Operation Manual

For
Model TC-24-25
Thermoelectric Module
Temperature Controller

June 13 , 2006
Drawing #3458 Rev. G

Table of Contents

Notice: Improper tuning of this temperature controller (or any temperature controller) can lead to excessive thermal cycling and/or overheating of the thermoelectric device, either of which are known to reduce the lifetime of any thermoelectric device. Care should be taken to prevent the temperature of the thermoelectric device from going beyond the range specified by the device manufacturer. Care should also be taken so that any thermal cycling of the thermoelectric device is a result of changes in the controller's set-point temperature and not instability at a given set point due to improper selection of the tuning variables.

Features

- Input voltage from (12 to 28) VDC
- Self-contained, (0.1 to 25) A current rating
- computer programmable via RS-485 communications port
- Bi-directional, solid state H-bridge operation for heating and cooling applications
- Control temperature of −20 °C to +100 °C using MP-2379 thermistor (supplied with controller)
- Proportional (P), Integral (I), and Derivative (D) control that can be selected as P, PI, PD, or PID; or Deadband (on/off) with an adjustable hysteresis
- Temperature resolution of 0.1 °C or 0.1 °F
- Control stability of up to ±0.1 °C or ±0.1 °F (when controlling a cold plate)
- Pulse-width modulation of output:
    - Selectable modulation frequency of 675 Hz or 2700 Hz
    - Controls up to 680 W
- 1500 VAC isolated RS-485 communications interface
- Set temperature selectable:
    - computer set with controller stand alone operation
    - Remote user set temperature using a potentiometer
    - 0 mA to 20 mA current loop
    - 0 VDC to 5 VDC adjustable range
    - Differential temperature control
- No computer programming experience required to use the communications software program (Supplied software is compatible with Windows 95/98/XP/NT)
- Command set is provided so programmers may create their own software interface or embedded controller applications
- Versatile alarm system:
    - Hardware output 5 VDC at 25 mA
    - Alarm cancel is selectable via computer-software communication or remote contacts
    - Second sensor also configurable as a heat-sink over-temperature shut-down
- Non-volatile memory retention of parameters (1,000,000 write cycles maximum; see command #31 in Appendix C for further details.)
- Operating temperature range of 0 °C to 65 °C
- Storage temperature range of -55 °C to +105 °C

General Description

The TC-24-25 is a bi-directional control for independent thermoelectric modules or in conjunction with auxiliary or supplemental resistive heaters for both cooling and heating applications. The "H" bridge configuration of the solid state MOSFET output devices allows for the bi-directional flow of current through the thermoelectric modules. Highly efficient N-channel output devices are used for this control mode.

This controller is programmable via an RS485 communication port for direct interface or via an RS485 to RS232 converter which can then be connected to the serial communications port of a computer. The RS485 communications interface has 1500 VAC isolation from all other electronic circuitry minimizing interference from noise or errant signals caused by common ground loops. The easily accessible communications link permits a variety of operational mode configurations. Field selectable parameters or data acquisition in a half-duplex mode can be performed. This controller will accept up to 32 addressable interfaces, over a maximum of 4,000 feet of communications cable.

Once the desired set parameters are established, the TC-24-25 can be disconnected from the computer, and it becomes a unique, stand-alone controller. All parameter settings are retained in non-volatile memory.

The user friendly, communications software requires no prior programming experience to establish operation. A command set is provided for qualified personnel to program a software interface or use as an embedded control.

Mechanically, the control printed circuit board is mounted to a metal bracket that is suitable for either horizontal or vertical orientation. Input and output connections are accessible via screw type terminal strips and fast-on terminals.

Technical Description

The TC-24-25 is capable of operating from an input supply voltage of (12 to 28) VDC, common to many available thermoelectric coolers. The self-contained MOSFET output devices deliver load currents from (0.1 to 25) A. (NOTE: consult appropriate installation instructions for power supply and heat sinking requirements for high current operation). This unit will control total load power up to 680 W with a finite temperature resolution of 0.1 °C or 0.1 °F.

The output signal to the thermoelectric module is pulse-width modulated and can be set for either 675 Hz or 2700 Hz operation. Pulse-width modulation (PWM) averages the amount of energy provided to the module and reduces the extreme temperature excursions that are experienced with a thermostatic control system. This tends to extend the life and reliability of the thermoelectric devices. The PWM control scheme affords control accuracy to within ±0.1 °C or ±0.1 °F at the control sensor.

The controller tuning structure allows designation of a variety of control features:
1) The Computer Set Value provides for manual control of the output, from 0% to ±100% of load power.
2) Proportional bandwidth (P) in degrees, Integral reset (1) in repeats per minute, and the Derivative rate (D) in minutes may be configured for P, PI, PD, or PID control.

3) Deadband control (on/off) with an adjustable hysteresis may also be selected. However, this control mode is not generally recommended.

4) Differential temperature control is provided when two input sensing thermistors are used. The unit will control the differential between Input 2 (reference temperature) and Input 1 (actual system temperature).

A control temperature range of –20 °C to +100 °C is standard when using TE Technology's standard thermistor sensor probe for the primary set temperature. Additional external set temperature input types may be selected. As mentioned above, a second thermistor can be used for differential control (or it could be used for alarm condition sensing). In addition, the controller could use a remote set temperature potentiometer, a (0 to 5) VDC signal, or a (0 to 20) mA current loop. These secondary inputs are used to define and "map" the secondary input to an adjustable temperature range in order to remotely control the set temperature. All temperatures may be consistently displayed in °C or °F.

Two types of control output modes may be selected. This determines the direction of the current flow through the thermoelectric module during the heat cycle. This current flow may be from wire-point WP1+ to wire-point WP2-. Alternatively, this current flow may be reversed from WP2+ to WP1- as selected in the configuration menu.

Several alarm settings may be selected, some of which provide a 5 VDC output, rated for 25 mA of current for alarm signaling. The settings can be selected for no alarm function, tracking alarm, and fixed-value alarm. Alarm set temperature values are entered in the setup menu. The computer-controlled selection is available for additional embedded controller input/output options. The alarm setup menu also provides for selection of an alarm latching condition. The alarm sensor may be either the control temperature sensor or a secondary thermistor sensor.

The various alarms have the ability to determine the status of the output power to the thermoelectric module or auxiliary heater. Power may be maintained during an alarm condition or the main power may be shut down.

Set-Up Instructions

1.0 Setup

NOTE: the maximum allowable ambient temperature for the controller is 65 °C. Furthermore, the maximum allowable temperature of the controller base (underneath the transistor-mounting area) is 80 °C.

1.1 Initial settings for the controller should be made using the supplied computer software. Make sure the computer is off and the controller is un-powered. Connect the RS-485 Communications Port from the controller to the RS-485 input on the computer or to an RS-232 to RS-485 converter. If a converter is used, connect the RS-232 port on the converter to an available RS-232 port (serial communications port) on the computer. See Appendix A "*RS-485 Cable Termination Requirements*" before removing any of the resistors on the JP1 terminal strip. See Appendix B "*Multiple Controller Wiring Diagram*" for wiring information. Contact TE Technology if additional information is required on the RS-232 to RS-485 converter that is supplied with the TC-24-25.

1.2 Attach the thermistor to the control location. Generally, this is the cold side of the cooler rather than the part itself that is to be cooled/heated. This provides better control stability. As much wire length of the thermistor should be thermally connected to the cold side as possible so that the thermistor and its wire leads are as equivalent in temperature as possible. This can be accomplished by using aluminum tape placed over the wire leads and adhered to the cold side of the cooler. This will help eliminate errors resulting from heat conducting along the wire leads and affecting the sensor reading.

The standard thermistor supplied with the TC-24-25 is the MP-2379. Appendix G "*Thermistor Styles for TC-24-25*" shows dimensional data on the MP-2379 and other thermistor styles readily available as well as temperature-resistance data. If you are using the MP-2379, it is recommended that use thermal grease (such as TE Technology's thermal grease, TP-1) between the thermistor and the surface to which it is being mounted.

If you want to use thermistors that have different resistance-temperature curves than the standard thermistor, it can be done as long as the operating resistance range is within that of the standard thermistor. The thermistor should be a negative temperature coefficient device. Because the temperature controller is really measuring the thermistor's resistance and converting this to a temperature, the temperature controller will be fooled into thinking that the thermistor is at a different temperature than it really is, and the Set-Temperature will be skewed accordingly. A loss of resolution and control stability may occur as a result. The user assumes all risks associated with making any substitutions and TE Technology assumes no liability whatsoever for the operation of the controller when a non-standard thermistor is used.

1.3 Connect the appropriate DC power (12* to 28 volts) to the controller between WP3+ and WP4- and the thermoelectric module between WP1 and WP2 in accordance with the "*Controller Wiring Diagram.*"

NOTE: Generally, there is approximately a 0.5 to 1.3 V drop from the power supply to the thermoelectric modules. You may wish to adjust the power supply accordingly to ensure full power is delivered to the cooler when needed, subject to the 28 V limit.

*NOTE: For operation below 15 V, move the jumper on JP4 so that it connects both pins together. The will allow proper operation down to 12 V. (See "*Controller Wiring Diagram*" for JP4 location.)

1.4 Turn power on to both the computer and power supply (which in turn powers up the controller). The on-board green LED will flash at a steady rate to indicate that the controller is energized correctly.

1.5 Insert the TC-24-25 software disk into the computer floppy-disk drive. To run the software from the floppy disk, select START, RUN from your Windows Desktop and then enter A:\TC-24-25.exe. This will load the software into your computer's RAM. Alternatively, copy the TC-24-25.exe file to your hard-disk drive and run the program from there.

1.6 The Main Menu screen will appear on your computer monitor. All selections are made from this screen. In the PC COMMUNICATIONS section, select the RS-232 port (1 through 4) to which the controller is connected by using the COMM PORT menu key. Assign a two-digit address code of "00" to the controller for the initial set-up in the ADDRESS OF CONTROLLER TO ACCESS box. The "00" code is the universal address which will communicate with all the controllers in a multiple controller system. Refer to Appendix C "*Communications Port Address Assignments*" for additional address code information and on how to install multiple controllers on a serial link. After making these selections, click on the INITIALIZE button.

1.7 NOTE: If you receive an error message, please refer to Appendix D "*RS-485 Troubleshooting Guide*."

2.0 Configure
2.1 In the CONFIGURE section, the various selections are used to establish the custom operating criteria for the controller. *NOTE: To avoid damage to the thermoelectric cooler, confirm that* OFF *is selected in the* OUTPUT ON/OFF *menu key, and then click the Send Box Values button prior to proceeding!*

2.2 First, select the PWM OUTPUT TIMEBASE menu key. Options for SLOW TIMEBASE 675Hz or FAST TIMEBASE 2700Hz will appear. Select the option that is appropriate for you. Generally, 675 Hz will work fine, and it is the recommended default.

2.3 Next, click on the SET TEMP TYPE INPUT 2 menu key to reveal the options available. COMPUTER SET VALUE is to be selected when using the software to set the desired control temperature. The other selections, POTENTIOMETER SET, 0 TO 5vdc SET, and 0 TO 20ma SET, are for external set temperature adjustments. Refer to the "*Controller Wiring Diagram*" and the "*TC-24-25 Block Diagram*" for additional information. The controller default setting for these options is the full range of the thermistor input sensor. The DIFF.SET=INP2+FIXED SET establishes an actual set temperature that is the sum of the temperature sensed by the optional,

secondary thermistor input sensor and the temperature entered as the FIXED SET TEMP value. This allows the controller to maintain a constant temperature difference between the primary thermistor temperature and the secondary thermistor.

2.4 Enter the SET TEMP HIGH RANGE and SET TEMP LOW RANGE values. These values are used to linearly scale the temperature range that you are controlling within to the full range of the external input. The set limit values must be within the temperature range that controller is capable of controlling to.

For example, suppose you are using a (0 to 5) VDC external input to control the set temperature. Suppose further that you enter -20 °C for the SET TEMP LOW RANGE and +100 °C for the SET TEMP HIGH RANGE. This sets up a linear scale of 5 V per 120 °C, or 0.0417 V/°C. So, to control to 10 °C, for example, you would set the external input voltage to 1.25 V.

2.5 Click the CONTROL TYPE menu key and select which type is appropriate for your application. The DEADBAND CONTROL is an on/off control and PID CONTROL is a proportional/integral/derivative control. COMPUTER CONTROL allows a constant, fixed percentage of power to be applied to the thermoelectric cooler. Generally, DEADBAND CONTROL should not be used unless care is taken to prevent the thermoelectric cooler from being damage by excessive thermal cycling.

2.6 Clicking on the CONTROL MODE menu key permits the selection of either HEAT WP1+ AND WP2- or HEAT WP2+ AND WP1-. These selections establish the polarity for the heating mode of the thermoelectric cooler. This selection allows you to reverse the current flow in the thermoelectric cooler without having to change the wiring.

NOTE: For TE Technology's standard products, the TE+ (red) wire should be attached to WP2 and the TE- (black) wire should be attached to WP1 as shown in the "Controller Wiring Diagram." The CONTROL MODE should then be set to HEAT WP1+ and WP2-.

2.7 The ALARM TYPE menu key permits the selection of available alarm options. NO ALARM PICKED indicates that no alarm parameters are desired. SET TRACKING ALARMS allows an alarm to be set with respect to the set temperature. It will move accordingly with a change of the temperature setting. This option can be used for a high alarm, low alarm, or both settings. FIXED VALUE ALARMS permits the setting of a fixed, absolute temperature either above or below the set point temperature or both. COMPUTER CONTROLLED ALARM is not an actual alarm, but provides for user activation of the alarm relay via the computer software. The "*Expansion Connector Wiring Diagram*" shows how customer-supplied LED's can be installed to signal various alarm conditions.

2.8 The POWER OUT SHUT DOWN IF ALARM menu key provides two selections. NO SHUT DOWN IF ALARM will let the controller continue to control to the set temperature. MAIN OUT SHUTDOWN IF ALARM shuts off power to the cooler when an alarm condition exists.

2.9　Associated with the ALARM TYPE configuration are the HIGH ALARM SETTING, LOW ALARM SETTING, and the ALARM DEADBAND settings.　If an alarm type has been selected, enter the desired high and low temperature values that you want to have trigger an alarm condition.　The ALARM DEADBAND option sets the hysteresis of the alarm values from 0.1 degrees to 100 degrees.

2.10　The ALARM LATCH menu key permits the selection of ALARM LATCH OFF or ALARM LATCH ON.　If ALARM LATCH OFF is selected, the controller will automatically reset if the alarm condition self-corrects when the corresponding temperature returns back to the temperature defined by the ALARM DEADBAND and alarm setting.　If ALARM LATCH ON is selected, the controller will maintain the alarm condition until it is manually cleared.　When ALARM LATCH ON is selected, and if an alarm condition exists, the alarm latch can be reset by clicking the SEND LATCH CLEAR button.

2.11　The CHOOSE SENSOR FOR ALARM menu key allows for the selection of either the CONTROL SENSOR thermistor or the INPUT 2 SENSOR thermistor for the alarm sensing.　(Note:　The INPUT 2 SENSOR thermistor cannot be used if you are using a potentiometer or voltage/current levels to control the set point.)　The INPUT 2 SENSOR thermistor can be attached to the heat sink in order to detect over-temperature conditions.

2.12　The CHOOSE DEG C OR DEG F UNITS menu key permits the selection of displaying °F or °C.

　　　NOTE: The EEPROM WRITE ENABLE, located just below the CONFIGURE SECTION, can be checked or unchecked depending on your requirements.　See Appendix C, command #31, for more information on EEPROM WRITE ENABLE.

2.13　Review all of the controller configuration selections.　If all the configuration selections are correct for the application, select the Send Box Values button to download these settings to the controller.

3.0　Tuning

3.1　You are now ready to tune the controller.　All selections for this portion will occur in the TUNING section of the controller software.　The various constants required by the controller to optimize the system performance are entered in this section.

3.2　The FIXED SET TEMP is the set temperature value entered in degrees.　This temperature must be within the range of the selected input sensor or the limits of low and high set ranges from the controller configuration setup.　Also, verify that the cooler is capable of safely operating at the entered set temperature.　This is particularly important if you are heating.　While you can control to +100 °C using the standard thermistor, many coolers are rated for at most 80 °C.

　　　If you selected COMPUTER CONTROL in the CONTROL TYPE menu key under the CONFIGURE section, the values that can be entered in the FIXED SET TEMP box range from −12.0 to +12.0.　This corresponds linearly to a fixed percentage of power output where −12.0 equals −100% power and +12.0 equals +100% power.

If the controller is configured as described in the "NOTE" in section 2.6, then -100% power will correspond to full-power cooling.

3.3 PROPORTIONAL BANDWIDTH is the temperature band in which 0% to 100% power will be applied to the cooler. The acceptable bandwidth values that may be entered are 1° to 100°. See Appendix E "*PID Tuning*" for additional information on settings.

3.4 INTEGRAL GAIN is used to slowly change the output power until the difference between the actual temperature and set temperature is zero. This value is expressed in repeats per minute, and the acceptable values that may be entered are 0.01 to 10 repeats per minute.

3.5 DERIVATIVE GAIN senses the rate of rise or fall of the system temperature and adjusts the cycle time of the controller to minimize overshoot or undershoot. This value is expressed in cycle rates per minute, and the acceptable values that may be entered are 0.01 to 10 cycles per minute.

3.6 CONTROL DEADBAND is the temperature band where the controller is turned on and off by either rising or falling temperatures where no heating or cooling takes place. This band is expressed in degrees, and the acceptable values that may be entered are 0.1 to 100.

3.7 Review the tuning parameters for correctness and then click the Send Box Values button to download these constants to the controller.

4.0 Calibration
4.1 The CALIBRATE section provides additional variables that can be used to fine-tune your system's operation. You may want to try controlling with the initial settings prior to entering values in this section.

4.2 INPUT 1 OFFSET is a manual method of compensating for the sensor 1 temperature and actual control temperature.

4.3 INPUT 2 OFFSET is a manual method for compensating for the sensor 2 temperature and actual temperature.

4.4 HEAT SIDE MULTIPLIER is a 0.01 to 2.00 numerical multiplier that compensates for the non-symmetrical response of the thermoelectric cooler between the heat and cool modes.

4.5 If you have entered values in the CALIBRATE box and they are desired settings, click the Send Box Values button to download these constants to the controller.

5.0 Controller Operation
5.1 Initial set-up of the TC-24-25 controller is complete.

5.2 Select ON in the OUTPUT ON/OFF menu key located in the CONFIGURE section. Then click the Send Box Values in the CONFIGURE section to turn the controller on.

5.3 Click the SAMPLE button to monitor the CONTROL SENSOR's temperature. This temperature is indicated in the TEMP box. If you have an INPUT 2 SENSOR thermistor attached, its temperature is indicated in the SECOND SENSOR box.

5.4 If all of the settings are satisfactory, you can turn off the computer and power supply, disconnect the controller from the RS-232 port, and turn back on the power supply. The controller remembers its last settings on EEPROM and will resume control based on that.

6.0 Custom Software
The controller does not specifically have to be used with the software that is provided. You could also use commercial software such as LabVIEW from National Instruments. This might be useful if you wanted to control a specific temperature profile over a particular amount of time. This is accomplished by communicating through the RS-232 port of the computer using the command set for the controller. The command set is given in Appendix F "*Serial Communications*."

Block Diagram

INPUT #1 SENSOR

```
TEMPERATURE
SENSOR
-20 °C TO 100 °C
```

SUMMING JUNCTION
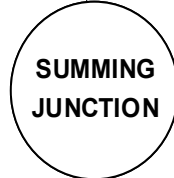
CONTROL

```
PID
PID W/ ALARM
DEADBAND
DEADBAND W/ ALARM
```

OUTPUTS

```
H-BRIDGE
1 TO 25 A PWM
675 OR 2700 Hz
```

```
REMOTE INDICATOR
RED/YELLOW/GREEN
LED'S
```

INPUT #2 AUXILLARY INPUT

```
10K OHM POTENTIOMETER
0 TO 5 VDC*
4 to 20 mA DC**
OR
0 TO 20 mA DC**
PC SET VALUE
DIFF SET = INPUT 2
```

*CONTROLLER INPUT IMPEDANCE 6.5K OHMS

**REQUIRES ADDITION OF EXTERNAL RESISTOR

Controller Wiring Diagram

TE COOLER

WP1 −
WP2 +

WP3 +
WP4 −
DC INPUT POWER
FROM POWER SUPPLY

JP1

6	RED
5	WHT/BLK	THERMISTOR
4	JUMPER JP1.4 TO JP1,1 TO SET RS485 ADDRESS
3	TO 99 FOR ADDING CONTROLLER TO COMM. LINK
2	4-20 MA+ 249 OHMS
1	SUPPLIED 4-20 MA−

OR

3
2
1
(CW)
OPTIONAL
5 K ohm
SET POT.

OR

2
1
OPTIONAL
THERMISTOR

JP3

3	(+)
2	(−)	120 OHMS
1	SHIELD

RS485
REMOVE RESISTOR
FROM ALL BUT
LAST UNIT ON
NETWORK
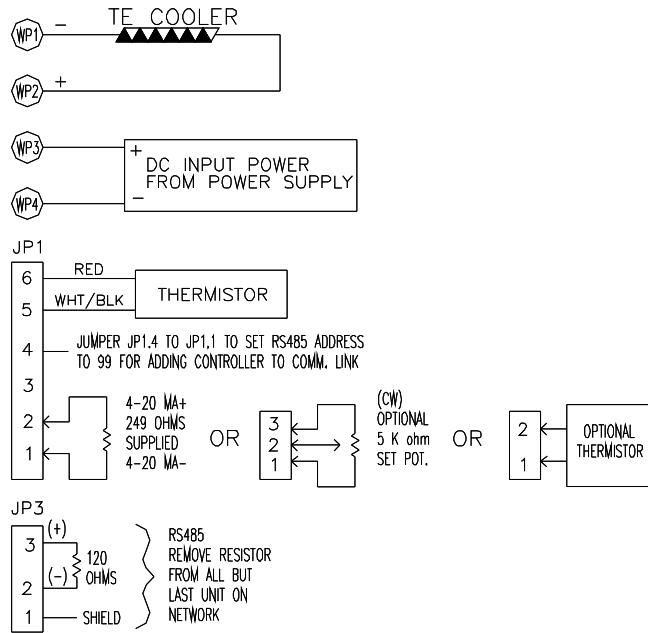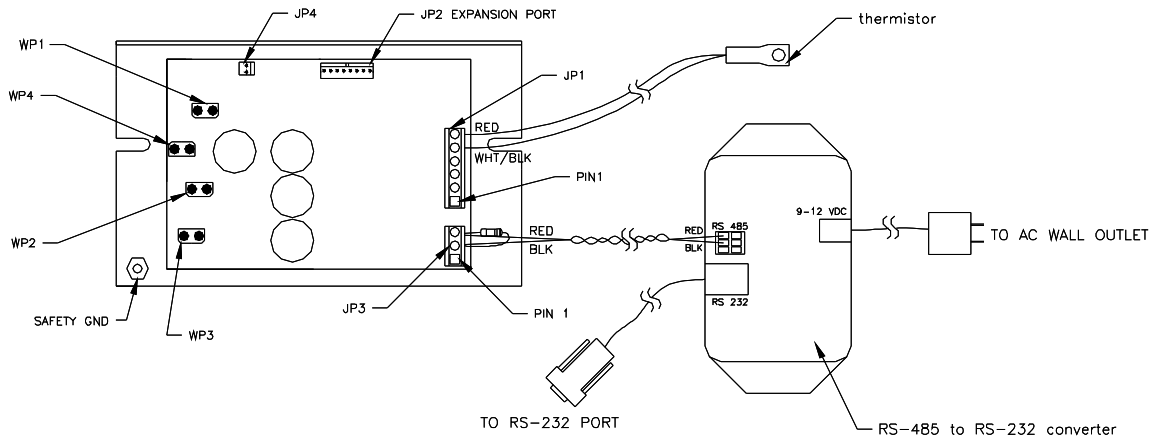
Expansion Connector Wiring Diagram

Note: The 25 mA current source is a true current source. Maximum compliance voltage is approximately equal to the input voltage to the temperature controller. No external current limit resistors are needed for the LED. The LED must be capable of being driven with a 25 mA continuous current.

Expansion Connector

Molex 22-23-2081

25 mA Current Source

JP2

Alarm Cancel

Input Common

High Alarm

Low Alarm

No Alarm

Customer- supplied Connector
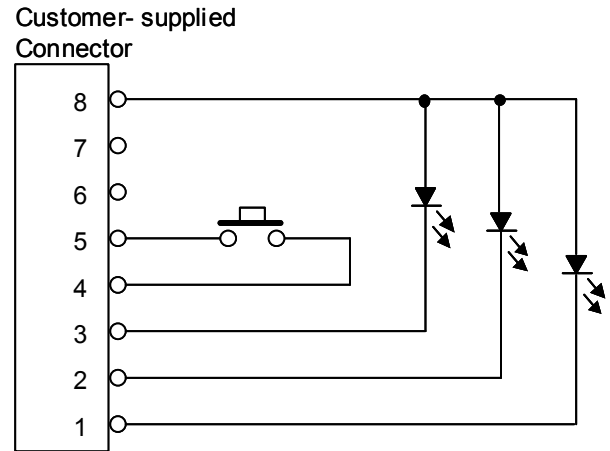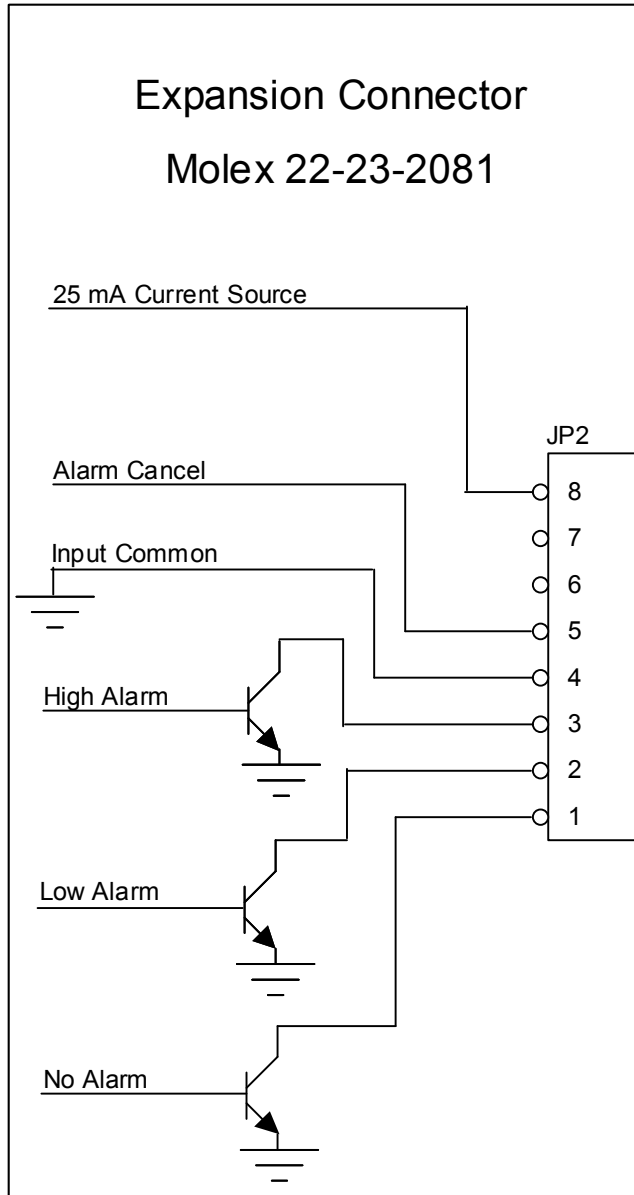
Note: Pins 6 and 7 not functionally defined.

Please do not connect.

Mechanical Package Drawing

4.20 CENT

DIMENSIONS IN INCHES

3.625

1.60

.186 TYP

.50 TYP

6.00

COMPONENT AREA

1.75

.63

3.15
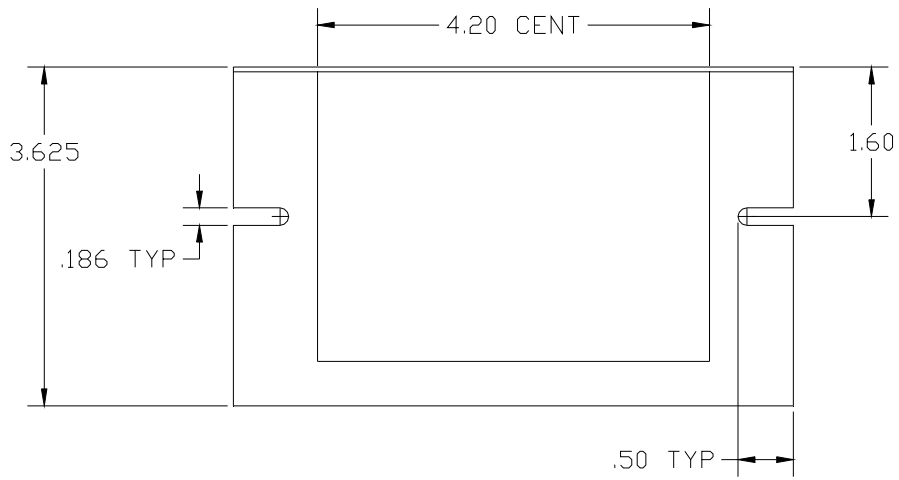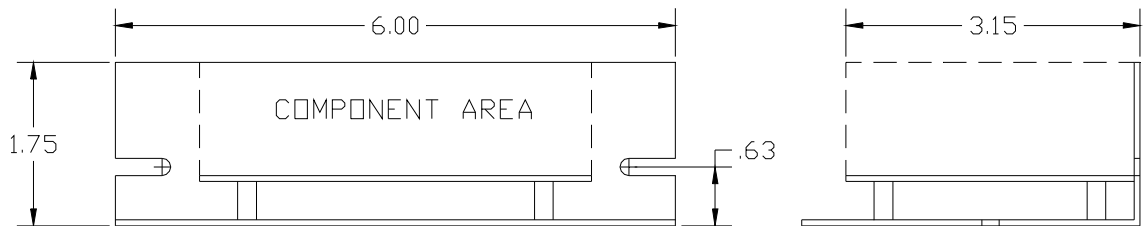
APPENDIX A RS-485 Cable Termination Requirements

A twisted pair of wires for RS-485 applications may connect up to 32 ports for half-duplex data transmission. An optional shield around the twisted pair helps reduce unwanted noise, and is connected to ground at one end.

Proper termination of the cable is very important. If the cable is not correctly terminated with its characteristic impedance, normally 120 ohms, distorted waveforms will result. Unwanted reflections signals may occur which can distort or interrupt data transmission.

Cable terminating resistors are required at each physical end of the cables to prevent theses unwanted reflections (Refer to Appendix B Multiple Controller Wiring Diagram). The typical differential output is 2 volts with two 120 ohm terminating resistors, causing 33mA of DC current in the cable when no data is being sent. The preferred terminating resistor type is a metal film rated at ¼ watt.

This termination method permits connections up to 4,000 feet of RS-485 cable.

NOTE:

1) If an RS-232 to RS-485 converter is being used (other than the one supplied with the TC-24-25), please check the converter manual to determine if a 120 ohm terminating resistor is included. The converter supplied with the TC-24-25 has a 120 ohm resistor already installed within the converter. Also, each TC-24-25 includes a 120 ohm terminating resistor. In multiple controller configurations, the resistor should be removed from each controller except for the last controller in the line. Again, refer to Appendix B Multiple Controller Wiring Diagram.

2) However, a string of TC-24-25 controllers may cause low signal levels from the RS-485 driver circuit depending on the driver circuit being used, line length, wire diameter, number of controllers, etc. In this case you may want to use a larger value (higher resistance) terminating resistor or remove it completely if you are experiencing communication problems.

APPENDIX B Multiple Controller Wiring Diagram

RS-485 PORT #1
(ORANGE WAGO CONNECTOR)

If using the supplied RS-232 to RS-485 converter, this 120 ohm resistor is already installed within the converter itself.

RS-232 PORT
(RJ11 CONNECTOR)

RS-232 TO RS-485 CONVERTER

+ PIN 3

– PIN 2

120 OHMS

RS-232 (COMM PORT)
PIN 1 – CTS
PIN 2 – RTS
PIN 3 – COM
PIN 4 – TXD
PIN 5 – RXD
PIN 6 – DSR
PIN OUTS PROVIDED FOR
REFERENCE ONLY

COMPUTER

PIN 3 RS-485
(RED WIRE)

PIN 2 RS-485
(BLACK WIRE)

Picture of Converter

RJ11
RS-232 PORT

TC-24-25
UNIT #1

+

–

RS-485 PORT #2

TC-24-25
UNIT #2

+

–

RS-485 PORT #3

Terminating Resistor
from JP3-3 to JP3-2

Thermistor wires to
JP1-5 and JP1-6
(Polarity not important)

TC-24-25
UNIT #30

+

–

RS-485 PORT #31

BLACK WIRE FROM
RS-485 TO JP3-2

RED WIRE FROM
RS-485 TO JP3-3

Picture of TC-24-25

TC-24-25
UNIT #31

+ (red wire)

– (black wire)

RS-485 PORT #32

120 OHMS

APPENDIX C Communications Port Address Assignments

The 00 Communications Port Address code is the universal address to which all controllers will respond.

Placing a jumper between pins JP1-4 and JP1-1 on the host controller will initiate a 99 Communications Port Address code, when the controller is powered. This code is used to set-up newly added controller to the serial link. This jumper should be removed upon completion of this set-up.

Additional Communications Port Address codes from 01 to 98 are used to identify individual controllers of the serial link. The total numbers of controllers that make up the serial link is 32 ports.

The CONTROLLER COMM. ADDRESS in the CONFIGURE section is the address that is sent to the controller and stored in non-volatile memory. This address must be unique to the controller.

The ADDRESS OF CONTROLLER TO ACCESS in the PC COMMUNICATIONS section indicates which controller the software should monitor and send data.

00 is the address that communicates with all controllers. 99 is the address of a controller when it has a jumper between pins JP1-4 and JP1-1 (address programmed in non-volatile memory on power-up). These two addresses cannot be given to specific controllers as they are reserved.

Assigning A New Controller Address
If the controller is the only one hooked up to the computer, ensure the SELECT COMM PORT in the PC COMMUNICATIONS section is indicating the comm port the controller is attached to. Enter 00 in the ADDRESS OF CONTROLLER TO ACCESS. Check the Enable New Controller Address box. Click the INITIALIZE button. In the CONFIGURE section, enter the new address in the CONTROLLER COMM. ADDRESS box. Click the Send Box Values button.

You can verify the controller is functioning under the new address by entering the address in the ADDRESS OF CONTROLLER TO ACCESS box under the PC COMMUNICATIONS section. Check the Enable New Controller Address box. Click the INITIALIZE button. Then click the SAMPLE button. A temperature readout should appear in the TEMP box.

Example: Adding a controller to a chain of controllers without pre-programming a specific address in the non-volatile memory
If you have multiple controllers on an RS-485 chain and you want to add a new controller without pre-programming a unique address, there is a slightly different procedure. With the systems unpowered, add the new controller to the chain and install a jumper between pins JP1-4 and JP1-1 on the controller you are adding. Next, power up the systems. When the new controller is turned on, it recognizes there is a jumper installed and changes its address to 99 in the non-volatile memory. Next, change the address to 99 in the ADDRESS OF CONTROLLER TO ACCESS box so you can communicate with this controller. Then, change the CONTROLLER COMM. ADDRESS box to 07 and click the Send Box Values button. This re-programs the non-volatile memory with an address of 07. Then, you can change the address to 07 and communicate with the controller again. Finally, you need to remove the jumper so it is not reprogrammed with an address of 99 on the next power-up.

APPENDIX D RS-485 Troubleshooting Guide

For troubleshooting always set the RS-485 port to 00, until correct communication is established.

You can perform a quick check of the comm. port (without having to initialize variables) by clicking the "CommCheck" button in the PC COMMUNICATIONS section of the software screen. You should have the controller connected to a comm. port and the controller powered up when performing the comm. check. A "COMM ERROR!" message will show if there is no hookup. If the connection is good a "COMM OKAY" message will quickly appear.

When you initialize, an error message my show up if there is any additional problems. The following table offers possible solutions corresponding to a particular error:

Error Message	Possible Cause	Solution
Comm Port Timeout	No power to TC-24-25 unit	Apply power to TC-24-25, review customer-hookup drawing for proper hookup.
Comm Port Timeout	RS-485 Address is wrong	Set to 00 the universal address.
Comm Port Timeout	Wrong Comm Port selected	Check computer hardware setting and set to the correct Comm Port.
Comm Port Timeout	Comm Port is not connected to converter or computer.	Check for correct connection of the converter to the computer, review converter specifications & computer for proper hookup.
Comm Port Timeout	Incorrect wiring of Comm Port to the converter or computer.	Check for correct wiring of the converter to the computer, review converter specifications & computer for proper hookup.
Comm Port Timeout	Converter is not connected to TC-24-25.	Check for correct connection of the converter to TC-24-25, review converter specifications & TC-24-25 customer drawing for proper hookup.
Comm Port Timeout	Incorrect wiring of the converter to TC-24-25	Check for correct wiring of the converter to TC-24-25, review converter specifications & TC-24-25 customer drawing for proper hookup.
Comm Port Open Error	No Comm Port available at this port setting.	Check computer hardware setting and set to the correct Comm Port.

Note: See also Appendix F, Section III RS485 or RS232 Communications Parameters regarding the insertion of a delay between sending characters if you are using your own software program.

APPENDIX E PID Tuning

Tuning the TC-24-25 temperature controller involves three variables: (P)ROPORTIONAL BANDWITH, (I)NTEGRAL GAIN, and (D)ERIVATE GAIN.

The control algorithm sums the three values of these terms to determine the output power.

P + I + D = > Power Applied

Most applications work satisfactorily with only the "P" and "I" values used.

Start the tuning process by setting the Integral and Derivative functions to zero. Then turn on the controller.

PROPORTIONAL BANDWITH is defined as the temperature range around the set point where the controller modulates (proportions) the output power. When the actual temperature deviates from the set temperature, the "**P**" term of the control equation is increased until the power output reaches 100%. Stated another way, the amount of temperature deviation required to increase the output to 100% is, by definition, the proportional bandwidth. The programmable bandwidth range of the TC-24-25 is from 1° to 100°. The units are shipped with a default setting of 20°.

Each thermal system has its own time constants determined by the thermal mass of the components and the placement of the sensor relative to the load. When the "I" and "D" terms are set to zero, and the bandwidth is too large, the temperature will never reach the set point. In this case the controller's output will approach zero as the temperature difference approaches zero, so the system will never get the required power to actually reach the set point. On the other hand, if the bandwidth is too small and there is any time lag between the cooling/heating element and the temperature sensor, the temperature will initially overshoot the set point and then settle into a pattern of oscillation above and below the set point.

Assuming the controller is configured for your requirements, start the tuning process by applying power with the default settings and observing the system's response. If the system comes into the proportional band and maintains a steady temperature near set point, without over shoot, the bandwidth setting is either satisfactory or too large. Reduce the bandwidth setting until the system just begins to oscillate. At this point, the bandwidth is too small. Note the bandwidth setting that just caused the system to oscillate, and record the period of oscillation for use in determining the Integral Gain setting. To set the proportional bandwidth, multiply the current bandwidth setting by 1.5 and use it as your new bandwidth setting. The system should come into control and maintain a steady temperature near the set point.

INTEGRAL GAIN monitors the difference between the set point and the actual temperature. Its function is to slowly change the output power until the difference between actual temperature and set temperature is zero.

The function works by integrating the error signal at fixed intervals. The intervals are expressed in repeats per minute. The acceptable range for the TC-24-25 is 0.01 to 10 repeats per minute. Start with a setting determined by the following formula:

Integral Gain = $1/(2 \times T)$ where "T" is the period of oscillation measured above. The period is expressed in minutes.

Example: The system's period of oscillation with the appropriately set Proportional Bandwith was 75 seconds. Therefore, the suggested Integral Gain is

Integral Gain = 1/(2 x 1.25 minutes) = 0.4 repeats/minute.

For slower response but better stability, reduce the Integral Gain.

DERIVATE GAIN senses the rate of change of the temperature and allows the controller to anticipate the power needed to compensate for rapid changes in system loading. This term is generally used only on very sluggish systems or where very quick response is necessary. The acceptable range for the TC-24-25 is 0.1 to 10 cycles per minute.

To determine an appropriate derivate rate, use the following formula:

Derivate Gain = Integral Gain/10.

Continuing the above example, the Derivate Gain would be 0.04 cycles per minute.

NOTE: DERIVATIVE GAIN is difficult to apply and often causes more trouble than it is worth. If you are not experienced in process control, you may be better off leaving the DERIVATIVE GAIN at zero.

APPENDIX F Serial Communications

I. Definitions:

All numeric values are in hexadecimal format.

Use lowercase ASCII characters.

(stx)   Start of text character (*) 2a hex.
(etx)   End of text character (carriage return) or 0d hex.
(ack)   Acknowledge character (^) 5e hex.

AA   Address characters are ASCII characters from 0 through 9 or a through f.
00 is universal address of all controllers when using a chain of the RS-485 based devices.

CC   Command characters are ASCII characters from 0 through 9 or a through f.

DDDDDDDD Hex two's-complement return or send value.
        1d = 00000001
        -1d=ffffffff

SS   The 8-bit (modulo 256) checksum of characters sent to/from the controlling computer. This is represented as 2 ASCII hex characters. The checksum calculation excludes the characters (stx), SS, (etx). *The TC-24-25 sums (in an 8-bit register) the ASCII values of the characters sent to/from the controlling computer. Any overflow is truncated, leaving the 8-bit (modulo 256) checksum. When the controller is receiving data, this number (as represented by two hex characters) is compared to the two ASCII character hex checksum sent by the controlling computer. The TC-24-25 will respond as shown below depending on whether or not the checksums match. When the controlling computer is receiving data the checksum sent by the controller can be used to make sure the data has not been received with an error. Remember, when finding the ASCII value for a hex number (a, b, c, d, e, and f) be sure to use lower case letters.*

To write a command to a controller, the controlling computer must send the following ASCII characters:
        (stx)AACCDDDDDDDDSS(etx)

If the temperature controller receives the command and the checksum is correct, the temperature controller will respond by sending back the "send value" and the checksum of those eight ASCII characters:
        (stx)DDDDDDDDSS(ack)

To query a controller, there is no send value so the controlling computer only needs to send the following ASCII characters:
        (stx)AACCSS(etx)
If the temperature controller receives the query and the checksum is correct, the temperature controller will respond by sending back a "return value" and the checksum of those eight ASCII characters:
        (stx)DDDDDDDDSS(ack)

If the checksum for a command or query is not correct the temperature controller will respond with eight upper case X's and then c0, which is the checksum of these eight X's:
   (stx)XXXXXXXXc0(ack)

Remember, AA = 00 is the universal address, and all controllers will respond (be careful!). If JP1-6 is jumped to JP1-3 when powered, then the controller's address will be 63 hex (used to setup newly added controller to the serial link). If the address is not correct or not as listed immediately above then the controller will not respond to any requests.

II. Examples:

Set the controller at address 01 to control via a computer programmable set point.
1. The controller address, AA, is by definition 01.
2. The control command, CC, for "INPUT2 DEFINE" is 29 hex.
3. A data value of "0" selects a computer communicated set value, so the eight-character send value DDDDDDDD is 00000000.
4. Compute the checksum (SS) by adding the ASCII values of the following characters: 0, 1, 2, 9, 0, 0, 0, 0, 0, 0, and 0:

ASCII Character:	Hex Value:
0	30 hex
1	31 hex
2	32 hex
9	39 hex
0	30 hex
0	30 hex
0	30 hex
0	30 hex
0	30 hex
0	30 hex
0	30 hex
0	30 hex
Sum	**024c hex**

   The 8-bit checksum is the 8 least significant binary bits of the sum, represented as 4c in hex.
5. Combining all of these characters in one string we send: (stx)0129000000004c(etx).
6. If the temperature controller receives the command and the checksum is correct, it will send back: (stx)0000000080(ack). If the checksum is not correct the temperature controller will send back: (stx)XXXXXXXXc0(ack).

Send the set temperature of 100.0 °F to the controller at address 01.
1. The controller address, AA, is by definition 01.
2. The control command, CC, for "FIXED DESIRED CONTROL SETTING" is 1c.
3. Multiply the desired set-point temperature by 10 (100.0 converts 1000d).
4. Convert 1000d to hex (03e8h) and add on leading zeros to make the eight-character send value DDDDDDDD (000003e8).
5. Compute the checksum (SS) by adding the ASCII values of the following characters: 0, 1, 1, c, 0, 0, 0, 0, 0, 3, e, and 8:

ASCII Character:	Hex Value:
0	30 hex
1	31 hex
1	31 hex
c	63 hex
0	30 hex
0	30 hex
0	30 hex
0	30 hex
0	30 hex
3	33 hex
e	65 hex
8	38 hex
Sum	**02b5 hex**

   The 8-bit checksum is the 8 least significant binary bits of the sum, represented as b5 in hex.
6. Combining all of these characters in one string we send: (stx)011c000003e8b5(etx).
7. If the temperature controller receives the command and the checksum is correct, it will send back: (stx)000003e8c0(ack). If the checksum is not correct the temperature controller will send back: (stx)XXXXXXXXc0(ack).

Read the actual temperature of the control thermistor (INPUT1) from the controller at address 01.
1. Let's assume the actual temperature is 25.0 °C, and the working units have been defined as °C. This means that the controller will return a value in °C.
2. The controller address, AA, is by definition 01.
3. The control command, CC, for "INPUT1" is 01 hex.
4. There is no send value, so we can just calculate the checksum (SS) by adding the ASCII values of the following characters: 0, 1, 0, and 1:

ASCII Character:	Hex Value:
0	30 hex
1	31 hex
0	30 hex
1	31 hex
Sum	**00c2 hex**

   The 8-bit checksum is the 8 least significant binary bits of the sum, represented as c2 in hex.
5. Combining all of these characters in one string we send: (stx)0101c2(etx).
6. If the temperature controller receives the command and the checksum is correct, it will send back: (stx)000000fae7(ack). The e7 at the end of the string is the checksum of "000000fa". The value "000000fa" hex converts to 250 in decimal. This number, when divided by 10 is 25.0, is the temperature in °C. As in the other examples, if the

checksum from the query were not correct the temperature controller would send back: (stx)XXXXXXXXc0(ack).

III. RS485 or RS232 Communications Parameters

A. Baud Rate 9600
B. No Parity
C. 1 Start Bit 1 Stop Bit

NOTE if you are using communications software **different** *from the one supplied with the controller: The demands of temperature control require a relatively large portion of the processing power of the onboard microcontroller. It is possible for a host computer to send data too quickly for the controller to receive and update. TE Technology recommends adding a delay between each character sent to allow the controller sufficient time to process the information. One millisecond might be a good delay time to use initially, but the exact time will vary depending on the host computer's hardware and the particular demands on the controller at the moment.*

IV. Commands

1. INPUT1 (controlled input value)
Write Command:	NA
Read Command:	01 hex
Interpret:	Divide returned fixed-point temperature value by 10.0 and convert to degrees F/C decimal value.

    Example:
    Receive 100.0 °F temp from unit (sensor type = 1).
    Send: *01010000000042(etx)
    Receive   *000003e8c0^
    Convert hex 000003e8 returned to decimal = (1000)
    Divide by 10.0 = (100.0°F)

2. DESIRED CONTROL VALUE (set value)
Write Command:	NA
Read Command:	03 hex
Interpret:	This command returns the set value determined by Input2 or as a fixed value set by communications (see #1 above for interpretation).

3. POWER OUTPUT
Write Command:	NA
Read Command:	04 hex
Interpret:	-255 represents –100% output.
	0 returned is 0% output.
	255 represent 100% output.

4. ALARM STATUS
Write Command:	NA
Read Command:	05 hex
Interpret:	0 returned means no alarms.
	Bit 0 = 1 means HIGH ALARM.

Bit 1 = 1 means LOW ALARM.

Bit 2 = 1 means COMPUTER CONTROLLED ALARM.

5. INPUT 2
    Write Command: NA
    Read Command: 06 hex
    Interpret: Input 2 reading as a thermistor temperature sensor.

6. ALARM TYPE
    Write Command: 28 hex
    Read Command: 41 hex
    Interpret: 0 sent or returned means no alarms.

    1 sent or returned means Tracking Alarm Mode.

    2 sent or returned means Fixed Alarm Mode.

    3 sent or returned means Computer Controlled Alarm Mode (see write command 2f hex).

7. INPUT2 DEFINE (the desired control temperature or "set temp" input definition)
    Write Command: 29 hex
    Read Command: 42 hex
    Interpret: This function tells the controller how the set-point temperature will be communicated.

    0 sent or returned means computer communicated set value.

    1 sent or returned means Potentiometer Input.

    2 sent or returned means 0 to 5 V Input.

    3 sent or returned means 0 to 20 mA Input.

    4 sent or returned means "Differential set": Desired Control Value = Temp2 + Computer Set.

    Range of values settable via commands 20 hex & 21 hex (HIGH ALARM SETTING and LOW ALARM SETTING).

8. RS485 ADDRESS
    Write Command: 2a hex
    Read Command: 43 hex
    Interpret: The address of a controller for use with multiple controllers on the link. This must be a 2-digit hex value. 00 is the universal address and 63h is reserved for when JP1-3 is jumpered to JP1-6 (installing a new controller the link).

9. CONTROL TYPE
    Write Command: 2b hex
    Read Command: 44 hex
    Interpret: 0 is deadband control.

    1 is PID control.

    2 is computer control. With this setting, the output power sent to the cooler is determined by sending a write command (0x1c) to INPUT1. The range of values then becomes -120 to +120, which corresponds to -100% output power to +100% output power.

10. CONTROL OUTPUT POLARITY
      Write Command: 2c hex
      Read Command: 45 hex
      Interpret: 0 is HEAT WP1+ and WP2-.
                           1 is HEAT WP2+ and WP1-.

11. POWER ON/OFF
      Write Command: 2d hex
      Read Command: 46 hex
      Interpret: 0 is off
                           1 is on.

12. OUTPUT SHUTDOWN IF ALARM
      Write Command: 2e hex
      Read Command: 47 hex
      Interpret: 0 is no shutdown upon alarming.
                           1 is to shutdown main output drive upon alarming.

13. FIXED DESIRED CONTROL SETTING
      Write Command: 1c hex
      Read Command: 50 hex
      Interpret: When writing, multiply the desired control temperature by 10 and
                           convert to hex. This becomes the "send value"
                           When reading, convert the "return value" to decimal and divide by
                           10.0 to convert to ° F/°C.

14. PROPORTIONAL BANDWIDTH
      Write Command: 1d hex
      Read Command: 51 hex
      Interpret: Fixed-point temperature bandwidth in °F/°C.
                           Multiply desired bandwidth by 10.
                           1 °F/°C bandwidth would be 10 decimal.
                           100 °F/°C bandwidth would be 1000.

15. INTEGRAL GAIN
      Write Command: 1e hex
      Read Command: 52 hex
      Interpret: Fixed-point gain in Repeats/min.
                           Multiply desired integral gain by 100.
                           0.01 rep/min would be 1 decimal.
                           1.00 rep/min would be 100 decimal.

16. DERIVATIVE GAIN
      Write Command: 1f hex
      Read Command: 53 hex

Interpret: Fixed-point gain in minutes.
Multiply desired derivative gain by 100.
0.01 min would be 1 decimal.
1.00 min would be 100 decimal.

17. LOW EXTERNAL SET RANGE
     Write Command: 20 hex
     Read Command: 54 hex
     Interpret: Value mapped to zero voltage of Input2.

18. HIGH EXTERNAL SET RANGE
     Write Command: 21 hex
     Read Command: 55 hex
     Interpret: Value mapped to 5 volt or maximum voltage of Input2.

19. ALARM DEADBAND
     Write Command: 22 hex
     Read Command: 56 hex
     Interpret: Temperature Input1 must move to toggle
alarm output.

20. HIGH ALARM SETTING
     Write Command: 23 hex
     Read Command: 57 hex
     Interpret: Temperature reference to compare against Input1 for high
alarm output.

21. LOW ALARM SETTING
     Write Command: 24 hex
     Read Command: 58 hex
     Interpret: Temperature reference to compare against Input1 for low
alarm output.

22. CONTROL DEADBAND SETTING
     Write Command: 25 hex
     Read Command: 59 hex
     Interpret: Temperature or count span Input1 must move to toggle
control output.

23. INPUT1 OFFSET
     Write Command: 26 hex
     Read Command: 5a hex
     Interpret: Value to offset Input1 by in order to calibrate external
sensor if desired.

24. INPUT2 OFFSET
     Write Command: 27 hex
     Read Command: 5b hex

Interpret: Value to offset Input2 by in order to calibrate external sensor if desired.

25. ALARM LATCH ENABLE
    Write Command: 2f hex
    Read Command: 48 hex
    Interpret: 1 is latching enabled.
                                  0 is latching disabled.
                                  If Alarm Type is equal to 3 then
                                  1 is Computer Alarm On.
                                  0 is Computer Alarm Off.

26. CONTROL TIMEBASE
    Write Command: 30 hex
    Read Command: 49 hex
    Interpret: Setting of 0 is 675 Hz timebase.
                                  Setting of 1 is 2700 Hz timebase.

27. ALARM LATCH RESET
    Write Command: 33 hex
    Read Command: NA
    Interpret: Send this command to reset the alarm latches.

28. HEAT MULTIPLIER
    Write Command: 0c hex
    Read Command: 5c hex
    Interpret: This multiplies the heater percentage of power to offset its effectiveness.
                                  100 is a multiplier of 1.00
                                  1 is a multiplier of 0.01

29. CHOOSE SENSOR FOR ALARM FUNCTION
    Write Command: 31 hex
    Read Command: 4a hex
    Interpret: 0 is for the Control Sensor Input.
                                  1 is for the Input2 Secondary Input.

30. CHOOSE °C or °F TEMPERATURE WORKING UNITS
    Write Command: 32 hex
    Read Command: 4b hex
    Interpret: 0 is °F
                                  1 is °C

31. EEPROM WRITE ENABLE

Write Command:	34 hex
Read Command:	4c hex
Interpret:	0 is disable EEPROM writes
	1 is enable EEPROM writes
Note:	This function is always stored to EEPROM. This feature is available for controllers whose EEPROM is revision D or later. (The EEPROM has a white sticker on it labeled "C74-114D" where the last letter indicates the revision level.)
Function Description:	Upon a power-up or reset condition, the controller performs an initialization of all command variables that have write commands by transferring the last values stored in non-volatile memory (EEPROM) to appropriately referenced static RAM locations. This action is performed so that the controller can run faster (RAM is faster than ROM). When the "EEPROM WRITE ENABLE" is enabled, any changes in the run-time values of the command variables are also stored in EEPROM as well in RAM and thus will be recalled upon a power-up or reset condition. When the "EEPROM WRITE ENABLE" is disabled, run-time values are stored only in RAM. This setting gives you the ability to change run-time values without changing your desired power-up settings. This will also alleviate a possible problem since the maximum number of writes to an EEPROM location is 1,000,000.

V. ASCII Reference Table

```
Dec   Oct   Hex   Binary        Description

000   000   00    00000000      ^@ ^` NULL NUL null c-@ c-`
001   001   01    00000001      ^A ^a SOH GTL c-A c-a start-of-heading
002   002   02    00000010      ^B ^b STX c-B c-b start-of-text
003   003   03    00000011      ^C ^c ETX c-C c-c end-of-text
004   004   04    00000100      ^D ^d EOT SDC end-of-transmission c-D c-d ..._._
005   005   05    00000101      ^E ^e ENQ PPC c-E c-e enquiry
006   006   06    00000110      ^F ^f ACK c-F c-f acknowledge
007   007   07    00000111      ^G ^g BELL BEL bell c-G c-g \a
008   010   08    00001000      ^H ^h BS GET backspace c-H c-h \b
009   011   09    00001001      ^I ^i TAB TCT HT tab c-I c-i \t
010   012   0A    00001010      ^J ^j LF lf linefeed c-J c-j \n
011   013   0B    00001011      ^K ^k VT vertical-tab c-K c-k \v
012   014   0C    00001100      ^L ^l FF ff formfeed page \f c-L c-l
```
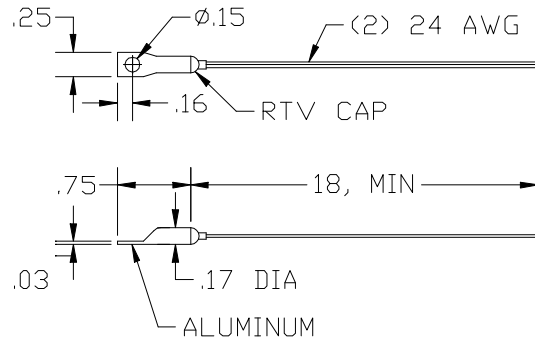
```
013   015   0D   00001101   ^M ^m CR cr carriage-return c-M c-m \r
014   016   0E   00001110   ^N ^n SO c-N c-n shift-out
015   017   0F   00001111   ^O ^o SI c-O c-o shift-in

016   020   10   00010000   ^P ^p DLE c-P c-p data-link-escape
017   021   11   00010001   ^Q ^q DC1 LLO go XON xon c-Q c-Q
018   022   12   00010010   ^R ^r DC2 c-R c-r
019   023   13   00010011   ^S ^s DC3 stop XOFF xoff c-S c-s
020   024   14   00010100   ^T ^t DC4 DCL c-T c-t
021   025   15   00010101   ^U ^u NAK PPU negative-acknowledge c-U c-u
022   026   16   00010110   ^V ^v SYN c-V c-v synchronous-idle
023   027   17   00010111   ^W ^w ETB end-of-transmission-block c-W c-w
024   030   18   00011000   ^X ^x CAN SPE c-X c-x cancel
025   031   19   00011001   ^Y ^y EM SPD c-Y c-y end-of-medium
026   032   1A   00011010   ^Z ^z SUB suspend c-Z c-z substitute
027   033   1B   00011011   ^[ ^{ ESC escape c-[ c-{ m-
028   034   1C   00011100   ^\ ^| FS field-separator c-\ c-|
029   035   1D   00011101   ^] ^} GS group-separator
030   036   1E   00011110   ^^ ^~ RS record-separator c-^ c-~
031   037   1F   00011111   ^_ ^DEL unit-separator US c-_ c-DEL

032   040   20   00100000   SPC space spc
033   041   21   00100001   ! exclamation-point
034   042   22   00100010   " straight-double-quotation-mark
035   043   23   00100011   # number-sign
036   044   24   00100100   $ @@ dollar-sign
037   045   25   00100101   % percent-sign
038   046   26   00100110   & ampersand
039   047   27   00100111   ' apostrophe
040   050   28   00101000   ( left-parenthesis
041   051   29   00101001   ) right-parenthesis
042   052   2A   00101010   * asterisk star
043   053   2B   00101011   + addition-sign
044   054   2C   00101100   , comma
045   055   2D   00101101   - subtraction-sign minus hyphen negative dash
046   056   2E   00101110   . period dot decimal
047   057   2F   00101111   / right-slash
048   060   30   00110000   0
049   061   31   00110001   1
050   062   32   00110010   2
051   063   33   00110011   3
052   064   34   00110100   4
053   065   35   00110101   5
054   066   36   00110110   6
055   067   37   00110111   7
056   070   38   00111000   8
057   071   39   00111001   9
058   072   3A   00111010   : colon
059   073   3B   00111011   ; semicolon
060   074   3C   00111100   < less-than
061   075   3D   00111101   = equals
062   076   3E   00111110   > greater-than, right-chevron
063   077   3F   00111111   ? question-mark, query
064   100   40   01000000   @ at-symbol, at-sign
065   101   41   01000001   A
066   102   42   01000010   B
067   103   43   01000011   C
068   104   44   01000100   D
069   105   45   01000101   E
070   106   46   01000110   F
```

```
071    107    47    01000111    G
072    110    48    01001000    H
073    111    49    01001001    I
074    112    4A    01001010    J
075    113    4B    01001011    K
076    114    4C    01001100    L
077    115    4D    01001101    M
078    116    4E    01001110    N
079    117    4F    01001111    O

080    120    50    01010000    P
081    121    51    01010001    Q
082    122    52    01010010    R
083    123    53    01010011    S
084    124    54    01010100    T
085    125    55    01010101    U
086    126    56    01010110    V
087    127    57    01010111    W
088    130    58    01011000    X
089    131    59    01011001    Y
090    132    5A    01011010    Z
091    133    5B    01011011    [ left-bracket, open-square
092    134    5C    01011100    \ left-slash, backslash bash
093    135    5D    01011101    ] right-bracket, close-square
094    136    5E    01011110    ^ hat, circumflex, caret, up-arrow
095    137    5F    01011111    _ UNT, underscore, underbar

096    140    60    01100000    ` accent-grave, backprime, backquote
097    141    61    01100001    a
098    142    62    01100010    b
099    143    63    01100011    c
100    144    64    01100100    d
101    145    65    01100101    e
102    146    66    01100110    f
103    147    67    01100111    g
104    150    68    01101000    h
105    151    69    01101001    i
106    152    6A    01101010    j
107    153    6B    01101011    k
108    154    6C    01101100    l
109    155    6D    01101101    m
110    156    6E    01101110    n
111    157    6F    01101111    o

112    160    70    01110000    p
113    161    71    01110001    q
114    162    72    01110010    r
115    163    73    01110011    s
116    164    74    01110100    t
117    165    75    01110101    u
118    166    76    01110110    v
119    167    77    01110111    w
120    170    78    01111000    x
121    171    79    01111001    y
122    172    7A    01111010    z
123    173    7B    01111011    { left-brace begin
124    174    7C    01111100    | logical-or vertical-bar
125    175    7D    01111101    } right-brace end
126    176    7E    01111110    ~ similar
127    177    7F    01111111    ^? DEL rubout delete
```
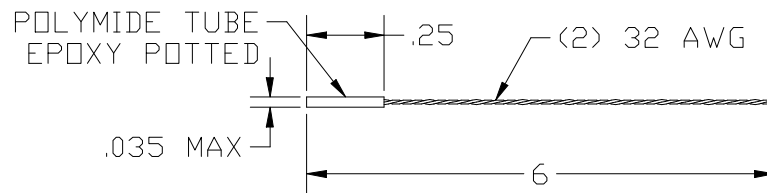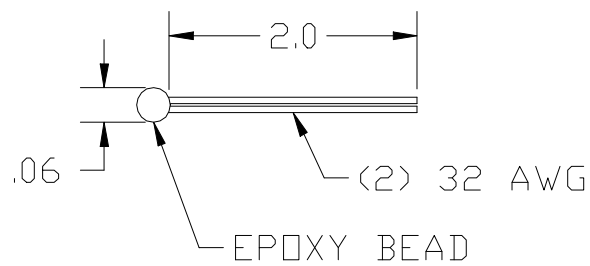
APPENDIX G Thermistor Styles for TC-24-25

.25   Ø.15   (2) 24 AWG

.16   RTV CAP

.75   18, MIN

.03   .17 DIA

ALUMINUM

MP-2379

POLYMIDE TUBE
EPOXY POTTED   .25   (2) 32 AWG

.035 MAX

6

MP-2444

2.0

.06

(2) 32 AWG

EPOXY BEAD

MP-2542

Temperature (°C) versus Resistance (ohms)
for MP-2379, MP-2444, and MP2542 Thermistors

°C	Ω	°C	Ω	°C	Ω	°C	Ω	°C	Ω	°C	Ω
-20	146735	1	46709	22	17136	43	7075	64	3227	85	1601
-19	138447	2	44397	23	16388	44	6801	65	3115	86	1551
-18	130677	3	42213	24	15676	45	6539	66	3008	87	1503
-17	123390	4	40150	25	15000	46	6289	67	2905	88	1457
-16	116554	5	38199	26	14356	47	6049	68	2806	89	1412
-15	110138	6	36354	27	13744	48	5820	69	2711	90	1369
-14	104113	7	34608	28	13161	49	5600	70	2620	91	1328
-13	98454	8	32957	29	12606	50	5391	71	2532	92	1288
-12	93137	9	31394	30	12078	51	5190	72	2448	93	1250
-11	88138	10	29914	31	11574	52	4997	73	2367	94	1212
-10	83438	11	28512	32	11095	53	4813	74	2288	95	1176
-9	79016	12	27183	33	10637	54	4637	75	2213	96	1142
-8	74855	13	25925	34	10202	55	4467	76	2141	97	1108
-7	70938	14	24731	35	9786	56	4305	77	2072	98	1076
-6	67249	15	23600	36	9389	57	4150	78	2005	99	1045
-5	63773	16	22526	37	9011	58	4001	79	1940	100	1014
-4	60498	17	21508	38	8650	59	3858	80	1878		
-3	57410	18	20541	39	8306	60	3721	81	1818		
-2	54498	19	19623	40	7976	61	3590	82	1761		
-1	51750	20	18751	41	7662	62	3464	83	1705		
0	49157	21	17923	42	7362	63	3343	84	1652		

Note: Tolerance is ±650 Ω, corresponding to ±1 °C
over a 0 °C to 100 °C range.