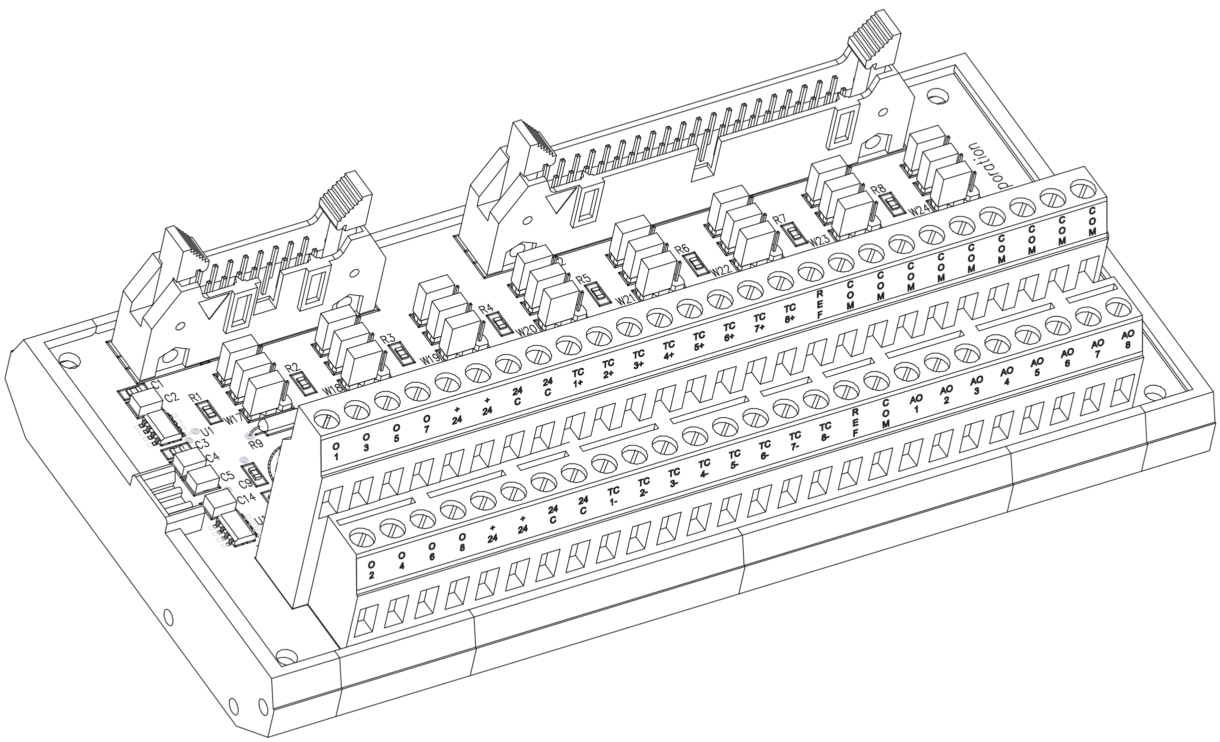
Model 2334 / Model 2335 Analog Interface Module Installation Guide (for use with the 2220 Analog I/O Module



Doc. No. 23345IG
Revision C
March 2002

Contents

Notes to Readers

The *Model 2334 / Model 2335 Installation Guide* provides the following information:

- System Description -- how the modules function.
- Overview -- illustrates the various features on the modules and lists available options.
- Pinout Diagrams -- pinout diagrams and jumper configuration information for each module.
- Specifications -- general, analog I/O, and temperature control specifications.
- Installation -- mounting the module and connecting it to a 2220 Analog I/O module.
- Application Notes -- describes how thermocouples function; how closed loop systems work; sample Quickstep programs.
- Special Purpose Registers -- how to use the special purpose registers in conjunction with the thermocouple interface.

Related Documents

The following documents contain additional information:

- For information on Quickstep, refer to the *Quickstep™ Language and Programming Guide* or the *Quickstep™ User Guide.*
- For information on the registers in your controller, refer to the *Register Reference Guide* (available at www.ctc-control.com).
- For information on Microsoft Windows or your PC, refer to the manuals provided by the vendor.

Formatting Conventions

The following conventions are used in this book:

ALL CAPS BOLDFACE	Identifies DOS, Windows, and installation program names.
Boldface	Indicates information you must enter, an action you must perform, or a selection you can make on a dialog box or menu.
Italics	Indicates a word requiring an appropriate substitution. For example, replace *filename* with an actual file name.
Text_Connected_With_Underlines	Indicates symbolic names used in Quickstep programs. Step Names are ALL_CAPITALS. Other symbolic names can be Initial_Capitals or lower_case.
SMALL CAPS	Identifies the name of Quickstep instructions in text.
`Courier font`	Identifies step names, comments, output changes, and Quickstep instructions appearing in the Quickstep editor.
Art Code [2217F1]	Identifies the file name of a particular graphic image.

Contacting Control Technology Corporation

Control Technology Corporation is located in Massachusetts. Our business hours are 8:30 AM to 5:00 PM. EST (Eastern Standard Time).

Contact Method	Address or Number
E-Mail:	
Technical Support:	help@ctc-control.com
Technical Publications:	techpubs@ctc-control.com
Website:	www.ctc-control.com
Telephone:	508.435.9595 and 800.282.5008
FAX:	508.435.2373
Mail:	Control Technology Corporation 25 South Street Hopkinton, MA 01748

Your Comments

Suggestions and comments about this or any other Control Tech document can be e-mailed to the Technical Publications Group at techpubs@ctc-control.com.

This page is intentionally left blank.

Getting Started

This page is intentionally left blank.

System Overview

The Model 2334 and Model 2335 are CTC's new line of analog interface modules. These modules act as interface boards to the Model 2220 analog I/O module and include support for thermocouples. Table 1–1 lists the available options for each model.

Table 1–1. Thermocouple Interface Module Options

Model	Configurable Inputs				Configurable Outputs			Fixed Inputs	Fixed Outputs	
	Thermocouple (J or K)	Current 4-20 mA	Voltage ±10 VDC	# Input Channels	Current 4-20 mA	Voltage ±10 VDC	# Output Channels	# Voltage Input Channels ±10 VDC	# Voltage Output Channels ±10 VDC	# Digital Output Channels 24 VDC
2334-J	√	√	√	4	√	√	4	4	4	8
2334-K	√	√	√	4	√	√	4	4	4	8
2335-J	√	√	√	8	N/A	N/A	N/A	N/A	8	8
2335-K	√	√	√	8	N/A	N/A	N/A	N/A	8	8
2335	N/A	√	√	8	N/A	N/A	N/A	N/A	8	8

You can define each I/O channel as a thermocouple, current, or voltage interface by setting the jumper for that channel. Refer to *Connection Diagrams* for jumper configuration information.

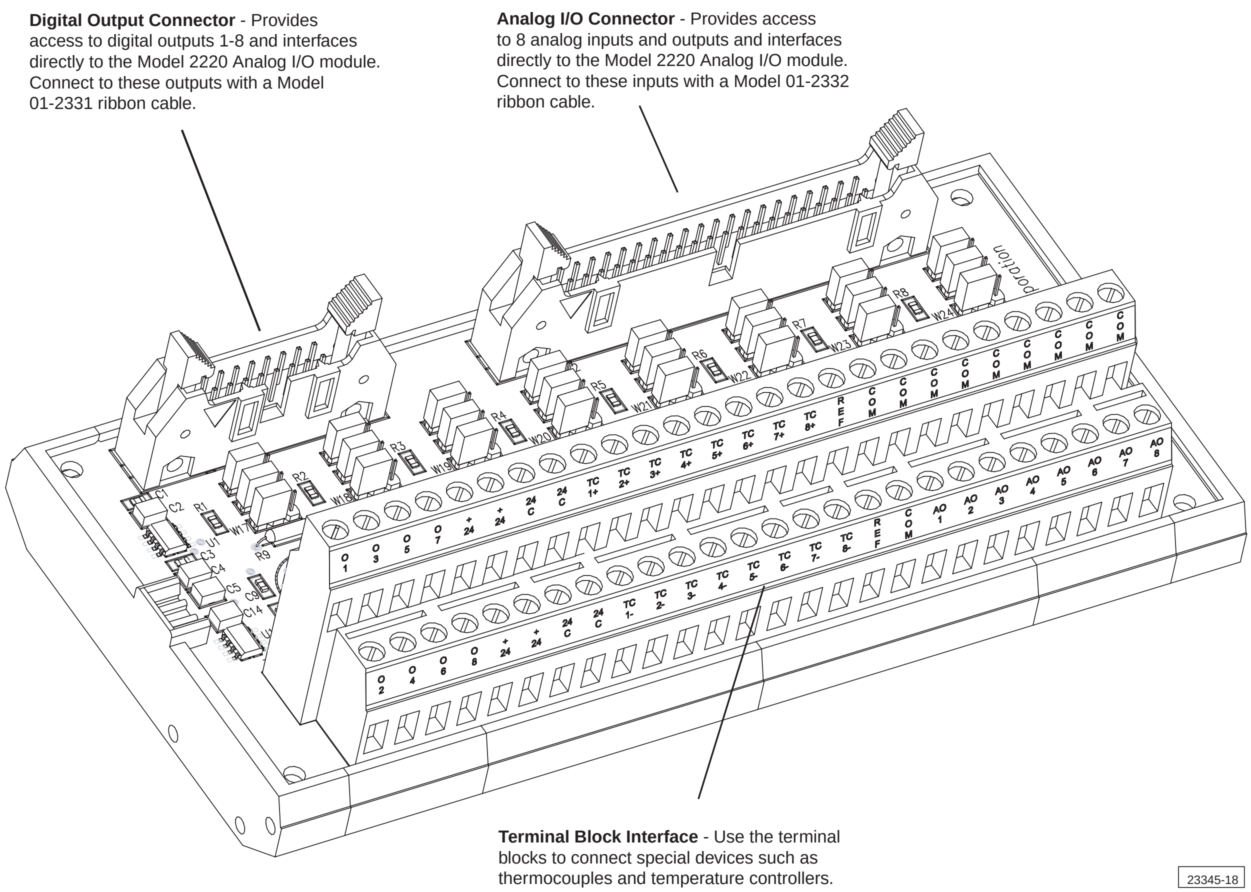
Each module includes a DIN rail mounting accessory for easy installation. Two interface cables (sold separately) are also available to connect to a 2220-102 or 2220-103 card:

Table 1–2. Interface Cables

Description	Part Number
Ribbon cable – 16-position, output interface, 2 ft.	01-2331
Analog interface cable – 40-position, 2 ft.	01-2332

You can use either model for closed-loop applications such as temperature control. You can also select either analog or PWM (pulse width modulation) output control.

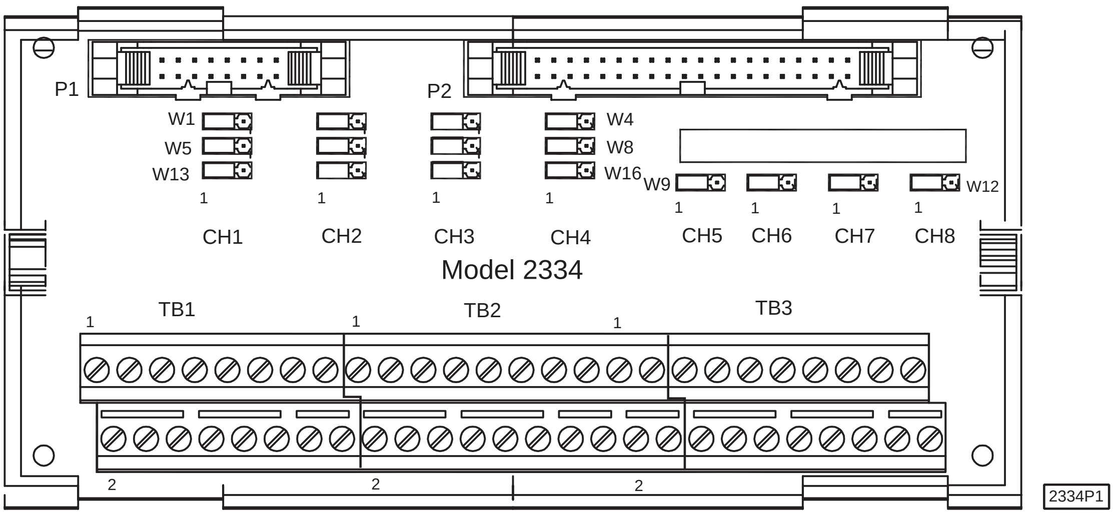
Description – Model 2334 / Model 2335

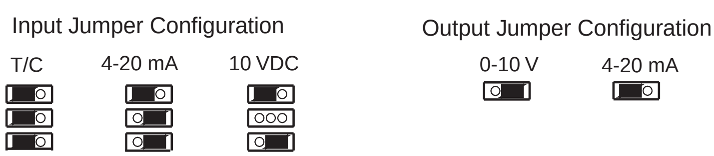


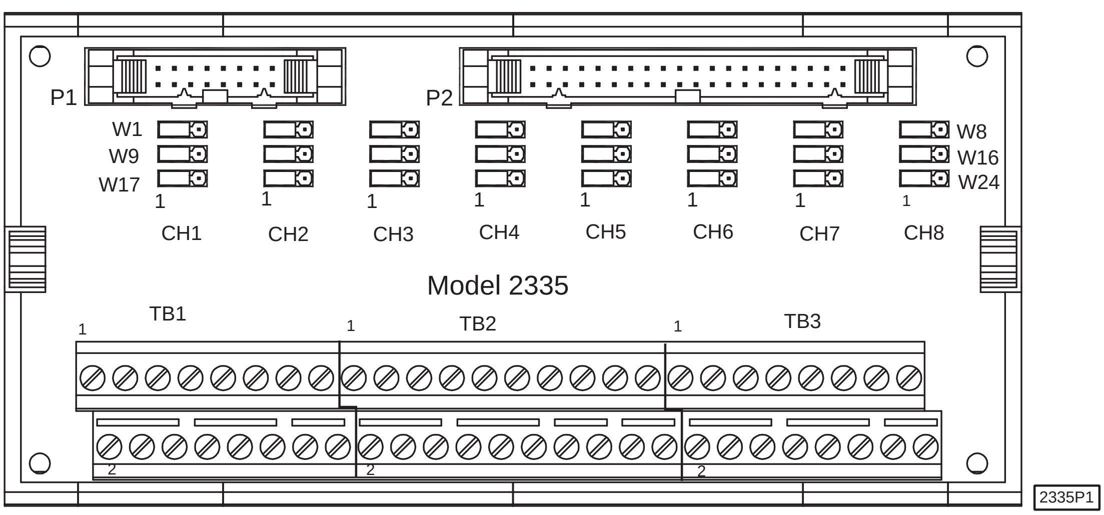
Connection Diagrams

Note

Some components are missing from the diagrams below to improve readability.







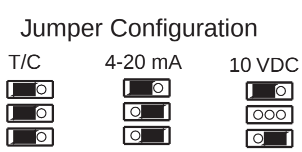


Table 1–3. 2334 Terminal Block Connections and Jumper Settings

TB1		TB2		TB3	
Pin #	**Signal**	**Pin #**	**Signal**	**Pin #**	**Signal**
1	Dig. Out1 [1]	1	[2] TC/AI 1+	1	COM
2	Dig. Out2	2	[2] TC/AI 1-	2	[2] AOUT / 4-20 mA 1
3	Dig. Out3	3	[2] TC/AI 2+	3	COM
4	Dig. Out4	4	[2] TC/AI 2-	4	[2] AOUT / 4-20 mA 2
5	Dig. Out5	5	[2] TC/AI 3+	5	COM
6	Dig. Out6	6	[2] TC/AI 3-	6	[2] AOUT / 4-20 mA 3
7	Dig. Out7	7	[2] TC/AI 4+	7	COM
8	Dig. Out8	8	[2] TC/AI 4-	8	[2] AOUT / 4-20 mA 4
9	+24 V	9	AI 5+	9	COM
10	+24 V	10	AI 5-	10	AOUT 5
11	+24 V	11	AI 6+	11	COM
12	+24 V	12	AI 6-	12	AOUT 6
13	24 V Return	13	AI 7+	13	COM
14	24 V Return	14	AI 7-	14	AOUT 7
15	24 V Return	15	AI 8+	15	COM
16	24 V Return	16	AI 8-	16	AOUT 8
		17	10 VDC (Ref.)		
		18	10 VDC (Ref.)		
		19	COM		
		20	COM		

1. The terminal blocks contain identification labels for the inputs and outputs. For example, 01 corresponds to Digital Output 1 (Dig. Out1).
2. The signal depends on the channel's jumper setting.

Table 1–4. 2335 Terminal Block Connections and Jumper Settings

TB1		TB2		TB3	
Pin #	Signal	Pin #	Signal	Pin #	Signal
1	Dig. Out1 [1]	1	[2] TC/AI 1+	1	COM
2	Dig. Out2	2	[2] TC/AI 1-	2	AOUT 1
3	Dig. Out3	3	[2] TC/AI 2+	3	COM
4	Dig. Out4	4	[2] TC/AI 2-	4	AOUT 2
5	Dig. Out5	5	[2] TC/AI 3+	5	COM
6	Dig. Out6	6	[2] TC/AI 3-	6	AOUT 3
7	Dig. Out7	7	[2] TC/AI 4+	7	COM
8	Dig. Out8	8	[2] TC/AI 4-	8	AOUT 4
9	+24 V	9	[2] TC/AI 5+	9	COM
10	+24 V	10	[2] TC/AI 5-	10	AOUT 5
11	+24 V	11	[2] TC/AI 6+	11	COM
12	+24 V	12	[2] TC/AI 6-	12	AOUT 6
13	24 V C	13	[2] TC/AI 7+	13	COM
14	24 V C	14	[2] TC/AI 7-	14	AOUT 7
15	24 V C	15	[2] TC/AI 8+	15	COM
16	24 V C	16	[2] TC/AI 8-	16	AOUT 8
		17	10 VDC (Ref.)		
		18	10 VDC (Ref.)		
		19	COM		
		20	COM		

1. The terminal blocks contain identification labels for the inputs and outputs. For example, 01 corresponds to Digital Output 1 (Dig. Out1).
2. The signal depends on the channel's jumper setting.

Table 1–5. Connection Diagram - Dedicated Digital Output Connector

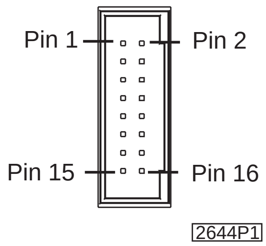
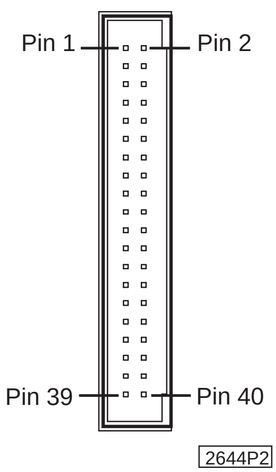
Dedicated Digital Output Connector	Pin #	Signal	Pin #	Signal
	1	D Output 1	2	D Output 2
	3	D Output 3	4	D Output 4
	5	D Output 5	6	D Output 6
	7	D Output 7	8	D Output 8
	9	Return	10	Return
	11	Return	12	Return
	13	+ 24 VDC	14	+ 24 VDC
	15	+ 24 VDC	16	+ 24 VDC

Table 1–6. Connection Diagram - Analog Input / Output Connector

Analog I/O Connector	Pin #	Signal	Pin #	Signal
	1	10 V Ref.	2	10 V Ref.
	3	Return	4	Return
	5	A Input 1+	6	A Input 1-
	7	Return	8	Return
	9	A Input 2+	10	A Input 2-
	11	A Input 3+	12	A Input 3-
	13	Return	14	Return
	15	A Input 4+	16	A Input 4-
	17	A Input 5+	18	A Input 5-
	19	Return	20	Return
	21	A Input 6+	22	A Input 6-
	23	A Input 7+	24	A Input 7-
	25	Return	26	Return
	27	A Input 8+	28	A Input 8-
	29	Return	30	Return
	31	A Output 1	32	A Output 2
	33	A Output 3	34	A Output 4
	35	A Output 5	36	A Output 6
	37	A Output 7	38	A Output 8
	39	Return	40	Return

Specifications

Note

All specifications are at 25°C unless otherwise specified.

Table 1–7. General Specifications

Description	Min.	Typical	Max.	Units
Analog Output Specifications				
Output voltage range	-10.000		+10.000	VDC
Output resolution		2.44		mV
Output settling time				
-10.000 to +10.000 V		0.2		ms
0 to 5.000 V		0.1		ms
Analog Input Specifications				
Differential input range	-10.000000		+10.000000	VDC
Common mode voltage range	-10		+10	VDC
Input resistance		10		MΩ
Input resolution (15-bit)		.00305		%FS
Input accuracy (25°C, 8-sample filtering)		.00305		%FS
Input conversion time (asynchronous)		2.083		ms
Input filter settings (default = 1 sample)	2.083		533.248	ms
Threshold triggering response (analog input to digital output response)		2.25		ms
Dedicated Digital Output Specifications				
On voltage (I_o = 500 mA)		.6	1.2	VDC
Off leakage (applied voltage = 24 VDC)		1	100	µA DC
Maximum output current [1]			500	mA DC

1. All digital outputs have short-circuit and overcurrent protection.

Table 1–8. Temperature Control Specifications

Description	Min.	Typical	Max.	Units
Absolute Maximum Ratings				
+Vs to -Vs			36	V
Common-Mode Input Voltage	(-Vs-0.15)		+ Vs	V
Differential Input Voltage	-Vs		+Vs	V
Operating Temperature Range				
Type J	-55		+125	°C
Type K	-40		+125	°C
Output Short-Circuit to Common	Indefinite			
Thermocouple Temperature Range thermocouple				
Type J	-200		+750	°C
Type K	-200		+1250	°C
Temperature Measurement				
Specified Temperature Range (+25°C to +100°C)				
Calibration Error [1]	-4		+4	°C
Stability vs. Temperature [2]		± 0.02	± 0.05	°C/°C
Gain Error	-1.5		+1.5	%
Nominal Transfer Function		10		mV/°C
Amplifier Characteristics				
Closed Loop Gain [3]				
Type J		180.6		V/V
Type K		245.5		V/V

1. This is a measure of the deviation from ideal with a measuring thermocouple junction of 175×C and a chip temperature of 60×C. The ideal transfer function is given by:

   Type J: Vout = 180.57 x (Vm-Va + (ambient in °C) x 53.21 µV/°C – 235 µV)
   Type K: Vout = 245.46 x (Vm-Va + (ambient in °C) x 41.27 µV/°C – 37 µV)

   where *Vm* and *Va* represent the measuring and ambient temperatures and are taken from the appropriate J or K thermocouple table. The ideal transfer function minimizes the error over the ambient temperature range of 25°C to 100°C with a thermocouple temperature of approximately 175°C.
2. This is defined as the slope of the line connecting the cold junction compensation errors measured at 25°C and 100°C ambient temperature.
3. Pin 6 is shorted to Pin 7.

Table 1–8. Temperature Control Specifications (Continued)

Description	Min.	Typical	Max.	Units
Input Offset Voltage				
Type J		(°Cx53.21)+235		µV
Type K		(°Cx41.27)-37		µV
Input Bias Current		0.1		µA
Differential Input Range	-10		+50	mV
Common-Mode Range	(-Vs-0.15)		(+Vs-4)	V
Common-Mode Sensitivity-RTO			10	mV/V
Power Supply Sensitivity-RTO		1	10	mV/V
Output Voltage Range				
Dual Supplies	(-Vs+2.5)		(+Vs-2)	V
Single Supply	0		(+Vs-2)	V
Usable Output Current [4]	±5			mA
3 dB Bandwidth		15		kHz

4. The current sink capability in the single supply configuration is limited to the current drawn to ground through a 50 kΩ resistor at output voltages below 2.5V.

Table 1–9. Firmware Revision Levels Required for PID Operation

Model Numbers	Firmware Revision Level [1 2]
2700	2.27
2700AP	3.05
2220-102, 2220-103	3.2

1. You can confirm firmware revision levels by doing a register read in Quickstep's monitor program. Use register 13003 to confirm the firmware revision in a 2600/2700 series controller.
2. Firmware revision levels are not equivalent to standard decimal numbers. For example, firmware revision level 2.10
   translates to:

   Major Revision Level 2
   Minor Revision Level 10

   If this value changes to 2.20, it translates to:

   Major Revision Level 2
   Minor Revision Level 20 (not revision level 2)

Module Installation and Connection

This section provides mounting instructions for the module and describes how to connect it to the 2220 module. Proceed as follows:

1. Remove the module from its anti-static bag. It is a printed circuit board that contains electrostatic discharge sensitive (ESD) devices. Improper handling could result in damage to the board. The following precautions are recommended when handling the board:

    - Make sure you are grounded electrically by either using a wrist strap connected to an electrically grounded workstation or by physically touching the controller case or something electrically connected to the controller case.

    - Avoid touching the leads or contacts of the circuit board and handle the board by its edges only.

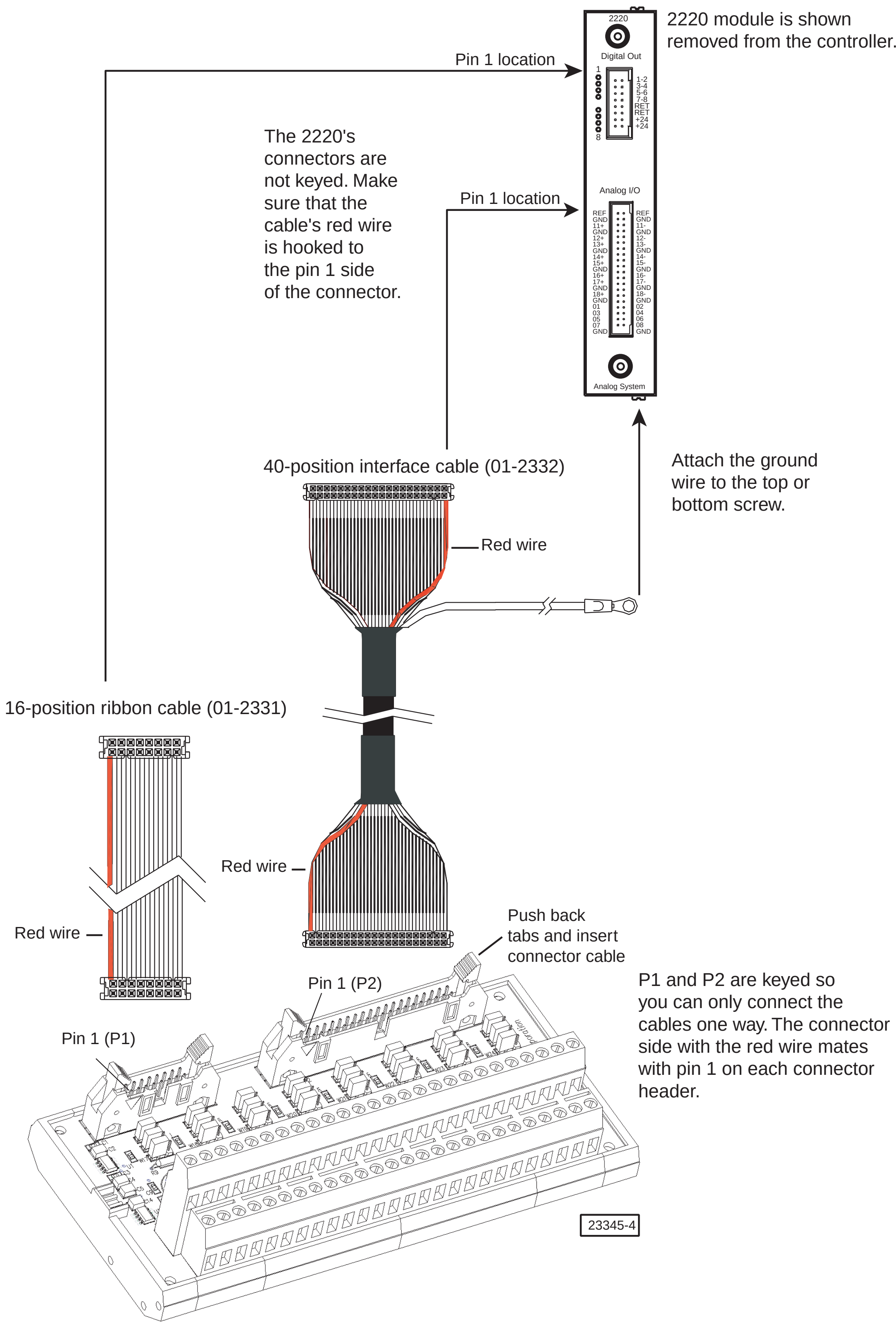
    - Transport circuit boards in protective, anti-static bags, bins or totes. Do not insert boards into materials such as plastic, polystyrene foam, clear plastic bags, bubble wrap, or plastic trays.

2. Snap the module's DIN rail mounting accessory onto a DIN rail.

3. Connect to the 2220 I/O module with the accessory cables mentioned in *System Overview*. For digital I/O connections, use the 16-position ribbon cable (01-2331) and connect to P1. For analog I/O connections, use the 40-position interface cable (01-2332) and connect to P2. Refer to Figure 1–1 for more information.

4. Connect any additional devices such as thermocouples or heaters to the terminal blocks. Refer to *Connection Diagrams* for pinouts and to *Wiring Configurations* for more information on wiring external devices.

Figure 1–1. Interconnection Diagram



Wiring Configurations

This section shows wiring information for the module's analog inputs and outputs as well as typical external devices such as heaters or thermocouples.

Analog Inputs

The analog inputs are opto-isolated from the controller's CPU logic circuitry. This reduces ground-looping and increases noise immunity. Figures 1–2 through 1–6 show wiring configurations for a differential signal, a single-ended signal, a potentiometer, a 4-20 mA device, and a thermocouple.

You can configure the first 4 channels on the 2334 and all 8 channels on the 2335 for ±10 VDC, 4-20 mA, or as thermocouple inputs. Channels 5-8 on the 2334 module are fixed, ±10 VDC inputs without configurable jumpers. Refer to Figure 1–2 for a typical use of these inputs.

Notes

1. Thermocouple inputs are only available with J/K units.
2. For more information on wiring fixed inputs, refer to the *2220 Analog I/O Module Installation Guide*.

Figure 1–2. Connecting a Differential Signal

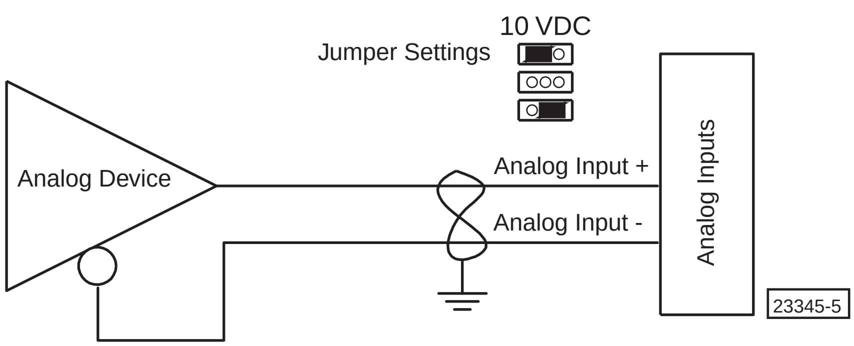


Figure 1–3. Connecting a Single-Ended Signal

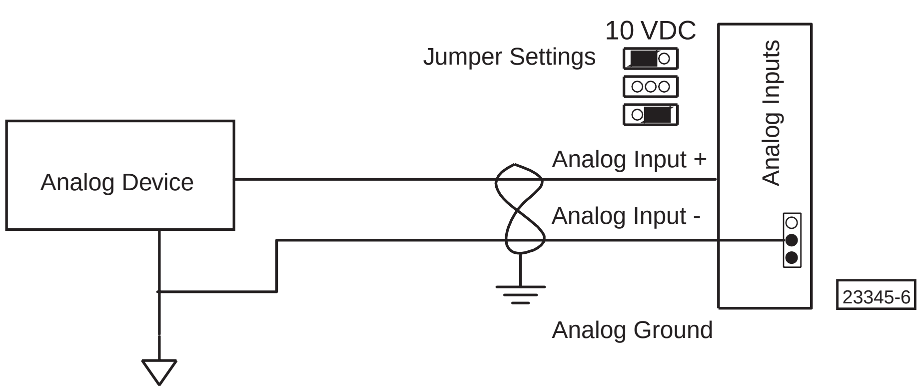
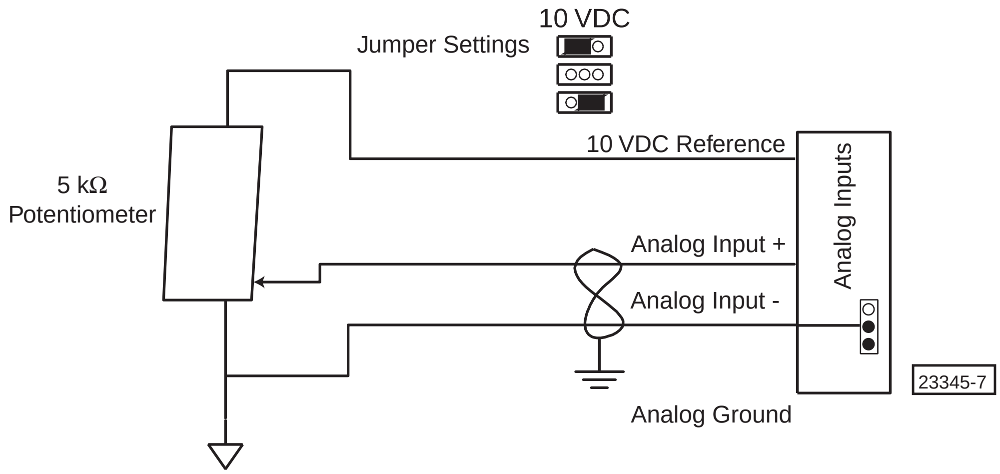


Figure 1–4. Connecting to a Potentiometer



4-20 mA Inputs

Some transducers produce an output signal as variable current instead of variable voltage. A 4-20 mA current signal is an industry standard and many transducers are available that produce signals in this range. You can sense these signals with a current loop circuit, which contains a power source, a current regulator (the transducer), and a way to sense the current (the analog input).

Most 4-20 mA transducers draw their power (for their own internal circuitry) from the current that flows through the signal loop. This is accomplished by creating a large enough voltage drop to supply power to the transducer.

You can configure the analog inputs to interface with a current loop by changing the jumper settings on a selected channel. Refer to Figure 1–5 for the 4-20 mA jumper setting and to *Connection Diagrams* for specific jumper locations. Connect the current loop as follows:

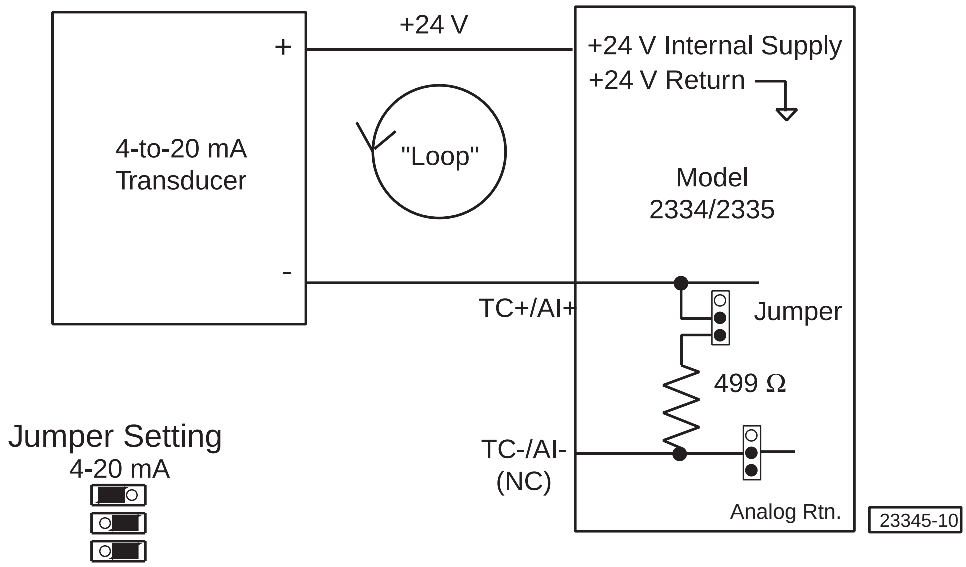
Note

You can supply power to the current loop circuitry by using the module's internal power supply or with an external supply.

1. Select a specific output for current loop operation by setting its jumper as shown below. This inserts a loop resistor between the analog input and the internal analog "return". The loop resistor's ohm value is 499 Ω.

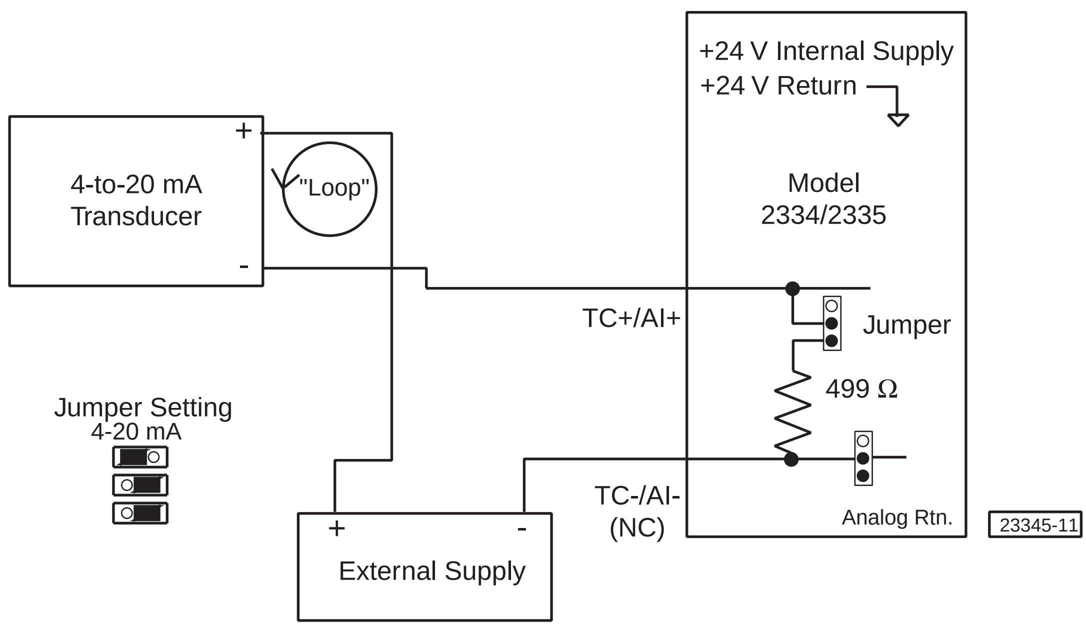
2. Connect a current-loop transducer to the analog input. You can supply power to the transducer with the module's 24 V supply (+ connection on the transducer), which is accessed through pins 17-20 on TB2. The return for the transducer (- connection) is connected directly to the analog input.

Figure 1–5. Connecting to a 4-20 mA Device



You can also use an external supply by connecting the positive (+) voltage to the transducer's (+) terminal and the return to the module's analog return (TC- terminal). Figure 1–6 provides more information on this setup.

Figure 1–6. Connecting to a 4-20 mA Device with an external power supply



As the transducer measures a controlled amount of current through the current loop, the resulting voltage drop across the internal loop resistor will vary between 1.996 V to 9.980 V. Your Quickstep program will interpret these values as a value from 1,996,000 to 9,980,000 (with a resolution of 305 counts). For more information on resolution and scaling, refer to *Setting Analog Input Range* in the *2220 Installation Guide* and *Using Analog Inputs and Outputs* in the *Quickstep Language and Programming Guide*.

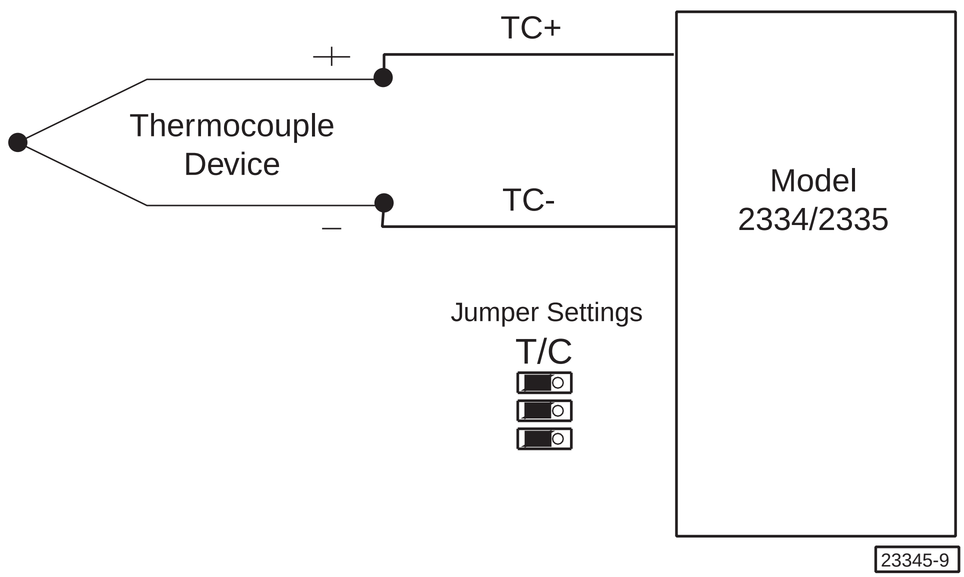
Note

Make sure that the transducer's specifications are compatible with the 2334/2335 modules.

Thermocouples

You can configure the module to work with J and K type thermocouples in applications ranging from simple temperature control to closed loop operation. Figure 1–7 shows a wiring diagrams for a thermocouple device.

Figure 1–7. Thermocouple Connection Diagram

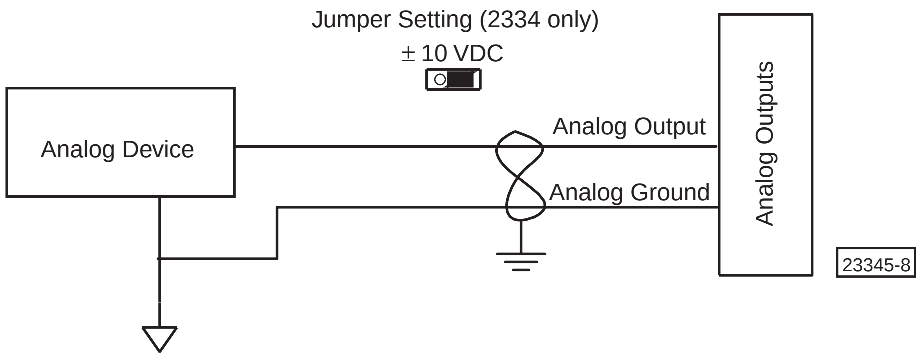


Analog Outputs

The 2334 has 8 analog output channels. You can configure Channels 1-4 as ±10 VDC analog outputs or as 4-20 mA outputs by setting the applicable jumper. Channels 5-8 are fixed, ±10 VDC outputs. The 2335 has 8 fixed, ±10 VDC analog outputs.

Figure 1–8 shows the wiring for a ±10 VDC analog output connection. The jumper only applies to Channels 1-4 on the 2334 module. Channels 5-8 on the 2334 and all channels on the 2335 are fixed and are not configurable with jumpers.

Figure 1–8. ±10 VDC Analog Output Connection



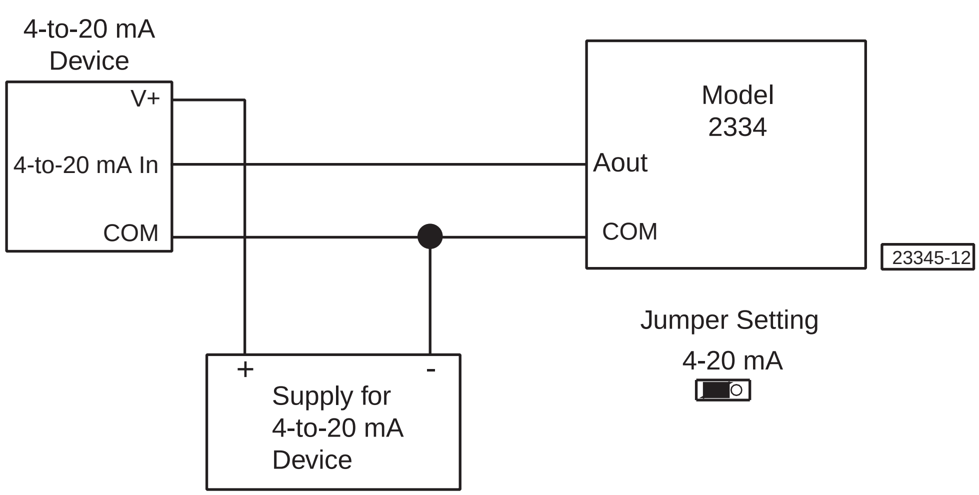
Note

All shields, which are part of a cable, are connected to ground on the controller end (side) of the cable.

4-20 mA Inputs (2334 only)

Figure 1–9 shows a typical 4-20 mA wiring diagram for Channels 1-4 on the 2334 module. This output type is only accessible on these particular channels and is not available elsewhere.

Figure 1–9. 4-20 mA Wiring Diagram for Channels 1-4



Temperature Control

The 2220-102 and 2220-103 have built-in PID loop circuitry that is used in temperature control applications. The 2334 and 2335 modules have thermocouple inputs that work with the 2220 and ±10 VDC analog outputs and/or 24 VDC PWM digital outputs to control a heater.

Figure 1–10 shows a 24 VDC, PWM digital output that is wired through an AC solid-state relay to control heater power in a temperature control application. The heater power is controlled by the fraction of time that the PWM signal is ON. The
heater rapidly turns ON and OFF with the PWM signal and operates at a fraction of its available power.

Figure 1–10. Heater Application with Digital Control

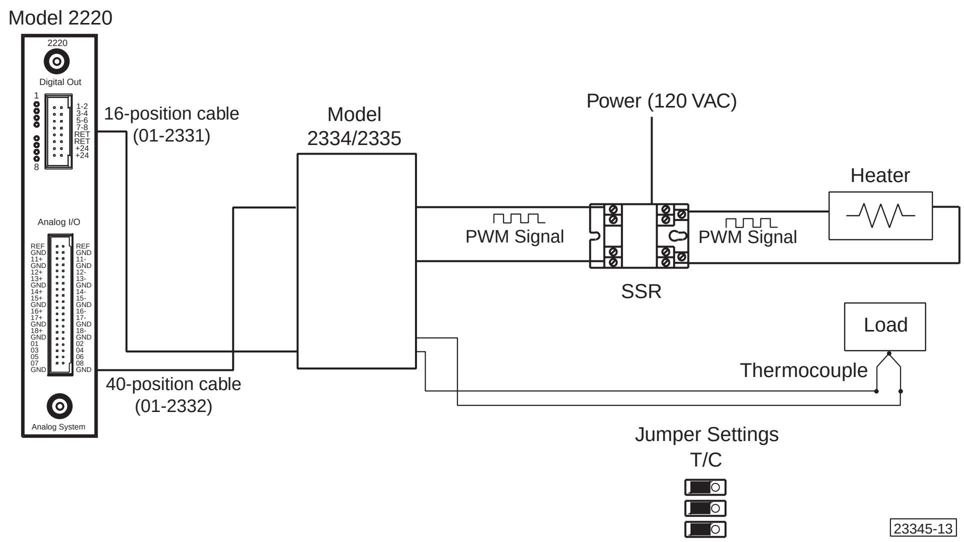
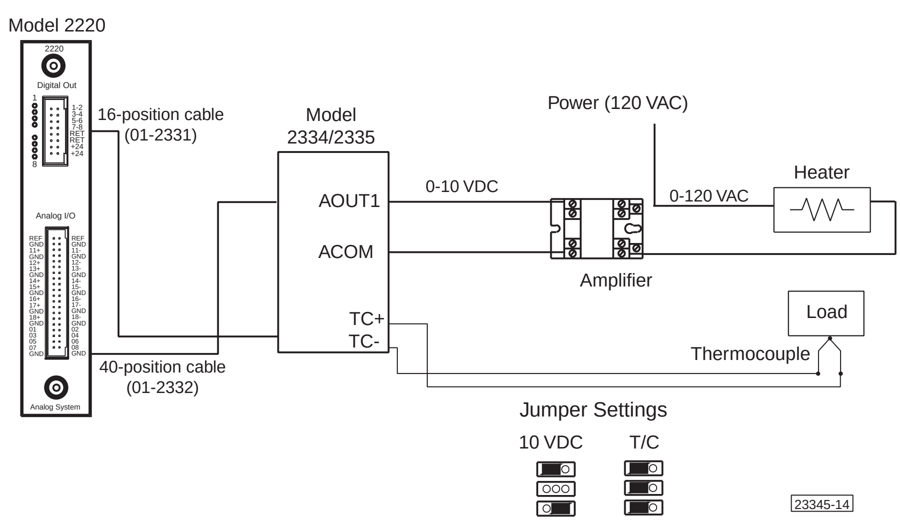


Figure 1–11 shows a heater that is controlled by a 0-10 VDC analog signal and an amplifier. Heater power is determined by the value of the analog output signal. As this value increases, more voltage is supplied to the heater. This increases the heater's power output.

Figure 1–11. Heater Application with Analog Control



This page is intentionally left blank.

Application Notes

This page is intentionally left blank.

Thermocouple Basics

This section describes thermocouples and how they function.

What is a Thermocouple?

A thermocouple is a temperature sensor that converts heat energy into an electrical signal. You can then determine the temperature by analyzing the signal with a device such as a thermocouple thermometer.

Thermocouples consist of two dissimilar metals that are joined at one end. This junction produces a small voltage between their other ends for a given temperature.

Types of Thermocouples

There are approximately a dozen types of thermocouples that are generally used in industrial applications, but the most common types are J, K, T, and E. The Model 2334 and Model 2335 are designed to work with J and K thermocouples.

These letter designations were created by the ISA (Instrumentation Society of America). The following conventions apply:

- A slash mark separates the materials of each thermocouple wire. For example, iron/constantin (type J) is a thermocouple with one iron wire and one constantin wire.
- Polarity is indicated by the order in which materials are listed. In our example, the iron wire to the left of the slash mark has a positive polarity when the measuring junction is at a higher temperature than the reference junction.

Thermocouples are divided into three functional classes: base metal, noble metal, and refractory metal. Base metal thermocouples, which include types J and K, measure temperatures under 1000°C. Noble metal thermocouples range up to 2000°C and refractory metal thermocouples range up to 2600°C.

J and K thermocouples are the types that work the Model 2334 and Model 2335. In particular:

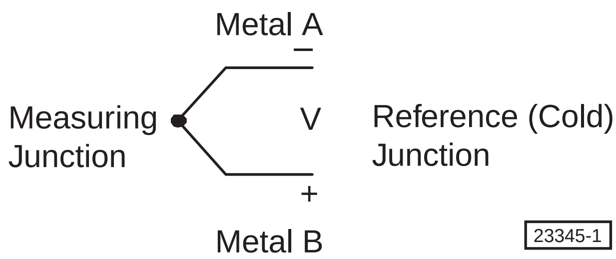
- Type J thermocouples are made of iron (+) and constantin (-). Their temperature range is 0 to 760°C and they are often used in vacuum, oxidizing, reducing, or inert atmospheres. This type of thermocouple is not recommended for use below 0°C because the iron element can rust and become brittle.
- Type K thermocouples are made of 10% Nickel/Chromium (+) and 5% Nickel/Aluminum/Silicon (-). Their temperature range is -200 to 1260°C and they are often used at high temperatures (over 540°C) because these metals resist oxidation.

How do they work?

In 1821, Seebeck first described the thermocouple principle. He discovered that current flows when two wires of dissimilar metals are joined together to form a circuit with at least two junctions that are at different temperatures. This phenomenon is called the Seebeck Effect and is the basis for thermocouple designs.

A thermocouple, as described above, consists of 2 wires made of different metals. These metals are joined at one end to form to form a measuring junction as shown in Figure 2–1.

Figure 2–1. Thermocouple Wiring Diagram



This junction is then exposed to the fluid or medium you want to measure. The other wire ends are usually terminated at a measuring instrument where they form a reference, or cold junction.

When the two junctions are at different temperatures, current then flows through the circuit. The voltage (in millivolts) resulting from the current flow is then measured to determine the temperature at the measuring junction. Ideally, the reference junction is held at a constant temperature and in many cases, the reference junction's temperature is maintained at the temperature of melting ice. This allows direct temperature measurement from an indicator without requiring a calculation for correction. This 0°C temperature is achieved with an ice bath.

Cold Junction Compensation

Thermocouples are commonly used to measure temperature because they're inexpensive, durable, and support a wide range of temperatures. However, there is a price to pay for all this flexibility. On the cold junction side, the thermocouple's terminating wires are connected to the voltmeter's leads. A second thermocouple is created because two dissimilar metals are joined together and the result is unwanted voltage. In many thermocouple installations, the measuring junction is also located several hundred feet away, which creates additional temperature fluctuations.

Additional problems arise because typical electronic instruments cannot really measure the actual cold junction temperature. They try to get as close as possible, but it's not enough to eliminate inaccuracies of up to a few degrees. Terminal blocks and plug-in connectors aggravate the problem even further because the actual cold junction is even further away from the cold junction transducer. The cumulative effect of all these variables may be as much as 5 to 10 degrees.

Ambient temperature changes cause most measuring instruments to drift by a few degrees. Typical thermocouple instruments take from a few minutes to a half hour to stabilize their temperature. Calibrating these instruments in a small application may not present much of a problem, but when several hundred instruments are involved, prolonged warm-up time can complicate matters considerably.

Compensating for Cold Junction Error

Some measuring instruments have circuitry that compensates for cold junction errors. Temperature is measured at the instrument's terminal and a cold junction compensating signal is then injected to offset errors. The overall accuracy depends on the accuracy of cold junction compensation with varying ambient temperatures over the instrument's normal temperature range.

Another way to combat this error is to house the terminations in an isothermal environment, which tries to maintain a constant temperature.

One final solution for minimizing errors is to allow enough time for instruments to warm up before calibration is performed. Equipment is also affected by the following temperature transients:

- Adjacent equipment is switched on or off
- Enclosure doors are opened or closed

Achieve the best calibration results by minimizing these interruptions and allowing the system to stabilize properly.

Temperature Control Systems

The Model 2334 and Model 2335 Analog Interface modules are designed to work with temperature control systems in industrial control applications that require accurate measurement of process temperature. The heart of any temperature control system is a controller and the temperature sensor that provides its input. The controller then com-pares the actual temperature to the desired control temperature, or setpoint, and sends an output signal to a control element.

Although the controller is extremely important, it is only one element of an entire control system. You must analyze your total system requirements when you select a controller. You must also consider:

1. **Type of input sensor and temperature range** - Generally, the sensor type is either a thermocouple or an RTD (resistance temperature detector). The Model 2334 and Model 2335 work with J and K type thermocouples. Before selecting a sensor type, you need to know the temperature range of your application since sensors are designed for certain temperature ranges. You must also ensure that the sensor's accuracy and resolution can meet your application requirements. The sensor's mounting location is also a factor in selecting a sensor type.

2. **Type of output hardware** - Hardware types include electromechanical relays, SSRs (solid-state relays), and analog outputs.

3. **Placement of sensor** - Good temperature control requires that you place the sensor in the correct location with respect to the application, or work being performed, and the heat source. You can achieve a high degree of accuracy if all three elements are in close proximity to one another.

4. **Control algorithms** - Algorithms are the methods used by a controller to restore system temperature to the desired level. These algorithms include On/Off, Proportional, and PID. PID and/or Autotune PID are used with the Model 2334 and Model 2335 and are discussed in more detail later in this section.

5. **Additional output requirements** - Your application may also require such items as temperature display, setpoint display, alarms, and so forth. Hardware requirements are determined by the heater used, power availability, the control algorithm chosen, and the hardware external to the controller that can handle the load.

The most commonly used hardware is:

- **Time Proportional or On/Off** - These outputs include mechanical relays, triacs (AC solid-state relays), and DC solid-state relay drivers (pulse). Time proportional outputs apply power to the load for a percentage of a fixed cycle time. Electromechanical relays are the most economical and are usually chosen for systems with small loads and cycle times greater than 10 seconds. AC and DC solid-state relays have no moving parts and can reliably drive external SSRs. They are also recommended for processes with short cycle times.

- **Analog Proportional** - These outputs include 4-20 mA DC, 0-5 VDC, and 0-10 VDC. Output levels are set by the controller. For example, if the level is set at 60%, the voltage output level would be 60% of 10V, or 6V. With a 4-20 mA output (a 16 mA span), 60% is equal to (.6 x 16) + 4, or 13.6 mA. These outputs are usually used with SCR controllers or proportioning valves.

Types of Controllers

This section discusses the three basic controller types: On/Off, Proportional, and PID. The type you choose depends on your application.

On/Off Control

This is the simplest form of temperature controller. The controller's output is either ON or OFF. The output is switched from one state to another when the temperature crosses the setpoint. For example, with cooling control, the output is ON when the temperature is above the setpoint and OFF when the temperature is below the setpoint. On/Off control is used in applications where precise control is not necessary.

Proportional Control

These controllers are designed to eliminate the constant cycling associated with On/Off control. A proportional controller decreases the average power supplied to the heater as the temperature approaches the setpoint. This slows down the heater by preventing it from overshooting the setpoint and allowing it to approach the setpoint and maintain a stable temperature. This effect, or proportioning action, is achieved by turning the output on and off for short intervals and occurs within a proportional band around the setpoint temperature. This band is expressed as a percentage of full scale in degrees. Proportional controllers are simple to operate and are often used on systems that are subject to wide temperature cycling.

PID Control

This controller type, which is used with the Model 2334 and Model 2335, provides proportional control with integral and derivative control (PID). These three adjustments help the controller to automatically compensate for changes in the system. Integral and derivative adjustments are expressed in units of time. They are also referred to by their reciprocals (reset and rate respectively).

PID terms are individually adjusted or tuned to a system by trial and error. Some PID controllers are also capable of autotuning, which attempts to automatically adjust the PID parameters. Once the PID controller makes these adjustments, it provides the most accurate and stable control of the three controller types.

Rate and Reset

Rate and reset are used to compensate for offsets and temperature shifts. When you use a proportional controller, the temperature usually increases or decreases from the setpoint until a stable temperature is obtained. The difference between this temperature and the setpoint is called offset and you can compensate for it by manual means or automatic means.

Manual reset allows you to shift the proportional band so the process stabilizes at the setpoint temperature. Automatic reset, or integral adjustment, integrates the deviation signal with respect to time and the resulting integral is then added to the deviation signal to shift the proportional band to return the process temperature to setpoint. Output power is then automatically increased or decreased.

The rate, or derivative adjustment, allows the controller to shift the proportional band in order to compensate for rapidly changing temperatures. The amount of this shift is proportional to the rate of temperature change.

A PID, or three-mode controller, combines proportional, integral (reset), and derivative (rate) actions and is usually used to control difficult processes.

Closed-Loop and Open-Loop Systems

Autotuning, which was briefly mentioned in the previous section, involves changing the parameter (PID) settings as a result of switching out the normal control and either triggering a limit cycle with a relay or performing an open-loop step response. Both methods disrupt normal, closed-loop control.

Closed-Loop Systems

A closed-loop system is a system that regulates itself after some initial input from an operator. After this occurs, the system continues to perform its task without human intervention.

For example, a thermostat/air-conditioning system is a closed-loop system. An operator initially sets a temperature on the thermostat. After that, if the ambient temperature rises above the thermostat setting, the thermostat turns on the air-conditioner and blows cold air into the zone controlled by the thermostat. When the zone temperature drops to the preset temperature (or below), the thermostat shuts off the air-conditioner. This type of setup is illustrated in Figure 2–2.

Figure 2–2. Closed-Loop System

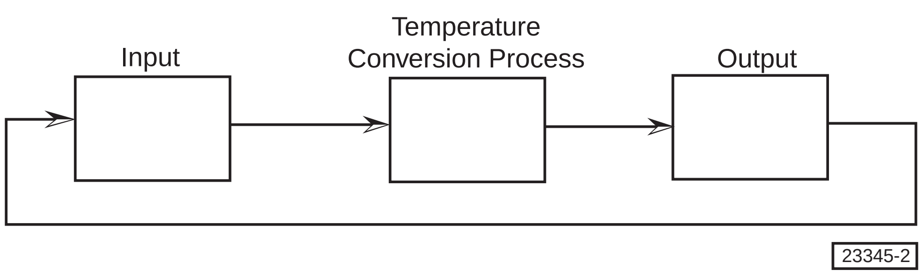


Table 2–1. Closed-Loop System Definitions

Control Loop Step	Definition	Example
Input	A command entered by the user that requires a desired outcome.	Temperature is set on a thermostat. The ambient temperature rises to the initial setting (or above). The thermostat turns the air-conditioner ON.
Process	System resources combined with an action.	The air-conditioner blows cold air into the zone and lowers the ambient temperature at a steady rate.
Output	Actual result of the process.	The ambient temperature falls to the thermostat setting (or below). The thermostat turns the air-conditioner OFF.

Open Loop Systems

Open-loop systems have no feedback mechanism. In other words, there is no loop connecting the system's output to its input. Figure 2–3 shows an open-loop system.

Figure 2–3. Open-Loop System

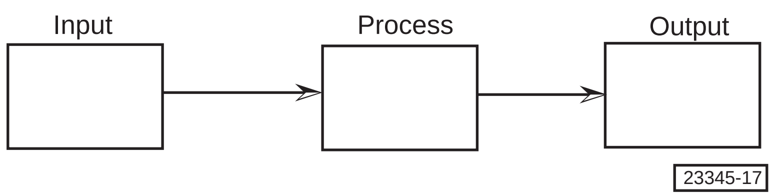


Table 2–2. Open-Loop System Definitions

Control Loop Step	Definition	Example
Input	A command entered by the user that requires a desired outcome.	An oven is turned on by the user.
Process	System resources combined with an action.	The oven is heated by running a heating element at 60% power.
Output	Actual result of the process.	Oven is heated to a temperature of 150 degrees Celsius but temperature is affected by external events.

For example, a heater and a load without a temperature control device to measure the temperature is an open-loop system. This system has an oven that is heated to a temperature of 150 °C by running a heating element at 60 % power, which is a setup that has worked in the past. Unfortunately, the oven is no longer operated under optimal conditions. The following items can all affect the oven's operating temperature:

- the oven door is opened and closed too often
- ambient temperature of the room containing the oven changes frequently
- heater and/or the oven's insulation are inefficient
- oven contents

When these conditions exist, they can change the oven's temperature on either a short-term or a long-term basis.

Because this system has no temperature feedback signal to send to the controller, it does not adjust for these temperature changes. This may cause an inaccurate oven temperature and a slow recovery to changes in temperature. If you add a thermocouple to the setup and use it to measure temperature, you create a closed-loop system. The controller can then increase and decrease the heater power to automatically adjust for these changes to the system, which results in more accurate readings and a faster recovery to the setpoint temperature.

Special Registers

This page is intentionally left blank.

Temperature Control Registers

The special registers described below are located on-board the Model 2220-102, -103 modules and only work with 2700 series controllers. These registers are volatile and lose their values when power is removed from the system.

The Model 2334 has 4 channels and the Model 2335 has 8 channels. Each channel has 10 possible PID parameters which are assigned to a particular register address. Registers 7101-7110 are for the first channel, registers 7111-7120 are for the second channel, and so forth.

Notes

1. R indicates that the controller can read the register and W indicates that the controller can write to the register.
2. All other registers function the same as those described below.

Register 7101 – Control – R/W

This register lets you select the type of output control for your module. Store the following values to specify output control:

0 = Off

1 = On PWM

2 = On Analog Out

Register 7102 – Setpoint – R/W

This register is used to specify a setpoint in degrees Celsius (°C). CTC recommends setting this to C*10.

Register 7103 – Proportional Gain (P) – R/W

This register lets you specify a P factor as part of a PID control system. The stored value can range from 1-65535.

Register 7104 – Integral Gain (I) – R/W

This register lets you specify an I factor as part of a PID control system. The stored value can range from 1-65535.

Register 7105 – Derivative Gain (D) – R/W

This register lets you specify a D factor as part of a PID control system. The stored value can range from 1-65535.

Register 7106 – Timeout – R/W

This register lets you set a timeout value for receiving a temperature reading from a temperature sensor. The stored value can range from 1-65535 seconds.

Register 7107 – Result – R/W

This register contains the PID calculation result of the temperature reading.

Register 7108 – Input Scaling – R/W

This register scales the analog input value. CTC recommends setting this register to 1000.

Register 7109 – Shutdown Temperature – R/W

This register lets you specify a shutdown temperature for your control system. CTC recommends setting this register to shutdown point (°C)*10.

Register 7110 – Output Scaling – R/W

This register scales the analog output value. The allowable range is 1-65535. This register is only used when the PID output type is set to Analog Out, or 2.

Other Channels

Registers 7111-7120	**Channel 2**
Registers 7121-7130	**Channel 3**
Registers 7131-7140	**Channel 4**
Registers 7141-7150	**Channel 5**
Registers 7151-7160	**Channel 6**
Registers 7161-7170	**Channel 7**
Registers 7171-7180	**Channel 8**

Setting up the PID Registers

The PID registers are volatile and lose their contents when power is cut from the controller or temperature control system. Therefore, you have to use non-volatile registers as a holding area for the PID values. When power is applied, make sure that the data stored in the non-volatile registers is transferred to the PID registers. In addition, if you update the PID registers, you also have to update the holding registers.

Sample Register Update Program

PID Control Parameters

Chapter 2 discussed the various types of temperature controllers. This section defines PID parameters and how they affect the control system error.

PID loops are networks that use Proportional, Integral, and Derivative adjustments to automatically compensate for changes in a temperature control system. Each parameter is factored into a PID correction equation that helps improve system response.

You can adjust, or tune, a system by trial and error or with auto-tuning methods. Manual and auto-tuning procedures are described in *Tuning Your Temperature Control System*.

Proportional (P) Parameter

The P parameter is the system's proportional gain. As the gain increases, the system responds more rapidly to changes in set-point but becomes progressively underdamped and unstable.

P causes the output to change in proportion to the value of the temperature error (T_E).T_E is calculated as

$T_E = (T_A - T_S)$

where T_A is the actual temperature and T_S is the set-point temperature.

This difference is then amplified and fed back to the correction signal. The correction signal is derived by multiplying system gain (P) and T_E or

P Correction = P_gain * ($T_A - T_S$)

Integral (I) Parameter

The I parameter integrates, or builds up, a corrective signal in response to steady-state error. This parameter is sensitive to even small amounts of error and greatly increases the system's accuracy in steady-state conditions. When this parameter is large enough, it drives the output back toward the setpoint.

The output level changes in proportion to the error over a period of time. In other words,

I correction = I_gain * Cumulative_error

where Cumulative_error is the accumulated amount of uncorrected error over time.

Derivative (D) Parameter

The D parameter senses and responds to rapidly changing rates of error and causes the output to change in proportion to the error's rate of change. It opposes rapid deviations in system output and reduces the response to disturbances and transient conditions. In other words,

D correction = D_gain * (T_E - T_L)

where T_L is the temperature error measured in the previous sample.

PID Correction Equation

Temperature control outputs are updated every 2.083 ms and the final PID equation is

PID correction = [P_gain * (T_A - T_S)] + [I_gain * Cumulative_error] + [D_gain * (T_E - T_L)]

Tuning your Temperature Control System

This section contains a manual tuning procedure and describes how autotuning works.

Setup

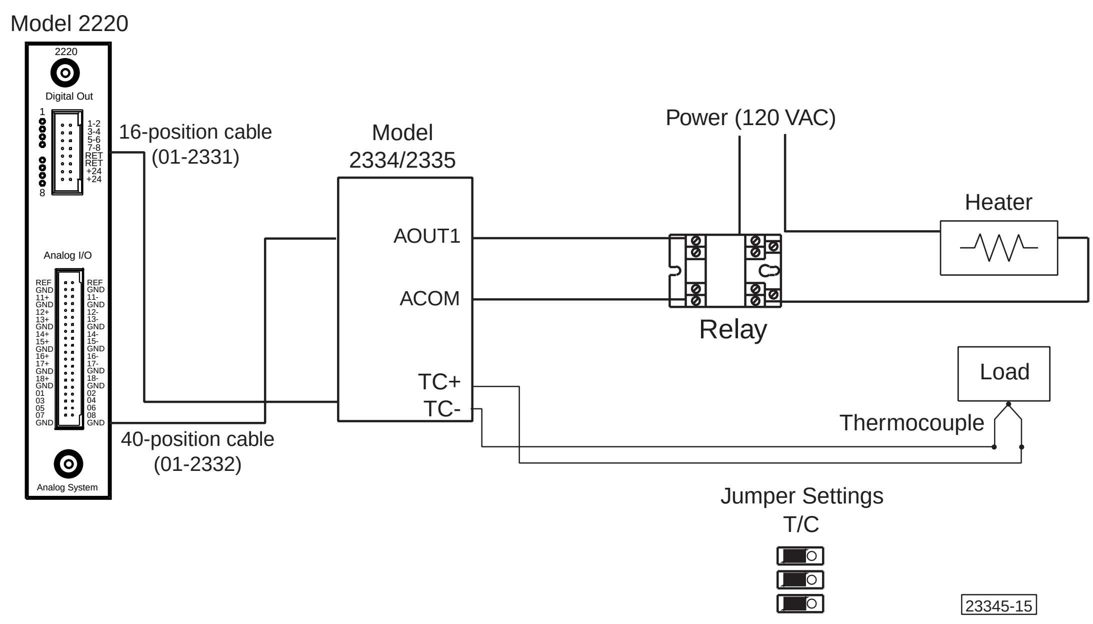
Before you tune your system, you should:

1. Make sure that all control loop components are operating correctly.
2. Test input processing tasks to ensure that the system output measurements are sampled correctly.
3. Test your output procedures to verify that all outputs are correctly scaled.
4. Make sure that the PID controller is processing the sampled input and generating an output signal that is consistent with the input.
5. Verify that the system is responding correctly to its control output.

Manual Tuning Procedure

This procedure describes how to manually tune your temperature control system by using CTC Monitor. A sample temperature control loop is shown in Figure 3–1.

Figure 3–1. Sample Temperature Control Loop

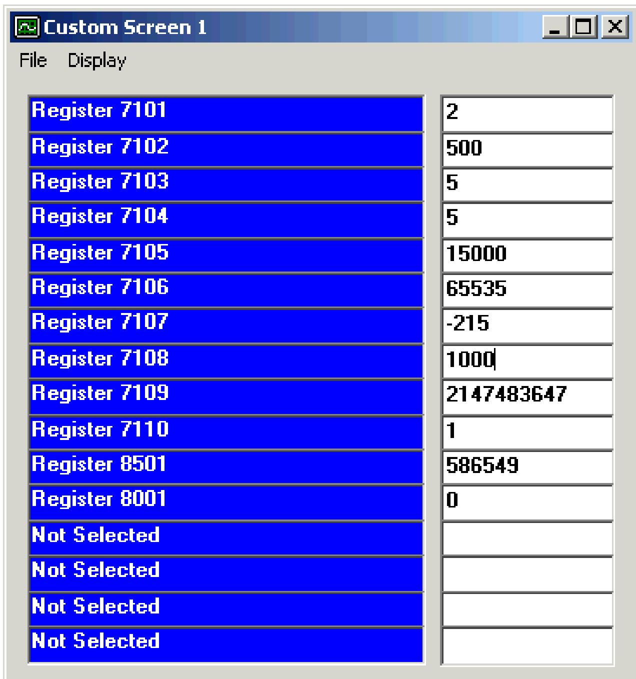


Tune the system as follows:

1. Launch CTC Monitor and create a custom screen.

2. Select **Display Resources** from the **Display** menu.

3. Set up registers 7101-7110, register 8501, and register 8001. Register 8501 displays the analog input value in microvolts (µV) and register 8001 displays the analog output value in millivolts (mV).



23345-16

4. Set register 7101 to 2, which turns on the analog output.

5. Set register 7102 to 500, which is a setpoint temperature of 50°C.

6. Set input scaling (Register 7108) to 1000 and output scaling (Register 7110) to 1.

7. Set the I and D parameters to 0.

8. Raise the P value until the temperature starts to oscillate.

9. Reduce the P value until the oscillation stops, then reduce it again by an additional 20 percent.

Note

The P-loop element is almost in a hair-trigger mode at this point. If you make slight changes to the setpoint, the temperature corrects immediately.

10. Increase the D parameter to improve phase margin and system stability. Continue to increase D by 30 percent until optimum results are achieved.

11. Increase I and monitor the temperature error (T_E). Raise I until T_E drops to zero quickly without overshooting.