Instruction Manual
for
Model TC-48-20
and
Model TC-48-20 OEM
Thermoelectric Cooler
Temperature Controller

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Drawing #4746 Rev. D

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General Safety Warnings

This manual is available in English only. It must be read and followed carefully before installation and operation. All warnings in this Operation Manual apply to both the TC-48-20 and TC-48-20 OEM versions of the controller. Where "TC-48-20" is referenced, it is used generically and interchangeably for both the TC-48-20 and the TC-48-20 OEM versions of the controller, except where otherwise specifically noted.

THE LATEST REVISION OF THIS MANUAL IS AVAILABLE AT www.tetech.com. Verify that you are using the latest revision available.

Do not use in an explosive or potentially explosive environment.

The TC-48-20 should not be used as a toy, or serious injury could result. The TC-48-20 should only be used for its intended purpose of providing temperature control of TE Technology's thermoelectric devices only. The controller is intended for light industrial, laboratory, or similar use. It is not for household use or medical use.

Do not use if the controller has been damaged.

Only qualified technicians should install and operate this controller with the appropriate personal protective equipment.

Do not use the TC-48-20 to control capacitive or inductive loads or the controller could be damaged and/or overheat. Examples of capacitive or inductive loads include but are not limited to: motors, fans, filters, and solenoids.

Do not allow the electrical connections or components on the printed circuit board, including those on the reverse side of the JP3, JP4 and JP5 connectors, to touch any electrically conductive surfaces.

Do not operate in an environment where the controller could come in contact with condensation, water, metal shavings, dirt or other contaminants, or electrically conductive materials.

Use ESD (Electro Static Discharge) protection when installing the controller or coming in contact with electrical connections or components on the controller.

Do not touch any of the electrical connections or components of the TC-48-20 while the controller is energized. Doing so can disrupt the function of the controller.

The printed circuit board underneath JP4 and exposed components on the printed circuit board could exceed 70 °C under normal operation. Use caution! Protect against accidental contact with hot surfaces.

Improper tuning of this temperature controller can lead to overheating of the load (e.g. cooling assembly, heater, etcetera) and other related equipment.

Use protection devices to prevent hazardous conditions and/or damage to equipment.

Each power input that is used must be fused separately. Alternately, a power supply with integral over current protection can be used if it is appropriately sized for protecting the controller/TE device.

JP4 Pin 1 (+ power in) and JP4 Pin 3 (+ load output) are connected to each other inside the controller. When JP4 Pin 1 is energized a voltage will be present on JP4 Pin 3, even if the output of the controller is off.

The TC-48-20 OEM is intended to be used with, or incorporated into, other machinery made by TE Technology, Inc. and must not be put into service until the relevant machinery into which it is to be incorporated into has been declared in conformity with the essential requirements of the Machinery Directive 2006/42/EC.

For more information regarding protection devices read TE Technology's Thermoelectric Cooling Assembly (TCA) Instruction manual which is available for download from TE Technology's website at www.tetech.com. The terms and provisions relating to protection devices as provided in the TCA Instruction manual are herby incorporated by reference. A copy of the TCA Instruction manual can also be sent via regular mail upon request.

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Features

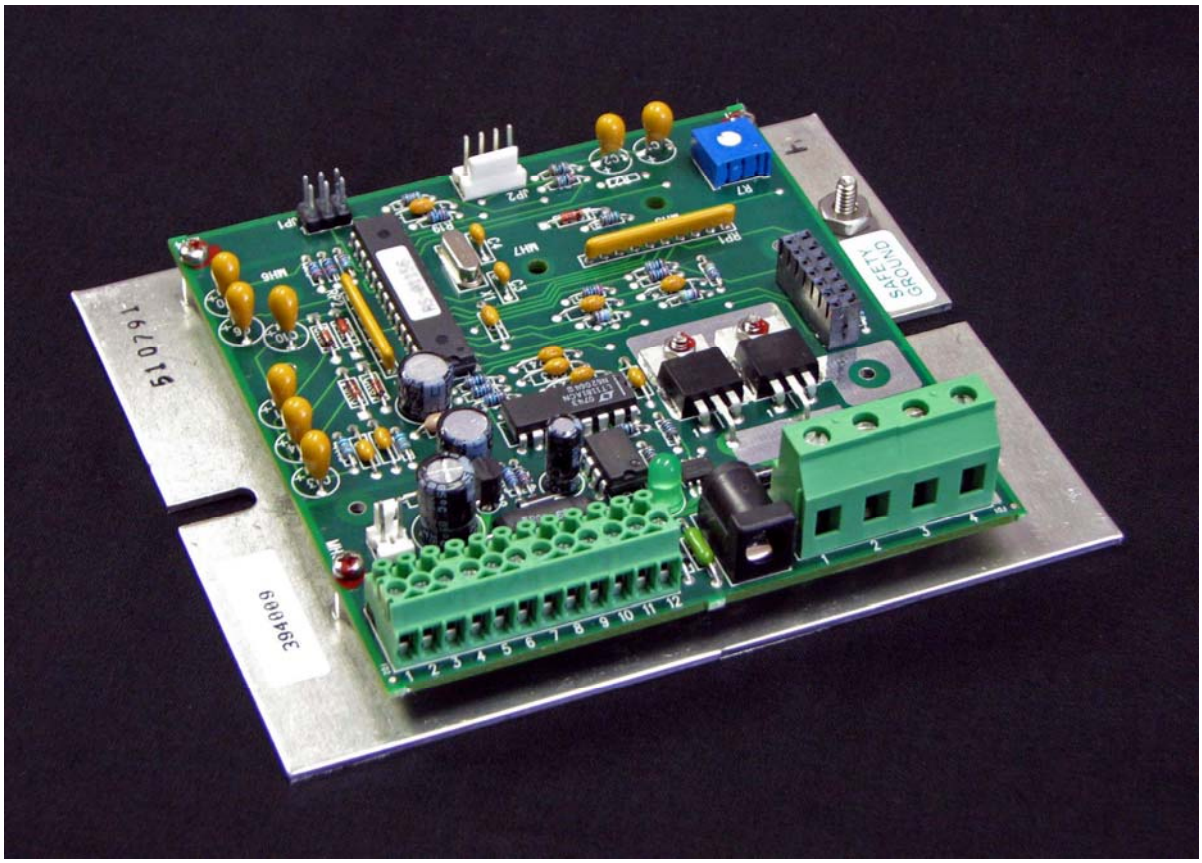
TC-48-20 Controller

The TC-48-20 is thermoelectric temperature controller capable of controlling up to 50 volts and 20 amps. Housed in a die-cast aluminum box, it incorporates a keypad and a liquid-crystal display capable of displaying two lines of text, each up to 16 characters long. The display allows the user to monitor the sensor temperature, output level, and menu settings. The integrated keypad accesses an easy-to-use menu system, allowing the user to adjust all of the basic controller parameters such as the set temperature, tuning parameters, and alarm parameters.

The controller can also be connected to a computer via RS232 port for more advanced program control, data graphing, and data logging. All of the controller parameters, including some of the advanced parameters not adjustable through the onboard menu, can be adjusted via this software. (The RS-232 cable is optional and can be purchased separately; the software is included.)

By choosing the appropriate power supply(s), the controller can control loads from 0 to <50 VDC via pulse-width modulation with the onboard power transistors. The turn-on and turn-off transition times for these transistors have been adjusted to reduce electro-magnetic interference when controlling high current levels. However, if a true linear-output control system is desired, the TC-48-20 can be used as the control head for controlling high-power, linear-output supplies. Some of these linear output supplies are available as basic switching power supplies, allowing the user to create a relatively low cost linear control system which generates much less waste heat when compared to a typical linear system. The TC-48-20 can also be configured to control DC heaters.

The TC-48-20 controller can be easily configured through its built in keypad. However, it can also interface with a computer through its serial port using the included software. The software provides all of the same configuration options that are available through the keypad plus additional programming features and the ability to log data to a computer. The command set for the controller is also provided to allow the creation of custom software applications with National Instruments LabVIEW, for example.



TC-48-20 OEM Controller

The TC-48-20 OEM is also available. This is a basic version of the controller for Original Equipment Manufacturers (OEM's). It is intended to be used in locations where the controller can be protected by a secondary enclosure and where the display, keypad, and box cover are not needed. The TC-48-20 OEM controller is the basic control circuit from the TC-48-20 mounted on an aluminum plate. One MP-3193 thermistor, software and operation manual on CD are included with each controller. The MP-3023 RS-232 cable is not included, but it can be ordered separately.

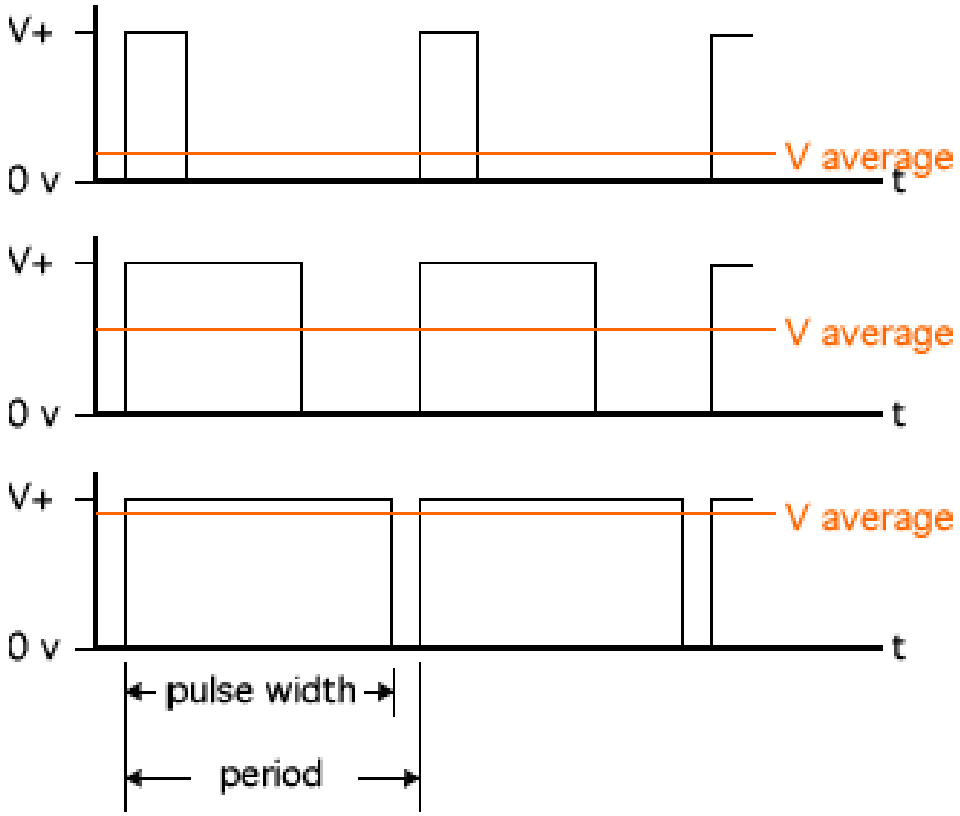
The TC-48-20 OEM uses the same main circuit board found in the TC-48-20. The connector numbers and wiring are the same for both versions of the controller. The Schematics, Hookup Diagrams, and Wiring Connections presented in this manual are the same for both controllers. However, only the TC-48-20 version of the controller is depicted for clarity.

Main Features

- Single or dual power supply configurations allow a wide range of output voltages:
  - Single power supply configuration:
    - ≥9 VDC, <50 VDC input, powering both controller and TE device
  - Dual power supply configuration:
    - ≥9 VDC, <50 VDC at 150 mA minimum for controller circuitry
    - ≥0 VDC, <50 VDC for TE device
- Maximum output current: 20 A combined TE device and alarm current (Note: controller does not have current limiting capability or internal fuse protection)
- Cool-only or heat-only control modes, menu selectable
- Temperature control range: –20 °C to +100 °C using the MP-3193 thermistor supplied with the controller, or -20 °C to +85 °C using a thermistor equivalent to 10 k-ohm, curve "B" from YSI Temperature, Inc.
- Optional secondary thermistor input for sensing alarm conditions
- Two available alarm outputs, capable of sinking up to 1 A each, for triggering alarms based on the primary (control) sensor and/or secondary sensor
- Best-case control stability ±0.1 °C (when controlling a cold plate)
- Proportional (P) bandwidth adjustment: 0.5 °C to 100.0 °C
- Integral gain (I) adjustment: 0.00 to 10.00 repeats per minute
- Derivative gain (D) adjustment: 0.00 to 10.00 cycles per minute
- Output: square wave, 337 Hz, pulse-width modulated, with soft start
- Analog proportional output signal for controlling programmable linear power supplies
- Operating temperature range (non-condensing, total combined alarm and load current):
  Minimum: 0 °C
  Maximum: 48 °C horizontal orientation, 20 A output; 55 °C vertical orientation, 20 A output; 53 °C horizontal orientation, 17 A output; 59 °C vertical orientation, 17 A output.
- Computer programmable via RS 232 communication; includes software (An optional RS-232 cable, part number MP-3023, is required)
- RoHS compliant

Pulse-width modulated power output

The TC-48-20 controller regulates the output power to the TE device using a method called pulse-width modulation (PWM). With PWM, power to the TE device is switched quickly "ON" and "OFF" at a constant frequency. This creates a square wave “pulse” of power with a constant time period. The “ON” time, or pulse width, can be varied to create an average output voltage (Vaverage) that is required by the TE device to maintain the set temperature.



The important advantage to PWM control is that it does not cause the extreme temperature excursions that are experienced with a thermostatic control system. This helps to extend the life and reliability of the TE device. At the same time, PWM control does not generate a large amount of waste heat as compared with most linear control systems, so large heat sinks are not required with the PWM temperature controller.

Linear control output

The controller also provides an analog proportional output signal. This cannot be used for powering TE devices directly, but it could be used for a variety of purposes including controlling programmable power supplies. For example, if the TE device were to require more than 20 A of current, or if true linear control were needed, the TE device could not be directly connected to the controller. However, the TE device could be connected to a higher current power supply that accepts an analog input, and the controller could then direct the power supply to apply its output proportional to the analog output from the controller. Because these power supplies usually have a linear output signal this method also reduces the electromagnetic noise that might otherwise come from a PWM type controller.

One such power supply that accepts an analog input is the RKW programmable series switching power supplies from Kepco (www.kepcopower.com). These power supplies accept a 0 to 5 volt input signal which causes the output voltage of the power supply to vary from 0 V to its full-scale voltage. These power supplies are available with full-scale voltages that range from 3.3 V to 48 V and they are available in 300, 600, and 1500 watt sizes. Because these are switching power supply there is again the added benefit of little waste heat as compared with most types of linear control systems. In addition, multiple power supplies can be operated in parallel to boost the total output power.

If you wish to limit the output voltage of the power supply to less than its full scale voltage you can adjust a controller parameter called the ANALOG OUTPUT MULTIPLIER. For example, assume you have chosen to use a Kepco RKW 24-65K model power supply. This is a 1500 watt power supply with a full-scale output of 24 V and 65 A. If you wish to limit the output voltage to approximately 20 V, you can set the analog multiplier to 0.83 (20V / 24V). This scales the analog output voltage to 4.15 V and thus limits the output voltage of the power supply accordingly. The ANALOG OUTPUT MULTIPLIER is scalable only by communicating with the controller via the software through the RS-232 interface. An RS-232 cable, part number MP-3023 or equivalent, is required to connect the controller to a computer. The factory default value for the ANALOG OUTPUT MULTIPLIER is 1.

Using alarm outputs for multi-speed fan control and other load control

The alarm outputs can be configured to operate a fan at two different speeds, which is useful for keeping fan noise to a minimum. For example, by using a second sensor to measure the ambient air temperature, ALARM 2 can be used to run the fan at high speed only when the ambient air temperature is high and increased cooling capacity is needed. Alternately, the second sensor can measure the heat sink temperature. If the heat sink temperature begins to rise because the ambient temperature is increasing or because the heat source is active, ALARM 2 is triggered to run the hot-side fan at full speed. An external resistor, placed in series with the fan, is required.

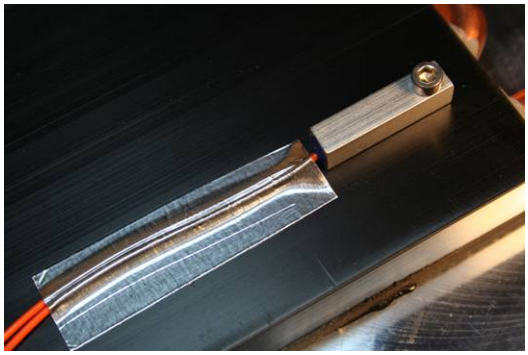
The alarms can also be configured to activate other loads such as pumps and resistive heaters. A fixed value resistor can be used in place of the second sensor, causing the controller to interpret the fixed resistance as a fixed temperature. Changing the alarm temperature above or below this fixed temperature will then cause the alarm, and consequently the load, to be activated or deactivated. The second sensor temperature display can also be turned off when the temperature data is not relevant.

Operating Instructions

1.0 Setup

1.1 Attach the thermistor at an appropriate temperature-control location. Locating the thermistor at the cold side of the TE device provides better control stability than locating it at the object, liquid, or air that is to be cooled/heated. However, in doing so, there will be a temperature difference between the TE device and the object, liquid, or air that is to be cooled/heated. The temperature set point can be adjusted to compensate for this temperature difference if necessary.

NOTE: When possible, it is recommended that at least 50 mm of the thermistor's wire be thermally connected to the cold side of the TE device as shown in the example below. This can be accomplished by placing aluminum tape over the thermistor wires and adhering the wires and tape to the cold side of the cooler, as shown below. If this is not done, the thermistor wires will be at a different temperature than the cold side and they will add or remove heat in the region of the thermistor, making the temperature reading **significantly less accurate** and thermal response time slower.



The wire leads of the thermistor can be lengthened if necessary. For longer lengths the use of twisted pair and/or shielded wire may be required to reduce noise.

In addition, the thermistor needs to have a good thermal connection to the temperature control location. When using the MP-3193, thermal grease should be applied to the interface of the thermistor and temperature-control location. The TP-1 thermal grease from TE Technology or other thermal grease can be used.

The TC-48-20 is supplied with the MP-3193 thermistor. Other thermistor styles directly compatible with the controller are available as options. See "*Thermistor Styles for TC-48-20"* for reference. In addition, the controller can be configured to use thermistors that have the same temperature-resistance curves as the 10 k-ohm, curve "B" thermistor from YSI Temperature, Inc. (Resistance versus Temperature curves are in Appendix A.)

If you want to use a thermistor that has a different resistance-temperature curve from the standard MP-3193 (See "*Temperature versus Resistance for MP-3193, MP-2444, and MP-2542 Thermistors"* for reference) or the 10 k-ohm thermistor, it can be done as long as the operating resistance range is within that of the standard thermistor. The thermistor must 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.

1.2 Connect the thermistor wire leads to JP5-1 and JP5-2. (See "*Controller Schematic*" and the "*Controller Hookup*" drawings for reference.)

1.3 A secondary thermistor can be connected to JP5-3 and JP5-4. The secondary thermistor can then used to monitor the hot side of the TE device for determining whether the TE device has exceeded its maximum

operating temperature. The controller can be configured to signal an alarm condition on either the control thermistor or the secondary thermistor or both.

1.4 The TC-48-20 can be used with either one or two separate DC power supplies, depending primarily on the nominal operating voltage of the TE device. If the maximum TE device input voltage is less than 9 V, then two power supplies must be used with the controller. If the TE device can use a voltage ≥9 V but <50 V, then the controller can be used with either one or two power supplies.

The controller can also be set up to provide linear control output when used with a power supply whose output can be controlled with a 0 to 5 V signal. The power supply can then provide a power output proportional to the signal sent by the controller. This setup is also useful for situations in which the TE device requires more power than what the controller itself can directly handle. However, this setup will reduce the overall control stability. The voltage signal from the controller is actually obtained by filtering the PWM output, and this introduces a slight delay in the control response. Also, there will be a delay in the response of the power supply since it too must process the correct power output based on the sensed voltage input from the controller.

When using one power supply for powering the controller and the TE device together, the power supply input voltage is passed directly through the controller to the TE device during the "ON" pulse. The user should choose an input voltage that is required for the TE device and yet is also ≥9 V but <50 V. The controller could be damaged if operated outside this voltage range.

When using two power supplies, the controller input power supply must be ≥9 V but <50 V at 150 mA minimum. The power supply input voltage for the TE device can be ≥0 V but <50 V.

The maximum allowable current through the controller is 20 A. The maximum allowable current draw for the TE device must therefore be less than 20 A depending on if and how much current is used to power alarm signals and the controller itself. The 20 A limit applies regardless of whether you are using one power supply or using two independent power supplies.

The controller does not have an internal fuse or circuitry to limit current. Therefore, an external fuse, appropriately sized for protecting the controller/TE device, should be connected between the power supply and the controller to prevent damage to the controller/TE device and to prevent injury to the user should an over-current condition occur. Alternately, a power supply with integral over current protection can be used if it is appropriately sized for protecting the controller/TE device.

When making a cooling system from a single TE device, the maximum operating voltage for that *system* is usually no more than 75% of the rated Vmax of the TE module. The 75% rule is based on the TE module being thermally connected to a "good" heat sink; system modeling should be done to verify this rule is applicable though. If multiple TE modules are used in series or series-parallel combination, the Vmax of the system will be approximately 75% of the rated Vmax of each TE module multiplied by the number of modules in series. Applying a voltage greater than the system maximum will not necessarily damage the controller (unless voltage and/or current limits are exceeded), but the TE device could be damaged by overheating as a result.

Power supply and TE Device wire leads should be kept as short as possible to minimize electrical losses and reduce the likelihood of generating unwanted electromagnetic interference. Use wires of a sufficient gage appropriate to the amount of electrical energy each wire is to carry. Wire insulation and size must also be appropriate to the ambient temperature and/or temperature of objects in contact with the wire. Wire leads supplied by TE Technology are for prototyping purposes and should be reviewed for appropriateness in the final application. Wire length must not exceed one meter. However, see also warnings about wire length under section 1.6.

Use protection devices to prevent hazardous conditions and/or damage to the load (e.g. cooling assembly, heater, etcetera) and other related equipment. Protection devices must operate independently of the temperature controller circuitry. Protection devices should be placed at all points on the load and related equipment where a hazardous condition can be detected. These protection devices should de-energize the TC-48-20, the load, and, as necessary, other related secondary equipment. It is further recommended that such devices require the user to remove and correct the root cause of a fault before allowing the TC-48-20, the load, and related equipment to be re-energized. Protection devices should include, but are not limited to:

- Fuses to prevent against electrical overloads,
- Over/under temperature thermostats to prevent against hazardous and/or damaging temperatures,
- Liquid flow meters to prevent against damage due to loss of coolant flow

The TC-48-20 controller (in conjunction with the standard and optional sensors) can detect under-temperature and over-temperature conditions, and it can be configured to de-energize the load when such a condition is detected. However, hazards and/or risk of loss or damage to the load (e.g. cooling assembly, heater, etcetera), and/or secondary equipment could still occur if the temperature controller and/or sensors were to malfunction. Therefore, independent, redundant protection devices are recommended in addition to the safeguards provided by the temperature controller. For the purposes of this manual the temperature controller and sensors are not considered protection devices.

The controller does not have an internal fuse or circuitry to limit current. Therefore, an external fuse, appropriately rated for protecting the controller/TE device, should be connected between the power supply and the controller to prevent damage to the controller/TE device and to prevent injury to the user should an over-current condition occur. Alternately, a power supply with integral over current protection can be used if it is appropriately sized for protecting the controller/TE device.

1.4.1 **One Power Supply Operation**:

Make sure the power supply is **NOT** energized while making electrical connections to the controller.

a) Connect the constant DC voltage power supply, ≥9 V but <50 V to the controller:
Positive (+) power supply terminal to JP4-1
Negative (-) power supply terminal to JP4-2

b) Do **NOT** connect the TE device to the controller at this time (unless you are certain the set point is within the allowable range of the TE device).

c) See the "*Controller Hookup Diagram (One Power Supply Setup)*" for further details.

1.4.2 **Two Power Supplies Operation**:

Make sure the power supplies are **NOT** energized while making electrical connections to the controller.

a) Connect the constant DC voltage power supply, ≥9 V and <50 V, 150 mA minimum, to the controller (for powering the controller electronics):

Positive (+) power supply terminal to JP5-6
Negative (-) power supply terminal to JP5-5

OR

Connect to JP3 via the DC power plug, ≥9 V and ≤16 V, 150 mA minimum (inside-positive; outside-negative)

Do not connect power to JP3 and JP5 at the same time; otherwise the controller and/or power supplies might be damaged and a risk of fire might result.

b) Connect the constant DC voltage power supply, ≥0 V but <50 V, to the controller (for powering the TE device):

Positive (+) power supply terminal to JP4-1
Negative (-) power supply terminal to JP4-2

c) Do **NOT** connect the TE device to the controller at this time (unless you are certain the set point is within the allowable range of the TE device).

d) See the "*Controller Hookup Diagram (Two Power Supplies Setup-Option 1)*" or "*Controller Hookup Diagram (Two Power Supplies Setup-Option 2)*" for further details.

1.4.3 **Linear Control Operation**:

Make sure the power supplies are **NOT** energized while making electrical connections to the controller.

a) Connect the constant DC voltage power supply, ≥9 V and <50 V, 150 mA minimum, to the controller (for powering the controller electronics):

Positive (+) power supply terminal to JP5-6
Negative (-) power supply terminal to JP5-5

OR

Connect to JP3 via the DC power plug, ≥9 V and ≤16 V, (inside-positive; outside-negative)

Do not connect power to JP3 and JP5 at the same time; otherwise the controller and/or power supplies might be damaged and a risk of fire might result.

b) Connect the remote voltage control points of the programmable power supply to the controller; consult the power supply manual for remote control setup:

Positive (+) remote control terminal to JP5-12
Negative (-) remote control terminal to JP5-5
NOTE: depending on the power supply remote control input requirements, an external voltage buffer might be required between the controller and the power supply.

c) Do **NOT** connect the TE device to the power supply at this time (unless you are certain the set point is within the allowable range of the TE device).

d) See the "*Linear Control Hookup Diagram*" for further details.

1.5 Turn on power to the power supply (which then powers the controller). When the controller is first turned on, it goes through an initialization sequence which shows the TE Technology website address and that the controller is indeed the TC-48-20. The display then switches to the primary screen.

Verify that the set point is set to a temperature that is within the allowable temperature range of the TE device and/or the application and that the controller is set to the appropriate cooling or heating mode.

The factory default is set to have output power to the TE device enabled when the controller is powered. This can only be turned off by using the software. Therefore, DO NOT CONNECT THE TE DEVICE TO THE OUTPUT OF THE CONTROLLER UNTIL THE APPROPRIATE CONTROL TEMPERATURE AND HEATING/COOLING MODE HAVE BEEN SET.

Set point adjustment and other parameter adjustments are described in the Section 2 below.

1.6 Turn off power to the controller and connect the TE device to the controller as follows:

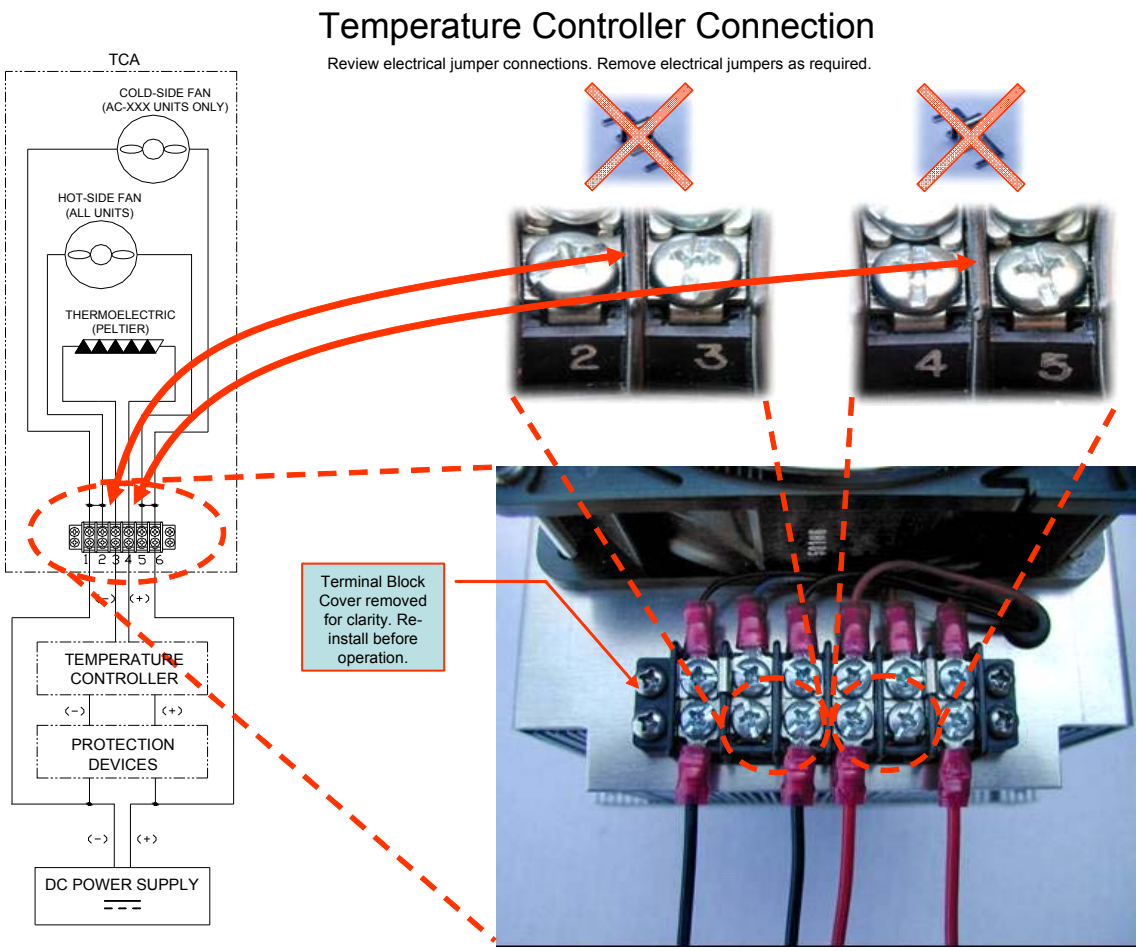
COOLING MODE:

a) Connect the positive (+) terminal of TE device to JP4-3
b) Connect the negative (-) terminal of TE device to JP4-4
c) Verify/set controller to “COOL” mode; see Section 2 below.

HEATING MODE:

a) Connect the negative (-) terminal of TE device to JP4-3
b) Connect the positive (+) terminal of TE device to JP4-4
c) Verify/set controller to “HEAT” mode; see Section 2 below.

TE Technology's standard thermoelectric cooling assemblies (TCA) usually have at least one fan on the heat sink. The standard configuration has the thermoelectric modules and fan(s) wired to a terminal block with jumpers across the terminals so that the fans and TE modules are connected electrically in parallel. However, this configuration is applicable only when applying power directly from the power supply. When using the TCA with the temperature controller, two jumpers **MUST** be removed so that the controller is controlling power only to the thermoelectric modules. There must be no electrical connection between the fans and the TE modules; fans must be connected directly to the power supply, not to the controller. *The controller will be damaged if this is not followed*. See the TCA manual for further details, but the picture below shows the basic setup.



The printed circuit board underneath the JP4 terminal block can reach a normal operating temperature of approximately 90 °C. The controller specifications are based on using wires connecting to JP4 to meet UL 1015 requirements and have a wire size of 2.02 mm^2 effective cross-sectional area, which is comprised of 41 strands of 0.254 mm diameter copper wire. The effective equivalent wire size is 14 AWG. The specifications are further based on a wire length of 410 mm between the power supply and the controller and a wire length of 920 mm between the controller and the TE device. Using wire with a smaller conductor cross section and/or shorter in length might cause abnormally high temperature to be present on the JP4 terminal block and wire. If smaller and/or shorter wire must be used, the amount of current the controller can safely accept might need to be decreased and/or the ambient temperature at which the controller can operate might need to be lowered.

The wires inserted into connector JP4 should have a strip length of 7 mm, be fully inserted into the connector, and the JP4 screw terminals should be tightened with a minimum torque of 0.5 N-m. The wires inserted into connector JP5 should have a strip length of 5 mm, be fully inserted into the connector, and the JP5 screw terminals should be tightened with a minimum torque of 0.25 N-m.

1.7 Turn on power supply to the controller and power supply to the TE device if applicable and adjust controller settings as necessary. Controller tuning is discussed in section 3. Remember, the factory default is set to have output power to the TE device enabled when the controller is powered. This can only be turned off by using the software. Therefore, you should also be prepared to de-energize the controller power in case there is an incorrectly set parameter which could cause a hazard.

NOTE: The factory default assumes a secondary thermistor is connected to the controller. ***When not using a thermistor on the second sensor input the user will need to adjust the ALARM 2 FUNCTION to KEEP OUTPUT ON.*** See section 2.3.10 and 2.3.11 for further details.

The keypad can reach a normal operating temperature of 70 °C.

When vertically mounted the terminal blocks should be positioned pointing upwards, with the direction of gravity parallel to the plane of the controller mounting surface. The maximum temperature specifications (vertical orientation) are based on this positioning. When mounted in an orientation between horizontal and vertical, the terminal blocks should be mounted in the upward most position (with the direction of gravity defined as point downward). These positions allow heat to rise upward, out of the opening of the box. Orientations differing from this could cause the controller to overheat.

Do not mount the controller to a surface which is exposed to a source of heat, such as from electronics, machinery, or solar radiation.

Do not cover the controller with any object or otherwise restrict natural convection airflow around the controller. Doing so could cause the controller to overheat.

Do not mount the controller to an insulating surface. Doing so could cause the controller to overheat.

Do not operate the controller in such a manner as to cause the surface temperature of the case or internal temperature to reach 70 °C. Otherwise the controller might be damaged and there might be a risk of fire as a result.

Do not allow the controller to be exposed to water (such as from dripping or leaking water lines or in which the controller is operating at or below the dew point temperature)

Do not allow metallic dust/shavings to enter into the controller box.

2.0 Display and Menu Options

Note: this section applies only to the TC-48-20. Setup, programming, and communications with the TC-48-20 OEM controller can only be accomplished by using the computer software with the optional MP-3023 RS232 cable. Changes made to the controller using the keypad are always stored in the EEPROM regardless of EEPROM WRITE ENABLE setting.

2.1 Initialization screen

1. Displays for 1.5 seconds: TE TECHNOLOGY
   www.tetech.com
2. Displays for 1.5 seconds: TE TECHNOLOGY
   TC-48-20 Rev. ****

2.2 Primary screen

TEMP = ###.# °C
OUT = ###% T2=##

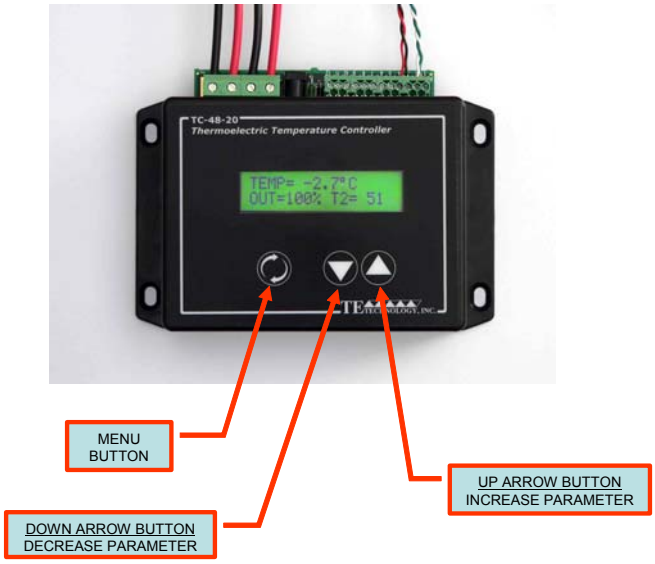
The controller displays information about the following items:
1) The temperature of the control sensor (TEMP) to a 0.1 °C resolution
2) The output level (duty cycle) to the thermoelectric modules (OUT)
3) The temperature of the second temperature sensor (T2)

- If the control sensor is either an open circuit or a short circuit (indicating that the sensor is not connected or has failed), the controller will display SENSOR 1 ERROR on the top line of the display instead of TEMP = ###.# °C. The output % will also be forced to 0% until the error is resolved.
- If a secondary sensor is not connected to the controller, T2= ### will not be displayed (unless it is forced to display by using the software menu setting).

If ALARM 1 or ALARM 2 has caused the power output to be turned off, the words ALARM and OUT= 0% will flash in alternating sequence in the place of the normal OUT=###% indicator. ***When not using a thermistor on the second sensor input the user will need to adjust the ALARM 2 FUNCTION to KEEP OUTPUT ON***.

Parameters Menu

When at the Primary Screen (shown below), depressing the MENU key allows the user to scroll through and adjust the various controller parameters.



- Press the “MENU” button momentarily to select the parameter to be changed.
- Press the Up/Down arrow keys to adjust the parameter value.
- If there is more than one value for any given parameter the MENU key will scroll from the first value to the next value and then on to the next parameter.
- Holding the Up/Down arrow keys will cause the value to increment faster.
- The display will return to the primary screen after eight seconds if no keys are depressed.

2.3.1 SET TEMPERATURE

Values: -20.0 °C to +199.0 °C, or as defined by the limits set by CONTROL RANGE
Default value = 25.0 °C

Description: SET TEMPERATURE is the control temperature that the controller tries to maintain. Note that controller set point should not be set outside the range suitable for the temperature sensor. Consult TE Technology for customization if you need a thermistor that can provide a different control range. Also, be sure that the set point is also appropriate to the TE device.

2.3.2 PROPORTIONAL BW

Values: 0.5 °C to 100.0 °C
Default value = 5.0 °C

Description: The proportional bandwidth is the temperature span over which the power is proportioned from 100% to 0% power, centered about the temperature set point. That is, the controller output decreases to 50% power as it reaches the set point and to 0% as it reaches the end of the bandwidth range below the set point (when in the cooling mode).

For example, suppose the controller is being operated in the cooling mode, the set point is 10.0 °C, and the bandwidth is set to 5 °C. The controller power starts to proportionally decrease as the sensor temperature cools below 12.5°C. The power will be reduced to 50% when the sensor is at 10.0 °C. Finally, the power will be at 0% when the sensor is at 7.5°C. (Of course, this example presumes that the INTEGRAL GAIN and DERIVATIVE GAIN are set to 0 and that the cooler would have enough capacity to cool to 7.5 °C.)

If the bandwidth is set too narrow, the temperature will oscillate around the set point. If the bandwidth is too wide, the controller will be slow to respond or may never reach set point.

2.3.3 INTEGRAL GAIN

Values: 0.00 to 10.00 (repeats per minute)
Default value = 1.00

Description: This corrects for any offset between the set temperature and the sense temperature by averaging the offset with respect to time. This essentially shifts the proportional bandwidth.

For example, suppose the set temperature is 10.0 °C, the bandwidth is set to 5 °C, and the controller settled to a constant 11.2 °C (corresponding to 74% power). If the integral control is then set to 1 repeat per minute, the controller will increase the power to 98% in 1 minute, providing extra cooling to move the temperature closer to the set temperature. In this example, after one minute of operation the controller calculated that the difference between the desired set temperature and the actual temperature was +1.2 °C. With a bandwidth of 5 °C, the controller uses the INTEGRAL GAIN to add an additional 24% output per minute (100% output / 5 °C * 1.2 °C = 24 %). This additional 24% output was added to the existing 74% output to yield 98% output. The integral portion of the output is continuously recalculated at the rate specified by the integral gain setting. The INTEGRAL GAIN always adds or subtracts from the present output power. Of course, the maximum output is limited to 100% and the minimum is limited to 0%.

If the integral control is set too high, the temperature will oscillate. If integral control is set too low, it will take a long time for the temperature to settle to steady state.

2.3.4 DERIVATIVE GAIN

Values: 0.00 to 10.00 (cycles per minute)
Default value = 0.00

Description: This senses the rate of change of the temperature and allows the controller to anticipate the power needed to compensate for rapid changes in the system loading. The derivate gain is generally used on very sluggish systems or where very quick response is necessary. It works in a similar way to the integral gain, but it acts upon the change in the error, not the absolute error.

2.3.5 SENSOR TYPE

Values: 15K-1 or 10K-1
Default value = 15K-1

Description:
15K-1 should be selected when using the supplied MP-3193 thermistor or other thermistors with equivalent temperature-resistance curves. See Appendix for further details.

10K-1 should be selected when using thermistors equivalent to 10 k-ohm, curve "B" temperature-resistance curve as defined by YSI Temperature, Inc.

If you are using two thermistors, they must have the same resistance versus temperature characteristics. Also be sure that you have selected the correct sensor type. Otherwise a dangerous condition could exist because the actual temperature could be higher or lower than the temperature being interpreted by the controller.

2.3.6 CONTROL MODE

Values: COOL or HEAT
Default value = COOL

Description:
COOL mode causes the controller to increase the output power when the control sensor temperature is greater than the set temperature.

HEAT mode causes the controller to increase the output power when the control sensor temperature is less than the set temperature. (This mode can also be used with resistive heaters.)

Note: If you are using a TE device in the cool mode and you want to switch to the heat mode, you must also switch the connection between JP4-3 and JP4-4.

2.3.7 CONTROL RANGE

Values: -20 to 199, applies to both HIGH and LOW settings
Default value for HIGH = 070
Default value for LOW = -20

Description: Sets the maximum and minimum temperatures available in the SET TEMPERATURE menu. This is a safety feature that helps to limit the set point to the safe operating temperature of the system being controlled. Adjustments are in 1 °C increments, and the high setting must be higher than the low setting.

Note: If the CONTROL RANGE is adjusted such that it is no longer inclusive of the SET TEMPERATURE, the controller will continue to control to that SET TEMPERATURE. However, once you scroll to the SET TEMPERATURE menu, the SET TEMPERATURE will automatically reset to be within the CONTROL RANGE, and the output power will adjust accordingly. The SET TEMPERATURE can then only be set within the CONTROL RANGE.

2.3.8 TEMP OFFSET

Values: -10.0 °C to +10.0 °C
Default value = 0.0 °C

Description: Offsets the control sensor value for both the display and control algorithm.

2.3.9 ALARM 1 TEMPS

Values: -20 to 199 or OFF for HIGH setting; -20 to 199 or OFF for LOW setting
Default value for HIGH = 60
Default value for LOW = -20

Description: This sets the high and low temperatures for signaling an alarm based on the control sensor temperature. Adjustments are in 1 °C increments, and the high setting must be higher than the low setting. If the HIGH setting is increased past 199, OFF is indicated and no alarm will be signaled based on the control sensor for over-temperature conditions. If the LOW setting is decreased past -20, OFF is indicated and no alarm will be signaled based on the control sensor for under-temperature conditions.

Note: If the controller senses an open circuit or a short circuit on the control sensor, the controller will automatically turn off output power, regardless of the ALARM 1 FUNCTION setting.

2.3.10 ALARM 1 FUNCTION

Values: KEEP OUTPUT ON or TURN OFF OUTPUT
Default value = TURN OFF OUTPUT

Description: This setting determines what action will be taken when there is an alarm condition on the control sensor. When KEEP OUTPUT ON is selected, output power to the TE device stays on during the alarm condition, and the alarm 1 signal on JP5-10 is activated. When TURN OFF OUTPUT is selected, output power to the TE device is turned off, and the alarm 1 signal on JP5-10 is activated.

⚠ The ALARM 1 and ALARM 2 outputs on JP5-10 AND JP5-11 will momentarily pulse on and off several times in the first second after the controller is turned on. This happens as the microprocessor in the controller configures itself, regardless of any alarm condition.

2.3.11 ALARM 2 TEMPS

Values: -20 to 199 or OFF for HIGH setting; -20 to 199 or OFF for LOW setting
Default value for HIGH = 60
Default value for LOW = -20

Description: This sets the high and low temperatures for signaling an alarm based on the optional, secondary sensor temperature. Adjustments are in 1 °C increments, and the high setting must be higher than the low setting. If the HIGH setting is increased past 199, OFF is indicated and no alarm will be signaled based on the secondary sensor for over-temperature conditions. If the LOW setting is decreased past -20, OFF is indicated and no alarm will be signaled based on the secondary sensor for under-temperature conditions.

Note: If the controller senses an open circuit or a short circuit with respect to the thermistor, the controller will signal an alarm condition (presuming it is not set to OFF). In addition, if the controller senses an open thermistor circuit, T2 will not be displayed in the primary screen.

2.3.12 ALARM 2 FUNCTION

Values: KEEP OUTPUT ON or TURN OUTPUT OFF
Default value = TURN OUTPUT OFF

Description: This setting determines what action will be taken when there is an alarm condition on the secondary sensor. When KEEP OUTPUT ON is selected, output power to the TE device stays on during the alarm condition, and the alarm 2 signal on JP5-11 is activated. When TURN OFF OUTPUT is selected, output power to the TE device is turned off, and the alarm 2 signal on JP5-11 is activated.

The ALARM 1 and ALARM 2 outputs on JP5-10 AND JP5-11 will momentarily pulse on and off several times in the first second after the controller is turned on. This happens as the microprocessor in the controller configures itself, regardless of any alarm condition.

2.3.13 ALARM LATCHES

Values: NO LATCHES, ALARMS 1&2 LATCH, ALARM2 LATCH, ALARM1 LATCH
Default value = NO LATCHES

Descriptions:
NO LATCHES: If an alarm condition occurs but then clears itself, the alarm signal will automatically turn off and power to the TE device will be restored (if ALARM 1 FUNCTION and ALARM 2 FUNCTION are set to TURN OUTPUT OFF).

If the alarm condition is recurring and the ALARM 1 FUNCTION and/or ALARM 2 FUNCTION is set to TURN OUTPUT OFF, the TE device can be damaged by thermal fatigue stress imposed by repeated long-term power cycling.

NOTE: The default deadband for the latch reset is 0 °C. However, the deadband can be reprogrammed using the RS232 interface to allow for the latch to reset at a specified temperature difference above/below the alarm set point. You can use the software provided with the controller or you can create your own software and use the controller commands as described in "*Serial Communications*" in the appendix.

ALARMS 1&2 LATCH: if an alarm condition occurs from either the control or secondary sensor or both, the controller will continue to signal an alarm until reset, even if the alarm condition is cleared. Power to the controller must be turned off and then on again to turn off the alarm signal. **Alternatively, press and hold the UP ARROW button for three seconds to clear the alarm signal and reset the latches.**

ALARM2 LATCH: if an alarm condition occurs from the secondary sensor, the controller will continue to signal the alarm until reset, even if the alarm condition is cleared. Power to the controller must be turned off and then on again to turn off the alarm. **Alternatively, press and hold the UP ARROW button for three seconds to clear the alarm and reset the latch.**

ALARM1 LATCH: if an alarm condition occurs from the control sensor, the controller will continue to signal the alarm until reset, even if the alarm condition is cleared. Power to the controller must be turned off and then on again to turn off the alarm**. Alternatively, press and hold the UP ARROW button for three seconds to clear the alarm and reset the latch.**

Multi-Speed Fan Control and control of other loads: The alarms can be used for controlling the hot-side fan of a TE device at two different speeds. The low-speed setting is useful for reducing noise when the demand for cooling is low. The high-speed setting can be triggered when an alarm condition is sensed to maintain cooling performance as required. Alarm deadband can be added to keep the fan speed from oscillating. See the "*Optional Multi-Speed Fan Control Setup*" drawing for further details. Note: each alarm output can handle other load types with up to 1 A of current draw. The controller can handle up to 20 A overall combines output and alarm current.

3.0 Controller Tuning

This tuning method follows the Ziegler-Nichols closed-loop tuning principals. Briefly, the controller will first be set to a high proportional bandwidth setting with no integral or derivative function (integral gain and derivative gain = 0). Then, the bandwidth is gradually decreased until the temperature approaches set point and a small, sustained oscillation in temperature is observed. The other tuning parameters are then readjusted based on the time period of the temperature oscillation (natural period) and the proportional bandwidth needed to cause this oscillation.

⚠ Improper tuning of this 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.

3.1 Set the desired control temperature in the SET TEMPERATURE menu.

3.2 Set the PROPORTIONAL BW to 20. This is just a starting value; the goal is to determine the proportional bandwidth at which the temperature of the TE device will first begin to oscillate. The bandwidth needs to be adjusted in incremental steps and allow the controller to reach steady state between each adjustment. You might be able to start with a smaller bandwidth, depending on the system, thereby reducing the time it takes to determine the proper bandwidth for good control stability.

3.3 Set the INTEGRAL GAIN and DERIVATIVE GAIN to zero.

3.4 Decrease the PROPORTIONAL BW incrementally, allowing the TE device to reach steady state at each increment, until the temperature of the TE device begins to oscillate. The system temperature will usually begin to oscillate before it actually reaches the set point temperature; this is normal. You can decrease the bandwidth in initial increments of 5 °C or perhaps even more. Then, once an initial oscillation is observed, increase the bandwidth in small increments until the oscillations are barely detectable.

Measure the time period of oscillation in minutes. This will be used to determine the INTEGRAL GAIN setting below.

3.5 Multiply the current PROPORTIONAL BW setting by 2.2 and enter this as the new bandwidth. The system should now maintain a steady state temperature near the set point.

3.6 The integral gain is calculated as follows: I = 0.54/T where I is the integral gain and T is the time period, in minutes, determined in section 3.4 above. Enter this value in the INTEGRAL GAIN setting.

3.7 The derivative gain is often times difficult to use and might cause more trouble than it is worth. If you are not experience with process control, you might be better off leaving the DERIVATIVE GAIN set to zero.

If you decide to use derivative gain, the other control parameters should be adjusted first.

a) Instead of multiplying the initial proportional bandwidth setting by 2.2, multiply it by 1.7, and enter this as the new PROPORTIONAL BW setting.
b) Calculate the integral gain as follows: I = 1.2/T, and enter this into the INTEGRAL GAIN setting.
c) Calculate the derivative gain as follows: D =0.075 x T, and enter this into the DERIVATIVE GAIN setting.

3.8 The control parameters are approximate settings. Further adjustments might be needed.

Tuning Example using proportional bandwidth and integral gain:

A. Suppose that smallest PROPORTIONAL BW setting that causes oscillation was determined to be 2.1 °C.

B. It was then observed that the natural period of this oscillation was 2 minutes.

C. The PROPORTIONAL BW setting should then be set to 4.6 °C (This is calculated from 2.1 °C x 2.2 = 4.6 °C.

D. The INTEGRAL GAIN should be set to 0.27 (This is calculated from 0.54/(2 minutes) = 0.27 repeats per minute).

4.0 Controller Software and RS-232 Communication

The TC-48-20 and TC-48-20 OEM can be controlled through the supplied software operating on a Windows based computer. In addition, see "*Serial Communications*" for descriptions of the command set for the controller. The command set can be used to create your own custom software using National Instruments LabVIEW, for example, if the supplied software does not quite meet your requirements.

A dedicated serial port is required. See "*RS-232 Communications Connections*" for proper connection to the serial port of the computer. **An optional serial port cable is available and is required to connect to the computer.** Contact TE Technology for more information. Always be sure the computer is shut down before connecting or disconnecting the controller from the computer.

Note: If you need to communicate to the controller via a USB port you can use our optional RS232 Adapter for USB to RS232 conversion in conjunction with the optional RS-232 cable. If you use your own USB to RS232 converter, be aware that some converters might "inject" noise on the transmit line from the computer. This will disrupt communication to the controller. This noise problem can be alleviated by adding a 0.001 microfarad, 50 V ceramic capacitor between JP5-7 and JP5-8.

Software Installation: insert the CD into your CD drive in any Windows 2000 (service pack 3) or Windows XP based computer and double-click the setup.exe file (the runtime engine requires a minimum of approximately 320 MB of hard-disk space and 256 MB of RAM). This process will install the National Instruments LabVIEW runtime engine, the TC-48-20.exe file, and various support files to your hard drive. The LabVIEW runtime engine is required since the TC-48-20.exe is actually an executable version of a LabVIEW .vi file. The computer will then ask you to restart. However, you might want to shut down the computer all the way first if you have not connected the controller to the serial port yet. If you have connected it already, then a simple restart will suffice.

To start the software, navigate to the directory in which you installed the TC-48-20.exe file (default location is C:\Program Files\TE Technology\TC-48-20\TC-48-20.exe), then double-click the .exe file. The software will start and you should see the following screen:

The pop-up screen reminds you that you must first establish communication between the controller and the computer. Click the OK button to clear the pop-up screen.

Next, click the COMMUNICATIONS PORT menu key and select the port to which you have the controller connected. Then click the CONNECT button. Controllers with firmware version H or later will display the version on the lower right side of the screen. If earlier than version H this area will be blank.

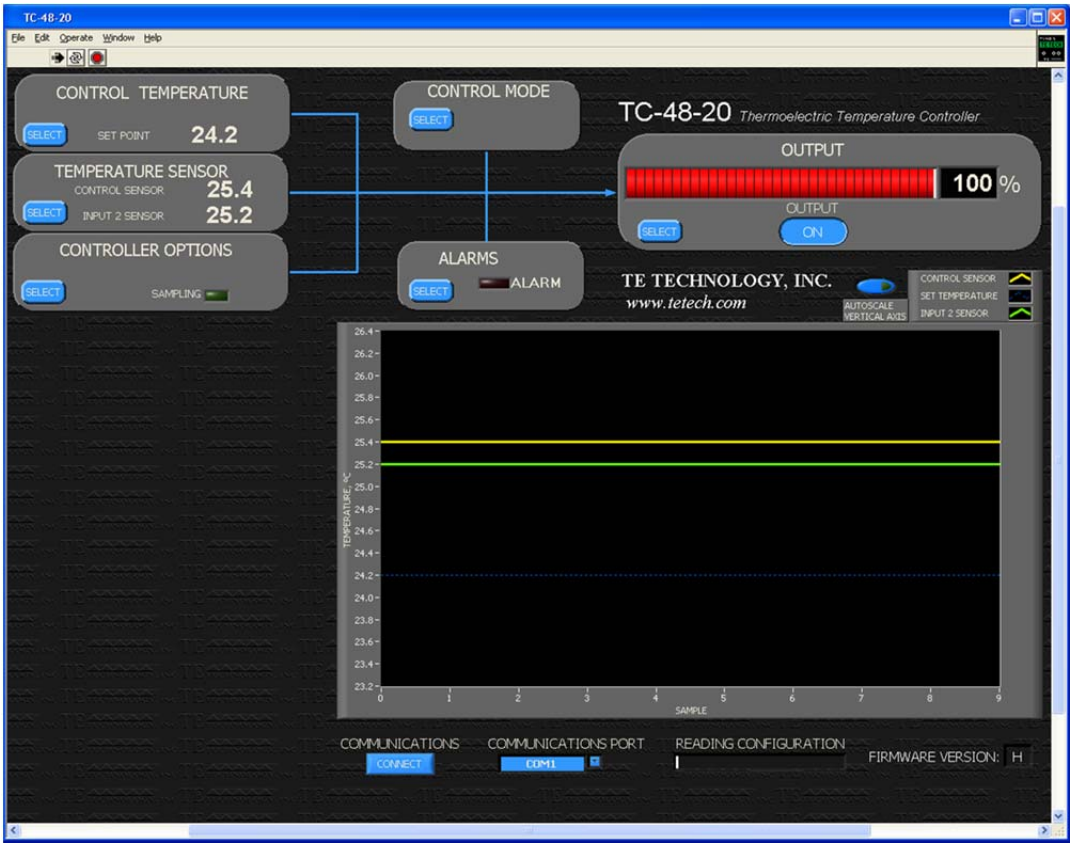
If you make changes to the controller setting via the keypad, the software will automatically detect this change the next time the software polls the controller.

If you are not able to establish communication with the controller, check the following conditions:

1) Verify the controller itself is on.
2) Make sure you selected the correct serial port and the interface cable is securely connected to the correct port.
3) Verify the cable is wired correctly to the controller.
4) Verify the computer serial port is configured per RS-232 standards.
5) Check that the serial port has not been disabled by your hardware configuration.

The controller software settings are arranged into six sections:

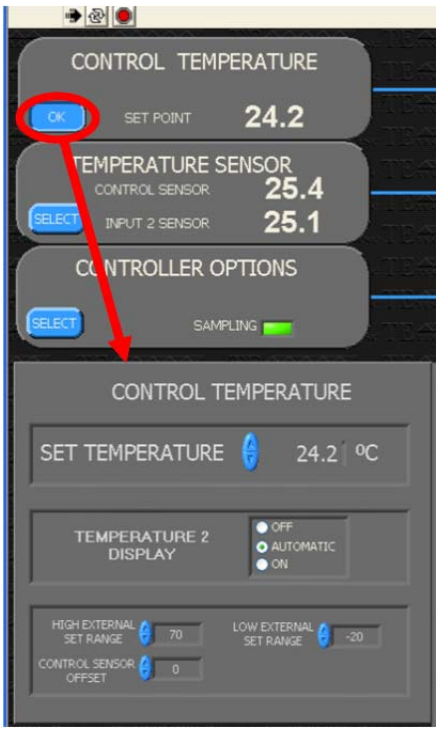
CONTROL TEMPERATURE	TEMPERATURE SENSOR
CONTROLLER OPTIONS	CONTROL MODE
ALARMS	OUTPUT



The options for each section box are revealed when you click the corresponding SELECT button. This opens up a menu box next to the left of the graph box. When you make a change to any of the menu options, the controller is updated immediately. The menu box is closed when you click the OK button on the corresponding section box.

CONTROL TEMPERATURE box

This shows the set temperature for the controller. The menu options allow for adjustment of the set temperature, whether a temperature from the secondary thermistor is displayed, and for adjusting the high and low limits of the set temperature. The values can be changed using the up or down menu buttons or by clicking on the number and typing in the desired value.



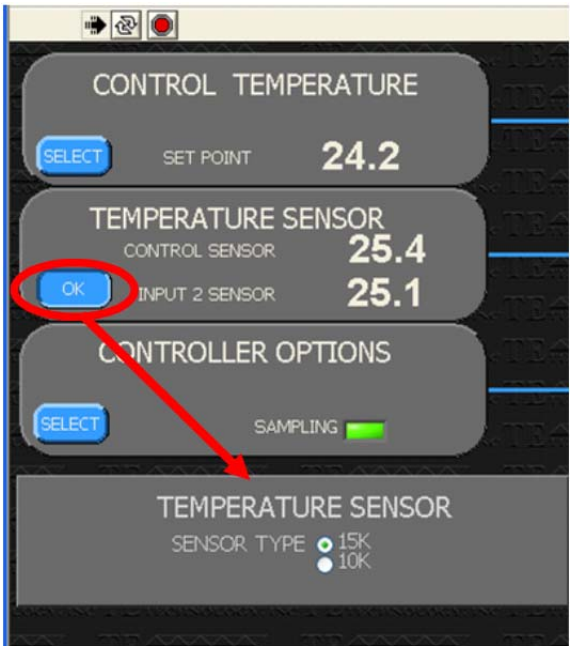
The allowable SET TEMPERATURE is limited to the range defined by the HIGH EXTERNAL SET RANGE and the LOW EXTERNAL SET RANGE.

The SET TEMPERATURE 2 DISPLAY can be set to OFF to prevent the display of the temperature of the secondary thermistor, regardless of whether a secondary thermistor is attached to the controller or not. If it is set to AUTOMATIC, then the controller will automatically display the temperature if a sensor is attached, and turn it off if no sensor is attached. Setting it to ON will always display the temperature from the secondary thermistor.

The CONTROL SENSOR OFFSET can be used to correct for known sensor errors or differences between the sensed temperature and the actual temperature.

TEMPERATURE SENSOR box

This shows the present temperature of the control sensor and the secondary sensor.



The menu options allow for selecting which temperature-resistance curve the controller is to reference for reporting the present temperatures of the thermistors. The 15K sensor type should be selected if using the MP-3193, MP-2444, or MP-2542 thermistor.

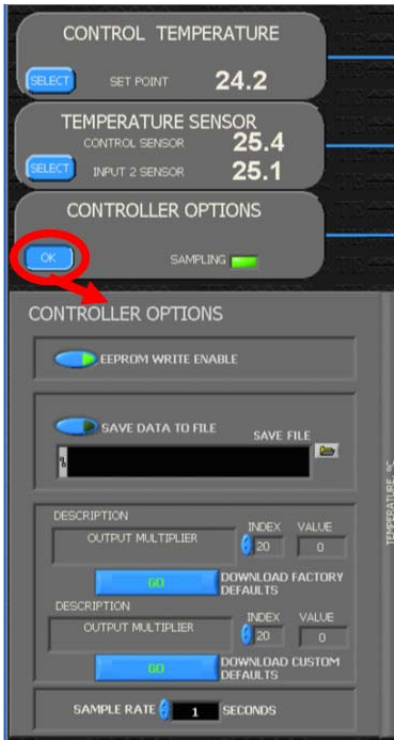
The 15K sensor provides an effective control range of -20 °C to +100 °C.

The 10K sensor provides for an effective control range of -20 °C to +85 °C. The temperature-resistance curve for the 10K sensor is the same as curve "B" from YSI Temperature, Inc. See "*Temperature versus Resistance*" below for further details on the 15K and 10K data.

If you are using two thermistors, they must have the same resistance versus temperature characteristics. Also be sure that you have selected the correct sensor type. Otherwise a dangerous condition could exist because the actual temperature could be higher or lower than the temperature being interpreted by the controller.

CONTROLLER OPTIONS box

The SAMPLING indicator will flash green each time the software updates the sensor temperatures and power output. The menu options allow for enabling/disabling EEPROM write enable, adjusting the sampling frequency and for determining where to save test data to a file. NOTE: if you use the software with controllers having firmware version G or earlier, the EEPROM WRITE ENABLE button will be disabled and grayed out. This control operates only on firmware versions H and later.



The EEPROM, Electrically Erasable Programmable Read Only Memory, is a non-volatile memory used to store controller settings. This allows the controller to remember its settings even after power to the controller has been turned off. The TC-48-20 and TC-48-20 OEM automatically turn on EEPROM WRITE ENABLE when power is applied to the controller regardless of whether EEPROM WRITE ENABLE was turned off when power to the controller was removed. With EEPROM WRITE ENABLE turned on, any changes to the controller settings are automatically written to EEPROM. With EEPROM WRITE ENABLE turned off, any subsequent changes to the controller settings are only saved in RAM and will not be stored to EEPROM. The maximum number of writes to an EEPROM location is 1,000,000. Even though this provides for many write cycles, you might want to turn EEPROM WRITE ENABLE off if for example you are writing your own code to ramp set points via the computer.

The SAMPLE RATE determines the amount of time the software waits before updating the status of the controller. This is particularly useful if you will be operating controller for a long time and you want to limit the amount of data you save. The minimum time is 1 second, and it can be adjusted in 1 second increments.

To SAVE DATA TO FILE, enter a filename in the text box, including the entire path to the file, such as <C:\PROGRAM FILES\TE TECHNOLOGY\TC-48-20\TESTDATA.TXT>. Alternatively, if you want to append data to an existing file, you can click the folder icon to select an existing file. Then click the SAVE DATA TO FILE button to begin saving test data. If you click the SAVE DATA TO FILE button before entering a filename and path in the text button, an error screen will pop up and a default filename and path will automatically be entered in the text box. Click the continue button on the error pop-up if applicable. The arrow on the button will turn green to indicate that the software is saving test data. The software saves the data into a TAB-delimited format which can then be readily imported into a spreadsheet program for further analysis.

To view the data in Microsoft Excel:

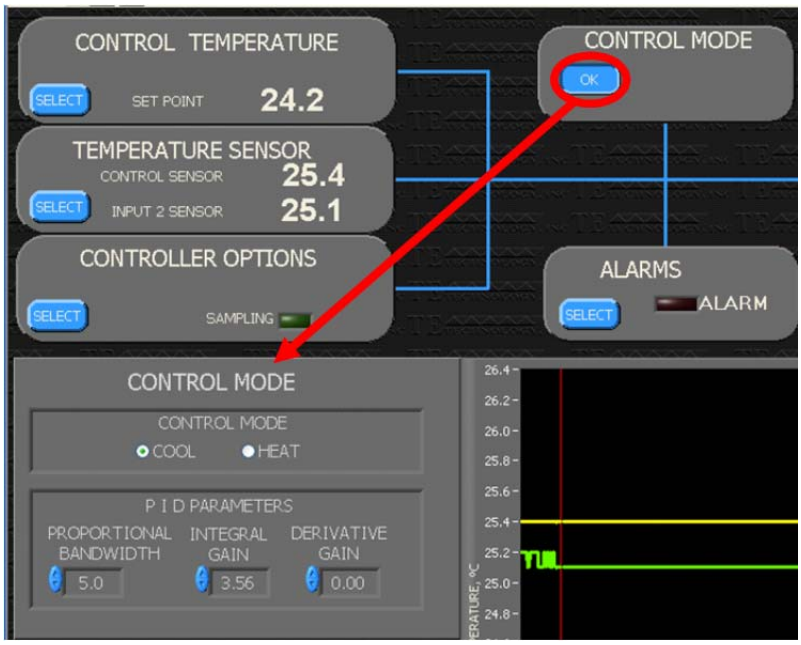
1. *Open a blank worksheet*
2. *Select **Data** > **Import External Data** > **Import Data,** and click **Next***
3. *Select the file you wish to import and click **Next***
4. *Choose to import **Delimited** Data Type and click **Next***
5. *Select **TAB** as the delimiter and click **Finish***

Clicking the GO button next to the "DOWNLOAD FACTORY DEFAULTS" label downloads the original default controller settings. You can review these settings by clicking on the INDEX scroll arrows. These default settings can not be changed.

Alternatively, you can click the GO button next to the "DOWNLOAD CUSTOM DEFAULTS" label to download customized settings from a pre-configured, comma-delimited text file which is saved in the C:\Program Files\TE Technology\TC-48-20\custom settings.csv (unless you changed your default install directory). You can change these settings as needed.

<u>CONTROL MODE box</u>

The menu options provide for adjusting whether the controller is in the heat or cool mode and for adjusting the proportional bandwidth, integral gain and derivative gain.

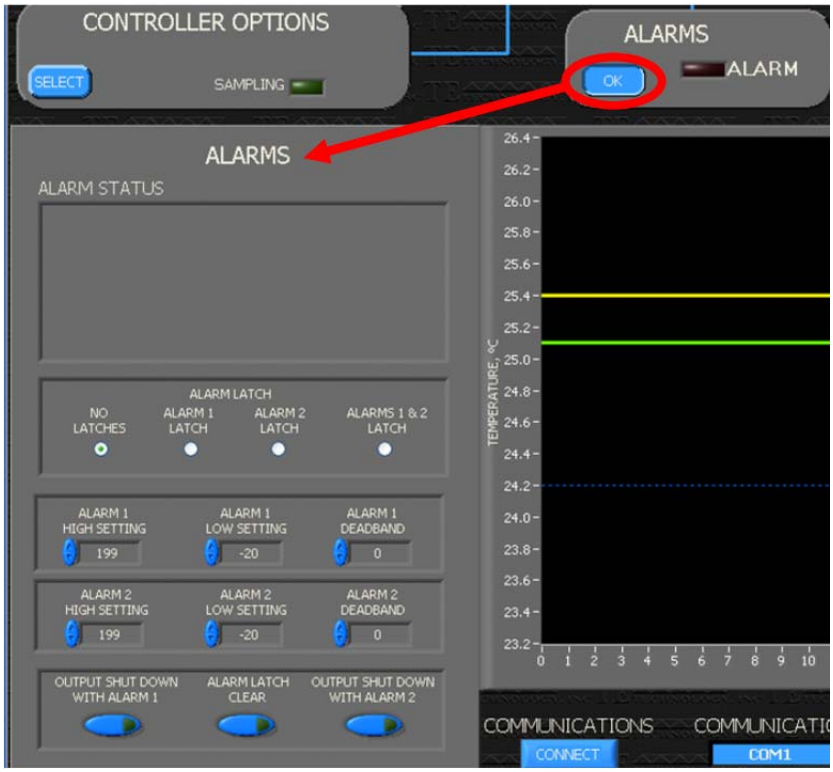


The COOL or HEAT control mode does not automatically reverse the polarity applied to the TE device. It only defines whether power is increased if the control sensor temperature rises above the set point (COOL mode) or decreases power if the control sensor temperature rises above set point (HEAT mode). The TE device connection to the controller will need to be physically reversed if you initially configure for COOL mode and then decide to switch to HEAT mode, for example.

See the Controller Tuning section for details on the proper settings for the PROPORTIONAL BANDWIDTH, INTEGRAL GAIN, and DERVATIVE GAIN settings.

ALARMS box

The ALARM indicator will be grey if no alarm condition exists. It will flash between yellow and red if an alarm condition exists. The menu provides for adjusting alarm settings.



The ALARM STATUS text box will indicate the nature of the alarm if an alarm conditions exists.

NO LATCHES: if an alarm condition clears itself, the alarm will automatically reset.

ALARM 1 LATCH: if an alarm is triggered from the control sensor, the software will continue to signal an alarm condition until the condition is cleared *and* the ALARM LACTH CLEAR button is clicked.

ALARM 2 LATCH: if an alarm is triggered from the secondary sensor, the software will continue to signal an alarm condition until the condition is cleared *and* the ALARM LACTH CLEAR button is clicked.

ALARM 1&2 LATCH: if an alarm is triggered from either the control or the secondary sensor, the software will continue to signal an alarm condition until the condition is cleared *and* the ALARM LACTH CLEAR button is clicked.

ALARM 1 HIGH SETTING: this sets the temperature at which an alarm will occur if the control sensor temperature exceeds the set value. The set value must be greater than the value set in the ALARM 1 LOW SETTING but less than 200. If the set value is set to greater than 199, no alarm will be signaled for any over-temperature condition.

ALARM 1 LOW SETTING: this sets the temperature at which an alarm will occur if the control sensor temperature becomes less than the set value. The set value must be less than the ALARM 1 HIGH SETTING but greater than -21. If the set value is less than -20, no alarm will be signaled for any under-temperature condition.

ALARM 1 DEADBAND: this defines a temperature difference above or below the ALARM 1 LOW SETTING or ALARM 1 HIGH SETTING at which the alarm status can be cleared (either automatically or manually depending on latch settings). For example, if ALARM 1 HIGH SETTING is set for 70 and the ALARM 1 DEADBAND is set for 10, and an alarm condition occurs, the control sensor would have to cool to 60 °C before the alarm can be reset.

The ALARM 2 HIGH SETTING, ALARM 2 LOW SETTING, and ALARM 2 DEADBAND function in the same manner as described above for ALARM 1 settings except that they are referenced to the secondary sensor.

OUTPUT SHUTDOWN WITH ALARM1: if this option is turned on and an alarm condition occurs relative to the primary sensor, then the controller will shut power off to the TE device. Power will automatically be restored if you have the NO LATCHES option selected. If the ALARM 1 LATCH or the ALARM 1&2 LATCH option is selected, then power will stay off, even if the alarm condition clears itself, until you click the ALARM LATCH CLEAR button.

OUTPUT SHUTDOWN WITH ALARM2: same as the OUTPUT SHUTDOWN WITH ALARM1 except as referenced to the secondary sensor.

<u>OUTPUT box</u>
This shows the percentage of maximum power output that the controller is providing to the TE device.

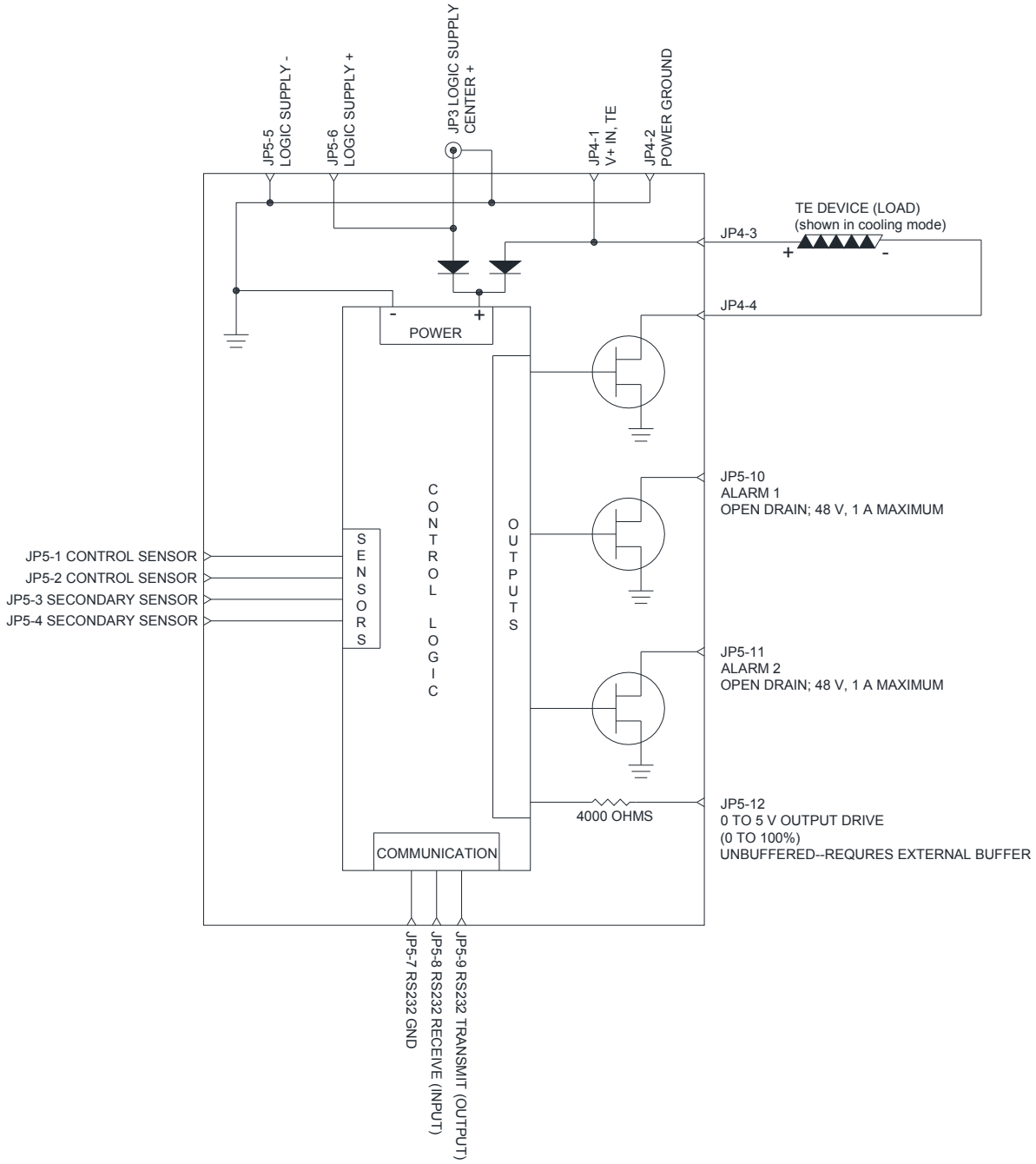
The output can be turned on and off by clicking the output button either ON or OFF. Whenever a change is made in the software, the controller is updated in real time. However, it might be beneficial to turn off the output first and then make all of your software/controller settings before turning on the output. **Be sure that the output is set to ON prior to shutting down the software though; otherwise, if you attempt to use the controller again without the software, you will not be able to turn the output on**.

The menu provides for adjusting the analog output voltage. The analog output voltage provided by the controller (see "*Controller Schematic* for further details") is a 0-5V DC control signal which corresponds to 0 to 100% power output. The ANALOG OUTPUT MULTIPLIER can be set from 0 to 1. When it is set to 1, the analog output voltage can range from 0 to 5 V. If, for example, it is set to 0.5, then analog output voltage can range from 0 to 2.5 V. This can be useful for limiting the output voltage of power supply.

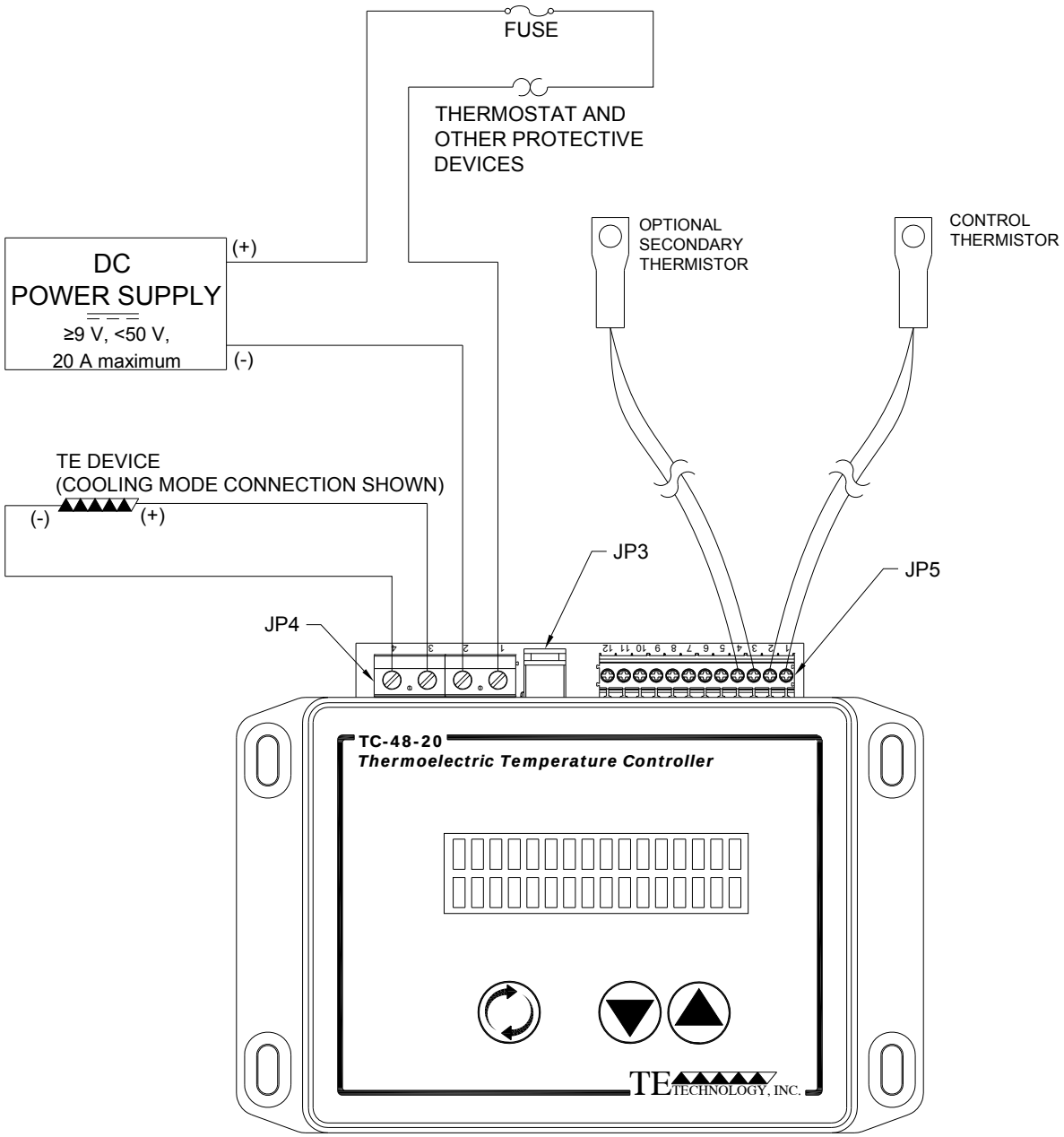
AUTOSCALE VERTICAL AXIS button

Clicking this button automatically scales the graph so that all data plots can be seen. You can also right-click on the axes for further options or enter minimum and maximum Y-axis numbers directly to rescale.

Controller Schematic



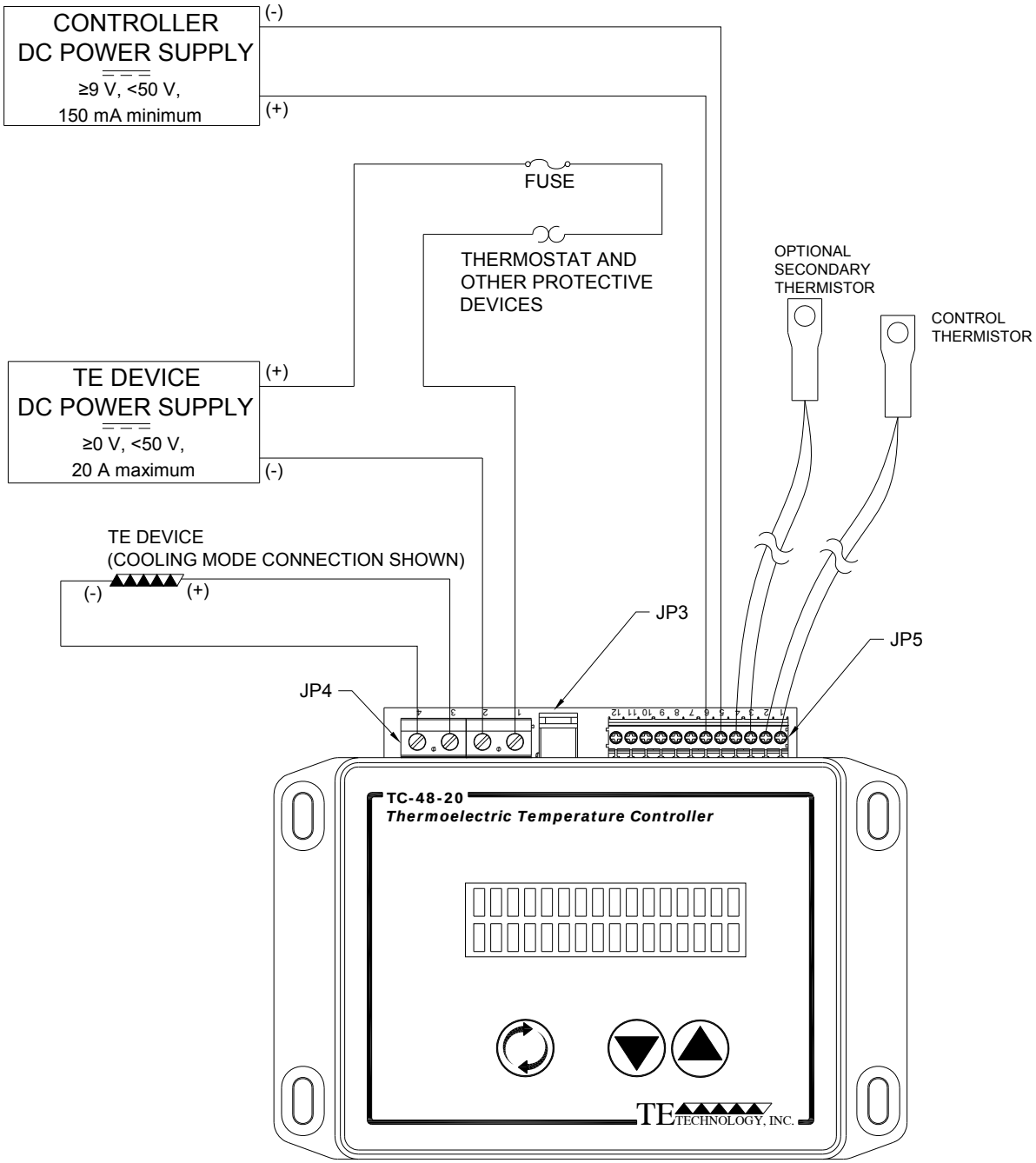
Controller Hookup Diagram (One Power Supply Setup)



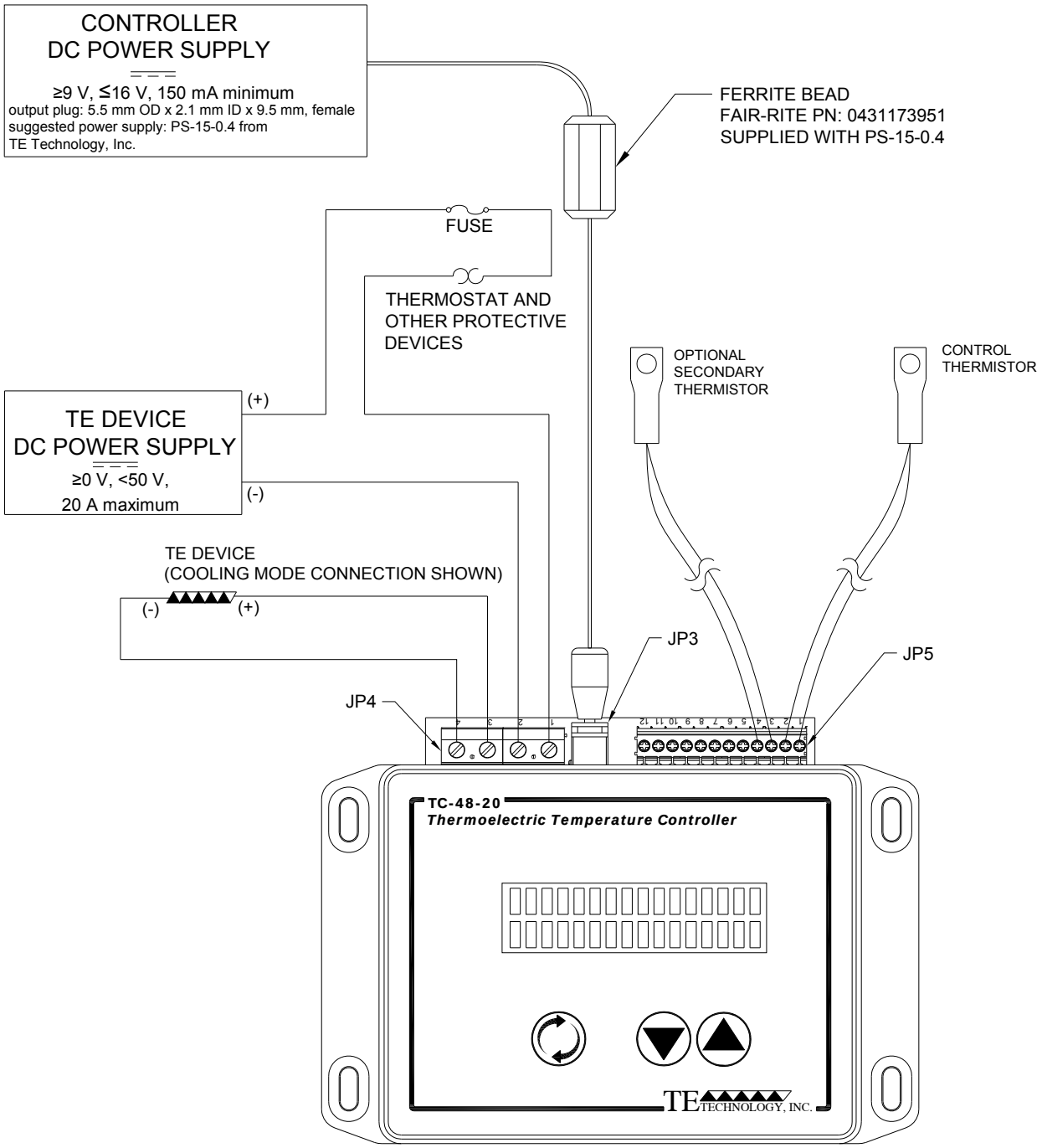
When one or more external fans are used on the TE device, these should be wired directly to a fixed voltage power supply for constant operation.

When connecting the controller to a TE Technology Thermoelectric Cooling Assembly (TCA) verify that the electrical jumpers (shorts) located on the TCA terminal block are installed/removed per the TCA operating manual before powering the controller.

Controller Hookup Diagram (Two Power Supplies Setup-Option 1)

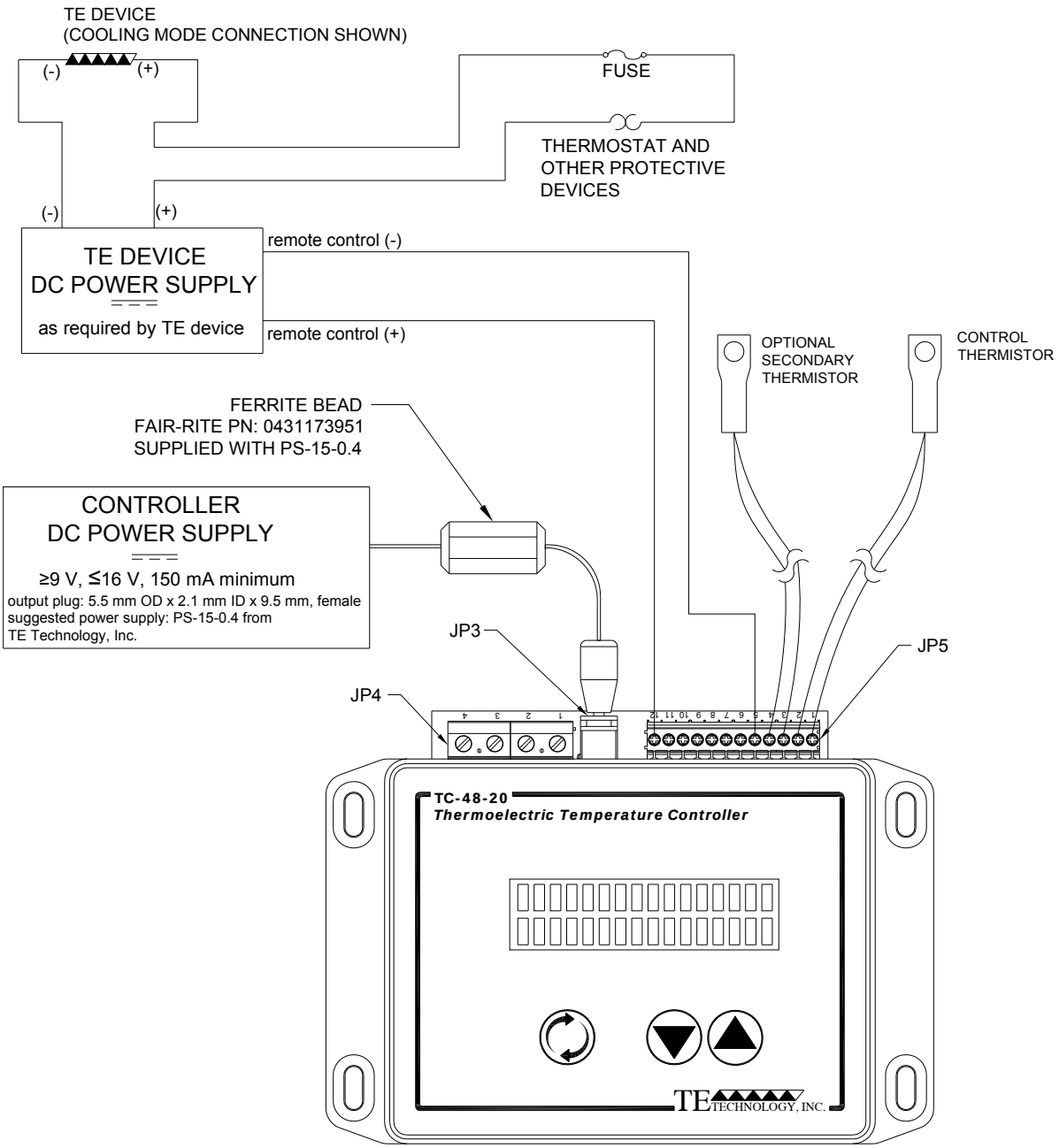


Controller Hookup Diagram (Two Power Supplies Setup-Option 2)



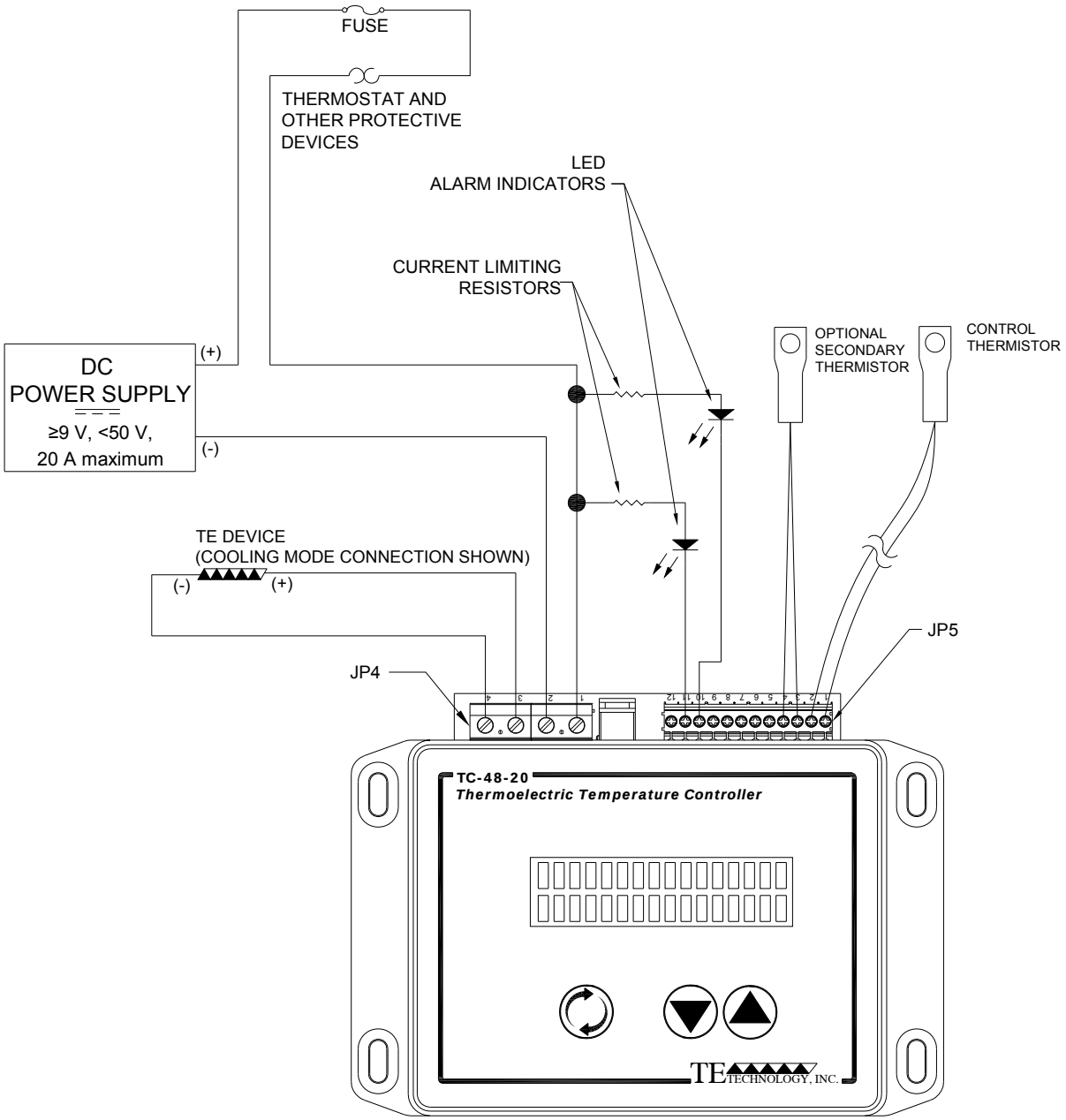
Linear Control Hookup Diagram

Note: Check the power supply manual to determine if an external buffer is required between the power supply and the voltage signal output from JP5-12.



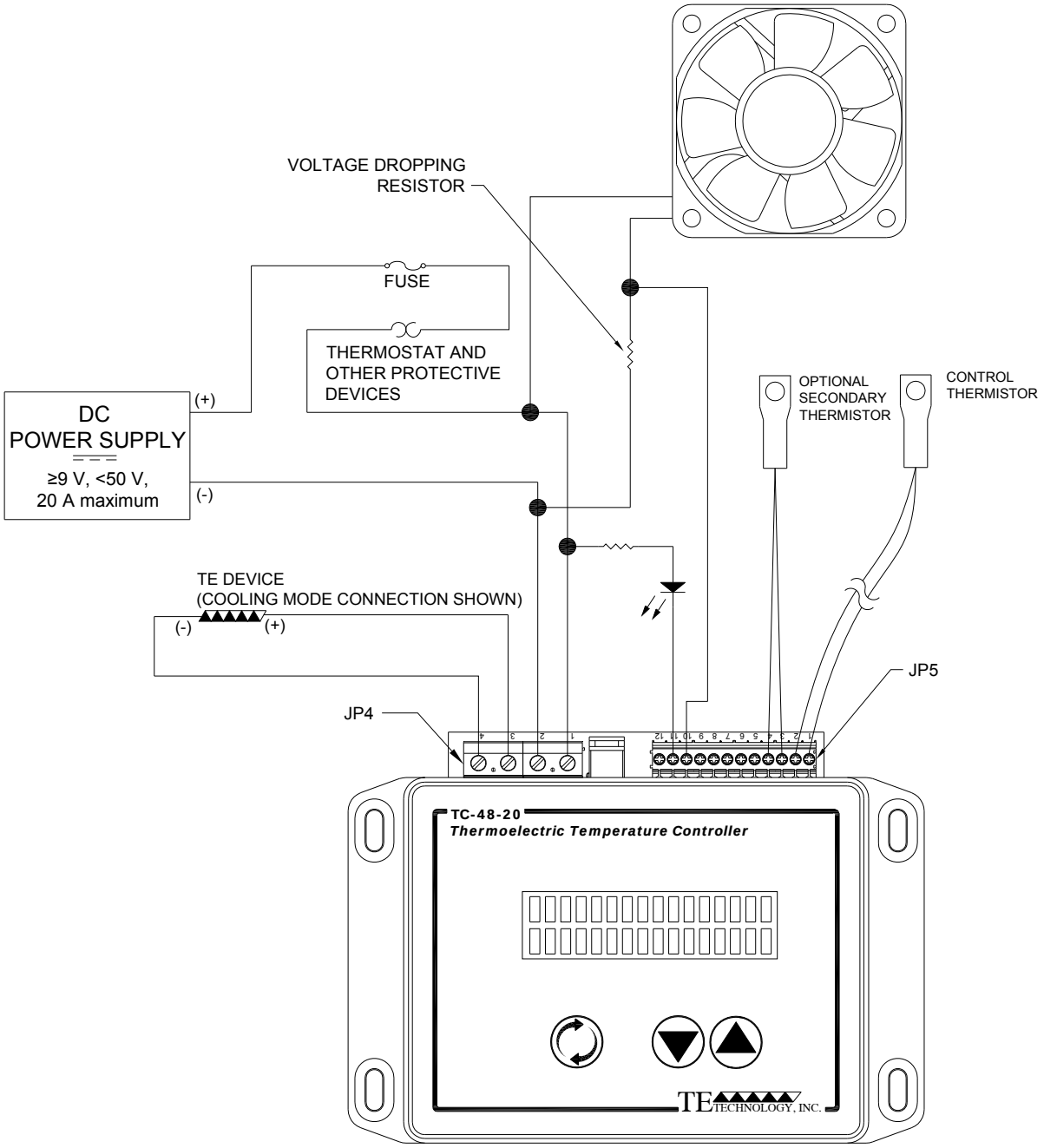
Optional External Alarms Setup

Other loads, requiring up to 1 amp of current, can also be controlled



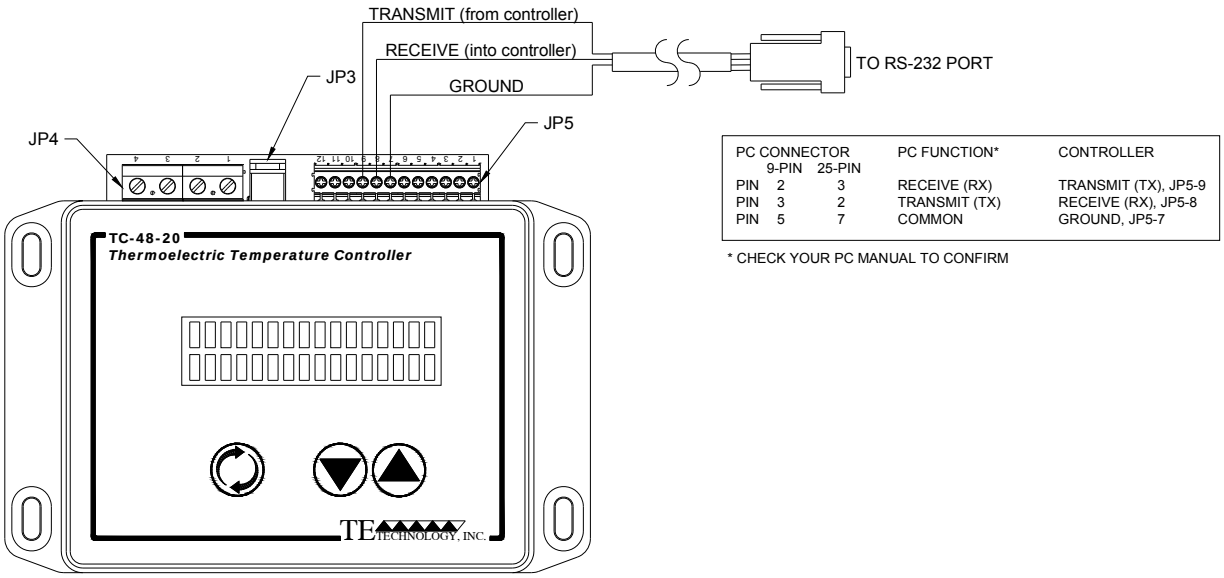
Optional Multi-Speed Fan Control Setup

Other loads, requiring up to 1 amp of current, can also be controlled



NOTE: ADJUST ALARM DEADBAND TO PREVENT FAN SPEED FROM RAPIDLY CYCLING.

RS232 Communications Connections



Note: the RS232 cable is not included as a standard accessory. However, TE Technology can provide this as optional accessory, part number MP-3023. If using the MP-3023, connect the leads as follows:

red lead to JP5-9
clear (or white) lead to JP5-8
black lead to JP5-7

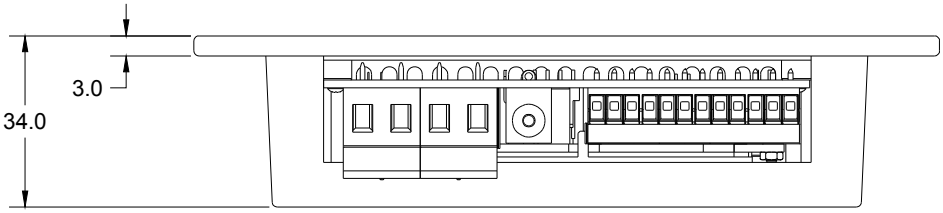
Note: other connections to controller have been removed for the sake of clarity.

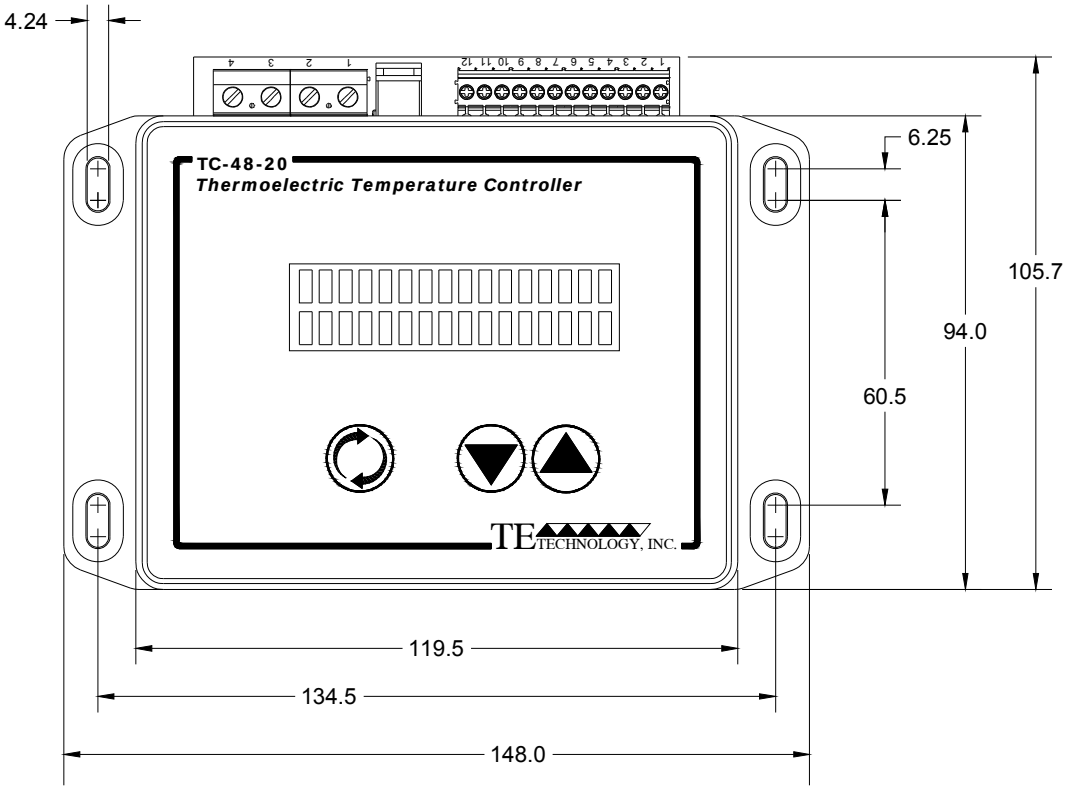
Note: If you are using a USB to RS232 converter, some converters might induce electronic noise and interfere with communication. If this occurs, install a 0.001 microfarad, 50V- rated, ceramic capacitor across JP5-7 to JP5-8.

RS232 Communications Parameters:

A. Baud Rate 115,200
B. No Parity
C. 1 Start Bit 1 Stop Bit

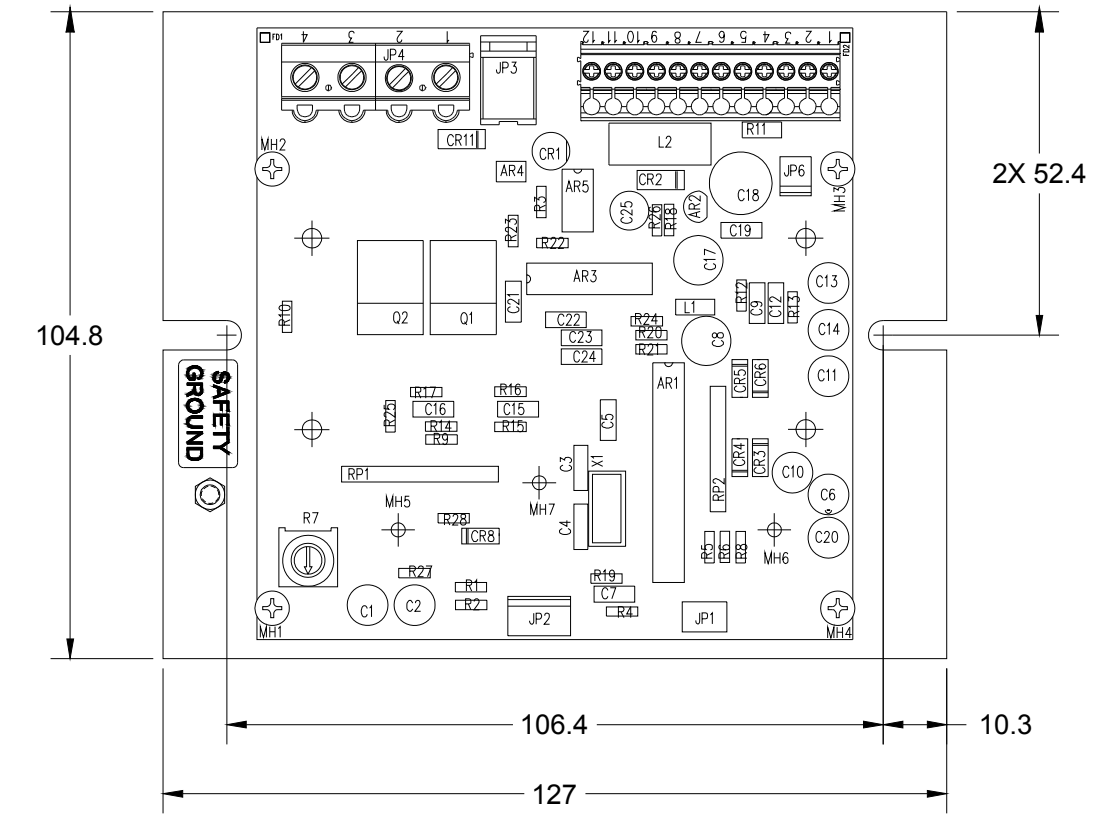
TC-48-20 Mechanical Package Drawing

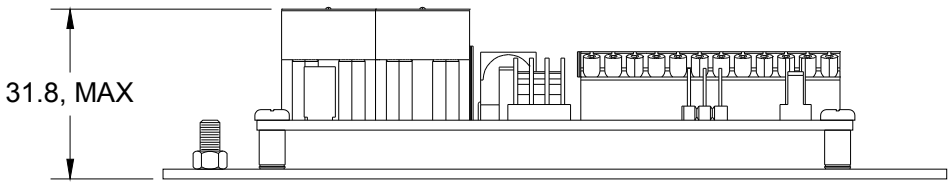




NOTE: ALL DIMENSIONS IN MILLIMETERS

TC-48-20 OEM Mechanical Package Drawing

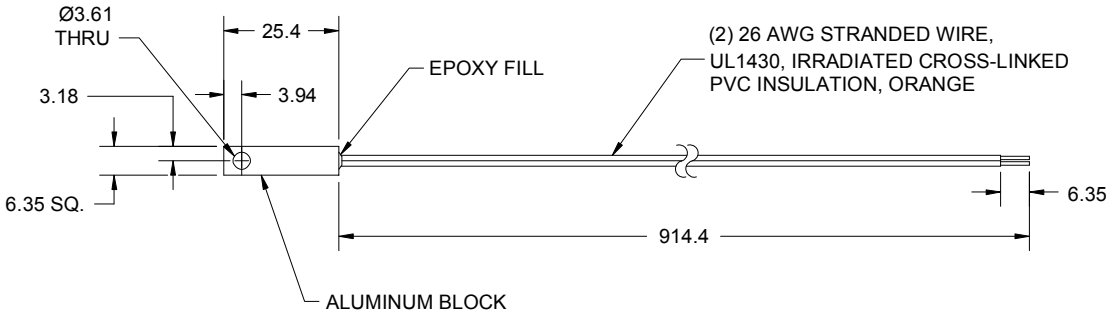




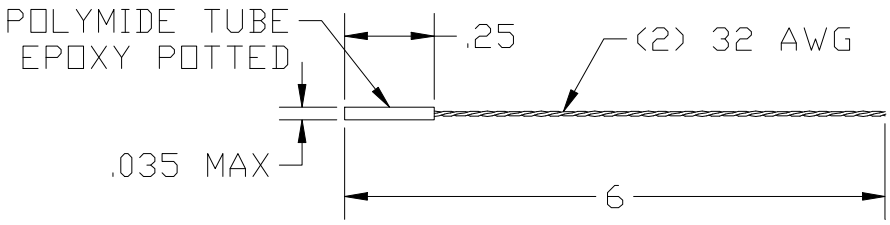
NOTE: ALL DIMENSIONS IN MILLIMETERS

Standard Thermistors Available for TC-48-20

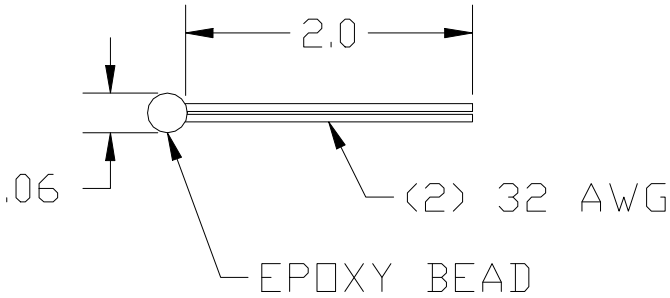
Note: All dimensions in millimeters. Standard 15 k-ohms.



MP-3193



MP-2444



MP-2542

Appendix A Temperature versus Resistance Curves
for MP-3193, MP-2444, and MP-2542 Thermistors (15 k-ohm)

-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 for standard thermistors is ±650 Ω, corresponding to ±1 °C over a 0 °C to 100 °C range.

Temperature versus Resistance Curves
for Compatible 10 k-ohm Thermistors

-20	97110	2	29500	24	10450	46	4202	68	1876
-19	91650	3	28060	25	10000	47	4042	69	1813
-18	86500	4	26690	26	9574	48	3889	70	1752
-17	81710	5	25400	27	9165	49	3743	71	1693
-16	77220	6	24170	28	8779	50	3603	72	1636
-15	72960	7	23020	29	8410	51	3469	73	1582
-14	69010	8	21920	30	8060	52	3340	74	1530
-13	65280	9	20880	31	7722	53	3217	75	1479
-12	61770	10	19900	32	7402	54	3099	76	1431
-11	58440	11	18970	33	7100	55	2986	77	1385
-10	55330	12	18090	34	6807	56	2878	78	1340
-9	52440	13	17260	35	6532	57	2774	79	1297
-8	49690	14	16470	36	6270	58	2675	80	1255
-7	47070	15	15710	37	6017	59	2580	81	1215
-6	44630	16	15000	38	5777	60	2488	82	1177
-5	42340	17	14330	39	5546	61	2400	83	1140
-4	40170	18	13680	40	5329	62	2316	84	1104
-3	38130	19	13070	41	5116	63	2235	85	1070
-2	36190	20	12500	42	4916	64	2157		
-1	34370	21	11940	43	4725	65	2083		
0	32660	22	11420	44	4543	66	2011		
1	31030	23	10920	45	4369	67	1942		

Appendix B Serial Communications

I. Definitions:

All numeric values are in hexadecimal format. Use lowercase ASCII characters.

Note: where applicable, the base of a number is indicated by its subscript. So, 20_{10} is the number 20 in decimal (base 10) format, and it converts to 14_{16} in hexadecimal (base 16) format.

(stx)	Start of text character (*) $2a_{16}$
(etx)	End of text character (carriage return) or $0d_{16}$
(ack)	Acknowledge character (^) or $5e_{16}$
CC	Command characters are ASCII characters from 0 through 9 or a through f.
DDDD	This is the ASCII representation of the hexadecimal return or send value. Negative numbers are represented by the hex 2's complement of the number (16-bit word size): 1 decimal = 0001_{16} in hex two's complement -1 decimal = $ffff_{16}$ in hex two's complement
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, and (etx). *TC-48-20 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-48-20 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)CCDDDDSS(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 four ASCII data characters, DDDD:

(stx)DDDDSS(ack)

To query a controller, there is no send value so the controlling computer only needs to send the ASCII command characters with the "D"s filled with zeros:

(stx)CC0000SS(etx)

If the checksum for a query is correct the temperature controller will respond by sending back a "return value" and then SS, which is the checksum of the four return value (DDDD) characters:

(stx)DDDDSS(ack)

If the checksum for a command or query is not correct the temperature controller will respond with four upper case X's and then 60, which is the checksum of these four X's:

(stx)XXXX60 (ack)

II. Examples:

A) Send the set temperature of 10.0 to the controller.

1. The control command, CC, for "DESIRED CONTROL TEMPERATURE (SET TEMPERATURE)" is 1c.
2. Multiply the desired set-point temperature by 10 (10.0_{10} x 10_{10} = 100_{10}).
3. Convert 100 decimal to hexadecimal (64_{16}) and add on leading zeros to make the eight-character send value DDDD (0064).
4. Compute the checksum (SS) by adding the hexadecimal values of the following ASCII characters: 1, c, 0, 0, 6, and 4:

ASCII Character:	Hexadecimal Value:
1	31
c	63
0	30
0	30
6	36
4	34
Sum	**$15e_{16}$**

The 8-bit checksum is the 8 least significant binary bits of the sum, represented as 5e in hexadecimal.

5. Combining all of these characters in one string we send: (stx)1c00645e(etx).
6. If the temperature controller receives the command and the checksum is correct, it will send back: (stx)0064ca(ack). If the checksum is not correct the temperature controller will send back: (stx)XXXX60(ack).

B) Send the set temperature of -1.5 °C.

1. The controller command, CC, is by definition 1c.
2. Multiply the desired set-point temperature by 10_{10} (-1.5 x 10 = -15).
3. Convert -15_{10} to hexadecimal by taking the two's complement of the number. (This can be easily done by using the formula $2^n - N$, where n is the word-bit size and N is the absolute value of the number being converted.) Hence, you have 2^{16} - 15 = 65521_{10}. This value then converts to $fff1_{16}$.
4. Compute the checksum (SS) by adding the hexadecimal ASCII values of the following characters: 1, c, f, f, f, 1,:

ASCII Character:	Hexadecimal Value:
1	31
c	63
f	66
f	66
f	66
1	31
Sum	**$1f7_{16}$**

The 8-bit checksum is the 8 least significant binary bits of the sum, represented as f7 in hexadecimal.

5. Combining all of these characters in one string we send: (stx)1cfff1f7(etx).
6. If the temperature controller receives the command and the checksum is correct, it will send back: (stx)fff163(ack). If the checksum is not correct the temperature controller will send back: (stx)XXXX60(ack).

C) Read the actual temperature of the control thermistor.

1. Let us assume the actual temperature is 2.5 °C
2. The control command, CC, for "CONTROL SENSOR TEMPERATURE" is 01.
3. There is no send value, so we calculate the checksum (SS) by adding the ASCII values of the characters 0, 1, 0, 0, 0, 0:

ASCII Character:	Hexadecimal Value:
0	30
1	31

0	30
0	30
0	30
0	30
Sum	**121_{16}**

The 8-bit checksum is the 8 least significant binary bits of the sum, represented as 21 in hexadecimal.

4. Combining the characters in one string we send: (stx)0100021(etx).
5. If the temperature controller receives the command and the checksum is correct, it will send back: (stx)0019ca(ack). The "ca" at the end of the string is the checksum of "0019". The value 0019_{16} converts to 25_{10}. This number, when divided by 10, is 2.5--the temperature in °C. As in the other examples, if the controller did not calculate the correct checksum from the query it would send back: (stx)XXXX60(ack).

III. RS232 Communications Parameters:

JP5 PINS 7, 8, and 9

Communications Parameters:

A. Baud Rate 115,200
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. If communications is disrupted are disrupted after repeated queries, TE Technology recommends adding a delay between each command sent to allow the controller sufficient time to process and respond to the query.*

IV. Serial Commands:

1. MODEL CODE

Write Command: NA
Read Command: 00
Interpret: 9613 returned.

2. CONTROL SENSOR TEMPERATURE

Write Command: NA
Read Command: 01
Interpret: Convert returned value to decimal and divide by 10.0_{10} for temperature in °C.

3. POWER OUTPUT

Write Command: NA
Read Command: 02
Interpret: 511_{10} represent 100% output.
0_{10} returned is 0% output.

4. SECONDARY SENSOR TEMPERATURE

Write Command: NA
Read Command: 04
Interpret: Convert returned value to decimal and divide by 10.0_{10} for temperature in °C

5. ALARM STATUS

Write Command: NA

Read Command: 03

Interpret: Convert the hex number to binary and interpret bits as follows:
All zeros==means no alarms.
Bit 0==1 means HIGH ALARM 1.
Bit 1==1 means LOW ALARM 1.
Bit 2==1 means HIGH ALARM 2.
Bit 3==1 means LOW ALARM 2.
Bit 4==1 means OPEN CONTROL SENSOR.
Bit 5==1 means OPEN SECONDARY SENSOR.
Bit 6==1 means a value has changed via keypad entry.
For example, suppose the returned value is 0009_{16}. This converts to 001001_2, which means that there is a low alarm condition for the secondary sensor and a high alarm condition for the control sensor. "Bit 0" is the rightmost bit, or the least significant bit.

6. DESIRED CONTROL TEMPERATURE (SET TEMPERATURE)

Write Command: 1c

Read Command: 50

Interpret: ASCII characters which represent a hex value in two's complement form. Convert the two's complement value to a decimal value and divide by 10.0 to represent the temperature as a degrees decimal value.

7. PROPORTIONAL BANDWIDTH

Write Command: 1d

Read Command: 51

Interpret: Proportional bandwidth in degrees.
For writing, multiply desired bandwidth by 10_{10} then convert to hexadecimal. For reading, convert to decimal then divide by 10_{10}
1 degree bandwidth would be 10_{10}.
20 degree bandwidth would be 200_{10}.

8. INTEGRAL GAIN

Write Command: 1e

Read Command: 52

Interpret: Gain in repeats/minute
For writing, multiply desired integral gain by 100_{10} then convert to hexadecimal. For reading, convert to decimal then divide by 100_{10}.
0.01 repeats/minute would be 1_{10}.
1.00 repeats/minute would be 100_{10}.

9. DERIVATIVE GAIN

Write Command: 1f

Read Command: 53

Interpret: Gain in minutes.
For writing, multiply desired integral gain by 100_{10} then convert to hexadecimal. For reading, convert to decimal then divide by 100_{10}.
0.01 minutes would be 1_{10}.
1.00 minutes would be 100_{10}.

10. ALARM1 TYPE

Write Command: 27
Read Command: 5b
Interpret: 0 no load effect.
1 load off on alarm.

11. ALARM2 TYPE

Write Command: 2a
Read Command: 5e
Interpret: 0 no load effect
1 load off on alarm

12. SENSOR CHOICE

Write Command: 20
Read Command: 54
Interpret: 0 = 15K sensor is selected.
1 = 10K sensor is selected.

13. CONTROL MODE

Write Command: 21
Read Command: 55
Interpret: 0 = COOLING mode.
1 = HEATING mode.

14. LOW SET RANGE

Write Command: 22
Read Command: 56
Interpret: This is used to set the lowest temperature that the controller set point can be set to.

15. HIGH SET RANGE

Write Command: 23
Read Command: 57
Interpret: This is used to set the highest temperature that the controller set point can be set to.

16. CONTROL SENSOR OFFSET

Write Command: 24
Read Command: 58
Interpret: Value to offset control sensor in order to calibrate external sensor if desired.

17. ALARM 1 LOW SETTING

Write Command: 25
Read Command: 59
Interpret: Temperature reference to compare against control sensor for high alarm output. Temperatures are in whole degree increments. To turn the low alarm OFF set the alarm temperature to -21_{10} ($ffeb_{16}$).

18. ALARM 1 HIGH SETTING

Write Command: 26
Read Command: 5a
Interpret: Temperature reference to compare against control sensor for high alarm output. Temperatures are in whole degree increments. To turn the high alarm OFF set the alarm temperature to 200_{10} ($00c8_{16}$).

19. ALARM 2 LOW SETTING

Write Command: 28
Read Command: 5c
Interpret: Temperature reference to compare against secondary sensor for high alarm output. Temperatures are in whole degree increments. To turn the low alarm OFF set the alarm temperature to -21 ($ffeb_{16}$).

20. ALARM 2 HIGH SETTING

Write Command: 29
Read Command: 5d
Interpret: Temperature reference to compare against secondary sensor for high alarm output. Temperatures are in whole degree increments. To turn the high alarm OFF set the alarm temperature to 200 ($00c8_{16}$).

21. ALARM LATCH FUNCTION

Write Command: 2b
Read Command: 5f
Interpret:
0 = NO LATCHES
1 = ALARM 1 LATCH
2 = ALARM 2 LATCH
3 = ALARM 1&2 LATCH

22. TEMPERATURE 2 DISPLAY

Write Command: 2c
Read Command: 60
Interpret:
0 = OFF
1 = AUTOMATIC
2 = ON

23. ALARM 1 DEADBAND

Write Command: 2d
Read Command: 61
Interpret: The span in temperature that the control sensor must move before the ALARM 1 output is toggled off.
For writing, multiply desired deadband by 10_{10} then convert to hexadecimal. For reading, convert to decimal then divide by 10_{10}.
1 degree would be 10_{10}
20 degrees would be 200_{10}

24. ALARM 2 DEADBAND

Write Command: 2e
Read Command: 62
Interpret: The span in temperature that the secondary sensor must move before the ALARM 2 output is toggled off.
For writing, multiply desired deadband by 10_{10} then convert to hexadecimal. For reading, convert to decimal then divide by 10_{10}.
1 degree would be 10 decimal
20 degrees would be 200 decimal

25. ANALOG OUTPUT MULTIPLIER

Write Command: 2f
Read Command: 63
Interpret: For writing, multiply desired analog output multiplier by 100_{10} then convert to hexadecimal. For reading, convert to decimal then divide by 100_{10}. Allowable range is 0 to 1.00_{10}.
1.00 multiplier is a value of 100_{10}
0.50 multiplier is a value of 50_{10}
0.00 multiplier is a value of 0

26. LATCH CLEAR

Write Command: 33
Read Command: NA
Interpret: Send this command to reset alarm latches.

27. OUTPUT ENABLE

Write Command: 30
Read Command: 64
Interpret: 0 = OFF
1 = ON

28. EEPROM WRITE ENABLE

Write Command: 31
Read Command: 65
Interpret: 0 = OFF
1 = ON

NOTE: this command valid only for firmware versions H and higher. EEPROM WRITE ENABLE is automatically turned "ON" whenever the controller is turned on. Note: for the TC-48-20 only, regardless of the EEPROM WRITE ENABLE setting, changes made to parameters via keypad are automatically stored in the EEPROM. This feature can not be turned off.

27. REVISION LEVEL

Write Command: NA
Read Command: 05
Interpret: 08 = H
09 = I
10 = J
11 = K
12 = L
13 = M
14 = N
15 = O
16 = P
17 = Q
18 = R
19 = S
20 = T
21 = U
22 = V
23 = W
24 = X
25 = Y
26 = Z

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