. For this example, we have entered a setting of 20. Press the **Enter** button. The final entry is the Rate (Derivative) display as follows.

```
Enter D: 000-200
       100
```

The user may select a rate setting from 000 to 999. For this example, we have entered a setting of 100. Press the **Enter** button. This completes the setting of a typical zone. Repeat this same procedure for other zones as necessary.

Once the zones have been programmed, you need to place the controller in zone mode. To do this, press the **AutoTune** button. Use the ▲ or ▼ button to select Zone. Then press **Enter** to accept the new tuning mode. Once zone is turned on, the instrument will update the control settings each time the setpoint is changed to a new zone. If the settings are changed manually, the controller will use the new setting while it is in the same zone and update to the zone table settings when the setpoint is changed to a value outside that zone.

Zone Setting WorkSheet

Zone 10 ———————————— Setpoint: ________ K

Heater Range **P** (1-999) **I** (1-999) **D** (1-200)

Off Low High ________ ________ ________

Zone 09 ———————————— Setpoint: ________ K

Heater Range **P** (1-999) **I** (1-999) **D** (1-200)

Off Low High ________ ________ ________

Zone 08 ———————————— Setpoint: ________ K

Heater Range **P** (1-999) **I** (1-999) **D** (1-200)

Off Low High ________ ________ ________

Zone 07 ———————————— Setpoint: ________ K

Heater Range **P** (1-999) **I** (1-999) **D** (1-200)

Off Low High ________ ________ ________

Zone 06 ———————————— Setpoint: ________ K

Heater Range **P** (1-999) **I** (1-999) **D** (1-200)

Off Low High ________ ________ ________

Zone 05 ———————————— Setpoint: ________ K

Heater Range **P** (1-999) **I** (1-999) **D** (1-200)

Off Low High ________ ________ ________

Zone 04 ———————————— Setpoint: ________ K

Heater Range **P** (1-999) **I** (1-999) **D** (1-200)

Off Low High ________ ________ ________

Zone 03 ———————————— Setpoint: ________ K

Heater Range **P** (1-999) **I** (1-999) **D** (1-200)

Off Low High ________ ________ ________

Zone 02 ———————————— Setpoint: ________ K

Heater Range **P** (1-999) **I** (1-999) **D** (1-200)

Off Low High ________ ________ ________

Zone 01 ———————————— Setpoint: ________ K

Heater Range **P** (1-999) **I** (1-999) **D** (1-200)

Off Low High ________ ________ ________

0 K ———————————— 0 K

Figure 3-4. Record of Zone Settings

3.4 INTERFACE AND MISCELLANEOUS FUNCTIONS

The following front panel keyboard function are related to the thermometry or temperature control aspects of the controller.

Function	Section
Baud	3.4.1
Analog Out	3.4.2
Defaults/Reset	3.4.3
PUP	3.4.4

3.4.1 Baud

If using the Serial Interface, the use must set the Baud rate. Pressing the **Baud** button brings up the following display.

```
Select With ▲ ▼
Baud: →300  1200
```

Use either the ▲, ▼, or **Baud** button to cycle the selector arrow (→) between choices. The available selections are 300 and 1200 Baud, with 300 being the default. Press **Enter** to accept the new Baud rate or **Escape** to return the normal display and retain the old setting. Other communication parameters are fixed as listed in Table 4-1.

3.4.2 Analog Out

The Analog Output provides a 0 to 10 volt (1 mA max) output that corresponds to the temperature reading. The default analog output has the 0 to 10 volts corresponding to 0 to 1000 K. The resolution is 1.22 mV (0.122 K) and the accuracy is ±0.04% of full scale output + measurement accuracy. The user also has the option to rescale the analog output; assigning new temperatures (in kelvin) to correspond to 0 and 10 V (minimum temperature resolution is 0.1 K).

To program the analog output, press the **Analog Out** button. You will see the following display.

```
Select With ▲ ▼
AnOut:→Def  User
```

The default selection is default, where the 1 to 10 volt output will correspond to 1 to 1000 K. A different (narrower) temperature range may be selected by using either the ▲, ▼, or **Analog Out** button to cycle the selector arrow (→) to User. Upon pressing the **Enter** button, you will see the Enter Maximum display. For this example, we will use the numeric keypad to enter a maximum temperature of 300 K. After making this entry, you should see the following display.

```
Enter Max AnaOut
    +0300.0 K
```

Press the **Enter** button. The Enter Minimum display will now appear. For this example, we will use the numeric keypad to enter a minimum temperature of 2 K. After making this entry, you should see the following display.

```
Enter Min AnaOut
     +0002.0 K
```

Press the **Enter** button. This completes the definition of the analog output. The 0 to 10 volt output will now correspond to 2 K to 300 K.

3.4.3 Factory Default Settings

The controller can be reset to factory default settings by pressing and holding the **Escape** button for ≈5 seconds. An alternate method is to turn off the unit, and press and hold the **Escape** button while turning the controller on. In either case, the user will see the following display.

CAUTION

Any user or SoftCal curves and zone settings are erased when the controller is initialized.

```
Select With ▲ ▼
Init RAM:→Yes No
```

Use either the ▲ or ▼ button to cycle the selector arrow (→) between choices. Press No if you do not wish to reinitialize the memory. Press Yes followed by the **Enter** button if you do wish to initialize the memory. After briefly flashing a “RAM Initialized” message, the controller will then be returned to factory settings as follows.

Heater	Off
Setpoint	0.0
Units	K
Input Type	Determined by Model Number
Filter	Off
TempComp	Off
Ramp Rate	Off
Curve	Determined by Model Number; user and SoftCal curves erased
SoftCal	V selected but not implemented
Zone Settings	Erased
Baud	300
Analog Out	Default (0 V = 0 K, 10 V = 1000 K)
AutoTune	Auto PID selected
P	50
I	20
D	100

3.4.4 Power Up (PUP) Configuration

A provision has been made to store a Power Up (PUP) configuration for the controller. This ensures that it will power up to a user-defined state after power down. Parameters including heater range, setpoint, gain, reset, units, and curve number are stored in non-volatile memory and preserved even when the line cord is disconnected.

To view PUP status, press and hold the Enter key for ≈5 seconds. You will see the following display.

```
Select With ▲ ▼
PUP: →On  Off
```

"On" indicates that the power up settings will change when settings on the instrument are made via the front panel or over the remote interface. "On" is the default PUP condition.

"Off" indicates that updates to the power up memory are disabled and the instrument will power up in the configuration it was in when the power up feature was turned off.

3.5 THERMOCOUPLE CONTROLLER OPERATION (CYC3214 ONLY)

The thermocouple input option is designed for thermocouple sensors. CHROMEGA®-AuFe (0.07%), CHROMEGA®-AuFe (0.03%), E, K, and T thermocouples are supported with internal curves that enable the controller to operate in temperature units (°C and K) as well as voltage in millivolts.

The thermocouple input utilizes a secondary temperature sensor to monitor the Reference Junction (room) temperature and provide curve compensation. Thermocouple (Reference Junction) Compensation can be disabled in order for the controller to be used with external compensation techniques.

3.5.1 Sensor Attachment

Thermocouple leads are attached to the terminal block by aluminum screws. Be sure to tighten the terminal screws carefully. Loose connections will result in unstable readings and control. The leads must be connected with the proper polarity or the input option will not operate properly. The positive terminal of the terminal block is on the side of the V+ label on the back panel and should correspond with the positive thermoelement listed for each type of thermocouple.

3.5.2 Thermocouple Curve Selection

To choose a thermocouple curve listed in Table 2-3. Refer to the instructions for curve selection in Section 3.2.5.

3.5.3 Thermocouple Compensation From Front Panel

To determine whether thermocouple compensation is selected or not, refer to Section 3.2.3.

3.5.4 Thermocouple Compensation From Remote Interface

To select or prevent thermocouple compensation over the remote interface, use the ACOMP command described in Chapter 4 - Remote Operation.

3.5.5 Internal Offset Adjustment

When a new or different thermocouple is attached to the controller, you must adjust the offset to compensate for discrepancies in thermocouple material, leads, and connections. Offset adjustment trimpots are provided inside the controller to allow offset calibration of the thermocouple.

1. Place the thermocouple in a reference bath of known temperature (liquid nitrogen, ice, etc.). Allow the system to stabilize to the reference temperature.
2. On the front panel, select the thermocouple input and the desired temperature units.
3. Turn on thermocouple compensation.
4. Remove the controller cover.
5. Adjust the offset adjustment trimpot (R22) so that the displays read the reference temperature.

NOTE

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

3.5.6 Curve Format

The input is hardware limited to reading input between -45 mV and +45mV. All curves should be limited in temperature so not to exceed these values. If thermocouple compensation is desired, the thermocouple curve must be normalized to zero in degrees Celsius. Compensation also limits the practical range of the card by approximately the room temperature voltage of the thermocouple used.

The controller is designed to operate on sensor curve data in the range of 0.00000 to 9.00000 volts so thermocouple voltage must be converted to this range before it is entered into a curve table. To obtain the proper table value from a thermocouple voltage, it must be summed with 45 millivolts to make it positive and multiplied by one hundred to shift the resolution.

A -45.0000 millivolt thermocouple voltage will result in a 0.00000 volt table value and +45.0000 millivolts will result in 9.00000 volts.

This Page Intentionally Left Blank

CHAPTER 4
REMOTE OPERATION

4.0 GENERAL

This section provides a description of the SERIAL I/O Interface. RS-232C is a standard of the Electronics Industries Association (EIA) describing of one of the most common interfaces between a computer and electronic equipment. To utilize this interface, a customer supplied computer is required equipped with a RS-232C Interface port. When a connection is made between the computer and the controller, the Serial Interface permits remote monitoring and control of the controller's control functions, which in turn controls the operation of the controller. See Figure 4-1.

The Serial Interface is capable of bi-directional communication, i.e., it can both transmit and receive information. In transmission (Tx) mode, RS-232C Interface converts parallel information to serial information and sends that information over a cable up to 50 feet long (or longer with proper shielding). In the receiving (Rx) mode, the RS-232C Interface converts the serial information back to parallel information for processing.

The remote operation chapter has three primary sections. The serial interface description is described in Section 4.1. The Serial interface command summary is provided in Section 4.2. A user Curve11 loading program is provided in Section 4.3.

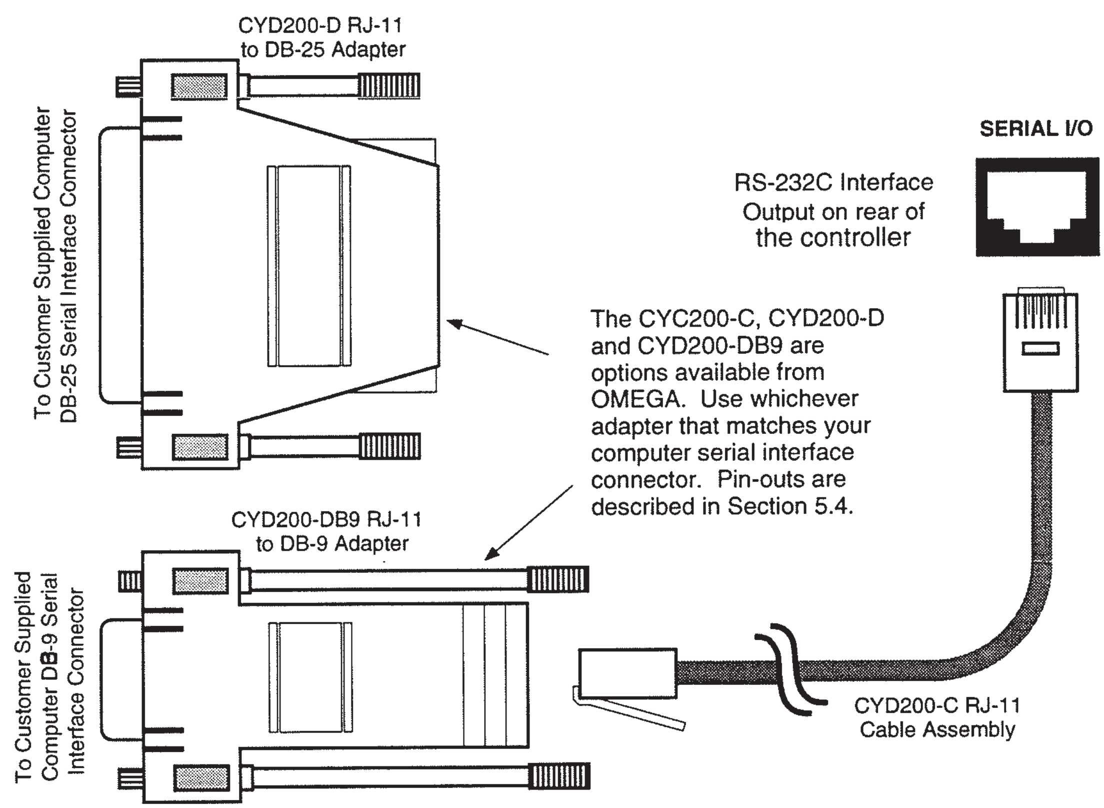


Figure 4-1. Optional Serial Interface Connections

4.1 SERIAL INTERFACE DESCRIPTION

The Serial Interface hardware configuration is described in Section 4.1.1.

Serial Interface settings are described in Section 4.1.2.

A sample BASIC program to establish communications between the computer and the controller is provided in Section 4.1.3.

Commands are divided into four types: Display, Channel, Control Process, and Curve. Individual commands are described in Section 4.2.

4.1.1 Serial Interface Configuration

The following is a technical description of the Serial Interface configuration. The controller operates at two different Baud rates: 300 or 1200. Press the **Baud** button and use the ▲, ▼, or **Baud** buttons to cycle the selector arrow (→) to the desired baud rate. Press **Enter** to accept the new baud rate or **Escape** to cancel the entry. The remaining communication parameters are fixed as defined in Table 4-1.

The connector used for the serial interface is a standard 6-wire RJ-11 (telephone) jack. OMEGA offers the optional CYD200-C 14-foot Cable Assembly, CYD200-D RJ-11 to DB25 Adapter, and the CYD200-DB9 RJ-11 to DB9 Adapter, as shown in Figure 4-1.

Table 4-1. Serial Interface Parameters

Transmission:	Three-Wire
Connector:	RJ-11 Modular Socket
Timing Format:	Asynchronous
Transmission Mode:	Half Duplex
Baud Rate:	300 or 1200
Bits per Character:	1 Start, 7 Data, 1 Parity, and 1 Stop
Parity Type:	Odd
Data Interface Levels:	Transmits and Receives Using EIA Voltage Levels
Terminator:	CR (0DH) LF (0AH)

4.1.2 Sample BASIC Serial Interface Program

The program in Table 4-2 is a sample interactive serial poll routine for the controller Serial Interface written in QuickBASIC V4.0. The following are examples using this BASIC program. (Input provided by the user is shown in **bold** type.)

`ENTER COMMAND?` **CUNI K**	Set Control Units. Instrument will set unit to kelvin units.
`ENTER COMMAND?` **CUNI?**	Control Units Query. Instrument will return appropriate unit, where K = kelvin.
`K`	
`ENTER COMMAND?` **CDAT?**	Sensor Data Query. Instrument will return appropriate sensor reading.
`+77.6`	
`ENTER COMMAND?` **TUNE 3**	Set Autotuning Status. Instrument will set Autotuning to PID.
`ENTER COMMAND?` **TUNE?**	Autotuning Status Query. Instrument will return appropriate setting, where 0 = Manual, 1 = P, 2 = PI, and 3 = PID.
`3`	
`ENTER COMMAND?` **RANG 0;RANG?**	Combination command of setting the heater to off and requesting heater status; where 0 = off and 1 = on.
`0`	
`ENTER COMMAND?`	

Table 4-2. QuickBASIC (V4.0) Serial Interface Program

```
      'This program is written in QuickBasic 4.0 for use
      'on an IBM PC or compatible.
      '
      'Enter the Controller command at the prompt. The Controller
      'response will then be displayed. "END" will exit the program.

      COUNT = 100
      TERM$ = CHR$(13) + CHR(10)

      OPEN "com1:300,o,7,1,RS" FOR RANDOM AS #1 LEN = 256
L1:   INPUT "ENTER COMMAND (END TO EXIT):", CMD$
      CMD$ = UCASE$(CMD$)
      IF CMD$ = "END" THEN CLOSE #1: END
      PRINT #1, CMD$ + TERM$

      IF INSTR(CMD$, "?") <> 0 THEN
        RS$ = ""
        N = 0
        WHILE (N < COUNT) AND ((INSTR(RS$, TERM$) = 0) OR (RS$ = ""))
          R$ = INPUT$(LOC(1), #1)
          IF R$ = "" THEN N = N + 1 ELSE N = 0
          RS$ = RS$ + R$
        WEND
        IF RS$ <> "" THEN
          RS$ = MID$(RS$, 1, (INSTR(RS$, TERM$) - 1))
          PRINT "RESPONSE:"; RS$
        ELSE
          PRINT "NO RESPONSE"
        END IF
      END IF
      GOTO L1

      END
```

4.1.3 Notes On Using The Serial Interface

Query commands end with a "**?**." The commands (along with a brief description) recognized by the controller are summarized by function in Section 4.2. Additional notes are as follows:

- Commands may be chained together when separated by a semi-colon (**;**). Multiple queries cannot be chained.
- Queries have the same syntax as the associated setting command followed by a question mark (**?**). They should return the same information that is sent.
- A query may be added to the end of a command string if the instrument is required to return information. For example, CUNI K;CUNI? commands the controller to set the temperature units to kelvin followed by a request that the controller return the temperature units to confirm the change had been made.
- Leading zeros and zeros following a decimal point are not needed in a command string, but they will be sent in response to a query. A leading "**+**" is not required but a leading "**–**" *is* required.
- If you enter a correctly spelled query without a "**?**," nothing will be returned. Incorrectly spelled commands and queries are ignored.
- When the term free field is used, it indicates that the decimal point is a floating entity and can be placed any appropriate place in the string of digits.
- [term] is used when examples are given and indicates where terminating characters should be placed by the user or where they appear on a returning character string from the controller .

4.2 SERIAL INTERFACE COMMAND SUMMARY

This section provides a summary of the Serial Interface Commands. The summary is divided into four command groups: Display, Control Process, Curve Commands, and Analog Output Commands.

A detailed list of Display Commands is provided in Section 4.2.1.

A detailed list of Control Process Commands is provided in Section 4.2.2.

A detailed list of Curve Commands is provided in Section 4.2.3.

A detailed list of Analog Output Commands is provided in Section 4.2.4.The commands are presented in the same order as shown below.

Display Commands

Command	Function	Page
✱IDN	Identification Query	5
CDAT?	Control Sensor Data Query	5
CUNI	Set Control Units	5
CUNI?	Control Units Query	5

Control Process Commands

Command	Function	Page
TUNE	Tune Status	6
TUNE?	Tune Query	6
SETP	Set Setpoint	6
SETP?	Setpoint Query	6
GAIN	Set Gain	7
GAIN?	Gain Query	7
RSET	Set Reset	7
RSET?	Reset Query	7
RATE	Set Rate	7
RATE?	Rate Query	7
RANG	Set Range	8
RANG?	Range Query	8
HEAT?	Heater Query	8
ZONE	Store Zone	8
ZONE?	Zone Query	8
RAMP	Enable/Disable Ramping	9
RAMP?	Ramping Enable/Disable Query	9
RAMPR	Set Ramp Rate in K/min.	9
RAMPR?	Ramp Rate Query	9
RAMPS?	Ramping Status Query	9

Curve Commands

Command	Function	Page
ACUR	Set Curve for A	10
ACUR?	Curve A Query	10
ACOMP	Set A Compensation	10
ACOMP?	A Compensation Query	10
ATYPE?	A Input Type Query	10
CUID?	Curve Identification Query	11
CURV11	Enter User Curve 11	11
CURV?	Curve No. Information Query	12
ECUR11	Edit User Curve 11	13
KCUR11	Delete User Curve 11	13
SCAL	SoftCal Entry	13

Analog Output Commands

Command	Function	Page
ANOD	Set Analog Output Default	14
ANOD?	Analog Default Query	14
ANOH	Set Analog Output Max. (High)	14
ANOH?	Analog Max. (High) Query	14
ANOL	Set Analog Output Min. (Low)	14
ANOL?	Analog Min. (Low) Query	14

4.2.1 Display Commands

This paragraph provides a detailed description of each Display Command. The display commands allow the interface to act as a virtual display. Display data, as well as format, can be transferred. An explanation of the command structure is shown below.

Brief Description of Function

Command Name → **CUNI?** Control Units Query

Syntax of what user must input → **Input:** `CUNI?`

Information returned in response to the query → **Returned:** `K, C, V, R, or M`

Explanation and definition of returned data → **Remarks:** Used to query the unit for current control units information. The character returned will be K for kelvin, C for Celsius, V for Volts, R for Ohms, or M for millivolts.

---

*IDN?

Identification Query.

Input: `*IDN?`

Returned: Manufacturer,model number,0,firmware date

Remarks: Identifies the instrument model and software level. "0" in the returned syntax is in place of the serial number.

Example: `OMEGA,CYC3211,0,121393[term]`

CDAT?

Sensor Data Query.

Input: `CDAT?`

Returned: `+/- 000.0`

Remarks: A free field is active here. The value returned is 7 characters: a sign, 5 digits and a decimal point. The last digit may be a null.

Example:

`+1.2345[term]`	Typical response for a voltage query.
`-123.4 [term]`	Typical response for a degrees Celsius query.
`+234.5 [term]`	Typical response for a kelvin or degrees Celsius query.

CUNI

Set Control Units Status.

Input: `CUNI K`, `CUNI C`, or `CUNI S`

Returned: Nothing

Remarks: Set units parameter with K for kelvin, C for Celsius, or S for the appropriate sensor units (volts, ohms, or millivolts).

Example: If operating in kelvin with a CYC3211, CUNI S[term] makes the units volts; being the sensor units for a diode sensor. The CYC3212 platinum controller has sensor units of ohms, and the CYC3214 thermocouple controller has sensor units of millivolts.

CUNI?

Control Units Query.

Input: `CUNI?`

Returned: `K`, `C`, `V`, `R`, or `M`

Remarks: Returns current control units setting. The character returned will be K for kelvin, C for Celsius, V for volts, R for Ohms or M for millivolts.

4.2.2 Control Process Commands

This paragraph provides a detailed description of each Control Process Command. These commands allow the interface to change any of the control parameters of the controller. Manual mode PID parameters are accessible as well as Autotuning status.

TUNE

Sets Autotuning Status.

Input: `TUNE X`

Returned: Nothing

Remarks: Set Autotuning status as follows: 0 = Manual, 1 = P, 2 = PI, and 3 = PID. Refer to Section 4.1 for further information on Autotuning settings.

TUNE?

Autotuning Query.

Input: `TUNE?`

Returned: `X`

Remarks: Returns current Autotuning status where 0 = Manual, 1 = P, 2 = PI, and 3 = PID. Refer to Section 4.1 for further information on Autotuning settings.

SETP

Sets Setpoint In Units Chosen For Control.

Input: `SETP XXX.X` for temperature, or `SETP X.XXXX` for voltage

Returned: Nothing

Remarks: Fill in the setpoint parameter with a value from 0 through 999.9 for temperature or 0 through 2.499 for voltage. Utilizes the free field format for the decimal point.

Example: If in kelvin:

1. `SETP 77.2[term]` will result in the display showing 77.2 K.
2. `SETP 123[term]` will result in the display showing 123.0 K.

If in Celsius:

3. `SETP -123[term]` will result in the display showing –123.0 C.
4. `SETP 123.456[term]` will result in the display showing 123.4 C.

SETP?

Setpoint Status Query.

Input: `SETP?`

Returned: ±`XXX.X` for temperature, or ±`X.XXXX` for voltage

Remarks: Returns current set point setting. The value returned will be 6 digits (a sign, 4 digits, and a decimal point).

Example: If using the examples above in the SETP command discussion—if in kelvin:

1. `SETP?[term]` will return `+077.2 [term]`.
2. `SETP?[term]` will return `+123.0 [term]`.

If in Celsius:

3. `SETP?[term]` will return `-123.0 [term]`.
4. `SETP?[term]` will return `+123.4 [term]`.

GAIN

Set Gain While In Manual Control Mode.

Input: `GAIN XXX`

Returned: Nothing

Remarks: The gain parameter can be filled in with an integer of 0 through 999.

Example: `GAIN 65 [term]` instructs the controller to set a control gain of 65. Gain corresponds to the Proportional (P) portion of the PID Autotuning control algorithm.

GAIN?

Gain Query.

Input: `GAIN?`

Returned: `XXX`

Remarks: Returns current gain setting in manual or AutoTune mode. The value returned is an integer from 000 through 999. Gain corresponds to the Proportional (P) portion of the PID Autotuning control algorithm.

RSET

Manual Mode Reset Setting.

Input: `RSET XXX`

Returned: Nothing

Remarks: The reset parameter can be filled in with an integer from 0 through 999. Reset corresponds to the Integral (I) portion of the PID Autotuning control algorithm.

RSET?

Reset Query.

Input: `RSET?`

Returned: `XXX`

Remarks: Returns current reset setting. The value returned is an integer from 000 through 999. Reset corresponds to the Integral (I) portion of the PID Autotuning control algorithm.

RATE

Manual Mode Rate Setting.

Input: `RATE XXX`

Returned: Nothing

Remarks: The rate parameter can be filled in with an integer from 0 through 200. Rate corresponds to the Differential (D) portion of the PID Autotuning control algorithm.

RATE?

Rate Query.

Input: `RATE?`

Returned: `XXX`

Remarks: Returns current rate setting. The value returned is an integer from 0 through 200. Rate corresponds to the Differential (D) portion of the PID Autotuning control algorithm.

RANG

Set Heater Status.

Input: `RANG 0`, `RANG 2` or `RANG 3`

Returned: Nothing

Remarks: Sets heater status where 0 = off, 2 = low, and 3 = high.

RANG?

Heater Status Query.

Input: `RANG?`

Returned: `0`, `2` or `3`

Remarks: Returns current heater status where 0 = off, 2 = low, and 3 = high.

HEAT?

Heater Power Status Query.

Input: `HEAT?`

Returned: `XXX`

Remarks: Returns the percent of full scale heater current, where the returned number represents one percent increments up to 100.

ZONE

Zone Storage.

Input: `ZONE XX,±SSS.S,R,PPP,III,DDD`

Returned: Nothing

Remarks: Stores the stated values of Setpoint, Heater Range, Gain, Rate, and Reset. Zone XX is between 01 and 10. ±SSS.S is the setpoint in kelvin, R is the heater range, PPP is the gain, III is the Reset, and DDD is the Rate. The heater Range is 0 for Heater off, 2 for Heater Low, and 3 for Heater High.

Example: `ZONE 1,100.0,2,100.0,100,20[term]` instructs the controller to store in Zone 1 a setpoint of 100.0 K, a Heater Range of 2 (Low), a Gain of 100, a Reset of 100, and a Rate of 20%.

ZONE?

Zone Storage Query.

Input: `ZONE?XX`

Returned: `±SSS.S,R,PPP,III,DDD`

Remarks: When entering the zone command, XX defines the zone between 01 and 10. Returned information is in the following format: ±SSS.S is the setpoint in kelvin, R is the heater range, PPP is the gain, III is the Reset, and DDD is the Rate. The heater Range is 0 for Heater off, 2 for Heater Low, and 3 for Heater High.

RAMP

Enable/Disable Ramp Function.

Input: `RAMP 0` or `RAMP 1`

Returned: Nothing

Remarks: RAMP 0 disables the ramping function while RAMP 1 enables ramping.

RAMP?

Ramping Enable/Disable Status Query.

Input: `RAMP?`

Returned: `0` or `1`

Remarks: Returns a 0 if the ramping function is disabled or a 1 if the ramping function is enabled.

RAMPR

Set Ramp Rate in Kelvin per Minute.

Input: `RAMPR XX.X`

Returned: Nothing

Remarks: XX.X is the ramp rate in Kelvin per minute between 0 and 99.9.

Example: `RAMP 10[term]` instructs the controller to make the ramp rate equal to 10 K/Min.

RAMPR?

Ramp Rate Query.

Input: `RAMPR?`

Returned: `XX.X`

Remarks: Returns the current value of the ramp rate.

RAMPS?

Ramping Status Query.

Input: `RAMPS?`

Returned: `0` or `1`

Remarks: Returns a 1 if the instrument is in the process of ramping or a 0 if not ramping.

4.2.3 Curve Commands

This paragraph provides a detailed description of each Curve Command. The commands allow the user to verify existing curves added at the factory or enter and delete the user defined curve over the interface.

ACUR

Assign Curve Number.

Input: `ACUR XX`

Returned: Nothing

Remarks: Fill in curve parameter with an integer from 0 through 12. Refer to Table 2-2 for a listing of sensor curve numbers.

ACUR?

Curve Number Query.

Input: `ACUR?`

Returned: `XX`

Remarks: Value returned is an integer from 00 through 12, corresponding to the currently selected sensor curve number. Refer to Table 2-2 for a listing of sensor curve numbers.

ACOMP

Set Room Temperature Compensation **(CYC3214 Thermocouple Only).**

Input: `ACOMP 0` or `ACOMP 1`

Returned: Nothing

Remarks: Select temperature compensation parameter with 0 for off or 1 for on.

ACOMP?

Room Temperature Compensation Query **(CYC3214 Thermocouple Only).**

Input: `ACOMP?`

Returned: `0` or `1`

Remarks: Returns current room temperature compensation status where 0 = off and 1 = on

---

ATYPE?

Input Type Query.

Input: `ATYPE?`

Returned: `SI`, `PT`, `TC`, or `ER`

Remarks: Returns input type where SI = silicon diode, PT = platinum, TC = thermocouple, and ER = error (improper switch setting).

CUID?

Curve Identification Query.

Input: `CUID?`

Returned: `WW,XXXXXXXXXXXXXXXXXX,Y,ZZ,...`

Remarks: Returns the header lines that identify the curves (standard sensor and user curve) loaded into each curve location. The information lines for the user curve will only be available if it is actually present. Information returned is defined as follows:

W = Curve number:	The value given here will be 00 through 11.
X = Curve description:	18 character information line. All 18 character spaces do not have to be used.
Y = Temp. coefficient:	N represents a negative temperature coefficient, while P represents a positive one.
Z = Number of points:	This value will be the number of points for that particular curve (usually 31, but can be up to 99).

Example:

```
00, STANDARD DRC-D ,N,31,
01, STANDARD DRC-E1,N,31,
02, STANDARD CRV 10,N,31,
03, STANDARD DIN-PT,P,31,
```
etc.

CURV11

Initiate User Curve.

Input: `CURV11,AAAAAAAAAAAAAAAAAA,W.WWWWW,XXX.X,Y.YYYYY,ZZZ.Z*`

Returned: Nothing

Note: Due to the limited 256 character buffer used by the serial interface, an entire curve cannot be loaded at once. The CURV11 command should be used to enter the first two points and then the ECUR11 command to add the remaining points one at a time up to a maximum of 97 points.

Remarks: This command is used to establish and enter the first two points of the user curve in the following format:

A = 18 characters for curve description (must be at least 1 character).
W = First voltage or resistance.
X = First temperature.
Y = Second voltage or resistance.
Z = Second temperature.

The data points are input with the units value first. This value will be voltage or R_{equiv}. The value will have one character before the decimal place and five after it (0.00000). The table below gives the conversion of raw units into the format required. The controller automatically fills in leading and trailing zeros.

The second value is the temperature. It has three character spaces before the decimal point and one after it (000.0). After both points are input, placement of an "*" terminates the sensor curve input.

To view a typical output after using this command, refer to the example under the CURV? command. When entering, omit the temperature coefficient, number of points, and endpoints.

The controller determines and stores whether the curve is a positive or negative coefficient curve. Based on temperature coefficient, the controller then stores the curve end points and also adds the number of points.

(Continued on next page)

CURV11 (Continued)

INPUT TYPE	UNITS	CONVERSION
Silicon Diode	Voltage	Input range is 0.00000 to 6.00000.
Platinum	Resistance	Input range is 0.00 to 299.99 Ω. 0.00 Ω looks like 0.00000 and 299.99 Ω looks like 2.99990 (0.01 times R).
Thermocouple	Millivolts	Input range is –45 to +45. Add 45 mV to make all positive 0-90 mV and multiply by 100 to make look like 0-9.00000 V. For example, a thermocouple voltage of 0.0000 mV would be entered as 45.00000V.

To aid in the automated loading of the User Curve, a QuickBASIC Curve Loading Program is provided in Section 4.3.

CURV?

Curve Number Information Query.

Input: `CURV? XX`

Returned: `AA,BBBBBBBBBBBBBBBBBB,C,XX,Y.YYYYY,ZZZ.Z`

Remarks: User must provide curve number (00 thru 12) with query. The instrument will return header line and all point information for that curve. Information returned is defined as follows:

A = Curve number:	The value will be from 00 to 12.
B = Curve description:	18 character information line. All 18 characters may not be used.
C = Temp. coefficient:	N represents negative temperature coefficient, while P represents positive.
X = Number of points:	The number of data points for that particular curve (usually 31, but can be up to 99).
Y = Units:	The value will be voltage or R_{equiv}. (Refer to CURV Command). The value will have 1 character before the decimal place and 5 after it (0.00000).
Z = Temperature:	The value will have 3 places before the decimal point and one after it (000.0).

Example:

```
00, STANDARD DRC-D ,N,31,
0.00000,499.9,0.19083,365.0,
0.24739,345.0,0.36397,305.0,
0.42019,285.0,0.47403,265.0,
0.53960,240.0,0.59455,220.0,
0.73582,170.0,0.54606,130.0,
0.95327,090.0,1.00460,070.0,
1.04070,055.0,1.07460,040.0,
1.09020,034.0,1.09700,032.0,
1.10580,030.0,1.11160,029.0,
1.11900,028.0,1.13080,027.0,
1.14860,026.0,1.07200,025.0,
1.25070,023.0,1.35050,021.0,
1.63590,017.0,1.76100,015.0,
1.90660,013.0,2.11720,009.0,
2.53660,003.0,2.59840,001.4,
6.55360,000.0[term]
```

ECUR11

Edit or Add A Data Point In User Curve 11.

Input: `ECUR11,X.XXXXX,YYY.Y`

Returned: Nothing

Remarks: Fill in the point to be added or edited, where X.XXXXX is voltage and YYY.Y is the temperature in kelvin. If the controller does not recognize either the units value or the temperature value, it will assume that you are entering a new point and place it in the proper ascending position.

Example: If the point to be edited was input as 0.19083,364.0 and should have been 0.19083,365.0, input the command as follows:

`ECUR 11,0.19083,365.0[term]`

The controller will recognize the units field and replace that data point with the new temperature value.

KCUR11

Delete User Curve 11 Data Command.

Input: `KCUR11`

Returned: Nothing

Remarks: Will delete all data stored for the User Curve 11.

SCAL

SoftCal™ Voltage Entry.

Input: `SCAL 12,X.XXXXX,Y.YYYYY,Z.ZZZZZ`

Returned: Nothing

Remarks: Stores the SoftCal voltage values at 4.2 K, 77.32 K, and 300 K, where X.XXXX = 4.2 K voltage, Y.YYYYY = 77.32 K voltage, and Z.ZZZZZ = 300 K voltage.

Example: `SCAL 12,1.6260,1.0205,0.5189[term]`

4.2.4 Analog Output Commands

This paragraph provides a detailed description of each Analog Output Command. The commands allow the user to control the output of the analog output over the interface.

ANOD

Set Analog Output Default.

Input: `ANOD 0` or `ANOD 1`

Returned: Nothing

Remarks: Set default off with ANOD 0 and on with ANOD 1. Default on gives 10 mV/K (10 V analog output for 1000 K and 0 V for 0 K).

ANOD?

Analog Default Query.

Input: `ANOD?`

Returned: `0` or `1`

Remarks: 1 indicates the default analog output scaling is in effect. The default scaling is 10 mV/K (10 V analog output for 1000 K and 0 V for 0 K).

ANOH

Set Analog Output Maximum (High).

Input: `ANOH XXX.X`

Returned: Nothing

Remarks: Set the analog output maximum (high), where XXX.X is between 0 and 999.9.

Example: `ANOH 500[term]` instructs the controller to make the 10 V output correspond to 500 K.

ANOH?

Analog Output Maximum (High) Query.

Input: `ANOH?`

Returned: `XXX.X`

Remarks: Returns the current value of the temperature in kelvin which gives 10 V output.

ANOL

Set Analog Output Minimum (Low).

Input: `ANOL XXX.X`

Returned: Nothing

Remarks: Set the analog output minimum (low), where XXX.X is between 0 and 999.9.

Example: `ANOL 100[term]` instructs the controller to make the 0 V output correspond to 100 K.

ANOL?

Analog Output Minimum (Low) Query.

Input: `ANOL?`

Returned: `XXX.X`

Remarks: Returns the current value of the temperature in kelvin which gives 0 V output.

4.3 USER CURVE 11 LOADING PROGRAM

To simplify the loading of User Curve 11, the following curve loading program is provided. The program is written in QuickBASIC V4.0. The user should create an ASCII file with the curve data in the same format as used in the CURV11 command. Immediately following the program are two sample user curve files. Then launch the Curve Loading Program where you will be prompted for a file name. The program will then open the ASCII file and download the data.

```
'*********************************************************************
'*  CURVE LOADING PROGRAM. NOTE: SPACING OF THE DATA STRING IS        *
'*  VERY CRITICAL, SEE THE ATTACHED SAMPLE CURVE. The curve data      *
'*  must be in an ascii file using the same format as the example.    *
'*********************************************************************

   CLS                                    'Clear Screen

   M$ = CHR$(13) + CHR$(10)               'Define M$ as <cr><lf> terminator
   CHECKER$ = SPACE$(3000)                'Preset variable lengths
   C$ = SPACE$(2000)
                                          'Get the file name to load
   INPUT "TYPE IN DRIVE NAME AND SERIAL NUMBER OF SENSOR AND PRESS ENTER";
   A$ B$ = A$

   OPEN B$ FOR INPUT AS #1                'Open ascii disk file
   LINE INPUT #1, C$                      'Read disk file into string C$
   STRIP$ = MID$(C$, 9)                   'Strip off the DRC series file header
   LOADER$ = "CURV11," + STRIP$           'Add the 300 series curve header
   PRINT LOADER$                          'Screen prints to show what is sent
   PRINT
   PRINT "COMMANDS SENT TO 321"
   PRINT                                  'Close disk file
   CLOSE #1
   OPEN "COM1:300,O,7,1,RS" FOR RANDOM AS #2 'Open com port for I/O
   LOADTRIM$ = LEFT$(LOADER$, 50)         'Pick out first 50 chars for first cmd
   LOADTRIM$ = LOADTRIM$ + M$
   PRINT LOADTRIM$;                       'Show command string on screen
   PRINT #2, LOADTRIM$;                   'Send curve create cmd to controller
   FOR Z = 1 TO 2000: NEXT Z

'*********************************************************************
'***   BEGINNING OF THE EDIT LOOP, WHICH ADDS ONE DATA POINT TO      ***
'***   THE CURVE AT A TIME USING THE ECUR COMMAND                    ***
'*********************************************************************

EDITLOOP:

   PREEDIT$ = MID$(LOADER$, 51)           'String clean-up

EDITLOOP1:

   LENGTH = LEN(PREEDIT$)                 'Check for end of string
   IF LENGTH < 14 THEN GOTO EDITEND

   EDITPIECE$ = LEFT$(PREEDIT$, 14)       'Pull data point from the
   PREEDIT$ = MID$(PREEDIT$, 15)          'string and send it to the controller
   EDITOUT$ = "ECUR11" + EDITPIECE$ + M$
```

```
   PRINT EDITOUT$;
   PRINT #2, EDITOUT$;
   FOR Z = 1 TO 5500: NEXT Z
   GOTO EDITLOOP1

EDITEND:                                      'End of edit loop

'********************************************************************
'***   This section reads back the the curve in 256 byte chunks   ***
'***   and displays the results on screen.                        ***
'********************************************************************

   PRINT
   PRINT "RESPONSE FROM INSTRUMENT, PLEASE WAIT"
   PRINT
   READCMD$ = "CURV?11" + M$
   PRINT READCMD$;
   PRINT #2, READCMD$;

READLOOP:

   LINE INPUT #2, CHECKCURVE$
   FCOUNT = LEN(CHECKCURVE$)
   PRINT CHECKCURVE$;
   IF FCOUNT = 256 THEN GOTO READLOOP

END
```

Sample ACSII File No. 1

```
XC06,S02TG120ACS2 8333,0.86045,325.0,0.90212,310.0,0.94350,295.0,0.98457,280.0,1.
02532,265.0,1.06566,250.0,1.09231,240.0,1.11874,230.0,1.14489,220.0,1.15784,215.0
,1.17072,210.0,1.18349,205.0,1.19616,200.0,1.20869,195.0,1.22109,190.0,1.23331,18
5.0,1.24534,180.0,1.25717,175.0,1.26875,170.0,1.28009,165.0,1.29116,160.0,1.30194
,155.0,1.31241,150.0,1.32258,145.0,1.33241,140.0,1.34192,135.0,1.35108,130.0,1.35
991,125.0,1.36840,120.0,1.37657,115.0,1.38440,110.0,1.39189,105.0,1.39908,100.0,1
.40597,095.0,1.41258,090.0,1.41894,085.0,1.42509,080.0,1.43712,070.0,1.44327,065.
0,1.44993,060.0,1.45288,058.0,1.45611,056.0,1.45973,054.0,1.46394,052.0,1.46904,0
50.0,1.47551,048.0,1.48412,046.0,1.49606,044.0,1.51300,042.0,1.53706,040.0,1.5525
0,039.0,1.57064,038.0,1.59183,037.0,1.61638,036.0,1.64461,035.0,1.67679,034.0,1.7
1316,033.0,1.75390,032.0,1.79917,031.0,1.84902,030.0,1.90348,029.0,1.96261,028.0,
2.02646,027.0,2.09484,026.0,2.16753,025.0,2.24441,024.0,2.32537,023.0,2.41034,022
.0,2.49920,021.0,2.63876,019.5,2.83726,017.5,3.05000,015.5,3.27618,013.5,3.51800,
011.5,3.71192,010.0,3.91739,008.5,4.13945,007.0,4.36487,005.6,4.57772,004.4,4.829
63,003.1,5.03503,002.1,5.12385,001.6,5.15376,001.4*
```

Sample ACSII File No. 2

```
XC06,DT-500CU D46254,0.37198,300.0,0.44204,275.0,0.54863,235.0,0.61840,210.0,0.73
229,170.0,0.84333,130.0,0.95137,090.0,1.00351,070.0,1.04031,055.0,1.07506,040.0,1
.08564,036.0,1.09194,034.0,1.09964,032.0,1.11028,030.0,1.11764,029.0,1.12731,028.
0,1.14093,027.0,1.16147,026.0,1.19192,025.0,1.23370,024.0,1.28745,023.0,1.43452,0
21.0,1.68003,018.0,1.91882,014.0,2.09621,010.0,2.32759,006.5,2.54962,003.6,2.6279
4,002.0,2.64172,001.4*
```

CHAPTER 5

SERVICE AND CALIBRATION

5.0 GENERAL

This chapter describes the service and calibration for the Temperature Controller. Section 5.1 provides general maintenance information. Changing power settings and fuse rating is described in Section 5.2. Rear panel connector definitions are provided in Section 5.3. Optional serial interface cable and adapters are described in Section 5.4. The operating software EPROM replacement procedure is provided in Section 5.5. Power up errors are described in Section 5.6. Changing sensor input type is described in Section 5.7. Paragraphs 5.8 thru 5.10 describe the calibration procedure for the CYC3211, CYC3212, CYC3214, respectively. Two calibrations for each model are provided: the first with the available precision equipment, the second without.

5.1 GENERAL MAINTENANCE

If the keyboard locks up, press the Escape key for ≈10 seconds. This will reset internal RAM to factory default values. The instrument would then require the various user setpoints be reentered.

If there is no power, ensure you are plugged into a live outlet and that both ends of the power cord are plugged in. Next check the fuse. Remove line cord then place a small slotted screwdriver in the slot of the small door at the rear of the unit to gain access to the fuse. See Figure 5-1. For 100/120 V operation, the fuse rating is 0.5 A and the fuse type is 3AG Slow Blow. For 220/240 V operation, the fuse rating is 0.25 A and the fuse type is 5x20 mm T. Test fuse with ohmmeter. Do not rely on visual inspection of fuse.

To clean the controller periodically to remove dust, grease and other contaminants, perform the following:

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

NOTE

Do not use aromatic hydrocarbons or chlorinated solvents to clean the controller. They may react with the silk screen printing on the back panel.

2. Clean surface of printed circuit boards (PCBs) using clean, dry air at low pressure.

5.2 CHANGING POWER SETTING AND FUSE RATING

There are two basic power configurations: domestic and foreign. Domestic has a single fuse on the hot. Foreign has a double fuse arrangement for the hot and neutral. Units with specific power requirements specified when purchased will be preconfigured at the factory for the proper power setting. If power settings are incorrect for your application, use the following procedure to change the power settings.

WARNING

To avoid potentially lethal shocks, turn off the instrument and disconnect it from the AC power line before performing this procedure. Only qualified personnel should perform this procedure.

1. Turn off unit.
2. Unplug line cord from rear of unit.
3. Use small screwdriver to open fuse drawer.
4. Pull out the fuse holder, rotate until the proper voltage setting is displayed through the window in the fuse drawer. Place fuse holder back in fuse drawer.
5. Remove existing fuse(s). Replace with proper fuse ratings as follows: 1.5 A for 100/120 VAC; or 0.75 A for 220/240 VAC.
6. Slide fuse drawer back into unit.
7. Plug line cord into rear of unit.
8. Perform initial setup and system checkout procedure in Section 2.12.

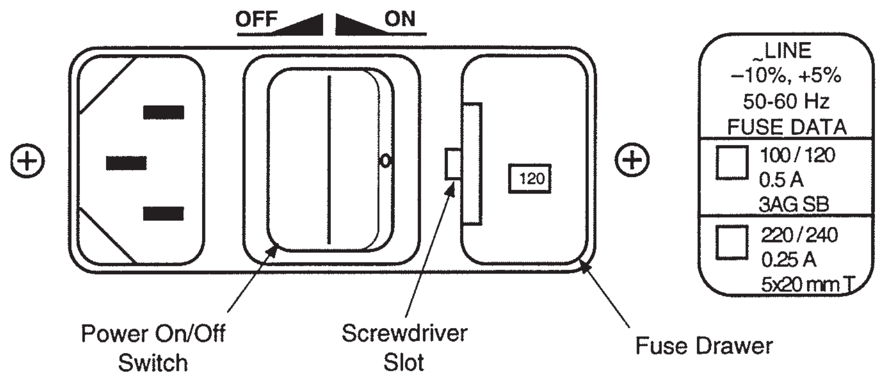
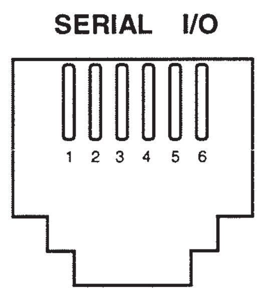


Figure 5-1. Power Fuse Access

5.3 REAR PANEL CONNECTOR DEFINITIONS

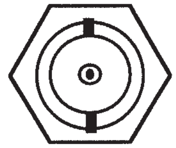
The Serial I/O, Analog Output, Sensor input, and Heater Output connectors are defined in Figures 5-2 through 5-5.



PIN	DESCRIPTION
1	RS-232C In (RxD)
2	RS-232C In (RxD)
3	RS-232C Ground
4	RS-232C Ground
5	RS-232C Out (TxD)
6	RS-232C Out (TxD)

Figure 5-2. SERIAL I/O RJ-11 Connector Details

ANALOG OUTPUT



PIN	DESCRIPTION
1	Analog Output – Center Conductor
2	Ground – Connector Shell

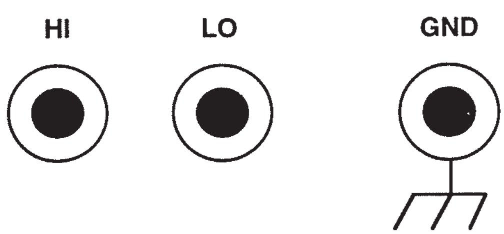
Figure 5-3. ANALOG OUTPUT Connector Details

SENSOR

PIN	DESCRIPTION
1	– Current
2	– Voltage
3	+ Current 500 μA (Platinum)
4	+ Voltage
5	+ Current 10 μA (Diodes)
6	Shield

Figure 5-4. Diode and Platinum SENSOR Connector Details

HEATER OUTPUT



PIN	DESCRIPTION
1	HI
2	LO
3	GROUND

Figure 5-5. HEATER Connector Details

5.4 OPTIONAL SERIAL INTERFACE CABLE AND ADAPTERS

To aid in Serial Interface troubleshooting, wiring information for the optional cable assembly and the two mating adapters are provided in Figures 5-6 through 5-8.

Figure 5-6. CYD200-C RJ-11 Cable Assembly Wiring Details

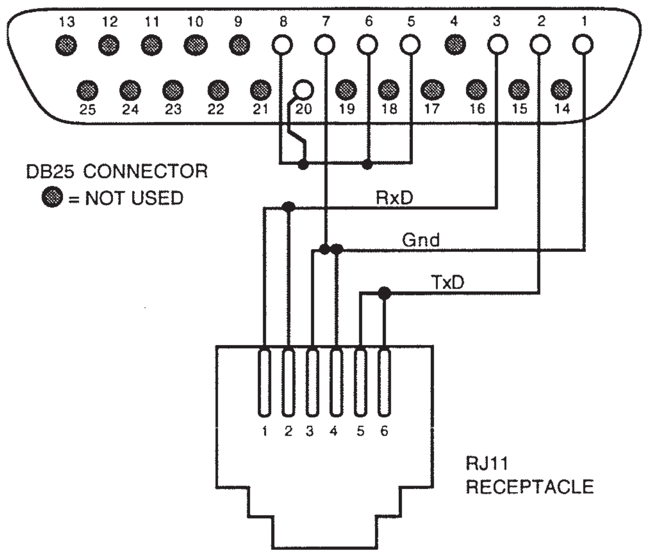


Figure 5-7. CYD200-D RJ-11 to DB-25 Adapter Wiring Details

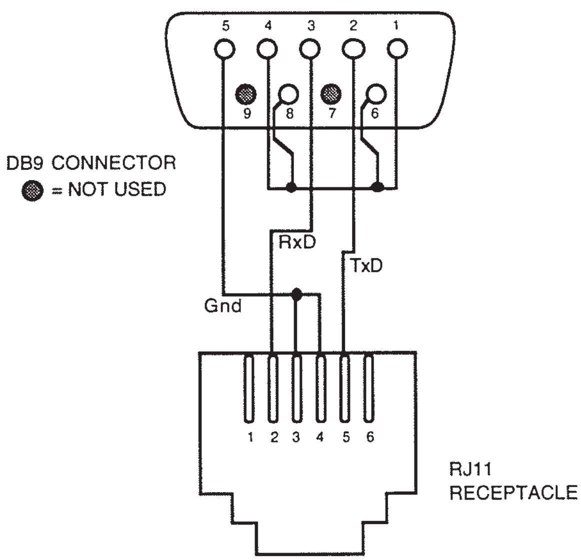


Figure 5-8. CYD200-DB9 RJ-11 to DE-9 Adapter Wiring Details

5.5 OPERATING SOFTWARE EPROM REPLACEMENT

The operating software for the controller is contained on two Erasable Programmable Read Only Memory (EPROM) Integrated Circuits (ICs). The EPROM are numbered U22 (Master) and U19 (Slave). The EPROMs will also have a label on top identifying the software version and date. See Figure 5-3. Please use the following procedure to replace either one or both the operating software EPROMs.

WARNING

To avoid potentially lethal shocks, turn off the instrument and disconnect it from the AC power line before performing this procedure. Only qualified personnel should perform this procedure.

1. Set power switch to off and disconnect power cord from rear of unit.
2. Use 5/64 hex key to remove four screws attaching top panel to unit.
3. Use 5/64 hex key to loosen two screws attaching bottom panel to unit.
4. Carefully remove back bezel.
5. Slide top panel back and remove from unit.
6. Locate software EPROM U22 (Master) or U19 (Slave) on main circuit board. Note orientation of existing EPROMs (circular notch on front of IC). See Figure 5-3.
7. Use IC puller to remove existing EPROM(s) from socket.
8. Noting orientation of new EPROM(s), use IC insertion tool to place new EPROM(s) into socket.
9. Replace top of enclosure and secure with four screws.
10. Replace back bezel and use 5/64 hex key to tighten two screws attaching bottom panel to unit.
11. Reconnect power cord to rear of unit and set power switch to on.
12. Proceed to Section 2.12 and perform the initial setup and system checkout. When replacing the operating software EPROM(s), all operating parameters will be returned to the factory default settings.

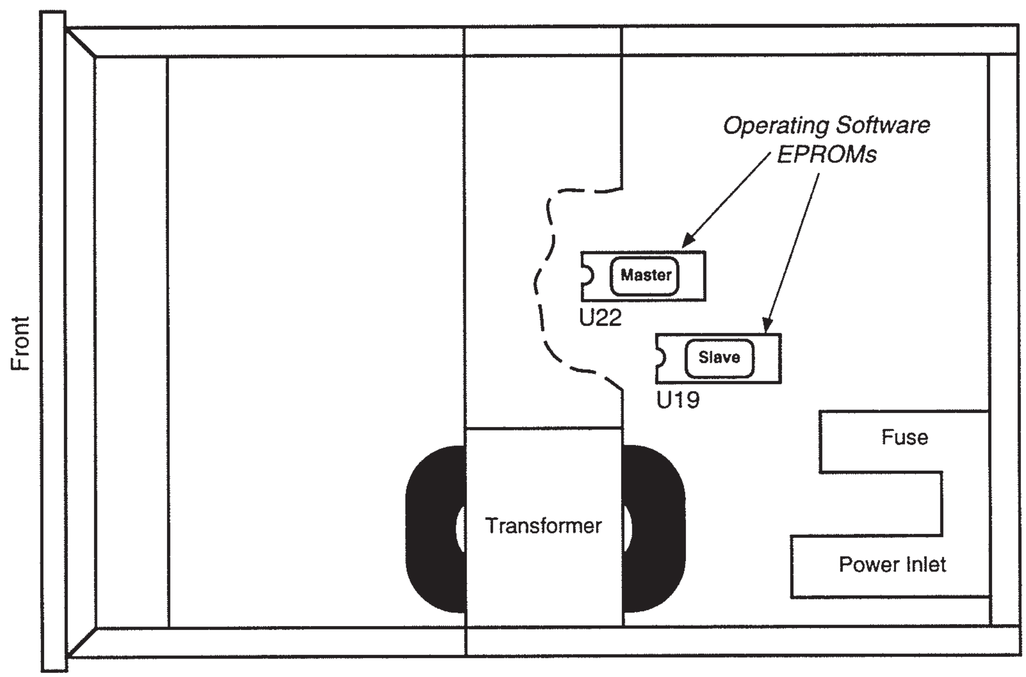


Figure 5-9. Location Of Operating Software EPROMs

5.6 ERROR MESSAGES

On power up, the controller does a check of the internal memory. There are two potential error messages. The first is usually recoverable, the second is not. The first error display is shown below.

```
RAMnotRecog.Er#2
Escape to Init.
```

This indicates that an attempt to read the internal non-volatile RAM for the Model ID was unsuccessful. In some situations, this error can be corrected by the user by initializing the controller's memory. There are three methods that can be used to reinitialize the instrument: (1) Press the Escape key when the error message is being displayed, (2) hold the Escape key down when the instrument is off and then turning the instrument on, or (3) holding the Escape key down for more than 5 seconds. Wait until a message is given before releasing the key.

The second error display is shown below.

```
RAM Rd/Wr    Er#1
Escape to Retry.
```

This error message indicates that an attempt to write and then read the internal non-volatile RAM was unsuccessful. This error is not correctable by the user. Please consult the factory.

There are two additional error messages associated with the sensor input. If an input signal from the sensor exceeding full scale is applied to the input leads, an overload condition is present and is indicated by "OL" on the display, as shown below.

```
    OL
```

If no signal or a signal of the wrong polarity is present at the input leads, a Zero Error is indicated by "Er27" on the display, as shown below.

```
   Er27
```

5.7 CHANGING SENSOR INPUT TYPE

Sensor input type (and hence the model number) are established at the factory before shipping. Sensor input type is set by setting two DIP switches on the main PCB inside the unit. If you wish to check the DIP switch settings, open the unit using the procedure in Section 5.5, Steps 1 thru 5. Use Figure 5-10 to locate DIP Switches **S1** and **S2**. The sensor input settings are switched identically to change input type. The settings are as follows.

DIP Switch S1 *

	Silicon Diode (CYC3211)	Platinum (CYC3212)	Thermocouple (CYC3214)
S1-1	Closed	Open	Open
S1-2	Open	Closed	Open
S1-3	Open	Open	Closed
S1-4	Open	Open	Closed

DIP Switch S2 *

	Silicon Diode (CYC3211)	Platinum (CYC3212)	Thermocouple (CYC3214)
S2-1	Closed	Open	Open
S2-2	Open	Closed	Open
S2-3	Open	Open	Closed
S2-4	Open	Open	Closed

**To change sensor input type, DIP switches on S1 and S2 must be switched identically.*

The controller must be recalibrated when switched between sensor input types.

5.8 CYC3211 (SILICON DIODE) CALIBRATION

There are two CYC3211 (Silicon Diode) calibrations provided. If you have a 100 kΩ, 0.01% 25 ppm precision resistor available, use the procedure in Section 5.8.1. If no precision resistor is available, use the optional procedure in Section 5.8.2.

5.8.1 CYC3211 Calibration (With Precision Resistor)

The CYC3211 calibration with precision resistor is presented in four parts. First is list of test equipment in Section 5.8.1.1. Second is the test setup in Section 5.8.1.2. Third is the input calibration in Section 5.8.1.3. Finally, analog output calibration is provided in Section 5.8.1.4. These procedures will be performed with power supplied to the unit. Due to the presence of lethal currents, only personnel experienced in working with live circuits should perform this procedure.

5.8.1.1 Test Equipment

This procedure requires the following test equipment:

- Digital Multimeter (DMM) with a 4½ digit display, capable of 4-lead resistive measurements.
- Precision Resistor, 100 kΩ, 0.01%, 25 ppm/°C.

5.8.1.2 Test Setup

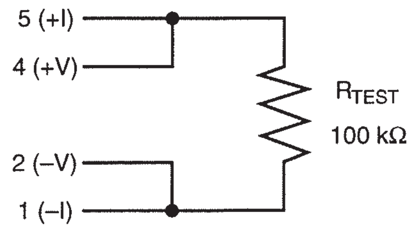
Calibration test setup is as follows:

WARNING

Lethal line voltage is present inside the box. Only qualified personnel should attempt to perform this procedure.

1. Set power switch to off and disconnect power cord from rear of unit.
2. Use 5/64 hex key to remove four screws attaching top panel to unit.
3. Use 5/64 hex key to loosen two screws attaching bottom panel to unit.
4. Carefully remove back bezel.
5. Slide top panel back and remove from unit.

6. Attach 100 kΩ precision resistor as shown below:



5.8.1.3 Input Calibration

Use the following procedure to perform the input calibration.

1. Place a short across the 100 kΩ resistor.
2. Power on instrument.
3. Allow instrument to warm up for at least one hour.
4. With DMM in DC voltage mode, attach test leads between TP2 (–) and TP1 (+).
5. Adjust R29 until DMM voltage reads 2.5000 ±0.0005 VDC.
5. Attach test leads to TP8 (GND1) and TP9 (Vref adj.).
7. Adjust R52 until DMM voltage reads 2.5000 ±0.0001 VDC.
8. Place positive test lead on TP7 (V+Buff).
9. Adjust R27 until DMM voltage reads 0.0000 ±0.0001 VDC.
10. Remove the short from the 100 kΩ resistor.
11. Configure the controller to display units in voltage.
12. Adjust R44 until the display reads exactly 1.0000 VDC.

5.8.1.4 Analog Output Calibration

Use the following procedure to perform the analog output calibration.

1. Attach test leads to TP3 (gnd1) and TP4 (Analog out).
2. Press and hold the Analog Out key until the controller enters the Analog output calibration mode.
3. Press the Up arrow key until Zero is selected.
4. With the DMM in DC voltage mode, adjust R22 until the voltage is 0.000 ±0.001 VDC.
5. Press the Up arrow key until Span is selected.
6. Adjust R18 until the voltage is 10.000 ±0.001 VDC.
7. Press Escape on the controller to exit the Analog output calibration mode.
8. Set power switch to off (0). Disconnect power cord and test resistor.
9. Replace top of enclosure and secure with four screws.
10. Replace back bezel and use 5/64 hex key to tighten two screws attaching bottom panel to unit.

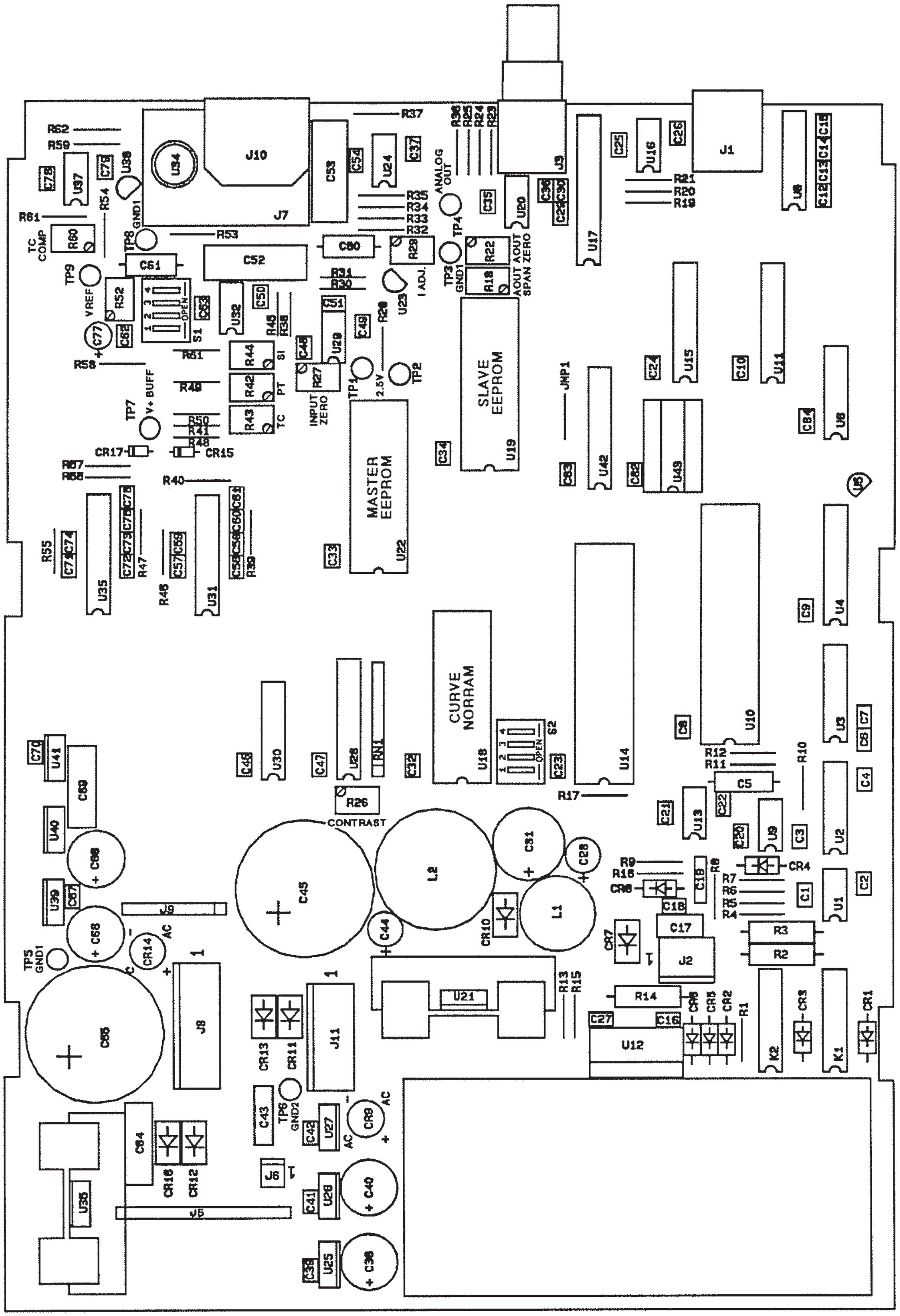


Figure 5-10. Typical PCB Layout

5.8.2 Optional CYC3211 Calibration (Without Precision Resistor)

The optional CYC3211 (Silicon Diode) calibration without precision resistor is presented in four parts. First is list of test equipment in Section 5.8.2.1. Second is the test setup in Section 5.8.2.2. Third is the input calibration in Section 5.8.2.3. Finally, analog output calibration is provided in Section 5.8.2.4. These procedures will be performed with power supplied to the unit. Due to the presence of lethal currents, only personnel experienced in working with live circuits should perform this procedure.

5.8.2.1 Test Equipment

This procedure requires the following test equipment:

- Digital Multimeter (DMM) with a 4½ digit display, capable of 4-lead resistive measurements.
- Resistor, 100 kΩ, as temperature stable as possible (20 – 50 ppm/°C), metal film preferred.

5.8.2.2 Test Setup

Calibration test setup is as follows:

WARNING

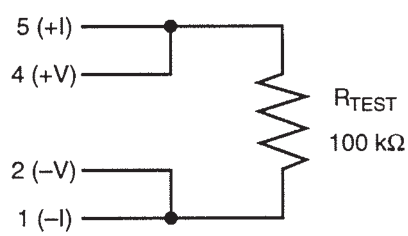
Lethal line voltage is present inside the box. Only qualified personnel should attempt to perform this procedure.

1. Set power switch to off and disconnect power cord from rear of unit.
2. Use 5/64 hex key to remove four screws attaching top panel to unit.
3. Use 5/64 hex key to loosen two screws attaching bottom panel to unit.
4. Carefully remove back bezel.
5. Slide top panel back and remove from unit.

5.8.2.3 Input Calibration

Use the following procedure to perform the input calibration.

1. Measure the resistance of the 100 kΩ resistor to the nearest 10 Ω and write it down.
2. Place a short across the 100 kΩ resistor and attach to sensor input.



3. Power on instrument.
4. Allow instrument to warm up for at least one hour.
5. With DMM in DC voltage mode, attach test leads between TP2 (–) and TP1 (+).
6. Adjust R29 until DMM voltage reads 2.5000 ±0.0005 VDC.
7. Attach test leads to TP8 (GND1) and TP9 (Vref adj.).
8. Adjust R52 until DMM voltage reads 2.5000 ±0.0001 VDC.
9. Place positive test lead on TP7 (V+Buff).
10. Adjust R27 until DMM voltage reads 0.0000 ±0.0001 VDC.
11. Remove the short from the 100 kΩ resistor.
12. Configure the controller to display units in voltage.
13. The current through the 100 kΩ resistor is 10 μA. Multiply 0.00001 times the resistance measured is Step 1. Adjust R44 until the display reads the result of the current times the resistance. For example, if the 100 kΩ resistor measured 100.25 kΩ, multiply 0.00001 times 100,250.00. The result would be 1.0025. R44 would be adjusted until the controller displays 1.0025 VDC.

5.8.2.4 Analog Output Calibration

Use the following procedure to perform the analog output calibration.

1. Attach test leads to TP3 (gnd1) and TP4 (Analog out).
2. Press and hold the Analog Out key until the controller enters the Analog output calibration mode .
3. Press the Up arrow key until Zero is selected.
4. With the DMM in DC voltage mode, adjust R22 until the voltage is 0.000 ±0.001 VDC.
5. Press the Up arrow key until Span is selected.
6. Adjust R18 until the voltage is 10.000 ±0.001 VDC.
7. Press Escape on the controller to exit the Analog output calibration mode.
8. Set power switch to off (0). Disconnect power cord and test resistor.
9. Replace top of enclosure and secure with four screws.
10. Replace back bezel and use 5/64 hex key to tighten two screws attaching bottom panel to unit.

5.9 CYC3212 (PLATINUM RESISTOR) CALIBRATION

There are two CYC3212 (Platinum Resistor) calibrations provided. If you have a 100 Ω, 0.01% 25 ppm precision resistor available, use the procedure in Section 5.9.1. If no precision resistor is available, use the optional procedure in Section 5.9.2.

5.9.1 CYC3212 Calibration (With Precision Resistor)

The CYC3212 calibration with precision resistor is presented in four parts. First is list of test equipment in Section 5.9.1.1. Second is the test setup in Section 5.9.1.2. Third is the input calibration in Section 5.9.1.3. Finally, analog output calibration is provided in Section 5.9.1.4. These procedures will be performed with power supplied to the unit. Due to the presence of lethal currents, only personnel experienced in working with live circuits should perform this procedure.

5.9.1.1 Test Equipment

This procedure requires the following test equipment:

- Digital Multimeter (DMM) with a 4½ digit display, capable of 4-lead resistive measurements.
- Precision Resistor, 100 Ω, 0.01%, 25 ppm/°C.

5.9.1.2 Test Setup

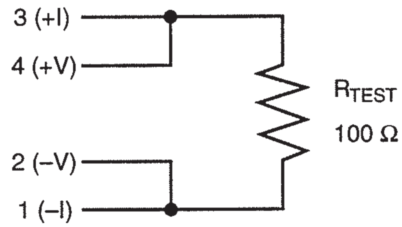
Calibration test setup is as follows:

WARNING

Lethal line voltage is present inside the box. Only qualified personnel should attempt to perform this procedure.

1. Set power switch to off and disconnect power cord from rear of unit.
2. Use 5/64 hex key to remove four screws attaching top panel to unit.
3. Use 5/64 hex key to loosen two screws attaching bottom panel to unit.
4. Carefully remove back bezel.
5. Slide top panel back and remove from unit.

6. Attach 100 Ω precision resistor as shown below:



5.9.1.3 Input Calibration

Use the following procedure to perform the input calibration.

1. Place a short across the 100 Ω resistor.
2. Power on instrument.
3. Allow instrument to warm up for at least one hour.
4. With DMM in DC voltage mode, attach test leads between TP2 (–) and TP1 (+).
5. Adjust R29 until DMM voltage reads 2.5000 ±0.0005 VDC.
6. Attach test leads to TP8 (GND1) and TP9 (Vref adj.).
7. Adjust R52 until DMM voltage reads 2.5000 ±0.0001 VDC.
8. Place positive test lead on TP7 (V+Buff).
9. Adjust R27 until DMM voltage reads 0.0000 ±0.0001 VDC.
10. Remove the short from the 100 Ω resistor.
11. Configure the controller to display units in ohms.
12. Adjust R42 until the display reads exactly 100.00 Ω.

5.9.1.4 Analog Output Calibration

Use the following procedure to perform the analog output calibration.

1. Attach test leads to TP3 (gnd1) and TP4 (Analog out).
2. Press and hold the Analog Out key until the controller enters the Analog output calibration mode .
3. Press the Up arrow key until Zero is selected.
4. With the DMM in DC voltage mode, adjust R22 until the voltage is 0.000 ±0.001 VDC.
5. Press the Up arrow key until Span is selected.
6. Adjust R18 until the voltage is 10.000 ±0.001 VDC.
7. Press Escape on the controller to exit the Analog output calibration mode.
8. Set power switch to off (0). Disconnect power cord and test resistor.
9. Replace top of enclosure and secure with four screws.
10. Replace back bezel and use 5/64 hex key to tighten two screws attaching bottom panel to unit.

5.9.2 Optional CYC3212 Calibration (Without Precision Resistor)

The optional CYC3212 (Platinum Diode) calibration without precision resistor is presented in four parts. First is list of test equipment in Section 5.9.2.1. Second is the test setup in Section 5.9.2.2. Third is the input calibration in Section 5.9.2.3. Finally, analog output calibration is provided in Section 5.9.2.4. These procedures will be performed with power supplied to the unit. Due to the presence of lethal currents, only personnel experienced in working with live circuits should perform this procedure.

5.9.2.1 Test Equipment

This procedure requires the following test equipment:

- Digital Multimeter (DMM) with a 4½ digit display, capable of 4-lead resistive measurements.
- Resistor, 100 Ω, as temperature stable as possible (20 – 50 ppm/°C), metal film preferred.

5.9.2.2 Test Setup

Calibration test setup is as follows:

WARNING

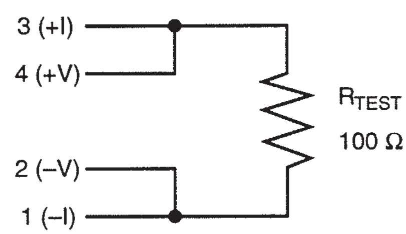
Lethal line voltage is present inside the box. Only qualified personnel should attempt to perform this procedure.

1. Set power switch to off and disconnect power cord from rear of unit.
2. Use 5/64 hex key to remove four screws attaching top panel to unit.
3. Use 5/64 hex key to loosen two screws attaching bottom panel to unit.
4. Carefully remove back bezel.
5. Slide top panel back and remove from unit.

5.9.2.3 Input Calibration

Use the following procedure to perform the input calibration.

1. Measure the resistance of the 100 Ω resistor to the nearest 0.01 Ω and write it down.
2. Place a short across the 100 Ω resistor and attach to sensor input.



3. Power on instrument.
4. Allow instrument to warm up for at least one hour.
5. With DMM in DC voltage mode, attach test leads between TP2 (–) and TP1 (+).
6. Adjust R29 until DMM voltage reads 2.5000 ±0.0005 VDC.
7. Attach test leads to TP8 (GND1) and TP9 (Vref adj.).
8. Adjust R52 until DMM voltage reads 2.5000 ±0.0001 VDC.
9. Place positive test lead on TP7 (V+Buff).
10. Adjust R27 until DMM voltage reads 0.0000 ±0.0001 VDC.
11. Remove the short from the 100 Ω resistor.
12. Configure the controller to display units in ohms.
13. Adjust R42 until the display reads the value of the 100 Ω resistor measured in Step 1. For example, if the resistance measured 100.28 Ω, R42 should be adjusted until the controller displays 100.28 Ω.

5.9.2.4 Analog Output Calibration

Use the following procedure to perform the analog output calibration.

1. Attach test leads to TP3 (gnd1) and TP4 (Analog out).
2. Press and hold the Analog Out key until the controller enters the Analog output calibration mode .
3. Press the Up arrow key until Zero is selected.
4. With the DMM in DC voltage mode, adjust R22 until the voltage is 0.000 ±0.001 VDC.
5. Press the Up arrow key until Span is selected.
6. Adjust R18 until the voltage is 10.000 ±0.001 VDC.
7. Press Escape on the controller to exit the Analog output calibration mode
8. Set power switch to off (0). Disconnect power cord and test resistor.
9. Replace top of enclosure and secure with four screws.
10. Replace back bezel and use 5/64 hex key to tighten two screws attaching bottom panel to unit.

5.10 CYC3214 (THERMOCOUPLE) CALIBRATION

There are two CYC3214 (Thermocouple) calibrations provided. If you have a Millivolt Voltage Standard (with microvolt resolution) available, use the procedure in Section 5.10.1. If no precision voltage source is available, use the optional procedure in Section 5.10.2.

5.10.1 MCYC3214 Calibration (With Millivolt Voltage Standard)

The CYC3214 calibration with Millivolt Voltage Standard is presented in six parts. First is list of test equipment in Section 5.10.1.1. Second is the test setup in Section 5.10.1.2. Third is the input calibration in Section 5.10.1.3. Fourth is the analog output calibration is provided in Section 5.10.1.4. Fifth is the thermocouple offset adjustment in Section 5.10.1.5. Finally, the internal thermocouple compensation calibration is provided in Section 5.10.1.6. These procedures will be performed with power supplied to the unit. Due to the presence of lethal currents, only personnel experienced in working with live circuits should perform this procedure.

5.10.1.1 Test Equipment

This procedure requires the following test equipment:

- Digital Multimeter (DMM) with a 4½ digit display, capable of 4-lead resistive measurements.
- Millivolt Voltage Standard (with microvolt resolution range).

5.10.1.2 Test Setup

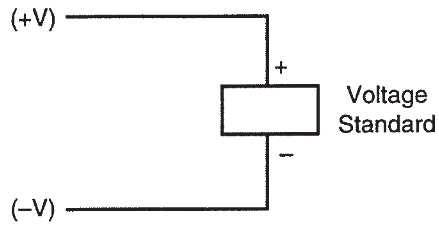
Calibration test setup is as follows:

WARNING

Lethal line voltage is present inside the box. Only qualified personnel should attempt to perform this procedure.

1. Set power switch to off and disconnect power cord from rear of unit.
2. Use 5/64 hex key to remove four screws attaching top panel to unit.
3. Use 5/64 hex key to loosen two screws attaching bottom panel to unit.
4. Carefully remove back bezel.
5. Slide top panel back and remove from unit.

6. Configure the Millivolt Voltage Standard as shown below:



5.10.1.3 Input Calibration

Use the following procedure to perform the input calibration.

1. Power on instrument.
2. Allow instrument to warm up for at least one hour.
3. Set Voltage Standard to zero volts.
4. Attach test leads to TP8 (GND1) and TP9 (Vref adj.).
5. Adjust R52 until DMM voltage reads 2.5000 ±0.0001 VDC.
6. Configure the controller to display units in millivolts.
7. Turn off temperature compensation.
8. Adjust R27 until controller display reads exactly 0.000 mV DC.
9. Change Voltage Standard to +44.000 mV.
10. Adjust R43 until controller display reads exactly 44.000 mV DC.
11. Switch Voltage Standard to -44.000 mV DC. The controller display should read -44.000 ±0.002 mV DC. If not, set Voltage Standard to zero volts and repeat steps 8 through 11.

5.10.1.4 Analog Output Calibration

Use the following procedure to perform the analog output calibration.

1. Attach test leads to TP3 (gnd1) and TP4 (Analog out).
2. Press and hold the Analog Out key until the controller enters the Analog output calibration mode.
3. Press the Up arrow key until Zero is selected.
4. With the DMM in DC voltage mode, adjust R22 until the voltage is 0.000 ±0.001 VDC.
5. Press the Up arrow key until Span is selected.
6. Adjust R18 until the voltage is 10.000 ±0.001 VDC.
7. Press Escape on the controller to exit the Analog output calibration mode.
8. Set power switch to off (0). Disconnect power cord and test resistor.
9. Replace top of enclosure and secure with four screws.
10. Replace back bezel and use 5/64 hex key to tighten two screws attaching bottom panel to unit.

5.10.1.5 Thermocouple Offset Adjustment

When a new or different thermocouple is attached to the instrument, and external thermocouple compensation is being used, it may be necessary to adjust the offset to compensate for discrepancies in thermocouple material, leads and connections. Use the following procedure to perform the thermocouple offset adjustment.

1. Open the controller enclosure. Refer to Section 5.10.1.2, Steps 1 – 5.
2. Place the thermocouple in a reference bath of known temperature (liquid nitrogen, ice, etc.) and install external compensation. Allow the system to stabilize to the reference temperature.
3. On the front panel of the controller, select the desired temperature units.
4. Turn off thermocouple compensation.
5. Adjust R27 until the display reads the reference temperature.
6. Close the controller enclosure. Refer to Section 5.10.1.4, Steps 8 – 10.

5.10.1.6 Internal Thermocouple Compensation Calibration

When a new or different thermocouple is attached to the instrument, and internal thermocouple compensation is being used, it may be necessary to adjust the offset to compensate for discrepancies in thermocouple material, leads and connections. Use the following procedure to perform the internal thermocouple compensation calibration.

1. Open the controller enclosure. Refer to Section 5.10.1.2, Steps 1 – 5.
2. Short across the input with as short as lead as possible.
3. Configure the controller to display units in °C.
4. Turn on thermocouple compensation.
5. Adjust R60 until display reads room temperature (25 °C nominal).
6. Close the controller enclosure. Refer to Section 5.10.1.4, Steps 8 – 10.

5.10.2 CYC3214 Calibration (Without Millivolt Voltage Standard)

The optional CYC3214 (Thermocouple) calibration without a millivolt voltage standard is presented in six parts. First is list of test equipment in Section 5.10.2.1. Second is the test setup in Section 5.10.2.2. Third is the input calibration in Section 5.10.2.3. Fourth is the analog output calibration is provided in Section 5.10.2.4. Fifth is the thermocouple offset adjustment in Section 5.10.2.5. Finally, the internal thermocouple compensation calibration is provided in Section 5.10.2.6. These procedures will be performed with power supplied to the unit. Due to the presence of lethal currents, only personnel experienced in working with live circuits should perform this procedure.

5.10.2.1 Test Equipment

This procedure requires the following test equipment

- Digital Multimeter (DMM) with a 4½ digit display, capable of 4-lead resistive measurements.
- Voltage source capable of providing a stable, nominal ±44.0 mV DC.

5.10.2.2 Test Setup

Calibration test setup is as follows:

WARNING

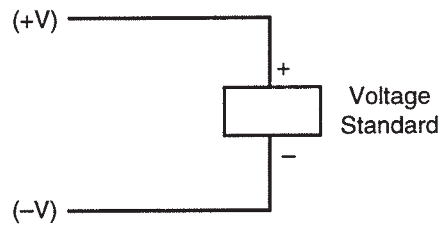
Lethal line voltage is present inside the box. Only qualified personnel should attempt to perform this procedure.

1. Set power switch to off and disconnect power cord from rear of unit.
2. Use 5/64 hex key to remove four screws attaching top panel to unit.
3. Use 5/64 hex key to loosen two screws attaching bottom panel to unit.
4. Carefully remove back bezel.
5. Slide top panel back and remove from unit.

5.10.2.3 Input Calibration

Use the following procedure to perform the input calibration.

1. Power on instrument.
2. Allow instrument to warm up for at least one hour.
3. Short across the input with as short a lead as possible.
4. Attach test leads to TP8 (gnd1) and TP9 (Vref adj.).
5. Adjust R52 until DMM voltage reads 2.5000 ±0.0001 VDC.
6. Configure the controller to display units in millivolts.
7. Turn off temperature compensation.
8. Adjust R27 until the controller display reads exactly 0.0000 mV DC.
9. Remove short from input and attach voltage source.



10. Adjust voltage source to a nominal +44.0 mV DC.
11. Attach the DMM to the input. DMM should be in the DC millivolt mode.
12. Adjust R43 until controller display exactly matches the DMM reading.
13. Reverse voltage source to -44.0 mV DC. The controller display should match the DMM reading within ±0.002 mV DC. If not, set voltage source to zero volts and repeat steps 8 through 13.

5.10.2.4 Analog Output Calibration

Use the following procedure to perform the analog output calibration.

1. Attach test leads to TP3 (GND1) and TP4 (Analog out).
2. Press and hold the Analog Out key until the controller enters the Analog output calibration mode.
3. Press the Up arrow key until Zero is selected.
4. With the DMM in DC voltage mode, adjust R22 until the voltage is 0.000 ±0.001 VDC.
5. Press the Up arrow key until Span is selected.
6. Adjust R18 until the voltage is 10.000 ±0.001 VDC.
7. Press Escape on the controller to exit the Analog output calibration mode.
8. Set power switch to off (0). Disconnect power cord and test resistor.
9. Replace top of enclosure and secure with four screws.
10. Replace back bezel and use 5/64 hex key to tighten two screws attaching bottom panel to unit.

5.10.2.5 Thermocouple Offset Adjustment

When a new or different thermocouple is attached to the instrument, and external thermocouple compensation is being used, it may be necessary to adjust the offset to compensate for discrepancies in thermocouple material, leads and connections. Use the following procedure to perform the thermocouple offset adjustment.

1. Open the controller enclosure. Refer to Section 5.10.1.2, Steps 1 – 5.
2. Place the thermocouple in a reference bath of known temperature (liquid nitrogen, ice, etc.) and install external compensation. Allow the system to stabilize to the reference temperature.
3. On the front panel of the controller, select the desired temperature units.
4. Turn off thermocouple compensation.
5. Adjust R27 until the display reads the reference temperature.
6. Close the controller enclosure. Refer to Section 5.10.1.4, Steps 8 – 10.

5.10.2.6 Internal Thermocouple Compensation Calibration

When a new or different thermocouple is attached to the instrument, and internal thermocouple compensation is being used, it may be necessary to adjust the offset to compensate for discrepancies in thermocouple material, leads and connections. Use the following procedure to perform the internal thermocouple compensation calibration.

1. Open the controller enclosure. Refer to Section 5.10.1.2, Steps 1 – 5.
2. Short across the input with as short as lead as possible.
3. Configure the controller to display units in °C.
4. Turn on thermocouple compensation.
5. Adjust R60 until display reads room temperature (25 °C nominal).
6. Close the controller enclosure. Refer to Section 5.10.1.4, Steps 8 – 10.

CHAPTER 6

OPTIONS AND ACCESSORIES

6.0 GENERAL

This chapter provides lists of Autotuning Temperature Controller options and accessories. Model number are listed in Section 6.1. Options are detailed in Section 6.2. Finally, accessories are detailed in Section 6.3.

6.1 MODELS

A list of Temperature Controllers is provided as follows.

MODEL NUMBER	DESCRIPTION OF THE MODELS
CYC3211	**Designed for use with Silicon Diode Temperature Sensors.**
CYC3212	**Designed for use with 100 Ω Platinum RTD Temperature Sensors.**
CYC3214	**Designed for use with Thermocouples.**

6.2 OPTIONS

A list of options is provided as follows.

MODEL NUMBER	DESCRIPTION OF THE OPTIONS
ATP-8000	**Precision Option, Floppy Disk.** The ATP-8000 Precision Option consists of breakpoint pairs from a Sensor Precision Calibration being loaded on a floppy disk in ASCII format for Customer downloading.
ATP8002-05	**Precision Option, Field Installation.** For field installation of the precision option for users who already own a controller. When ordering, please specify your instrument serial number and calibrated sensor model and serial number. A new NOVRAM will be sent for Customer installation.

6.3 ACCESSORIES

Accessories are devices that perform a secondary duty as an aid or refinement to the primary unit. An accessory that is available is as follows:

	DESCRIPTION OF ACCESSORY
	Detachable 120 Vac Line Cord.*

* Accessory included with a new controller.

Accessories (Continued)

MODEL NUMBER	DESCRIPTION OF ACCESSORIES
CYD200-C	**RJ-11 Cable Assembly**. Four-Wire Cable Assembly with RJ-11 plugs on each end. Used with RS-232C Interface. Cable is 14 feet (4.6 meters) long. See Figure 6-1.
CYD200-D	**RJ-11 to DB-25 Adapter**. Adapts RJ-11 receptacle to female DB-25 connector. Used to connect Model 622/647 to RS-232C Serial Port on rear of Customer's computer. See Figure 6-2.
CYD200-DB9	**RJ-11 to DE-9 Adapter**. Adapts RJ-11 receptacle to female DE-9 connector. Used to connect Model 622/647 to RS-232C Serial Port on rear of Customer's computer. See Figure 6-3.
CYC321-SHC	**Sensor/Heater Cable Assembly.** This cable assembly is used for Silicon Diode and 100 Ω Platinum RTD Temperature Sensors.
CYW4	**OMEGACryogenic Wire**. OMEGA provides cryogenic wire, CYW4, in varying lengths and in 32 and 36 gauge sizes. Refer to the OMEGA Temperature Catalog for details.
CYAG	**Apiezo "N" Grease, 25 gram Tube**. General purpose grease well-suited for cryogenic use because of its low viscosity. It is often used as a means of thermally anchoring cryogenic sensors as well as lubricating joints and o-rings. Contains high molecular weight polymeric hydrocarbon additive which gives it a tenacious, rubbery consistency allowing the grease to form a cushion between mating surfaces.
CYIF	**Indium Foil (5 Pieces).** Indium is a semi-precious non-ferrous metal, softer than lead, and extremely malleable and ductile. It stays soft and workable down to cryogenic temperatures. May be used as a sealing gasket for covers, flanges, and windows in cryogenic applications.
CYC321-HTR-25	**25 Ω Cartridge Heater.** The heater features precision-wound nickel-chromium resistance wire, magnesium oxide insulation, two solid pins, non-magnetic package, and has UL and CSA component recognition. The heater is 25 W, 6.35 mm (0.25 inch) diameter by 25.4 mm (1 inch) long. The 25 W rating is in dead air. In cryogenic applications, the cartridge heater can handle many times this dead air power rating.
CYC321-HTR-50	**50 Ω Cartridge Heater.** The heater features precision-wound nickel-chromium resistance wire, magnesium oxide insulation, two solid pins, non-magnetic package, and has UL and CSA component recognition. The heater is 25 W, 6.35 mm (0.25 inch) diameter by 25.4 mm (1 inch) long. The 25 W rating is in dead air. In cryogenic applications, the cartridge heater can handle many times this dead air power rating.

* Accessories included with a new controller.

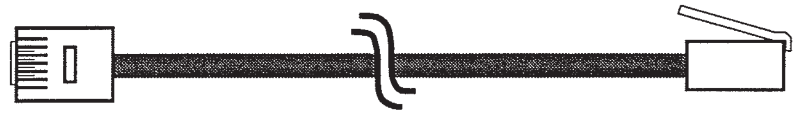


Figure 6-1. CYD200-C RJ-11 Cable Assembly

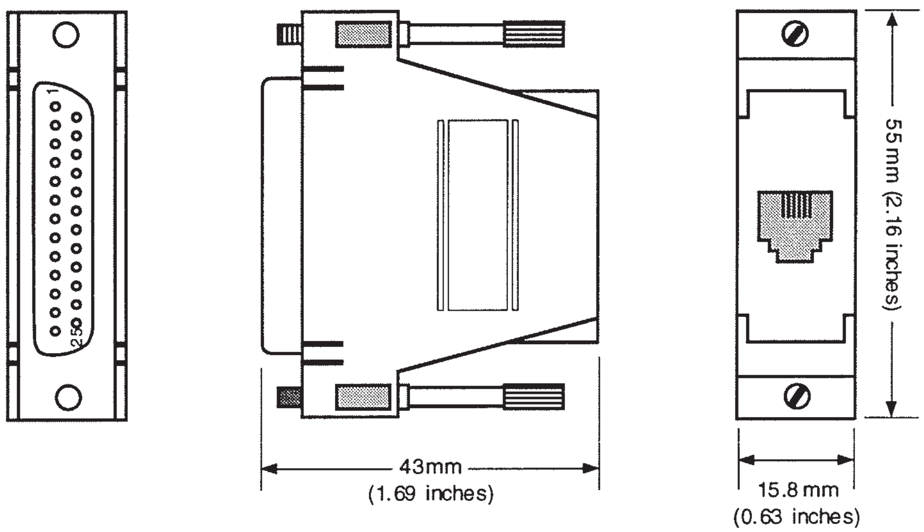


Figure 6-2. CYD200-D RJ-11 to DB-25 Adapter

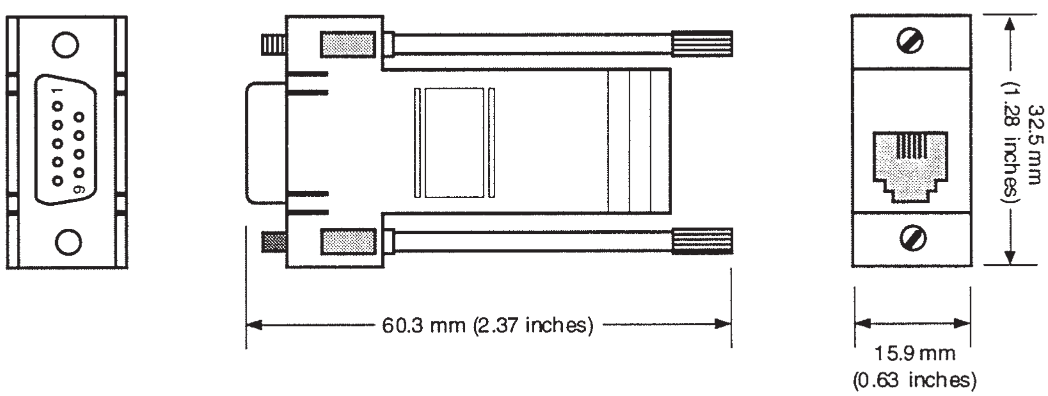


Figure 6-3. CYD200-DB9 RJ-11 to DE-9 Adapter

This Page Intentionally Left Blank

APPENDIX A

GLOSSARY OF TERMINOLOGY

Absolute Zero – Believed to be the lowest possible temperature; the temperature at which molecular motion stops and at which heat is completely gone. Defined as 0 K, calculated to be –273.15 °C or –459.67 °F.

American Standard Code for Information Exchange (ACSII) – A standard code used in data transmission, in which 128 numerals, letters, symbols, and special control codes are represented by a 7-bit binary number as follows:

b7 b6 b5 →					000	001	010	011	100	101	110	111
b4	b3	b2	b1	Row \ Col.	0	1	2	3	4	5	6	7
0	0	0	0	0	NUL	DLE	SP	0	'	P	@	p
0	0	0	1	1	SOH	DC1	!	1	A	Q	a	q
0	0	1	0	2	STX	DC2	"	2	B	R	b	r
0	0	1	1	3	ETX	DC3	#	3	C	S	c	s
0	1	0	0	4	EOT	DC4	$	4	D	T	d	t
0	1	0	1	5	ENG	NAK	%	5	E	U	e	u
0	1	1	0	6	ACK	SYN	8	6	F	V	f	v
0	1	1	1	7	BEL	ETB	'	7	G	W	g	w
1	0	0	0	8	BS	CAN	(	8	H	X	h	x
1	0	0	1	9	HT	EM	)	9	I	Y	i	y
1	0	1	0	10	LF	SS	*	:	J	Z	j	z
1	0	1	1	11	VT	ESC	+	;	K	[	k	(
1	1	0	0	12	FF	FS	,	<	L	~	l	‾
1	1	0	1	13	CR	GS	–	=	M	]	m	)
1	1	1	0	14	SO	RS	.	>	N	^	n	|
1	1	1	1	15	SI	US	/	?	O	_	o	DEL

American Wire Gage (AWG) – Wiring sizes are defined as diameters in inches and millimeters as follows:

AWG	Dia. In.	Dia. mm	AWG	Dia. In.	Dia. mm	AWG	Dia. In.	Dia. mm	AWG	Dia. In.	Dia. mm
1	0.2893	7.348	11	0.0907	2.304	21	0.0285	0.7230	31	0.0089	0.2268
2	0.2576	6.544	12	0.0808	2.053	22	0.0253	0.6438	32	0.0080	0.2019
3	0.2294	5.827	13	0.0720	1.829	23	0.0226	0.5733	33	0.00708	0.178
4	0.2043	5.189	14	0.0641	1.628	24	0.0207	0.5106	34	0.00630	0.152
5	0.1819	4.621	15	0.0571	1.450	25	0.0179	0.4547	35	0.00561	0.138
6	0.1620	4.115	16	0.0508	1.291	26	0.0159	0.4049	36	0.00500	0.127
7	0.1443	3.665	17	0.0453	1.150	27	0.0142	0.3606	37	0.00445	0.1131
8	0.1285	3.264	18	0.0403	1.024	28	0.0126	0.3211	38	0.00397	0.1007
9	0.1144	2.906	19	0.0359	0.9116	29	0.0113	0.2859	39	0.00353	0.08969
10	0.1019	2.588	20	0.0338	0.8118	30	0.0100	0.2546	40	0.00314	0.07987

Asphyxiant Gas – A gas which has little or no positive toxic effect but which can bring about unconsciousness and death by displacing air and thus depriving an organism of oxygen.

Baud – A unit of signaling speed equal to the number of discrete conditions or signal events per second. A baud as a signal element must be at least one complete cycle in length in order to carry information. Baud and bits per second (bps) are *not* interchangeable. Baud rate indicates how fast signals are being sent, where bps shows the rate at which information is being transferred.

Binary Coded Decimal (BCD) – A coding system in which each decimal digit from 0 to 9 is represented by four binary digits as follows:

DECIMAL DIGIT	BINARY CODE	DECIMAL DIGIT	BINARY CODE
0	0000	5	0101
1	0001	6	0110
2	0010	7	0111
3	0011	8	1000
4	0100	9	1001

Boiling Point – The temperature at which a substance in the liquid phase transforms to the gaseous phase; commonly refers to the boiling point of water which is 100 °C (212 °F) at sea level.

BNC – Abbreviation for Bayonet Nut Connector.

Caution – An operation or maintenance procedure, practice, condition, statement, etc., which, if not strictly observed, could result in damage or destruction of equipment, or loss of effectiveness.

Celsius (°C) – A temperature scale that registers the freezing point of water as 0 °C and the boiling point as 100 °C under normal atmospheric pressure. Formerly known as "centigrade." Originally devised by Anders Celsius (1701-1744), a Swedish astronomer. To convert Fahrenheit to Celsius: subtract 32 from °F then divide by 1.8, or: °C = (°F- 32)/ 1.8.

CGS System of Units– A coherent system in which the basic units are the centimeter, gram, and second.

Cryogenic – Refers to the field of low temperatures, usually –130 °F or below, as defined by 173.300(f) of Title 49 of the Code of Federal Regulations.

Cryostat – A low temperature thermostat.

Decibels (dB) – The standard unit for expressing transmission gain or loss and relative power levels. Decibels indicate the ratio of power output to power input: $dB = 20 \log_{10} V_1/V_2$. The term "dBm" is used when a power of one milliwatt is the reference level.

Degree – An incremental value in the temperature scale, i.e., there are 100 degrees between the ice point and the boiling point of water in the Celsius scale and 180 degrees between the same two points in the Fahrenheit scale.

Dewar – A vacuum bottle used to contain liquid nitrogen and other supercooled gases.

Fahrenheit (°F) – A temperature scale that registers the freezing point of water as 32 °F and the boiling point as 212 °F under normal atmospheric pressure. Originally devised by Gabriel Fahrenheit (1686-1736), a German physicist residing in Holland who developed the use of mercury in thermometry. To convert Celsius to Fahrenheit: multiply °C by 1.8 then add 32, or: °F = (1.8 x °C) + 32.

Gaussian System (Units) – A system in which centimeter-gram-second units are used for electric and magnetic qualities.

Greek Alphabet – The Greek alphabet is defined as follows:

Alpha	α	Α	Iota	ι	Ι	Rho	ρ	Ρ
Beta	β	Β	Kappa	κ	Κ	Sigma	σ	Σ
Gamma	γ	Γ	Lambda	λ	Λ	Tau	τ	Τ
Delta	δ	Δ	Mu	μ	Μ	Upsilon	υ	Υ
Epsilon	ε	Ε	Nu	ν	Ν	Phi	φ	Φ
Zeta	ζ	Ζ	Xi	ξ	Ξ	Chi	χ	Χ
Eta	η	Η	Omicron	ο	Ο	Psi	ψ	Ψ
Theta	θ	Θ	Pi	π	Π	Omega	ω	Ω

Hertz (Hz.) – A unit of frequency equal to one cycle per second.

Hazard Communication Standard (HCS) – The OSHA standard cited in 29 CFR 1910.1200 requiring communication of risks from hazardous substances to workers in regulated facilities.

International System of Units (SI) – A universal coherent system of units in which the following six units are considered basic: meter, kilogram, second, ampere, Kelvin degree, and candela. The MKSA system of units is a constituent part of this system . The International System of Units, or Système International d'Unités (SI), was promulgated in 1960 by the Eleventh General Conference on Weights and Measures.

Kelvin (K) – An absolute scale of temperature, the zero point of which is approximately –273.15°C. Scale units are equal in magnitude to Celsius degrees. Originally devised by Lord Kelvin, William Thompson, (1824-1907), a British physicist, mathematician, and inventor. To convert Fahrenheit to kelvin, first convert °F to °C, then add 273. To convert Celsius to kelvin, add 273.

Liquid Helium (LHe) – Used for low temperature and superconductivity research: minimum purity 99.998%. Boiling point @ 1 atm = 4.2 K. Latent heat of vaporization = 2.4 Btu/liter. Liquid density = 0.275 lbs/liter.

EPA Hazard Categories: Immediate (Acute)
Health and Sudden Release of Pressure Hazards
DOT Name: Helium, Refrigerated Liquid

DOT Label: Nonflammable Gas
DOT Class: Nonflammable Gas
DOT ID No.: UN 1963

Liquid Nitrogen (LN_2) – Also used for low temperature and superconductivity research and for its refrigeration properties such as in freezing tissue cultures: minimum purity 99.998%, O_2 8 ppm max. Boiling point @ 1 atm = 77 K. Latent heat of vaporization = 152 Btu/liter. Liquid density = 0.78 lbs/liter.

EPA Hazard Categories: Immediate (Acute)
Health and Sudden Release of Pressure Hazards
DOT Name: Nitrogen, Refrigerated Liquid

DOT Label: Nonflammable Gas
DOT Class: Nonflammable Gas
DOT ID No.: UN 1977

Material Safety Data Sheet (MSDS) – OSHA Form 20 contains descriptive information on hazardous chemicals under OSHA's Hazard Communication Standard (HCS). These data sheets also provide precautionary information on the safe handling of the gas as well as emergency and first aid procedures.

MKSA System of Units– A system in which the basic units are the meter, kilogram, and second, and the ampere is a derived unit defined by assigning the magnitude $4\pi \times 10^{-7}$ to the rationalized magnetic constant (sometimes called the permeability of space).

Normally Closed – Abbreviation: N.C. A term used for switches and relay contacts. Provides a normally closed circuit when actuator is in the free (unenergized) position.

Normally Open – Abbreviation: N.O. A term used for switches and relay contacts. Provides a normally open circuit when actuator is in the free (unenergized) position.

Note – An operation or maintenance procedure, practice, condition, statement, etc., which is essential to emphasize. Multiple warnings, cautions, or notes will be prefaced with bullets.

PID – Acronym for Proportional, Integral, and Derivative. A three-mode control action where the controller has time proportioning, integral (auto reset), and derivative action. The integral function, also known as reset, automatically adjusts the temperature at which a system has stabilized back to the set point temperature, thereby eliminating droop in the system. The derivative function, also known as rate, senses the rate at which a system's temperature is either increasing or decreasing and adjusts the cycle time of the controller to minimize overshoot or undershoot.

Pop-off – Another term for relief valve.

Prefixes – Standard International System of Units (SI) prefixes used throughout this manual are as follows:

Factor	Prefix	Symbol	Factor	Prefix	Symbol
10^{18}	exa	E	10^{-1}	deci	d
10^{15}	peta	P	10^{-2}	centi	c
10^{12}	tera	T	10^{-3}	milli	m
10^{9}	giga	G	10^{-6}	micro	µ
10^{6}	mega	M	10^{-9}	nano	n
10^{3}	kilo	k	10^{-12}	pico	p
10^{2}	hecto	h	10^{-15}	femto	f
10^{1}	deka	da	10^{-18}	atto	a

Pounds per Square Inch (psi) – A unit of pressure. 1 psi = 6.89473 kPa. Variations include psi absolute (psia) measured relative to vacuum (zero pressure) where one atmosphere pressure equals 14.696 psia and psi gauge (psig) where gauge measured relative to atmospheric or some other reference pressure.

Quench – A condition where the superconducting magnet goes "normal," i.e., becomes non-superconductive. When this happens, the magnet becomes resistive, heat is generated, Liquid Helium is boiled off, and the Magnet Power Supply will shut down due to the sudden increase in current demand.

Relief Valve – A type of pressure relief device which is designed to relieve excessive pressure, and to reclose and reseal to prevent further flow of gas from the cylinder after reseating pressure has been achieved.

Roman Numerals – Letters employed in the ancient Roman system of numeration as follows:

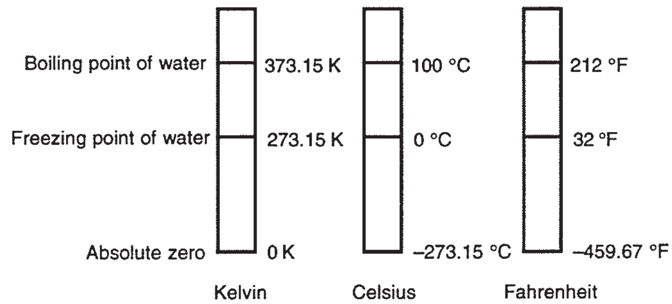
I	1	VI	6	L	50
II	2	VII	7	C	100
III	3	VIII	8	D	500
IV	4	IX	9	M	1000
V	5	X	10		

Root Mean Square (RMS) – The square root of the average of the squares of the values of a periodic quantity taken throughout one complete period. It is the effective value of a periodic quantity

Susceptance – In electrical terms, susceptance is defined as the reciprocal of reactance and the imaginary part of the complex representation of admittance: [suscept(ibility) + (conduct)ance].

Susceptibility – In the use of OMEGA equipment, susceptibility involves subjecting a sample material to a small alternating magnetic field. The flux variation due to the sample is picked up by a sensing coil surrounding the sample and the resulting voltage induced in the coil is detected. This voltage is directly proportional to the magnetic susceptibility of the sample.

Temperature – A fundamental unit of measurement which describes the kinetic and potential energies of the atoms and molecules of bodies. When the energies and velocities of the molecules in a body are increased, the temperature is increased whether the body is a solid, liquid, or gas. Thermometers are used to measure temperature. The temperature scale is based on the temperature at which ice, liquid water, and water vapor are all in equilibrium. This temperature is called the triple point of water and is assigned the value 0 °C, 32 °F, and 273.15 K. These three temperature scales are defined as follows:



Warning – An operation or maintenance procedure, practice, condition, statement, etc., which, if not strictly observed, could result in injury, death, or long-term health hazards to personnel.

APPENDIX B

HANDLING OF LIQUID HELIUM AND NITROGEN

B1.0 GENERAL

Liquid Helium (LHe) and liquid nitrogen (LN_2) may be used in conjunction with the controller. Although not explosive, the following are safety considerations in the handling of LHe and LN_2.

B2.0 PROPERTIES

LHe and LN_2 are colorless, odorless, and tasteless gases. Gaseous nitrogen makes up about 78 percent of the Earth's atmosphere, while helium comprises only about 5 ppm (Reference 1). Most helium is recovered from natural gas deposits. Once collected and isolated, the gases will liquify when properly cooled. A quick comparison between LHe and LN_2 is provided in Table B-1.

Table B-1. Comparison of Liquid Helium to Liquid Nitrogen

PROPERTY	LIQUID HELIUM	LIQUID NITROGEN
Boiling Point @1 atm, in °K	4.2	77
Thermal Conductivity (Gas), w/cm–°K	0.083	0.013
Latent Heat of Vaporization, Btu/liter	2.4	152
Liquid Density, pounds/liter	0.275	0.78

B3.0 HANDLING CRYOGENIC STORAGE DEWARS

All cryogenic containers (dewars) must be operated in accordance with the manufacturer's instructions. Safety instructions will also be posted on the side of each dewar. Cryogenic dewars must be kept in a well-ventilated place where they are protected from the weather and away from any sources of heat. A typical cryogenic dewar is shown in Figure B-1.

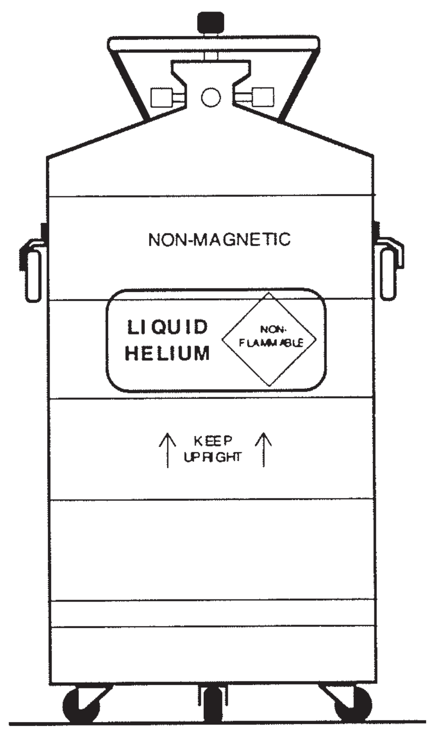


Figure B-1. Typical Cryogenic Storage Dewar

B4.0 LIQUID HELIUM AND NITROGEN SAFETY PRECAUTIONS

Transferring LHe and LN_2 and operation of the storage dewar controls should be in accordance with the manufacturer/supplier's instructions. During this transfer, it is important that all safety precautions written on the storage dewar and recommended by the manufacturer be followed.

WARNING

- Liquid helium and liquid nitrogen are potential asphyxiants and can cause rapid suffocation without warning. Store and use in area with adequate ventilation. DO NOT vent container in confined spaces. DO NOT enter confined spaces where gas may be present unless area has been well ventilated. If inhaled, remove to fresh air. If not breathing, give artificial respiration. If breathing is difficult, give oxygen. Get medical help.
- Liquid helium and liquid nitrogen can cause severe frostbite to the eyes or skin. DO NOT touch frosted pipes or valves. In case of frostbite, consult a physician at once. If a physician is not readily available, warm the affected areas with water that is near body temperature.

The two most important safety aspects to consider when handling LHe and LN_2 are adequate ventilation and eye and skin protection. Although helium and nitrogen gases are non-toxic, they are dangerous in that they replace the air in a normal breathing atmosphere. Liquid products are of an even greater threat since a small amount of liquid evaporates to create a large amount of gas. Therefore, it is imperative that cryogenic dewars be stored, transfers accomplished, and systems operated in open and well ventilated areas.

Persons transferring LHe and LN_2 should make every effort to protect eyes and skin from accidental contact with liquid or the cold gas issuing from it. Protect your eyes with full face shield or chemical splash goggles. Safety glasses (even with side shields) are not adequate. Always wear special cryogenic gloves (Tempshield Cryo-Gloves or equivalent) when handling anything that is, or may have been, in contact with the liquid or cold gas, or with cold pipes or equipment. Long sleeve shirts and cuffless trousers that are of sufficient length to prevent liquid from entering the shoes are recommended.

B5.0 RECOMMENDED FIRST AID

Every site that stores and uses LHe and LN_2 should have an appropriate Material Safety Data Sheet (MSDS) present. The MSDS may be obtained from the manufacturer/distributor. The MSDS writeup will specify the symptoms of overexposure and the first aid to be used. A typical summary of these instructions is provided as follows.

If symptoms of asphyxia such as headache, drowsiness, dizziness, excitation, excess salivation, vomiting, or unconsciousness are observed, remove the victim to fresh air. If breathing is difficult, give oxygen. If breathing has stopped, give artificial respiration. Call a physician immediately.

If exposure to cryogenic liquids or cold gases occurs, restore tissue to normal body temperature (98.6°F) as rapidly as possible, then protect the injured tissue from further damage and infection. Call a physician immediately. Rapid warming of the affected parts is best achieved by bathing it in warm water. The water temperature should not exceed 105 °F (40 °C), and under no circumstances should the frozen part be rubbed, either before or after rewarming. If the eyes are involved, flush them thoroughly with warm water for at least 15 minutes. In case of massive exposure, remove clothing while showering with warm water. The patient should not drink alcohol or smoke. Keep warm and rest. Call a physician immediately.

References:

1. Linde Union Carbide Document No. L-3499H, Dated December 1988, Safety Precautions for Oxygen, Nitrogen, Argon, Helium, Carbon Dioxide, Hydrogen, and Fuel Gases

APPENDIX C

CURVE TABLES

C1.0 GENERAL

The following are curve tables applicable to the Autotuning Temperature Controller.

Table C-1. Standard Diode and Platinum Curves

Breakpoint	Standard CURVE 10		Platinum 100 Ohm	
Number	Temp (K)	V	Temp (K)	Ω
1	499.9	0.00000	000.0	0.00000
2	475.0	0.09032	030.0	0.03820
3	460.0	0.12536	032.0	0.04235
4	435.0	0.18696	036.0	0.05146
5	390.0	0.29958	038.0	0.05650
6	340.0	0.42238	040.0	0.06170
7	280.0	0.56707	042.0	0.06726
8	230.0	0.68580	046.0	0.07909
9	195.0	0.76717	052.0	0.09924
10	165.0	0.83541	058.0	0.12180
11	140.0	0.89082	065.0	0.15015
12	115.0	0.94455	075.0	0.19223
13	095.0	0.98574	085.0	0.23525
14	077.4	1.02044	105.0	0.32081
15	060.0	1.05277	140.0	0.46648
16	044.0	1.08105	180.0	0.62980
17	036.0	1.09477	210.0	0.75044
18	031.0	1.10465	270.0	0.98784
19	028.0	1.11202	315.0	1.16270
20	027.0	1.11517	355.0	1.31616
21	026.0	1.11896	400.0	1.48652
22	025.0	1.12463	445.0	1.65466
23	024.0	1.13598	490.0	1.82035
24	020.0	1.21555	535.0	1.98386
25	015.5	1.29340	585.0	2.16256
26	012.0	1.36687	630.0	2.32106
27	009.0	1.44850	675.0	2.47712
28	003.8	1.64112	715.0	2.61391
29	002.0	1.68912	760.0	2.76566
30	001.4	1.69808	800.0	2.89830
31	000.0	6.55360	999.9	6.55360

Table C-2. Thermocouple Curves – CHROMEGA ® versus Gold/Iron

Breakpoint	CHROMEGA ® vs. Au-0.07 at.% Fe	
Number	Temp (K)	V_{TC}(mV)
1	1.4	– 5.2982
2	3.0	– 5.2815
3	4.8	– 5.2594
4	7.0	– 5.2285
5	10.5	– 5.1742
6	19.0	– 5.0315
7	26.0	– 4.9126
8	48.0	– 4.5494
9	58.0	– 4.3810
10	70.0	– 4.1733
11	80.0	– 3.9952
12	90.0	– 3.8132
13	100.0	– 3.6270
14	110.0	– 3.4370
15	120.0	– 3.2435
16	135.0	– 2.9477
17	150.0	– 2.6452
18	165.0	– 2.3372
19	180.0	– 2.0242
20	200.0	– 1.6004
21	220.0	– 1.1693
22	245.0	– 0.6232
23	270.0	– 0.0705
24	300.0	+ 0.5986
25	305.0	+ 0.7158
26	310.0	+ 0.8431
27	315.0	+ 0.9944
28	320.0	+ 1.1940
29	325.0	+ 1.4841

Table C-3. Thermocouple Curves – CHROMEGA® versus Copper

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

This Page Intentionally Left Blank

APPENDIX D

APPLICATION NOTES

D1.0 GENERAL

The following applications notes are included with this manual:

1. Fundamentals For Usage Of Cryogenic Temperature Controllers – Application Note.
2. CY7 Series Temperature Sensors Installation and Operation – Application Note.
3. Measurement System Induced Errors In Diode Thermometry – Article Reprint.
4. Standard Curve 10 – Technical Data.

This Page Intentionally Left Blank

FUNDAMENTALS FOR USAGE OF CRYOGENIC TEMPERATURE CONTROLLERS

by

Dr. John M. Swartz
Lake Shore Cryotronics, Inc.
64 East Walnut Street
Westerville, Ohio 43081

Lawrence G. Rubin
MIT National Magnet Laboratory
170 Albany Street
Cambridge, Mass. 02139

I Introduction

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

II Characteristics of Cryogenic Temperature Control Systems

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

(1) The values of heat capacity (lower), C_p, and thermal conductivity (often higher), κ, are such that much shorter thermal time constants ($\tau \alpha C_p/\kappa$) are the rule at low temperatures.

(2) The temperature sensor used in a furnace is almost always one of a variety of thermocouples with sensitivities in the 10-100uV/°C range. In the cryogenic regime, resistance thermometers (both metallic and semiconductive), diode, and capacitance thermometers provide from one to three orders-of-magnitude higher sensitivity.

(3) The heat input for furnaces is almost always derived from a line frequency source, and is controlled by relays, variable transformers, saturable reactors, or SCRs. Experiments performed in a cryostat usually involve low level signals, and hence require a low noise background. For that reason, ripple-free direct current, usually controlled by a series transistor bank, should be used to power the heater.

(4) As one traverses the cryogenic regime from the liquid helium range up towards room temperature, there can be quite large *variations* in both the thermal time constants and thermometer sensitivities.

(5) In the case of the furnace in which the load does not experience large endo- or exothermic reactions, the heat input required to maintain a set point temperature is approximately constant. This is because the heat loss through a fixed thermal conductance to the room temperature environment outside the furnace is also constant. However, there are cryogenic systems where the low temperature environment provided by, e.g., a surrounding cryogen such as a liquid helium or liquid nitrogen bath, may vary drastically as the level of the cryogen changes. In addition, the thermal conductance to the outside world is highly dependent on the gas pressure (vacuum) maintained in the cryostat. The resulting variations in "cooling power" will cause the heat input requirements to be anything *but* constant. A few cryogenic systems employ a controller cooling loop, but this type of system will not be discussed.

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

III Proportional Control

The block diagram in Figure 1 shows a system in which only proportional control is being used. In this system, the desired control temperature setting (set point) is being compared to the sensor signal and the difference, or error signal (including polarity), is amplified within the controller. When the sensor temperature corresponds to the set point temperature (in voltage for a diode or resistance for a resistor), the sensor signal will be equal to, but opposite in polarity to the set point signal and the error signal will be zero. In older instruments, the set point is normally calibrated in millivolts or volts or resistance, corresponding to the sensor output signal. Most modern controllers have stored within them the appropriate voltage-temperature or resistance-temperature sensor characteristic so that the set point can be calibrated directly in temperature. However, as discussed in Section 7, this convenience feature can compromise the resolution and accuracy of the controller.

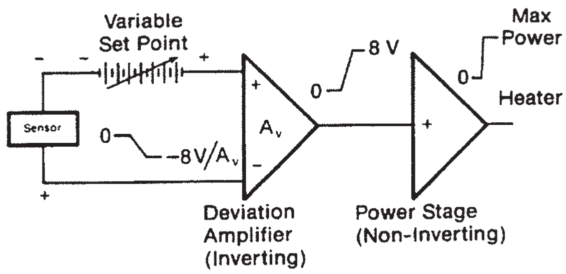


Figure 1. Block diagram of Cryogenic Temperature Controller A_V is amplifier voltage gain.

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

Let us examine the behavior of the sensor signal—set point—deviation circuit in a modern cryogenic controller, the OMEGA CYC3211In Figure 2, the amplifier output (deviation gain times error) is plotted against the error signal for two amplifier gains: $A_V = 100$ and $A_V = 1000$. "Gain" in this closed loop system refers not to the power gain, as in an audio amplifier, but is related to the maximum amount of error signal allowed before the controller is directed to produce full output power. The CYC3211 requires a 0 to 8 volt signal from the deviation amplifier to drive the power output stage from zero-to-maximum. In Figure 2, for $A_V = 1000$, there is a narrow band of error signals (0 to -8 mV) within which the proportional action occurs. This "proportional band" expands tenfold for $A_V = 100$, and so on for lower gains; obviously, gain and proportional band are inversely related. Proportional band is expressed as a percentage of full scale range.

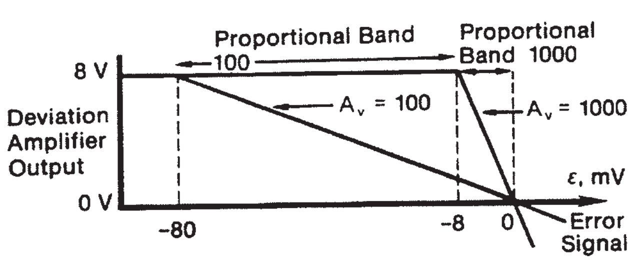


Figure 2. Output plot of the deviation amplifier showing Proportional Bands for gain settings of 100 and 1000. For the CYC3211, the maximum available gain is 1000.

Note that the proportional band in mV can be converted to temperature in kelvin if the sensitivity of the sensor in mV/K is known. As an example, suppose the sensor producing the error signal in Figure 2 had a sensitivity of 1 mV/K and the set point full scale range was 100 mV = 100 K.

The proportional band would then be 8% (or 8 K) and 80% (or 80 K) for $A_V = 1000$ and 100, respectively. In cryogenic applications, this terminology is less significant; gain, which is multiplicative, is usually more useful, since it is more easily understood by the user.

The power output stage of a cryogenic controller may or may not have variable gain associated with it. If the controller has several output power stage ranges (for example, 5, covering 5 orders of magnitude in power) as does the CYC3211, then the controller output into a 50 ohm load and with a gain of 200 for 5 watts and 50 watts would have the response shown in Figure 3. Note that the *overall* voltage and power gain of the controller is modified by changing the output power settings.

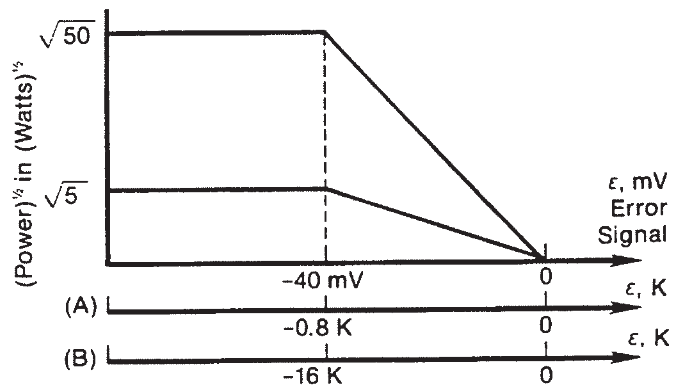


Figure 3. Output Power versus error signal in voltage or equivalent temperature of sensor for two different power settings: (A) corresponds to a sensor sensitivity of -50 mV/K; (B) corresponds to a sensor sensitivity of -2.5 mV/K. Note that the curves are linear in voltage, *not* power.

To illustrate the effect of the sensor, in more detail consider the idealized curve (Figure 4) for an OMEGA silicon diode which has a nominal sensitivity of –50 mV/K, below 30 kelvin and –2.5 mV/K above 30 kelvin. Figure 3 illustrates the effect of converting the voltage error signal (horizontal axis) to its equivalent temperature error for the two sensitivity regions of the silicon diode sensor.

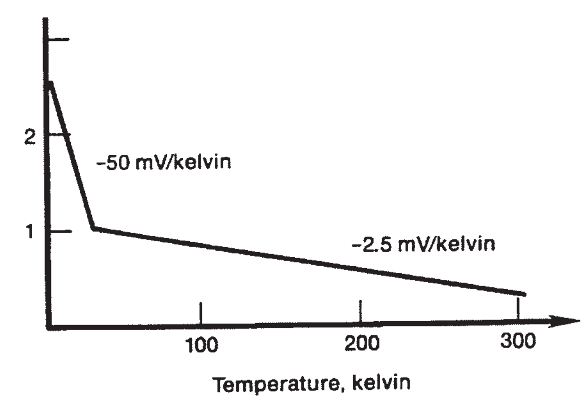


Figure 4. Idealized curve for OMEGA's CY7 Series silicon diode temperature sensors.

These curves introduce the concept of loop gain dP/dT (watts/ kelvin), which includes the gain of the sensor as well as that of the deviation amplifier and power output stage. As the transition in temperature from above 30 kelvin to below 30 kelvin is made, the loop gain is increased by a factor of 20 because of the increased sensitivity of the silicon diode thermometer. Because of noise and thermal phase lag, the deviation amplifier gain will normally have to be reduced by the same factor so that the loop gain remains relatively constant.

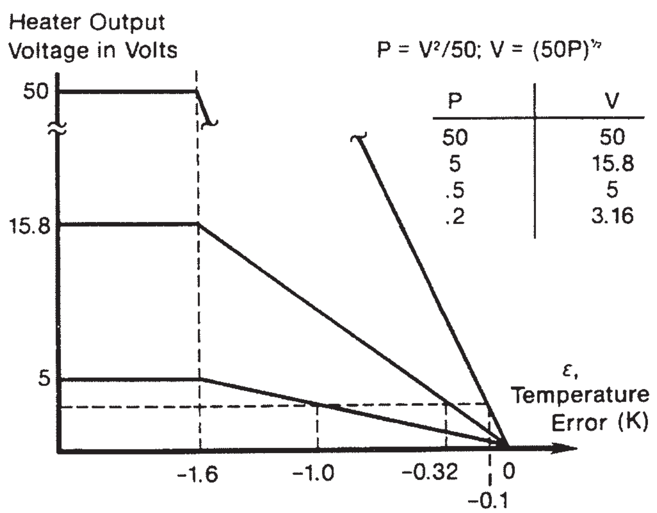


Figure 5. Effect of output power setting on offset for a proportional controller *only.*

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

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

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

The Real World

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

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

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

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

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

IV Proportional (GAIN) Plus integral (RESET) Temperature Control

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

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

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

Before we switch the discussion back to real systems, let us deal with the nomenclature and units involved in integral control. Automatic reset action can be expressed in terms of a time constant (minutes) or its inverse, reset rate (repeats per minute). The reset time constant is the time required—measured in minutes—for the reset circuit to integrate to full output with an input signal which is *constant* and equal to the proportional band error signal. The amount of reset action can also be measured in "repeats per minute," or the number of times which the integrator can integrate between zero and full output in a time period of one minute for the constant proportional band error signal. Thus, if the time constant were, say, two minutes, this is the same as saying that the reset circuitry repeats the proportional action in two minutes, or 1/2 repeats per minute.

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

The Real World Revisited

Since a real cryogenic system has non-zero thermal resistance, the value of the reset is important in setup of the controller. The amount of reset desired is dependent on: (1) the time required for the control sensor to reach equilibrium once it enters the proportional band; and (2) the amount of output signal required from the reset action to overcome the cooling power of the cryogenic system. For example, assume that 50% output is required and the time to reach equilibrium is 3 seconds (0.05 minutes). Therefore, the repeats per minute is 10 and the time constant is 0.1 minutes. In actuality, this is not easy to determine without a few tries. Almost always, however, the time constant increases with increasing temperature so that if one is operating over a broad temperature range, finding the appropriate time constants for the two extremes will bracket the appropriate time constants within that temperature range. Once the correct time constant has been selected, the system should settle to its control set point within two or three time constants. If significant overshoot is still occurring, the system design should be carefully reviewed.

Particular attention should be paid to the balance between heat input and cooling power, heater and radiation shield design, and to the placement of the control sensor with respect to the heater. In complex systems, it is useful to have a "sample" sensor as a temperature monitor to insure that there is not a significant gradient across the sample block. In an extreme case, such as at temperatures near 1 kelvin, even the few microwatts of power associated with the control sensor excitation must be considered in the system design.

V Adding Derivative (RATE) To The Temperature Control Loop

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

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

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

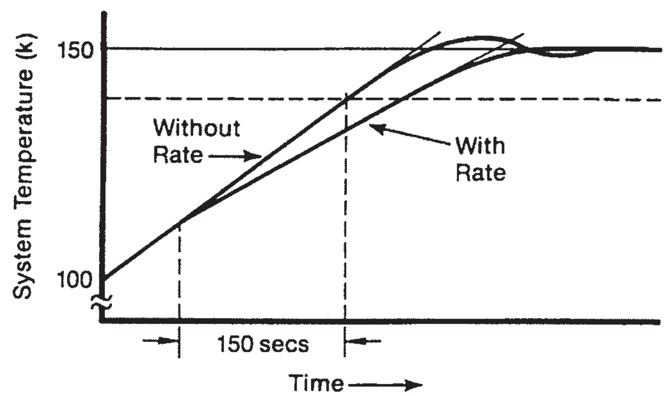


Figure 6. The effect of adding Rate to the control circuit to dynamically widen the proportional band and reduce the overshoot which would occur in its absence.

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

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

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

VI Sensor Considerations

Sensor Gain Revisited: Since a controller will amplify input noise as well as sensor signal, it becomes important to consider sensor performance when designing a complete system. The Silicon Diode Series Sensors have a voltage-temperature characteristic which lend themselves to cryogenic temperature control use because of their high sensitivity at low temperatures (Figure 3). Coupled with this sensitivity is an extremely low noise level which results, which comply with the relevant portions of MIL STD 750C.

It is therefore possible to obtain short-term control at low temperatures which can approach 0.1 mK in specially designed systems Even above 30 K, where the sensitivity is reduced by a factor of 20, short term controllability is better than 2 mK.

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

VII Analog Versus Digital Control

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

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

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

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

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

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

For Further Reading

1) E.M. Forgan, "On the Use of Temperature Controllers in Cryogenics." Cryogenics 74 (1974), pp. 207-214. This is a cogent discussion of the interaction between the electrical and thermal response times in a typical *cryogenic* control system. The mathematical analyses are straightforward and relatively easy to follow.

2) A series on "Process Control" published in the journal, Measurements & Control, Part 3, "On/Off and Proportional Control," September 1984, pp. 165-170; Part 4, "Reset and Rate Control," October 1984, pp. 133-145; Part 5, "Selecting the Mode of Control," December 1984, pp. 132-136. Some of this material has appeared in "Principles of Temperature Control," available from Gulton Industries, West Division. Unlike reference 1, the discussion is not related to cryogenics but temperature control system principles are briefly and clearly explained.

Papers on digital temperature control systems tend to be complicated and often difficult to read for the non-specialist. References 3, 4 and 5 have been selected as examples of lucid discussions of the subject.

3) C.L. Pomernacki, "Micro Computer-Based Controller for Temperature Programming the Direct Inlet Probe of a High Resolution Mass Spectrometer," Review of Scientific Instruments, 48 (1977), pp. 1420-1427.

4) W.M. Cash, E.E. Stansbury, C.F. Moore, and C.R. Brooks, "Application of a Digital Computer to Data Acquisition and Shield Temperature Control of a HighTemperature Adiabatic Calorimeter," Review of Scientific Instruments, 52 (1981), pp. 895-901.

5) R.B. Strem, B.K. Das, and S.C. Greer, "Digital Temperature Control and Measurement System," Review of Scientific Instruments, 52 (1981), pp. 1705-1708.

This page is intentionally blank

CYC7 Series Temperature Sensors Application Notes

INSTALLATION AND OPERATION

There are three aspects of using a temperature sensor which are critical to its optimum performance:

- the proper electrical and thermal installation of the connecting leads which run to the sensor
- the actual mounting of the sensor to the sample assembly
- the measurement electronics used for reading and recording temperature data from the sensor

Connecting Leads

Although the majority of the CY7 series sensors are two lead devices, measurements should preferably be made using a four wire configuration to avoid all uncertainties associated with the lead resistance. This is done by using four connecting leads to the device and connecting the V+ and I+ leads to the anode and the V- and I- leads to the cathode as shown in Figure 1. The exact point at which the connecting leads are soldered to the device leads results in negligible temperature measurement uncertainties.

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

An excessive heat flow through the connecting leads to any temperature sensor can create a situation where the active sensing element (for the CY7 Series this is the diode chip) is at a different temperature than the sample to which the sensor is mounted. This is then reflected as a real temperature offset between what is measured and the true sample temperature. Such temperature errors can be eliminated by proper selection and installation of the connecting leads.

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

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

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

Sensor Mounting

General Comments

Before installing the CY7 Series sensor, identify which lead is the anode and which lead is the cathode by referring to the accompanying device drawings. Be sure that lead identification remains clear even after installation of the sensor, and record the serial number and location.

The procedure used to solder the connecting leads to the sensor leads is not very critical and there is very little

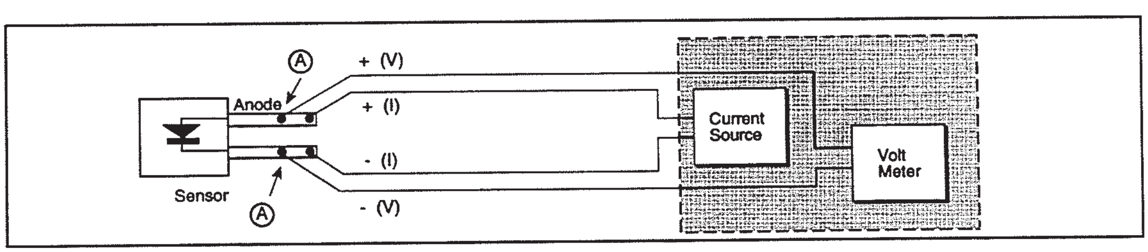


Figure 1. Four-Wire Configuration for CY7 Series Sensor Installation

REFERENCES

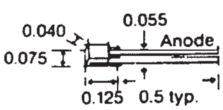
Krause, J.K. and Swinehart, P.R. (1985). Demystifying Cryogenic Temperature Sensors. *Photonics Spectra.* August, 61-68.

Krause, J.K. and Dodrill, B.C. (1986). Measurement System Induced Errors in Diode Thermometry, *Review of Scientific Instruments* 57 (4), 661-665.

Sparks, L.L. (1983). Temperature, Strain, and Magnetic Field Measurements. In *Material at Low Temperatures*, Ed. by R.P. Reed and A.F. Clark. American Society of Metals, Metals Park, 515-571.

White, G.K. (1979). *Experimental Techniques in Low Temperature Physics*. Clarendon Press, Oxford.

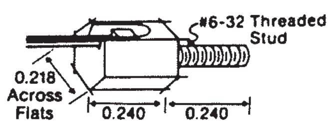
CY7-SD



Dimensions in inches unless otherwise noted.

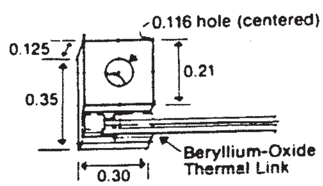
Basic Sensor package style.
Temperature Range: 1.4K to 475K
Mass: 0.03g

CY7-ET



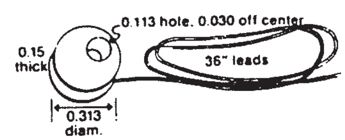
Basic Sensor soldered onto SAE-threaded copper adapter.
Temperature Range: 1.4K to 325K
Mass: 1.4g

CY7-BO



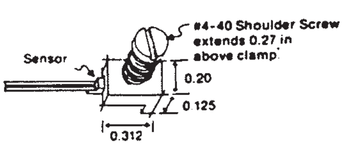
Basic Sensor soldered onto bolt-on copper block with leads thermally anchored to block.
Temperature Range: 1.4K to 325K
Mass: 1.5g

CY7-CU/CY7-DI



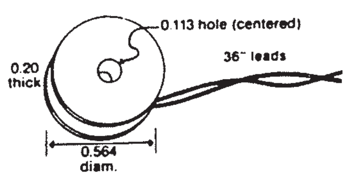
Basic Sensor Mounted into bolt-on disk with leads thermally anchored to disk with low temperature epoxy. CU version is 4-leaded. DI is 2-leaded.
Temperature Range: 1.4K to 325K
Mass (excl. leads): 4.3g

CY7-CO



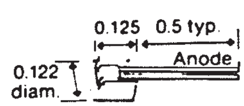
Basic Sensor with spring-loaded brass clamp to hold Sensor to sample.
Temperature Range: 1.4K to 475K
Mass (w/o Sensor): 1.7g

CY7-CY



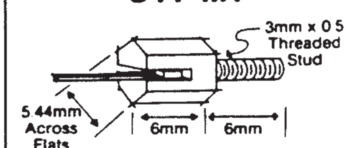
Basic Sensor epoxied into relatively large, copper disk. 30AWG stranded copper lead pair is thermally anchored to disk. Temperature Range: 1.4K to 325K
Mass (excl. leads): 4.3g

CY7-LR



Basic Sensor soldered into cylindrical copper adapter.
Temperature Range: 1.4K to 325K
Mass: 0.15g

CY7-MT



Basic Sensor soldered into metric-threaded copper adapter.
Temperature Range: 1.4K to 325K
Mass: 1.4g

Measurement System Induced Errors In Diode Thermometry

John K. Krause and Brad C. Dodrill

Lake Shore Cryotronics, Inc., 64 East Walnut Street, Westerville, Ohio 43081
(Received 3 June 1985; accepted for publication 2 December 1985)

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

INTRODUCTION

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

I. PROBLEM DEFINITION

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

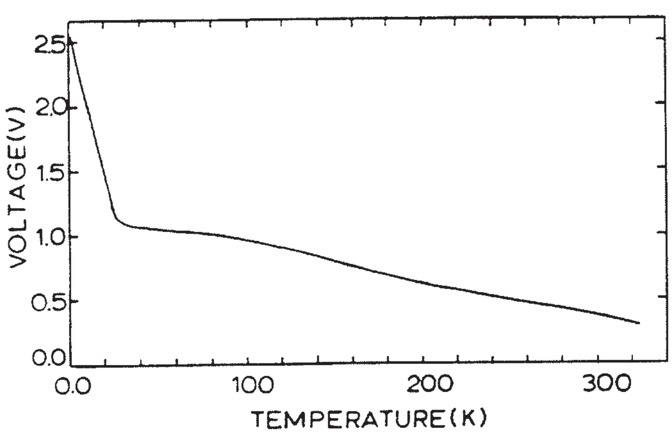


Figure 1. Voltage-temperature curve for a typical silicon diode temperature sensor at a constant current of 10,uA.

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

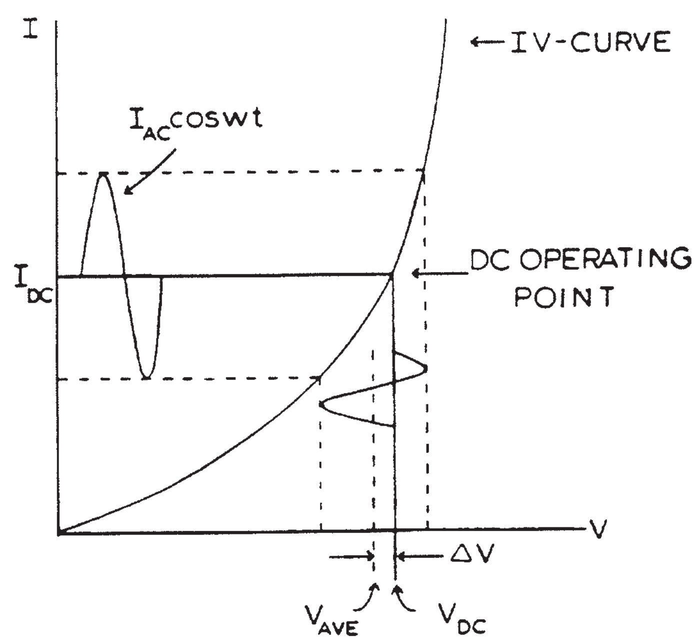


Figure 2. IV curve for a silicon diode sensor showing the effect of an induced ac current superimposed on the dc operating current I_{dc}. The expected dc operating voltage is V_{dc}, which is shifted from the average voltage V_{ave}, indicated by the voltmeter in a dc measurement mode.

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

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

II. EXPERIMENTAL

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

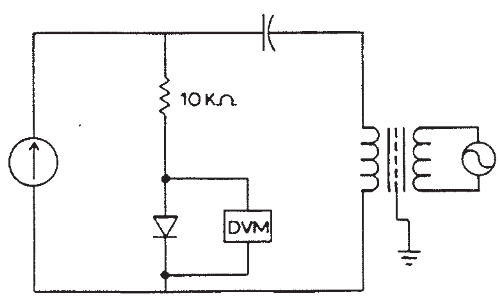


Figure. 3 Schematic diagram of the measurement circuit

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

Although detailed measurements were taken on only one diode, other diodes were randomly selected and spot checked at all three temperatures and frequencies to verify consistency with the measured data. The diodes tested were of the DT-500 series of Lake Shore Cryotronics, Inc. and

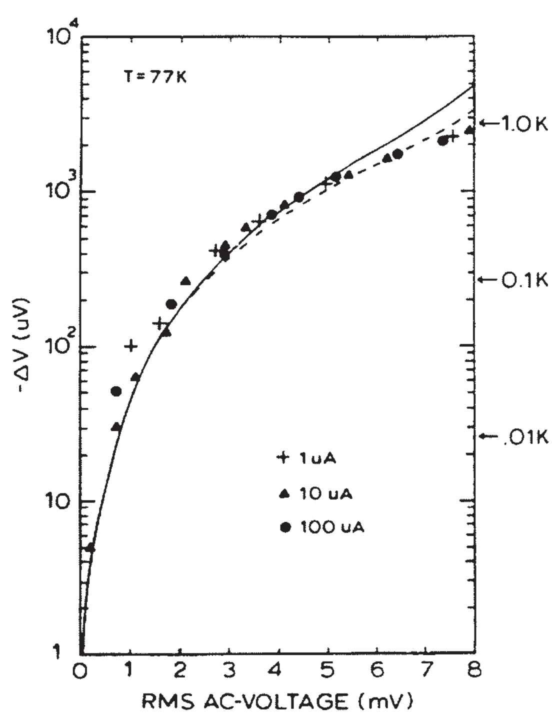


Figure 4. dc offset voltage as a function of rms ac voltage across a silicon diode temperature sensor operating at 77 K. The symbols represent data recorded at three different dc operating currents with a 60 Hz signal superimposed. The solid curve gives the results of the small signal model while the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

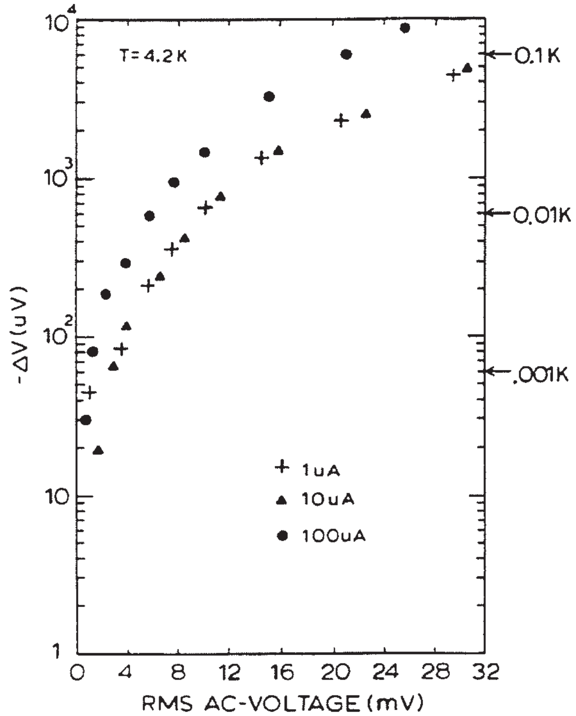


Figure 5. dc offset voltage as a function ofrms ac voltage across a silicon diode temperature sensor operating at 4.2 K. The symbols represent data recorded at three different dc operating currents with a 60-Hz signal superimposed. Equivalent temperature erron are indicated along the right edge.

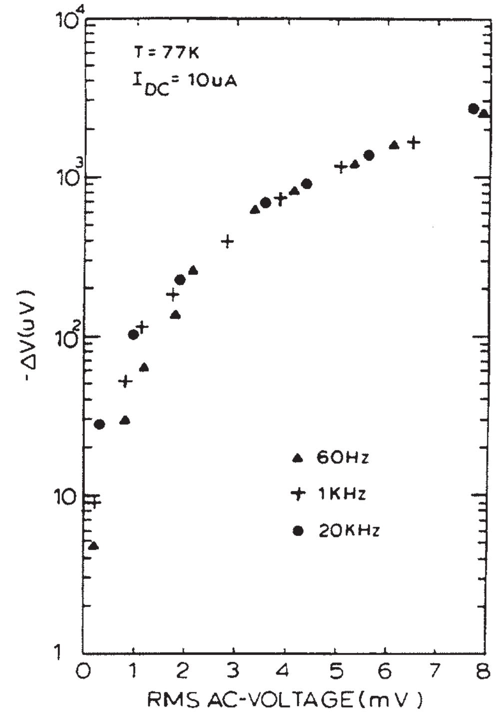


Figure 6. dc offset voltage as a function ofrms ac voltage across a silicon diode temperature sensor operating at 77 K. The symbols represent data recorded at a 10-µA dc current with the ac current modulation at 60, 1000, and 20,000HIz

have been in production long enough to have a substantial reliability and calibration history.

III. RESULTS AND DISCUSSION

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

Figures 4 and 5 give the offset voltage as a function of the ac (rms) voltage across the diode for dc currents of 1, 10, and 100µA with the ac current modulation at 60 Hz. The equivalent temperature error corresponding to the de offset voltage is indicated along the right edge of the figure. Figures 6 and 7 give similar plots but at a fixed 10-µA dc current with the ac current modulation at 60, 1000, and 20,000 Hz. The magni-

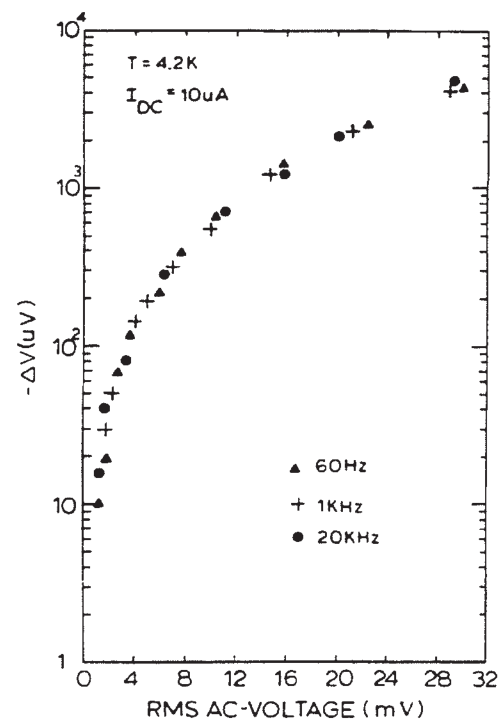


Figure 7. dc offset voltage as a function of fins ac voltage across a silicon diode temperature sensor operating at 4.2 K. The symbols represent data recorded at a 10µA dc current with the ac current modulation at 60, 1000, and 20 000 Hz.

tude of the dc offset voltages is consistent with what has been observed in measurement systems when corrective action has been taken to eliminate noise problems. Special note should be taken of the dc current independence in Fig. 4 and the frequency independence in Figs. 6 and 7. The data taken at 305 K have not been shown as the results are qualitatively very similar to the 77-K measurements and can be adequately described by the mathematical model which is presented below.

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

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

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

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

The only adjustable parameter in Eq. (1) which is necessar for the present analysis is the parameter n. This parmeter can be determined quite easily from the IV charactenstics of the silicon diode temperature sensor. The parameter I_s is eliminated by normalizing the IVcurve to an arbitrarily chosen point on the curve. The value of n = 1.8 was found to give a relatively good fit to the IV data for both 305 and 77 K and has been assumed in the present discussion.[7]

Equation (1) can now be solved for V(I):

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

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

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

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

$$\Delta V = \overline{V} - V(I_{dc})$$

$$= \frac{nkT}{e}\ln\left[\frac{1}{2}\left(1+\sqrt{1-\left(\frac{I_{ac}}{I_{dc}+I_S}\right)^2}\right)\right] , \qquad (4)$$

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

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

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

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

where

$$2(eV_{rms} / nkT)^2 \le 1$$

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

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

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

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

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

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

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

IV. CONCLUDING REMARKS

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

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

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

[1] A. S. Grove, *Physics and Technology of Semiconductor Devices* (Wiley, New York, 1967), Chap. 6.

[2] S. M. Sze, *Physics of Semiconductor Devices* (Wiley Interscience, New York, 1969), Chap. 4.

[3] D. A. Fraser, *The Physics Of Semiconductor Devices* (Clarendon, Oxford, 1983).

[4] R. V. Aldridge, Solid-State Electron. 17, 617 (1974).

[5] V. Chopra and G. Dharmadurai, Cryogenics 20, 659 (1980).

[6] D. A. Kleinman, Bell Syst. Tech. J. 35, 685 (1956).

[7] P. IL Swinehart, L.A. Smith, and J.K. Krause (private communication); values are consistent with numerous other measurements made at Lake Shore Cryotronics, Inc.

[8] R. Morrison, *Grounding and Shielding Techniques in Instrumentation* (Wiley, New York, 1977), Vol. 2.

This page is intentionally blank

STANDARD CURVE #10
Measurement Current = 10μA ±0.05%

T (K)	Voltage	dV/dT (mV/K)	T (K)	Voltage	dV/dT (mV/K)	T (K)	Voltage	dV/dT (mV/K)
1.40	1.69812	-13.1	16.0	1.28527	-18.6	95.0	0.98564	-2.02
1.60	1.69521	-15.9	16.5	1.27607	-18.2	100.	0.97550	-2.04
1.80	1.69177	-18.4	17.0	1.26702	-18.0	110.	0.95487	-2.08
2.00	1.68786	-20.7	17.5	1.25810	-17.7	120.	0.93383	-2.12
2.20	1.68352	-22.7	18.0	1.24928	-17.6	130.	0.91243	-2.16
2.40	1.67880	-24.4	18.5	1.24053	-17.4	140.	0.89072	-2.19
2.60	1.67376	-25.9	19.0	1.23184	-17.4	150.	0.86873	-2.21
2.80	1.66845	-27.1	19.5	1.22314	-17.4	160.	0.84650	-2.24
3.00	1.66292	-28.1	20.0	1.21440	-17.6	170.	0.82404	-2.26
3.20	1.65721	-29.0	21.0	1.19645	-18.5	180.	0.80138	-2.28
3.40	1.65134	-29.8	22.0	1.17705	-20.6	190.	0.77855	-2.29
3.60	1.64529	-30.7	23.0	1.15558	-21.7	200.	0.75554	-2.31
3.80	1.63905	-31.6	24.0	1.13598	-15.9	210.	0.73238	-2.32
4.00	1.63263	-32.7	25.0	1.12463	-7.72	220.	0.70908	-2.34
4.20	1.62602	-33.6	26.0	1.11896	-4.34	230.	0.68564	-2.35
4.40	1.61920	-34.6	27.0	1.11517	-3.34	240.	0.66208	-2.36
4.60	1.61220	-35.4	28.0	1.11212	-2.82	250.	0.63841	-2.37
4.80	1.60506	-36.0	29.0	1.10945	-2.53	260.	0.61465	-2.38
5.00	1.59782	-36.5	30.0	1.10702	-2.34	270.	0.59080	-2.39
5.50	1.57928	-37.6	32.0	1.10263	-2.08	280.	0.56690	-2.39
6.00	1.56027	-38.4	34.0	1.09864	-1.92	290.	0.54294	-2.40
6.50	1.54097	-38.7	36.0	1.09490	-1.83	300.	0.51892	-2.40
7.00	1.52166	-38.4	38.0	1.09131	-1.77	310.	0.49484	-2.41
7.50	1.50272	-37.3	40.0	1.08781	-1.74	320.	0.47069	-2,42
8.00	1.48443	-35.8	42.0	1.08436	-1.72	330.	0.44647	-2.42
8.50	1.46700	-34.0	44.0	1.08093	-1.72	340.	0.42221	-2.43
9.00	1.45048	-32.1	46.0	1.07748	-1.73	350.	0.39783	-2.44
9.50	1.43488	-30.3	48.0	1.07402	-1.74	360.	0.37337	-2.45
10.0	1.42013	-28.7	50.0	1.07053	-1.75	370.	0.34881	-2.46
10.5	1.40615	-27.2	52.0	1.06700	-1.77	380.	0.32416	-2.47
11.0	1.39287	-25.9	54.0	1.06346	-1.78	390.	0.29941	-2.48
11.5	1.38021	-24.8	56.0	1.05988	-1.79	400.	0.27456	-2.49
12.0	1.36809	-23.7	58.0	1.05629	-1.80	410.	0.24963	-2.50
12.5	1.35647	-22.8	60.0	1.05267	-1.81	420.	0.22463	-2.50
13.0	1.34530	-21.9	65.0	1.04353	-1.64	430.	0.19961	-2 50
13.5	1.33453	-21.2	70.0	1.03425	-1.87	440.	0.17464	-2.49
14.0	1.32412	-20.5	75.0	1.02482	-1.91	450.	0.14985	-2.46
14.5	1.31403	-19.9	80.0	1.01525	-1.93	460.	0.12547	-2.41
15.0	1.30422	-19.4	85.0	1.00552	-1.96	470.	0.10191	-2.30
15.5	1.29464	-18.9	90.0	0.99565	-1.99	475.	0.09062	-2.22

CONFORMANCE TO STANDARD CURVE #10

Curve Band (Suffix)	Accuracy (Tolerance)		
	2K-100K	100K-305K	305K-475K
-1 (1.4K-475K)	± 0.25K	± 0.5K	± 1K
-2 (1.4K-475K)	± 0.5K	± 1.0K	± 2.0K
-3 (1.4K-475K)	± 0.5K	± 1% of T	± 1% of T
-4 (1.4K-475K)	± 1K	± 1% of T	± 1% of T
-7 (10K-425K)	± 1.5K	± 1.5% of T	± 1.5% of T

Subject	Paragraph, Figure (F), Table (T) Number

D

E

F

G

H

I - J - K

L

Subject	Paragraph, Figure (F), Table (T) Number

M - N

O

P

Q

R

Subject	Paragraph, Figure (F), Table (T) Number

S

Subject	Paragraph, Figure (F), Table (T) Number

T

U

V - W

X - Y - Z

This Page Intentionally Left Blank

MADE IN USA

WARRANTY

OMEGA warrants this unit to be free of defects in materials and workmanship and to give satisfactory service for a period of **13 months** from date of purchase. OMEGA Warranty adds an additional one (1) month grace period to the normal **one (1) year product warranty** to cover handling and shipping time. This ensures that OMEGA's customers receive maximum coverage on each product. If the unit should malfunction, it must be returned to the factory for evaluation. OMEGA's Customer Service Department will issue an Authorized Return (AR) number immediately upon phone or written request. Upon examination by OMEGA, if the unit is found to be defective it will be repaired or replaced at no charge. However, this WARRANTY is VOID if the unit shows evidence of having been tampered with or shows evidence of being damaged as a result of excessive corrosion; or current, heat, moisture or vibration; improper specification; misapplication; misuse or other operating conditions outside of OMEGA's control. Components which wear or which are damaged by misuse are not warranted. These include contact points, fuses, and triacs.

OMEGA is glad to offer suggestions on the use of its various products. Nevertheless, OMEGA only warrants that the parts manufactured by it will be as specified and free of defects.

OMEGA MAKES NO OTHER WARRANTIES OR REPRESENTATIONS OF ANY KIND WHATSOEVER, EXPRESSED OR IMPLIED, EXCEPT THAT OF TITLE AND ALL IMPLIED WARRANTIES INCLUDING ANY WARRANTY OF MERCHANTABILITY AND FITNESS FOR A PARTICULAR PURPOSE ARE HEREBY DISCLAIMED.

LIMITATION OF LIABILITY: The remedies of purchaser set forth herein are exclusive and the total liability of OMEGA with respect to this order, whether based on contract, warranty, negligence, indemnification, strict liability or otherwise, shall not exceed the purchase price of the component upon which liability is based. In no event shall OMEGA be liable for consequential, incidental or special damages.

Every precaution for accuracy has been taken in the preparation of this manual; however, OMEGA ENGINEERING, INC. neither assumes responsibility for any omissions or errors that may appear nor assumes liability for any damages that result from the use of the products in accordance with the information contained in the manual.

SPECIAL CONDITION: Should this equipment be used in or with any nuclear installation or activity, purchaser will indemnify OMEGA and hold OMEGA harmless from any liability or damage whatsoever arising out of the use of the equipment in such a manner.

RETURN REQUESTS / INQUIRIES

Direct all warranty and repair requests/inquiries to the OMEGA ENGINEERING Customer Service Department. BEFORE RETURNING ANY PRODUCT(S) TO OMEGA, PURCHASER MUST OBTAIN AN AUTHORIZED RETURN (AR) NUMBER FROM OMEGA'S CUSTOMER SERVICE DEPARTMENT (IN ORDER TO AVOID PROCESSING DELAYS). The assigned AR number should then be marked on the outside of the return package and on any correspondence.

FOR **WARRANTY** RETURNS, please have the following information available BEFORE contacting OMEGA:

1. P.O. number under which the product was PURCHASED,
2. Model and serial number of the product under warranty, and
3. Repair instructions and/or specific problems relative to the product.

FOR **NON-WARRANTY** REPAIRS OR **CALIBRATION**, consult OMEGA for current repair/calibration charges. Have the following information available BEFORE contacting OMEGA:

1. P.O. number to cover the COST of the repair/calibration,
2. Model and serial number of product, and
3. Repair instructions and/or specific problems relative to the product.

OMEGA's policy is to make running changes, not model changes, whenever an improvement is possible. This affords our customers the latest in technology and engineering.

OMEGA is a registered trademark of OMEGA ENGINEERING, INC.

Where Do I Find Everything I Need for Process Measurement and Control? OMEGA...Of Course!

TEMPERATURE

- Thermocouple, RTD & Thermistor Probes, Connectors, Panels & Assemblies
- Wire: Thermocouple, RTD & Thermistor
- Calibrators & Ice Point References
- Recorders, Controllers & Process Monitors
- Infrared Pyrometers

PRESSURE/STRAIN FORCE

- Transducers & Strain Gages
- Load Cells & Pressure Gauges
- Displacement Transducers
- Instrumentation & Accessories

FLOW/LEVEL

- Rotameters, Gas Mass Flowmeters & Flow Computers
- Air Velocity Indicators
- Turbine/Paddlewheel Systems
- Totalizers & Batch Controllers

pH/CONDUCTIVITY

- pH Electrodes, Testers & Accessories
- Benchtop/Laboratory Meters
- Controllers, Calibrators, Simulators & Pumps
- Industrial pH & Conductivity Equipment

DATA ACQUISITION

- Data Acquisition and Engineering Software
- Communications-Based Acquisition Systems
- Plug-in Cards for Apple, IBM & Compatibles
- Datalogging Systems
- Recorders, Printers & Plotters

HEATERS

- Heating Cable
- Cartridge & Strip Heaters
- Immersion & Band Heaters
- Flexible Heaters
- Laboratory Heaters

ENVIRONMENTAL MONITORING AND CONTROL

- Metering & Control Instrumentation
- Refractometers
- Pumps & Tubing
- Air, Soil & Water Monitors
- Industrial Water & Wastewater Treatment
- pH, Conductivity & Dissolved Oxygen Instruments

M2005/1294