Operating Manual
Model 3001 Thermoelectric Cooler Driver

Spin One
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1. Basics of Thermoelectric Cooling

A Thermoelectric Cooler (TEC) is a solid-state electrically-driven heat exchanger that can pump heat, in a direction depending on the polarity of the applied voltage, between the two flat surfaces of the cooler. The coolers operate by the Peltier Effect, by which a temperature difference can be induced when an electrical current flows through a junction of dissimilar metals. The typical thermoelectric cooler consists of alternating blocks of N-type and P-type bismuth telluride semiconductors sandwiched between, and soldered to, two opposing thin ceramic (alumina) plates. The typical TEC is a few millimeters thick, with surface areas ranging between ¼ and 5 sq. cm. The larger units are capable of pumping several tens of watts and assemblies with several coolers connected "thermally" in parallel and electrically in series can be constructed with cooling capacities limited only by the size of the electrical supply available, the number of coolers used and the size of the budget. A typical large thermoelectric cooler may operate at 5 to 10 amps, with an electrical resistance of between ½ ohm and a few ohms, depending on the geometry and number of the semiconductor junctions. Therefore, assemblies of several large series-connected thermoelectric coolers may be expected to have a voltage drop of as much as 45 volts at 10 amps of operating current, and be capable of pumping as much as a few hundred watts of heat. When used for cooling purposes, the heat that is pumped from the load through the TEC to a heat reservoir, along with the resistive heating associated with the Peltier process, is often dissipated to the surrounding air via a finned heat sink or to a water-cooled plate, the heat being removed from the water at some remote location. Usually, the temperature to be controlled is that of the heat load from which heat is removed. The temperature of the load is measured with one of several types of sensors that provide resistance, voltage or current signals. The signal is converted into a "temperature", compared with a desired operating temperature, and a command signal is derived to supply current to the TEC to force the load temperature to match the desired temperature. The time-dependence of the current supplied to the TEC must be carefully tailored to compensate for the finite thermal response time of the often massive assemblies to which large heat loads are attached.

The Model 3001 was intended for use in cooling one or more high-power laser diodes and/or the solid-state laser crystal assemblies pumped by these diode lasers. However, the Model 3001 is not limited to this application and may be used, for example, to drive a water chiller, or for other cooling tasks.

Efficient design of TEC assemblies requires a thorough understanding of their properties and limitations and is not covered within this manual. A technical note on the use of TECs for cooling electrical loads will be available from Spin One.

2. A Comment About Operating Current

Thermoelectric coolers are available in a wide range of electrical operating characteristics. Importantly, thermoelectric coolers may be chosen to have high or low resistance, while still providing the same heat pumping capacity. This is especially true for high power applications when cooling assemblies may consist of several individual TECs connected electrically in series, while operated thermally in parallel. The designer is then faced with the choice of selecting a TEC assembly, and therefore a TEC driver, that operates at high current and low voltage, or low current and high voltage. As long as operating voltages do not rise to levels that make safety compliance difficult, the higher voltage option is the desired choice, simply because the objective is to pump heat at the TEC, not to dissipate heat in connecting wire. Smaller-gauge cable also simplifies the problem of connector selection at enclosure walls.

3. Specifications - Model 3001.1

Maximum TEC Current:	+/- 10.4 Amps bipolar (heating or cooling).
Maximum TEC Voltage:	+/- 46.5 Volts.
Maximum Power Output:	475 Watts at 30 ^{o}C ambient 475 Watts at 35 ^{o}C ambient. 395 Watts at 40 ^{o}C ambient.
Derating:	Derate 16 W/^{o}C at ambient temperature above 35 ^{o}C.
Maximum Output Noise:	10 ma RMS
Temperature Range, Storage:	-20 ^{o}C to +60 ^{o}C ambient, <90% RHNC.
Temperature Range, Operating:	0 ^{o}C to +40 ^{o}C ambient, <80% RHNC..
TEC Control Range:	+100 ^{o}C to -100 ^{o}C (limited by the choice of temperature sensor, TEC heat sink architecture and heat load).
Line Voltage and Current:	Automatic Line Voltage Selection, 100-130 VAC, 6.5 Amps at maximum output power. 200-240 VAC, 3.5 Amps at maximum output power.
Sensor Operating Range	
Temperature, LM335 sensor	-40.00 ^{o}C to +100.00 ^{o}C
Temperature, AD590 sensor	-25.00 ^{o}C to +100.00 ^{o}C
Temperature, 100 Ω Platinum RTD sensor	-100.00 ^{o}C to +100.00 ^{o}C
Resistance (NTC Thermistor, 100 ma current source).	00.00 KΩ to 100.00 KΩ
Resistance (NTC Thermistor, 10 ma current source).	000.0 KΩ to 1000.0 KΩ
Display Resolution	
Temperature, LM335 sensor	0.01 ^{o}C
Temperature, AD592 sensor	0.01 ^{o}C
Temperature, 100 Ω Platinum RTD sensor	0.01 ^{o}C
Resistance (100 ma source).	0.01 KΩ
Resistance (10 ma source).	0.1 KΩ
TEC Voltage	0.01 V
TEC Current	0.01 A
Measurement Accuracy*	
Temperature, LM335 sensor	+/- 0.1 ^{o}C
Temperature, AD592 sensor	+/- 0.1 ^{o}C
Temperature, 100 Ω Platinum RTD sensor	+/- 0.2 ^{o}C
Resistance, 10KΩ NTC Thermistor,	+/- 0.1 %
Resistance, 100KΩ NTC Thermistor,	+/- 0.1 %
TEC Voltage	+/- 1%
TEC Current	+/- 1%
Drift	< .001 ^{o}C (at constant ambient and thermal load, using a properly-mounted sensor, after 1 hr. warm-up, tested at 120 W output)
Temperature Coefficient	.03 ^{o}C/^{o}C
Miscellaneous	
Weight:	10 lbs. (4.5 Kg)
Dimensions:	12” W. x 12.5” D x 3.5” H (304mm x 317mm x 89mm)
Sensor Selection:	Back-panel DIP switch.
Sensor Calibration:	Separate trim adjustments for each sensor.
Display type:	5 digit LED numeric display with ½” characters, easily visible from a distance in a bright or darkened laboratory.

* Specified temperature accuracy may be achieved for sensors that have been calibrated and linearized over a specific temperature range common to most laser diodes, (usually +5 C - +45 C) using the calibration procedures described in the operating manual.

Specifications - Model 3001.2

Maximum TEC Current:	+/- 12.5 Amps bipolar (heating or cooling).
Maximum TEC Voltage:	+/- 46.5 Volts.
Maximum Power Output:	555 Watts at 30 °C ambient 475 Watts at 35 °C ambient. 395 Watts at 40 °C ambient.
Derating:	Derate 16 W/C at ambient temperature above 35 °C.
Maximum Output Noise:	10 ma RMS
Temperature Range, Storage:	-20 °C to +60 °C ambient, <90% RHNC.
Temperature Range, Operating:	0 °C to +40 °C ambient, <80% RHNC..
TEC Control Range:	+100 °C to -100 °C (limited by the choice of temperature sensor, TEC heat sink architecture and heat load).
Line Voltage and Current:	Automatic Line Voltage Selection, 95-130 VAC, 7.5 Amps at maximum output power. 200-240 VAC, 4 Amps at maximum output power. Power Factor: 0.99

Sensor Operating Range

Temperature, LM335 sensor	-40.00 °C to +100.00 °C
Temperature, AD590 sensor	-25.00 °C to +100.00 °C
Temperature, 100 Ω Platinum RTD sensor	-100.00 °C to +100.00 °C
Resistance (NTC Thermistor, 100 ma current source).	00.00 KΩ to 100.00 KΩ
Resistance (NTC Thermistor, 10 ma current source).	000.0 KΩ to 1000.0 KΩ

Display Resolution

Temperature, LM335 sensor	0.01 deg. °C
Temperature, AD592 sensor	0.01 deg. °C
Temperature, 100 Ω Platinum RTD sensor	0.01 deg. °C
Resistance (100 ma source).	0.01 KΩ
Resistance (10 ma source).	0.1 KΩ
TEC Voltage	0.01 V
TEC Current	0.01 A

Measurement Accuracy†

Temperature, LM335 sensor	+/- 0.1 °C
Temperature, AD592 sensor	+/- 0.1 °C
Temperature, 100 Ω Platinum RTD sensor	+/- 0.2 °C
Resistance, 10KΩ NTC Thermistor,	+/- 0.1 %
Resistance, 100KΩ NTC Thermistor,	+/- 0.1 %
TEC Voltage	+/- 1%
TEC Current	+/- 1%
Drift	< .001 °C (at constant ambient and thermal load, using a properly-mounted sensor, after 1 hr. warm-up, tested at 120 W output)
Temperature Coefficient	.03 °C/°C

Miscellaneous

Weight:	10 lbs. (4.5 Kg)
Dimensions:	12” W. x 12.5” D x 3.5” H (304mm x 317mm x 89mm)
Sensor Selection:	Back-panel DIP switch.
Sensor Calibration:	Separate trim adjustments for each sensor.
Display type:	5 digit LED numeric display with ½” characters, easily visible from a distance in a bright or darkened laboratory.

† Specified temperature accuracy may be achieved for sensors that have been calibrated and linearized over a specific temperature range common to most laser diodes, (usually +5 C - +45 C) using the calibration procedures described in the operating manual.

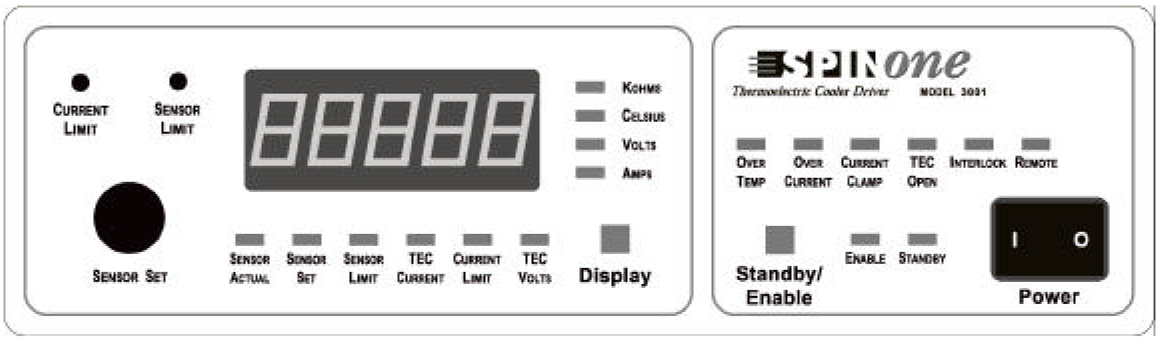


Figure 1. Front View, Model 3001

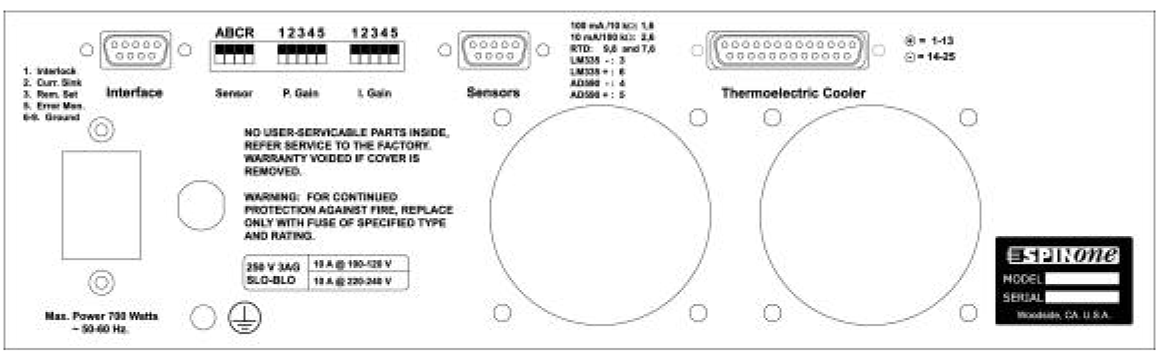


Figure 2. Rear View, Model 3001

4 Quick Setup

If you want to bypass all of the details and move ahead to operating your TE coolers, then follow these steps! However, we strongly encourage you to read and study the remainder of the details provided in the manual as soon as possible to get the best performance from your Model 3001 TEC driver.

4.1 Connect the TEC. Refer to Figure 2, "Thermoelectric Cooler". We spent some time considering the best high-current output connector and cable assembly. We decided on a very conventional 25-pin D-Sub connector/cable assembly for several reasons:

a. They are supplied pre-assembled as connector/cable sets.
b. They are very flexible and provide electrical shielding.
c. They are inexpensive and can be purchased at many computer stores or electronics supply warehouses.
d. Regardless of the selection of cable architecture, you will most likely need to use a connector at the TEC end to provide strain-relief between the TEC leads and the TEC Drive cable; Spin One provides such a connector that allows easy solder connections.

Connection to TEC Drive will require a DB-25 cable (wired straight through, with male/female connectors, equivalent to Amp #621796-4) which may be obtained at most large computer supply stores or Spin One (part # 6000.0002). Lengths up to 10 feet have been tested at Spin One. The only limitation on length is controlled by the maximum desired ohmic drop along the cable length; this loss decreases the electrical power deliverable to the TEC. Spin One provides a special connector (part #0030.0050) to be used at the TEC. Regardless of your TEC geometry, the TEC should be wired so that when the + lead of the #0030.0050 board is positive with respect to the - lead of the board, heat is pumped such that the temperature sensor gets colder. Remember that the Model 3001.1 is capable of currents to 10.4 amps (Model 3001.2 to 12.5 A) when selecting the wire gauge for the connection to the TEC.

4.2 Connect the Temperature Sensor. Refer to Figure 3, "Sensor Wiring". A DB-9 cable is used (wired straight through, with male/female connectors, equivalent to Amp #621808-2 or Spin One #6000.0001). We're assuming that you're using an LM335 temperature sensor, which provides an easy, direct temperature reading with little need for conversion. For other temperature sensors, please refer to the section "Selecting And Installing A Temperature Sensor". Set the back panel "Sensor Selector" as shown in Figure 4; the Model 3001 is pre-set at the factory for an LM335.

4.3 Install an interlock connector. Plug the connector Spin One #0030.0060 into the "Interface" connector on the back panel. Pins 1 and 6 are already jumpered within the supplied connector to enable the interlock feature. See Section 9 for further details about the suggested use of the interlock.

4.4 Install a line connector. Spin One provides a connector for 120 VAC mains used in the United States. Contact Spin One for other cable sets for international use. For operation in the United States, insure that a 3AG, 10 A fuse (Littlefuse part # 314010 or equivalent) is installed in the fuse connector adjacent to the mains connector. Adapters are available from Spin One to allow the use of an international 5 x 20 mm fuse. The Model 3001.2 is shipped with the 5 x 20 mm fuse.

4.5 Apply power to the Model 3001. Refer to the front panel diagram (Figure 1) and set the power switch to "On" (I). Cooling fans start immediately and various panel lights will activate. A red LED on the front panel may activate: this issue will be resolved below. If no red lights appear, the "Standby" LED will illuminate in approximately five seconds after the mains power has been activated.

4.6 Set The Maximum Temperature. Using the "Display" button, toggle it repeatedly to scroll the display through the various readout data. Note the value displayed in "Sensor Actual" and "Sensor Limit". The "Sensor Limit" value represents the maximum acceptable temperature above which the Model 3001 will revert to the "Fault" mode, disabling power to the TEC. When using a properly-calibrated LM335 sensor, the "Sensor Actual" position will display the sensor temperature in degrees Celsius, while the "Sensor Limit" display position will display the fault temperature set by the "Sensor Limit" knob on the front panel. If the "Sensor Limit" is set below the present "Sensor Actual" value, the front panel will indicate a temperature fault (red LED) and prevent the application of power to the TEC and also prevent the activation of the on-board high-current power supply. After the "Sensor Limit" control has been reset, the "Standby/Enable" button must be pressed once to reset the fault indication, and move to the "Standby" mode.

4.7 Set The Maximum TEC Current. Not only is there an inherent maximum current specified for a TEC by the manufacturer, there is a system-dependent maximum current set by the temperature difference between the two TEC faces and the heat load to be pumped. If either current is exceeded, the TEC can instead, become a heater, or at the very least, a very inefficient cooler. Some basic reference to the design manuals that accompany your TEC will help avoid these pitfalls. The maximum current is set with the "Current Limit" knob on the front panel and selected for display with the "Display" scroll button. If you do not know what current limit is appropriate for your thermal design, you should set the current limit to about one-half of the manufacturer's maximum current rating for the TEC as a good starting point.

4.8 Set the Desired Temperature. The "Sensor Set" front panel knob sets the desired operating temperature (in degrees Celsius for the LM335 sensor). Its setting my be monitored by selecting the corresponding readout using the "Display" button.

4.9 Applying Power To Your TEC. If red fault lights remain displayed after adjusting the temperature and current limits, depress the "Standby/Enable" button. This should reset the fault condition. The "Standby" light should illuminate, indicating that power can be applied to the

TEC. If a suitable heat-removal mechanism has been installed or enabled (in the case of air or water-cooling), apply power to the TEC by depressing the “Standby/Enable” button. Please read the section on the use of the Interface connector for safety schemes for protecting your TE coolers and load.

With the display set to “Sensor Actual”, monitor the sensor temperature as it approaches the selected operating temperature. Some optimization of the Integral and Proportional Gain settings (back panel) will be needed to minimize the time required for the temperature to settle and this optimization is discussed in Section 8.

4.10 Front Panel Indications - Current Clamp. Especially at the beginning of a cooling process when there is a large difference between the actual and set temperatures, the system will drive the TEC at the maximum current you have set at the front panel, and the “Current Clamp” LED will illuminate. As the actual temperature settles to the set temperature, the TEC current will approach a steady-state value just sufficient to hold the temperature constant and the “Current Clamp” LED will likely extinguish. In situations where the TEC is being operated at its limit beyond which it cannot provide added cooling (possibly due to inadequacies in TEC system design, excessive TEC hot-side temperature, excessive heat load or simply a low TEC current limit) the TEC driver will always be operating at current limit, the “Current Clamp” LED will be illuminated and most likely, the TEC will no longer be able to “pull” the heat load to the desired temperature. Therefore, operating in the “Current Clamp” mode is perfectly natural when the TEC driver is working hard to pull the thermal load to a newly-selected temperature. However, if the actual temperature shows no sign of approaching the set temperature, this should be a warning that the TEC architecture may be operating beyond its design limits.

There are conditions in which the "Current Clamp" indicator will illuminate but, when selecting the display to indicate TEC current and TEC current limit, it will be seen that the TEC current has not reached the TEC current limit. In this case, the Model 3001 is most likely operating at it’s maximum output voltage and the resistance of the TEC assembly is too high to allow current flow at the TEC current limit. This is due to an inappropriate selection of TECs for the required heat-pumping requirements.
Please see the section “Front Panel Indicators” for details on the meaning of the various other indicator LEDs.

4.11 Maximum Power Dissipation

The Model 3001 is rated at a maximum power output of 475 W at an ambient temperature of 35 C. Any combination of output voltage and current below their respective maxima may be used as long as the total power output is below 475W. At power outputs above this level, the internal temperature will rise above acceptable limits and the system will automatically and safely shut down. At ambient temperatures above 35 C, the system must be derated at a rate of approximately 16 W/C. While the maximum power output for the Model 3001.1 is always 475

W, at ambient temperatures below 35 C, the Model 3001.2 may be up-rated at approximately the same rate, up to a maximum power output of 555 W (at 30 C).

5. Front Panel Controls and Indicators

Please refer to Figure 1.

Power Switch
Applies line voltage to the Model 3001. As per international convention, the rocker switch is in the "Off" position when the "0" is depressed and in the "On" position when the "|" is depressed.

Standby/Enable Button
This pushbutton serves multiple purposes:
1. When the system is in the "Standby" state as indicated by the "Standby" LED indicator, depressing this button will shift the system into the "Enabled" state, applying power to the TEC if one is so connected to the back panel "TEC Drive" connector.
2. When the system is in the "Enabled" state as indicated by the "Enabled" LED indicator, depressing this button will shift the system into the "Standby" state, removing power from the TEC.
3. When the system is in the "Fault" state, as indicated by illumination of one of the red LED indicators and the absence of either the "Standby" or "Enabled" LED, depressing this button will attempt to deactivate the "Fault" state and return the system to the "Standby" state if the condition that led to the fault has been removed.

Sensor Set Control
When the "Local" control condition is selected on the back panel, the Sensor Set selects the command temperature in a way particular to the type of sensor used. For example, if an LM335 sensor is used, the Sensor Set control selects a voltage corresponding to the temperature in degrees Celsius. If a thermistor is used, the Sensor Set control selects a voltage corresponding to the resistance of the sensor, in turn related to its temperature by the Steinhart-Hart equation. The TEC driver will work to match the Sensor Set and Sensor Actual readings. When the "Remote" control condition is selected on the back panel, the Sensor Set control is inactive. The appropriate signal for setting the command temperature is now supplied from the back panel Interface connector. Refer to Section 9 which describes the use of the Interface connector for remote control of temperature.

Sensor Limit Control
The Sensor Limit control will set an upper limit on the allowed temperature for the sensor selected on the back panel. For the LM335, AD590/AD592 and Platinum sensors, the Sensor Limit sets a maximum voltage corresponding to the maximum allowed temperature of the sensor. If this temperature is exceeded, the system goes into an Over Temp fault state and disables the application of power to the TEC. For the NTC thermistors, the sensor limit control

corresponds to a minimum allowable resistance for the thermistor. See also the section on "Selecting a Temperature Sensor".

Current Limit Control

The Current Limit control selects the maximum allowed TEC current. The system will "clamp" the commanded current to not exceed the selected value.

Display Button, Display LEDs and Units LEDs

This button selects the desired quantity to be presented on the numeric display. Toggling (pressing repeatedly) scrolls the display through the list of displayable data. The "Units" display LEDs indicate which mathematical units are associated with the data being displayed. For example, when the Display LED corresponding to "TEC Current" is illuminated, the "Units" display LED corresponding to "Amps" is also illuminated.

Light Emitting Diode (LED) Status Indicators

Green LEDs: Indicate the general operating status of the system under various normal operating conditions.

Yellow LEDs: When illuminated, indicate that the system is functioning properly, but that the system is not in its "steady state" operating mode ("steady state" = TEC operating, with the TEC current at a nominal value sufficient to hold the temperature sensor at the set temperature.)

Red LEDs: When illuminated, indicate that the system has faulted. There is no danger to the TEC driver, TEC assembly or the user, but the main high-current supply within the Model 3001 has been disabled and the user should determine the cause of the fault before using the TEC driver. The red LED illuminated indicates the type of fault responsible for triggering the fault condition. To test to see that the fault has actually been "cleared", the user may simply depress the "Standby/Enable" button to test for the removal of the fault condition.

Over Temp. (Over Temperature). This red LED indicates that either the sensor has exceeded the temperature limit set point, or that the internal system power supply has exceeded its operating temperature limit. If the sensor temperature is below the Sensor Limit, then it is most likely that the cooling fans or air inlets have been blocked, or the ambient temperature is above specified limits. See the remarks in section 4.11 regarding maximum power output versus ambient temperature.

Over Current. This red LED is an indication that the high-current supply has exceeded an internal preset limit. The circuitry that senses the supply current is quite sensitive to enable good protection of the system Power FET switches and may be triggered by either short circuits at the TEC output lines or by severe transient voltage spikes generated by peripheral equipment. Because of extensive protection circuitry within the Model 3001 TEC driver, it is most unlikely that any damage has occurred if the Over Current LED is activated. If a short is suspected on the TEC Drive lines, this should be removed and the system reset with the Standby/Enable button. Since the TEC Drive lines are designed to "float" with respect to system or Earth grounds, connections between either the + or - TEC output lines will activate the Over Current LED and disable the internal high-current supply.

Interlock. This red LED is an indicator that the interlock pins #1 and #6 on the rear panel Interface connector are not connected or that the enclosure cover is not in place. System operation is not possible until both of these two conditions are corrected.

Standby. This yellow LED indicates that the system has passed its "Power Delay" phase, is free of faults and is ready to provide current to the TEC.

Enabled. This green LED indicates that current is being supplied to the TEC load.

Current Clamp. This yellow LED indicates that the system is supplying the maximum TEC current selected by the Current Limit control. This is not a fault condition, it simply means that the system is "trying its hardest" to drive your heat load to the selected temperature as quickly as possible. This condition is to be expected, especially when the "Enable" button has just been activated and when there is a large difference between the Set and Actual temperatures.

TEC Open. This yellow LED indicates that the connections to the TEC appear to be open. This LED is activated when the system is enabled and it tries to supply current to the TEC. If none flows (or an unexpectedly low amount of current flows), the LED is activated. While this is not a condition sufficient to warrant a shut-down of the high-current power supply, the source of the error should be determined, since the TEC will not be extracting heat from the load under these conditions. In such a case, with an active head-load applied to the TEC, the system would eventually trigger the Over Temp fault, shutting down the system.

Remote. This green LED indicates that the "Remote" switch has been selected on the back panel and that the Sensor Set signal must now be provided from the back panel "Interface" connector.

6. Selecting and Installing a Temperature Sensor

Several different temperature sensors may be used with the Model 3001, each having advantages and disadvantages. These aspects, their electrical connection, calibration and use are described below. Although the Model 3001 has been carefully calibrated at the factory for the "typical" sensor of each type (including 10 feet of interconnecting cable), there are always differences between sensors of the same type. Calibration of the various sensors that may be used with the Model 3001 usually requires obtaining a pair of "standards" at 0 C and 100 C. For most applications, a well-mixed slurry of ice and water will serve as the 0 C standard, while vigorously-boiling water can serve as the 100 C standard. Of course, users at elevations that differ radically from sea level will need to compensate accordingly.

It is expected that you will calibrate the sensor before installing it into a permanent fixture or location within the TEC assembly used for your particular task.. For calibration, you will need to temporarily wire the sensor to the Model 3001 Temperature Sensors connector on the back panel of the Model 3001 by simply soldering wires to the sensor. When the sensor is placed in the temperature standards, you will need to electrically insulate its lead wires from the water itself; placing the sensor snugly within a simple plastic "sandwich bag" will work well. You will need a few moments for the sensor to equilibrate to the standard as the air within the sandwich bag will tend to insulate the sensor.

Electrical connections for all sensors are described in Figures 3 and 4. You may wish to use the #0030.0050 Connector Board at the TEC end to simplify the use of DB-25 and DB-9 connector cables. The numbering on the connector board mimics the numbering of the DB-9 connector. ¼" mounting holes are provided so that the board can be attached to the typical optical table with ¼-20 tapped holes on 1" centers. The board offers some flexibility in that the sensor wiring connections can be made directly to the board or connectors can be installed (Waldom 22-01-3027) so that the sensor can be unplugged. It is possible to install several sensors simultaneously to the connector board. However, because several of the sensors share the same ground connection (pin 6), this wire may carry several sensor currents simultaneously, each contributing to an offset error. Therefore, if more than one sensor is used, they should all be calibrated simultaneously to eliminate such errors.

Finally, please refer to the section "Compensation" for important suggestions regarding the mounting of temperature sensors for best control accuracy, bandwidth and drift.

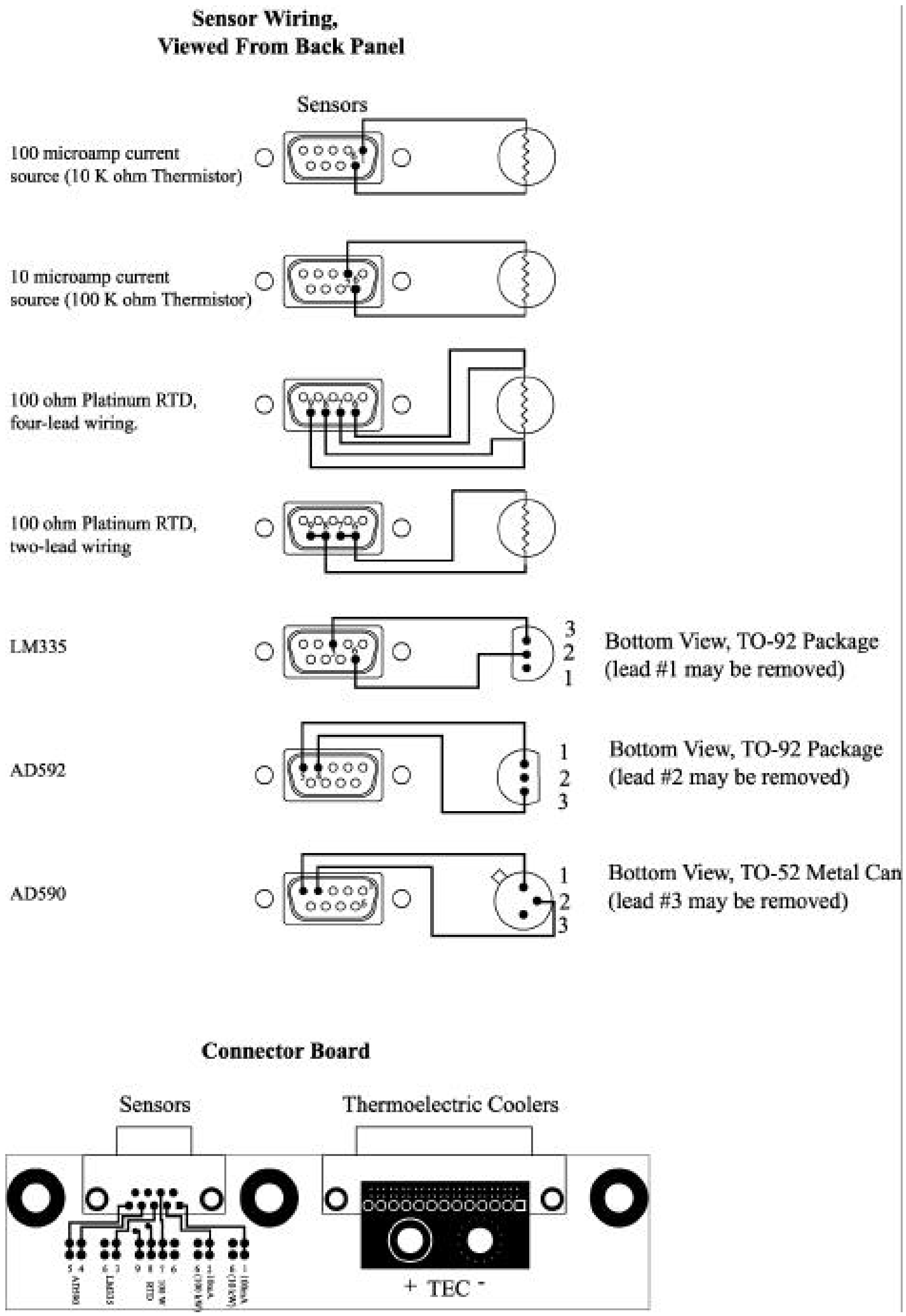


Figure 3. Sensor Wiring

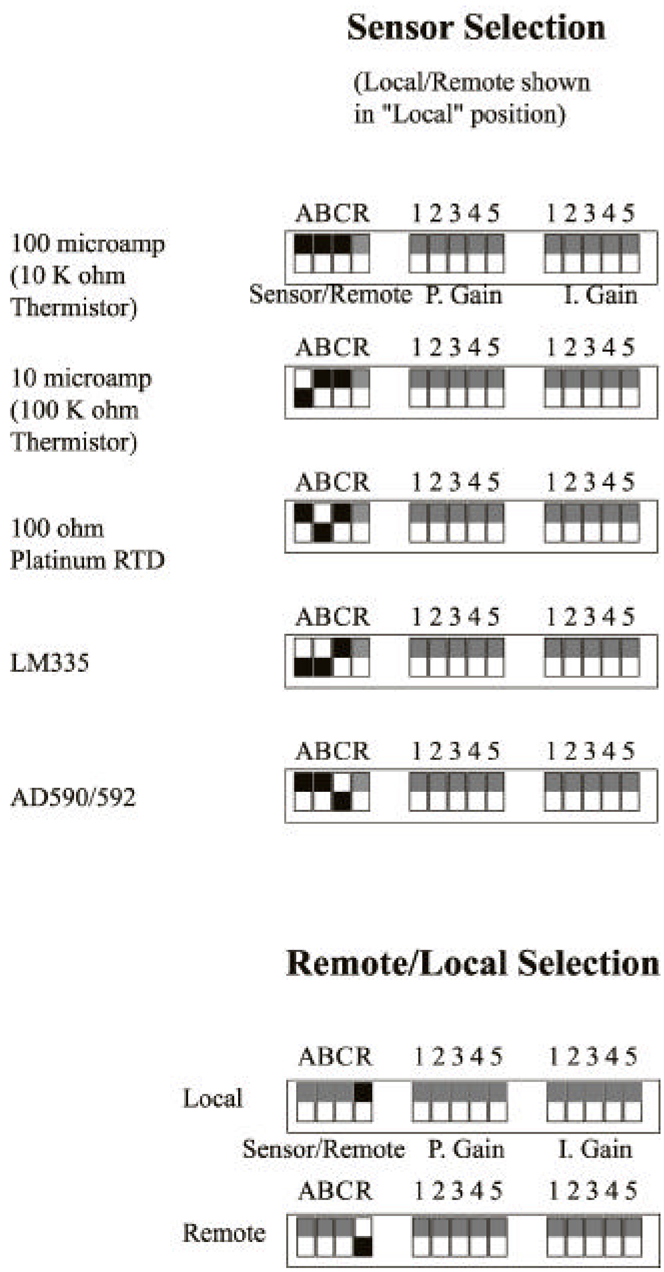


Figure 4. Sensor Selection

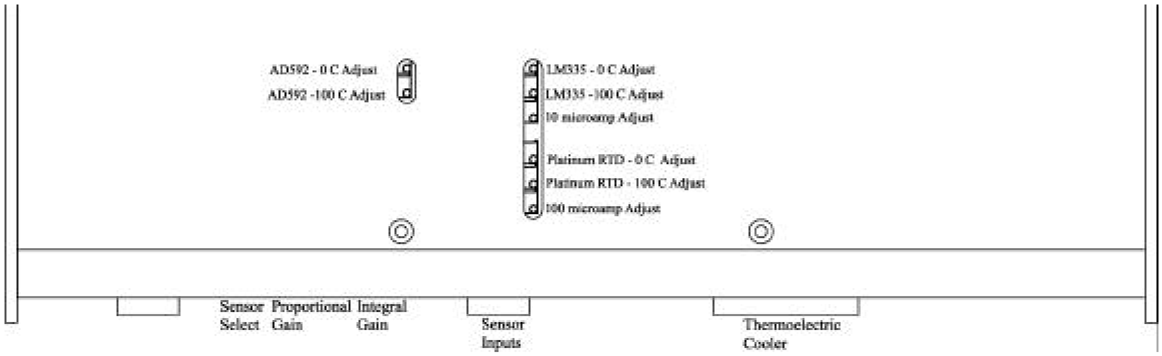


Figure 5. Calibration Adjustments

LM335

The LM335 sensor is a TO-92 package element that provides a voltage in direct proportion to its absolute temperature in Kelvin. Indeed, when driven by a simple current source, the voltage drop across this element will be 10 mV/Kelvin. For use in the Model 3001, an appropriate offset of 2.7315 volts (corresponding to 273.15 Kelvin) is subtracted and an appropriate multiplier applied to provide a display reading in Celsius. The LM335 is rather inexpensive and extremely linear as supplied, but may be adjusted for offset and gain with trim controls on the Model 3001. The operating temperature range of the LM335 is -40 C to +100 C. Since most thermoelectric coolers have a maximum operating temperature of 85 C, it is unlikely that the LM335 will be used near its maximum temperature.

For some applications, the physical size of the TO-92 package may be somewhat large, making close contact to the device to be sensed somewhat difficult. Usually, this is not much of a problem if the sensor is incorporated into the design of the cooled assembly from the beginning. The LM335 is easily affixed to the item to be monitored with a bit of thermally-conductive epoxy, such as Tra-Bond #BA-2151 (www.tra-con.com).

A disadvantage to using the LM335 is that it is a voltage source. Therefore, the use of very long lines from the Model 3001 to the LM335 can induce an additional fixed voltage drop between the sensor and Model 3001. Over the typical temperature range that one might expect to use the sensor, this effect can be calibrated out with the use of the trim controls as described in the next section.

Calibration of the LM335

Although the Model 3001 is supplied from the factory already calibrated for the typical LM335, you may wish to make these adjustments yourself. The LM335A version is accurate to within better than 0.5 C over its entire temperature range when calibrated, and can certainly be calibrated to an uncertainly of 0.1 C over an operating range that would be typical for most uses requiring thermoelectric coolers.

a. Connect the sensor as described in Figure 3 and make the appropriate "Sensor Selection" as shown in Figure 4.

b. Consult Figure 5 which shows the location of the calibration trimpot access slots in the top panel.

c. Put the Model 3001 into "Standby" mode and select "Sensor Actual" using the Display button.

d. Submerge the LM335 in the 0 C standard, allow it to equilibrate and adjust the trim potentiometer "LM335 - 0 C Adjust" for a reading of "00.00" on the numeric display.

e. Submerge the LM335 in the 100 C standard, allow it to equilibrate and adjust the trim potentiometer "LM335 - 100 C Adjust" for a reading of "100.00".

You may wish to verify the temperature calibration of the LM335 with a conventional K-type thermocouple and digital meter, such as a Fluke #52 or equivalent. Be careful to insure that the two sensors are measuring the same object! It is very easy to believe that there is a calibration error when the sensors are actually experiencing different environments.

AD592/AD590

The AD592 is a temperature-dependent current source, providing a current of 1 microamp per Kelvin. The AD590 is its higher-precision/higher-cost cousin. Because both are current sources (not voltage sources) they can be used with long lines without the problems of voltage drop in the lines. They are available in a variety of package styles and are also more expensive than the previously-described LM335.

Calibration of the AD592/AD590

Although the Model 3001 is supplied by the factory already calibrated (gain and offset) for the typical AD592, you may wish to make these adjustments yourself.

a. Connect the sensor as described in Figure 3 and make the appropriate "Sensor Selection" as shown in Figure 4.

b. Consult Figure 5 which shows the location of the calibration trimpot access slots in the top panel.

c. Put the Model 3001 into "Standby" mode and select "Sensor Actual" using the Display button.

d. Submerge the AD592 in the 0 C standard, allow it to equilibrate and adjust the trim potentiometer "AD592 - 0 C Adjust" for a reading of “00.0” on the numeric display.

e. Submerge the AD592 in the 100 C standard, allow it to equilibrate and adjust the trim potentiometer "AD592 - 100 C Adjust" for a reading of “100.00”.

10 kW and 100 kW NTC (Negative Temperature Coefficient) Thermistors

Thermistors are non-linear, negative temperature coefficient devices. That is, the resistance decreases with temperature following the so-called Steinhart-Hart equation. A “10 kΩ”thermistor is constructed to be nominally 10 kΩ at 25 C and to vary in resistance by about 4.7% per each degree C. Therefore, to achieve a 0.1 C temperature resolution, a 0.47% change of resistance must be measurable, amounting to 0.047 kΩ for a 10 kΩ thermistor at 25 C. These thermistors can be “linearized” over a portion of their total usable range or they can be matched nearly exactly with the knowledge of the so-called Steinhart-Hart coefficients. The major advantage of these sensors is that they can be made extremely small. However, since most high-power cooling applications that would use the Model 3001 have components with large, cooled surface areas, the small size of a thermistor may be of little advantage.

Thermistors are available from a range of manufacturers in a variety of package styles and calibration accuracies. Additionally, all thermistors are not fabricated with the same “mix” so will have different basic calibration characteristics. Some 10 kΩ thermistors are provided with either a precision temperature calibration in the form of a look-up table, or a precision measurement of the Steinhart-Hart coefficients. This can raise the cost of the thermistor somewhat, but the additional cost is well worth the time that one would otherwise spend in calibration. The thermistors supplied by Spin One as accessories are so-called “H” mix, manufactured by Yellow Springs Inc. and are accurate to 0.2 deg C between thermistors. They are in the form of epoxy-coated beads, nominally 0.095” in diameter, with bare wire leads. Contact Spin One for detailed information on the thermistors, or alternate thermistors that might be available.

Rather than converting the thermistor resistance to a temperature, the Model 3001 displays the actual thermistor resistance by providing a constant current through the thermistor and measuring the voltage drop across the device. A 100 microamp and 10 microamp current source are provided; the 100 microamp source is used for the 10 kΩ thermistor and the 10 microamp source is used for the 100 kΩ device. Other resistances may be chosen; select the current source that gives the best combination of significant digits on the display yet still minimizes the self-heating of the thermistor. To set the desired temperature, the user must select, with the Sensor Set knob, the desired sensor resistance in kohms corresponding to the desired load temperature. We have included a table of the resistance values of a typical 10 kΩ thermistor available from Spin One (see Figure 6).

The Model 3001 has been calibrated with a precision resistance standard, but the user may recalibrate with a resistance standard or a temperature standard. To recalibrate, the user must know either the sensor resistance at a temperature corresponding to either the 0 C or 100 C standards, or the sensor resistance at some other temperature that is measured with a secondary standard, such as a K-type thermocouple and digital meter. "100 microamp Adjust" may be adjusted to reset the 10 kΩ sensor (100 microamp source); "10 microamp Adjust" is adjusted for the 100 kΩ sensor (10 microamp source).

a. Connect the sensor as described in Figure 3 and make the appropriate "Sensor Selection" as shown in Figure 4.

b. Consult Figure 5 which shows the location of the calibration trimpot access slots in the top panel.

T	Ω	T	Ω	T	Ω	T	Ω	T	Ω	T	Ω
-10	47,540	10	18,790	30	8194	50	3893	70	1990	90	1084
-9	45,270	11	17,980	31	7880	51	3758	71	1928	91	1053
-8	43,110	12	17,220	32	7579	52	3629	72	1868	92	1023
-7	41,070	13	16,490	33	7291	53	3504	73	1810	93	994.2
-6	39,140	14	15,790	34	7016	54	3385	74	1754	94	966.3
-5	37,310	15	15,130	35	6752	55	3270	75	1700	95	939.3
-4	35,570	16	14,500	36	6500	56	3160	76	1648	96	913.2
-3	33,930	17	13,900	37	6258	57	3054	77	1598	97	887.9
-2	32,370	18	13,330	38	6026	58	2952	78	1549	98	863.4
-1	30,890	19	12,790	39	5805	59	2854	79	1503	99	839.7
0	29,490	20	12,260	40	5592	60	2760	80	1458	100	816.8
+1	28,150	21	11,770	41	5389	61	2669	81	1414	101	794.6
2	26,890	22	11,290	42	5193	62	2582	82	1372	102	773.1
3	25,690	23	10,840	43	5006	63	2497	83	1332	103	752.3
4	24,550	24	10,410	44	4827	64	2417	84	1293	104	732.1
5	23,460	25	10,000	45	4655	65	2339	85	1255	105	712.6
6	22,430	26	9605	46	4489	66	2264	86	1218	106	693.6
7	21,450	27	9227	47	4331	67	2191	87	1183	107	675.3
8	20,520	28	8867	48	4179	68	2122	88	1149	108	657.5
9	19,630	29	8523	49	4033	69	2055	89	1116	109	640.3

Figure 6. NTC Resistance Versus Temperature: YSI44006 (10k @ 25C, "H" mix, nominally accurate to 0.2 deg. C)

c. Put the Model 3001 into "Standby" mode and select "Sensor Actual" using the Display button.

d.   Submerge the NTC thermistor in a standard of your choice, allow it to equilibrate and adjust the trim potentiometer "100 microamp Adjust" for the 10 kΩ sensor (100 microamp source) or "10 microamp Adjust" for the 100 kΩ sensor (10 microamp source). Refer to Figure 6 if you have installed the 10 kΩ thermistor supplied by Spin One.

100 W Platinum RTD (Resistance Temperature Detector)

The 100 Ω platinum RTD is a device whose resistance varies nearly linearly with temperature at a rate of .385 Ω/C, starting at 100 Ω at 0 C. So, in principle, the element has a resistance of 107.7 Ω at 20 C. The Model 3001 need only measure the resistance of the sensor at a given temperature, subtract 100 Ω and apply the appropriate scale factor to convert the resistance into a temperature in degrees C. However, the resistance of the lead wires leading to the sensor itself can easily be a measurable fraction of the sensor resistance, and these lead wires also respond to temperature changes in the operating environment, even if the lead wires are not in thermal contact with the heat load.

To determine how much effect a pair of lead wires can have on the measurement process. Consider the typical 9-pin D-sub cable that one can use for the temperature sensors cable; consider a lead resistance of 20 feet of #26 copper wire added to the nominal 100 Ω resistance of the RTD. The additional 20 feet of wire has a resistance of 0.83 Ω, which would appear to be an effective temperature error of 2.2 C. Further, if we allow for a change in the room temperature of the operating environment of 10 C, this adds an additional 0.036 Ω to the lead wire, or an additional error of 0.1 C.

The calibration procedure described below can null the added fixed resistance of the lead wire, but it cannot remove the effect of the temperature-dependent component. A technique that will remove all lead wire effects is described in Figure 3c. Note that, rather than using only two wires to the resistive sensor (as is done for the 10 kΩ and 100 kΩ thermistors), four wires are used for the platinum sensor. In this architecture, two “supply” wires provide current through the RTD, and two separate “sense” wires measure the voltage drop across the RTD. Although all four wire have an equal resistance associated with them, negligible current flows through the sense wires, so the voltage drop within these wires is negligible.

Along with this drawback, platinum sensors have the disadvantage that the resistance change with temperature is small, leading to possible gain and offset errors caused by the large gain needed in the sensor amplifier. Finally, platinum RTDs have the advantage of coming in an infinite number of package styles, simplifying their integration into an existing or new TEC design. Thin film versions of platinum RTDs are available that are competitive both in price and size as compared with NTC thermistors.

The Model 3001 has been precalibrated for a 100 Ω, .00385 Ω/Ω/C thermistor. If you wish to use a 100 Ω element, “straight out of the box” with no recalibration, the four-wire connection as described in Figure 3c will be necessary. However, when used in an environment in which the sensor may be calibrated to "null out" the added lead resistance and also in which the slight temperature-dependent change of the lead wire resistance may be neglected, the two-wire connection may be used. Re-calibration of the Model 3001 for a 100 Ω Platinum RTD is very similar to the procedure for the LM335 or AD592/AD590 and is described below:

a. Connect the sensor as described in Figure 3 and make the appropriate "Sensor Selection" as shown in Figure 4.

b. Consult Figure 5 which shows the location of the calibration trimpot access slots in the top panel.

c. Put the Model 3001 into "Standby" mode and select "Sensor Actual" using the Display button.

d. Submerge the Platinum RTD in the 0 C standard, allow it to equilibrate and adjust the trim potentiometer "Platinum RTD - 0 C Adjust" for a reading of "00.0" on the numeric display.

e. Submerge the Platinum RTD in the 100 C standard, allow it to equilibrate and adjust the trim potentiometer "Platinum RTD - 100 C Adjust" for a reading of "100.00".

f. While the platinum RTD temperature/resistance dependence is nominally linear, a small temperature-squared dependence should be considered if 0.1 C accuracy is expected. As shown in the table below, if the RTD is calibrated at 0 C and 100 C, the error component will be 0.36 C at 50 C. To distribute this error over the 0-100 C range, the zero point ("Platinum RTD - 0 C Adjust") may be reset downward by 0.18 C, thereby providing a +/- 0.2 C accuracy over the full 0-100C range. Similarly, a different amount of offset may be used, to reduce the error to zero at a specific point.

Actual Temperature (deg. C)	**Actual Resistance (ohms)**	**Calculated Temperature (based on 0.385 W/C)**	**Calculated Resistance (based on 0.385 W/C)**	**Temperature Error**
-20	92.16	-20.36	92.3	0.36
0	100.00	0.00	100.0	0.00
20	107.79	20.24	107.70	0.24
40	115.54	40.36	115.40	0.36
60	123.24	60.36	123.10	0.36
80	130.90	80.24	130.80	0.24
100	138.51	100.00	138.50	0.00

Table 1. Platinum RTD Error Based On 0.385 W/C

7. Theory Of Operation.

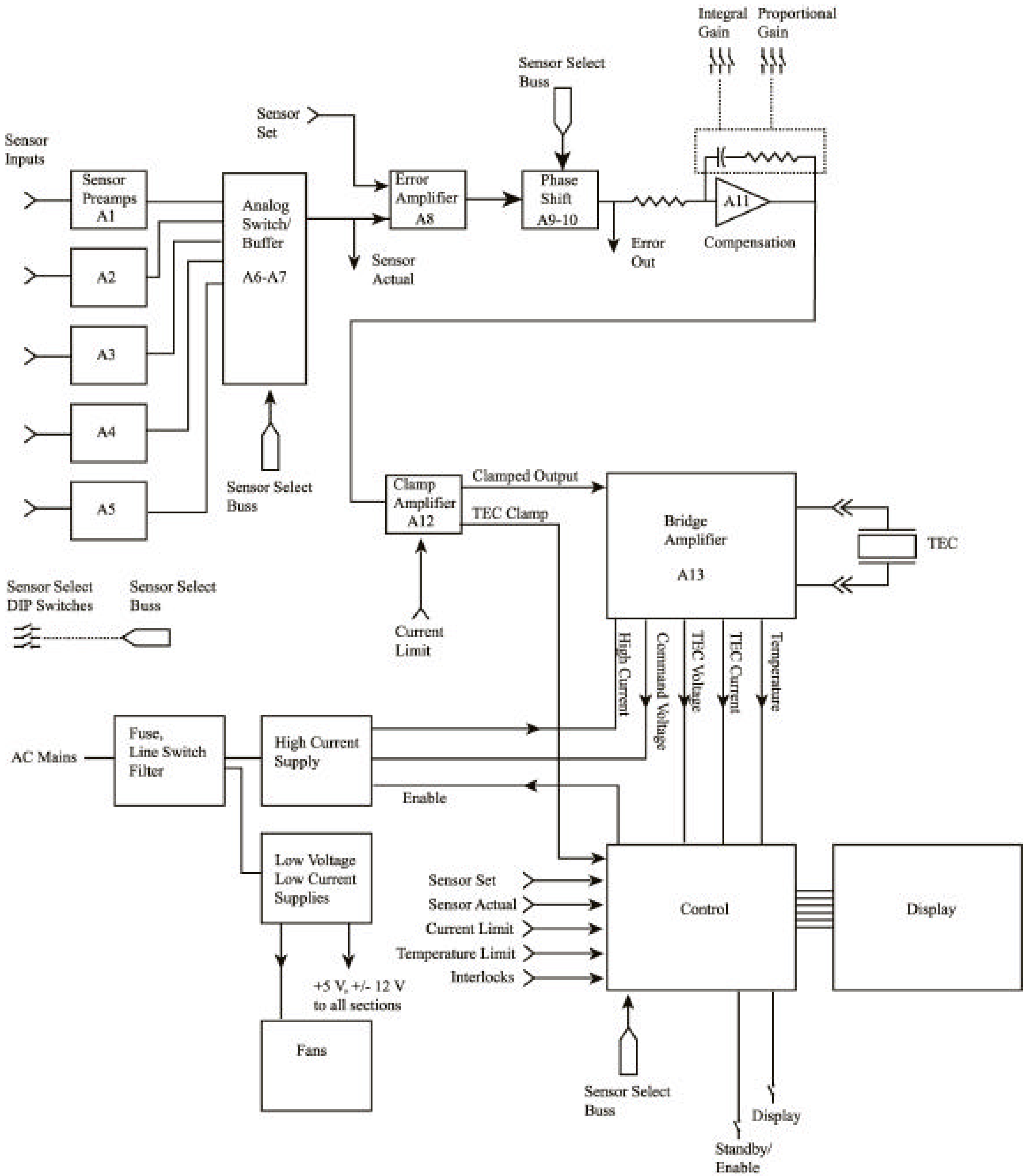


Figure 7. System Block Diagram, Series 3001

The Model 3001 connects to one or more temperature sensors at its input, and provides current to an assembly of one or more thermoelectric coolers at its output. Each sensor is provided with appropriate gain and offset trim adjustments within a separate sensor preamp A1-A5. Current sources are provided for the NTC thermistors, the Platinum RTD, and the LM335. A voltage source is provided for the AD590/AD592. Following the sensor preamps, an analog multiplexer A6 selects which sensor signal is to be used, the selection being made by three poles of a four-pole DIP switch on the back panel, and the signal is buffered by A7 to form the "Sensor Actual" signal.

A "Sensor Set" signal, the desired operating temperature, is obtained from either the front panel Sensor Set control (Local), or it is obtained from Pin 4 on the back panel Interface connector (Remote), permitting control from an outside source. This selection is made by the Local/Remote DIP switch on the back panel and indicated by the Remote status LED on the front panel.

The Sensor Actual signal is compared with the Sensor Set signal and the difference is present at the output of the error amplifier A8. Since the 10 kΩ and 100 kΩ thermistor sensors are negative-temperature-coefficient devices, while the remaining sensors are all positive-temperature-coefficient, the phase of the dependence of the error signal with sensor temperature must be inverted when the thermistors are selected. This inversion is performed by A9-A10 and the resultant Error Out signal is provided at pin 5 of the Interface back panel connector. Monitoring the Error Out signal is useful in setting the gain and time constant selection DIP switches on the back panel.

The Error Out signal is sent to the integrator A11 where the Integral and Proportional gains are set to achieve minimum temperature error and settling time. The output of the integrator is sent to the clamp amplifier A12 and limited by the front-panel-selected Current Limit signal.

The output of the clamp amplifier A12 is sent to the Bridge Amplifier A13 which is of the H-bridge configuration, allowing full bi-polar operation with a single-ended power supply. As a result, the high-current output of the Bridge Amplifier must "float" and remain isolated with respect to ground. TEC current and voltage are monitored within A13 and their signals are supplied to the front panel display. A proprietary LoadTrac circuit (patent applied for) controls the output of the single-ended high-current supply to minimize power dissipation in the Bridge Amplifier

The Control section has a variety of tasks, including

a. Selection of the operating states of Power Delay, Standby, Enabled or Fault,
b. Fault detection,
c. Front panel display control.

When power is first applied to the system, the Model 3001 goes into the Power Delay state for approximately 5 seconds. During this time, the low-voltage power supplies are activated and fault sensors are reset. At the end of this period, the system goes into the Standby state as indicated by the front panel status indicator, and the high-current supply for the Bridge Amplifier is enabled. Fault sensing is also activated in the Standby state. If any faults are detected, the system switches to the Fault state as indicated by one of the red front-panel LEDs and remains in this state even if the cause of the fault is removed. To reset the Fault state, the front-panel

Standby/Enable button is depressed, which attempts to reset the fault detectors and switch the system to the Standby state. If the condition which led to the fault has not been removed, the system remains in the Fault state. If the system remains in the Standby state, it may then be switched to the Enabled state, at which point power is applied to the TECs and temperature control is activated.

The front panel display is controlled by the "Display" button which selects the parameter to be numerically displayed on the LED readout. Display of the quantities "Sensor Actual" and "Sensor Select" depend on the type of sensor selected as per the DIP switches on the back panel. For example, if the "100 microamp source" (10 kΩ thermistor) is the selected sensor, "Sensor Select" and "Sensor Actual" will be in units of kΩ. The TEC parameters of "Current", "Current Limit" and "Voltage" are independent of sensor choice.

8. Compensation - Setting the Control Loop Parameters

This section discuss the correct setting of the Integral and Proportional gain selection switches on the back panel of the model 3001. We do not discuss control theory to a great extent, but simply provide a rough guide to the proper setting of the selection switches and some suggestions regarding the proper placement of the temperature sensor in your TEC assembly.

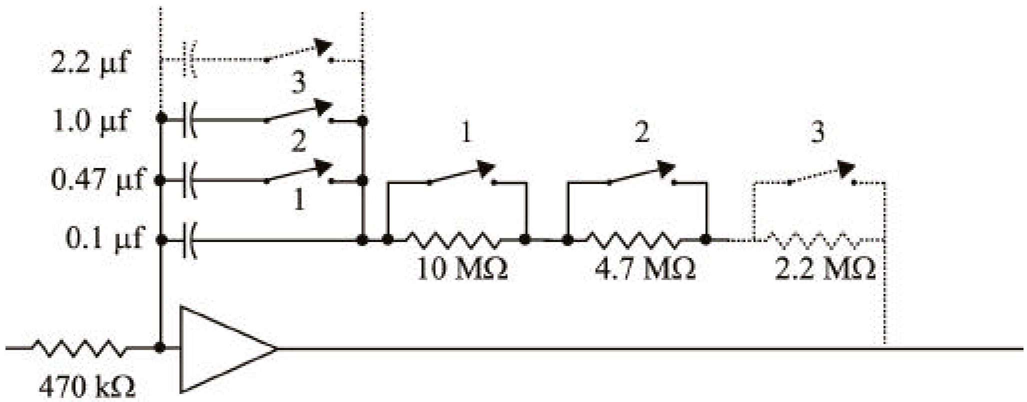
Sensor Placement

The most sophisticated compensation circuit will have little hope of correcting for a poor choice of temperature sensor placement. For best control stability and transient response, place the temperature sensor as close to the TEC cold surface as possible. In this case, it is often possible to get very fast temperature control while sacrificing some small temperature error between the sensor and heat load.

For the application in which the least temperature error is desired, perhaps at the expense of slower response to changes in thermal loading, the sensor may be placed close to the heat load. In all cases, it is best to try to reduce the "thermal distance" between the TEC cold surface and the heat load, and the "load" should be mounted on a structure with the least possible amount of thermal mass. For example, when cooling laser diode bars, there will always be some internal temperature drop between the diode junction and the mounting plate which will need to be considered. The additional temperature difference between the sensor and mounting plate may be added to this internal temperature drop.
Finally, to obtain the lowest possible temperature drift, we cannot overemphasize the importance of thermal isolation of the sensor from the ambient environment and of close thermal connection to the load to be controlled. We have spent hours chasing down a problem with drift that we first thought might be a control loop problem, only to discover that the culprit was air currents flowing over a temperature sensor that we nominally thought was thermally well-isolated.

Setting The Control Loop Parameters

Figure 8 shows the details of the Proportional-Integral compensation circuit. Two basic parameters can be adjusted; the feedback loop capacitance C (which controls the Integral gain) and the resistance R (which controls the Proportional gain). Resistors are added in series when each section of the 5-position DIP switch is moved "up" so that the proportional gain is increased approximately 6 dB per switch step as shown in Figure 9. Capacitors are added in parallel as each Integral gain switch position is moved "down". However, Integral gain is inversely proportional to the capacitance so again, Integral gain increases by about 6 dB per switch step "up".



Integral Gain Switch Position	Proportional Gain Switch Position
"1" = 0.47 µf	"1" = 10 MΩ
"2" = 1.0 µf	"2" = 4.7 MΩ
"3" = 2.2 µf	"3" = 2.2 MΩ
"4" = 4.4 µf	"4" = 1.1 MΩ
"5" = 8.8 µf	"5" = .68 MΩ

Figure 8. Basic Closed Loop Compensation Circuit

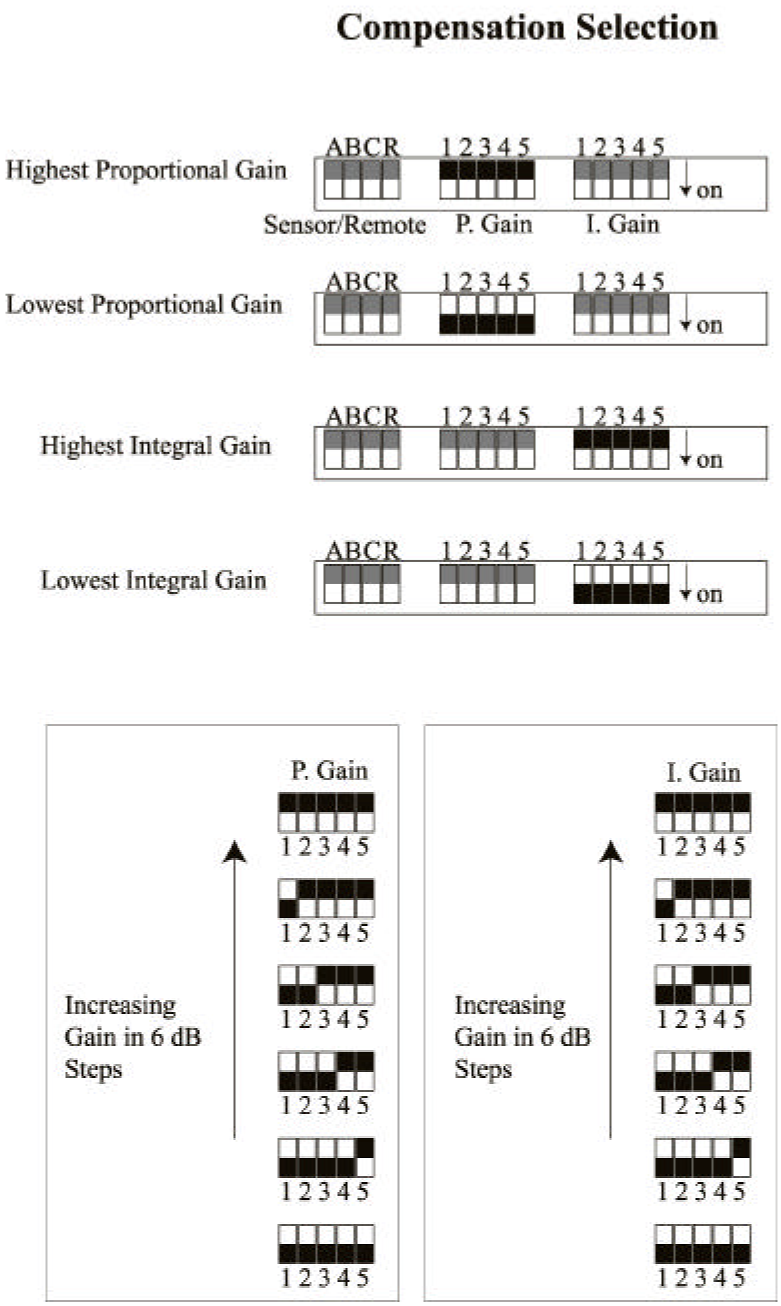


Figure 9. Integral And Proportional Gain Selection

The Proportional and Integral gain selections on the Model 3001 have been factory pre-set to those appropriate for the typical large cold plate on which one or more high-power diodes or other heat loads might be mounted. These settings should be reset if they are found not to be appropriate for your particular application. To adjust these parameters, it is helpful to be able to observe the behavior of the control loop in real time. This can be achieved by monitoring the Error Out pin on the back panel Interface connector with a slow-sweep oscilloscope or chart recorder. The chart recorder is best since it can observe slow changes that occur over periods of several seconds or longer, but some common digital oscilloscopes have the capability to act like chart recorders when their horizontal sweep rates are set very low.

Figure 9 shows the individual DIP switch poles moved up sequentially from right to left. However, given the capacitance and resistance values shown in Figure 8, the user may select any combination of DIP switch positions to obtain gain steps different than those shown. The integral gain is inversely proportional to the sum of the capacitors added when the DIP switch poles are in the down position and the proportional gain is proportional to the sum of the resistances added when the DIP switch poles are in the up position.

The basic approach to setting the integrator compensation is to monitor the Error Out signal while the system is perturbed (quickly reset the Sensor Set temperature a few degrees up or down from the Sensor Actual temperature). The Proportional gain should then be increased in small steps from the factory setting until the Error Out signal oscillates without damping. The proportional gain is then decreased one step, and then the Integral gain is then increased or decreased a step at a time as needed to maximize the damping rate.

9. Using the Interface Connector

The interface connector provides several control connections to the outside world. Connections are shown in Figure 10.

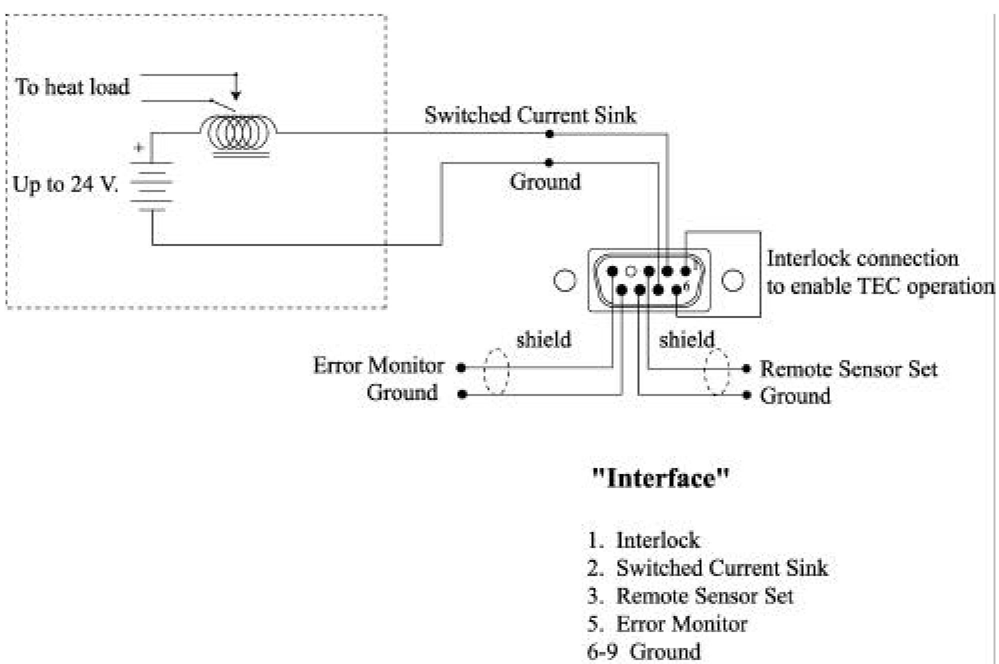


Figure 10. Interface Connector

Interlock

Pins 1 and 6 must be connected to allow the Model 3001 to switch into the "Enabled" mode and to supply current to the TEC. These connections may be permanently jumpered at the connector or they may be connected remotely. In particular, the user may wish to operate this closure with a water flow sensor that may be part of a closed-loop heat exchanger that removes heat from the hot side of the TEC. In this way, the Model 3001 would not be enabled unless there was a way to insure adequate heat removal from the "hot" side of the thermoelectric cooler.

Switched Current Sink

This connection forms a current-limited (250 ma) sink to ground that is activated when the system is in the "Enabled" mode. For example, when the Model 3001 is used to drive a TEC that cools a laser diode or other heat load which may be damaged by high temperature, this connection may be used to prevent the activation of the heat load or laser diode until the TEC is actually operating. Or, it may be used to activate a pump or fan to provide cooling to a heat sink affixed to the hot side of a TEC.

Remote Sensor Set

When the back panel "Remote" DIP switch is activated, the Sensor Set temperature command may be input from the Remote Sensor Set input. The voltage input will depend on the type of temperature sensor used. The following chart indicates the relationship between the Sensor Set voltage and the Set Temperature (for the LM335, AD590/AD592 or Platinum RTD) or the Set Resistance (for the 10 kΩ and 100 kΩ thermistors).

Sensor Type	+1 volt corresponds to:	+10 volts corresponds to:	-1 volt corresponds to:
LM335	+10 deg. C	+100 deg. C	-10 deg. C
AD592	+10 deg. C	+100 deg. C	-10 deg. C
100 Ω Platinum RTD	+10 deg. C	+100 deg. C	-10 deg. C
10 kΩ thermistor	10 kΩ	100 kΩ	not applicable
100 kΩ thermistor	100 kΩ	1 MΩ	not applicable

Error Out

This connection is useful when fine-tuning the temperature compensation. The voltage at this pin corresponds to the difference between the set and actual temperature (in the case of the LM335, AD590/AD592 and Platinum RTD) or resistance (in the case of the 10 kΩ and 100 kΩ thermistors). A positive voltage indicates that the set temperature is higher than the actual temperature (LM335, AD590/AD592 and Platinum RTD) or that the set resistance is lower than the actual resistance (10 kΩ and 100 kΩ thermistors).

Sensor Type	+0.1 volt corresponds to:
LM335	+1 deg. C error
AD592	+1 deg. C error
100 Ω Platinum RTD	+1 deg. C error
10 kΩ thermistor	1 kΩ error
100 kΩ thermistor	10 kΩ error

Output Impedance:	10 kΩ
Maximum voltage out:	+/- 12 V.

10. Troubleshooting

Symptom	Possible Problem/Solution
1. Model 3001 appears totally inactive with power switch in "on" position.	a. Line cord not connected to mains or mains inactive. b. Blown back panel fuse; replace with type listed on back panel. c. Blown internal fuses; refer to factory for service.
2. Unit appears active with power switch "on" but "Interlock" front panel fault is illuminated and cannot be reset by depressing "Standby/Enable"	a. Check that the "Interlock" pins (1 and 6 of the "Interface" connector) are connected. b. Check to see that the upper calibration panel is properly installed.
3. "Over Temp" fault is indicated. Fault cannot be reset by depressing "Standby/Enable".	a. No temperature sensor is installed. b. Incorrect sensor selection made on back panel. c. Compare "Sensor Limit" versus "Sensor Actual" on the display panel. For the LM335, AD590/AD592 and Platinum RTD, "Sensor Limit" must be less than "Sensor Actual". For the 10 kΩ and 100 kΩ thermistors, "Sensor Limit" must be greater than "Sensor Actual". d. The Model 3001 has overheated internally. Check to see that the fans are operating when the power is switched on, that none of the ventilation slots are blocked and that the ambient temperature is below the specified limit. Allow the unit to cool for 10 minutes and attempt to reset the fault by depressing "Standby/Enable". See remarks in section 4.11 regarding maximum output power versus ambient temperature.
4. "Over Current" fault is indicated. Reset is possible but fault returns when the system is "Enabled".	a. Check to see that neither the +Out or -Out lines of the Thermoelectric Cooler connector is shorted to ground.
5. "Open Load" fault is indicated. Reset is possible but fault returns when the system is "Enabled".	a. No Thermoelectric Cooler cable is connected. b. No Thermoelectric Cooler is connected.

6. "Standby" light flashes briefly and repeatedly and Reset is not possible.	a. Blown internal fuse associated with high-current power supply. Refer to factory for service.
7. TEC operates but "Sensor Actual" never reaches "Sensor Set".	a. Incorrect sensor selection on back panel. b. Current Limit set too low. c. Current Limit set too high. d. Excess thermal load for the Thermoelectric Cooler selected. e. Excess Thermoelectric Cooler hot side temperature.
8. "Sensor Actual" reaches "Sensor Set" but their difference oscillates.	a. Incorrect loop compensation parameters set on back panel. Refer to "Compensation" section of operating manual.

11. Accessories

A variety of accessories are available for the Model 3001. Some of these are shipped with the Model 3001 itself, but all can be ordered separately.

5300.0001	10 kΩ NTC thermistor (.095" dia epoxy bead with 32 AWG bare wires)
5300.0002	100 Ω thin-film Platinum RTD (.08" x .09" x .055 thick with bare leads).
3130.0001	LM335A sensor.
3130.0002	AD590 sensor.
6000.0002	25-pin D-Sub cable for TEC connection (10 feet).
6000.0001	9-pin D-Sub cable for sensor connections (10 feet).
0030.0060	Interface connector (DB-9 style).
4300.0001	10A/3AG fuses (box of 5, for use in USA).
4300.0002	10A/ 5x20 mm fuses (box of 5, for international use other than USA).
4301.0001	Fuse Adapter, 3AG type.
4301.0002	Fuse Adapter, 5x20 mm type.
0030.0050	TEC/Sensor connector board (assembled).
*********	International line cords (specify country; consult factory for part number and price).