User Manual

PTC10

Programmable Temperature Controller

Version 3.290 (June 25, 2015)

Certification
Stanford Research Systems certifies that this product met its published specifications at the time of shipment.

Warranty
This Stanford Research Systems product is warranted against defects in materials and workmanship for a period of one (1) year from the date of shipment.

Service
For warranty service or repair, this product must be returned to a Stanford Research Systems authorized service facility. Contact Stanford Research Systems or an authorized representative before returning this product for repair.

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Contents

Safety and preparation for use

Line voltage

The PTC10 operates from an 88 to 264 VAC power source having a line frequency between 47 and 63 Hz.

Power entry module

A power entry module, labeled AC POWER on the back panel of the PTC10, provides connection to the power source and to a protective ground.

Power cord

The PTC10 package includes a detachable, three-wire power cord for connection to the power source and protective ground.

The exposed metal parts of the box are connected to the power ground to protect against electrical shock. Always use an outlet which has a properly connected protective ground. Consult with an electrician if necessary.

Grounding

A chassis grounding lug is available on the back panel of the PTC10. Connect a heavy duty ground wire, #12AWG or larger, from the chassis ground lug directly to a facility earth ground to provide additional protection against electrical shock.

Line fuse

Use a 10 A/250 V 3AB Slo-Blo fuse.

Operate only with covers in place

To avoid personal injury, do not remove the product covers or panels. Do not operate the product without all covers and panels in place.

Serviceable parts

The PTC10 does not include any user serviceable parts inside. Refer service to a qualified technician.

Symbols found on SRS products

Symbol	Description
	Alternating current
	Caution - risk of electric shock
	Frame or chassis terminal
	Caution - refer to accompanying documents
	Earth (ground) terminal
	Battery
	Fuse
	On (supply)
	Off (supply)

Specifications

PTC10 temperature controller

Maximum PID rate	50 or 60 Hz, depending on AC line frequency
Data logging rate	10 samples/second/channel – 1 sample/hour/channel (can be set independently for each channel or globally for all channels)
Display resolution	0.001 °C, °F, K, V, A, W, etc. if –1000 < displayed value < 1000; 6 significant figures otherwise
PID feedback auto-tuning	Single step response or relay tuning with conservative, moderate, and aggressive response targets
Display	320 × 240 pixel touchscreen; numeric and graphical data displays.
Alarms	Upper and lower temperaturelimits or rate-of-change limits can be set on each channel. If exceeded, an audio alarm and a relay closure occur.
Computer interface	USB, Ethernet, and RS-232; optional GPIB (IEEE488.2)
Power	10 A, 88 to 132 VAC or 176 to 264 VAC, 47 to 63 Hz or DC
Dimensions	17"× 5" × 18" (WHL)
Weight	25 lbs.
Warranty	One years parts and labor on defects in material and workmanship.

PTC320 thermistor, diode, and RTD reader

Inputs	One input for 2-wire or 4-wire thermistor, diode, or RTD
Connector	6-pin 240° push-pull DIN socket
Thermistors	
Range	0 – 30, 100, 300Ω; 1, 3, 10, 30, 100, 300 kΩ; 2.5 MΩ
Excitation current	
30 Ω range	200 µA
100 Ω range	100 µA
300 Ω range	50 µA
1 kΩ range	30 µA
3 kΩ range	20 µA
10 kΩ range	10 µA
30 kΩ range	5 µA
100 kΩ range	3 µA
300 kΩ range	2 µA
2.5 MΩ range	1 µA
Initial accuracy	
30 Ω range	±0.025 Ω
100 Ω range	±0.06 Ω
300 Ω range	±0.1 Ω
1 kΩ range	±0.2 Ω
3 kΩ range	±0.6 Ω
10 kΩ range	±1.3 Ω
30 kΩ range	±4 Ω
100 kΩ range	±10 Ω
300 kΩ range	±250 Ω
2.5 MΩ range	±30 kΩ
Drift due to temperature	
30 Ω range	±0.002 Ω/°C
100 Ω range	±0.006 Ω/°C
300 Ω range	±0.006 Ω/°C
1 kΩ range	±0.01 Ω/°C

3 kΩ range	±0.03 Ω/°C
10 kΩ range	±0.1 Ω/°C
30 kΩ range	±0.15 Ω/°C
100 kΩ range	±0.5 Ω/°C
300 kΩ range	±3 Ω/°C
2.5 MΩ range	±2000 Ω/°C
RMS noise	
30 Ω range	0.003 Ω
100 Ω range	0.006 Ω
300 Ω range	0.012 Ω
1 kΩ range	0.02 Ω (= 2 mK for 300Ω thermistor at 25°C)
3 kΩ range	0.03Ω (= 0.8 mK for 1 kΩ thermistor at 25°C)
10 kΩ range	0.06Ω (= 0.6 mK for 2252Ω thermistor at 25°C)
30 kΩ range	0.1Ω (= 0.3 mK for 10 kΩ thermistor at 25°C)
100 kΩ range	0.3 Ω (= 0.2 mK for 30 kΩ thermistor at 25°C)
300 kΩ range	3 Ω
2.5 MΩ range	25 Ω

Diodes

Excitation current output	10 µA
Initial accuracy	± 100 ppm
Drift	±5 ppm/°C
Voltage input	0 – 2.5 V
Initial accuracy	10 µV + 0.01% of reading
Drift	±5 ppm/°C
RMS noise	1.5 µV

RTDs

Range	0 – 30, 100, 300Ω; 1, 3, 10, 30, 100, 250 kΩ, 2.5 MΩ
Excitation	
30 Ω range	5 mA
100 Ω range	2 mA
300 Ω range	1 mA
1 kΩ range	500 µA
3 kΩ range	200 µA
10 kΩ range	100 µA
30 kΩ range	50 µA
100 kΩ range	10 µA
300 kΩ range	5 µA
2.5 MΩ range	1 µA
Initial accuracy	
30 Ω range	±0.004 Ω
100 Ω range	±0.008 Ω
300 Ω range	±0.02 Ω (=±50 mK for Pt100 RTD at 25°C)
1 kΩ range	±0.04 Ω
3 kΩ range	±0.1 Ω
10 kΩ range	±0.2 Ω
30 kΩ range	±1 Ω
100 kΩ range	±2.5 Ω
300 kΩ range	±16 Ω
2.5 MΩ range	±30 kΩ
Drift due to temperature	
30 Ω range	±0.0006 Ω/°C
100 Ω range	±0.001 Ω/°C
300 Ω range	±0.0015 Ω/°C (=±5 mK/°C for Pt100 RTD at 25°C)
1 kΩ range	±0.005 Ω/°C
3 kΩ range	±0.01 Ω/°C
10 kΩ range	±0.03 Ω/°C

30 kΩ range	±0.06 Ω/°C
100 kΩ range	±0.2 Ω/°C
300 kΩ range	±3 Ω/°C
2.5 MΩ range	±2000 Ω/°C
RMS noise	
30 Ω range	0.00012 Ω
100 Ω range	0.0003 Ω
300 Ω range	0.0006 Ω (= 1.4 mK for Pt100 RTD at 25°C)
1 kΩ range	0.0013 Ω
3 kΩ range	0.003 Ω
10 kΩ range	0.006 Ω
30 kΩ range	0.012 Ω
100 kΩ range	0.07 Ω
300 kΩ range	0.25 Ω
2.5 MΩ range	25 Ω

PTC321 Pt RTD reader

Inputs	Four 4-wire inputs for 100Ω Pt RTDs
Connector	5-pin, 3.5mm header
Range	0 – 400 Ω
IEC751 Pt100 RTDs	–215 °C to 850 °C
Excitation current	1 mA
Initial accuracy	±30 mK
Drift due to temperature	1.4 mK/°C
Drift due to time	±15 mK/year (at 25°C ambient temperature)
Noise	2 mK RMS (at 25°C sensor temperature and 10 samples/s)
Signal detection	Card detects open and short circuit conditions

PTC323 thermistor, diode, and RTD reader

Inputs	Two inputs for 4-wire thermistor, diode, or RTD
Connectors	One 9-pin D-sub socket
Thermistors	
Range	0 – 10, 30, 100, 300Ω; 1, 3, 10, 30, 100, 300 kΩ; 2.5 MΩ, or auto
Excitation current	
10 Ω range	1 mA
30 Ω range	300 µA
100 Ω range	100 µA
300 Ω range	30 µA
1 kΩ range	10 µA
3 kΩ range	3 µA
10 kΩ range	1 µA
30 kΩ range	300 nA
100 kΩ range	100 nA
300 kΩ range	30 nA
2.5 MΩ range	1 µA
Initial accuracy (AC current, at midrange)	
10 Ω range	±0.007 Ω
30 Ω range	±0.03 Ω
100 Ω range	±0.07 Ω
300 Ω range	±0.25 Ω
1 kΩ range	±0.6 Ω
3 kΩ range	±2 Ω

10 kΩ range	±6 Ω
30 kΩ range	±25 Ω
100 kΩ range	±150 Ω
300 kΩ range	±1 kΩ
2.5 MΩ range	±3 kΩ
Typical drift due to temperature (at midrange)	
10 Ω range	± 0.0002Ω/°C
30 Ω range	± 0.0004Ω/°C
100 Ω range	± 0.002Ω/°C
300 Ω range	± 0.004Ω/°C
1 kΩ range	± 0.01Ω/°C
3 kΩ range	± 0.06Ω/°C
10 kΩ range	± 0.2Ω/°C
30 kΩ range	± 1Ω/°C
100 kΩ range	± 3Ω/°C
300 kΩ range	± 20Ω/°C
2.5 MΩ range	± 30Ω/°C
RMS noise (DC, at midrange)	
10 Ω range	0.0003 Ω
30 Ω range	0.001 Ω
100 Ω range	0.002 Ω
300 Ω range	0.006 Ω
1 kΩ range	0.02 Ω
3 kΩ range	0.06 Ω
10 kΩ range	0.2 Ω
30 kΩ range	1.0 Ω
100 kΩ range	6 Ω
300 kΩ range	40 Ω
2.5 MΩ range	10 Ω

Diodes

Excitation current output	10 µA
Initial accuracy	± 100 ppm
Drift	±5 ppm/°C
Voltage input	0 – 2.5 V
Initial accuracy	10 µV + 0.01% of reading
Drift	±5 ppm/°C
RMS noise	3 µV

RTDs

Range	0 – 10, 30, 100, 300Ω; 1, 3, 30, 300, 250 kΩ, 2.5 MΩ, or auto
Excitation	
10 Ω range	3 mA
30 Ω range	3 mA
100 Ω range	2 mA
300 Ω range	1 mA
1 kΩ range	500 µA
3 kΩ range	200 µA
1 kΩ range	50 µA
30 kΩ range	50 µA
100 kΩ range	5 µA
300 kΩ range	5 µA
2.5 MΩ range	1 µA
Initial accuracy (AC current, at midrange)	
10 Ω range	±0.005 Ω
30 Ω range	±0.005 Ω
100 Ω range	±0.008 Ω
300 Ω range	±0.015 Ω (=±50 mK for Pt100 RTD at 25°C)

1 kΩ range	±0.05 Ω
3 kΩ range	±0.1 Ω
10 kΩ range	±0.25 Ω
30 kΩ range	±1 Ω
100 kΩ range	±4 Ω
300 kΩ range	±13 Ω
2.5 MΩ range	±3 kΩ
Typical drift due to temperature (at midrange)	
10 Ω range	± 0.0001Ω/°C
30 Ω range	± 0.0001Ω/°C
100 Ω range	± 0.0002Ω/°C
300 Ω range	± 0.0004Ω/°C
1 kΩ range	± 0.001Ω/°C
3 kΩ range	± 0.003Ω/°C
10 kΩ range	± 0.01Ω/°C
30 kΩ range	± 0.02Ω/°C
100 kΩ range	± 1Ω/°C
300 kΩ range	± 2Ω/°C
2.5 MΩ range	± 50Ω/°C
RMS noise (at midrange)	
10 Ω range	0.0001 Ω
30 Ω range	0.0001 Ω
100 Ω range	0.0002 Ω
300 Ω range	0.0003 Ω (= 1.4 mK for Pt100 RTD at 25°C)
1 kΩ range	0.0007 Ω
3 kΩ range	0.002 Ω
10 kΩ range	0.007 Ω
30 kΩ range	0.008 Ω
100 kΩ range	0.12 Ω
300 kΩ range	0.2 Ω
2.5 MΩ range	10 Ω

PTC330 thermocouple reader

Inputs	Four optoisolated thermocouple inputs
Connector	Mini thermocouple jacks
Thermocouple types	E, J, K, N, or T
Range	±500 mV
Type E	–270 °C to 980 °C (range of calibration table with cold junction at 25°C)
Type J	–210 °C to 1177 °C
Type K	–270 °C to 1342 °C
Type N	–270 °C to 1281 °C
Type T	–270 °C to 383 °C
Input capacitance	<1 pF
Accuracy	±500 mK (over 12 months)
Noise	20 mK RMS (at 10 samples/s)
Drift due to temperature	20 mK/°C (type K thermocouple at 164.0 K)
CMRR	100 dB
Common mode isolation	250 VAC

PTC420 AC output card

Output	One line voltage output switched by solid-state relay
Connector	NEMA 5-15 (3-prong North American wall socket); a heater cable with a mating plug on one side and stripped ends on the other is included

Output voltage	120/240 VAC
Max. output current	5 A
On/off cycle time	Adjustable between 1 and 240 s
Max. line voltage	250 VAC
Surge current	100 A max. (non-repetitive)
Output resolution	0.1% at 10 s cycle time
Heater resistance (min.)	24 Ω (110 VAC), 46 Ω (230 VAC)

PTC430 50 W DC output card

Output	One linear, unipolar DC current source
Connector	Two banana jacks, 0.75 inch center-to-center spacing
Range	50 V 1A, 20 V 2 A, 50 V 0.5A, 20 V 0.5 A,50 V 0.1A, or 20 V 0.1 A
Output resolution	24 bits with dithering enabled or 16 bits with dithering disabled
Accuracy	±1 mA (1 A range)
	±0.1 mA (0.5 A range)
	±0.01 mA (0.1 A range)
Noise (rms), 50 Ω load,	6 µA (50 V 1 A and 20 V 2 A ranges)
DC–10 Hz	1.5 µA (0.5 A range)
	0.2 µA (0.1 A range)

PTC431 100W DC output card

Output	One unipolar DC current source
Connector	#6 screw terminals. Accepts 12–22 AWG wire or #6 spade terminals up to 0.31" wide. Max torque 9 in-lb.
Range	50 V 2A, 50V 0.6A, 50V 0.2A, 20V 2A, 20V 0.6A, 20V 0.2A
Output resolution	16 bits
Accuracy	±1 mA (2 A range)
	±0.5 mA (0.6 A range)
	±0.2 mA (0.2 A range)
Noise (rms), 25 Ω load,	5 µA (2 A range)
DC–10 Hz	1.5 µA (0.6 A range)
	0.5 µA (0.2 A range)

PTC440 TEC driver

Output	One linear, bipolar DC current source
Input	One 2- or 4-wire thermistor/RTD/IC temperature sensor input
Connector	One 15-pin DB15-F

TEC driver

Output current	-5 A – +5A
Maximum power	50W
Compliance voltage	12 V (at 0 A current)
Output resolution	0.15 mA
Accuracy	±5 mA
Current noise	0.02 mA (at 0.5A current, 22 ohm resistive load, 0.01-10 Hz bandwidth)

Temperature sensor input

Compatible sensors	
Thermistors	2 or 4-wire NTC thermistors
RTDs	4-wire platinum RTDs, 100 – 1000Ω at 0°C

IC sensors	LM335, AD590, or equivalent
Excitation current	10 µA, 100 µA, or 1 mA
Input range	
Resistance	1Ω – 250 kΩ
Voltage	0 – 2.5V
Current	0 – 1 mA
RMS electronic noise (sensor at 25°C)	
10 µA excitation	
1 kΩ thermistor	0.7 Ω = 15 mK
2252 Ω thermistor	0.6 Ω = 5 mK
10 kΩ thermistor	1 Ω = 4 mK
100 µA excitation	
1 kΩ thermistor	0.1 Ω = 1.5 mK
2252 kΩ thermistor	0.1 Ω = 0.7 mK
10 kΩ thermistor	0.2 Ω = 0.5 mK
1 mA excitation	
100 Ω Pt RTD	0.005 Ω = 6 mK
LM135/235/335	4 mK RMS
AD590/592	6 mK RMS
Initial accuracy	
10 µA excitation	
1 kΩ thermistor	1.2 Ω = 30 mK
2252 Ω thermistor	10 Ω = 100 mK
10 kΩ thermistor	66 Ω = 150 mK
100 µA excitation	
1 kΩ thermistor	0.06 Ω = 1.6 mK
2252 kΩ thermistor	0.1 Ω = 10 mK
10 kΩ thermistor	0.5 Ω = 1.1 mK
1 mA excitation	
100 Ω Pt RTD	0.004 Ω = 5 mK
LM135/235/335	70 mK
AD590/592	400 mK (sensor at 25°C)
Thermal drift	
10 µA excitation	
100 µA excitation	
1 mA excitation	
LM135/235/335	
AD592/592	

Analog I/O

Inputs/outputs	4 voltage I/O channels, independantly configurable as inputs or outputs
Connector	4 BNC jacks
Range	±10 V
Resolution	24-bit input, 16-bit output
ADC noise	30 µV RMS = 100 µV p-p (10 samples/s)

Digital I/O

Digital I/O

Inputs/outputs	8 optoisolated TTL lines, configurable as either 8 inputs or 8 outputs
Connector	One DB-25F

Relays

Outputs	4 independent SPDT relays

Connector	One 12-pin 3.5mm header
Maximum current	5 A
Maximum voltage	250 VAC

Introduction

The PTC10 is a high-performance, general-purpose laboratory temperature controller that can monitor and control temperatures with millikelvin resolution. Its features include:

Modular design

The PTC10 can accept up to four I/O cards, each of which can read up to four temperature sensors and/or drive one heater. The instrument can be customized by selecting the I/O cards best suited to your application. The PTC10 also comes standard with four ±10V I/O channels that can be used with external amplifiers to read signals and drive heaters.

Reads up to 16 temperature sensors

Temperature input cards are available for reading thermocouples, RTDs, thermistors, and diodes. For optimal signal-to-noise ratio, each temperature input channel has its own 24-bit ADC.

Drives up to 6 heaters

Three kinds of heater driver cards are available for driving resistive heaters and thermoelectric devices. Depending on the model of driver card used, two or three heaters can be directly driven at full power. In addition, the unpowered voltage I/O channels included as standard equipment can be used to drive heaters with the help of an external amplifier.

Graphical touchscreen display

The PTC10 can display temperature measurements and heater output on graphs or numeric displays. Any combination of channels can be displayed, and four different channel combinations can be saved and recalled. Touchscreen operation makes the instrument versatile and easy to use.

Logs data to USB memory devices

Up to 10 data points/second/channel can be logged to standard USB memory sticks and hard drives. The data can be transferred to a computer by simply plugging the USB device into a PC and copying the log files. Windows applications are included to graph PTC10 log files and to convert them to various ASCII text formats.

Up to 6 feedback loops

The PTC10 can control up to six different temperatures (one for each heater output) by continually adjusting the amount of power supplied to heaters. Each feedback loop can run as fast as 50 or 60 Hz, depending on the frequency of your AC power.

Runs user programs

A macro programming language makes it possible to customize the functionality of the instrument. Conditional statements, variables, and subroutine calls are supported. Up to 10 user programs can run concurrently.

Computer communications

The PTC10 can receive text commands and send responses over USB, RS-232, Ethernet, and an optional GPIB interface. All aspects of PTC10 operation can be controlled over these interfaces. Eight digital I/O lines are also provided; these can interact with user programs to control most aspects of the instrument's operation.

I/O cards

The PTC10's input and output signals are provided on removable circuit boards. The chassis has four wide and two narrow slots for these I/O cards. The wide slots (which are labeled 1–4 on the back panel) can be occupied by optional temperature input and/or heater driver cards. The narrow slots (slots 5 and 6) are occupied by general-purpose analog and digital I/O cards included as standard equipment.

Replacing I/O cards

Cards can be added, removed, or rearranged by the user. No firmware setup is needed; the system automatically recognizes the new cards and configures the front-panel controls appropriately. For most purposes, the six slots are identical and cards do not need to be arranged in any particular order. However, the lower-numbered slots are preferred for output cards because these slots get the most cooling from the fan. In addition, alarms can only activate relays on a digital I/O card if the card is installed in slot 6.

Some channel-specific settings (PID feedback parameters, alarm settings, sensor type, custom calibration data, and filter settings) may be lost when I/O cards are replaced or rearranged. However, each card's factory calibration is stored on the card and is not lost.

To add or replace an I/O card:

1. Unplug the PTC10 from the wall; otherwise, even if the instrument is switched off, live line voltage could be present. Removing and installing I/O cards while the power is turned on may permanently damage the instrument.
2. Remove the PTC10's top cover by unscrewing the four large Philips head screws on the sides of the cover and lifting the cover straight up.
3. Remove the two flathead Phillips screws immediately to the right of the card's slot on the back panel.
4. Remove the I/O card by pulling up alternately on the front and back of the card.
5. Install the new I/O card. Put the back of the card in place first, then press firmly down on the front of the card. Ensure that the top of the card is level with the tops of all the other cards.
6. Re-install the two back-panel screws and re-attach the top cover. The card can be damaged if the screws are not installed.
7. Turn the PTC10 on. The new card should automatically appear on the Select screen, and remote commands for the new card should automatically become available.

PTC320 thermistor/diode/RTD card

The PTC320 is a single-channel, multi-range input card that can read a variety of temperature sensors. It can read resistances between 1 Ω and 2.5 MΩ, and can also read diode temperature sensors.

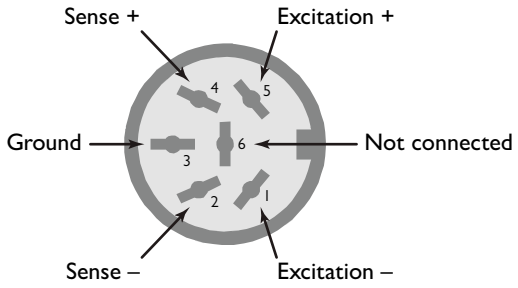
Standard calibration curves are included for the following sensors. The "Range" column indicates the range of the standard calibration curve; outside this range, no reading appears for the sensor. It may be possible to obtain a larger range by uploading a custom calibration curve.

Sensor class	Manufacturer	Calibration type	Range, K
Diode	Scientific Instruments	Si410	1.0–450
		Si430	1.0–400
		Si440	1.0–500
	LakeShore; Omega	DT-470 (=CY7)	1.4–475
		DT-670 (=CY670)	1.4–500
	Cryo-Con	S700	1.5–475
		S800	1.4–385
		S900	1.5–500
Ruthenium oxide	LakeShore	RX-102A	0.050–40
		RX-103A	1.2–40
		RX-202A	0.050–40
	Scientific Instruments	RO600	1.0–300
	Cryo-Con	R400	2.0–273
		R500	0.050–20
RTD	All	IEC751 (DIN43760)	48.15–1173.15
		US	48.15–1173.15
Thermistor	Measurement Specialties, Inc. (formerly YSI); Omega	100 Ω	193.15–373.15
		300 Ω	193.15–373.15
		1000 Ω	193.15–373.15
		2252 Ω	193.15–523.15
		3000 Ω	193.15–523.15
		5000 Ω	193.15–523.15
		6000 Ω	193.15–523.15
		10000 Ω, type B	193.15–523.15
		10000 Ω, type H	193.15–523.15
		30 kΩ	233.15–523.15
		100 kΩ	233.15–423.15
		300 kΩ	298.15–423.15
		1 MΩ	298.15–423.15

Other resistive and diode sensors can be used with the PTC320, but require custom calibration curves. For example, rhodium-iron, germanium, and carbon-glass sensors have too much sensor-to-sensor variability to use a standard curve, and therefore must be custom-calibrated.

Connecting the sensor

The PTC320 has a 6-pin DIN socket that mates with standard 6-pin push-pull DIN plugs (i.e. Digi-Key CP-1060-ND). This is the pinout of the socket, as it appears when looking at the back panel:



The outer shell of the plug is connected to the PTC10's chassis.

The PTC320 passes an excitation current through the attached RTD, thermistor, or diode, and senses the induced voltage. For the most accurate results all sensors should be read with a four-wire configuration, using separate sense and excitation leads. However, for convenience the PTC320 can also read sensors attached with only two leads.

To make a two-wire measurement, connect one end of the sensor to pin 1 (Excitation –) and the other to pin 5 (Excitation +). An inaccuracy is introduced because the resistance of the leads affects the measurement; however, some thermistors have such a high resistance that the lead resistance may be negligible in comparison.

A four-wire measurement eliminates the effect of lead resistance. In the four-wire configuration, two of the wires carry the excitation current, while the other two wires sense the voltage that the current produces across the sensor. RTDs sold with four wires normally have two wires of one color, both attached to one side of the RTD, and two of a different color attached to the other side. In this case, the RTD should be wired to the PTC320 in one of the following two ways (assuming the leads are white and black):

	Pin 1	Pin 2	Pin 3	Pin 4	Pin 5
Option 1	White	White	Unconnected	Black	Black
Option 2	Black	Black	Unconnected	White	White

RTDs with two wires can be modified by connecting two additional wires, one on each side of the sensing element and as close to the sensing element as possible.

The higher the resistance of a sensor, the more its leads pick up noise from ambient electromagnetic radiation. The noise level of high-resistance thermistors in particular can often be improved by using a shielded cable and connecting the shield to pin 3.

Excitation current

The excitation current provided to the sensor is automatically determined by the PTC320. For resistive sensors, the current is determined by the type of sensor and the measurement range as shown in the table below. When a diode sensor is in use, the card always produces a 10 µA excitation.

Measurement range	RTD excitation	Thermistor excitation	Diode excitation
30 Ω	5 mA	200 µA	
100 Ω	2 mA	100 µA	
300 Ω	1 mA	50 µA	
1 kΩ	500 µA	30 µA	
3 kΩ	200 µA	20 µA	
10 kΩ	100 µA	10 µA	
30 kΩ	50 µA	5 µA	
100 kΩ	10 µA	3 µA	
300 kΩ	5 µA	2 µA	
2.5 V (2.5 MΩ)	1 µA	1 µA	10 µA

Excitation current produced by the PTC320

The thermistor excitation current results in about 1 µW of power being dissipated in the thermistor at the high end of each measurement range. Therefore, if the dissipation constant of the thermistor is above 1 mW/°C, the measurement error due to self-heating should be less than 1 mK.

PTC321 RTD reader

Resistance temperature detectors (RTDs) use the resistance of a metal wire or film to indicate temperature. RTDs are usually made of platinum which, being very non-reactive, produces sensors with exceptional long-term stability. However, platinum RTDs are also expensive and have a limited temperature range.

Typically, the sensor's resistance is measured by passing an excitation current through it and measuring the resulting voltage drop. A four-wire RTD has two wires to carry the current and two to measure the voltage. Negligible current flows through the voltage-measuring wires, ensuring that the resistance of the wires doesn't affect the measured voltage.

RTDs usually have the "European" temperature coefficient of 0.00385 Ω/Ω/°C (IEC751 standard). The "American" coefficient of 0.00392 Ω/Ω/°C is less common, even in America.

The PTC321 RTD reader reads up to four 100 ohm platinum RTDs with a 1 mA excitation current. The current through the RTD can be reversed with each reading to null out parasitic thermocouple voltages.

The PTC321 has a range of 10–400 Ω, allowing it to read 100 Ω European-type platinum RTDs in the temperature range –215 to 850°C. RTDs with other base resistances can also be used, but over a smaller temperature range.

The PTC321 is calibrated at ambient temperatures of 25 and 35°C. An on-board temperature sensor continuously interpolates between these two calibrations to account for thermal drift of the board's electronic components. Since the PTC10 enclosure is usually elevated 2 to 3 degrees above ambient temperature, the accuracy of the PTC321 may be reduced if the ambient temperature rises above about 32°C.

To further improve measurement stability, the PTC321 can control the main enclosure fan to keep the card at a constant temperature (see the Channel.PCB button).

A narrow flange is available for the PTC321. With this flange mounted, the card can be plugged into either slot 5 (normally occupied by the analog I/O card) or slot 6 (normally occupied by the digital I/O card). Since all six slots of the PTC are identical except for their width, the I/O cards can be arranged in any order as long as they fit into the slots. To order the narrow flange from SRS, contact sales and ask for part number 7-01920-720.

Connecting the RTDs

RTDs are connected to the PTC321 with removable 5-pin, 3.5 mm terminal plugs (e.g., Weidmuller part number 169045). The supplied plugs use a tension clamp to hold the RTD wires. To install the RTD wires:

1. One side of the plug has two rows of five holes. Hold the plug with these holes facing you, with the row of five small holes on the right and the five larger holes on the left.
2. Each pair of holes is blocked by a metal clip. Place a small screwdriver into one of the small holes and firmly push it into the narrow gap to the right of the clip. The screwdriver should go in about half an inch and push the clip to the left.
3. The larger hole should open up. Place a stripped wire into the hole and remove the screwdriver.

Plugs with screw clamps (e.g., Weidmuller 161409) can also be used. It's easier to connect the RTD wires to these plugs, but the wires often come loose, resulting in noisy temperature measurements. The tension clamps are a little more difficult to install but produce a more reliable connection.

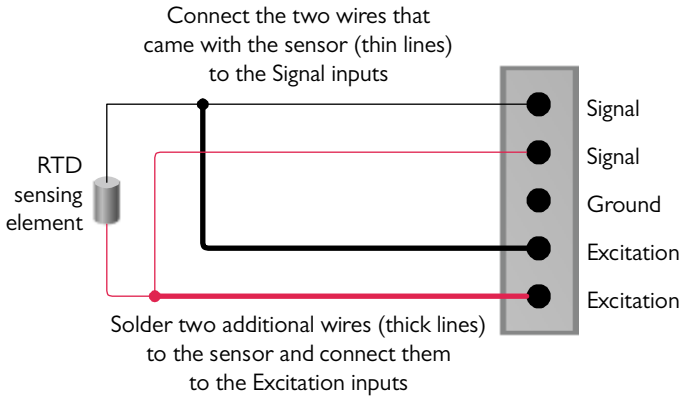
On each connector, the top two pins receive the resistance signal, the middle pin is a ground that can be connected to a shield or left unconnected, and the lower two pins provide the excitation current.

Commercial 4-wire RTDs usually have two wires of the one color connected to one end of the resistive sensor, and two of a different color connected to the other end. There is normally no shield. In this case, the RTD plug should be wired in one of the following ways (assuming black and white wires):

	Pin 1	Pin 2	Pin 3	Pin 4	Pin 5
Option 1	White	Black	Unconnected	White	Black
Option 2	Black	White	Unconnected	Black	White

If the plug is wired any other way, no reading appears when the sensor is plugged into the RTD reader.

RTDs with two wires must be modified by soldering two additional wires to the existing wires, one on each side of the sensing element and as close to the sensing element as possible. The diagram below shows how to connect the wires to the PTC321.



Connecting a 2-wire RTD to the PTC321 RTD reader

PTC323 2-channel thermistor/diode/RTD card

The PTC323 is a two-channel, multi-range input card that can read a variety of temperature sensors. It can read resistances between 1 Ω and 2.5 MΩ, and can also read diode temperature sensors.

Standard calibration curves are included for the following sensors. The "Range" column indicates the range of the standard calibration curve; outside this range, no reading appears for the sensor. It may be possible to obtain a larger range by uploading a custom calibration curve.

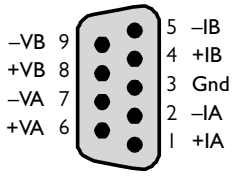
Sensor class	Manufacturer	Calibration type	Range, K
Diode	Scientific Instruments	Si410	1.0–450
		Si430	1.0–400
		Si440	1.0–500
	LakeShore; Omega	DT-470 (=CY7)	1.4–475
		DT-670 (=CY670)	1.4–500
	Cryo-Con	S700	1.5–475
		S800	1.4–385
		S900	1.5–500
Ruthenium oxide	LakeShore	RX-102A	0.050–40
		RX-103A	1.2–40
		RX-202A	0.050–40
	Scientific Instruments	RO600	1.0–300
	Cryo-Con	R400	2.0–273
		R500	0.050–20
RTD	All	IEC751 (DIN43760)	48.15–1173.15
		US	48.15–1173.15
Thermistor	Measurement Specialties, Inc. (formerly YSI); Omega	100 Ω	193.15–373.15
		300 Ω	193.15–373.15
		1000 Ω	193.15–373.15
		2252 Ω	193.15–523.15
		3000 Ω	193.15–523.15
		5000 Ω	193.15–523.15
		6000 Ω	193.15–523.15
		10000 Ω, type B	193.15–523.15
		10000 Ω, type H	193.15–523.15
		30 kΩ	233.15–523.15
		100 kΩ	233.15–423.15
		300 kΩ	298.15–423.15
		1 MΩ	298.15–423.15

Other resistive and diode sensors can be used with the PTC320, but require custom calibration curves. For example, rhodium-iron, germanium, and carbon-glass sensors have too much sensor-to-sensor variability to use a standard curve, and therefore must be custom-calibrated.

Connecting the sensor

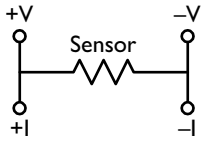
The sensors are connected via a 9-pin D-sub (DB9) socket that mates with any standard DB9 plug, such as Amphenol L717SDE09P with backshell 17E-1657-09. One plug and backshell is

provided with each PTC323.Here is the pinout of the socket, as it appears when looking at the PTC10's back panel:



Sensor In 1, for example, should be connected to pins +IA, –IA, +VA, and –VA as described below. Cable shields should be connected to pin 3, which is chassis ground.

The +I and –I pins provide a small current that should be routed to the temperature sensor through two wires, preferably a shielded twisted pair. When these leads are properly connected, a voltage equal to the excitation current multiplied by the sensor resistance is produced across the sensor. Two additional pins, +V and –V, are provided to measure the sensor voltage. These pins should be connected to the sensor with two additional wires (preferably a second shielded twisted pair) as shown in the figure below: +V should be connected to +I as close as possible to the temperature sensor, and likewise –I should be connected to –V as close as possible to the sensor. Unlike the I leads, essentially no current flows through the V leads, which allows them to accurately transmit the sensor voltage to the PTC323.Using four wires instead of two ensures that the PTC323 measures the resistance of the sensor and not the wires going to the sensor.



Four-wire sensors usually have two wires of one color attached to one side of the RTD, and two of a second color attached to the other side. In this case, the RTD should be wired to thePTC10 in one of the following two ways (assuming the leads are white and black):

	–V	–I	Ground	+V	+I
Option 1	White	White	Unconnected	Black	Black
Option 2	Black	Black	Unconnected	White	White

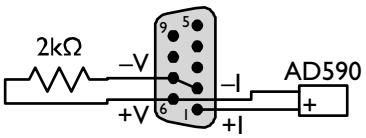
Two-wire sensors can be converted to four-wire sensors by soldering two additional wires, one on each side of the sensing element and as close to the sensing element as possible.

The higher the resistance of an RTD or thermistor, the more sensitive it is to ambient electromagnetic noise. Therefore, it's important in these cases to use a shielded cable.

Diode sensors can be connected in either direction. If no reading appears, change the current direction from Forward to Reverse.

Diode sensors are especially susceptible to electromagnetic noise because the diode rectifies any noise picked up by the sensor leads, increasing the measured voltage. It may be necessary to place the sample within an electromagnetically shielded enclosure and to put EMI filters not only the on the sensor leads but also on all other leads entering the enclosure. The filters should be located at the point where the wires enter the enclosure, and the enclosure itself should be grounded. D-sub and circular connectors with built-in filters, as well as individual filters, can be obtained from Spectrum Advanced Specialty Products. We have found their 4000 pF pi filters to be effective. These filters include capacitors to ground, which should be connected either to the ground pin (pin 3) of the PTC323's sensor input connector or to chassis ground.

The PTC323 can read AD590 sensors if the sensor is connected in series with a 2 kΩ resistor as shown below. Note that the diagram shows the sensor connected to channel A, but it can also be connected to channel B. The diagram shows the back of the DB9 connector, that is, the side that you solder to, with pin 1 in the bottom-right corner.



The 2 kΩ resistor must have a low temperature coefficient of resistance (TCR). Ordinary resistors have a TCR of about 100 ppm/°C, which means that the sensor reading will drift upward by about 30 mK for each 1°C rise in ambient temperature. Thermal drift can be reduced substantially by using a 5 ppm/°C resistor available from SRS; ask for part number 4-02502-457. For even better stability, a 1 ppm/°C resistor such as the Riedon USR2G-2KX1, available from Digi-Key, can be used. In any case, to minimize noise and drift, the resistor should be soldered directly to the pins on the DB9 plug and covered up with the backshell.

Because AD590 sensors are highly sensitive to electromagnetic interference, the AD590 wires and package must be shielded, with the shield connected to pin 3 of the DB9 connector.

Excitation current

The excitation current provided to the sensor is automatically determined by the PTC323. For resistive sensors, the current is determined by the type of sensor and the measurement range as shown in the table below. When a diode sensor is in use, the card always produces a 10 µA excitation.

Measurement range	RTD excitation	Thermistor excitation	Diode excitation
10 Ω	3 mA	1 mA	
30 Ω	3 mA	300 µA	
100 Ω	2 mA	100 µA	
300 Ω	1 mA	30 µA	
1 kΩ	500 µA	10 µA	
3 kΩ	200 µA	3 µA	
10 kΩ	50 µA	1 µA	
30 kΩ	50 µA	300 nA	
100 kΩ	5 µA	100 nA	
300 kΩ	5 µA	30 nA	
2.5 MΩ	1 µA	1 µA	
2.5 V			10 µA

Excitation current produced by the PTC323

The thermistor excitation current dissipates a maximum of 10 µW of power in the sensor at the 10 Ω range. Sensor self-heating decreases as the measurement range is increased, such that the maximum self-heating at the 300 kΩ range is only 300 pW. This feature is important for cryogenic systems, in which the sensor resistance increases and heat conductivity decreases as the temperature approaches 0 K.

PTC330 thermocouple reader

How thermocouples work

If the two ends of a conductive wire are held at different temperatures, the charge carriers (which, in a metal, are electrons) at the hot end move faster than those at the cold end. Since the electrons are free to diffuse throughout the wire, they behave somewhat like a gas that expands when it's heated: the hot end of the wire develops a lower density of electrons relative to the cold end. As a result, the hot end has a slight positive charge and the cold end a slight negative change, producing a voltage difference between the two ends. The exact voltage depends on the temperature at each end and the composition of the wire.

A thermocouple has two wires that develop different voltages in response to a given temperature difference. The wires are welded together at one end (the "hot junction") and the voltage difference is measured at the other (the "cold junction"). If we know the cold junction temperature, we can then calculate the hot junction temperature. Normally, we measure the cold junction temperature with another sensor such as an RTD or a thermistor.

Thermocouple calibration tables generally assume that the cold junction is at 0 °C. Therefore, to convert the thermocouple voltage to a temperature, it's necessary to calculate what the thermocouple voltage would be if the cold junction were at 0°C. For example, say a type K thermocouple is used to measure the temperature of some liquid nitrogen. The thermocouple reader measures a voltage of -6.829 mV and also determines that the cold junction is at 25°C. The calibration table indicates that the voltage of a type K thermocouple at 25°C is 1.000 mV. So we add 1 mV to the reading and look up the result, -5.829 mV, in the calibration table. The result is the temperature of the inaccurately named "hot junction", -196°C.

Choosing a thermocouple

Thermocouples are inexpensive and can sense a wide range of temperatures, but without frequent calibration they are accurate to no more than 1°C, partly because they tend to oxidize or otherwise react with gases in their environment. Thermocouples made from thinner wires oxidize more quickly and therefore exhibit more calibration drift than heavier-gauge thermocouples.

When selecting a thermocouple type, there's generally a tradeoff between sensitivity and stability. That is, thermocouples that produce the largest voltages also have a lot of calibration drift. With the exception of type "B", the letters that describe thermocouples (E, J, K, etc.) appear to be assigned in order of increasing long-term stability, with type C being the least stable and type T the most. Therefore, if your application requires low noise, it might be best to choose type E; for the best absolute accuracy, type T might be more appropriate.

Each PTC330 input supports one of the following thermocouple types:

Type E thermocouples have one chromel (90% nickel, 10% chromium) and one constantan (60% copper, 40% nickel) wire. It has a large voltage change per degree (68 µV/°C), resulting in excellent signal-to-noise ratio. However, its long-term stability is not very good. Type E thermocouples are resistant to oxidation, but corrode if used in a vacuum or other reduced-oxygen environment.

Type J thermocouples have one iron and one constantan wire. Above 500°C, oxidation of the iron results in poor stability. This thermocouple is mainly used in legacy applications.

Type K thermocouples have one chromel and one alumel (95% nickel, 2% manganese, 2% aluminum, 1% silicon) wire. With a wide temperature range and good stability, it's the most popular type of thermocouple. Type K thermocouples are resistant to oxidation, but corrode if used in a vacuum or other reduced-oxygen environment.

Type N thermocouples have one "Nicrosil" (nickel with 14% chromium and 1% silicon) and one "Nisil" (nickel with 4.4% silicon and 0.1% magnesium) wire. They are designed for high stability, especially at temperatures above 500°C. However, their sensitivity is low.

Type T thermocouples have one copper and one constantan wire. They are very accurate and can be used in reducing atmospheres, but their temperature range is limited.

The following table summarizes some properties of thermocouples. Two temperature ranges are given: the range that the thermocouple itself can withstand without losing its calibration, and the range supported by the PTC10's built-in calibration tables, assuming that the cold junction temperature is 25 °C. If the thermocouple temperature is outside the PTC10's range, no reading appears on the display and any feedback loops for which the thermocouple is an input do not function.

The "standard calibration" accuracy is the IEC 584-2 standard for thermocouple-to-thermocouple material variation. Not all commercial thermocouples may follow this standard; for example, Omega specifies an accuracy of 2.2°C for its type J and K thermocouples. Greater accuracy is possible if your thermocouple is custom calibrated. The accuracy values in this table only apply to the thermocouple itself and don't take into account the electronic accuracy of the PTC330.

Type	Temperature range, °C		Sensitivity, µV/°C at 25°C	Accuracy	
	Thermocouple	PTC10, cold junction at 25°C		Standard calibration, °C, at 0°C	Custom calibration, °C, <300°C
E	–200 to 870	–245 to 1025	60.9	1.7	1
J	0 to 760	–185 to 1225	51.7	1.5	0.1
K	–200 to1260	–245 to 1395	40.6	1.5	0.1
N	–270 to 1300	–245 to 1325	26.5	1.5	
T	–200 to 350	–245 to 425	40.6	0.5	0.1

Connecting thermocouples to the PTC330

The PTC330 thermocouple reader is factory-configured to read one of the above thermocouple types. The thermocouple must be equipped with a miniature jack such as Omega part number SMPW-J-M for type J, SMPW-K-M for type K, etc. The jacks on the PTC330 are color coded according to the American (ANSI) color coding scheme, i.e. type J jacks are black, type K jacks are yellow, etc. The colors may not conform to the standard colors used in other countries.

The thermocouple jacks are connected with thermocouple extension wires to a cold junction block inside the PTC10. The cold junction temperature is measured with a platinum RTD temperature sensor. The cold junction temperature is recorded so that if unexpected drift or other artifacts appear in the thermocouple readings, it can be determined whether the artifacts are due to erratic behavior of the cold junction. If readings are displayed in sensor units (see the System.Other.Units button), the raw thermocouple EMFs are displayed in millivolts, not corrected for the cold junction temperature, and the cold junction temperature is displayed in ohms.

The PTC330's inputs are optically isolated and the thermocouples can come in direct contact with electrically live metal. In this case, however, the noise level and accuracy of the measurement may be affected.

The PTC330 hardware is calibrated at ambient temperatures of 25 and 35°C. An on-board temperature sensor continuously interpolates between these two calibrations to account for thermal drift of the board's electronic components. Since the PTC10 enclosure is usually elevated 2 to 3 degrees above ambient temperature, the accuracy of the PTC330 may be compromised if the ambient temperature rises above about 32°C.

To further improve measurement stability, the PTC330 can control the main enclosure fan to keep the card at a constant temperature (see the manual entry for the Channel.PCB control).

PTC420 AC output card

The PTC420 AC output card has a solid-state relay that delivers mains current to the heater. It is intended for control of large heaters including heating mantles, heating tape, and heating blankets. The relay is either on or off; when on, the full AC mains voltage appears on the output. To vary the output power, the PTC420 switches the relay on and then off once every 10 seconds (by default) with a variable duty cycle.

The card can deliver at most 5 A of current. If the resistance of the heater is too small, the card delivers more than its rated current and may be shut down by its internal protection circuitry. In some cases the card may be damaged. The minimum permissible heater resistance depends on the AC line voltage as shown in the table below. The table also shows the maximum power that the card can deliver.

Line voltage, V	Example locations	Min heater resistance, ohms	Max power at min heater resistance, W	Max power at heater resistance *R*, W
100	Japan	20	500	10000 / *R*
120	Canada, US	24	600	14400 / *R*
220	Russia	44	1100	48400 / *R*
230	Europe	46	1150	52900 / *R*
240	China, Australia	48	1200	57600 / *R*

The total AC current delivered at any one time by the all the PTC420 cards in a single chassis cannot exceed 10 A. If it does, the PTC10's main fuse will blow.

PTC430 50 W DC output card

The PTC430 DC output card can deliver up to 50 W of power and is intended for precise control of small heaters. The card offers two voltage ranges (50 V and 20 V) and three current ranges (1A, 0.5A, and 0.1A). An auto-range feature continuously adjusts the current and voltage ranges to the smallest values needed to achieve the power specified with the channel's Hi Lmt setting.

The PTC430's maximum power output depends on the resistance of the heater; see the table below.

Heater resistance (*R*), Ω	Optimum output range	Maximum power, W
> 500	50 V 0.1 A	2500/*R*
500	50 V 0.1 A	5
100 – 500	50 V 0.5 A	2500/*R*
100	50 V 0.5 A	25
50 – 100	50 V 1 A	2500/*R*
50	50 V 1 A	50
20 – 50	50 V 1 A	*R*
20	20 V 2 A	20
10 – 20	20 V 2 A	400/*R*
10	20 V 2 A	40
< 10	20 V 2 A	4*R*

Maximum output power and optimum output range as a function of heater resistance

If the heatsink temperature of a DC output card exceeds 60°C, the card's internal protection circuitry shuts down the output. This is likely to occur if one of the 50V output ranges is used when the heater resistance is under 20Ω; if the ambient temperature outside the chassis is above 30°C; if the PTC's vents are blocked; and/or if the system fan is turned off or not working. If the heater resistance is less than 20Ω, select the "auto" range or one of the 20 V ranges to prevent thermal shutdown.

The temperature of the heatsink can be monitored by setting the System.Display.T(PCB) button to "Show", then turning the PTC10 off and back on again. A new display labeled "T(PCB)" should appear on the Select screen directly underneath the current value of the DC output card. If T(PCB) exceeds 60°C, the card's output will be shut down.

If the 50 V 1 A range is used and the average heater resistance is less than 65Ω, up to three DC output cards can be installed in a single chassis and run at full power simultaneously. If four DC output cards are installed and the average output current at any given moment exceeds 0.8A, a system reset may occur to protect the power supply from overload.

If any other range is used or the average heater resistance is greater than 65Ω, up to four DC output cards can be installed in a single chassis and run at full power.

Hardware faults

The PTC430 continuously monitors for unsafe operating conditions. If such a condition occurs and persists for more than 2 seconds, the PTC430's output is shut down. In addition, one of the following error messages appears in a pop-up window on the PTC10's screen:

- **Ground fault**: The PTC430's output is on, and the current flowing out of the card's positive terminal is not the same as the current flowing into the negative terminal. This error can occur if one of the leads is shorted to an external ground.
- **Unexpected output current**: The PTC430's output is off, but current is flowing into the negative terminal anyway. This error may indicate that the heater is shorted to a power source other than the PTC430. It can also indicate a failure of the PTC430's current output circuitry.
- **DC output card overheated**: Either the resistance of the heater is too low; the positive and negative terminals are shorted to each other; the PTC10's chassis fan has been turned off; or the chassis fan is no longer functioning. Try reducing the maximum output voltage or current, and make sure the front panel fan is running.

To re-enable the PTC430's output, disable the outputs by pressing the Output Enable key, then re-enable the outputs by pressing the Output Enable key twice.

PTC431 100W DC output card

The PTC431 DC output card can deliver up to 100 W of power and is intended for precise control of small heaters. The card offers two voltage ranges (50 V and 20 V) and three current ranges (2A, 0.6A, and 0.2A). An auto-range feature continuously adjusts the current and voltage ranges to the smallest values needed to achieve the power specified with the channel's Hi Lmt setting.

The 20V range can be used to limit the output voltage for safety purposes. Selecting this range does not otherwise affect the performance of the card. On the other hand, the 0.6A and 0.2A current ranges offer lower noise levels and are intended to be used when very precise temperature control is needed.

The maximum power that the PTC431 can deliver depends on the resistance of the heater; see the table below.

Output range	Heater resistance (*R*), Ω	Maximum power, W
50 V 2 A	<10	0
	10 – 25	4*R*
	25	100
	>25	2500/*R*
50 V 0.6 A	<75	0.4*R*
	75	33
	>75	2500/*R*
50 V 0.2 A	<250	0.04*R*
	250	10
	>250	2500/*R*

Maximum output power as a function of output range and heater resistance

If the heatsink temperature of a DC output card exceeds 60°C, the card's internal protection circuitry shuts down the output. This is likely to occur if the heater resistance is under 10Ω; if the ambient temperature outside the chassis is above 30°C; and/or if the system fan is turned off or not working.

Although up to four PTC431 cards can be installed in a chassis, only two can be run at full power at any given time. If more than two PTC431 cards are installed, their output should be limited to half their maximum value, either by using the 20V range or by setting the upper limit to 50W.

Hardware faults

The PTC431 can detect certain unsafe operating conditions. If such a condition occurs and persists for more than 2 seconds, the PTC431's output is shut down (to re-enable the output, disable all outputs by pressing the Output Enable key, then re-enable the outputs by pressing the Output Enable key twice). In addition, one of the following error messages appears in a pop-up window on the PTC10's screen:

- **Measured heater current differs from desired value**: The PTC431's output is on, and the current at the positive terminal differs from the desired current by more than 0.25A.

This error can occur if the card is out of calibration. It can also mean that the card has been damaged and is no longer capable of correctly regulating its output current or of producing its rated output current.

- **Current at + and – heater terminals is different**: The PTC431's output is on, and the current at the positive terminal differs from the current at the negative terminal by more than 0.25A. This error can occur if one of the leads is shorted to an external ground.
- **Output is off but heater current was detected**: current is flowing into the negative terminal even though the positive terminal isn't producing any current. This error may indicate that the heater is shorted to a power source other than the PTC10. It can also indicate a failure of the card's current output circuitry.
- **Output card overheated**: Either the resistance of the heater is less than 10 ohms; the positive and negative terminals are shorted to each other; the ambient temperature is too high; or the PTC10's chassis fan is not working. Try reducing the maximum output voltage or current, and make sure the front panel fan is running.

PTC440 TEC driver

The PTC440 includes a current source to drive a thermoelectric cooler and a sensor input for a thermistor, RTD, or IC temperature sensor. The card has a single 15-pin D-sub connector for both sections. The pinout follows. Pins 7 and 8 are shown in bold because they must be connected in order to read a sensor; the other sensor pins are optional. Likewise, at least one TEC current+ pin and one TEC current– pin must be connected to use a TEC; the other TEC pins are optional.

15	Sensor signal –	**8**	**Sensor excitation –**
14	Sensor excitation +	**7**	**Sensor signal +**
13	Not connected	6	Sensor shield
12	TEC sense –	5	TEC shield
11	Not connected	4	TEC current –
10	TEC sense +	**3**	**TEC current –**
9	Not connected	2	TEC current +
		1	**TEC current +**

TEC driver section

A thermoelectric cooler (TEC), also referred to as a Peltier device, is a solid-state electric heat pump that can both heat and cool, depending on the direction of current flow. Thermoelectric coolers are generally used for precise temperature control of small objects in the range of -100–100°C.

With its high-current, low-voltage output, its ability to change the direction of current flow, and circuitry to protect the TEC from excessive voltages, the PTC440 is primarily intended to drive TEC devices. However, it can also drive low-resistance (optimally 2.4 ohm) resistive heaters. In this case, the lower output limit should be set to 0 A and the heater should be connected to pins 1 and 3.

If the TEC is unplugged while current is flowing, or if the current is turned on when no TEC is present, the card's output is disabled and remains disabled until its output is set to zero. This feature ensures that the voltage between the output terminals is always zero when a TEC is plugged in. A nonzero voltage would produce a destructive current spike when the TEC is plugged in.

Therefore, if the PTC440 does not produce any output current, turn the current off and back on again, either by pressing the PTC10's "Output Enable" button three times or setting the output value to zero with the Channel.value control.

Connecting the TEC

Connect the TEC to pins 1 and 3. Pins 2 and 4 can also be connected to reduce contact resistance.

The PTC440 is a current source, that is, it has direct control over the current that passes through the TEC but not the voltage. Since thermoelectric coolers are easily destroyed by both voltages and currents even slightly above their rated maximum, the PTC440 provides a voltage input (Vmon) to monitor the TEC voltage. The connections for this input are the TEC sense + and TEC sense – pins. If these leads are connected to the TEC at the same locations as the TEC + and – leads, respectively, Vmon shows the voltage across the TEC. If the leads are not connected, Vmon shows the voltage at the PTC's back panel.

If only a small current passes through the TEC even at its maximum voltage, the TEC may have been damaged by excessive current or voltage.

Maximum TEC voltage

The TEC driver has four voltage ranges: 3, 6, 9, and 12V. In general, the lowest possible voltage range should be used; besides potentially damaging the TEC, the larger voltage ranges create excess heat inside the PTC chassis and cause the PTC's fan to run at high speed.

However, when selecting a voltage range, it's important to account for the resistance of the wires you've used to connect the TEC. This resistance can significantly reduce the voltage available to the TEC. For example, if the wires have a resistance of 0.5 ohms and a 5A current is flowing through them, the wires will reduce the available voltage by 2.5V. Therefore, if the 3V range is selected, the maximum voltage across the TEC will only be 0.5V. If the TEC sense leads have been connected, this is the maximum voltage that will appear in the Vout display.

To minimize such voltage losses, heavy-gauge wires should be used to connect the TEC. Standard DB-15 cables in particular should not be used because their thin wires absorb most of the PTC440's output power.

The Vmon channel has a voltage limit, Vmax. If the voltage at the TEC exceeds Vmax, the PTC440's output is shut off. The output will remain disabled until it is set to zero using either the Output Enable key or the "off" button on the Channel Setup screen. If the sense leads have been connected, the lead resistance does not have to be taken into account when setting Vmax.

In some cases, the output may exceed Vmax every time the PID feedback is enabled. To avoid this, temporarily set the ramp rate to a low value (i.e. 1 °C/s) when enabling the feedback.

Temperature input section

The PTC440 has a sensor input that can read thermistors, RTDs, AD590, and LM135/LM235/LM335 temperature sensors. The PTC440's temperature input should only be used when temperature stability of ~0.1°C is acceptable. For more demanding applications the sensor should be read with a dedicated input card such as the PTC320 (for thermistors, RTDs, and diodes), PTC321 (for 100 Ω RTDs only), or PTC330 (thermocouples). These cards provide lower noise and greater accuracy than the PTC440.

Connecting the temperature sensor

RTDs: 4-wire RTDs should be used to ensure accuracy. Two of the wires are normally white and are connected to one end of the resistive sensor, while the other two are black, red, or yellow and are connected to the other end. There is normally no shield. In this case, the RTD should be wired in one of the following ways (assuming black and white wires):

	Pin 7	Pin 8	Pin 14	Pin 15
Option 1	White	Black	White	Black
Option 2	Black	White	Black	White

Thermistors: Two-wire thermistors should be connected to pins 7 and 8.

LM135/LM235/LM335: The LM135, LM235, and LM335 are integrated circuit temperature sensors. If an excitation current between 400 µA and 5 mA is passed through the sensor, the voltage drop across the sensor is 10 mV/K. The three models have different temperature ranges, with the LM135 having the largest range and the LM335 the smallest. For the best possible accuracy the sensors can be connected in a 4-wire configuration, just like an RTD. However, it is more common to connect the device in a 2-wire configuration, leavings pins 14 and 15 of the PTC440 unconnected. The first row of the table below lists the four sensor input pins on the PTC440's output connector; the second and third rows show which leads of the LM135/235/335 should connect to those pins.

	Pin 7	Pin 8	Pin 14 (optional)	Pin 15 (optional)
8-pin SOIC	Pin 8	Pin 4	Pin 8	Pin 4
Other packages	+	–	+	–

AD590/AD592: The AD590 and AD592 are an integrated circuit temperature sensors. When a voltage between 4 and 30V is applied to the device's two terminals, a current of 1 µA/K flows through the device. The two models have different packages and temperature ranges, with the AD590 having a range of -55 – 150°C and the AD592 a range of -25 – 125°C. The AD590/592 can be connected in a 2- or 4- wire configuration as shown in the table below. For the 2-wire configuration, leave PTC440 pins 14 and 15 disconnected.

	Pin 7	Pin 8	Pin 14 (optional)	Pin 15 (optional)
8-pin SOIC	Pin 2	Pin 3	Pin 2	Pin 3
Other packages	+	–	+	–

Sensor excitation current

The excitation current provided to resistive sensors can be set to 10 µA, 100 µA, 1 mA, or auto. In auto current mode, the sensor resistance is continuously monitored and the excitation current is adjusted whenever the sensor resistance rises above or drops below the levels shown in the table below. The "auto" setting always produces a 10 µA excitation when a diode sensor is in use, or 1 mA when an LM335 or AD590 sensor is in use.

Sensor resistance	Excitation current
<2 kΩ	1 mA
1– 20 kΩ	100 µA
>10 kΩ	10 µA

Excitation current produced by the "auto" current setting on the PTC440 TEC driver (for resistive sensors only)

Note that the resistance ranges overlap; if the sensor resistance is between 1 and 2 kΩ, for example, the TEC driver can use either 1 mA or 100 µA excitation. If possible, the excitation current is kept at its previous value.

A slight temperature glitch may occur when the PTC440 switches from one range to the next. If these glitches could disrupt your experiment, set the excitation current manually.

A/D rate

Some TECs are capable of very fast response rates. If the temperature of your TEC changes very quickly (on the order of 1 second) when a current is passed through it, it's recommended to reduce the system A/D rate (set with the System.Other.A/D rate command) from its default 100 ms to 50 ms. Operating the PID feedback loop at a faster rate allows it to more precisely control the system temperature and, therefore, results in a more stable temperature.

PTC510 analog I/O card

This card is included as standard equipment and fits in either of the two narrow I/O card slots. Each of its four channels can be either an input (±10V, 24-bit ADC) or an output (±10V, 16-bit DAC). Each channel has a red back-panel LED that lights up when the channel is an output.

The analog I/O channels can be used as PID inputs or outputs. Since each channel can only supply up to 10 mA of current, the analog I/O can't be used to drive a heater directly, but can be connected to an external amplifier.

If the I/O type of an analog I/O channel is "set out" or "meas out", buttons to configure the channel's PID feedback appear on the Channel Setup screen. The corresponding remote instructions are also available. If the channel's I/O type is "input", the PID instructions are not available and the PID feedback loop is disabled. Instead, controls and remote instructions for an alarm, lowpass filter, difference filter, time derivative, and offset/gain calibration appear. These controls disappear, the remote instructions are not available, and the functions are disabled when the channel is an output.

PTC520 digital I/O card

This card is included as standard equipment and fits in either of the two narrow I/O card slots, although for compatibility with the PTC's alarms it should be installed in slot 6. It offers four relays, each capable of passing up to 5A of current. It also has eight isolated TTL I/O lines on a 25-pin connector that's compatible with the pinout of the standard PC parallel port. The TTL lines can be used as inputs or outputs, but all eight must have the same direction.

The relays are hosted on a single 12-pin pluggable terminal block. The four relays are labeled "A" through "D", and each relay has three connections labeled "NC" (normally open), "COM" (common), and "NO" (normally open). The relay is in its "normal" or "deactivated" state when the PTC is turned off, when its outputs are not enabled, or when the relay is set to 0. In this state, the "NC" pin is connected to the "COM" pin and the "NO" pin is unconnected. When the relay is set to 1 and the outputs are enabled, the relay is activated: the "NO" pin is connected to the "COM" pin and the "NC" pin is unconnected.

The relays appear on the PTC10 display as a single 4-bit integer value between 0 and 15. If no relays are activated, the value is 0. Each relay, if activated, adds the following to the displayed value:

Relay	Value
A	1
B	2
C	4
D	8

Therefore, if the relay channel reads "2", only relay B is activated. If the channel reads "6", relays B and C are activated. Conversely, setting the relay channel to 6 activates relays B and C, and deactivates the other relays. To set an individual relay from a macro or serial port without affecting the states of other relays, use a bitwise operator; for example, the remote command

```
relays |= 4
```

activates relay C, while the remote command

```
relays &= 11
```

deactivates relay C. See the "Remote programming" section of this manual for more information on remote commands.

The eight TTL lines are located on a standard 25-pin D-sub connector with the following pinout (the pin numbers are usually printed next to the pins on D-sub connectors):

1	Unconnected	14	Unconnected
2	D0	15	Unconnected
3	D1	16	Unconnected
4	D2	17	Unconnected
5	D3	18	Unconnected
6	D4	19	Gnd
7	D5	20	Gnd
8	D6	21	Gnd
9	D7	22	Gnd
10	+5V	23	Gnd
11	+5V	24	Gnd
12	Gnd	25	Gnd
13	Unconnected		

Since the digital I/O lines are floating, at least one "gnd" pin must be connected to the signal ground of whatever system the digital I/O is interfaced with. Alternatively, if the digital I/O lines are configured as inputs, a +5V pin can be shorted to any of the inputs D0 to D7 to pull them high, or a "gnd" pin shorted to the inputs to pull them low. The +5V pins are current-limited with 4.7 kΩ resistors and are not intended to power a remote system.

The status of the eight digital I/O lines is reported on the PTC10 display as a single eight-bit integer value. Each I/O line is assigned an integer value as shown in the following table:

Bit	Value
D0	1
D1	2
D2	4
D3	8
D4	16
D5	32
D6	64
D7	128

The "DIO" value shown on the PTC10's display is the sum of the values of all set bits. For example, if only bits D1 and D3 are set, a DIO value of 2 + 8 = 10 is displayed.

Using the remote interface, macros can be defined that associate the digital I/O lines with most functions of the PTC10. The remote interface provides bitwise operators to set and query the relays and digital I/O lines.

The DIO lines can be used to pass a single, 8-bit value into or out of the PTC. The PTC treats the DIO like any other channel; for example, its value can be plotted or used in a PID feedback loop.

Virtual channels

The digital I/O card has three virtual channels with the default names V1, V2, and V3. These channels are not connected to any physical inputs or outputs. Instead, macros or remote commands can assign arbitrary values to these channels, or the channels can automatically follow the value of another channel. Like "real" channels, the values of virtual channels can be plotted on the Plot screen, displayed on the Numeric screen, and logged to RAM and USB.

Each virtual channel can either an input or an output (see the Channel.IO Type button). If it's an input, a virtual channel can follow the value of another channel (see the Channel.Follow button), and its value can be modified by applying a lowpass filter, subtracting a difference channel, taking its derivative with respect to time, or applying offset/gain factors. By doing these calculations on a virtual channel that has been configured to follow a sensor input (instead of doing them directly on the sensor input channel), the raw sensor input is preserved and can still be viewed.

If the virtual channel is an output, it has a PID feedback loop that can be used for cascade control (see the description of the Channel.PID.Casc button in the Operation section). Unlike other outputs, virtual outputs aren't forced to zero when the PTC's outputs are disabled with the Output Enable button. However, virtual PID feedback loops do stop running when the PTC10's outputs are disabled.

When the value of a virtual channel is changed by a macro or from the front panel, the new value does not become effective until an ADC conversion occurs. Therefore, if a macro sets the value of a virtual channel and then immediately reads the value back, the old value may be returned.

Operation

Quick start tutorial

Turn the instrument on

Plug the PTC10 in and turn it on with the power switch located next to the AC power inlet. The SRS logo should appear on-screen immediately. It remains on-screen for about 30 seconds while the system boots.

The Select screen

The PTC10 boots up with the "Select" screen showing. This screen has a button for each physical input or output on the PTC's back panel. There may also be buttons for other values such as heater resistance.

The Select screen has one column for each I/O card. The leftmost four columns are for optional I/O cards; some of these columns will be empty if fewer than four such cards are installed.

Every PTC10 includes as standard equipment a ±10V analog I/O card and a digital I/O card. The AIO column on the Select screen shows the four channels on the analog I/O card, while the DIO column is for the digital I/O card. V1, V2, and V3 are virtual channels that can be used to perform real-time calculations.

In addition to the buttons that represent physical outputs, the Select screen can have buttons that represent internal data channels. In the figure above, for example, the thermocouple card has a button for the cold junction temperature. It's also possible to display buttons for heater current, voltage, and resistance; use the "Extras" button on the System setup screen to set this option.

The Select screen controls which channels are shown on the Numeric, Plot, and Channel Setup screens. To select a channel, touch a button on the Select screen; the button becomes lighter, indicating that the channel is selected. Touch the button again to deselect the channel.

Configure the sensor inputs

If you're using a PTC320 or PTC323 thermistor/diode/RTD input card, it may be necessary to select the sensor type and calibration curve.

1. Select one or more inputs on the Select screen.
2. Press the "Channel" key to display the channel settings screen. The top of this screen has one tab for each selected channel. Touch one of the tabs to display the settings for that channel.
3. Touch the "Sensor" button and select the appropriate sensor type (RTD, thermistor, diode, etc.)
4. Set the Range to "Auto".
5. In the "C al" column, touch the "Type" button and select the appropriate calibration curve.

If the sensor reading does not appear

The sensor reading is blank whenever it falls outside the limits of the calibration data or input hardware. This normally occurs when no sensor is connected, but can also occur if the sensor is incorrectly configured. In this case, try the following steps:

1. Ensure that the sensor is correctly connected. Thermistors and RTDs should normally be connected with four wires. Thermocouples and diodes must not be connected backwards.
2. Measure the resistance of the sensor with an ohmmeter to ensure that one of the wires is not broken.
3. Bring up the channel setup screen for the input channel and check the following settings:

Sensor: must agree with the type of sensor that is in use.
Range: set to Auto or, if a fixed range is selected, make sure it's larger than the sensor resistance.
Current: Forward, Reverse, or AC. If the current is off, no sensor reading will appear.
Cal **Type**: must agree with the type of sensor that is in use.
Cal **R0**: for RTDs only; must agree with the type of sensor that is in use.

4. Go to the System Setup screen and change the Units to "Sensor". Now the reading will appear in ohms or volts instead of degrees. Is the value correct?
5. If you're using a custom calibration table, make sure that the sensor resistance or voltage is within the range of the calibration table.
6. If you're using a resistive sensor and the reading in ohms is incorrect, remove the sensor and instead connect a resistor of about the same value to the PTC10. If the reading is still incorrect, the unit may need to be returned to SRS for recalibration.

Plot data

To plot data on-screen:

1. On the Select screen, select the channels that you'd like to plot. Make sure that no other channels are selected.
2. Press the Plot key on the PTC10's front panel.

Once the Plot screen is showing, press the Plot key repeatedly to cycle between four screen arrangements:

- One plot for each channel
- All channels on a single plot
- Ponytail plot: all channels on a single plot, offset such that each channel starts at zero

- Custom: channels are assigned to plots with the "Plot" button on the channel setup screen, described on page 62.

Touch anywhere within the right half of the plot to zoom in. To zoom out, touch the left half of the plot (but not left of the Y axis). Drag left and right to pan; touch the words "X lock" that appear in the bottom-left corner of the screen to return to viewing real-time data.

Test the outputs

Before trying to run a PID feedback loop for the first time, it's helpful to verify that your heater is working by setting its current or power to a low value and seeing if any current flows. To do this, plug your heater into the PTC10's back panel and set the output as follows:

1. Enable the outputs by pressing the Output Enable key twice. The red Output Enable light should turn on.
2. Select the output channel on the Select screen, then press the Channel key to display the channel setup screen.
3. Touch the Value button and enter a small value for the current or power (one that won't damage your system).
4. The Value button should display the value that you entered. If it's blank or displays zero, the PTC is not detecting the heater.
5. Verify that your heater is warming up.
6. To turn the current off, touch the Off button on the channel setup screen.

If Value button is blank or the heater doesn't start warming up, try the following:

- Verify that the heater leads are not shorted to ground or to each other.
- If the heater is resistive, unplug it from the PTC10 and measure its resistance with a multimeter. Make sure that the resistance is appropriate for the output card:
  - PTC420 AC output card: 24Ω – 300Ω (120VAC), 46Ω – 600Ω (230VAC)
  - PTC430 50W DC output card: 1Ω –1kΩ
  - PTC431 100W DC output card: 10Ω – 1kΩ
- Display the heater resistance: go to the System screen and, in the "Display" column, touch the "Extras" button and select "Show". Return to the Select screen. Underneath the heater power there should now be buttons for heater current (labeled "I 1" if the heater output card is in slot 1), voltage ("V 1"), and resistance ("R 1"). Turn the heater on again. Is the heater resistance the same as what you measured with a multimeter? Is the voltage or current at the maximum that the output can produce?
- Verify that the PID mode is set to off.
- On the channel setup screen, make sure that the output's hi limit and range are both greater that the output value that you entered.
- If the output is a PTC440 TEC driver, disable and re-enable the outputs. The PTC440's output is automatically disabled if you try to output a current when no TEC device is connected, or if the voltage exceeds the Vmax setting.
- If you've previously set up an alarm (see "Configure the alarm", below), it could be disabling the output. For example, if you move a sensor from one input to another, remember to disable the alarm on the old input.

Set the data logging rate

By default, the PTC10 records one data point per second to each channel's log. To change this rate, press the System key on the front panel. Under the "Log" column, touch the "Interval" button and select from the list of available options. The log interval only affects how often data is recorded; it does not affect PID feedback performance.

It is also possible to assign a different log interval to each channel; see the description of the Channel.Logging control on page 62.

Save data to and retrieve data from a USB memory device

If there's no USB memory device plugged into it, the PTC10 only stores the most recent 4096 data points for each channel, and the data is lost if the PTC10 is turned off. A USB memory stick can be used to keep a permanent record of logged data.

Save data to a USB device

1. Plug the USB memory stick into the port on the back of the instrument.
2. Wait about 5 seconds until the message "Please wait while the USB drive is opened" appears on-screen. The message stays on-screen for several seconds while the log files are opened, then the message disappears.
3. Look for a small, grayed-out triangle in the upper-right corner of the screen. This is the USB logging indicator. Touch the triangle. When the triangle turns white (which can take a few seconds), the PTC10 is saving data to the USB device.
4. Before turning the instrument off or removing the USB device, touch the USB logging indicator again and wait for it to turn grey. This step is very important to prevent damage to the USB device. If this step is skipped, the USB device should be re-formatted in a PC before using it again.

View saved data on a Windows PC

Once data has been logged to the USB memory stick, the stick will contain one or more log files for each channel. Each file has the same name as a PTC10 channel plus the extension ".ptc". If the .ptc file gets too big, a new log file with a numeric extension such as .000, .001, etc. is opened. By default, the log files are located in the root directory of the USB device.

A software package available at no charge from the SRS website (www.thinksrs.com, click Downloads > Software) includes a "FileGrapher" program that displays graphs of PTC10 log files and a "PTCFileConverter" program that converts log files to ASCII text files readable by most other programs. To use FileGrapher, either double-click its icon or drag a log file onto the icon. To use PTCFileConverter, double-click the icon to modify the conversion options and/or select files to convert; or, just drag one or more log files onto the icon to convert them with the current options.

Interface with a computer

The System setup menu, which can be displayed by pressing the "System" button on the PTC10's front panel, has controls for setting up the PTC10's RS-232, GPIB, and Ethernet interfaces (under the "COM" and "IP" columns). The USB interface requires no setup on the PTC10 but does require installing a driver on the PC.

The RS-232 port requires RTS/CTS flow control, which some PC serial ports do not support. If the PTC10 sometimes drops characters from the RS-232 messages that it receives, try using the USB interface instead.

The USB port uses the Linux gadget serial driver, which is a common driver that is already installed on some PCs. If the PC asks for a driver, follow these instructions:

Install the USB driver for Windows PCs

1. Download the driver from the SRS website at www.thinksrs.com; click Downloads > Software. Unzip the downloaded file.
2. Using a standard USB A–B cable, plug the PTC10 into the PC.
3. The New Hardware Found wizard appears on the PC. Tell the wizard not to search the web for the driver; select the option to select the driver from a list or specific location. If asked to specify the hardware type, select "Ports". Click "Have disk", browse to the file that you downloaded, and select "gserial-Windows7.inf" (for Windows 7) or "gserial.inf" (for older versions of Windows). You may get a message saying that the driver has not passed Windows logo testing.
4. Once the installation is complete, the PTC10 should appear as a COM port on your computer, and the USB connection can be used just like an RS-232 connection.

Read data from the PTC10

All RS-232, GPIB, USB, and Ethernet messages sent to the PTC10 must end with a linefeed (decimal 10 = hex 0x0a = '\n'). The PTC10 will not process the message until the linefeed is received. Instructions are not case-sensitive.

The most recent value (i.e., the value read at the most recent ADC conversion) of a single channel can be queried by sending the name of the channel, followed by a question mark.

```
3A?
29.9313
```

Omit any spaces from the channel's name; for example, to query the value of channel "Out 1", send the command:

```
Out1?
0.00000
```

The most recent value of all channels can be retrieved with a single getOutput instruction (the question mark is optional in this case):

```
getOutput?
0.000000, 0.000000, 29.98424, 25.86019, 27.49236, NaN, 27.45483,
NaN, 268.9367, NaN, NaN, 0.000000, 10.04576, 10.04574, 10.04572,
NaN, NaN, NaN, 0, 0
```

Sensors that are disconnected or out of range report a value of "NaN" (not a number). To determine the order of the channels in the getOutput response, send the getOutputNames query:

```
getOutputNames?
Out 1, Out 2, 3A, 3B, 3C, 3D, Cold J 3, 4A, 4B, 4C, 4D, 5A, 5B,
5C, 5D, V1, V2, V3, DIO, Relays
```

This order does not change unless I/O cards are added, removed, or rearranged.

A third option for reading data is the getLog instruction, which returns the latest data point written to the log. By default, a logged value is the average of ten ADC conversions. Therefore the values returned by getLog are not as noisy as the values returned by the getOutput and <channel>? instructions, both of which return the result from the most recent ADC conversion only. In addition, getLog makes it easier to retrieve data acquired at consistent time intervals. For example, begin by sending this command, which retrieves the last point in channel 3A's log:

```
getLog "3A", last
27.53936
```

Note that the channel name must be in quotes if it contains a space. Next, send the following command:

```
getLog "3A", next
27.57375
```

Each time this command is sent, the PTC10 waits until a new point is added to channel 3A's log, then returns the new data point.

Control a temperature

The PTC10 can control the temperature of one or more external devices. Each device must include a heater or cooler, and a temperature sensor that monitors the temperature of whatever is being heated or cooled.

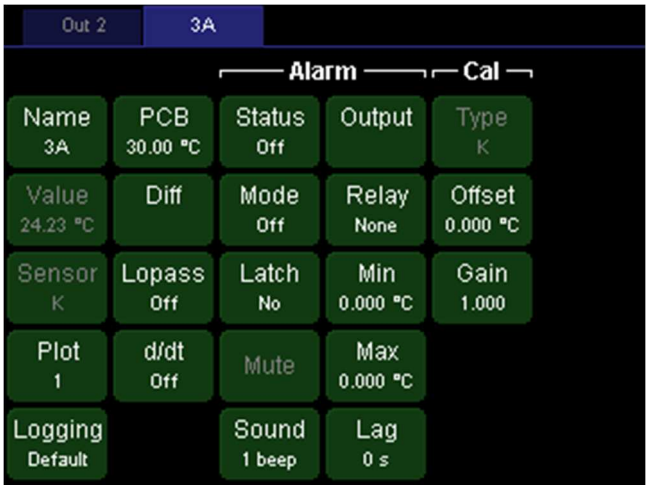
Each of the PTC10's output channels has a proportional-integral-differential (PID) feedback algorithm that can monitor a temperature reading and determine how much power to send to the heater or cooler. The algorithm uses a set of three gain factors to determine how much and how quickly the heater or cooler power should be adjusted when the temperature deviates from its desired value. These gain factors must be properly set before the PTC10 can control the temperature of your system.

Start by plugging the heater and temperature sensor into the PTC10's back panel. The sensor must be in thermal contact with the heater — the better the thermal contact is, the more precise the temperature control will be.

Enable the lowpass filter

For good PID feedback performance, it's important to lowpass-filter the temperature input. On the Select screen, touch the buttons for the heater output and the sensor input that you plan to use, making sure that they and no other channels are highlighted. In this example, we're using heater "Out 2" and thermocouple input "3A":

Press the "Channel" key. At the top of the screen are two tabs, one for each of the two channels you selected. Touch the tab for the temperature sensor.

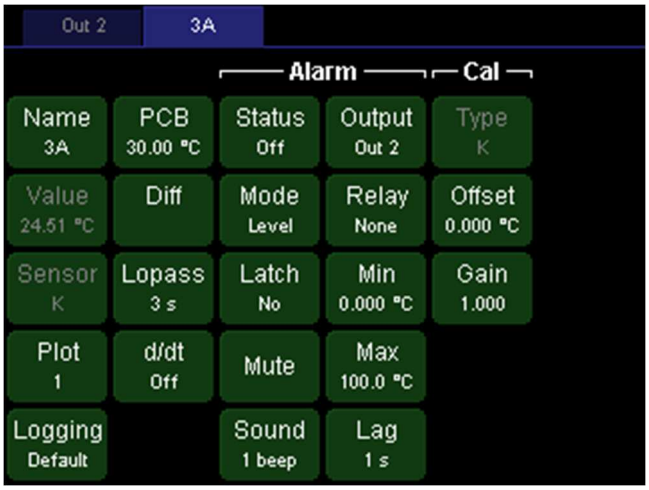


Touch the "Lopass" button to display the list of available lowpass filter time constants. To get more information about the Lopass setting, press the "Help" key, which displays a pop-up window with a brief description of whichever is currently showing on the screen. Touch the "OK" button or press the Help key again to dismiss the help window.

In the Lopass menu, select one of the six options. Select the largest value that is less than the response time of your heater. The lowpass filter reduces noise, improving the accuracy of the PID tuning process and the performance of the tuned PID feedback loop.

Configure the alarm

To protect your system from being damaged by excessive heater power (which can occur if, for example, the PID feedback is configured incorrectly or the sensor becomes disconnected), it's important to set up an alarm. The alarm automatically shuts off the heater whenever the temperature exceeds limits that you specify, whenever the sensor becomes disconnected, and whenever the temperature becomes too high or low for the sensor to measure. On the Setup screen for your temperature sensor, under the Alarm heading, set the options as follows:



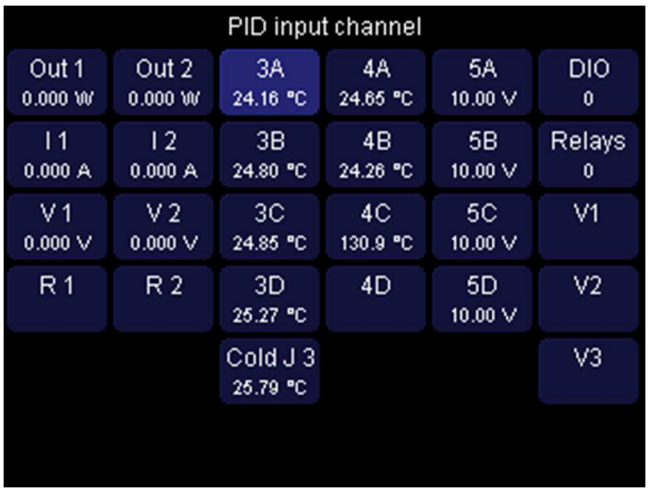
- **Status**: Thus button shows you if the alarm is currently triggered. It can be used to turn off latching alarms, but it doesn't have any effect on non-latching alarms.
- **Mode**: Set to "on" to enable the alarm.
- **Latch**: Set to "no". A latching alarm, once triggered, must be turned off manually.
- **Sound**: 1 beep.
- **Output**: select the heater output channel. Whatever channel you select will be forced to zero whenever the alarm is beeping, preventing "runaway feedback" from damaging your system if the sensor is disconnected or incorrect feedback parameters are entered.
- **Relay**: For the best possible security, the output should be routed through one of the four relays (A, B, C, or D) and the Relay button should be set to A, B, C, or D accordingly. The relay will physically disconnect the heater whenever the alarm is beeping.

- **Min**: If the PTC10 is controlling a thermoelectric cooler, set the min to the lower temperature limit of your system. Otherwise, this value should be set well below the lowest temperature that could normally be produced, so that the min setting can only be exceeded if something is wrong with the sensor.
- **Max**: Set to the upper temperature limit of your system.
- **Lag**: Set to 1 s. This will prevent small glitches, such as those caused by autoranging, from triggering the alarm.

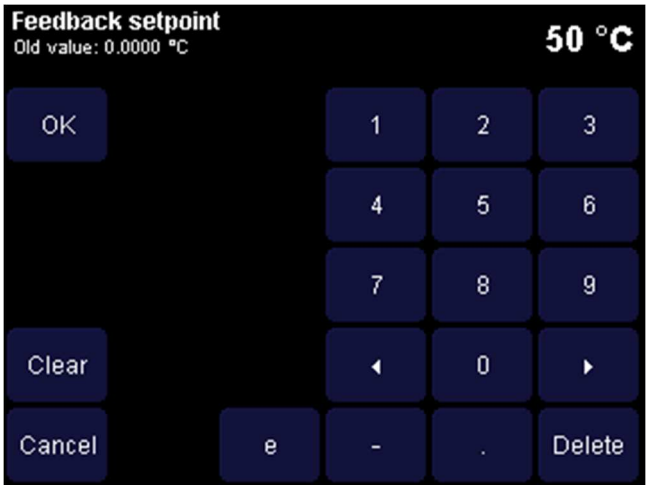
Configure the PID feedback loop

The next step is to tell the instrument which temperature sensor to control and the desired temperature of that sensor.

Make sure the "Channel" screen is still visible and touch the tab for the heater output channel, "Out 1" in this example. In the first "PID" column, touch the "Input" button. A window showing all available input channels appears. Touch the temperature input channel, "3A" in this example. Sensor 3A is now the PID input for heater Out 1.



Next, touch the "Setpoint" button and enter the desired temperature. Touch "OK" once you've entered the setpoint. Since the feedback is disabled, the temperature will not actually start to change yet.



Configure the feedback autotuner

Next, provide a rough estimate of the response time and response magnitude of whatever system you're heating or cooling.

Make sure the "Channel" screen is showing, with the tab for the heater output channel selected. In the "Tune" column, look at the "Step Y" and "Lag" controls. If the output is increased to the value shown in "Step Y", would you expect to see a noticeable rise in temperature within the time shown in "Lag"? Would the amount of power shown in "Step Y" damage your system? Change these values if necessary.

Touch "D" and set the derivative gain to 1. Any nonzero value tells the tuner to enable derivative feedback, which makes the feedback more responsive. If D is set to zero, the tuner uses a different tuning algorithm that leaves derivative feedback disabled. This is sometimes necessary to avoid excessive noise in the feedback output.

Start the feedback autotuner

If the system has never been tuned, start with the heater output turned off and the temperature of your process or experimental apparatus stabilized at the ambient temperature. If the system has been tuned before, it's better to enable the feedback and wait for the temperature to stabilize at the setpoint. In either case, the key to successful autotuning is to start with a stable temperature.

If the outputs are disabled, turn them on by pressing the "Output Enable" key twice. The red Output Enable LED turns on and the PTC10 beeps (if pressed again, the Output Enable key immediately turns all the PTC10's outputs off; inputs are not affected).

In the PID menu, touch "Mode" and select "auto" to start the autotuner. A status window appears and is updated every few seconds.

The tuner begins by freezing the heater output for one-third of the Lag time and measuring how much the temperature changes during this time. This establishes a baseline figure for temperature drift and noise. The tuner then changes the heater output by amount set with the Step Y control and waits for the Lag time to pass. If the temperature does not change by at least ten times the baseline figure, the tuning process fails. Otherwise, the tuner continues the tuning process.

If the tuning process fails, Step Y or Lag may need to be increased, or you may need to ensure that the temperature is more stable before tuning. In any event, you'll need to wait for the temperature to re-stabilize before trying to tune again.

While the tuner is running, you can press the "Plot" button to see a graph of heater output and temperature. Press the "Plot" button several times, until the traces appear on two separate graphs. To show the status message again, press the "Channel" key, and under "Tune", touch the "Status" button.

When tuning is finished, the PID feedback is automatically enabled. If the temperature is below the setpoint, the PTC10 starts increasing power to the heater. The temperature may overshoot the setpoint, but should eventually settle down to the setpoint.

Since the optimum PID parameters usually vary with temperature, if you tuned at ambient temperature it may be helpful to re-tune once the setpoint has been reached.

Acquiring and logging data

Input filters

The PTC10 offers several numeric filters that can be used to modify raw sensor readings. Except for the sensor calibration, the filters are disabled by default and can be enabled by the user. In the order in which they are applied, the filters are:

1. Sensor calibration (converts sensor reading in ohms, volts, etc. to temperature)
2. Follow filter (virtual channels only; makes the channel equal to another channel)
3. Offset/gain (multiplies a channel by a gain and adds an offset)
4. Difference (takes the difference between two channels)
5. Lowpass (filters out noise)
6. Derivative (takes the derivative of the signal with respect to time)

The filters can interact with each other. For example:

- If the settings of filters 1–4 are changed and the lowpass filter is enabled, the effect of the new setting on the sensor reading is lowpass filtered.
- Changing the gain may have unpredictable results if the difference filter is enabled, and changing the offset has no effect if the derivative filter is enabled.
- Custom calibration tables have no effect if the follow filter is enabled.

Custom calibration tables

A custom calibration table can be applied to any channel. To use a custom calibration, create a text file containing the calibration information as described below. The name of the file should be the name of the channel plus the extension ".txt". Create a directory named "cal" within the top-level directory of a USB storage device, and put one .txt file into the directory for each channel to be calibrated. Plug the storage device into the PTC10, and the PTC10 automatically loads the files.

If you are using a calibrated Lake Shore sensor, the PTC10 will accept the .dat calibration file included with the sensor. Just rename the file to <channel name>.txt, copy the file into the cal directory of your USB stick, and plug the USB stick into the PTC10.

To verify that a particular file has loaded, display the "Select" screen by pressing the "Select" menu key. If a channel uses a custom calibration, the upper-left corner of its button is clipped. For more details, select the relevant channel, press the "channel" menu key, and look in the "Cal" column. The "Type" button should read "custom", and a "Details" button should appear at the bottom of the column. Press the "Details" button to view the first three and last three calibration points, or a message describing why the calibration data could not be read.

Each time a USB device is plugged into the PTC10, the PTC10 searches the Cal directory and loads any calibration tables found there into RAM. If the USB device is unplugged, the calibration tables remain in RAM. However, if the PTC10 is switched off, all calibration tables in RAM are lost. Therefore, once a custom calibration table is leaded, it remains in effect until one of the following occurs:

- The instrument is turned off or rebooted. Once this occurs the custom calibration table must be reloaded from the USB device, for example by leaving the device plugged in when the instrument is turned back on.

- A USB device with a different calibration file is plugged into the PTC10.
- The calibration type (set with the Channel.Cal.Type button) is changed to "standard".

The following actions have no effect on custom calibration tables:

- Unplugging the USB device with the calibration tables while the PTC10 is turned on.
- Plugging in a USB device that does not contain a calibration file for the channel.

It can take several seconds for the PTC10 to recognize a USB device. Therefore, when an instrument is turned on with a USB device plugged in, the default calibration may remain in effect for several seconds before the custom calibration is loaded.

A calibration table is an ASCII text file containing a units declaration followed by pairs of numeric values representing the displayed and measured values. For example, here's a calibration table for a 100Ω platinum RTD. The first line indicates that at 0°C the sensor has a resistance of 100 ohms:

```
units = °C
  0, 100.00
 10, 103.90
 20, 107.79
 30, 111.67
 40, 115.54
 50, 119.40
 60, 123.24
 70, 127.08
 80, 130.90
 90, 134.71
100, 138.51
```

Units declaration: The first line indicates which units this channel will be displayed in once the calibration table is loaded. This line is optional; if it's omitted, the units are assumed to be Kelvins. The units can be any string of 4 or fewer characters but must not contain any spaces (to type the degree sign on Windows computers, hold down the alt key and type "0176" on the number pad). Anything on this line after the units is ignored; therefore, the XY data must begin on the second line.

If the display units are "°C", "°F", "K", or "mK", the PTC10 automatically converts calibrated readings to the units specified by the System.Display.Units control. If any other units are specified, they override the System.Display.Units control and the control has no effect on the channel's reading. Such non-standard units can be used, for example, to convert data to non-temperature units.

All text after the units declaration and before the first numeric value is ignored, as long as the text does not contain any numeric values (i.e., digits, periods, or plus or minus signs). If the units declaration is not present, all text before the first numeric value is ignored.

Calibration data: The second line of the sample table above contains a calibration point consisting of two numeric values: the first is the value that's displayed on the front panel, and the second is the corresponding value that's measured or produced at the back panel. This line indicates that when the measured value is 100 ohms, the PTC10 should show a reading of 0 °C.

The displayed value must be expressed in whichever units are declared in the first line of the calibration table, or in Kelvins if no units are declared.

The measured value must be expressed in the native units of the channel: ohms for resistive sensors, volts for diode sensors and analog I/O channels. For heater driver channels, the native units are by default watts, but can be changed to percent, volts, or amps with the "Units" control in

the Channel menu. If in doubt, have the PTC10 display its readings in native units by touching the System.Display.Units button and then selecting "Sensor". The calibration table must be expressed in the units in which the reading now appears.

A calibration table must contain at least two calibration points, and the entire file cannot contain more than 4095 characters (about 100–200 calibration points). Commas should not be used within numeric values.

The PTC10 uses a cubic spline algorithm to interpolate between the calibration points, except between the first and last two calibration points, where a less accurate linear interpolation algorithm is used.

The data points do not have to be equally spaced; they can be closely spaced in critical temperature areas and more widely spaced in outlying areas. For RTDs, the interval between data points should be 10°C or less to ensure the best possible (0.1 mK) interpolation accuracy. For thermistors, an interval of 1°C or less should be used.

The numeric values may be separated from each other with one or more commas, spaces, tabs, and/or newlines. It's not actually necessary to put each calibration point on a separate line as shown above.

The displayed value must either increase or decrease monotonically throughout the table; that is, it must consistently increase or decrease throughout the entire file. The value cannot change direction and the file cannot contain two displayed values that are the same. Likewise, the measured value must also increase or decrease monotonically. However, the displayed and measured values can go in opposite directions.

The calibration data must cover the entire expected range of measurements, which in the example above is 0 to 100°C. When readings fall outside the range of the calibration file, no data appears on the display, and any PID feedback loops that use the affected channel are frozen.

The order of the data points can be reversed (measured value first, displayed value second) by adding a tilde to the beginning of the file. The tilde must be the first character in the file, appearing before the units declaration and any other header information.

Errors in calibration tables

If the calibration file can't be read, no readings appear for the affected channel. This condition occurs if the file has any values after the header with no numeric characters, if the values are not monotonically increasing or decreasing, or if the file ends with a temperature value.

If a channel is renamed, the calibration file also has to be renamed, or the custom calibration will no longer be read the next time the PTC10 is turned on.

Press the Channel.Cal.Details button to see the first and last three data points in the custom calibration, or, if the calibration couldn't be read, a description of the problem.

Virtual channels

The PTC10 has three virtual channels with the default names V1, V2, and V3. These channels are not directly connected to a physical input or output. Instead, they can be used to mirror another channel, or a macro can assign them a value. A custom calibration table, offset/gain factors, difference filter, lowpass, and/or derivative filter can be applied to the mirrored data. Virtual channels can have alarms or PID feedback loops; their value can be graphed and saved to a log.

One use of virtual channels is to allow different sets of filters to be applied to a single channel. A virtual channel can be used, for example, to show the derivative of channel 3A with respect to time. By using a virtual channel to perform this function (instead of just enabling channel 3A's d/dt filter), the raw data is preserved and can be viewed alongside the derivative.

Since a virtual channel's value can be set by a macro, the channel can be used to reveal internal PTC parameters that cannot otherwise be graphed or saved to the log. For example, a virtual channel can be made to mirror a feedback setpoint. The channel can also display the results of a calculation, such as the value of channel 3A divided by the value of channel 3B.

Logging data to USB

The most recent 4096 data points from each channel are stored in internal RAM. At the default logging rate of 1 point per second, this corresponds to about one hour of data. Data older than one hour disappears from the graph.

To create a permanent record of data, or to plot more than an hour of data, the PTC10 can store data on removable USB memory devices such as USB hard drives or flash memory keys. The back panel of the PTC has two plugs for such devices; the PTC logs data to the last USB device to be plugged in. When a USB device is plugged in, it takes the PTC10 several seconds (normally about 5 seconds, but sometimes up to 30 if the device contains a lot of files) to recognize the device and for the USB logging feature to become available.

A small white triangle appears in the upper-right corner of the screen whenever data is being logged to USB. If a USB stick is present but isn't being used, the triangle is grayed out. If no USB stick is present, the triangle disappears completely. To log data to a USB device, plug the device into the PTC, touch the grayed-out triangle, and wait a few seconds until it turns white. Touch the white triangle to stop logging.

Data is still stored in RAM while logging to USB. Therefore, if the USB device is unplugged, the last hour of data can still be displayed on the Plot screen.

Do not unplug a USB device or switch the PTC10 off while the PTC10 is logging to the device. Either of these actions causes loss of data and corruption of the device's file system. To turn logging off, touch the USB logging triangle in the upper-right corner of the screen and wait for it to become grayed out.

If a USB device is unplugged while data is being logged to it, repair the device by inserting it into a PC and running chkdsk. Periodic defragmentation is also recommended, since the process of continuously appending data to multiple log files can result in highly-fragmented drives.

ADC sampling and logged data

The PTC10 has two different sampling rate settings: one controls how often data is acquired, and another controls how often it's stored.

A/D rate

The A/D (analog-to-digital conversion) rate controls how often a data point is acquired from each channel. All channels are read at the same A/D rate, which by default is 100 ms or 10 samples per second. The A/D rate mainly affects the performance of feedback loops: the faster the A/D rate is, the more quickly the PID loops can respond to changing temperatures; the slower the A/D rate, the less noise there is in the PID output.

By default, the A/D conversion process is synchronized with the AC line voltage and the A/D rate can only be set to multiples of the AC line period. For example, if the A/D rate is set to 100 ms, A/D conversions occur every six cycles of the AC voltage if the PTC10 is plugged into a 60 Hz AC wall socket, or every five cycles for 50 Hz AC. This prevents 60 Hz noise from aliasing into temperature readings, which would cause a slow sinusoidal variation in the readings. 60 Hz noise still creates a constant offset in temperature readings, but the offset is usually too small to be of

concern with thermocouple readings and can be removed from RTD readings using current reversal.

By moving the "Trigger source" jumper on the motherboard to the "1 MHz clock" position, it is possible to set the A/D rate to any value between 10 and 1000 ms with a resolution of 1 μs (note that the jumper should only be moved while the system is switched off). However, the A/D conversions will no longer be perfectly synchronized to the AC line voltage, even if the A/D rate is set to a multiple of the line period. As a result, low-frequency sinusoidal noise may appear in your temperature sensor readings. The frequency of the noise is the difference between the AC line frequency and the closest multiple of the ADC conversion rate in Hertz. For example, if the A/D conversion rate is 10 Hz and the AC line frequency is 60.1 Hz, a sine wave with a frequency of $60.1 - (6 \cdot 10) = 0.1$ Hz may be superimposed on your temperature readings.

Log rate

The log rate controls how often channel readings are logged. The log rate can be set independently for each channel; the default is one point per second. Normally the time between log points should be longer than the time between A/D samples, in which case multiple A/D readings are averaged together to create each logged value. If, on the other hand, the time between log points is shorter than the time between A/D samples, each A/D reading is recorded more than once in the log.

The plot screen always displays logged data. Therefore, a slow log rate reduces the noise visible in the graphs and may produce a stairstep appearance, while a fast log rate produces graphs with more detail.

Format of PTC10 log files

The PTC10's log files use a binary data format. The "PTCFileConverter" program, available for download from the SRS website, can convert the binary files to various text formats readable by other programs.

Each log file stores data for one channel and consists of a header followed by one or more records. Each record contains a record header followed by zero or more floating-point data values. The floating-point values within a record are evenly spaced in time and are expressed in the same units as on the PTC's front-panel display. Not-a-number values (0x7fc00000 if interpreted as an integer) are recorded if the sensor is out of range, or if the sensor or heater is unplugged for less than 100 log points. If the sensor or heater is unplugged for more than 100 data points, no values are recorded and a new record is created when the sensor or heater is plugged in.

A new record is created under the following conditions:

- When the PTC10 starts logging to the USB device
- When the logging interval is changed
- When the system time is set
- When a sensor or heater is plugged in after being unplugged for more than 100 log points (in which case, no data points are logged while the sensor is unplugged)

By default, log files are given the name of the channel followed by the extension ".ptc", i.e. "ChannelName.ptc". If the file has more than 256 records or the file size reaches 2 GB, the file is closed and a new log file with a numeric extension ("ChannelName.000", "ChannelName.001", etc.) is created. The highest allowed numeric extension is 999.

A description of the file format follows. All values are little endian.

File header:

Bytes 0–3: Format identifier. 4 ASCII bytes: 'PTC0', equivalent to the 4-byte unsigned integer 0x50544330.
Bytes 4–7: File format version number. The version number is always 1. Any other number indicates that the format differs from this description. 4-byte unsigned integer.
Bytes 8–11: Location of first record, in bytes from the beginning of the file. The file format allows additional information in ASCII format to be included in the space between the file header and the first record. Currently, no additional information is included. 4-byte unsigned integer. Must be at least 12 and is normally 12.

Record:

Bytes 0–3: number of data points in this record; if -1, this is the last record, and the number of data points is equal to the number of bytes following this record header divided by four. 4-byte signed integer.
Bytes 4–11: the time that the first data point in the record was acquired, expressed in milliseconds since January 1, 1970. 8-byte unsigned integer.
Bytes 12–19: number of milliseconds between data points. 8-byte unsigned integer.
Bytes 20–23: checksum. The sum of all data points in the record if the raw data values are read as if they were 4-byte integers instead of floating-point values. The checksum is not valid if the number of data points is -1. 4-byte signed integer.

This is the end of the record header. The data values begin immediately after:

Bytes 24–27: data point 0. 4-byte IEEE floating-point value.
Bytes 28–31: data point 1. 4-byte IEEE floating-point value.
etc.

The size of a log file cannot exceed 2 GB, or about 500 million data points per channel. At the default 1 second log rate, this limit is reached in about 15 years.

Using the system fan

The PTC10's fan regulates the temperature of the I/O cards.

Automatic fan control

At every A/D conversion, each I/O card reads internal temperature sensors and determines how fast it needs the system fan to run. The main system processor reads the desired fan speed from each I/O card and, if the System.Other.Fan control is set to "auto", sets the fan to the fastest requested speed.

For the PTC430 DC output card and PTC440 TEC driver, the requested fan speed depends on the temperature of the card's heatsink, the amount of current being delivered, the voltage range, and the voltage drop across the heater.

For the PTC320 thermistor/diode/RTD reader, PTC321 RTD reader, and PTC330 thermocouple reader, the requested fan speed depends on the card's internal temperature and the temperature specified with the Channel.PCB control. If the card temperature is below its Channel.PCB setting, the card doesn't request any cooling and its temperature is unregulated. Since the default PCB setting is 30°C, the temperature is normally regulated only if the PTC10 gets unusually warm.

To improve the thermal stability of the input cards, the Channel.PCB setting of one card can be reduced to a value just below its normal temperature, such that the fan is always running and the card's temperature is continuously kept at the Channel.PCB value. However, if the PTC10 outputs a large heater current, the fan speed increases to keep the output card cool and the temperature of the input cards may fall out of regulation.

Manual fan control

If the PTC10's fan produces unacceptable vibration or noise, the fan speed can be manually set by changing the System.Other.Fan control to a value other than auto. In this case, the fan speed requested by the I/O cards is ignored. If the fan is turned off completely, the user must ensure that the temperature inside the PTC10 does not exceed 35°C or damage to the PTC10 may occur. In addition, temperature inputs may not be accurate at elevated temperatures.

The PTC430 DC output card and PTC440 TEC driver are prone to overheating if the fan speed is manually set to a value that is too low, especially if the card is operated at a high voltage range and heater resistance is low. If the PCB temperature of one of these cards exceeds 60°C, its output is automatically shut off. Set the output to zero to re-enable it, for example, by pressing the Output Enable key (which will disable all the PTC's outputs), or by pressing the Channel.Off button.

Besides the main system fan, the PTC10 also has an internal fan that periodically turns on to keep the main power supply cool. This fan is unaffected by any user-accessible setting.

Using PID feedback

How stable is the PTC10's feedback control?

The stability of the PTC10's feedback is usually limited not by the PTC10 itself but by all the things outside the PTC10: the sample that's being heated, the heater, and the environment. The key factor is how rapidly the sample can be heated or cooled relative to how rapidly the temperature changes due to environmental factors such as ambient temperature variations. Some of our customers have reported achieving 1 mK stability, although it's often necessary to optimize the mechanical design of the system before this goal can be reached.

To ensure that the sample can be heated or cooled rapidly, the heater must have adequate power, it must be in good thermal contact with the sample, and the entire system must be as small as possible. If the system is an environmental chamber, consider using a flow-through configuration in which fresh air is continually introduced into the chamber and is heated or cooled before it enters the chamber. This can be accomplished using a chassis-mount fan with a built-in heater. This configuration can produce a much quicker response than heating the chamber itself.

The rate at which the system can be cooled should ideally equal the rate at which it can be heated. Systems based on resistive heaters often cool very slowly if they're insulated to protect them from ambient temperature variations or if they operate close to the ambient temperature. Because PID feedback uses the same algorithm for both heating and cooling, the response time of the feedback will be limited by the cooling rate, even while the system is heating up. Performance can be dramatically improved either by adding a fan to help cool the system or by using a TEC device, which can both heat and cool.

Ambient temperature variations must also be minimized. To achieve 1 mK stability it's often necessary to enclose the temperature-controlled system within a larger chamber that's also temperature controlled.

Basic PID feedback concepts

To control a temperature, the PTC10 must be connected to a temperature sensor that measures the temperature in question, and to a heater or cooler that raises or lowers the temperature when power is applied. Although the heater/cooler will just be called a "heater" in this discussion, the following principles apply whether it is a resistive heater, a thermoelectric device that can both heat and cool, or a cooling-only device such as a fan.

The PTC10 supplies a varying current, voltage, or power to the heater, and assumes that the measured temperature will increase or decrease in a roughly linear fashion with this output signal. It is also assumed that the measured temperature depends not only on the PTC10's output, but also on external factors that vary unpredictably such as, for example, the ambient room temperature. Therefore, to maintain a consistent temperature, the heater power has to be determined by an algorithm that can monitor the temperature (T) and continually adjust its heater output (Y) with the goal of keeping the temperature at a predetermined "setpoint", even as outside factors change the amount of heater output required to maintain that temperature.

In the PTC10, as in most other temperature controllers, the algorithm used is *PID feedback*, which is actually a combination of three algorithms.

The **proportional** feedback algorithm determines the error, i.e. the difference between the desired temperature (the setpoint) and the actual temperature T. The output Y_P of the proportional feedback algorithm is just the error multiplied by a constant, *P*:

$$E(t) = (\text{setpoint} - T(t))$$
$$Y_p(t) = P \cdot E(t)$$

As the actual temperature approaches the setpoint, the proportional output Y_p decreases to zero, at which point no power is supplied to the heater.

Normally, however, some power is required to keep the heater at the setpoint, which is why the **integral** feedback algorithm is needed. It multiplies the error by a constant (*I*) and adds the result to the previous integral output:

$$Y_i(t) = I \cdot E(t) + Y_i(t-1)$$

As the actual temperature approaches the setpoint, the rate of change of the integral output Y_i drops to zero. In effect, integral feedback sets the steady-state heater power.

Derivative feedback tries to predict what the temperature will be in the future by multiplying the rate of temperature change by a constant, *D*:

$$Y_d(t) = D * (T(t-1) - T(t))$$

If the temperature is increasing (and *D* is positive), derivative feedback reduces power to the heater; if the temperature is decreasing, derivative feedback increases power to the heater.

The output of the PID feedback loop (i.e., the heater power) is the sum of the three feedback algorithms:

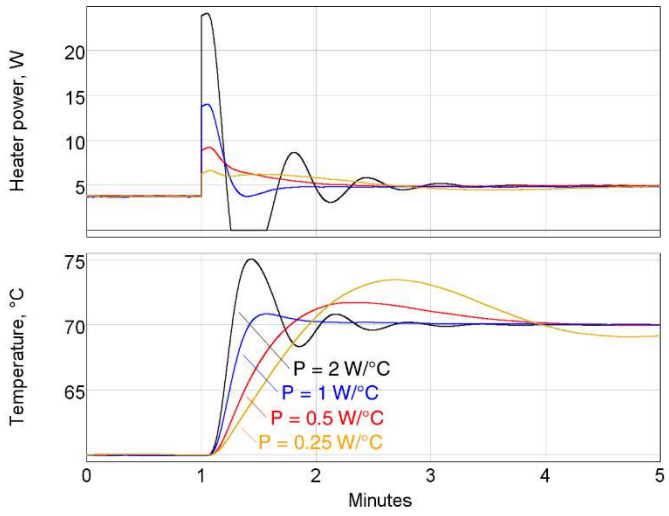
$$\text{Heater power} = Y_p(t) + Y_i(t) + Y_d(t)$$

The key challenge to using a PID feedback loop is determining the best feedback gains. The constants *P*, *I*, and *D* are different for every apparatus and must be determined experimentally. As a general rule, if the gains are too low, the feedback won't respond enough to temperature variations; if they are too high, the feedback responds too much and overshoots the setpoint, and both heater power and temperature may begin to oscillate. The faster the temperature changes in response to the heater, the larger the gains can be.

Manual tuning

In this section we will use step response curves to illustrate some basic aspects of how the three feedback parameters *P*, *I*, and *D* affect feedback performance.

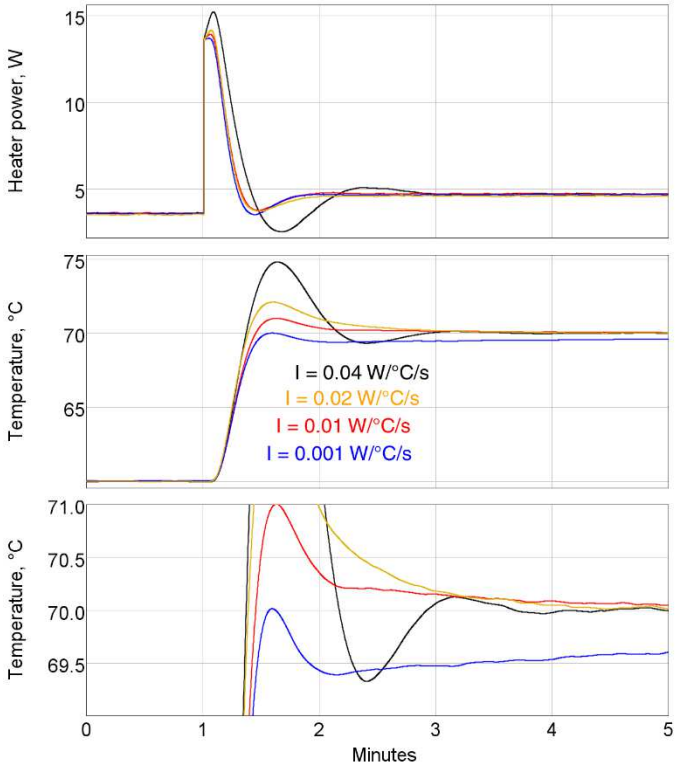
Proportional: the figure below illustrates the effect of changing the proportional gain *P*. The top graph shows the power being delivered to a heater by a PID feedback loop during four separate tests, while the bottom graph shows the temperature of the heater during the same tests. Each test is identical except for the value of *P*. At 1 minute, the setpoint is increased from 60 to 70°C. When $P = 1$ W/°C (second curve from top), the feedback loop exhibits a perfect response; that is, the temperature rapidly increases to 70°C with a slight overshoot that serves to minimize the settling time. If *P* is increased to 2 W/°C, the temperature responds more quickly but then overshoots the setpoint by an excessive amount, causing the system to oscillate.



Interestingly, decreasing the proportional gain to 0.5 or 0.25 W/°C also results in more overshoot and can even cause oscillations, despite the fact that the heater response is smaller and the temperature rise slower. By reducing the proportional feedback response, we've forced the integral feedback to take more responsibility for raising the heater power — and as the next figure illustrates, the integral feedback has a greater tendency to overshoot and oscillate.

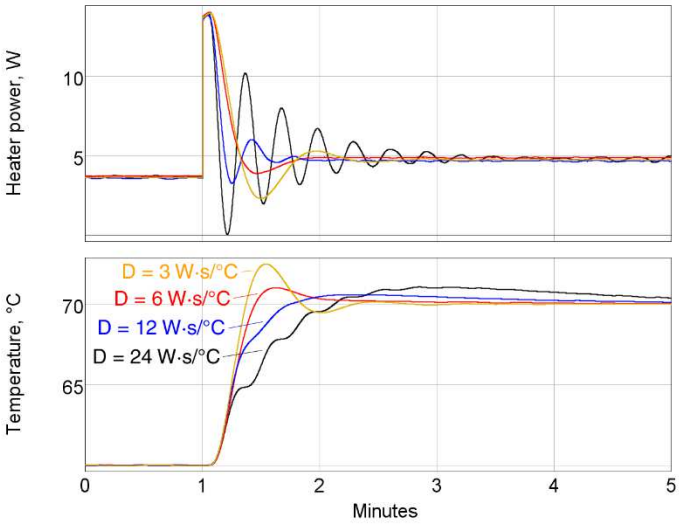
Integral: as with proportional gain, increasing the integral gain *I* also results in a larger heater response, but integral feedback doesn't respond as quickly. Integral feedback is slow because it works by adjusting its previous output, rather than re-calculating its output from scratch at each feedback cycle. Therefore, integral feedback has a tendency to overshoot the setpoint and cause oscillations.

When *I* is reduced to 0.001 W/°C/s, the temperature at first responds quickly due to the action of the proportional feedback. However, close inspection (see the lowest trace in the bottom graph) reveals that the temperature doesn't actually reach the 70° setpoint within the time period shown. Without enough integral gain, temperature errors tend to persist. As an approximate guide, the integral gain should be about one-tenth the proportional gain.



Derivative: derivative feedback reduces the heater output whenever the temperature is rising rapidly. In the example below, when the derivative gain *D* is increased from 3 to 6 W·s/°C, the amount of overshoot and oscillation decreases. The temperature rise is also a little slower, but because there is less oscillation the system stabilizes at 70°C sooner.

However, if the derivative gain is too large, it too can produce oscillations — because when the temperature is rising rapidly, derivative feedback reduces the heater output, which causes the temperature to rise more slowly, which makes the derivative feedback increase the heater output, and so on.

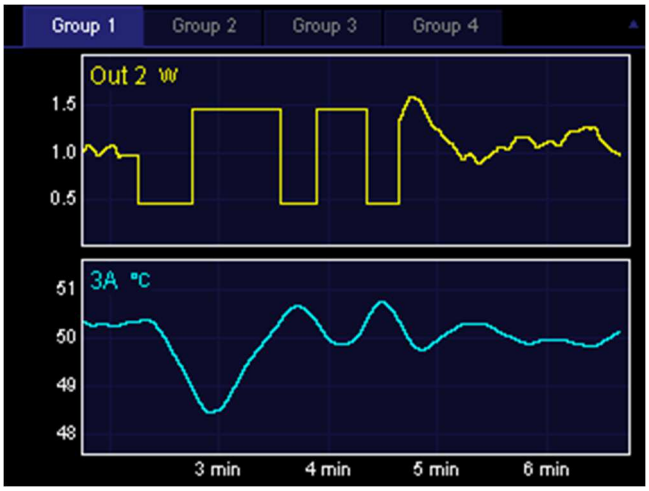


With the right amount of derivative feedback, we can increase *P* and *I* to levels that would otherwise cause oscillations, and thereby obtain faster, more responsive feedback control.

Automatic tuning algorithms

During automatic tuning, the PTC10 changes the heater power, measures how much and how quickly the temperature changes in response, and then estimates the optimum values of the gain factors *P*, *I*, and *D*. Two tuning algorithms are available on the PTC10: the relay tuner and the step response tuner.

Relay tuner



Heater power (top) and sensor temperature (bottom) during relay autotuning. Step Y is 1 W, Lag is 30 s, feedback is initially on, and the system starts with the temperature stabilized at the 50°setpoint. After the tuning has finished, the feedback turns on and re-stabilizes the system at 50°C after a few cycles of oscillation.

The relay tuner creates a temperature oscillation by switching the heater between two output values:

$$\text{Output}_{\text{high}} = \text{Output}_{\text{I}} + (\text{Step Y})/2$$
$$\text{Output}_{\text{low}} = \text{Output}_{\text{I}} - (\text{Step Y})/2$$

where Output_{I} is the initial output and Step Y is the value specified in the "Step Y" control. Note that the relay tuner cannot be started unless the output is greater than (Step Y)/2. For best results, the output should be greater than Step Y.

The relay tuner begins by disabling the feedback (if the feedback was on) and measuring the drift and noise of the feedback input signal in the absence of any changes to the feedback output. The drift-and-noise measurement continues for one-third the amount of time specified with the "Lag" control; the resulting drift-and-noise value is the difference between the largest and smallest input signal observed during this time.

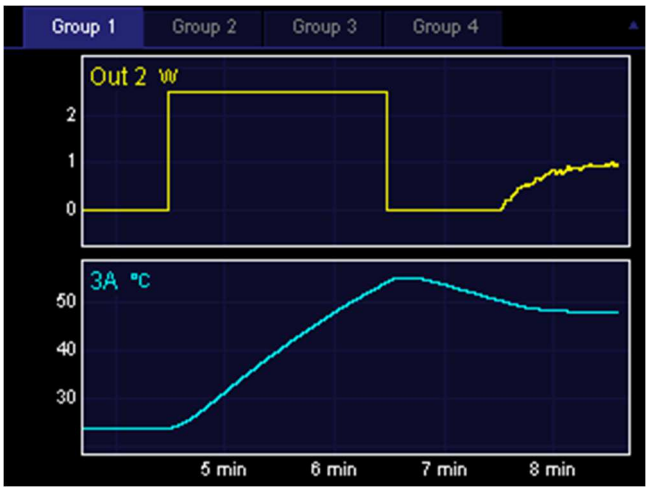
After the drift and noise measurement, the relay tuner sets the heater output to $\text{Output}_{\text{low}}$ for the Lag time to start the oscillation. If during this period the feedback input does not change by at least ten times the drift-and-noise value, an error message is displayed in the Status window and tuning is

cancelled. If this occurs, either 1) ensure that the temperature is stable before starting the step response; 2) increase step Y; or 3) if it looks like the temperature didn't have enough time to respond, increase the Lag time.

The tuner then sets the output to the $Output_{high}$ value. Then, each time the temperature crosses its initial value (50 °C in the figure above), the output is switched from high to low or low to high. This produces a temperature oscillation 180° out of phase with the output oscillation. The tuner performs two oscillation cycles, not including the kick start, and measures the period and amplitude of the second oscillation.

The relay tuner has to wait several times for the temperature to cross its initial value. If the temperature measurement is disturbed during this time (for example, if the temperature sensor is moved, or if the sensor is in an oven and the oven door is opened), the temperature may never cross its initial value and the tuner may run indefinitely without finishing.

Step response tuner



Heater power (top) and sensor temperature (bottom) during step response autotuning. Step Y is 2.5 W, Lag is 45 s, feedback is initially off, and the system starts at room temperature. After the step response is complete, the feedback turns on and the temperature drops before stabilizing at the 50°C setpoint.

The step response tuner makes a single change to the amount of power delivered to the heater, and measures how much and how quickly the temperature changes in response.

The step response tuner begins by disabling the feedback (if the feedback was on), and measuring the drift and noise of the feedback input in the absence of any changes to the output. The drift-and-noise measurement takes one-third the period specified with the "Lag" control; the resulting drift-and-noise value is the difference between the largest and smallest input signal during this time.

Next, the step response tuner increases the output by the value specified with the "Step Y" control. The tuner then waits for the amount of time specified with the "Lag" control. If during this period the feedback input does not change by at least ten times the drift-and-noise value, an error message is displayed in the "Status" window and tuning is cancelled. If this occurs, either 1) ensure that the temperature is stable before starting the step response; or 2) increase step Y; or 3) if it looks like the temperature didn't have enough time to respond, increase the Lag time.

The tuner continuously measures how quickly the feedback input changes, (i.e., the slope of the feedback input with respect to time). Tuning ends once the lag period has passed and the most

recent slope is less than half the largest slope. The tuner then calculates the maximum slope, the lag time, and the total response, and uses these values to calculate the PID gains.

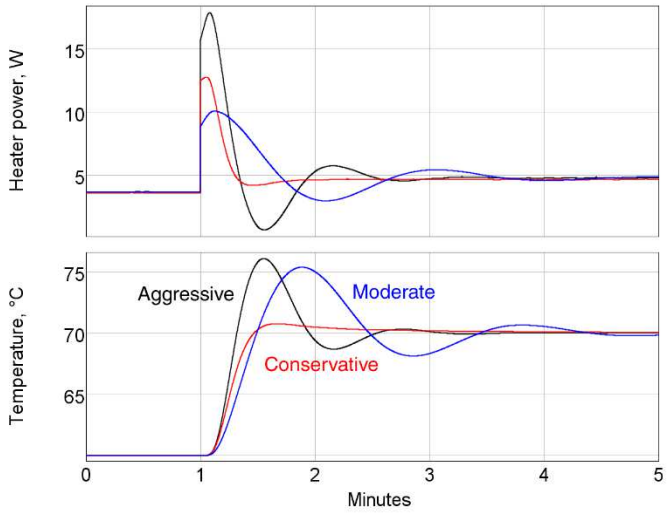
Because the slope calculation is sensitive to noise, it's important to enable the "lopass" filter on the feedback input channel to achieve accurate tuning results. Since the relay tuner does not require a slope measurement, it's less sensitive to noise than the step response tuner.

If the tuning mode is set to "Auto", the PTC10 selects the relay tuner if both its high and low outputs are within the heater's limits; otherwise, it selects the step response tuner. For example, if the output is off (and can't go negative) when autotuning is started, the step response tuner runs because the relay tuner would require a negative output.

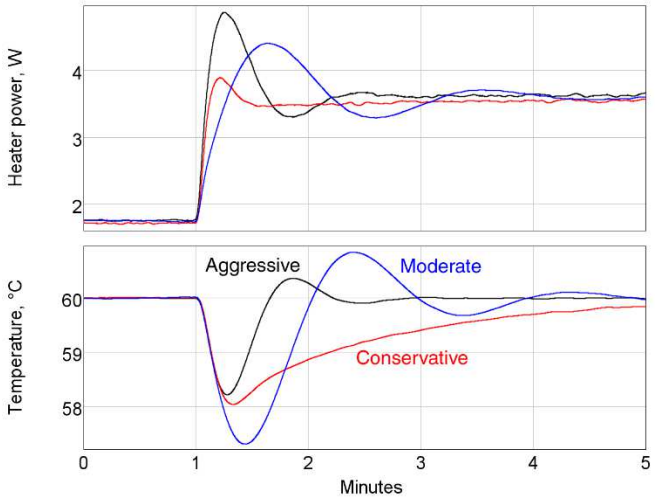
Aggressive, moderate, and conservative tuning

Both the step response and relay tuners offer aggressive, moderate, and conservative tuning options. Conservative tuning theoretically produces zero overshoot and is usually the best choice when the temperature needs to follow a changing setpoint. The aggressive tuning option theoretically produces 25% overshoot (although in fact it tends to be larger) and is usually the best choice for applications in which the setpoint is constant. Moderate tuning produces a very stable feedback loop that behaves reasonably in a wide variety of situations.

The figure below compares the system's behavior when we change the setpoint from 60 to 70°C after relay tuning with the aggressive, moderate, and conservative options. In this case, the conservative tuning produces the best response.



However, the results are much different if we look at how the system responds to a thermal disturbance. The next figure shows how well the system recovers when we start blowing air over the heater with a fan. The setpoint is a constant 60°C. In this case, aggressive tuning produces the best response.



The actual behavior of your system might vary significantly from the behavior shown in these figures. In any event, the feedback gains determined by the automatic tuning algorithms should generally be regarded as only a starting point. In critical applications, the gains normally need to be manually adjusted to achieve good feedback performance.

Using the automatic tuner

Start with a stable temperature. Before the autotuner is started, the temperature must be stable. If the system hasn't been tuned before, the easiest way to get a stable temperature is to let the system sit undisturbed for a long period of time with the heater off. On the other hand, if the PID gains have been set before and just need to be re-optimized, it may be easier to turn the feedback loop on and let the feedback stabilize the temperature. The autotuner can be started with the feedback either on or off.

Disable or enable derivative feedback. Because derivative feedback has a tendency to amplify sensor noise, it may sometimes be preferable to disable it. If the derivative feedback gain is set to zero before autotuning begins, derivative feedback is disabled and the autotuner calculates P and I feedback gains, leaving the derivative feedback set to zero. In contrast, if the derivative feedback gain is initially nonzero, the autotuner calculates P, I, and D feedback gains using a more aggressive algorithm. Therefore, setting D to a nonzero value (the exact value doesn't matter) before autotuning produces faster-acting feedback but more noise. If your temperature sensor is noisy or you're not using a lowpass filter, leave D set to zero.

Set the step size and lag time. Two controls on the channel setup screen help the PTC10 to separate the effect of the heater from random temperature fluctuations. "Step Y" controls how much the PTC10 increases the heater output, and "Lag" controls how long the PTC10 waits for a response. If either value is too small, the PTC10 may, after attempting to tune, display a message saying that there was an insufficient response. If the values are too large, tuning will take longer than necessary and your heater will get excessively hot.

Start tuning. To begin tuning, go to the channel setup screen and set the tuning mode to "Auto".

If the tuner finishes successfully, a high-pitched tone plays and the feedback mode automatically changes to manual, turning the feedback loop on. If the tuner was unsuccessful (Output Enable was off, the heater was unplugged, the temperature sensor was unplugged, the heater was out of range, or the response was insufficient), a low-pitched tone plays and the feedback mode changes to off, disabling feedback control.

When PID tuning is started, a window with information about the autotuner's progress appears. This window can be dismissed by touching the "OK" button or any menu key. Dismissing the window does not cancel autotuning; to cancel autotuning, either 1) set the tuning Mode control to "Off"; 2) touch the output channel's "Off" button; or 3) disable all outputs by pressing the "Output Enable" key.

If the status window is dismissed, it can be shown again by touching the "Status" button in the output's "Channel" menu.

Explanation of error messages produced by the autotuner

One of the following messages appears in the Tuning Status window if tuning was unsuccessful. If tuning fails and you don't see a message, press the Channel > Tune > Status button.

Tuning was cancelled because the response was less than 10 times the noise and drift

This message indicates that the heater produced an insufficient temperature response. It can result from any of the following factors:

- The temperature was not stable before the autotuner was started, or the temperature was changed by some external factor after the autotuner was started. In particular, after running the autotuner, it's necessary to wait for the temperature to re-stabilize before running the autotuner again.
- The autotuner disturbance size (Step Y) was not large enough to create a noticeable change in the temperature.
- The autotuner wait time (Lag) was not long enough for the heater to change the temperature.

To determine the source of the problem, look at a dual plot with the heater output on one plot and the sensor temperature on the other. Make sure that the temperature was stable before the heater turned on and that it changed significantly after the heater was turned on.

Autotuning was cancelled because the Tune->Mode control was set to "Off"

This message indicates that the user turned off autotuning (by setting the autotuning mode to "off") while it was running.

Autotuning was cancelled because the PID mode was set to manual.

The user turned off PID feedback while the tuner is running. The tuner is unable to run when PID feedback is turned off.

Autotuning was cancelled because the PID mode was set to \"follow\"

The user changed the PID mode to "Follow". The tuner is unable to run in this mode.

Tuning was cancelled because the input was disconnected

No sensor signal was detected. Ensure that a sensor is plugged in and that its reading is not blank. If the reading is blank, an incorrect sensor range, sensor type, or calibration may be selected.

Unable to tune feedback because the outputs are disabled. Press the Output Enable button to enable outputs.

The outputs must be enabled before autotuning, or else the CTC100 will not be able to provide any power to the heaters.

Unable to tune feedback because the heater is disconnected

This message appears when the heater is connected to channels Out 1 or Out 2 and the measured heater resistance is less than 1 ohm or greater than 10,000 ohms.

Unable to tune feedback due to a hardware fault in the heater output

This message appears when the heater is connected to channels Out 1 or Out 2 and the current at the + and – terminals is not equal, or current was detected when the heater was supposed to be off, or the measured current differs from the expected current. Make sure that the heater is not shorted to ground or to another power supply.

Unable to tune feedback because the heater is under range
Unable to tune feedback because the heater is over range

If Step tuning is selected, the heater output must be less than the maximum output minus Step Y. If Relay tuning is selected, the heater output must be less than the maximum output minus Step Y/, and greater than the minimum output plus Step Y/2.

Suggestions for best tuning results

- While tuning, use the "Plot" display to graph the heater output and the temperature on separate graphs. Make sure that you can see the temperature begin to rise or fall after the heater output changes.
- If tuning fails, let the temperature stabilize and try increasing the step Y or lag before attempting to tune again. You may also need to increase the lowpass filter time constant.
- The temperature must be stable when tuning is started. Either the feedback must be running and stabilized at the setpoint, or the heater must be off and the temperature stabilized at the ambient temperature.
- Set the lowpass filter on the input (temperature) channel to a value just below the expected response time of the system. The step response tuner in particular requires adequate lowpass filtering to produce accurate results.
- Make sure the system doesn't experience any temperature disturbances during the tuning process.
- Since the ideal feedback parameters usually vary with temperature, run the tuning algorithm at about the temperature at which the feedback will be used. If the system has never been tuned before you may need to tune at room temperature, then let the feedback bring the system to its working temperature, and re-tune at the working temperature.
- The autotuning algorithm assumes that the temperature is a linear function of heater power. In most cases it isn't, which means that the results produced by the algorithm may not be perfectly accurate and may need to be manually adjusted.

Front-panel controls

The front panel has six menu keys to the left of the display labeled "Select", "Numeric", etc. These keys can be pressed at any time to display one of the six main screens. Each of the main screens except for the Program screen has six columns of buttons, usually with a column name at the top of each column. Each button has a name in large text and, usually, a value beneath the name in smaller text.

In this manual, buttons are referred to by the name of the screen (Select, Numeric, Plot, etc.), the name of the column (if any), and the name of the button, separated by dots. For example, "System.Log.Interval" refers to the Interval button in the Log column of the System screen. The text "System.Log.Interval" can also be sent to the PTC10 over one of its communications ports (RS-232, USB, etc.) as a remote command.

The front panel also has a "Help" button that displays help text for whatever is currently on-screen, and an "Output Enable" button that turns all the PTC10's outputs on and off.

USB logging indicator

When the PTC10 is logging to a USB memory device, a small white triangle appears in the upper-right corner of all screens; if a USB device is present but the PTC10 is not logging to it, the triangle is drawn in dark blue. If no USB device is present, the triangle doesn't appear at all. The triangle confirms that the system is logging to USB and can also be used to start and stop USB logging. Touch the triangle to turn USB logging off (equivalent to pressing the System.Log.Log To button and selecting "RAM"). When the system is not logging to USB, touch the grayed-out triangle to turn USB logging on. If a USB memory device is present but not functioning (i.e., if the device is full, not formatted, or defective), the triangle will remain grayed-out and not turn white.

Removing the USB memory device or powering down the PTC10 without first ejecting the device causes loss of data and corruption of the memory device. A corrupted device should be repaired by plugging it into a PC and running a program such as chkdsk (Windows) or fsck (Linux).

"Help" key

The "Help" key displays a popup screen that provides more information about whichever window is currently visible. For example, to get a description of the "Value" setting in the "Channel" menu, first touch the "Channel" key to bring up the Channel screen, then touch the "Value" button to bring up the Value input window, and then press the "Help" key. The "Help" key does not work with pop-up windows that just display text and don't provide any opportunity for changing a value, like the "Output Enable" window that appears when you press the "Output Enable" key.

"Output Enable" key

When the PTC is turned on, all outputs are disabled (however, inputs function normally). This safety feature gives you a chance to adjust the PTC's settings before it begins to provide power to the heaters. To turn on the outputs, press the "Output Enable" key twice. A red light next to the "Output Enable" key turns on to indicate that the outputs are active, and any PID feedback loops that were previously running begin to provide power to the heaters.

If the outputs are enabled, pressing the "Output Enable" key once disables all outputs, setting them to zero. Inputs continue to function normally. In an emergency situation, the Output Enable

key is the quickest way to turn off the PTC's outputs. Re-enabling the outputs immediately returns all outputs to their previous values.

In certain cases it may be desirable to have the PTC power up with the outputs enabled to ensure that feedback loops automatically resume after a power failure. This can be accomplished with a startup macro (see the "Startup macros" section).

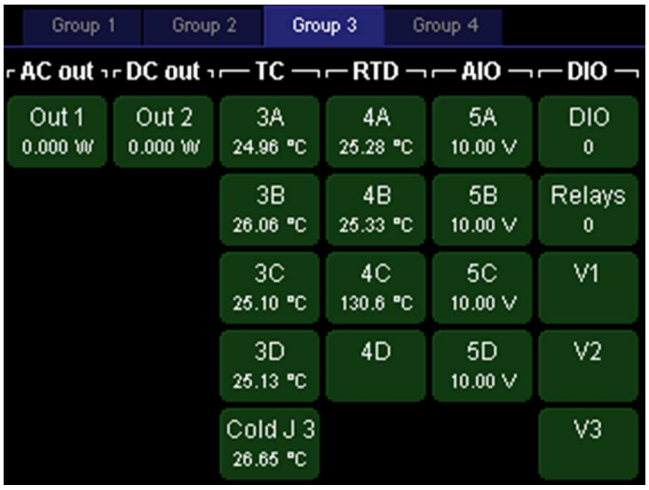
The Output Enable key is not intended to prevent electric shocks. When handling exposed heater wires, always disconnect the wires from the PTC10 or unplug the PTC10 from the wall.

Press and hold the "Output Enable" key for 3 seconds to put the PTC10 into standby mode. In standby mode, the outputs are turned off, data acquisition and macros are paused, the front panel display and system fan are shut off, and the system does not respond to remote commands. RTD excitation currents are still on, and an internal cooling fan may switch on occasionally. Press the "Output Enable" key again to leave standby mode.

"Select" screen

Each column of buttons on this screen represents one I/O card, and each button shows the name and the current value of an I/O channel. The value may not appear if no sensor or heater is connected to the channel.

The PTC10 includes two I/O cards as standard equipment: a 4-channel, ±10V analog I/O (AIO) card in slot 5, and a digital I/O (DIO) card in slot 6. These cards appear in the two right-most columns of the Select screen. The remaining four columns show any optional I/O cards that have been installed.



Buttons turn red if the channel's alarm is triggered; that is, if the alarm is enabled and the reading is outside of the alarm limits or no sensor is connected. The name of the channel appears in bold if the channel uses a custom calibration table.

Touch one or more buttons to select which channels you'd like to view on the Numeric, Plot, and Channel screens. The top of the Select screen has four Group tabs that let you save and recall up to four groups of selected channels. Touch one of the tabs or repeatedly press the "Select" button to change the selection group.

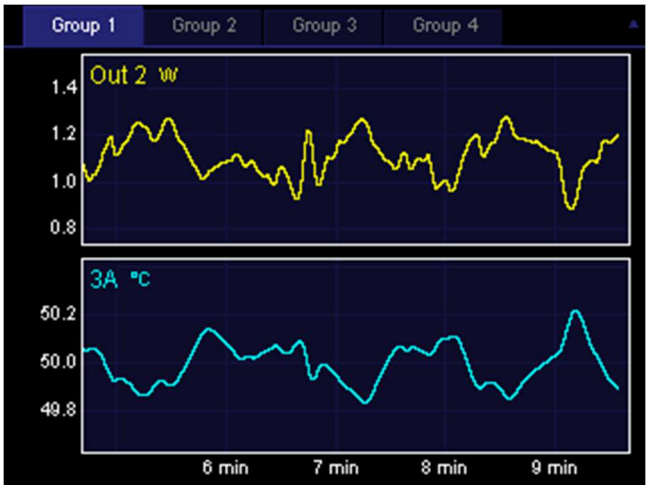
"Numeric" screen

This screen displays the current values of the selected channels as numbers. The more channels that are selected, the smaller the displays are. If enough space is available, an annunciator may appear that indicates whether the sensor or heater is disconnected ("N/A"), over range ("Hi"), under range ("Lo"), if outputs are disabled ("Off"), or if an internal error has occurred ("Err").

Input displays turn red whenever the input's alarm is triggered. The name of the channel appears in bold if the channel uses a custom calibration table.

Repeatedly press the "Numeric" button to cycle through the four selection groups. Touch one of the channel displays to show setup menu for the channel.

"Plot" screen



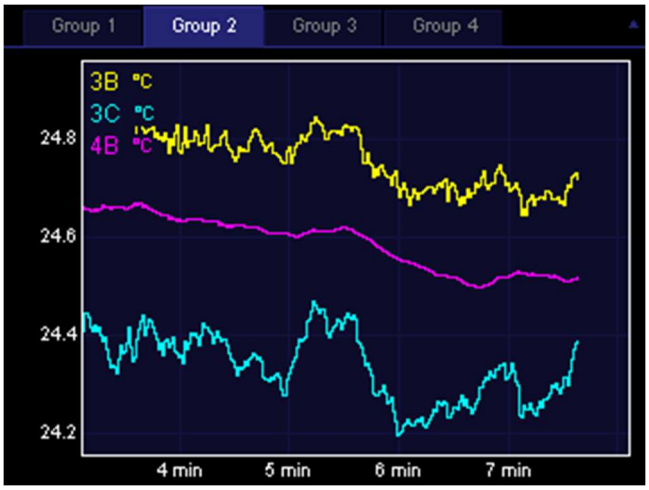
This screen shows logged data from the selected channels on one or more graphs. Press the Plot key repeatedly to cycle between the four formats described below (single, multi, custom, and ponytail).

The Plot screen always shows logged data. If, for example, the log interval is set to 10 s, the graph will have a "stairstep" appearance with a step every 10 seconds.

Touch the tabs at the top of the screen to change the selection group. Each of the four groups remembers its graph format (single, multi, etc.), X range, and Y range. Therefore, when you change the selection group, the graph's range may also change.

Single plot

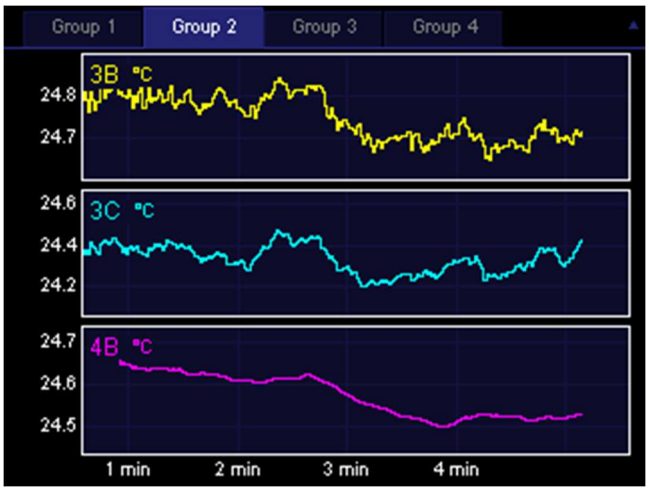
Up to eight selected channels are shown together on one graph with a single Y axis. If more than eight channels are selected, only the first eight are shown.



Single plot mode showing the ambient temperature measured by two thermocouples (channels 3B and 3C) and one Pt100 RTD (4B). RTDs have a much lower noise level than thermocouples.

Multi plot

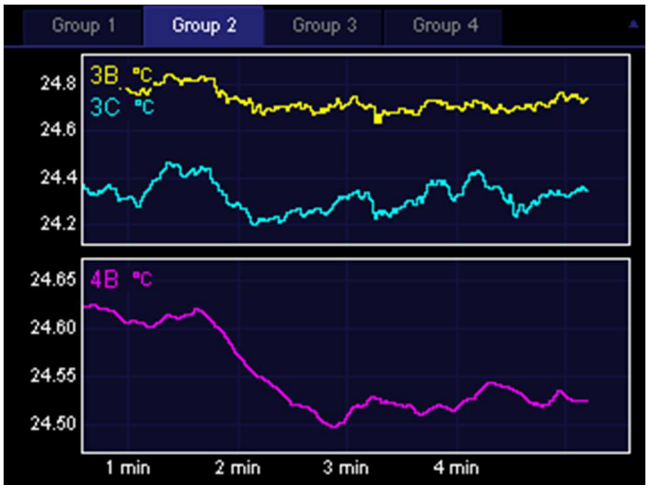
Each channel is shown in its own graph with an independent Y axis. If more than eight channels are selected, only the first eight are shown.



In multi plot mode, each sensor gets its own graph. The X scale is the same for all 3 graphs, but the Y scale is different.

Custom plot

Each channel is assigned to a plot according to its Channel.Plot setting.

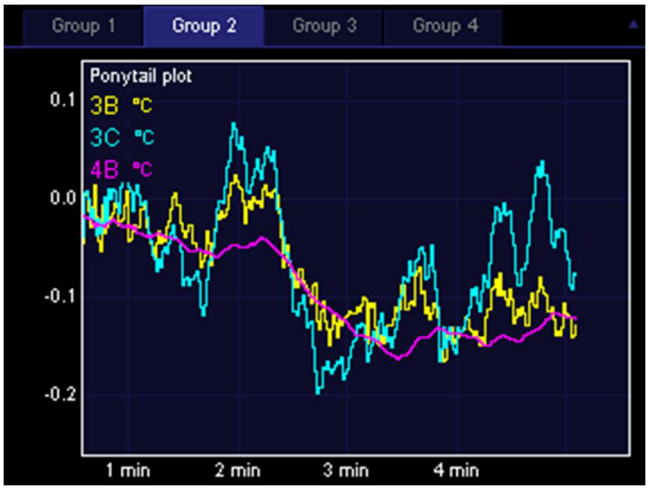


In custom plot mode, the user can manually assign each channel to a graph. Here the thermocouple inputs have been assigned to plot 1 and the RTD input to plot 2.

Ponytail plot

Like Single plot, up to eight selected channels are shown together on one graph. Each trace is offset by its initial value so that the trace begins at zero. The offset is recalculated whenever you touch the graph to zoom or pan, or whenever you switch to another screen and back to the Plot screen. If you don't touch the PTC's controls, the offset is never recalculated.

Using the ponytail plot does not affect how channel values are logged; the offsets are only applied to the plots, not to the log files.



In ponytail plot mode, all traces are offset so that they start at zero.

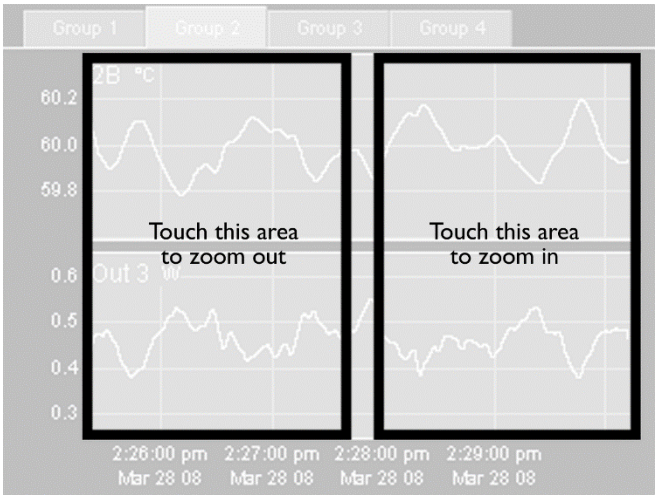
Zooming and panning

To change the X axis scale of a plot, touch anywhere inside the plot:

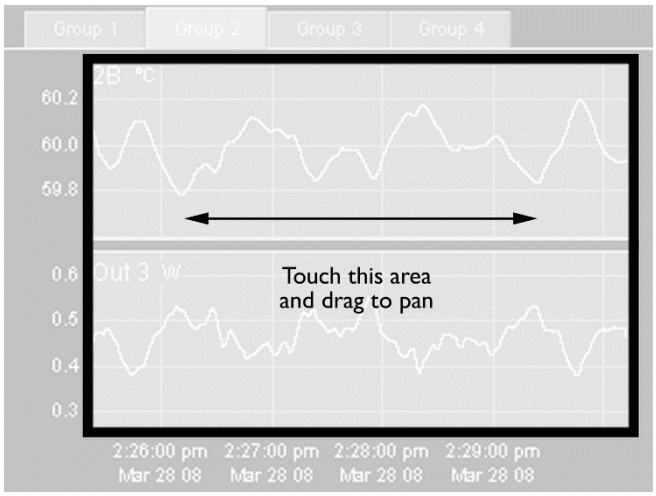
- Touch the right half of the plot to zoom in
- Touch the left half to zoom out
- Drag to pan.

Whenever the most recent data is visible on the graph, the graph automatically scrolls to keep the most recent data visible. If the most recent data is not visible, the words "X lock" appear in the bottom-left corner of the screen to indicate that scrolling is disabled. To show current data and resume scrolling, touch the words "X lock".

Graphs that appear together on a screen always have the same X axis range. However, each selection group has its own, independent X axis range.



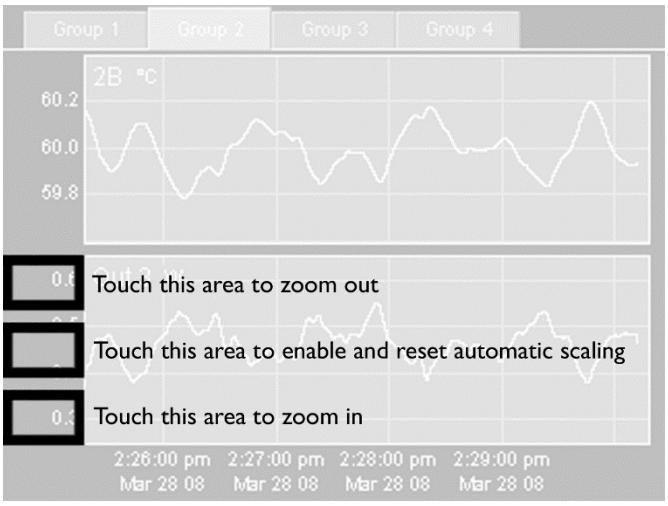
How to change the X axis scale



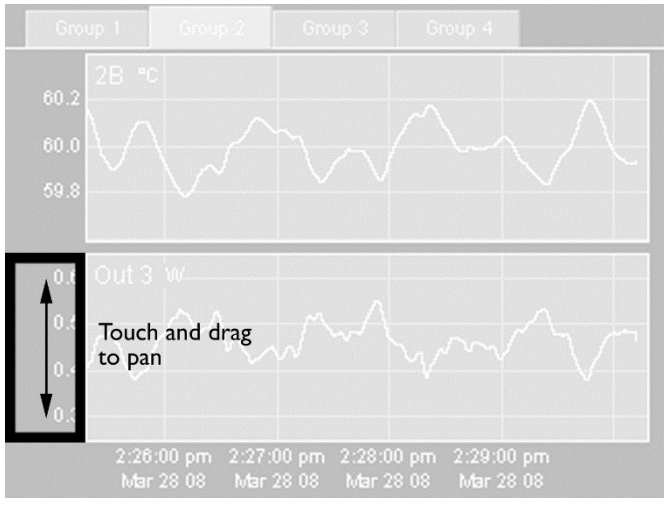
How to pan the graph horizontally

By default, the PTC10 continually adjusts the Y-axis scale to accommodate all the data on the graph. Each graph has its own, independent Y axis scale. To change the Y axis scale for a particular graph, touch the area to the left of its Y axis.

- Touch the top third of the Y axis to zoom out. Automatic scaling is disabled, so the Y axis scale no longer changes as new data is acquired.
- Touch the middle third to 1) re-enable automatic scaling and 2) reset automatic scaling, that is, ignore previously-acquired data and adjust the Y range to accommodate only new data.
- Touch the bottom third to zoom in. Automatic scaling is disabled.
- Drag to pan.



How to change the Y scale of the bottom graph



How to pan the bottom graph vertically

"Program" screen

A program is a set of one or more instructions that can be used to customize the behavior of the instrument. Programs can be input over the RS-232, GPIB, USB, or Ethernet interface, from the program screen, or as a files on a USB memory device. Regardless of how a program was input, its progress can be monitored from the program screen.

The Program screen has an Input window, which shows text received over RS-232 or GPIB; a Messages window, which shows responses and error messages from the PTC10; and a Progress window, which shows the list of instructions that make up the current program.

If a program is not running, you can compose or modify a program by touching a line in the Progress window. Touching a blank line brings up a list of possible commands. Touching a line that already contains an instruction brings up a list of three options: you can add a new instruction on the line above the one that was touched; delete the instruction that was touched; or replace the instruction that was touched.

The Program screen has six buttons:

Play symbol

If a program is displayed but not running, press this button to start the program. If a program is running in the currently-selected tab, the button is highlighted and pressing it stops the program.

Pause symbol

Press this button to temporarily pause the program running in the currently-selected tab. Press the button again to resume running the program.

Clear

Erases all text from the Input, Messages, and Progress windows. Unless it has previously been saved, the current program is lost. This button cannot be pressed while a program is running in the current tab.

Load

Touch this button and a list of programs stored in memory is displayed. Programs can be stored in memory with the Program.Save button, by sending a "define" instruction to a remote interface, or by attaching a USB device with text files contained in a "Macros" folder. Select a program from the list and its component instructions are displayed in the Progress window, replacing whatever was previously in the window.

The Program.Load button can be used to edit a previously-saved program: load the program, then edit it in the Progress window, and finally re-save the program with the Save button.

To call a previously-saved program as a subroutine from a program that you're composing, don't use the Program.Load button, since it would erase the rest of the program. Instead, touch the "Progress" window and select the saved program from the list of commands. The Program.Load button cannot be pressed while a program is running in the current tab.

Save

Saves the current program, as shown in the Input window, to memory. You'll be asked to supply a name for the program. Up to 15 programs can be saved. If 15 programs are already saved, the Save button will have no effect.

Saved programs can be run using the "Load" button or called as subroutines by touching a line in the "Progress" window. Saved programs can also be called by sending their name (like any other instruction) over one of the remote interfaces.

Delete

Touch this button to display a list of programs stored in memory. Select a program from the list and it will be deleted from memory. The Program.Delete button does not affect the status of currently-running macros.

Sending programs over RS-232, USB, GPIB, or Telnet

Programs can be entered from a remote interface such as RS-232, USB, Telnet, or the optional GPIB port. Each line of text sent to the PTC10 is run as a separate program (the entire program must be on a single line). If two or more lines are sent to the PTC10 in quick succession, the programs may run concurrently; that is, the PTC10 does not finish running the first program before beginning the second. However, the first program sent will always begin running before the second program. If it's preferable to run programs sequentially, begin each line with the *PHO instruction.

See the "remote interface" section of this manual for more details.

Preparing programs as files on USB memory devices

The PTC10 can also read programs that are stored as text files in a USB memory device. This is the best way to enter longer programs.

Create a "Programs" folder in the root directory of the memory device. Type the program in a word processing or text editor program, and save it as a .txt file in the "Programs" folder. Plug the memory device into the PTC10. On the Program menu, touch the Load button and the name of the program should appear along with any programs that have been saved in the PTC10's internal memory. The program can be run just as if it were saved in the PTC10's memory; however, after the USB device is unplugged, the program is no longer available.

While the PTC10 is running you can unplug the USB device, use a PC to edit a program stored on the device, plug the USB device back into the PTC10, and run the new version of the program. To ensure that the PTC10 runs the new version of the program, use the Program screen's Load button to re-load the program.

Programs that are prepared as files can contain up to 4096 characters, and may include multiple lines and comments (an apostrophe, i.e. a single quote mark, indicates that the rest of the line is a

comment). Except for the first newline after a comment, all whitespace is ignored; each line can be empty or can contain one or more instructions.

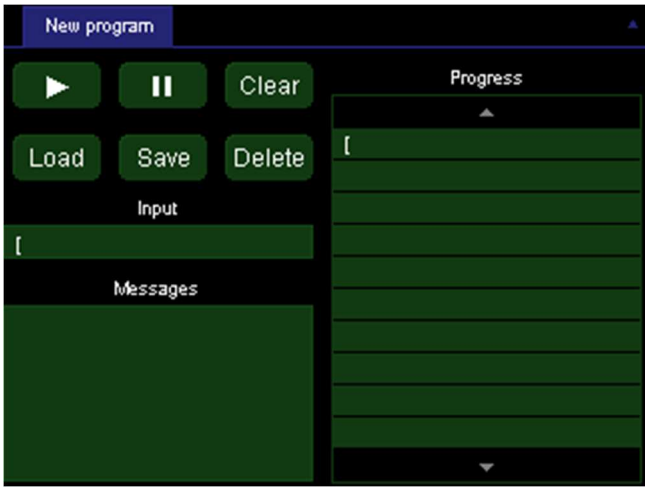
Preparing programs from the front panel

Simple programs, such as a series of temperature ramps, can be entered from the front panel.

To enter a program from the front panel, press the "program" button and then touch the Progress window. A list of available top-level commands appears.

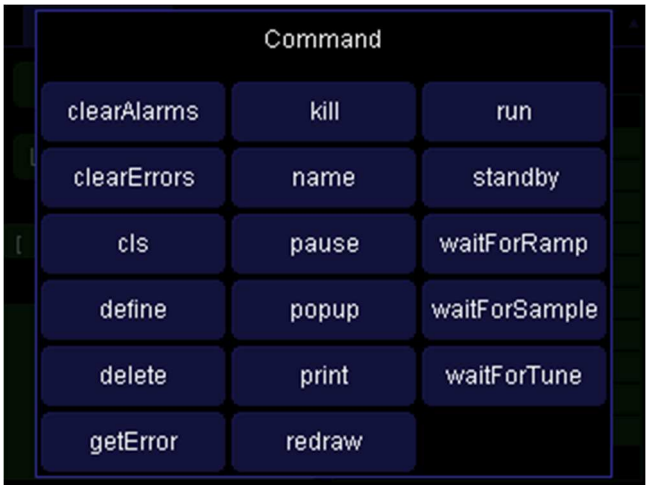
Any button with a name ending in a dot brings up a sub-menu when pressed. For example, the commands to change the feedback setpoint or alarm limits for a channel are accessed by first touching the "channel" button.

Touch the left square bracket (the button in the upper-left corner). Square brackets surround blocks of code to be repeated. You're returned to the "Program" screen, where the first line in the "Progress" window is now a left square bracket.

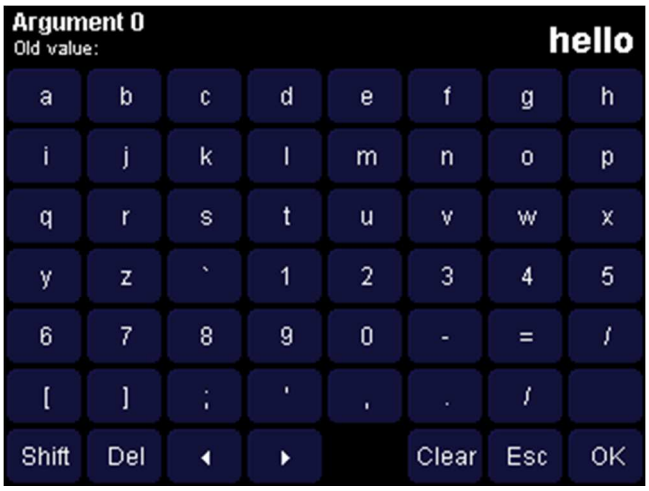


Touch the Progress window again, anywhere beneath the first line. The list of possible instructions appears. Select "program." from the list. Touching this button brings up a list of

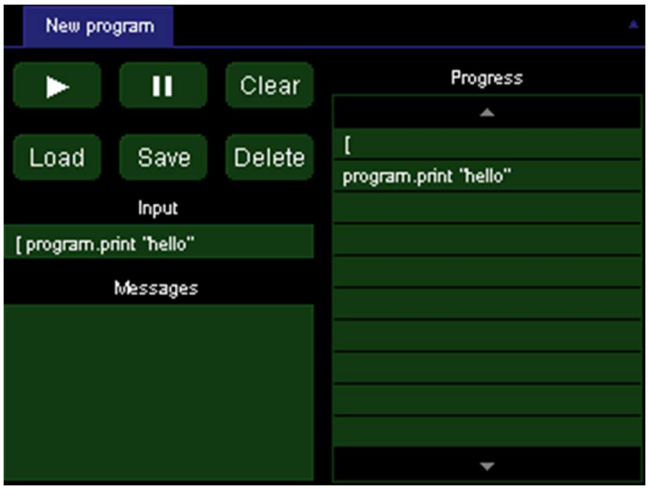
instructions that affect the program. For example, “cls” clears the Messages window; “name” assigns a name to the program; and “kill” ends a named program.



Select “print”. An alphanumeric input screen appears where you can enter an argument for the “program.print” instruction. Type “hello”.



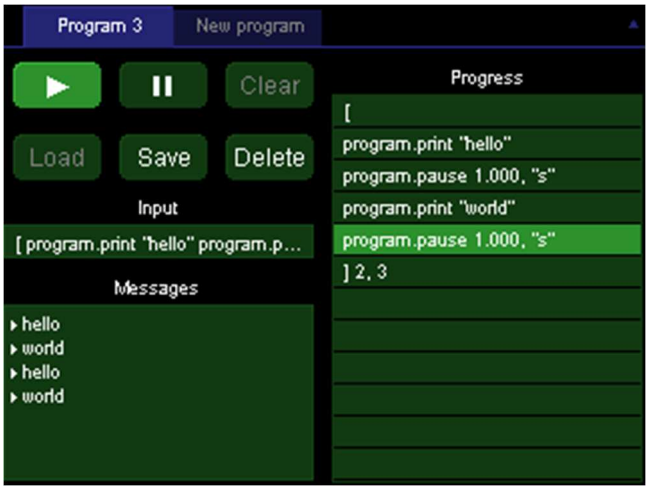
Touch the OK button. You are returned to the Program screen and the instruction “program.print “hello”” appears in the second line of the Progress window.



Now enter the instruction: "program.pause 1 s". The pause instruction has two arguments that must be entered separately. First you'll be shown a numeric input screen where you can type "1". Touch "OK" and you'll get a second menu where you can enter the units ("s"). The completed instruction will pause the program for one second.

Next, enter the instruction "program.print world" followed by "program.pause 1 s". Finally, enter the instruction "] 3". This makes the program repeat everything between the square brackets three times.

Press the start button. While the program is running, the current instruction is highlighted and the total number of repetitions as well as the number of repetitions remaining appears next to the right square bracket. In addition, while the program is running a new tab (labeled "New program") appears at the top of the screen. By touching this tab, you can enter and start a second program while the first program is still running.



When the program is done, the messages "hello" and "world" should appear three times in the Messages window.

Once the program is finished you can press the start button to run the program again, the "Save" button to save the program, or the "Clear" button to erase the program and the Messages window.

Running concurrent macros

Since a macro can run for a long period of time or even indefinitely, it's possible to start a new macro before the previous macro has finished. It's also possible to run multiple instances of a saved macro simultaneously.

The PTC can run at most ten concurrent macros (including the startup macro, macros received over all I/O ports, and macros started from the Program screen). If an eleventh macro is started, a "Too many macros" assembly error is generated and the macro does not run.

If the PTC10 is turned off and turned back on again, macros that were running when the PTC10 was turned off are not restarted.

"Channel" screen

The "Channel" screen includes controls for all settings that affect individual data channels. Sensor calibration, PID feedback parameters, and alarms are all set up through this screen. Note that the layout of the screen varies depending on which channel is selected; for example, only output channels have PID controls, while only input channels have alarm controls.

Only one channel can be set up at a time. One tab appears at the top of the screen for each channel in the current selection group; select the tab for the channel you want to set up. Repeatedly pressing the "Channel" button cycles through the four selection groups.

Name

Sets the name of the channel. The name must have 10 or fewer characters.

Value

If the channel is an input, this button shows the most recent reading but is grayed out, indicating that the reading can't be changed from the front panel. If the channel is an output, the reading is not grayed out and pressing this button allows you to enter a new output value. However, if PID feedback is turned on or Output Enable is off, changing the value will have no effect.

Off

Sets the PID feedback mode to Off, cancels any PID tuning processes currently operating on the channel, and sets the channel's output to zero or the "Low lmt" value, whichever is higher. This button is only available for output channels.

Low lmt

This control, which is only available for output channels, sets the minimum output. However, if the minimum is greater than zero, the output is still set to zero whenever outputs are disabled with the "Output Enable" key. Limits are always expressed in the same units as the value. The limits should normally be changed when the output units are changed, since the limits are not automatically converted to the new units.

Hi lmt

This control, which is only available for output channels, sets a maximum limit on the output. It's typically used to prevent the PID feedback loop from delivering excessive power to a heater. If the high limit is less than the low limit, the low limit takes precedence.

Range

If the I/O card has more than one range, pressing this button displays a menu of available ranges. If the card only has a single range, this button is grayed out.

IO type

Each output channel has an ADC that can measure the actual output. The "IO type" button determines whether the output that you see on the screen is the value measured by the ADC ("Meas out") or the value requested by the user or the PID feedback loop ("Set out").

The PTC's general-purpose analog and digital I/O channels are bidirectional, (i.e. they can be used to monitor external signals, or to produce signals). In these cases, the IO type button has three settings: "Set out" means that the channel outputs a voltage and the value you see on-screen is the value you asked for. "Meas out" means that the channel outputs a voltage and the value you see on-screen is the value measured by the ADC. "Input" means that you can drive the channel with an external voltage, and the channel will measure that voltage.

Plot

Indicates which plot the channel will appear in when the "Plot" screen is showing, the plot type is Custom (see the "Plot Screen" section above), and the channel is selected on the "Select" screen. Choose one of eight plots for the channel to appear in, where plot 1 is the uppermost plot. If no channels are assigned to a given plot, the plot won't appear on the "Plot" screen. For example, if all selected channels are assigned to plot 4, only one plot appears on the Custom plot screen.

Logging

By default, each channel's value is written to the log once every second. This global log rate can be changed on the "System" screen (System.Log.Interval). The Logging button makes it possible to override the global log rate for individual channels.

Cycle (AC output card only)

The PTC420 has a solid-state relay that can either deliver full power or no power to the heater. To more precisely control the power delivered to the heater, power is switched on for some fraction of a preset cycle time, then switched off for the remainder of the cycle. For example, if the cycle time is 10 seconds, the relay might switch on at time t = 0 s, off at t = 1 s, on at 10 s, off at 11 s, on at 20 s, and so on. This would produce 10% of the maximum output.

The Cycle instruction sets the on/off cycle time. Shortening the cycle period will reduce temperature swings associated with switching the current on and off, but will also reduce the lifetime of the relay. The cycle time must be between 1 and 240 seconds inclusive.

Dither (DC output card only)

The DC output card has a 16 bit DAC. For greater resolution, the least significant bit can be dithered. Dithering is enabled by default.

Current (4-channel RTD reader and 1-channel thermistor/diode/RTD reader only)

Controls the direction of the sensor excitation current. Reverse the current to detect offsets due to parasitic thermocouple EMFs or 60 Hz noise. In AC mode, these offsets are automatically removed by reversing the current at each ADC reading; each reported temperature is based on the average of the last two ADC readings (cutting measurement bandwidth in half). The PTC320 thermistor/diode/RTD reader's excitation current can be turned off entirely with this control.

Current (TEC driver card only)

Controls the amount of excitation current (1 mA, 100 µA, 10 µA, or auto) provided to the temperature sensor. The sensor excitation current on the TEC driver card cannot be reversed.

The table below shows the excitation current produced by the "auto" current setting on the PTC440 TEC driver when a resistive sensor is in use. The sensor resistance is continuously monitored and the excitation current is adjusted whenever the sensor resistance rises above or drops below the levels shown in the table. The "auto" current setting always produces 1 mA when an LM335 or AD590 sensor is in use.

Sensor resistance	Excitation current
<2 kΩ	1 mA
1– 20 kΩ	100 µA
>10 kΩ	10 µA

Excitation current produced by the "auto" current setting on the PTC440 TEC driver (for resistive sensors only)

The overlap of the resistance ranges keeps the PTC440 from rapidly switching back and forth between two excitation currents. If, for example, the sensor resistance is between 1 and 2 kΩ, the PTC440 can select either 1 mA or 100 µA excitation, and if possible, it keeps the excitation at its previous value.

Slew (Only appears on the "Out" channel of TEC driver cards)

Sets the maximum positive and negative rate of change of the TEC driver output. The rate must be between 0 and 1000 amps per second, and the default value is 100 amps per second (which corresponds to an unlimited slew rate at 10 samples/second). Each time the TEC current is set (either by a PID feedback loop or with the Channel.value control), it ramps to the new value at this slew rate.

Rapid changes in the TEC current can create electromagnetic interference (EMI) in the temperature sensor and any other sensors near the TEC. The resulting spikes in the temperature reading can cause feedback oscillations or noisy temperature readings.

For the slew rate setting to be effective, the A/D rate (set with the System.Other.A/D rate control) should less than or equal to 100 ms. The slew rate is implemented with a software algorithm that runs at each A/D conversion, and the TEC driver output has a 13 Hz lowpass filter. If the A/D rate is set (for example) to 1000 ms, the algorithm only changes the TEC output current once each second and the output current therefore changes in discrete steps, each of which may exceed the desired slew rate.

When outputs are disabled by pressing the Output Enable button or with the "OutputEnable off" remote command, the TEC output turns off immediately, regardless of the slew rate setting. When outputs are re-enabled, the TEC output ramps up to its previous value at the desired slew rate.

Vmax (Only appears on the "Vmon" channel of TEC driver cards)

Sets the maximum voltage that the PTC440 TEC driver can output. This control is intended to protect thermoelectric coolers from damaging voltages. If the measured voltage across the TEC is above Vmax for more than one second, current to the TEC is automatically shut off. The first time this occurs after the system is turned on, a "hardware fault" window also pops up on the front-panel display. To turn the current back on again, set the channel's output to zero (for example, by touching the "Off" button on the Channel menu, or by disabling and re-enabling all outputs with the Output Enable button).

If the output current suddenly increases and the slew rate setting is too high, it is still possible to damage the TEC even if Vmax is set to an appropriate value. To prevent such damage, the output voltage should, if possible, also be limited by setting the output range to the lowest possible value (e.g., 3V 5A, 6V 5A, or 9V 5A); and by setting the "Lo lmt" and "Hi lmt" controls for the output channel to current values that do not produce excessive voltages.

The TEC voltage can also be limited using the Vmon channel's alarm. Set the Channel.Alarm.Mode control to "level", the Channel.Alarm.Latch control to "yes", and the min and max to the desired voltage limits. Touch the Channel.Alarm.Output button and select the TEC output channel. The Channel.Alarm.Lag control can be set to 1 s to prevent noise spikes from inadvertently triggering the alarm, or left at 0 s to better protect the TEC from rapid voltage increases.

PCB (RTD, thermistor, and thermocouple readers only)

Sets the maximum printed circuit board (PCB) temperature for all channels on the selected card. If the card's temperature exceeds the maximum and System.Other.Fan is set to "Auto", the PTC10 increases the fan speed to reduce the card's temperature. The PCB control only appears for I/O cards that have internal temperature sensors.

The PCB temperature is always in °C, regardless of the System.Display.Units setting. The default setting is 30°C.

Thermal drift of the RTD or thermocouple inputs can be reduced by setting the PCB temperature of one card to a lower value. This value should be a few degrees above room temperature, (i.e., 25°C). Reducing the maximum PCB temperature results in tighter regulation of the PTC10's internal temperature, particularly of the selected card, at the expense of more fan noise.

However, if a DC output card is being used the system might sometimes turn up the fan speed to prevent thermal damage to the output card, causing larger internal temperature variations.

Diff (input channels only)

The value of the channel selected with the "Diff" button is continuously subtracted from whichever channel is selected in the tab bar at the top of the "Channel" menu. To turn the difference feature off, touch "Diff", then touch whatever channel is currently selected. The "Diff" button then shows an empty value.

Channels with a difference filter can be used as the input for PID feedback loops, in which case the feedback maintains a constant temperature differential between two locations, rather than a constant absolute temperature.

Lopass (input channels only)

If a non-zero value is selected, a 6th-order RC lowpass filter is applied to the selected channel. The lowpass filter removes noise with a period shorter than the indicated time constant but also increases the effective response time of a sensor.

The lowpass filter should always be enabled on the temperature inputs of all PID control loops. This is especially true when using step response PID tuning or when derivative feedback is enabled (i.e., the derivative gain is nonzero), since these algorithms calculate the change in temperature over time and therefore produce poor results if high-frequency noise is present. The filter's time constant should be just below the response time of the system. When using an AC output card for PID control, the filter constant should be longer than the cycle time of the output.

When a sensor is disconnected and then reconnected to a lowpass-filtered channel, the PTC allows one second for the reading to settle. During this time, no reading appears. The output of the lowpass filter is then set equal to the next ADC reading so that you don't have to wait for the reading to gradually settle to its new value.

Units (PTC420 AC output card and PTC430 DC output card only)

By default, the output of these heater driver cards is measured in watts. Using the "Units" button, the output units of the AC output card can be changed to "%" (i.e., percentage of the maximum output) and the output units of the DC output card can be changed to "A" (heater current) or "V" (heater voltage).

d/dt (input channels only)

Derivative. If this control is set to "On", the value of the channel is replaced with its derivative with respect to time. Since the derivative is normally somewhat noisy, the lowpass filter should be enabled when the derivative filter is used.

Follow (virtual input channels only)

This button only appears for virtual channels that are configured as inputs. Once a channel is selected, the virtual channel's value continuously follows the value of the selected channel. Difference, derivative, or other filters may be applied to the virtual channel to modify the value. For example, select "Follow"; then, on the menu that appears, touch the button for channel 3A (assuming that channel 3A exists). The virtual channel now echoes the value of channel 3A. Next select "Diff" and then touch the button for channel 3B. The value of the virtual channel is now the difference between channels 3A and 3B.

Sensor (input channels only)

Selects the sensor type. The button only appears on input channels that support more than one sensor type. The list of available sensor types varies with the I/O card.

Changing the sensor type has three effects. First, it changes the calibration curve that the PTC10 uses to convert raw sensor readings into temperature. Second, changing the sensor type may affect how the PTC hardware acquires data from the sensor. For example, if the sensor type of a PTC320 I/O card is changed from Thermistor to Diode, the PTC acquires voltage instead of resistance readings.

Finally, changing the sensor type affects which buttons appear in the Channel.Cal column as well as the list of options that the Channel.Cal.Type button offers. For example, if the sensor type is "RTD", the Channel.Cal.Type button offers a list of standard RTD types, and the RTD's Callendar-van Dusen coefficients appear in the Channel.Cal column. If the sensor type is "Therm" (thermistor), the Channel.Cal.Type button offers a list of standard thermistor types, and the thermistor's Steinhart-Hart coefficients appear in the Channel.Cal column.

"ROX" indicates a ruthenium oxide sensor, while E, J, K, N, and T refer to thermocouple types. Since the PTC330 thermocouple reader's hardware determines which type of thermocouple can be read, the thermocouple type cannot be changed on this card.

Some resistive cryogenic temperature sensors such as Rhodium-Iron, Germanium, and Carbon-Glass are not included in the list of available sensor types because they do not have standard calibration curves. To use these sensors, set the Sensor type to thermistor, RTD, or ROX and load a custom calibration table. See "Custom Calibration Tables" in the Introduction section of this manual for more information on custom calibration tables.

Polarity (relays channel of digital I/O card only)

This setting only applies to the Relays channel on the digital I/O card. Changing the polarity reverses the state of all four relays.

The Polarity setting ensures that the relays are in an acceptable state when the PTC10 is switched off. When the Polarity is 0, the relays revert to the "alarm off" state when the PTC10 is switched off. When the Polarity is 1, they revert to the "alarm on" state.

The "Relays" value shown on the front panel is the sum of four individual relay values: relay A can have a value of 0 or 1, relay B can have a value of 0 or 2, relay C can have a value of 0 or 4, and relay D can have a value of 0 or 8. When the polarity is changed, the value of each relay stays the same, but its meaning changes as shown in the table below.

Relay state →	**Default (power off)**		**Relay value = 0 (alarm off)**		**Relay value = 1, 2, 4, or 8 (alarm on)**	
Back panel pin →	**NC**	**NO**	**NC**	**NO**	**NC**	**NO**
Polarity = 0	Closed	Open	Closed	Open	Open	Closed
Polarity = 1	Closed	Open	Open	Closed	Closed	Open

The "default" state is what the relays revert to when the PTC10 is switched off. If no alarms are configured, they will stay in that state when the PTC10 is turned back on again.

Channel screen: Alarm column

Each input channel has an alarm. If enabled, the alarm is triggered if any of the following conditions occur:

- The input (or its rate of change) exceeds the user-specified minimum and maximum values
- The input exceeds the measurement range of the I/O card
- The sensor is disconnected (except on analog I/O channels, which cannot detect disconnected sensors)

When an alarm is triggered, it can do any of the following:

- Play a sound
- Trigger a relay on the digital I/O card
- Shut off an output channel

The alarm can be programmed to remain triggered until it is manually shut off (latching alarm), or to shut itself off as soon as the input returns to a value within the alarm limits (non-latching alarm). The alarm can also be programmed to ignore momentary glitches.

To determine which alarms are currently triggered, look at the Select screen. A small white dot in the upper-right corner of a button indicates that the channel's alarm is in the triggered state.

It's very important to set at least one alarm if your heater can output enough power to damage your system. The alarm should be configured to disable the heater output when triggered. For additional protection, the heater output can be routed through one of the PTC10's relays and the relay associated with the alarm. Without such a safety mechanism, it's possible for the PTC10 to enter a "runaway feedback" condition if a sensor becomes unplugged or malfunctions, or if the PID feedback is incorrectly set up.

The following controls are available for input channels only:

Status

Indicates if an alarm condition is currently present on this channel. If a latching alarm has been triggered, touch the Status control and set its status to "Off" to turn the alarm off. This control can also be used to artificially turn the alarm on to test the sound, output channel disabling, and GPIB status reporting.

To test an alarm, enable the alarm with the Mode control and then set its Status to "On". The alarm immediately turns on. If the alarm is non-latching, it turns off in less than a second; if it is latching, it stays on until the Status is set to "Off". The Lag setting has no effect on this test.

Mode

Enables or disables the alarm. The following three alarm modes can be selected:

Off: the alarm never sounds.

Level: the alarm sounds whenever the input exceeds the values set with the Min and Max controls. The alarm also sounds whenever the input is disconnected or the sensor value exceeds the range of the input.

Rate /s: the alarm sounds whenever the rate of change of the input (in degrees per second) exceeds the Min or Max values. The alarm also sounds whenever the input is disconnected or the sensor value exceeds the range of the input.

Latch

If set to "Yes", the alarm, once triggered, stays on until it is turned off with the Status or Mode control. If set to No, the alarm turns itself off once the input is again within the alarm limits.

Mute

Temporarily silences the alarm sound but does not otherwise affect the alarm. Once this button is touched, the alarm stays muted until the alarm condition goes away or until the button is touched again.

Sound

Controls which sound plays when the alarm goes off.

Output

The alarm, when triggered, can shut off one of the PTC's output channels, setting the output to zero and temporarily disabling that channel's feedback loop. Once the alarm status returns to "Off", the output returns to its previous value and the feedback is re-enabled. This feature can be used to guard against runaway feedback loops or to otherwise protect equipment from damage due to

excessive temperatures. For example, one or more backup temperature sensors can be programmed to shut off a PID output to prevent damage in case the primary sensor fails.

Touching the "output" button brings up a list of output channels; from this list, select the channel to be shut off. If a channel is already selected, touching it again de-selects the channel and no channel will be shut off when the alarm triggers.

Relay

If a digital I/O card is installed in slot 6, the alarm can switch one of its four relays on. It's possible to assign more than one alarm to a given relay, in which case the relay will turn on if any one of the alarms is triggered.

Min

The lowest permissible value of the input. The alarm is triggered if the input (or the rate of change of the input) becomes lower than this value.

Max

The highest permissible value of the input. The alarm is triggered if the input (or the rate of change of the input) exceeds this value.

Lag

Prevents noise or glitches from inadvertently triggering the alarm. The alarm will not be triggered until the input has continuously exceeded the min or max setting for this number of seconds. The lag applies when the alarm is being switched and when it is being switched off.

Channel screen: Cal column

This menu is only available for input channels.

Type

The Calibration Type control affects how raw sensor readings are converted to temperature measurements. This control does not affect how the sensor is read.

The "Type" option appears on temperature input channels and on channels for which custom calibration tables have been loaded. It does not, by default, appear on the four analog I/O channels, the digital I/O channel, the relay channel, and virtual channels.

If the I/O card only supports a single calibration curve, the calibration type is grayed out and cannot be changed, unless a custom calibration is loaded.

If the selected channel uses a custom calibration table, its calibration type reads "Custom". To stop using the custom calibration, touch the Type button and select "Standard". The Type button then reverts to the normal list of calibration types supported by the I/O card.

The available calibration types depend on the sensor type.

RTDs: Choose "ITS-90" for RTDs with an alpha of 0.00385; "US" for RTDs with an alpha of 0.00392; or "Custom" to enter your own Callendar–van Dusen calibration coefficients.

Thermocouples: Indicates the thermocouple type (E, J, K, N, or T). Cannot be changed, since the thermocouple type is determined by the back-panel connector.

Thermistors: The available calibration types are named according to the resistance of the thermistor at 25°C. Thermistors from Omega, Measurement Specialties, Inc. (formerly YSI), and others that conform to the same calibration curve are supported. Note that unlike RTDs and thermocouples, there are no international standards for thermistors. Therefore, thermistors from

different companies may not be compatible with each other or with the PTC10's built-in calibrations even though they have the correct resistance at 25°C.

Diodes: Choose from the list of commercial cryogenic diodes. See the description of the PTC320 I/O card on page 2 for more information on standard diode calibrations.

A (RTD, thermistor, and diode calibrations only)
B (RTD, thermistor, and diode calibrations only)
C (RTD, thermistor, and diode calibrations only)
R0 (RTD calibrations only)

Custom calibration coefficients. These settings let you define custom calibration curves for some sensor types without making a custom calibration table. The values can only be changed if the calibration type is set to "Custom" and a custom calibration table is not in use.

RTDs: If the sensor is an RTD, A, B, C, and R0 are the constants for the Callendar–van Dusen equation:

$$R_t = R_0(1 + At + Bt^2 + (t - 100)Ct^3) \text{ below } 0°C$$
$$R_t = R_0 (1 + At + Bt^2) \text{ above } 0°C$$

where R_t is the measured resistance of the RTD in ohms, R_0 is the resistance of the RTD at 0°C, also in ohms, and t is the temperature in °C.

If a standard RTD calibration is selected (i.e. IEC751 or US), preset values of A, B, and C are used. The value of R0, however, is not preset and can be modified.

The Callendar-van Dusen equation is not an exact representation of an RTD's characteristics, but is accurate to about 50 mK in the range -200 – 400°C. In contrast, class A commercial RTDs that have not been individually calibrated are accurate to 150 mK at 0°C and 950 mK at 400°C.

If you're calibrating your own sensor and the calibration points are separated by less than 50°C, it's usually easier and more accurate to load the calibration in the form of a calibration table instead of calculating the Callendar-van Dusen coefficients.

Thermistors: If the sensor is a thermistor and the calibration type is set to "custom", the A, B, and C settings are the Steinhart-Hart coefficients. The temperature T (expressed in K) is calculated from the thermistor resistance R (in ohms) using the following equation:

$$T = (A + B \cdot \ln(R) + C \cdot \ln^3(R))^{-1}$$

If a standard thermistor calibration is selected, the A, B, and C controls show best-fit coefficients for whichever curve is selected. These figures are approximations only and are not actually used to calculate the temperature unless the calibration type is changed to "Custom".

Diodes: If the sensor is a diode and the calibration type is set to "custom", the A, B, and C settings are a polynomial fit to the diode calibration curve:

$$T = A - BV - CV^2$$

where T is the temperature in Kelvins and V is the voltage across the diode in volts. Note that polynomial fits are only accurate within a limited temperature range.

If a standard diode calibration is selected, the A, B, and C controls show best-fit coefficients for whichever curve is selected. These figures are approximations only and may not produce the same results as the standard calibration curve.

A standard diode or bipolar junction transistor can be connected to the PTC320 input card and used as a low-cost temperature sensor. In this case a custom calibration must be used. If the voltage

across the diode is measured at two known temperatures, the calibration coefficients can be calculated as follows:

$$B = -(T_1 - T_2) / (V_1 - V_2)$$
$$A = T_1 + (V_1 \cdot B) + 273.15$$
$$C = 0$$

where V_1 is the voltage (expressed in volts) at temperature T_1 (expressed in °C), and V_2 is the voltage at temperature T_2. The resulting calibration is a linear approximation. For greater accuracy, a custom calibration table should be used instead of the A, B, C coefficients; see page 32.

Offset
Gain

The offset/gain filter modifies the value of an input channel as follows:

$$\text{output} = (\text{input} \cdot \text{gain}) + \text{offset}$$

where input is the input to the offset/gain filter, and output is the output of the filter. This filter can be used as a simple way to adjust sensor calibrations.

The offset/gain filter is applied after the sensor calibration and after the "follow" filter, but before the other input filters (difference, lowpass, and derivative).

Channel screen: PID column

This menu is only available for output channels. In addition, if no Input channel is selected, all of the other PID buttons are grayed out

Input

The temperature sensor whose temperature the PID feedback loop regulates. It's possible to use one temperature sensor as the input for more than one PID loop.

Mode

If the PID mode is "Off", PID feedback is inactive and the output can be set manually with the "Value" control.

If the mode is "On", PID feedback actively controls the heater output, ideally maintaining the input channel at the setpoint.

If the mode is "Follow", the output is continuously set equal to the input, with a gain and offset applied. There is no PID feedback in follow mode.

Setpoint

The temperature at which the PID feedback loop tries to keep the input.

Zero pt (Follow mode only)

In "Follow" mode, this value is subtracted from the input. Thus, when the input is equal to this value, the output is zero. In follow mode, the output is determined by the equation:

$$\text{Output} = (\text{Input} - \text{Zero pt})\text{Gain}$$

Ramp

This button is used to set the ramp rate in degrees per second, controlling how quickly the PTC10 heats or cools your system.

Whenever the feedback setpoint is changed, the PTC10 gradually adjusts the ramp temperature (see the description of the "Ramp T" control, below), increasing or decreasing it at the ramp rate until it reaches the new setpoint. The PID feedback loop, in turn, attempts to control the sensor temperature such that it tracks the ramp temperature. Assuming the feedback is properly tuned and that your heater can respond quickly enough, the sensor temperature should rise or fall at the ramp rate until it reaches the new setpoint.

If Ramp is set to zero, ramping is disabled and the PTC10 heats or cools your system at the maximum possible rate.

Ramp T

The Ramp T button shows the temperature that the PID feedback is currently trying to maintain. Ramp T is equal to the setpoint unless 1) the feedback is disabled or 2) a temperature ramp is currently in progress.

If the feedback is disabled, Ramp T follows the sensor temperature. When the feedback is enabled, Ramp T increases or decreases at the ramp rate until it reaches the setpoint. This ensures that the temperature of your sample ramps smoothly to the setpoint at the rate specified by the "Ramp" control. If it's preferable to reach the setpoint more quickly, touch the Ramp T button and enter the setpoint value.

Once it reaches the setpoint, Ramp T will remain exactly equal to the setpoint until the setpoint is changed. When the setpoint is changed, Ramp T increases or decreases at the ramp rate until it reaches the new setpoint.

If the feedback is disabled, Ramp T immediately starts to follow the sensor temperature again. It doesn't ramp to the sensor temperature because the feedback is now off.

The Ramp T button can be used to monitor the progress of temperature ramps. The sensor temperature could also be used for this purpose, but is subject to noise, external disturbances, and other artifacts that in some cases could make it difficult to determine the intended temperature.

P

Sets the proportional gain factor. The PID equation is:

$$\text{Output}_t = Pe_t + 0.5IT((e_0 + e_1) + (e_1 + e_2) + \ldots (e_{t-2} + e_{t-1}) + (e_{t-1} + e_t)) + (D/T)(e_t - e_{t-1})$$

where P, I, and D are the derivative gains, e_t is the error (the difference between the setpoint and the PID input signal) at time t, and T is the ADC sampling time. Thus, larger values of P, I, or D produce a faster feedback response. Increasing P or I tends to create oscillations, while increasing D reduces oscillations but adds noise. Negative values of P, I, and D should be used if the output drives a fan or other device that cools the sample.

Gain (Follow mode only)

In follow mode, the input is multiplied by this value before being sent to the output. See Zero pt.

I

Sets the integral gain factor. Integral gain should normally be about one-tenth of proportional gain.

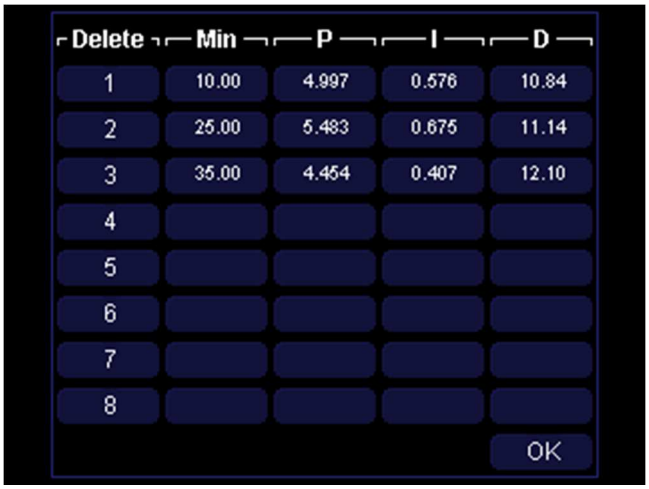
D

Sets the derivative gain factor.

Zone

This control stores up to eight sets of feedback parameters. Each set can be associated with a temperature range (or zone) and automatically recalled when the setpoint enters that range. The zone can also be manually selected, ignoring the temperature.

To view a table of all stored feedback parameters, touch the 'Zone' button and then select 'Edit'. The table that appears has a row for each zone and columns for the zone's minimum temperature, and the P, I, and D feedback gains. By default, zone 1 is selected and contains the current values of these parameters; the rest of the table is empty. Touch one of the parameter cells to modify its value. If a particular set of parameters is no longer needed, touch its zone number in the 'Delete' column to clear the entries for that location.



The PID zone editor

To manually select a zone, touch the 'Zone' button and select one of the zone numbers, 1–8. The feedback parameters immediately change to the values stored in the corresponding row of the Zone table. If the selected zone contains empty cells, the feedback parameters don't change and are copied into the empty cells.

Whenever the feedback parameters change (for example, if the feedback is tuned), the selected zone is automatically updated with the new values.

To have the PTC10 automatically select zones based on the temperature, assign each zone a minimum temperature using the "Min" column of the memory table. The min temperatures can be in any order; they do not have to be monotonically ascending or descending. Next, set the zone to 'Auto'. The CTC100 automatically selects the zone with the largest Min value that is less than the ramp temperature ('Ramp T'). Memory locations without min values are never recalled in 'auto' mode.

Ffwd

Touch the "Ffwd" button to select a feedforward input channel. The value of the selected channel is added to the PID feedback output at each A/D conversion. If the PID mode set to "off", outputs are disabled, or no PID input channel is selected, changes to the feedforward channel's value have no effect on the PID output. To disable feedforward, touch the "Ffwd" button and then touch the selected input channel.

Feedforward can be used to compensate for environmental or other factors that affect the feedback loop in predictable ways. The feedforward channel typically must be scaled using offset/gain factors (in the channel's "cal" menu) or a custom calibration table.

Casc

Cascade control. A cascade control system consists of two (or more) PID loops. As in a normal PID system, a primary PID loop monitors a temperature that needs to be regulated (the primary temperature). However, instead of driving the physical output (heater, valve, etc.), the output of the primary loop becomes the setpoint for a secondary PID loop. The secondary loop monitors a secondary temperature reading and controls the physical output. The secondary temperature reading is typically a temperature that is not in and of itself critical to the application, but responds more quickly to the control output than the primary reading.

For example, the temperature of an incubator might need to be kept constant using a forced-air heater. In this case, the primary temperature is the air temperature inside the incubator, while the secondary temperature might be the temperature of the hot air entering the incubator (the vent temperature). The primary loop controls the air temperature in the incubator by telling the secondary loop how hot the vent air should be. The secondary loop regulates the temperature of the vent air by controlling the power to a heater coil. The advantage of cascade control is that variations in the vent temperature can be accounted for much more quickly than would be possible with a single PID loop.

To use cascade feedback, select one of the PTC10's virtual channels (V1, V2, or V3) and then press the "Channel" key. Make sure the direction of the channel is "Set out" or "Meas out", and then touch the button labeled "Casc". A list of output channels appears. Touch one of the channels to make its PID setpoint track the value of the virtual channel.

To disable cascade control, touch the "Casc" button and then touch the selected channel to de-select it.

Channel screen: Tune column

This menu, which is only available for output channels, configures the PID autotuner. See the "Automatic PID Tuning" section for more details.

Mode

Use this button to start the autotuning process. The button is greyed out if a PID input channel has not been selected. Select "Step" to start the step response autotuner; "Relay" to start the relay autotuner. See "automatic tuning algorithms" on page 43 for more information.

Step Y

The size of the disturbance that the autotuner applies to the output. It should be large enough to increase the temperature by several degrees, or significantly more than any noise or other temperature variations that would normally occur over several minutes. If Step Y is too small, the autotuner will produce inaccurate PID feedback parameters. If Step Y is too large, the tuning process will increase the temperature of your experiment to unacceptably high levels.

Step Y can be changed while autotuning is in progress, but it doesn't take effect until the next time autotuning is started.

.

Lag

Controls how long the autotuner waits before it first checks the response of the system to the output disturbance. This time should be long enough for the temperature to rise noticeably after the output is increased by Step Y. If Lag is too small, the autotuner will mistake small noise spikes for the system's response to the output disturbance. If Lag is much larger than it needs to be, the autotuner will produce inaccurate results.

If the Lag setting is changed while autotuning is in progress, it doesn't have any effect until the next time autotuning is started.

Status

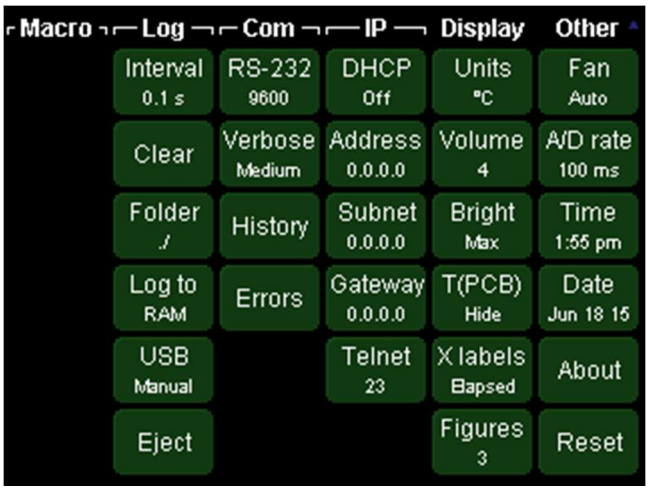
Touch this button to display a text box with information on the progress of the autotuner.

Type

Controls which PID tuning rules are used by the auto-tuner. The "Cons" (conservative) setting results in minimal overshoot (ideally, zero overshoot) but very slow response. Conversely, the "Aggr" (aggressive) setting results in much faster feedback response but typically ~25% overshoot. The "moderate" setting provides intermediate results. For each of these three tuning types, the relay tuner uses more aggressive tuning rules than the step response tuner.

If the "auto" setting is selected, the step response tuner uses the conservative tuning; the relay tuner uses aggressive tuning if the derivative gain is nonzero and conservative tuning if D is zero before tuning. This setting works well if the step response tuner is used for an initial rough tuning at room temperature and the relay tuner is used for a final tuning once the system has reached its target temperature.

"System" screen



The System screen includes controls for all settings that affect the entire instrument. Time and date, Ethernet and GPIB parameters, and data logging are set up through this screen.

Nothing happens if the System button is pressed when the System screen is already showing.

Systems screen: Macro column

Buttons with the names of up to six currently-defined macros appear in this menu. Pressing one of these macro buttons runs the corresponding macro, and the button remains selected (i.e., highlighted, or in the "down" position) as long as the macro continues to run.

A macro button appears to be selected whenever a macro with the name shown on the button is running. Touching a selected macro button stops all currently-running macros with that name. See the Macro Names topic in the Remote Programming section for more information on macro names.

System screen: Log column

Interval

Sets the default time between log points. Each channel also has its own log interval setting that can override this default. If the interval is set, for example, to 1 s, the PTC saves a data point once per second, and each point represents the average reading over one second period.

Clear

Press this button and select 'yes' to erase all data from the current log folder on the USB device. The PTC10's RAM is also cleared.

Folder

Sets the USB device folder into which the PTC10 writes log files. If the folder does not exist, it is created. If the folder does exist and contains PTC10 log files, the PTC10 appends data to the existing log files. Only data from the current folder can appear on the plot screen.

Log to

If set to "USB", the PTC10 logs data from its I/O channels to the USB device. If set to "RAM", newly-acquired data points are saved for about an hour (depending on the log rate) in the PTC10's internal memory and then erased. In this case, the Plot screen only shows at most an hours' worth of data. If set to "none", the PTC10 does not store data at all, and the plots on the Plot screen are always empty.

If the USB device is unplugged, the System.Log.Log To button automatically changes to "RAM" to indicate that data is no longer being written to USB.

USB

This setting determines whether or not the PTC automatically logs to USB memory devices. If set to "Auto" (the default mode), the PTC immediately starts writing log data to any USB storage device that's plugged into the instrument. The System.Log.Log To button automatically switches to "RAM" when a USB device is unplugged, and to "USB" when a USB device is plugged in. As long as there's a USB flash key or hard drive with available memory plugged into the PTC, data will be logged to it.

In "Manual" mode, each time a USB device is plugged in, the user must touch the Log To button and select the "USB" option before any data is saved to the USB device. The System.Log.Log To button automatically switches to "RAM" when the USB storage device is unplugged, and it stays on "RAM" when a USB device is plugged in. If you unplug a device and plug it back in, the PTC stops logging data to the device and newly-acquired data is not permanently saved.

System screen: COM column

RS-232

Sets the RS-232 baud rate. The RS-232 interface always has 8 bits, 1 stop bit, and no parity.

GPIB

Sets the primary GPIB address. The address must be a value between 0 and 31, inclusive, but in most GPIB systems 0 is reserved for the controller-in-charge and should not be used.

Verbose

Determines how the PTC10 responds to RS-232, GPIB, and USB messages. In "low" mode, the PTC10 only sends messages in response to queries. This mode should be selected for IEEE488.2 compatibility. In "medium" mode, the PTC10 also sends an error message if an instruction could not be processed (error messages always begin with "Error"). In "high" mode, the PTC10 also sends a message in response to each instruction that sets or gets a parameter, and the message includes the parameter name. Example responses are shown in the table below.

Verbose level	Response to instruction…		
	2A?	xyz	2A = 37.47
Low	37.4722	(no response)	(no response)
Medium	37.4722	Error: "xyz" is not a valid instruction	(no response)
High	2A.Value = 37.4722	Error: "xyz" is not a valid instruction	2A.Value = 37.47

History

This button brings up a window that that shows the contents of the last twelve messages sent or received over the COM ports. The window is helpful for debugging communications issues.

Errors

This button produces a window that shows the last six errors caused by COM port communications.

System screen: IP column

DHCP

Enables or disables the Dynamic Host Configuration Protocol. If DHCP is set to "on" and a DHCP server is present on the network, the other IP settings are automatically configured and are grayed out.

Address

Sets the IP address.

Subnet

Sets the subnet mask.

Gateway

Sets the gateway for communications outside of the local network. In general, this setting is not needed since the PTC does not initiate communications outside the local network.

Telnet

Sets the telnet port for Ethernet communications. Remote commands can be sent to the PTC through a telnet connection on the selected port. The port must be a value between 0 and 65535, inclusive, and should normally be either 23 (the default) or a value greater than 1024.

System screen: Display column

Units

Sets the temperature units for the entire instrument. Temperature measurements are both displayed and logged in the specified units. If the units are changed in the middle of an experiment, there will appear to be a large jump in all of the temperature records. PID setpoint values are not adjusted to compensate for the new units.

Five units options are available: °C, K, mK, °F, and Sensor. If the Sensor option is selected, sensor measurements are not converted to temperature and instead appear in the native units of the sensor, i.e. millivolts for thermocouples, volts for diode sensors, and ohms for resistive sensors.

Bright

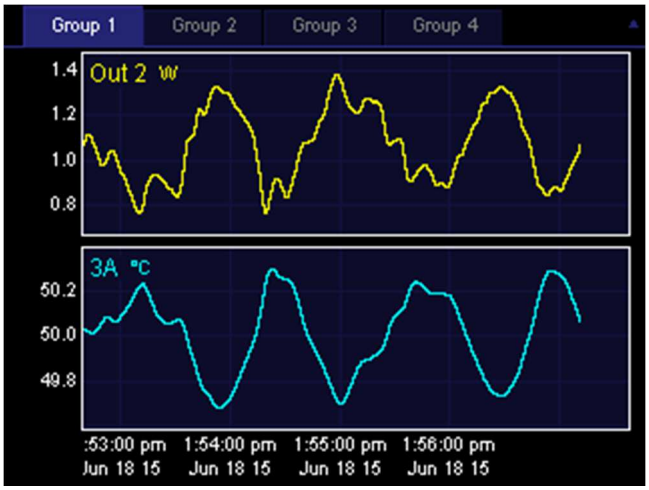
Sets the brightness of the screen. If "Off" is selected, the screen turns completely off but can be turned on again for 2 seconds by touching the screen.

Extras

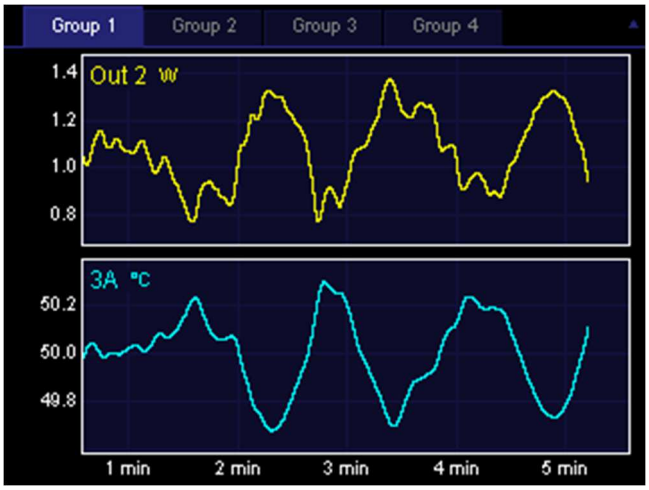
If set to Show, various extra channels that display printed circuit board (PCB) temperature, heater current, heater voltage, and heater resistance are displayed. A system restart is required before the PCB temperature is displayed.

X labels

Set to "Absolute" to label vertical grid lines with the full time and date. Set to "Elapsed" to display more concise, easy-to-read labels that indicate the amount of time between grid lines. The elapsed time is reset to zero once per minute, hour, or day, depending on the X range of the graph.



Absolute X labels



Elapsed X labels

Figures

Sets the number of figures that are shown after the decimal point on the Numeric tab of the Show Data screen, and in values sent in response to remote queries. Fewer digits are shown if the value is greater than 1000 or less than -1000, or if the requested number of digits doesn't fit into the available space. This setting does not affect logged data or plots.

System screen: Other column

Fan

Controls the speed of the front-panel fan. If a PTC430 DC output card or PTC440 TEC driver is being used, the fan should generally be set to Max or Auto, otherwise the card may overheat and be permanently damaged. The accuracy of temperature measurements may be reduced if the fan is disabled.

Volume

Sets the speaker volume. The volume affects all sounds played, including alarms.

Time

The system time. Changing the time does not affect time stamps on previously-acquired data points. Therefore, if the time is advanced by one hour, a one-hour gap appears in the plot. Conversely, if the time is set back by one hour, any data taken over the last hour is no longer plotted, and newly-acquired data appears in its place. The data is not actually erased from the USB log; it just doesn't appear on the plot.

Date

The system date. Changing the date can affect the display of previously-acquired data; see the "Time" entry above.

About

Displays a text box with information about the firmware version and installed I/O cards.

Reset

Resets one of the following:

Running macros: stops all running macros. Has no effect on saved macros.

Saved macros: deletes all saved macros from local memory. Does not delete macros from USB memory devices. Has no effect on running macros.

Display: Resets all settings in the System screen's Display column to their factory defaults. Returns the front panel to the Select menu, de-selects all channels in all groups, and erases locally-stored log data (data on USB drives is not affected). Returns all plots to autoscaled X and Y with a 1 minute X range and changes the plot location of all channels to 1. If a *TRG remote command was previously received, re-enables automatic A/D conversions. Hides internal monitor channels ("extras").

Ports: Closes all I/O ports and re-opens them. USB and Telnet connections are lost. The port settings (baud rate, IP address, etc.) remain unchanged.

Port settings: Resets all I/O port settings to their factory defaults.

Channels: Resets the settings on the Channel menu for all channels to their factory defaults. Also sets the A/D rate to 100 ms.

Log: Resets the default log rate to 1 second, sets the log rate for each channel to the default, and enables automatic logging to USB. If a USB storage device is attached, erases log files in the root directory and begins logging to USB.

All: resets all of the above items.

Firmware updates

The PTC10's firmware can be updated by copying a new firmware file onto a USB stick, plugging the USB stick into the PTC10, and issuing a remote command. Besides the CPU firmware, each I/O card has its own firmware that can be upgraded.

When the firmware is updated, a few of your settings may revert to their default values (if, for example, the meaning of the setting has changed in the new firmware). In general, though, firmware updates do not affect your settings or I/O card calibration data.

CPU firmware updates

1. The firmware update package supplied by SRS contains a "release-image.img" file and an "update.txt" macro. Copy the "release-image.img" file to the root directory of a USB flash drive or hard drive. Copy the "update.txt" macro into a directory named "macros" on the root directory of the USB drive.
2. Plug the USB device into the PTC10 and wait until a window that says "Opening USB drive" appears and then disappears.
3. Press the System key on the PTC10's front panel. If you don't have too many other macros defined, there should be a button labeled "Update" in the leftmost column. Press the "Update" button.
4. The PTC10 erases the existing firmware and then loads the new firmware. The entire process should take about 20–30 seconds.
5. At this point, the old firmware is still running. Turn the PTC10 off and back on again to start using the new firmware.

I/O card firmware updates

1. The firmware update package supplied by SRS contains 10–20 files with names that end in ".hex", plus a number of macros named "U1.txt", "U2.txt", etc. Copy the .hex files to the root directory of a USB flash drive or hard drive. Copy the .txt files into a directory named "macros" on the root directory of the USB drive.
2. Plug the USB device into the PTC10 and wait until a window that says "Opening USB drive" appears and then disappears.
3. Press the System key on the PTC10's front panel. If you don't have too many other macros defined, there should be buttons labeled "U1", "U2", etc. in the leftmost column.
4. Press button U1 to update the firmware of the I/O card in slot 1, U2 for slot 2, etc.
5. While the firmware is updating, the front-panel LCD and fan turn off. After about 15 seconds, power is restored to the front panel and a status message is displayed on-screen.
6. At this point the new firmware is already running; however, after all firmware updates are complete, the PTC10 should be turned off and back on again to ensure that the I/O card is properly initialized.

Replacing the memory backup battery

The PTC10 has a CR2032 battery that is responsible for keeping the following information in memory:

- Time and date
- Most user settings
- User macros that have been saved with the "define" instruction or with the "Save" button in the Program window
- The instrument's serial number

If the battery fails, these settings will be lost each time the PTC10 is switched off. Factory calibration data is stored in EEPROM and is not affected by loss of the CR2032 battery voltage.

The battery can be replaced as follows:

1. Unplug the PTC10 from the wall. This is important since otherwise live AC voltage may be present inside the chassis even if the PTC10 is switched off.
2. Remove the four black screws that secure the top cover. Lift the cover off of the instrument.
3. Looking at the front of the PTC10, the battery should be clearly visible. It is a 20 mm diameter coin cell located 8 inches directly behind the LCD screen. The PTC10 only has one battery.
4. Remove the battery by pulling the coin cell toward you and sliding it to the left. It can be somewhat difficult to remove.
5. Install a new battery with the + side facing toward the rear of the instrument.
6. Replace the PTC10's lid.
7. After turning the PTC10 back on, reset the instrument's time and date and any other user settings.

A new battery should last for 6 years.

Remote programming

The PTC10 can be remotely controlled over RS-232, USB, Ethernet, and the optional GPIB port. All of these ports are always enabled and accept the same commands. In addition, the front panel controls are always enabled.

To control the PTC10 remotely, you transmit lines of ASCII text to one of its ports. No action is taken until one of the following end-of-line characters is received:

- a linefeed (decimal 10 = hex A = '\n'), or
- a carriage return (decimal 13 = hex D = '\r') followed by a linefeed (decimal 10 = hex A = '\n').

The PTC's replies always end with a carriage return followed by a linefeed.

Each line of text sent to the PTC is treated as a macro, meaning that it can contain one or more instructions as well as conditional statements and repeated blocks. The macro starts running immediately and, if it takes long enough to complete, its progress can be monitored on the Program screen. While the macro is running, more macros can be sent to the PTC. Up to 10 macros can run at the same time, although only the first four are shown on the Program screen.

Macros that are sent to one of the I/O ports have to be written on a single line, otherwise they will be interpreted as several macros to be run concurrently. Each macro can have a maximum of 1024 characters, while individual instructions or instruction arguments can have a maximum of 256 characters. Instructions and arguments are case insensitive and can be separated by one or more whitespace characters as well as by special characters such as parentheses, brackets, equals signs, etc.

Macros can be saved under a name, and a macro can call other, saved macros by name (macros must not, however, call themselves recursively). If a macro is saved under a name that is the same as an instruction, the saved macro takes precedence if the command is issued with a capital first letter; the instruction takes precedence if the command has a lower-case first letter.

Macros can also be stored as text files on a USB memory device. When the USB device is plugged into the PTC10, the macro can be run from the Program window or called from other macros, just like a saved macro. It's easier to edit long macros when they are saved as text files, since they can then include multiple lines and comments.

Most macro instructions correspond directly to buttons on the Channel and System screens. The instruction names are usually the same as the button names. For example, the instruction to change the RS-232 baud rate is "System.COM.RS-232"; the corresponding button is found in the "System" screen, in the "COM" column, and is named "RS-232".

Connecting to the PTC10

RS-232

The PTC10's RS-232 connector is a 9-pin female D-sub connector. The PTC10 is a DCE device and should be connected to a PC with a straight-through, DB9 male to DB9 female RS-232 cable (sometimes called a "modem cable", as opposed to a "null modem cable"). Depending on the

capacitance of the cable, the maximum cable length is about 50 feet at 9600 baud and 4 feet at 115200 baud. The pin assignments are:

Pin	Description
1	Not connected
2	PTC10 data out
3	PTC10 data in
4	Not connected
5	Signal ground
6	Not connected
7	RTS (Request to Send; PTC flow control in)
8	CTS (Clear to Send; PTC flow control out)
9	Not connected

The RS-232 outputs (pins 2 and 8) are not active unless a voltage greater than +2.7 V or less than –2.7 V is present at the receive pin (pin 3). The outputs are ±5V instead of the more standard ±10V, and may therefore not work with some older computers. However, the PTC10 can still receive ±10V signals. The RS-232 interface does not echo characters back as they are received.

The RS-232 interface uses an RTS/CTS hardware flow control protocol in which the PTC10 pulls pin 8 high to indicate that the PC can send data, and low to indicate that the PC should not send data. Similarly, the PTC10 stops sending data whenever the PC pulls pin 7 low.

Of the PC serial ports tested by SRS, only about half actually supported RTS/CTS flow control. If your serial port doesn't support RTS/CTS, the computer may never transmit data to the PTC10, it may stop after several characters, or it may never stop transmitting, in which case the PTC10 will drop characters from some received RS-232 messages. The Aten Technology UC232A USB-to-Serial converter cable has been tested and is compatible with the PTC10. USB-to-serial converters based on the Prolific PL-2303 chip are also compatible.

If the RS-232 interface does not respond at all, make sure the baud rate is set correctly and also make sure that each line of text sent to the PTC10 ends with a linefeed character (decimal 10 = hex 0x0a = '\n'). The System.COM.History window can sometimes help to debug communication issues.

USB device port

The PTC10 has a single USB 1.1 Device interface that can be connected to a PC with a standard USB A-to-B cable. The PTC10 appears on the PC as a COM port. Any application software that can communicate with a standard RS-232 port can then be used to send remote commands to the PTC10. The USB interface is about as fast as the RS-232 interface at its fastest baud rate (250000 baud).

When a Windows PC is first connected to the PTC10's USB interface, the PC may display a "New Hardware Found" dialog. If it does, the "USB drivers" package for PTC10 should be downloaded from the SRS website (www.thinksrs.com). Then, in the "New Hardware Found" dialog, click the "Have Disk…" button and point the installer to the gserial.inf file in the downloaded package. No additional setup is needed.

The USB "driver" provided by SRS is not actually a driver; it's a text file that tells Windows to use a shared driver (usbser.sys) provided by Microsoft as a normal part of Windows. More specifically, the PTC10 is a Communications Device Class, Abstract Control Model (CDC-ACM)-compliant peripherial, and since CDC communications are built in to Windows and Macintosh,

it's not necessary to install a driver on those operating systems. However, Windows requires an information file (gserial.inf) to associate the PTC10 with the appropriate driver.

On Linux systems, the Gadget Serial Driver can be used to communicate with the PTC10.

If the PC does not register the presence of the PTC10, unplug the USB cable and plug it back in. In addition, if the PTC10 is turned off and back on again while the PC application is running, the application must be closed and re-opened before it can communicate with the PTC10. This is a limitation of Windows that applies to all CDC devices.

When using LabView, ensure that the National Instruments VISA driver is version 4.0 or later. Older versions of the driver cannot communicate with the PTC10. The latest version can be downloaded for free from the National Instruments website.

Usbser.sys has been reported to cause Windows to crash if ReadFile is called with a timeout value that is too small. The crashes are especially common when more than one CDC device is in use.

USB host port

Macros can be imported from a USB mass storage device such as a hard drive or flash key. The macros should be saved as text files with names ending with ".txt", and should be copied to a folder named "macros" in the root directory of the USB device. When the device is plugged into the PTC10, buttons with the names of the text files appear on the System screen. A file can then be run by touching the button with the corresponding file name.

In addition, one macro can be saved in the root directory of the USB device under the name "autorun.txt". The autorun.txt macro automatically runs each time the USB device is plugged into the PTC10.

The USB storage device should have a FAT16 or, preferably, a FAT32 format. The number of extraneous files should be kept to a minimum since a directory structure with large numbers of files slows down the PTC10's response.

GPIB

PTC10 units equipped with the GPIB option can be connected to GPIB interface devices. Any standard GPIB cable can be used to connect the PTC10, but due to space restrictions a single-ended cable, such as a National Instruments X5 cable, is recommended. A right-angle X4 cable can also be used.

No more than three GPIB cables should be stacked on a single GPIB connector, and no more than 14 devices can be connected to a single GPIB interface. The total length of all GPIB cables must not exceed 2 meters per instrument or 20 meters, whichever is less.

Ethernet

Remote commands can be sent to the PTC10's Ethernet interface using telnet port 23. The IP address and subnet mask have to be set before the Ethernet interface can be used.

It's not necessary to connect to your building's network to use an Ethernet connection; the PTC10 can be connected directly to a computer. A special crossover cable may be needed for some older PCs, but in general a standard Cat 5 cable can be used.

Follow the following procedure to test an Ethernet connection:

1. Connect the PTC10 to your computer with a standard Cat5 Ethernet cable.

2. Enter a suitable IP address into the PTC10's System menu. The IP address should be within your computer's subnet. If you're testing a direct connection (i.e. nothing else is connected to the network), try using your computer's IP address, but change the last digit.
3. Enter a Subnet mask. If you're using a direct connection, this must be the same as the subnet mask on your computer.
4. Open a DOS window on your computer. If necessary, install the Windows telnet client by typing: `pkgmgr /iu:"TelnetClient".` In the DOS window, type `telnet 0.0.0.0`, but replace 0.0.0.0 with the Ethernet address you just entered.
5. Type `popup hello` and press Enter (note that the first time you type a command, the characters aren't echoed back). You should see a popup window on the PTC10's screen.
6. Type `Description` and press Enter. The PTC10 should return an instrument description string.

If your PC application doesn't support telnet, various serial port redirectors are available that map a telnet connection to a COM port. We have successfully tested the following on Windows XP:

Serial Port Redirector (FabulaTech; www.fabulatech.com): Set the Protocol to "Raw Data" and flow control to "None"; disable all other options.

TCP-Com (TAL Technologies; www.taltech.com): select "Create Virtual COM port", make sure flow control is set to "None", select the "Connector" (COM1, COM2, etc.) and click the Activate button.

Windows XP computers introduce a 150 ms delay after receiving the first character of each message from the PTC, limiting the speed of the Ethernet connection. Windows Vista and Linux computers do not have this issue.

Communication, assembly, and run-time errors

If the PTC is unable to receive a macro due to an I/O port (RS-232, USB, GPIB, or Ethernet) problem, a communication error is generated and the macro does not run.

Once the macro is received, the PTC assembles the macro. During this process, the PTC analyzes the text to ensure the following:

- Each instruction is valid.
- The arguments for each instruction are valid; for example, if the instruction takes an integer value, the argument must be an integer; if the instruction has a list of acceptable values, the argument must be one of those values. Numeric values are not tested to see if they fall within acceptable limits, since those limits may change as the macro runs.

If the macro fails these tests, an assembly error is reported and none of the macro's instructions are executed. If the System.COM.Verbose setting is Medium or High, the error is reported by sending an I/O port message that begins with the word "Error". If the Verbose setting is "Low", a message is placed on the error queue and can be retrieved with the "geterror" instruction.

During assembly, calls to other macros are replaced with the text of the macros. The called macros are also analyzed for syntax errors.

No instructions are executed until the macro is successfully assembled. At this point, the assembled macro is displayed on the Program screen and the macro starts to run. As each instruction is executed, several different kinds of run-time errors can occur:

- The instruction tries to change a value that can't be changed; for example, it tries to set the value of an input channel.
- The instruction existed at assembly time but not at run time; for example, the name of a channel was changed after assembly, and the instruction uses the old channel name.
- The instruction tries to set a parameter to a value outside the allowed limits.

If a run-time error occurs, the instruction in question is not executed but the macro continues to run. If Verbose is set to Medium or High, an error message is sent to the I/O port; if Verbose is set to Low, a message is placed on the error queue.

Concurrent macros

A macro can run for a long period of time or even indefinitely. When the PTC10 receives a macro over an I/O port, the new macro may start running before the previous macro has finished. It's also possible to run multiple instances of a saved macro simultaneously.

The PTC can run up to 10 concurrent macros received over any one I/O port and up to 20 total concurrent macros (including the startup macro, macros received over all of the I/O ports, and macros started from the Program screen). If more than this number of macros is received, a "Too many macros" assembly error is generated and the macro does not run.

If the PTC10 is turned off and turned back on again, macros that were running when the PTC10 was turned off are not restarted.

When a macro is sent to the PTC over an I/O port, at least one instruction is executed before any other macros received from the same port begin to run. Therefore, if each message sent to an I/O port contains only one instruction, the instructions always run sequentially in the order that they were sent. If some messages contain two or more instructions, the PTC may execute them concurrently and replies may not be received in the expected order.

An instruction's *parent* macro is the macro that contains the instruction. If more than one instance of a saved macro is running, the term "parent macro" refers only to one specific instance.

Macro names

While it is running, each macro is automatically assigned a name. The name can be used by the "kill" instruction to stop the macro and also appears as a tab on the Program screen. It is possible to have two or more macros with the same name running.

If the macro was started by a remote command that was 32 or fewer characters long, the macro name is the same as the remote command. If the command was more than 32 characters long, the PTC10 assigns the name "Program XY", where XY is a two-digit number.

If the macro was started from the Program screen, the contents of the Input field become the macro name unless the Input field contains more than 32 characters, the macro is assigned the name "Program XY", where XY is a two-digit number.

If the macro was started by pressing a macro button on the System screen, the macro name is the same as the text on the macro button. If the name is too long for the button and has been truncated on screen, the macro name is the full name the macro was defined under, not the truncated name.

A macro can change its own name with the "name" instruction.

Use the "kill.list" remote instruction to get the names of all currently-running macros.

Command syntax

<instruction> = <value>
<instruction> += <value>
<instruction>?

Most instructions must be followed by a numeric or text argument separated from the instruction by whitespace and/or an optional equals sign. Numeric values can be incremented using the + operator. There is no - operator, but the + operator can be used with negative arguments.

Values that are selected from a list of possible arguments can also be incremented using the + operator, in which case an integer argument must be supplied that indicates how many places to advance in the list of possible arguments. If the value is incremented past the end (or beginning) of the list, it wraps back to the beginning (or end) of the list.

A question mark after the instruction queries the current value of a variable. The result is sent to the remote interface and also appears on the Program screen (if the program in question is selected on the tab bar).

Examples:

```
"Out 1.value" = 5
```

Sets heater driver "Out 1" to 5 watts. The equals sign, and the whitespace before and after the equals sign, is optional. Everything is case-insensitive. Since the channel name "Out 1" has a space, the entire instruction has to be enclosed in quotes (to simplify instructions like this, the channel could be assigned a new name that doesn't include a space, like "Out1"). Note that the argument is outside the quotes.

The command:

```
"Out 1.value" += 1
```

increases the value of "Out 1" by 1 watt. Whitespace before and after both the + and = signs is optional. Likewise, this command:

```
"Out 1.value" += -1
```

decreases the value of "Out 1" by 1 watt, while the query:

```
"Out 1.value?"
```

is a request for the value of "Out 1".

```
2A.lopass += 1
```

Since the lowpass filter setting must be chosen from a list of possible values ("1 s", "3 s", "10 s", etc.), this instruction sets the filter to the next setting on the list, rather than incrementing the lowpass time constant by one second. For example, if the filter setting was "3 s", it is now "10 s".

Spaces are optional in all instructions that include a space. Omitting the spaces eliminates the need for quotation marks around instructions. However, spaces are required in arguments. For example:

```
"Out 1.IO type" = "meas out"
```

is equivalent to…

```
Out1.IOtype = "meas out"
```

However, the argument "meas out" cannot be shortened to "measout".

(…)
"…"

Instructions and arguments are normally separated from each other by spaces. If an instruction or argument contains spaces, it must be enclosed in parentheses or quotation marks, otherwise it will be interpreted as multiple instructions and arguments. In general, this type of mistake is caught before the macro starts to run; as a result, the macro doesn't run and an error is generated.

Parentheses can be nested; quotation marks cannot. Using two quotation marks in a row before an instruction results in an "empty instruction" assembly error.

These two instructions are equivalent:

```
print "Hello world!"
print(Hello world!)
```

If the argument doesn't contain any spaces, it's not necessary to enclose it in quotes or parentheses.

```
print Hello!
```

Whitespace before or after parentheses or quotes is optional.

[…]n

A group of instructions can be repeated by enclosing it in square brackets and placing the number of repetitions after the right bracket.

```
[print Hello  pause 1 s  print world!  pause 1 s]3
```

Whitespace is not necessary before or after square brackets.

If the left bracket is omitted, all instructions from the beginning of the macro to the right bracket are repeated. If the right bracket is omitted, all instructions after the left bracket do not run.

A negative number after the right bracket causes the group of instructions to repeat indefinitely. Therefore,

```
[print Hello pause 1 s]-1
```

is equivalent to

```
while (1) { print Hello pause 1 s }
```

list
<submenu>.list
<instruction>.list

If appended to the name of any menu (System, Channel, etc.) or submenu (System.COM, Channel.PID, etc.), the ".list" suffix prints the available instructions for the menu or submenu. If appended to an instruction, the ".list" suffix prints the arguments required for the instruction. "List" on its own prints out a list of top-level menus. A question mark after the ".list" query is optional. The .list suffix is only available for instructions that set some sort of variable and is not available for program flow instructions such as if, while, abort, and kill.

Examples (the first line in each example is the remote command; the second line is the reply):

```
Out1.list
pid., Name, Value, Off, Low lmt, Hi lmt, Units, IO type, Plot,
Logging, Stats, Points, Average, SD, Selected, Debug, Cycle,
Reset
```

The reply is a list of instructions that can be appended to "Out 1". In the reply, the dot at the end of "pid." indicates that "pid" is a submenu; that is, "Out 1.pid." is not a complete instruction.

```
Out1.pid.list
Input, P, I, D, Setpoint, Mode, Step Y, Lag, Sq root, Ramp,
Memory, T min
```

Since "Out 1.pid" is a submenu, the reply lists the instructions available in the submenu.

```
Out1.pid.setpoint.list
pid.Setpoint: float
```

Since "Out 1.pid.setpoint" is an instruction, the reply indicates that it takes a single floating-point argument.

```
Out1.value.list
Out 1.Value: float (0.000 - 1200)
```

If an argument has minimum and maximum values, these are shown in the reply. In this case, "Out 1.value" takes a single floating-point instruction in the range 0 – 1200. However, most arguments do not have minimum or maximum values.

```
pause.list
pause: float, { ms, s, min, hr }
```

The "pause" instruction requires two arguments: 1) a floating-point argument with no bounds, and 2) one of "ms", "s", "min", or "hr".

<instruction>.help

Prints the help text for any instruction that sets some sort of variable. The help suffix is not available for program flow instructions such as if, while, abort, and kill.

if (…) { … }
while (…) { … }
else { … }

Conditional statements consist of the "if" or "while" statement followed by a condition, one or more instructions in curly brackets, and possibly an "else" clause. The condition must be in parentheses if it contains spaces or if it compares two or more values.

The condition can contain numeric values, queries that do not require any arguments, and comparison operators ("!=", "=" "<", "<=", ">", and ">="). The condition can also include '||' (or) operators and '&&' (and) operators. For example, the following macro waits until temperature 4A is between 39 and 41 degrees:

```
while (4A < 39 || 4A > 40) { pause 1 s }
```

The pause instruction is not necessary, but it helps to reduce the load on the CPU.

Conditional statements *must* be followed by curly brackets, otherwise the statement has no effect. There is no "else if" statement. Parentheses cannot be used within a conditional statement to affect the order in which parts of the statement are evaluated.

The condition must contain one or more terms; in the example above, the first term is "4A" and the second is "39".

When the name of a channel is used as a conditional term, it is sometimes unclear whether it should be treated as a query of the channel's value or as a character string. In these cases, the channel name can be preceded by a dollar ($) or pound (#) sign. The dollar sign ensures that a conditional term is treated as a string. For example:

```
if (Out1.PID.Input==$3A) { Out1.PID.Input = 3B }
```

In this example, the dollar sign ensures that the name of the PID input channel (Out1.PID.Input) is compared with the string "3A", not the numeric value of channel 3A. Dollar signs can only be used in this way within "if" or "while" conditions.

Conversely, a channel name (or any other conditional term) can be preceded with a pound sign (#) to force the PTC10 to treat it as a query. The pound sign is required if you've changed a channel name to a numeric value that don't contain any letters. For example, if you've renamed one of the I/O channels "2", this statement:

```
while (#2<50) { pause 1 s }
```

pauses the macro until the value of channel "2", not the number 2, is greater than or equal to 50.

Remote instructions

General instructions

#<variable> <value>

Defines a variable and assigns it a floating-point value. The value can then be queried with #<variable>? and can also be used as an argument for any instruction that takes a numeric argument.

The #<variable> instruction consists of a pound sign (#) immediately followed by a variable name. The variable name can be any string up to 32 characters long, but spaces are not allowed within the variable name or between the pound sign and the variable name. Variable names are not case-sensitive. For example:

```
#x=10.2 #x?
```

defines a variable "x" and sets its value to 10.2, then queries the value of x.

Variables are can only be used within the macro in which they are defined (i.e. their parent macro), and in macros called by that macro. Macros cannot access variables defined by other, concurrently-running macros. In addition, once a macro finishes, all variables defined by the macro are deleted. The value of an undefined variable is zero.

When macros are sent over a serial port (as opposed to being loaded from a text file on a USB storage device), the macro can have at most one line, and therefore all variables must be defined and used on a single line. Therefore, if the command

```
#x=10.2
```

is sent over the serial port, and at a later time the command

```
#x?
```

is sent over the serial port, the response is "0" because the PTC runs each line of text as a separate macro, and the variable "x" has not been defined in the second macro.

The four basic arithmetic operations (+, -, /, *), power ('^'), bitwise 'and' ('&'), and bitwise 'or' ('|') can be applied to variables:

```
#x=2 #x+=8 #x-=1 #x*=2.6 #x/=7 #x^=2 #x&=2 #x|=2
```

Spaces are not allowed before the *, /, -, and ^ operators. The equals sign is optional and can be replaced with a space.

Once defined, a variable can be substituted for any numeric argument. For example, the macro:

```
#y=5 Out1=#y
```

sets the value of channel "Out 1" to 5.

When #<variable> is used as an argument, a question mark can optionally be added after the variable name to indicate that the variable is being queried:

```
#y=5 Out1=#y?
```

Variables can be used within conditional statements. The macro:

```
#x=0 while (#x<5) { #x+=1 Out1=#x pause 1 s }
```

cycles through the "while" loop five times at a rate of once per second, setting channel "Out 1" to 1, 2, 3, 4, and then 5.

The PTC10's macro system does not support equations. For example, a statement of the form "#x = #y + #z" is not allowed. More generally, when a variable is used as an argument to another instruction, the argument must only contain the "#<variable>" query and cannot include any other text or variables.

The PTC10's digital I/O card offers three virtual channels that behave like variables, but with some important differences. While a variable is private to the macro that defined it, the value of a virtual channel can be accessed by any macro. The value of a virtual channel also persists after the macro ends. Also, the value of a virtual channel is only updated when an ADC conversion occurs, but the value of a variable is updated without any lag when an instruction changes its value. Finally, virtual channels can be plotted on-screen and logged to USB, while variables cannot (except by assigning their value to a virtual channel).

#<instruction>

A single-instruction query with no arguments, if preceded by a pound sign, can be substituted for any numeric argument. The instruction cannot contain quotes, parentheses, or spaces. For example:

```
Out1.PID.setpoint = #Out2.PID.setpoint
```

sets Out 1's feedback setpoint equal to Out 2's setpoint. The PTC10 automatically appends a question mark to the argument (resulting in the query "Out2.PID.setpoint?"), and evaluates the resulting instruction at run time.

#list?

Prints a comma-separated list of macro variables that have been defined within the parent macro.

abort

Stops the macro. This instruction only affects its parent macro. Use the "kill" instruction to stop other, concurrently-running macros.

customCal <channel>, <calibration table>

Loads a custom calibration table. The calibration table must be formatted as described in the "Custom calibration table" section (page 32), except the table must be on a single line, it must be enclosed in quotes, and the maximum table length is 256 characters. If the channel name contains a space, the space must be included. For example:

```
customCal "In 1", "units = °C 0, 100.00, 10, 103.90, 20, 107.79, 30, 111.67"
```

The next time the PTC10 is powered down or rebooted, the custom calibration table will be forgotten and the channel will revert back to its most recently used built-in calibration.

description

Writes a string similar to the following to the I/O port:

```
PTC10 Programmable Temperature Controller, version: 0.135, S/N
92001
```

It's not necessary to use a question mark with this instruction.

getLog[.xy][.reset][.v] <channel>, <time>

Gets a data point from the log. The first argument is the name of a channel. The <time> argument is one of the following:

- The desired time of the data point, in milliseconds since 1970. If the time is not available in the log, the point at the closest available time is returned.
- The word "first", to get the oldest point in the log.
- The word "last", to get the most recent point in the log.
- The word "next", to get the point after the previous point that the getLog instruction fetched from the channel. If the point has not been acquired yet, the PTC waits for it to be acquired. If the getLog instruction has not been used on this channel since the PTC was turned on or since the getLog.reset instruction was last issued, the last point in the log is returned.

If the ".xy" option is added to the instruction, both the time (in milliseconds since 1970) and the value of the point are reported; otherwise, only the value is reported.

The "reset" option resets the "next" argument for all channels; the next time the instruction "getLog <channel>, next" is issued for any given channel, the last point in that channel's log will be reported. No arguments should be used with the "reset" option.

The ".v" (verbose) option adds the name of the channel to the reply. The name of the channel is also added if the System.Com.Verbose setting is "High".

For example, the macro

```
getLog.reset; while (1) { getLog 3A, next }
```

transmits the value of 3A each time a new value is logged.

The "getLog? <channel>" query returns the number of data points that can be read with the "getLog <channel>, next" instruction before the most recent point is reached. For example, to read all logged data for channel 3A, first issue the following instructions:

```
getLog 3A, first; getLog? 3A
```

Then, send the instruction "getLog 3A, next" the indicated number of times.

Errors: if the channel does not exist, a run-time error occurs.

getOutput

Returns a single comma-separated string containing the current value of all channels.

getOutput.names

Returns a single comma-separated string containing the names of all channels.

getOutput.units

Returns a single comma-separated string containing the units of all channels.

group { 1, 2, 3, 4 }

Changes the channel selection group.

lasttouch

Indicates how many seconds have elapsed since the user last touched the touchscreen or pushed a button. If the user has not touched the touchscreen or a button since the PTC was turned on, the return value indicates how many seconds have elapsed since the PTC10 finished booting.

<macro name>

Once a macro has been defined, it can be called by including its name in another macro (the "parent macro"). When the parent macro is assembled, the macros it calls are expanded to their component instructions. Up to six levels of subroutine calls are allowed.

Variables declared in the parent macro are also valid in, and can be modified by, the child macro. For example, define a macro called "multiplyXY" by sending the following text:

```
define multiplyXY (#x*=#y)
```

Subsequently, "multiplyXY" can be called to modify the variables of a parent macro:

```
#x=3 #y=4 multiplyXY #x?
12.0000
```

A subroutine macro must consist of one or more complete instructions with arguments. Macro calls cannot be used to substitute text into arguments.

Like normal instructions, macro names are not case-sensitive. However, if a macro has the same name as a built-in instruction, the macro takes precedence if it is called with a capitalized first letter; the instruction takes precedence if it is called with a lower-case first letter.

Errors: A child macro cannot be both defined and called by a parent macro. The result will be either an assembly-time "not a valid instruction" error, or, if a macro with the child's name already exists, the old macro will be called instead of the newly-defined one. Invalid instructions in the child macro result in assembly-time errors when the parent macro is assembled.

menu { Select, Numeric, Plot, Program, Channel, System, Help, Output Enable }
menu <integer>

Makes the system behave as if one of the eight front-panel buttons has been pressed. The argument can be the name of a front-panel button ("Output enable" can be abbreviated "Output") or a numeric value between 1 and 8, inclusive: 1 for "Select", 2 for "Numeric", 3 for "Plot", 4 for "Program", 5 for "Channel", 6 for "System", 7 for "Help", and 8 for "Output Enable". "Menu += 1" advances the PTC to the next menu; issuing the "Menu += 1" instruction while the System menu is showing brings up the Select menu, not Help.

outputEnable { on, off }

Enables (outputEnable = on) or disables (outputEnable = off) all heater outputs and ±10V analog outputs. Issuing this instruction is the same as pressing the Output Enable button, but no pop-up window appears and the user doesn't have to confirm that the outputs should be enabled.

selectNone

Deselects all channels in all selection groups.

systemtime <text>
systemtime.dmy <day>/<month>/<year>
systemtime.hms <hours>:<minutes>:<seconds>
systemtime.mdy <month>/<day>/<year>
systemtime.ms <integer>
systemtime.smh <seconds> <minutes> <hours> <day of month> <month> <year>

The "systemtime" instruction is similar to the System.Other.Time and System.Other.Date instructions, but 1) allows both time and date to be set or queried with a single instruction; 2) provides the time to the second instead of the minute; and 3) supports several different formats:

- "**Systemtime**" sets or reports the time and date in the same format as System.Other.Time and System.Other.Date, i.e. "Apr 7 2008 11:48 am".
- "**Systemtime.dmy**" sets the date in the format day/month/year or day-month-year.
- "**Systemtime.hms**" sets the time in the format hours:minutes:seconds, where hours is a value between 1 and 23.
- "**Systemtime.mdy**" sets the date in the format month/day/year or month-day-year.
- "**Systemtime.ms**" reports the time as the number of milliseconds since midnight on January 1, 1970 UTC.
- "**Systemtime.smh**" provides the time as six integers indicating the seconds, minutes, and hours since midnight, the day of the month, the number of the month, and the year.

IEEE 488.2 Instructions

The following instructions are intended for use with the GPIB interface, but can be issued through any of the PTC's I/O ports. These instructions ignore the Verbose setting: a query instruction always returns the value only, while a set instruction always returns nothing. They also do not take the ".list" or ".help" suffixes.

Integer arguments can be supplied as hexadecimal values with the prefix "0x" (the number zero followed by a lower-case letter x); for example:

```
*ASE 0x10
```

sets the Alarm Status Register to hex 10 (decimal 16). Queries always return values in decimal format.

***ASE <integer>**
***ASE?**

Sets (or gets) the value of the Alarm Status Enable (ASE) register. If a bit of the ASR is set and the same bit of the ASE is also set, bit 0 of the Status Byte register is set.

***ASR?**

Returns the current value of the Alarm Status Register (ASR), and then clears the register. The ASR is a 32-bit integer that indicates which alarms were triggered since the last time the *ASR? command was issued. Each of the PTC's input channels is assigned a bit in the Alarm Status Register. When an alarm is tripped, the channel's bit in the Alarm Status Register is set. The bit is not cleared when the alarm turns off. Use the <channel>.alarm.mask instruction to determine which bit a particular channel is associated with.

***CLS**

Clear Status. Sets all status registers to zero, disabling all standard events.

***DMC <macro name> <macro content>**

Define Macro Command. Identical to the "define" instruction. Defines a macro, saving the text in the PTC10's local memory.

***EMC { 0, 1 }**
***EMC?**

Enable Macro Commands. Sending the command "EMC 0" disables macro expansion but does not affect macros that are already running. *EMC? queries whether macros ar(.s enabled and returns either 0 (macros disabled) or 1 (macros enabled). Since the state of the *EMC control does not persist when the PTC10 is rebooted, macros are always enabled when the PTC10 is turned on.

***ESE <integer>**
***ESE?**

Sets (or gets) the value of the Standard Event Status Enable (ESE) register. If a bit in the ESR register is set and the corresponding bit in the ESE register is also set, bit 5 of the Status Byte register is set.

***ESR?**

Returns the value of the Event Status Register (ESR), and then clears the register. The eight bits of the Event Status Register are assigned as follows:

Bit	Value	Description
7	128	Power On: set when the instrument is turned on.
6	64	User Request: set when the user touches the front panel or presses a menu key.
5	32	Command Error: set when an assembly error occurs in a GPIB macro.
4	16	Execution Error: set when a runtime error occurs in a GPIB macro.
3	8	Device Dependent Error: always 0.
2	4	Query Error: always 0.
1	2	Request Control: not used. always 0.
0	1	Operation Complete: set by the *OPC command.

***GMC? <macro name>**

Get Macro Command. Prints out (to the serial port) the text of a macro.

***IDN?**

Returns the following identification string:

```
Stanford Research Systems, PTC10, <serial number>, <version>
```

where <serial number> is the instrument's serial number and <version> is the firmware version number.

***LMC?**

Learn Macro Command. Returns a comma-separated list containing the names of all available macros.

***NOP**

No Operation. Does nothing.

***OPC**

Operation Complete. Pauses the parent macro until all ongoing PTC operations have finished, then sets the Operation Complete bit in the Event Status register. The *OPC instruction is intended to indicate that all previous instructions in the macro have been completed.

Most PTC10 instructions are non-overlapping; that is, each instruction is fully processed before the next instruction in the macro is begun. The exceptions are PID autotuning (i.e., <channel>.PID.tune.mode) and ramp-to-setpoint (the <channel>.setpoint, if <channel>.ramp is nonzero). It's also possible to overlap instructions by sending a macro before the previous macro has finished.

The *OPC instruction waits for all autotuning processes to finish, regardless of whether they were started by the parent macro or not. It also waits for all setpoint ramps to finish, regardless of how those ramps were started. Finally, if two or more macros are running at the same time, the *OPC instruction waits until all other macros started by the source port have finished running before setting the Operation Complete bit. If the GPIB port starts two or more macros that contain *WAI?, *OPC?, or *OPC instructions, the result is a deadlock and all of the macros pause indefinitely. Macros started by the front panel or another port are ignored.

While the *OPC instruction is waiting, new commands received over the source port are held in the input buffer. The commands are not processed until the *OPC instruction is finished waiting.

***OPC?**

Identical to the *OPC command, except that instead of setting the Operation Complete bit, *OPC? writes "1" to the I/O port once all tuning processes, setpoint ramps, and GPIB macros have finished.

***PHO**

Port holdoff. Prevents the I/O port that received this instruction from processing any incoming messages until the current macro (the macro that contains the *PHO instruction) has finished running. Once the current macro is finished, the I/O port returns to its normal state and the *PHO instruction has no further effect. Not a standard IEEE488.2 instruction.

***PMC**

Purge Macro Commands. Erases all locally-stored macros. Does not affect macros stored on USB memory devices.

***RST**

The *RST instruction is equivalent to turning the instrument off and back on again, except the Power On bit of the Event Status Register is not set. *RST has the following effects:

- Outputs are disabled (as if the "Output enable" button were pressed).
- All currently-running macros are stopped, regardless of whether the macros were started by the GPIB interface, another I/O port, or the Program screen.
- The instrument returns to the Select screen.
- Partially-received instructions on all I/O ports are cleared.
- All pending transmissions on all I/O ports are cancelled.
- The error queues for all I/O ports are cleared.
- The plot screen returns to showing the most recent data on autoscaled Y axes.
- The instrument automatically triggers at the rate set with the "A/D rate" control.

- Clears all locally-stored log data. Logs on USB devices are not affected. If data is not being logged to a USB storage device, the Plot screen shows no accumulated data immediately after a *RST command.

***SRE <integer>**
***SRE?**

Sets (or gets) the value of the Service Request Enable (SRE) register. If a bit of the Status Byte register is set and the same bit of SRE is also set, a GPIB Service Request is generated.

***STB?**

Returns the value of the Status Byte (STB) register. The 8 bits of the Status Byte are assigned as follows:

Bit	Value	Description
7	128	Unassigned. Always 0.
6	64	Requested Service: set when the PTC10 issues a GPIB service request.
5	32	Event Summary Bit: set when a bit is set in both the ESE and ESR registers.
4	16	Message Available: set when data is waiting to be read on the GPIB port.
3	8	Unassigned. Always 0.
2	4	Error Available: set when errors are waiting in the error queue. This bit will never be set unless System.COM.Verbose is set to Low.
1	2	Unassigned. Always 0.
0	1	Alarm: set when an alarm is triggered, if the bit that's set in the alarm's mask (see the <channel>.alarm.mask instruction) is also set in the ASE register.

***TRG**

Trigger command. Identical to the Group Execute Trigger (GET) bus message. Causes all channels to read their outputs. The amount of time that it takes to process this command is twice the value of the "A/D rate" setting.

After receiving a trigger command, the PTC10 stops automatically acquiring data. The inputs are only read, and PID feedback loops only update their outputs, when a *TRG or GET message is received. PID feedback outputs will not function properly unless the PTC receives *TRG commands or GET bus messages at the rate specified with the "System.Other.A/D rate" instruction.

To resume automatic sampling, set the A/D rate using the "System.other.A/D rate" instruction. For example,

```
"System.other.A/D rate" = 100
```

sets the PTC to automatically sample every 100 milliseconds.

***TST?**

Self-test. Returns a numeric error code that indicates whether data has been dropped and whether ADC conversions are occurring at the correct rate.

- First two digits: number of read misses or 30, whichever is smaller.
- Third digit: the lowest-numbered slot from which data was dropped; zero if no data has been dropped.
- Fourth and fifth digits: ADC conversion rate; 00 = 100% of the expected value (as set by System.Other.A/D rate); 01=101% of expected, 99=99%, etc. A value of 99 or 101% is usually not a problem and indicates that the line frequency is not exactly 50 or 60 Hz, or that the PTC's clock is running slightly slow or fast. A value significantly different from

100% may indicate a problem with the circuit that synchronizes the ADC conversions to the AC line frequency.

The first 3 digits are cleared each time *TST? is issued.

For example, 13400 would indicate 13 read misses on slot 4 since the last time *TST? was issued, and that the system clock is operating normally.

***WAI**

Wait to Continue. Pauses the parent macro until other macros started by the port that received the parent macro, all PID tuning processes (regardless of how they were started), and all setpoint ramps have finished. Identical to the *OPC command, but doesn't provide any explicit indication to the I/O port when the wait is complete.

Program submenu

The "program." prefix can be used but is not necessary for these instructions.

abortMacro <text>

Defines an abort macro. The abort macro is run if the macro that defined it is aborted with an "abort" or "kill" instruction, or is stopped from Program or System screens. The abort macro is not run if the macro ends normally, if a *RST instruction is issued, if a reset(running macros) instruction is issued, or if a reset(all) instruction is issued. The abort macro also does not run if the macro is aborted before the abortMacro instruction is processed. The abortMacro instruction only affects the macro that called it, and has no effect on any other macros.

clearerrors

Erases all error messages for the port over which the instruction was transmitted. Also clears all messages from the System.Com.Errors window, regardless of which port generated them.

cls

Clears the "messages" window on the program screen, if the program is selected on the program screen's tab bar.

There is no "cls?" query

define <macro name> <macro content>

Saves a macro. The first argument is a file name under which to save the macro; the second argument is the content of the macro. Once a macro is saved, it can be called from another macro by issuing the file name like any standard instruction. The saved macro can also be started from the Program screen via the Load button or by touching the Progress window.

If a macro is already saved under the indicated name, the old macro is overwritten. If a file name conflicts with the name of a built-in instruction, the macro takes precedence if the command is issued with a capitalized first letter; the built-in instruction takes precedence if the command is issued with a lower-case first letter.

A single macro cannot both define a macro and call it, because submacro calls are expanded before the parent macro runs.

Example:

```
define Hello([print "Hello world!" pause 1 second]3)
```

The macro "Hello" can now be run by issuing the remote command:

```
Hello
```

Errors: If the macro name is longer than 32 characters, it is truncated to 32 characters. If the macro content is longer than 256 characters, it is truncated to 256 characters. The "define" instruction does not check the contents of the macro for syntax errors.

delete <name>
delete.all

Deletes a saved macro. "Delete.all" deletes all locally-saved macros but does not delete macros stored on attached USB devices. Deleting a macro has no effect on currently-running macros.

geterror

If verbose mode is set to "Low", error messages generated by remote commands are not transmitted over the remote interface. Instead, they are stored in an error buffer that can hold up to 20 messages. Each I/O port (USB, RS-232, etc) has its own error buffer. The "geterror" instruction returns the oldest message stored in the buffer, and then removes the message from the buffer. If the buffer is empty, "no errors" is returned.

Only errors generated by the port over which the "geterror" instruction was received are reported. If, for example, a "geterror" instruction is transmitted over the USB port, it only reports errors caused by messages that were received by the USB port.

"Geterror" does not remove messages from the System.Com.Errors window.

kill <string>
kill.all

Stops all currently-running macros with the given runtime name. The runtime name is assigned with the "name" instruction and is not necessarily the same as the file name that a macro may be saved under.

The kill.all instruction stops all currently-running macros regardless of name or which port started the macro.

There is no "kill?" query.

name <string>

Assigns a runtime name to the currently-running macro. A remote command or another macro can then use the "kill" instruction to stop the named macro. In addition, the name appears on the macro's tab in the Program screen. The name can be any alphanumeric string up to 32 characters long, and more than one macro can have the same name.

Macros are assigned a default runtime name in the form "ProgramN", where N is an integer that increments each time a new macro is started. A macro's runtime name has no relationship to its file name (see the "define" command). The "name" command does not change the file name that a macro is defined under, and defined macros are not automatically assigned their file name as their runtime name.

Errors**:** If the runtime name is more than 32 characters long, it is truncated to 32 characters.

pause <time> { ms, s, min, hr }

Pauses the program for the indicated amount of time. For example:

```
print hello  pause 2 s  print world!
```

prints the word "hello" on the program screen and also transmits "hello" to the serial port that the command was received from. After two seconds, the macro prints and sends the "world!". The

pause instruction only affects the macro that it's a part of. All other macros continue to run normally.

There is no "pause?" query.

popup <string>
popup.close

Produces a popup window on the PTC10's screen with the supplied message. The message can be any alphanumeric string up to 128 characters long. If a help window or another popup is already showing, it is closed and replaced with the new popup. The user has to press a menu button or the popup window's "ok" button to dismiss the window.

The popup.close instruction closes any popup or help window currently visible, regardless of how the window was created.

If a popup window is visible on-screen, the popup? query returns the content of the popup window. If no popup window is present, the popup? query returns the following text:

```
No popup window is present
```

portholdoff { on, off }

Prevents the IO port that received the parent macro from receiving any more macros until the parent macro has finished running or until a portholdoff = off instruction is encountered. Same as *PHO.

print <string>

Prints the indicated message. The message can be any alphanumeric string up to 128 characters long. If the program is selected on the program screen, the message appears in the "Messages" area of the program screen. If the program was initiated from the remote interface, the message is also sent through the same remote interface that was used to transmit the program to the PTC.

There is no "print?" query.

redraw

Redraws the current top-level menu. This instruction closes all pop-up windows that may have been showing, including input windows, the Help window, windows produced with the "popup" instruction, the PID status window, COM port error and history windows, and warning message windows.

There is no "redraw?" query.

run <macro name>

Starts a child macro that runs concurrently with the parent macro. The child macro runs invisibly in the background; any messages that it generates are not printed, and the macro has no effect on the *OPC and *WAI instructions. The parent macro continues to run while the child macro runs.

The "run" instruction should only be used when a child macro needs to run in a separate thread from the parent macro. Otherwise, macros should be called as subroutines, by including their name in the parent macro without the "run" instruction.

standby

Puts the PTC10 into standby mode, in which the outputs are turned off, data acquisition is paused, macros are paused, the front panel display and system fan are shut off, and the system does not respond to remote commands. The PTC321's excitation currents remain on, and the chassis

cooling fan may switch on occasionally. Press the "Output Enable" key to exit standby. There is no remote command to leave standby mode.

waitForRamp

Pauses the macro until all PID setpoint ramps are complete. To wait for a particular channel's setpoint ramp to finish, use a "while" loop; for example:

```
while (Out1.PID.setpoint != Out1.PID.actual) { pause 1 s }
```

waitForSample

Causes the macro to pause until an ADC conversion occurs.

waitForTune

Pauses the macro until all PID tuning processes are complete. To wait for a particular channel's tuning process to finish, use a "while" loop; for example:

```
while (Out1.Tune.Mode != Off) { pause 1 s }
```

System submenu

System.Log submenu

system.log.clear { yes, no }

"system.log.clear yes" erases all log files from the current folder on the USB device. "system.log.clear no" has no effect. "system.log.clear?" always returns "no".

system.log.folder <folder name>

Determines which folder on the USB memory device receives log data. If the folder does not exist, it is created. If the folder does exist and it already contains PTC10 logfiles, new data points are appended to the existing files.

system.log.interval { off, 0.1 s, 0.3 s, 1 s, 3 s, 10 s, 30 s, 1 min, 3 min, 10 min, 30 min, 1 hr }

Sets the default log interval, which determines how often each channel's value is written to the log. Individual channels can override this value using the <channel>.logging instruction.

system.log.Log to { RAM, USB, None }

Set this parameter to USB to begin logging data to a USB memory device, if one is present. Set it to "RAM" to stop logging data to the USB device and store data in local memory, and to "None" to disable logging altogether. If set to "None", no data appears on the Plot screen.

Errors: if "USB" is selected and no USB storage device is present, this parameter automatically switches to "None".

system.log.USB { Auto, Manual }

If set to Auto, any time a memory device is plugged into one of the PTC10's USB ports, the PTC automatically begins logging to it. If set to Manual, each time a USB device is plugged in, a "system.log.log to" instruction must be issued to begin logging data to it, or the user must touch the USB logging indicator in the upper-right corner of the screen.

System.COM submenu

system.com.RS-232 { 2400, 4800, 9600, 14400, 19200, 28800, 38400, 57600, 115200, 250000 }

Sets the baud rate for the RS-232 interface. The interface always has no parity, 8 bits, and 1 stop bit.

system.com.verbose { Low, Medium, High }

Affects how the system replies when a remote instruction is processed. In the "Low" setting, which is intended to be compatible with GPIB communication standards, only successful queries generate a reply. The "Medium" setting also sends a message whenever an error occurs, and the "High" setting also sends a message whenever an instruction sets a parameter. In addition, the "High" setting echoes back the name of the parameter that was set or queried.

		Response to instruction…	
Verbose level	**2A?**	**xyz**	**2A = 37.47**
Low	37.4722	(none)	(none)
Medium	37.4722	Error: "xyz" is not a valid instruction	(none)
High	2A.Value = 37.4722	Error: "xyz" is not a valid instruction	2A.Value = 37.47

System.IP submenu

system.IP.Address <string>

Sets the PTC10's IP address. The IP address should be in dotted-decimal notation, i.e. "172.16.0.0".

Errors: If part of the specified IP address is not in the correct format (i.e. contains a non-numeric character or a value that is not between 0 and 255), that portion of the IP address is set to zero. The IP address cannot be changed if system.IP.DHCP is set to "on".

system.IP.DHCP { On, Off }

Enables or disables the Dynamic Host Configuration Protocol. If DHCP is enabled and a DHCP server is available on your network, the IP address, subnet, and gateway are automatically set and cannot be changed manually.

system.IP.Gateway <string>

Sets the address of the Ethernet gateway. This value does not need to be set to carry out Telnet communications and is only included to support Internet features that may be added to future versions of the PTC10 firmware.

Errors: The gateway cannot be changed if system.IP.DHCP is set to "on".

system.IP.MAC <string>

Sets or queries the media access control address. This value is set at the factory and should not generally be changed unless the PTC10's nonvolatile memory has been erased. The address should be specified in six groups of two hexadecimal digits separated by colons, i.e., "00:19:b3:06:00:00"

The default MAC address is 00:19:b3:06:ab:cd, where abcd is the hexadecimal representation of the last four digits of the instrument's serial number.

system.IP.Subnet <string>

Sets the subnet mask. The subnet mask should be in dotted-decimal notation, i.e. "255.255.0.0".

Errors: If part of the specified subnet mask is not in the correct format (i.e. contains a non-numeric character or a value that is not between 0 and 255), that portion of the mask is set to zero. The subnet cannot be changed if system.IP.DHCP is set to "on".

system.IP.Telnet <integer>

Sets the telnet port for Ethernet communications. Remote commands can be sent to the PTC through a telnet connection on the selected port. The port must be a value between 0 and 65535, inclusive, and should normally be either 23 (the default) or a value greater than 1024.

System.Display submenu

system.display.Bright { Off, 2, 3, 4, 5, 6, Max }

Sets the brightness of the front-panel LCD display. If "Off" is selected, touch the front panel to turn the display on for 2 seconds.

system.display.Figures { 0, 1, 2, 3, 4, 5, 6 }

Sets the number of figures that appear after the decimal point in the replies to remote queries of floating-point values, as well as on the Numeric tab of the Show Data screen. Fewer figures appear after the decimal point if the value is greater than 1000 or less than -1000.

system.display.Stats { Off, On }

Controls whether statistics are visible in the plot. If Stats is set to On and the plot type is single or multiple, the average and standard deviation for each channel for which statistics collection has been enabled (with the <channel>.stats instruction) is shown next to the channel name. Ponytail plots instead show the offset of each channel.

"system.display.Extras" { Hide, Show }

If set to Show, various internal monitor channels are displayed. These channels display printed circuit board (PCB) temperatures for the I/O cards as well as heater current, voltage, and resistance. The system must be restarted before the PCB temperatures are shown.

system.display.Type { Single, Multiple, Custom, Ponytail }

Controls the type of plot. On a Single plot, all selected channels appear on a single Y axis. "Multiple" generates a separate plot for each selected channel. "Custom" assigns each selected channel to a plot based on the channel's Plot setting. "Ponytail" produces a single plot with all selected channels, but each channel's trace is offset by its initial value. The offset is recalculated whenever the user scrolls or zooms the graph.

system.display.Units { °C, K, °F, Sensor }

Sets the system units. Setting the units does not change previously-acquired data; that is, if a value of 22°C is recorded in the log and the units are then changed to °F, it will appear that a value of 22°F was recorded. If the units are set to "Sensor", thermocouple readings are shown in millivolts and RTD and thermistor readings are shown in ohms, and custom calibration tables are ignored (see the "Custom calibration" section).

system.display.X labels { None, Absolute, Elapsed }

Controls the type of label shown at the bottom of the plot. Absolute shows the time and date, while Elapsed shows the relative time in seconds, minutes, hours, or days.

system.display.X range <milliseconds>

Sets the X range of the plot. Only the plot for the currently-selected group is affected.

Errors**:** a run-time error occurs if the argument is less than 10000 (10 seconds) or greater than 2592000000 (30 days).

System.Other submenu

system.other.A/D rate { 20 ms, 40 ms, 60 ms, 80 ms, 100 ms, 120 ms, 140 ms, 160 ms, 180 ms, 200 ms, 220 ms, 240 ms, 260 ms, 280 ms, 300 ms, 400 ms, 500 ms, 600 ms, 700 ms, 800 ms, 900 ms, 1000 ms } (50 Hz line frequency)
system.other.A/D rate { 16.7 ms, 33.3 ms, 50 ms, 66.7 ms, 83.3 ms, 100 ms, 150 ms, 200 ms, 250 ms, 350 ms, 400 ms, 500 ms, 600 ms, 700 ms, 800 ms, 900 ms, 1000 ms } (60 Hz line frequency)
system.other.A/D rate { float } (1 MHz trigger source)

Sets the A/D conversion time. This setting also determines how often PID feedback loops run. Different arguments are available depending on whether the line frequency is 50 or 60 Hz. If the "Trigger source" jumper on the PTC10's motherboard is moved to the "1 MHz clock" position, the A/D sampling can set to any value between 10 and 1000 ms.

system.other.fan { off, low, medium, high, max, auto }

Controls the system fan speed. If a DC output card is in use the fan should be set to max or auto, otherwise the system could be permanently damaged. Turning the fan off can reduce the accuracy of temperature measurements.

system.other.date <date string>
system.other.time <time string>

Sets the time and date. Note that setting the time and date can adversely affect the display of previously-acquired data. The time string should be in the form "10:57 am", while the date string should include the month, day, and year in that order, i.e. "Apr 7 2008" or "4/7/08".

system.other.reset { Running macros, Saved macros, Front panel, ports, Port settings, User settings, All }

Resets one of the PTC10's subsystems. The options have the following effects:

Running macros: stops all running macros. Has no effect on saved macros.
Saved macros: deletes all saved macros from local memory. Does not delete macros from USB memory devices. Has no effect on running macros.
Display: Resets all System.Display settings to their factory defaults. Returns the front panel to the Select menu, de-selects all channels in all groups, and erases locally-stored log data (data on USB drives is not affected). Returns all plots to autoscaled X and Y with a 1 minute X range and changes the plot location of all channels to 1. If a *TRG remote command was previously received, re-enables automatic A/D conversions. Hides the internal temperature display, T(PCB).
Ports: Closes all I/O ports and re-opens them. USB and Telnet connections will be lost. The port settings (baud rate, IP address, etc.) remain unchanged.
Port settings: Resets all I/O port settings to their factory defaults.

Channels: Resets the settings on the Channel menu for all channels to their factory defaults. Also sets the A/D rate to 100 ms.

Log: Resets the default log rate to 1 second, sets the log rate for each channel to the default, and enables automatic logging to USB. If a USB storage device is attached, erases log files in the root directory and begins logging to USB.

All: resets all of the above items.

system.other.Volume { off, 1, 2, 3, 4, 5, 6, 7, max }

Controls the volume of all tones and alarm sounds played through the front-panel speaker.

<channel> submenu

<channel>

To set the value of an output channel, send the name of the channel followed by the new value. For example,

```
5A = 2.5
```

sets the value of channel 5A to 2.5V, assuming that channel 5A is an output and Output Enable is on.

To read the value of any channel, send the name of the channel followed by a question mark. For example,

```
5A?
```

queries the value of channel 5A.

Errors: a run-time error occurs if this instruction is used to set the value of an input channel.

<channel>.Average

If statistics collection is enabled for this channel (using the <channel>.Stats instruction), this query prints the average over the most recent *n* A/D samples, where *n* is set with the <channel>.Points instruction.

<channel>.Current { Forward, Reverse, AC } (PTC321 4-channel RTD reader)
<channel>.Current { Forward, Reverse, AC, off } (PTC320 1-channel thermistor reader)

Selects the direction of the excitation current passed through RTDs and thermistors. The current direction can be switched from forward to reverse to check for offsets caused by thermal EMFs. In AC mode, the current direction is switched with each ADC reading and each measurement is the average of the two most recent readings, thereby eliminating errors caused by thermal EMFs. On the PTC320, this control also offers the ability to switch the excitation current off entirely.

<channel>.Current { 1 mA, 100 µA, 10 µA, Auto } (PTC440 TEC driver)

Determines how much excitation current is passed through the sensor. Type alt-0181 to enter the µ character on a PC.

If "auto" is selected, the excitation current is set at every ADC conversion according to the measurement range or sensor resistance; see page 63 for a description of how the auto excitation current is determined.

<channel>.Cycle <int (seconds)>

This instruction is only available on the PTC420 AC output card. The PTC420 has a solid-state relay that can either deliver full power or no power to the heater. To more precisely control the power delivered to the heater, power is switched on for some fraction of a preset cycle period, then switched off for the remainder of the period. The Cycle instruction sets the length of that period. Shortening the cycle period will reduce temperature swings associated with switching the current on and off, but will also reduce the lifetime of the relay. The cycle time must be between 1 and 240 seconds inclusive.

Errors**:** Attempting to set the cycle time for any channel other than the output of a PTC420 AC output card produces an assembly-time "unrecognized instruction" error.

<channel>.d/dt { On, Off }

Derivative. If this control is set to "On", the value of the channel is replaced with its derivative with respect to time. Since the derivative is normally somewhat noisy, the lowpass filter should be enabled when the derivative filter is used.

<channel A>.Diff <channel B>

Enables or disables the difference filter. When a valid Channel B is selected, the value of channel A is replaced with the difference between channel A and channel B (e.g., A–B). If channel B does not exist, the difference feature is disabled and channel A's output reverts to its normal value. Channel A must be an input.

Examples:

```
2A.diff(2B)
```

Replaces the output of channel 2A with the value (2A – 2B). Channel 2B is unaffected.

```
2A.diff()
```

Removes the differencing function from channel 2A.

Channels with a difference filter can be used as the input for PID feedback loops, in which case the feedback maintains a constant temperature differential between two locations, rather than a constant absolute temperature.

Errors: if channel A is not an input, a "not a valid instruction" error is produced at assembly time.

<channel>.Dither { On, Off }

This instruction is only available on the PTC430 DC output card. The PTC430 uses a 16-bit DAC to generate its output. If dither is set to On, the card dithers its least significant bit to obtain greater resolution.

Errors**:** Attempting to set the dither value for any channel other than the output of a PTC430 DC output card produces an assembly-time "not a valid instruction" error.

<channel>.Follow { channel name }

This instruction is only available for virtual channels (channels V1, V2, and V3) that are configured as inputs. If the argument is a valid channel name, the value of the virtual channel is updated with the value of the argument channel each time an ADC conversion occurs. To exit follow mode, issue the Follow instruction with an empty argument.

<channel>.IO type { Input, Set out, Meas out }

This instruction is only available for output channels. It determines the channel's direction. Not all options are available for every output channel. If set to "Input", the channel does not output anything, but just measures whatever value is present. If the IO type is "Set out", the channel outputs voltage, current, or power, and the channel reading reflects the most recently requested output, regardless of what value actually appears on the output. If the IO type is "Meas out", an ADC is used to measure the output and the channel value reflects the ADC reading. The difference between "Set out" and "Meas out" is especially noticeable with an AC output card.

Errors**:** If a channel's direction cannot be changed due to hardware limitations, attempting to set its IO type generates a run-time "locked parameter" error.

<channel>.Logging { Off, 0.1 s, 0.3 s, 3 s, 10 s, 30 s, 1 min, 3 min, 10 min, 30 min, 1 hr, Default }

Sets the log interval for this channel. "Default" makes this channel's log interval the same as the global default interval (see the System.Log.Interval instruction). "Off" disables logging for this channel.

<channel>.Lopass { Off, 1 s, 3 s, 10 s, 30 s, 100 s, 300 s }

Sets the time constant for a 6th-order lowpass RC filter. This instruction is only available for input channels.

<channel>.Low lmt <float>
<channel>.Hi lmt <float>

These instructions are available for output channels only. They determine the minimum and maximum output and can be used to prevent the PID loop from delivering excessive power to a heater. The limits must be specified in the same units that the output is expressed in. The limits must normally be reset when the output units are changed, since the limits are not converted to the new units.

<channel>.Name <string>

Changes the name of this channel. A macro cannot change a channel's name and then use the new name to set or get the channel's parameters. This is because the PTC10 checks the syntax of a macro before the macro runs. Since the channel's name hasn't been changed at this point, the PTC10 will produce an "unrecognized instruction" error if it sees any instructions beginning with the new channel name.

<channel>.Off

This instruction is only available for output channels. It cancels any active autotuning process, turns PID feedback off, and sets the channel's output to zero or the channel's lower limit (see the "<channel>.Low lmt" instruction), whichever is higher.

<channel>.PCB <max temp in °C> (PTC320, PTC321, PTC330 I/O cards only)

Maximum PCB temperature. If the temperature of the card exceeds this value and System.Other.Fan is set to Auto, the PTC10 increases the fan speed to cool the card down. The PCB temperature is always expressed in °C, regardless of the System.Display.Units setting.

<channel>.Plot { 1, 2, 3, 4, 5, 6, 7, 8 }

The Plot screen can display up to eight graphs, each of which can contain up to eight traces. The Plot command indicates which of these the channel should appear in when Custom plot order is selected. Plot 1 is the topmost graph. If no channels are assigned to a plot, that plot will not appear.

<channel>.Points <integer>

Controls the maximum number of ADC readings used to calculate the average and standard deviation. Note that this refers to the number of ADC readings, not the number of log points. Each time the number of points is changed, the accumulated statistics are cleared.

Errors: if the number of points is not between 2 and 6000 inclusive, a run-time "parameter out of bounds" error occurs.

***Channel*.Polarity { 0, 1 }** (Digital I/O card relay channel only)

Sets the polarity of the relays. If both the polarity and the relay value are zero, the normally closed (NC) pins on the back panel are connected to the neighboring COM pins and the normally open (NO) pins are disconnected. If the polarity is 1, the reverse is true.

<channel>.Range { ... } (PTC320, PTC323, PTC430, and PTC440 I/O cards only)

This instruction sets the input or output range for a particular channel. It is only available if more than one range is available. The list of possible options depends on the I/O card.

Errors**:** If the hardware only offers a single range, attempting to change the range generates a "not a valid instruction" error.

<channel>.SD

If statistics collection is enabled for this channel (using the <channel>.Stats instruction), this instruction prints the standard deviation over the most recent <points> A/D samples.

<channel>.Selected { On, Off }

Controls whether or not a channel is selected. Selected channels are added to the current selection group and appear on the Numeric, Plot, and Channel screens. Examples:

```
2A.selected(on)
```

adds channel 2A to the current selection group, if it hasn't already been added.

```
2A.selected = off
```

removes channel 2A from the current selection group.

<channel>.Sensor { RTD, Thermistor, Diode, ROX, E, J, K, N, T }

Selects the sensor type for this channel. This instruction is only available for input channels that support more than one sensor type. The available arguments depend on the I/O card.

Changing the sensor type may affect how the PTC hardware acquires data from the sensor. For example, if the sensor type of a PTC320 I/O card is changed from Thermistor to Diode, the PTC acquires voltage instead of resistance readings.

The sensor type also affects the options available in the <channel>.Cal submenu. For example, if the sensor type is set to "RTD", the <channel>.cal.type instruction offers a list of RTD types, and settings for the RTD's Callender-van Duzen coefficients appear in the <channel>.cal submenu.

Select "ROX" for a ruthenium oxide sensor.

E, J, K, N, and T refer to thermocouple types. Since the PTC10's thermocouple input hardware determines which type of thermocouple can be read, the thermocouple type can be queried but not changed with the Sensor instruction.

Some resistive cryogenic temperature sensors such as Rhodium-Iron, Germanium, and Carbon-Glass are not included in the list of available sensor types because they do not have standard calibration curves. To use these sensors, set the Sensor type to Thermistor, RTD, or ROX and

load a custom calibration table (see "Custom Calibration Tables" in the Introduction of this manual).

Channel.Slew <float> (Output channel of PTC440 TEC driver only)

Sets the maximum positive and negative rate of change of the TEC driver output. The rate must be between 0 and 1000 amps per second, and the default value is 100 amps per second (which corresponds to an unlimited slew rate at 10 samples/second). Each time the TEC current is set (either by a PID feedback loop or with the Channel.value control), it ramps to the new value at this slew rate.

Rapid changes in the TEC current can create electromagnetic interference (EMI) in the temperature sensor and any other sensors near the TEC. The resulting spikes in the temperature reading can cause feedback oscillations or noisy temperature readings.

For the slew rate setting to be effective, the A/D rate (set with the System.Other.A/D rate control) should less than or equal to 100 ms. The slew rate is implemented with a software algorithm that runs at each A/D conversion, and the TEC driver output has a 13 Hz lowpass filter. If the A/D rate is set (for example) to 1000 ms, the algorithm only changes the TEC output current once each second and the output current therefore changes in discrete steps, each of which may exceed the desired slew rate. When the A/D rate is smaller than 100 ms, the lowpass filter smooths the steps into a continuous ramp.

When outputs are disabled by pressing the Output Enable button or with the "OutputEnable off" remote command, the TEC output turns off immediately, regardless of the slew rate setting. When outputs are re-enabled, the TEC output ramps up to its previous value at the desired slew rate.

<channel>.Stats { on, off }

Using the remote interface, the average and standard deviation of the most recent *n* ADC readings can be continuously calculated, where *n* is defined using the <channel>.Points instruction. The values can be displayed on the graph screen using the System.Display.Stats instruction or queried with the <channel>.Average and <channel>.SD instructions.

<channel>.Stats Turns sliding-window statistics collection on or off for a channel. When statistics collection is turned on, the average and standard deviation over the most recent *n* ADC readings are calculated at each ADC conversion and can be displayed on the single or multiple plot screens or queried via the Average and SD instructions. *n* is the smaller of 1) the number of ADC readings acquired since statistics collection was enabled; 2) the number defined with the <channel>.Points instruction; or 3) the number of ADC readings acquired since the Points instruction was last issued.

This command is only available through the remote interface.

<channel>.Units { W, % } (PTC420 AC heater driver only)
<channel>.Units { W, A, V } (PTC430 DC heater driver only)

By default, the outputs of the AC and DC heater driver cards are measured in watts. Using the "Units" instruction, the output units of the AC output card can be changed to "%" (i.e., percentage of the maximum output) and the output units of the DC output card can be changed to "A" (heater current) or "V" (heater voltage). Note that the "low lmt" and "hi lmt" settings are not automatically converted to the new units.

<channel>.Value <float>

If the indicated channel is an output, <channel>.value changes the channel's output value. Regardless of whether the channel is an input or an output, <channel>.value? returns the current value of the channel. Attempting to set its value of an input channel produces a run-time error.

Attempting to set the value of an output channel when outputs are disabled also produces a run-time error. Setting the value of an output channel under feedback control has no effect, but no error is generated.

Examples:

```
"Out 1.value" = 1.0
```

Sets channel Out 1 to output 1 watt of power. Note that the instruction has to be enclosed in quotes because the channel name has a space in it. The argument is not included in the quotes.

```
2A.value?
```

Queries the output of channel 2A. The response is:

```
37.4722
```

if System.Com.Verbose is set to Low or Medium, or

```
2A.value = 37.4722
```

if System.Com.Verbose is set to High. If sensor 2A is not connected or is out of the range of its calibration data, the reported value is "NaN" (not a number).

For input channels and measured output channels, the current value reported by the PTC10 is the most recent ADC reading (after being calibrated and filtered). This value may be different than the most recently-logged point, which is the value that appears on the plot and in general corresponds to an average of several ADC readings.

If a channel is an input, attempting to set its value generates a "locked parameter" error.

<channel>.Vmax <float> (Vmon channel of PTC440 TEC driver only)

Sets the maximum voltage that the PTC440 TEC driver can output. This setting is intended to protect thermoelectric coolers from damaging voltages. If the TEC voltage increases above Vmax for more than one second, current to the TEC is automatically shut off. The first time this occurs after the system is turned on, a "hardware fault" window also pops up on the front-panel display. To turn the current back on again, set the channel's output to zero by touching the "Off" button on the Channel menu, or by disabling and re-enabling all outputs with the Output Enable button.

If the output current suddenly increases and the slew rate setting is too high, it is still possible to damage the TEC even if Vmax is set to an appropriate value. To prevent such damage, the output voltage should also be limited by setting the output range to the lowest possible value (e.g., 3V 5A, 6V 5A, or 9V 5A); and by setting the "Lo lmt" and "Hi lmt" controls to values that do not produce excessive voltages.

<channel>.alarm submenu

<channel>.alarm instructions can only be applied to input channels. Issuing a <channel>.alarm instruction for an output channel results in an assembly-time "unrecognized instruction" error.

<channel>.alarm.lag <int (seconds)>

The alarm lag adds glitch tolerance by preventing the alarm from triggering until the signal has continuously exceeded the alarm limits for the preset number of seconds.

<channel>.alarm.latch { No, Yes }

A latching alarm, once triggered, continues to sound until the status or mode is set to off.

<channel>.alarm.min <float>
<channel>.alarm.max <float>

These instructions set the alarm limits. The alarm is triggered whenever the signal exceeds these limits. The limits are specified in the same units in which the channel value is displayed. If the channel's units are changed, the limits are not automatically updated.

<channel>.alarm.mask?

Returns a 32-bit integer with one bit set, indicating which bit in the Alarm Status Register this alarm sets whenever the alarm is tripped. The Alarm Status Register is part of the GPIB status reporting system; see the IEEE488 commands section for more information.

Errors**:** attempting to change the value of the mask produces a run-time "locked parameter" error.

<channel>.alarm.mode { Off, Level, Rate /s }

Enables the alarm. The alarm can be programmed to trigger when the level of the signal exceeds the preset limits, or when the rate of change per second exceeds the limits. The rate of change is calculated over two successive A/D conversions and is therefore susceptible to noise.

<channel>.alarm.mute { True, False }

Turns off the alarm sound. Has no effect on the alarm relay. The alarm stays muted until the alarm condition disappears.

<channel>.alarm.output { channel name }

Associates an output channel with the alarm. This output is shut off whenever the alarm is triggered: the output is set to zero and its feedback loop (if any) is disabled. Once the alarm status returns to "Off", the output returns to its previous value and the feedback loop resumes if (it was running to begin with). This feature can protect equipment from the excessive temperatures that can occur if a PID feedback loop is poorly tuned.

To turn this feature off, issue the alarm.output command with an empty argument, i.e.:

```
4A.alarm.output()
```

<channel>.alarm.relay { None, A, B, C, D }

If a digital I/O card is installed in slot 6, an alarm can trigger one of its relays. The alarm.relay instruction determines which of the card's four relays is triggered.

<channel>.alarm.sound { None, 1 beep, 2 beeps, 3 beeps, 4 beeps }

Controls which sound plays if the alarm goes off.

<channel>.cal submenu

All <channel>.cal.* instructions are only available for input channels.

<channel>.cal.A
<channel>.cal.B
<channel>.cal.C
<channel>.cal.R0 <float>

These instructions set custom calibration coefficients for RTD, thermistor, or diode inputs with a custom calibration type. See the description of the A, B, C, and R0 buttons on page 69 for more information.

Errors: Attempting to set cal.A, cal.B, or cal.C if cal.Type is not set to Custom produces a run-time "locked parameter" error. Attempting to use any of these instructions on a channel that is not an RTD, thermistor, or diode input produces an assembly-time "unrecognized instruction" error.

<channel>.cal.Gain <float>
<channel>.cal.Offset <float>

Sets an offset and gain for the channel. The offset and gain are applied after the sensor signal is converted to temperature. These instructions provide an easy way to make adjustments to a sensor's calibration.

Errors: Attempting to set cal.Offset or cal.Gain on a channel that is not an input produces an assembly-time "unrecognized instruction" error.

<channel>.cal.Type { IEC751, US, Custom } (RTD sensor type)
<channel>.cal.Type { 100, 300, 1000, 2252, 3000, 5000, 6000, 10000B, 10000H, 30k, 100k, 300k, 1M, Custom } (Thermistor sensor type)
<channel>.cal.Type { DT-470, DT-670, Si410, Si430, Si440, S700, S800, S900, Custom } (Diode sensor type)
<channel>.cal.Type { RX-102A, RX-103A, RX-202A, RO600, R400, R500 } (ROX sensor type)
<channel>.cal.Type { B, E, J, K, N, R, S, T } (Thermocouple sensor type)
<channel>.cal.Type { Custom, Standard } (Channels with custom calibration tables)

Determines which calibration curve is used for a particular channel. The available arguments depend on the value of the <channel>Sensor setting. See the description of the Type button on page 68 for more information.

<channel>.PID submenu

All <channel>.PID instructions only exist for output channels. Attempting to apply a .PID instruction to an input channel results in a "not a valid instruction" error.

By default, each PID loop has no assigned input channel. In this state, the only .PID instruction that can be issued is the .PID.input instruction. If a macro attempts to change the setpoint, the feedback gains, etc., a "locked setting" error is generated and the macro continues to run. An error message is only printed if Verbose is set to High.

<channel>.PID.D <derivative>
<channel>.PID.I <integral>
<channel>.PID.P <proportional>

These instructions set the PID gain factors. The PID equation is:

$$\text{Output}_t = Pe_t + 0.5IT((e_0 + e_1) + (e_1 + e_2) + \ldots (e_{t-2} + e_{t-1}) + (e_{t-1} + e_t)) + (D/T)(e_t - e_{t-1})$$

where P, I, and D are the derivative gains, e_t is the error (the difference between the setpoint and the PID input signal) at time t, and T is the ADC sampling time. Thus, larger values of P, I, or D

produce a faster feedback response. Increasing P or I tends to create oscillations, while increasing D reduces oscillations but adds noise. Negative values of P, I, and D should be used if the output drives a fan or other device that cools the sample.

Errors**:** Attempting to set P, I, or D when no PID input channel is selected produces a run-time "locked parameter" error. Attempting to set I or D when the PID mode is set to Follow also produces a run-time "locked parameter" error. Issuing a "P" instruction when the PID mode is set to Follow produces an assembly-time "Unrecognized instruction" error.

<channel>.PID.Ffwd { channel name }

Selects a feedforward input channel. If a valid channel is selected and the PID mode is set to "on", the value the value of the feedforward channel is added to the PID output at each ADC conversion. To disable this feature, issue the "<channel>.ffwd" instruction with an empty argument.

This feature can be used to implement feedforward control. The feedforward input should be some quantity with a known and predictable effect on the feedback system. The feedforward channel's cal.offset and cal.gain controls can be used to scale the feedforward effect.

<channel>.PID.Gain <gain>
<channel>.PID.Zero pt <zero point>

These instructions are only available when the PID mode is set to Follow. They are used to adjust the offset and gain applied to the input. In follow mode, the output is determined as follows:

$$\text{Output} = (\text{Input} - \text{Zero pt}) \times \text{Gain}$$

Therefore, when the input is equal to the zero point, the output is zero.

Errors: Issuing a zero point or gain instruction when the PID mode is set to On or Off produces an assembly-time "Unrecognized instruction" error.

<channel>.PID.Input <channel name>

Sets the PID input channel, which is the temperature that the PID feedback loop controls. If the channel name does not exist, any previously-selected input is deselected, leaving no PID input selected, and the PID feedback is disabled.

<channel>.PID.Zone { 1, 2, 3, 4, 5, 6, 7, 8, Auto }

Sets the PID temperature zone. A set of PID gains and a minimum temperature can be assigned to each of the eight locations. If the zone is set to Auto, the PID gains are automatically recalled based on the PID setpoint and the <channel>PID.T min setting of each zone. This feature, known as zoned feedback, is useful if the responsiveness of your system varies with the temperature. In this case, feedback stability can be improved by using different PID gains, depending on the temperature.

All eight PID zones can be viewed as a table on the front panel; see the description of the Zone button on page 72. If you don't already know the feedback parameters to be loaded into the table, it's usually easier to use the front panel rather than remote commands to determine the correct parameters and load them into the table. However, if the feedback parameters are already known, they can be loaded into the table with a macro such as the following:

```
Out1.PID.Zone 1      ' select the first line of the table
```

```
                    '   and disable zoned feedback
Out1.PID.Tmin 25    ' fill in the first line of the table…
Out1.PID.P 1.5
Out1.PID.I 0.13
Out1.PID.D 0.04

Out1.PID.Zone 2     ' select the second line of the table
Out1.PID.Tmin 35
Out1.PID.P 0.75
Out1.PID.I 0.05
Out1.PID.D 0.03

Out1.PID.Zone 3     ' select the third line of the table
Out1.PID.Tmin 1000  ' ensure that this line is never used

Out1.PID.Zone Auto  ' enable zoned feedback
```

Errors: Attempting to change the zone when no PID input channel is selected produces a run-time "locked parameter" error.

<channel>.PID.Mode { Off, On, Follow }

Enables and disables PID feedback. Turning feedback off freezes the output at its current value but does not set the output to zero. Setting the mode to "On" starts PID feedback using the current PID gains. In "Follow" mode, the output is continuously set to the same value as the channel selected with the "input" instruction. An offset and gain can be applied using the "Zero pt" and "Gain" instructions.

The input must be stable before either Step or Relay tuning is started. Furthermore, the output must be greater than half the step height before relay tuning is started. The best time to start a step response is when the system is first turned on at the beginning of the day, i.e. the heater is cold and its temperature stable. After the step response finishes, the feedback mode changes to manual and the heater ramps up to the setpoint. Once the temperature is stabilized at the setpoint, relay tuning can be used to produce more accurate PID parameters. When relay tuning is complete, the PID mode changes to manual.

Errors: Attempting to set the PID mode when no PID input channel is selected produces a run-time "locked parameter" error.

<channel>.PID.Ramp <ramp rate>

Ramp rate. Determines the setpoint ramp rate in degrees per second. If the ramp rate is nonzero, whenever the feedback setpoint is changed the feedback will gradually ramp the temperature to the new setpoint. If the ramp rate is set to zero, setpoint ramping is disabled and the PTC changes the temperature at the fastest possible rate.

Errors: Attempting to set the ramp rate when no PID input channel is selected produces a run-time "locked parameter" error.

<channel>.PID.RampT <float>

Ramp temperature. The ramp temperature is an internally-generated setpoint for the PID feedback loop; it is the temperature that the PTC10 is trying to maintain at the present moment. If the feedback is not running, the ramp temperature always equals the sensor temperature, since the PTC10 has no control over the sensor temperature when the feedback is not running. When the feedback is started, the ramp temperature automatically increases or decreases at the ramp rate until it reaches the setpoint. This feature allows you to bring your system up to its operating temperature at a controlled rate. The actual temperature of your experimental system should

ideally follow the ramp temperature, perhaps lagging a few seconds behind, depending on how quickly your system responds and how well the PID parameters have been tuned.

Once it reaches the setpoint, the ramp temperature remains at the setpoint as long as the feedback is running. If the setpoint is changed, the ramp temperature automatically increases or decreases at the ramp rate until it reaches the setpoint. If the feedback is disabled, the ramp temperature immediately begins to track the sensor temperature.

To start a temperature ramp, enable the feedback, set the ramp rate, and then change *Channel*.PID.Setpoint to the desired end point of the ramp. In general, the ramp temperature should not be directly set by the user, except perhaps as a way to cancel a ramp; for example,

```
Out1.PID.RampT = #Out1.PID.setpoint
```

tells the PTC10 to stop gradually ramping the temperature and instead proceed as quickly as possible to the setpoint. On the other hand,

```
Out1.PID.setpoint = #Out1.PID.RampT
```

stops ramping by freezing the temperature at its current value.

The following line can be used to pause a macro until the ramp is complete:

```
while (Out1.PID.RampT != Out1.PID.setpoint){ pause 1 s }
```

Errors**:** Attempting to set the ramp temperature when no PID input channel is selected produces a run-time "locked parameter" error.

<channel>.PID.Setpoint <setpoint>

Sets the PID setpoint. The PID loop attempts to keep the input at this value by changing the output.

Errors**:** Attempting to set the setpoint when no PID input channel is selected produces a run-time "locked parameter" error. Issuing a setpoint instruction when the PID mode is set to Follow produces an assembly-time "Unrecognized instruction" error.

<channel>.PID.T min <t min>

Sets the minimum temperature of the current PID memory location. This instruction has no effect until the PID memory location is set to Auto.

Errors: Attempting to set the minimum zone temperature when no PID input channel is selected produces a run-time "locked parameter" error.

<channel>.Tune submenu

See the "Automatic PID Tuning" section of this manual for more information on using these instructions.

<channel>.Tune.Lag <seconds>
<channel>.Tune.Step Y <height>

These parameters provide the PID autotuners with initial guesses of the system's response magnitude and time. "Step Y" controls the height of the step response or relay disturbance, while "Lag" determines how long the tuner waits before it first evaluates the effect of the disturbance. If either Lag or step Y is too small, the autotuning algorithm will be susceptible to noise. Step Y

should be high enough to produce a temperature rise of several degrees, and Lag should be long enough for the temperature to rise noticeably.

Errors: Attempting to set step Y or Lag when no PID input channel is selected

<channel>.Tune.Mode { Off, Auto, Step, Relay }

Starts or stops PID autotuning. "Step" starts the step response tuning algorithm; "Relay" starts the relay tuning algorithm. In "Auto" mode, the PTC begins a step response if the PID output is less than half of the "Step Y" value, or relay tuning if the output is greater than half of the "Step Y" value. "Off" cancels any PID autotuning that's currently in progress.

<channel>.Tune.Type { Cons, Moderate, Aggr, Auto }

Determines how the PID tuner sets the feedback gains. "Cons" results in slow feedback response rates with little overshoot of the setpoint. "Aggr" results in fast response, but much more overshoot. "Moderate" produces intermediate results. "Auto" uses the conservative setting with the step response tuner and the aggressive setting with the relay tuner.

Error codes

Error codes are returned by the "getError" instruction when system.com.verbose is set to "low".

-100 – -199: assembly errors

Produced before the macro starts to run and prevent the macro from starting.

-102: Empty instruction. The instruction consisted of two quotes or parentheses in a row, with no text in between.
-113: Invalid instruction. The instruction was not recognized.
-109: Multiple argument error. Two or more arguments were expected, and the arguments provided did not conform to the types of arguments expected.
-121: Numeric argument error. A numeric value was expected, but a non-numeric argument, or no argument, was provided.
-158: List argument error. The argument must be chosen from a list of possible values, but the argument provided is not in the list.
-180: Too many macros. The maximum number (10) of macros is already running, including the startup macro, macros received from all I/O ports, and macros started from the Program screen. At least one macro must finish before any new macros can be started.
-185: Excessive recursion. A macro may call another macro, which can call another macro, and so on, but only 6 levels of recursion are allowed. This error is always generated if a macro calls itself.
-186: Assembled macro exceeds 1024 lines. When a macro is assembled, all of its subroutine calls are expanded into their component instructions (thus, the assembled macro only contains native instructions). The assembled macro cannot be longer than 1024 lines.

-200 – -299: runtime errors

Produced after the macro starts running. After a runtime error occurs, the macro continues to run.

-221: Locked parameter. The parameter is locked (on the front panel, the control is grayed out) and cannot be changed.
-222: Argument out of range. The argument was a numeric value and was too large or too small.
-224: Bad argument. The argument must be chosen from a list of possible values, and the argument provided is not on the list.
-225: Out of memory. At attempt was made to define a macro, but ten macros are already defined in RAM.

Startup macro

Each time the PTC boots up, it looks for a macro called "Startup". If the macro has been saved in the internal RAM or in a "Macros" folder on an attached USB storage device, it is automatically run.

For example, the following remote command defines a startup macro that displays a message each time the PTC boots up:

```
define Startup(popup "Power has cycled")
```

Sample macros

The sample macros are shown on multiple lines for clarity, but if they are sent to the PTC10 via the RS-232, GPIB, USB, or Ethernet port, each macro must be formatted as a single line, otherwise each line will be treated as a separate macro.

The sample macros can be used as written by saving them to a USB device, as follows:

1. Enter the macro into a text editor such as Notepad. Save the macro as an ASCII text file with the extension ".txt". Copy the file into a directory named "macros" on a USB memory stick or hard drive.
2. Plug the USB stick or drive into the PTC10.
3. Press the PTC10's "System" key. A button with the macro's file name should appear in the "Macros" column. Touch the button to start running the macro. The button remains highlighted as long as the macro is running. Touch the highlighted button to stop the macro.

To make the macro run automatically whenever the PTC10 boots up, enclose the macro in the following statement::

```
define Startup(<macroText>)
```

where <macroText> is the content of the macro. Send the macro over a serial port or run it from a USB stick. The macro won't actually run; instead, a Startup macro is defined that runs each time the PTC10 boots up.

Temperature profiles

The following macro ramps the temperature controlled by channel Out 1 to 100°C at a rate of 1°C/second. Once the ramp is complete, the system pauses for 1 minute at 100°C and then ramps the temperature down to 80°C. After another 1 minute pause, the system is allowed to cool back to room temperature by changing the feedback setpoint to 0 degrees (without ramping). The macro is shown as it would appear if entered from the front panel, with the optional "channel." and "program." prefixes:

```
channel.Out1.PID.ramp 1        ' set the ramp rate
channel.Out1.PID.setpoint 100  ' start a ramp to 100 degrees
program.waitForRamp            ' wait for the ramp to finish
program.pause 1 min            ' wait for 1 minute
channel.Out1.PID.setpoint 80
program.waitForRamp
program.pause 1 min
channel.Out1.PID.ramp 0        ' disable ramping
channel.Out1.PID.setpoint 0
```

The advantage of this macro is that it's easy to enter from the front panel. However, the waitForRamp instruction actually waits for all setpoint ramps to end, whether or not they were started by the macro. Therefore this macro may produce unintended delays if two or more PID feedback loops are ramping at the same time.

A more elaborate version of the macro eliminates this issue by comparing the current value of the ramp (Out1.PID.actual) with the endpoint of the ramp (Out1.PID.setpoint). This macro is shown without the optional "channel." and "program." prefixes:

```
Out1.PID.ramp = 1
Out1.PID.setpoint = 100
while (Out1.PID.actual!=Out1.PID.setpoint) { pause 1 s }
pause 1 min
while (Out1.PID.actual!=Out1.PID.setpoint) { pause 1 s }
pause 1 min
Out1.PID.ramp = 0
Out1.PID.setpoint = 0
```

A third option is to wait for the measured temperature to reach the ramp endpoint:

```
Out1.PID.ramp = 1
Out1.PID.setpoint = 100
while (2A < 99.5 || 2A > 100.5) { pause 1 s }
pause 1 min
Out1.PID.setpoint = 80
while (2A > 80) { pause 1 s }
pause 1 min
Out1.PID.ramp = 0
Out1.PID.setpoint = 0
```

The "pause 1 s" instructions aren't strictly necessary, but reduce the load on the CPU.

Control a feedback setpoint with an analog input

The next macro makes the setpoint of channel Out1 follow the value of analog input 5A. The macro converts the -10V – +10V analog voltage to a temperature between 0 and 100 degrees; another way to scale the analog voltage would be to use channel 5A's offset and gain controls. The contents of the macro are placed in an infinite-repeat block (square brackets followed by a negative number). The "waitforSample" instruction ensures that the block doesn't run any more often than necessary (i.e., once per ADC sample).

```
[
  waitforSample
  if (Out1.PID.Mode==on) {
    #x = #5A
    #x+=10
    #x*=5          ' note: spaces are not allowed before the '*'
    Out1.PID.setpoint = #x
    }
 ]-1
```

The setpoint is only updated when the feedback is turned on. Although not necessary, this precaution keeps the macro from generating run-time errors when the setpoint is locked.

PID input scheduling

This macro selects the input sensor for a PID feedback loop based on a measured temperature. If channel 3A reads less than 50 degrees, channel 3A is selected as the PID input; otherwise, channel 3B is the PID input.

```
[
  pause 1 s
  if (3A<50 && Out1.PID.input==$3B) { Out1.PID.input = 3A }
  if (3A>50 && Out1.PID.input==$3A) { Out1.PID.input = 3B }
]-1
```

In the first conditional statement, the dollar sign before the term "3B" prevents the PTC from converting it to the numeric value of channel 3B.

Show channels with tripped alarms on the Numeric screen

This macro turns selection group 1 into a display of channels with tripped alarms. Once per second, if group 1 is selected, all channels whose alarm mode is "on" are selected; all other channels are deselected. The macro is best used with the Numeric screen visible, but also works with the Select or Plot screens.

```
[
  if (group==1) { selectAlarmed }
  pause 1 s
]-1
```

Make a virtual channel show the PID setpoint

Virtual input channels have a "follow" control that can be used to make the channel echo the value of any other channel. With a macro, the virtual channel can likewise be made to echo any PTC10 parameter — not just channel values. The following macro uses a virtual channel to echo a feedback setpoint. This macro makes it possible, for example, to graph the setpoint on the "Plot" screen alongside other variables, or (using the "Diff" button) to graph the difference between the setpoint and the actual temperature:

```
[waitForSample  V1=#Out1.PID.actual]-1
```

Each time an ADC conversion occurs, this macro sets channel V1 equal to the actual setpoint of channel "Out 1" (if channel Out 1's setpoint is ramping, Out1.PID.setpoint is endpoint of the ramp, while Out1.PID.actual is the current value of the ramp; if the setpoint is not ramping, the two values are the same). Because the macro is contained within a "[…]-1" statement it repeats indefinitely, running as a background task.

Using the "diff" function on channel V1, the difference between the actual temperature and the feedback setpoint can be plotted. This can be helpful for monitoring the accuracy of setpoint ramps.

Linearizing outputs when interfacing with external power supplies

For applications that require more heater power than the PTC10 can deliver, the PTC10's analog outputs can be used to control a programmable power supply. Since the analog input on programmable power supplies usually sets the voltage or current supplied to the heater, the temperature rise of the heater roughly depends on the square of the PTC's output. For example, if a 1 V output increases the temperature by 1 degree over ambient, a 2 V output would increase the temperature by about 4 degrees. Such variation in the "gain" of the feedback system causes sluggish response at low output values and/or feedback oscillations at high outputs. Feedback performance can be made more consistent by linearizing the PID output vs. temperature response curve.

One way to linearize the PID output is to apply a custom calibration table to the output channel (see page 32 for a description of how to make and upload calibration tables). In this case, the calibration table is a file containing comma-separated data in the format "X1, Y1, X2, Y2, …", where Xn is the analog output, in volts, to be produced when the PID algorithm requests output

Yn. To produce such a table experimentally, set the analog output to a series of different voltages. At each analog IO voltage Xn, measure the temperature Yn at which the system stabilizes.

Another way to linearize the PID output is by using a macro to apply a simple equation to the PID output. Use a virtual channel, for example channel V1, to host the PID feedback loop. Set the IO type of channel V1 to "Meas out", then configure channel V1's PID loop with the appropriate input sensor and temperature setpoint. Set the IO type of analog I/O channel 5A to "Set out" or "Meas out" and disable channel 5A's PID feedback loop. Next, run the following macro, which sets channel 5A to the square root of channel V1 each time an ADC conversion occurs.

```
[
  waitForSample
  #x = #V1
  #x^=0.5
  5A = #x
]-1
```

Control instrument functions with the digital IO lines

This macro enables the feedback for channel "Out 1" whenever bit 0 of the digital I/O is high, and disables the feedback whenever the bit is low. The program runs indefinitely.

```
' start with the feedback turned off
Out1.PID.mode = off

' this loop repeats indefinitely
while (1) {
  ' wait for DIO bit 0 to go high, then turn feedback on
  while (DIO & 0x01 = 0) { pause 0.25 s }
  Out1.PID.mode = manual

  ' wait for DIO bit 0 to go low, then turn feedback off
  while (DIO & 0x01 = 1) { pause 0.25 s }
  Out1.PID.mode = off
}
```

The next macro lets DIO bit 1 control which temperature sensor serves as the input for channel Out 1's feedback loop:

```
[
  #x = DIO
  #x &= 2

  ' if bit 1 is clear and the PID input channel is not 3A,
  ' set the PID input channel to 3A
  if (#x==0 && Out1.PID.input!=$3A) { Out1.PID.input=3A }

  ' if bit 1 is set and the PID input channel is not 3B,
  ' set the PID input channel to 3B
  if (#x==2 && Out1.PID.input!=$3B) { Out1.PID.input=3B }

  pause 0.25 s
]-1
```

Within an "if" or "while" statement, the "$" prefix prevents the following text from being treated as a query. If the $ prefix were left out, the statement would attempt to compare the name of the PID input channel to the value of channel 3A, rather than to the string "3A".

Drive a solid state relay with the digital IO lines

In some high-power applications, the current to a heating or cooling unit is provided by an external power supply and modulated with an external solid state relay (SSR). To modulate the heater or cooler power and obtain accurate temperature control, a variable duty cycle square wave, similar to pulse width modulation but typically with a much longer cycle time, is required from the PTC10. For example, to supply half of the maximum power to the heater, the PTC10 would need to turn the relay on for 5 seconds, off for 5 seconds, on for 5 seconds, etc.

The following procedure transforms the output of a PID feedback loop into a variable duty cycle square wave that can be output on the PTC10's digital IO lines and used to drive a solid state relay. The macro works well as long as a period of about 10 seconds or longer and a resolution of 0.1 seconds is acceptable. If a much shorter period or greater resolution is needed, it would be better to fabricate an external analog-to-PWM circuit and drive it with an analog I/O channel.

First, make channel V1 the feedback output, and make it produce a value between 0 and 100. To do this, select channel V1 and set the following parameters:

- Low lmt: 0
- Hi lmt: 100
- IO type: Meas out
- PID input: select the temperature channel that you'd like to control
- PID mode: set this to "off" for now
- PID setpoint: set this to the desired temperature

Next, select channel DIO and set the following parameters:

- IO type: set out
- PID input: should be blank; or, the PID mode should be off.

Now run the following macro by sending it over a serial port (in which case it all has to be on one line) or by copying it onto a USB stick (save it as a .txt file in a directory named "macros"):

```
[
  waitForSample
  #d = 0
  if (#V1>#t) { #d = 1 }
  DIO = #d
  #t += 1
  if (#t>100) { #t = 0 }
 ]-1
```

To test the macro, set V1's value to 50 and plot channel DIO. You should see a square wave with a duty cycle of 50% and a period of 10 seconds: high for 5 seconds, low for 5 seconds, high for 5 seconds, etc. Reduce V1 to 25 and the duty cycle should go to 25%.

Before the feedback can be used, the PID gain factors will need to be set by using the automatic tuning feature on channel V1. If tuning is successful, the feedback should now operate normally.

If more than one feedback loop is required, set up channels V2 and/or V3 as described for channel V1, and add these lines after the { #d = 1 } statement:

```
  if (#V2>#t) { #d+=2 }
  if (#V3>#t) { #d+=4 }
```

The macro can automatically run every time the PTC10 is turned on; just send the command "define Startup (…)", replacing the … with the macro contents.

PC applications

SRS offers a package of PC applications for displaying PTC10 logfiles and converting them to ASCII . The package can be downloaded free of charge from the SRS website at www.thinksrs.com; click on Downloads > Software. Once unzipped, the applications can be run by double-clicking the .exe icons or dragging PTC log files to the .exe icons. It is not necessary to run an installation program.

PTCFileConverter

PTCFileConverter is a Windows utility that converts one or more binary PTC log files into a single text file that can be imported by popular application software. It can also downsample log files to make large files more manageable.

Double-click the program icon to open the setup window, which has six input fields and two buttons. Once the fields have been filled in, files can be converted by clicking the "Start" button. Or, click the "Close" button and then drag one or more files onto the PTCFileConverter icon. In this drag-and-drop mode, the setup window is not displayed and the files are immediately converted using the most recently-saved settings (the "Input folder or file" setting is ignored).

Input folder or file

Select the PTC log file or files that you'd like to convert. If you select a directory, when the "Start" button is pressed PTCFileConverter will convert all PTC log files in the directory (but not in its subdirectories) and combine them into a single output file.

Files that do not contain any data (empty PTC log files or files that are not PTC log files) are ignored and do not appear in the output file.

Output file

If a Text or HTML output format is selected, this field determines the name of the output file. If you do not specify a directory, the output file will be saved in the same folder as the input file. If you do not specify an extension, ".txt" or ".html" will be appended to the file name when the file is saved.

If Binary output format is selected, this field determines the output folder. The output files are saved to this folder and have the same name as the input files. The output folder must be different from the input folder.

Output format

The converted data can be saved as a text file, an HTML file, or a binary file. In either case, the output is a table with a timestamp column plus one column per channel, and one line per sampling period. Text files can be saved with a tab, comma, or space between the entries on each line.

HTML files are useful because they are easily viewed and are also easily imported into many application programs; however, this format should only be used for short datasets (less than a thousand points) because HTML browsers are very slow when displaying large tables. Within an HTML table, the first cell of each record (see "Log File Structure", above) is highlighted in yellow, indicating that either 1) the logging rate was changed; 2) the sensor was disconnected for at least 100 log points and then reconnected; or 3) logging was stopped and restarted.

If the "Binary" output format is selected, the output files are written in the PTC log format (the same format as the input files). Use this format if you'd like to open resampled files in FileGrapher. One output file is produced for each input file, and the output files have the same names as the input files. Use the "Output file" field to specify the directory in which the output files should be saved (since they have the same names, the output files must be saved in a different directory than the input files). The Timestamp setting is ignored when binary output files are produced.

Timestamp

When converting data to a text or HTML file, this setting determines how the time of each data point is recorded:

- "Date and Time" records the time to the nearest second in the format "March 26, 2015 6:43:11 PM".
- "Milliseconds since 1970" is a single 64-bit decimal value that indicates how many milliseconds have elapsed since midnight on January 1, 1970.
- "Elapsed seconds", "Elapsed minutes", "Elapsed hours", and "Elapsed days" record the time as a single floating-point value that indicates how much time has elapsed since the first point in the log.

Resample

Check the "Resample" box to allow PTCFileConverter to downsample or upsample log files. If "Resample" is checked, PTCFileConverter either averages points together or duplicates points so that the log rate of the output file is the value set in the "Resample period" field. For example, if the input log has one point per second and the "Resample Period" is set to 10 seconds, checking the "Resample" box produces an output file in which each point is the average of 10 input points.

Gaps between logfile records (see "Log File Structure", above) are not resampled. Therefore, if the instrument was turned off in the middle of a log, or a sensor was unplugged for more than 100 data points, the gap in the log file remains even after resampling.

PTC log files with a large number of data points can be cumbersome to display and often cannot be imported into application programs. The resample feature is useful for reducing the number of data points in the output file. In addition, different PTC channels can be logged at different time intervals and it's often useful to resample the data so that data points appear at the same interval for all channels.

Resample period (seconds)

If the "Resample" control is checked, the "Resample period" field controls how many seconds each line of data in the output file represents. If the "Resample" control is not checked, the "Resample period" field has no effect.

Start

Press the Start button to begin the conversion.

Close

Press the Close button to save all settings and close PTCFileConverter.

Clicking the "X" button in the upper-right corner of the window closes the program without saving any settings.

FileGrapher

FileGrapher is a Windows utility that plots PTC log files.

To plot a file, either drag a PTC log file onto the File Grapher icon or double-click the FileGrapher icon and then select "Open" from the "File" menu. Once the file has been plotted, a file selection window appears that shows all of the PTC files in the same directory as the plotted file.

Click on a file in the file selection window to plot it. Shift-click or Control-click to plot two or more files at the same time. The first file listed in the selection window always appears as a black trace; the second file is always red, the third blue, the fourth orange.

To zoom in on a graph, draw a rectangle around the area that you'd like to zoom in on. To zoom out to the previous zoom area, double-click on the graph. Triple-click on the graph to show all data.

When FileGrapher opens a file, it reads the entire file into a buffer in RAM. Very large files may not fit in the program's memory or may take a long time to load and display. If this occurs, use PTC File Converter to downsample the file before opening it with FileGrapher.

File menu

Open

Opens a directory for plotting. All PTC files in the directory are shown in the selection window and the selected file is plotted. All unsaved changes to data in the old directory are lost.

Close

Closes the selected directory. All unsaved changes to data are lost and the selection window closes.

Save GIF

Saves the graph as a GIF file.

Save data

Saves a trace as a text file or a binary (.ptc) file. See the PTC File Converter documentation for more information on data saving options.

Exit:

Quits the program.

Edit menu

Items in the Edit menu may affect how data buffers are graphed, but do not affect the contents of the buffers.

Plot options

Opens a window that controls the appearance of the graph. Click "Apply" to update the graph with the new settings; "OK" to update the graph and close the window; "Cancel" to undo all changes since the last time the graph was updated and close the window.

- **Automatically scale X**: if checked, the graph is automatically scaled to show the full time span of the data.
- **X minimum**: if "Automatically scale X" is checked, this box indicates the time at the left-hand edge of the graph; any values entered here by the user are ignored. If "Automatically scale X" is not checked, the time entered here determines the time at the left-hand edge of the graph.
- **X maximum**: if "Automatically scale X" is checked, this box indicates the time at the right-hand edge of the graph; any values entered here by the user are ignored. If "Automatically scale X" is not checked, the time entered here determines the time at the right-hand edge of the graph.
- **Automatically scale Y**: if checked, the graph is automatically scaled to show the full vertical span of the data. The graph is automatically rescaled as necessary whenever the data is modified.
- **Y minimum**: if "Automatically scale Y" is checked, this box indicates the lower limit of the graph; any values entered here by the user are ignored. If "Automatically scale Y" is not checked, the value entered here determines the lower limit of the graph.
- **Y maximum**: if "Automatically scale Y" is checked, this box indicates the upper limit of the graph; any values entered here by the user are ignored. If "Automatically scale Y" is not checked, the value entered here determines the upper limit of the graph.
- **Suppress X axis label**: if checked, the graph's X axis is not labeled. This option is intended for use when two or more graphs with the same X range are stacked on top of each other.
- **Number of X divisions**: controls the number of vertical gridlines. The value entered is approximate; the program may draw slightly more or fewer gridlines in order to put the gridlines on round time values.
- **Number of Y divisions**: controls the number of horizontal gridlines. The value entered is approximate; the program may draw slightly more or fewer gridlines in order to put the gridlines on round Y values.
- **Y axis label**: The text entered here is displayed to the left of the graph.
- **Annotation**: The text entered here is displayed inside the plot area. Enter the string "<names>" to display a list of the plotted files, each shown in the color in which it is plotted.
- **Annotation position**: Controls where on the plot the annotation appears.

The following options appear when the "More options" button is clicked:

- **Subtract baseline**: if checked, "baseline" data is subtracted from every plot in the graph. To set the baseline data, display a graph and select "Set as baseline" from the Edit menu.
- **Subtract average**: if checked, each trace is offset such that its average value is 0.
- **Y offset between traces**: can be used to separate traces that are on top of each other. One times this constant is added to trace 2; two times this constant is added to trace 3; three times this constant is added to trace 4; and so on.
- **Colors**: the colors used in the graph can be defined in this section. Each color is a set of three numbers between 0 and 255 for red, green, and blue brightness. Enter "255,255,255" (without the quotes) for white and "0,0,0" for black.
- **Show tick marks**: some data files can include "tick marks" to mark events. If the "show tick marks" box is checked, the tick marks are shown as small spikes in the graph.
- **Antialias**: if checked, the plot is drawn with antialiased lines. This improves the appearance of the graph but also significantly increases the amount of time that it takes to draw the graph.

- **Axis linewidth**: the width of the box surrounding the plot, in pixels.
- **Grid linewidth**: the width of the plot gridlines, in pixels.
- **Plot linewidth**: the width of the plot traces, in pixels. Values other than 1 may significantly increase the amount of tie that it takes to draw the graph.

Show statistics

Shows information such as the average, minimum, and maximum values for all data within the graph's X range. Only information for the buffer plotted in black is shown.

Linear regression

The linear regression feature can be used to determine how much one temperature sensor is miscalibrated compared to another. You are asked to choose an X and a Y buffer (the log files for two different temperature sensors). The software then determines the offset and gain of the X buffer relative to the Y buffer. Check the "Apply equation to X buffer" box to multiply the X buffer by the gain factor and then add the offset.

Command line

Opens a File Grapher command line window. The commands described in the table below can be typed into the command line. Sequences of commands can be stored as macros and then recalled either from the command line or the Special menu.

Align X axes

Sets the X axis range of all graphs to be equal to the X axis range of the selected graph.

Add graph

Adds another graph to the display. When more than one graph is displayed, you can select a graph by clicking on it. Most operations only apply to the selected graph.

Overall plot size

Changes the size of the entire plot window and all the graphs in the window.

Set as baseline

When this option is selected, the channel that is currently displayed becomes the baseline and is subtracted from all displayed data. Selecting this option does not modify the data in any way, just the way the data is displayed.

Clear baseline

Disables the baseline feature. This option is grayed out if no baseline is currently set.

Subtract average

When selected, each file's data is displayed with its average subtracted. Selecting this option does not modify the data in any way, just the way the data is displayed.

Process menu

The process menu lets you modify data. The operations are applied to an internal copy of the data (i.e., a buffer) and do not affect log files on disk. When you select an item from the process menu, a dialog may appear asking which of the currently-plotted buffers you'd like to apply the operation to.

Add buffer

Adds two buffers together. You're asked to select two buffers from among the buffers that are currently plotted: the buffer to be modified (buffer 1) and the buffer to add (buffer 2). When you click "Apply" or "OK", each point in buffer 1 is added to the first point in buffer 2 that has a time equal to or greater than the time of the point in buffer 1.

Subtract buffer

Subtracts one buffer from another.

Multiply by buffer

Multiplies two buffers together.

Divide by buffer

Divides one buffer by another.

Add constant

Adds a constant to each point in a buffer. You're asked to select one of the currently-plotted buffers and to provide a numeric value. When you click "Apply" or "OK", the value is added to each point in the selected buffer.

Subtract constant

Subtracts a constant from each point in a buffer.

Multiply by constant

Multiplies each point in a buffer by a constant.

Divide by constant

Divides each point in a buffer by a constant.

Kelvin to Celsius

Assuming the contents of a buffer are expressed in Kelvins, converts the data to °C.

Celsius to Kelvin

Assuming the contents of a buffer are expressed in °C, converts the data to Kelvins.

Celsius to Fahrenheit

Assuming the contents of a buffer are expressed in °C, converts the data to °F.

Fahrenheit to Celsius

Assuming the contents of a buffer are expressed in °F, converts the data to °C.

Align start time

Shifts one buffer in time so that its earliest time matches the earliest time of another buffer. Useful for comparing results from two different experiments.

Average plotted buffers

Replaces the contents of whichever buffer is plotted in black with the average of all plotted buffers.

Copy

Creates a new buffer that contains a copy of all data from an existing buffer.

Crop

Creates a new buffer that contains a copy of data from an existing buffer. Only points that falls within the graph's X range are copied.

Derivative

Replaces each data point with the difference between it and the succeeding point.

Downsample

Reduces the number of points in a buffer by averaging two or more neighboring points together and storing the result in a single point. You're asked to provide a "downsampling constant", which is the number of neighboring points to average together. A downsampling constant of 3, for example, reduces the number of points in the buffer to one-third of its previous value.

Lowpass

Removes noise by replacing each data point with a weighted average of all data acquired before the point. This filter emulates an analog RC lowpass filter and is similar to the PTC's lowpass filter except that it's first-order rather than sixth-order.

Median filter

Removes single-point noise spikes with a sliding-window median filter. The filter replaces each data point with the median value of itself, the previous point, and the next point.

Normalize

Subtracts a constant from a buffer, then multiplies the buffer by another constant, such that the minimum value in the buffer is zero and the maximum value is one.

Revert to saved

Re-loads a buffer from disk, discarding the effects of all operations performed with the Process menu.

Smooth

Removes noise using a sliding-window Gaussian filter. Smoothing replaces each data point with a weighted average of data acquired before, during, and after the point.

Subtract average

Subtracts the average value of a buffer from all data points in the buffer.

Subtract initial

Subtracts the value of the first point in a buffer from all data points in the buffer.

Subtract slope

Subtracts the overall slope from a buffer.

Undo

Undoes the last operation performed with the Process menu.

Special menu

This contents of this menu are defined in the file Resource\SpecialMenu.rsc. Each item in the menu is the name of a macro which is located in the Resource directory.

Small plot size
Displays a single graph in a 200 x 375-pixel window.

Medium plot size
Restores the default single graph in a 294 x 486-pixel window.

Large plot size
Displays a single graph in a 600 x 1000-pixel window.

Add small header
Adds a 50-pixel-tall graph with no X axis labels above the current graph**.**

Add large header
Adds a 100-pixel-tall graph with no X axis labels above the current graph.

Remove headers
Removes all graphs except for the bottom graph.

Command line and macro instructions

Instruction	Description
add "*buffer1*", "*buffer2*"	add two buffers: buffer1 = buffer1 + buffer2
addGraph[b] 350	add a new graph to the display; specify height; option b=put new graph below current graph
addx "*buffer*", 0.0	add constant: buffer = buffer + constant
alignAll	align the start times of all buffers
annotation "*annotation*"	draws an annotation in the corner of the graph specified with annotationPosition
annotationPosition "*position*"	sets the position of the annotation to "top left", "bottom center", etc.
antialias on/off	set antialiasing on or off; off by default
autoscale[XY] on/off	sets automatic X and Y axis scaling on or off; on by default
axisDivisions 4,4	set the number of X and Y grid lines
break[Pos][Neg] "*sourceBuffer*", "*resultBase*"	break buffer at marks [positive/negative marks only]
cp[n] "*buffer*" [, "*buffer2*",...]	clear the plot, then plot the indicated *n* buffers
clearMark 1	clears the indicated mark (use drawMarks to see mark numbers)
clearMarks	clears all stored marks
clearPlot	remove all buffers from the plot
copy "*sourceBuffer*", "*destinationBuffer*"	make a copy of a buffer
crop "*sourceBuffer*", "*destinationBuffer*"	crop sourceBuffer to the time segment currently visible on the plot
directory "*directoryName*"	set the current directory
div "*buffer1*", "*buffer2*"	divide one buffer by another: buffer1 = buffer1 / buffer2
diva "*buffer1*"	divide a buffer by its average
divx "*buffer*", 1.0	divide by constant: buffer = buffer / constant
drawMarks	draws a vertical red line on the plot at the location of each stored mark
fontSize 10	set the size of the font used to label the graph axes
hideMarks	hide tick marks
level "*buffer*"	subtract the average slope from a buffer
linewidth[pga] 1	set the width of the plot (option p), grid (g), and/or axis (a) lines in pixels
load "*buffer*", "*fileName*"	load a file into a new buffer; specify a name for the buffer and the name of the file to load
lowpass "*buffer*", 1.0	lowpass-filter a buffer; specify the time constant in seconds
markLevel "*buffer*", 1.0, 1.0	stores marks that indicate when the specified buffer enters a level plus or minus a tolerance
median "*buffer*"	median filter a buffer
moveMark 1, 0.0	moves the indicated mark (use drawMarks to see mark numbers) forward 0.0 seconds
mpy "*buffer1*", "*buffer2*"	multiply two buffers: buffer1 = buffer1 * buffer2
mpyx "*buffer*", 0.0	multiply by constant: buffer = buffer * constant
norm "*buffer*"	normalizes a buffer, i.e. performs linear scaling such that all y values are between 0 and 1

normAll	normalizes all buffers
plot[*n*] "*buffer*" [, "*buffer2*",...]	add the current contents of *n* buffers to the plot
plotAll	clear plot, then plot all currently-existing buffers
remove "*buffer*"	delete a buffer
removeAll	delete all buffers
removeGraph	remove the currently-selected graph
removeTrace *traceColor*	remove a trace from the plot, by plot color (black, red, blue, orange, green, or cyan)
rep	replot the currently-plotted buffers, reflecting all changes made since the last plot
rev "*buffer*"	revert to last-saved version
riseStats[column] "*buffer*"	display rise statistics for a buffer; "column" option defines columns
roundYAxis on/off	if set to on, automatically-scaled y axes will be set to a round number of units; off by default
saveData "*buffer*", "*fileName*"	save a buffer as a text file
savePlot "*fileName*"	save the current plot as a GIF in the current directory
selectGraph 0	selects the indicated graph; 0=first graph to be added, 1=second graph, etc.
selectionWindow[add/remove] "*buffer*"	add or remove a graph from the graph selection window
setDefaultBounds	sets the current size and position of the FileGrapher window as the default
setMarks[Pos][Neg] "*buffer*"	store [positive/negative] marks from the specified buffer (for use with break and riseStats)
setSize 500,350	set the x and y size of the plot in pixels; -1 = no change
showBuffers	list names of all currently-existing buffers
showMarks	show tick marks on all plotted buffers
smooth "*buffer*", 0	apply a Gaussian smoothing filter; specify radius in data points
sub "*buffer1*", "*buffer2*"	subtract two buffers: buffer1 = buffer1 - buffer2
subx "*buffer*", 0.0	subtract constant: buffer = buffer - constant
suba "*buffer*"	subtract average: buffer = buffer - ave(buffer)
subi "*buffer*"	subtract initial: buffer = buffer - buffer[0]
undo "*buffer*"	undoes the last operation that modified the indicated buffer
wave "*buffer1*", "*buffer2*", 1.0	weighted average: buffer1 = (buffer1 + buffer2*weighting factor) / (1 + weighting factor)
xLabel "*state*"	Sets the X-axis label to "date*Time*" (date and time), "elapsed*Time*" (elapsed time), or "off" (none),
yLabel "*text*"	Label the Y axis of the graph with the indicated text

Circuit description

Each of the PTC10's circuit boards has a 4-digit model number, i.e. "PTC2104". The first number indicates the general type of board (2=core system board, 3=input card, 4=output card, 5 = input and output card). The second and third numbers indicate the specific type of board. The last number, which is sometimes omitted, indicates the revision.

Core system cards

PTC211 CPU board

The CPU (U102) is a Motorola ColdFire running at 90 MHz. The ColdFire's 32-bit data bus is directly connected to 16 MB of SDRAM (U201) and to an expansion connector (J202) used for the GPIB option. All remaining bus components only use the upper 16 data bits and are connected to the CPU through a set of transceivers (U520, U530, U540) to avoid overloading the ColdFire's bus drivers, which can drive a maximum of 50 pF.

A 4 MB flash chip (U202) stores the PTC10's software. When the instrument is first switched on, a bootloader program copies the firmware from flash into SDRAM, after which the flash is no longer used. 512 kB of SRAM (U204) with battery backup holds all user settings; if the battery fails, all user settings revert to their default value.

A jumper, J201, can be installed to prevent the part of flash memory that contains the bootloader from being overwritten. As long as the bootloader is present, the flash can be reprogrammed through the serial port. If the bootloader is somehow erased, the card must be reprogrammed at the factory.

The LCD controller (U401) contains the PTC's video memory and generates drive waveforms for the LCD display. Because the LCD display must be driven with +5V signals, while the LCD controller produces +3.3V signals, a 3.3-to-5 V level translator is provided. Also on the ColdFire's data bus are the Ethernet and USB host/device controllers (U440 and U600).

Voltage supervisor U101 resets the ColdFire if the +3.3V supply voltage drops below 3.1V or if the reset button (S101) is pressed. The supervisor also provides battery power to the SRAM and prevents the SRAM chip select from going low when power to the rest of the card is shut off.

Other components on the CPU card include a real-time clock (which runs off of battery power when the PTC is switched off) and transceivers that interface the ColdFire to the backplane bus. The EEPROM and battery monitor circuits are not used. The CPU card has an RS-232 transceiver which is only used for updating the firmware and for debugging; the RS-232 transceiver for user communications is on the backplane board.

PTC221 backplane

The backplane contains a proprietary parallel bus that connects the CPU card to the six I/O cards and the front panel. The bus has four wide and two narrow I/O card slots. Except for their width, all six slots are equivalent.

The backplane also includes +5V and +3.5V switching power supplies for the PTC's digital components. A 1.8V digital supply is available but not used. +8, +20, and -20V switching supplies provide power for most of the PTC's low-noise analog circuitry. Jumper J203 connects the analog supply ground to the system ground; if removed, the analog supplies operate with a floating ground.

A circuit is available (U201, U202) to synchronize the switching frequency of the various switching supplies with each other, potentially reducing noise. The circuit is normally not used since it doesn't have a noticeable effect on noise levels.

An AC power bus (J100–J104) distributes 120 or 220VAC power to any PTC420 AC output cards that are installed. The AC power connectors have a lifetime of 25 mate/unmate cycles.

Connected to the AC bus is a line trigger circuit that synchronizes the A/D sampling (actually the CONV* signal; see the description of pin C18 below) with the 50 or 60 Hz line frequency. If this circuit fails, the PTC may become unresponsive. Jumper J160 can be used to synchronize the

CONV* signal to a 1 MHz clock instead of the line frequency; in this case, the A/D sampling period can be set to any integer multiple of 1 µs rather than being limited to an integer multiple of the line period, but 60 Hz interference is inevitable. Jumper J160 should not be moved while the PTC is turned on.

The pinout of the I/O card connectors on the backplane bus is described below. The pin numbers and some pin names are printed next to each I/O card's backplane connector.

Power

A31–A32: 8V. An analog supply used to generate +5V.
B31–B32: +20V. An analog supply used to generate +15V.
C31–C32: -20V. An analog supply used to generate -15V.
A29–A30, B29–B30, C29–C30: AGND. Ground for the analog supplies. May be floating relative to digital ground.
A27–A28: +3.3V. Powers the ColdFire CPU and other components on the CPU card.
B27–B28, B12–B22, A3, A12, A14, A18, B3, C3, C19: DGND. Ground for the +3.3V and +5V supplies.
C27–C28: +5V. Powers the Atmel microcontrollers and all other digital components on the I/O cards.
A25–A26, B25–B26, C25–C26: +24V. Connects directly to the PTC10's 24V "brick" power supply. Used for all high-current outputs.
A23–A24, B23–B24, C23–C24: 24VR. Ground return for the +24V supply.
A1, A2, B1, B2, C1, C2: 24VGND. Ground for +24V.

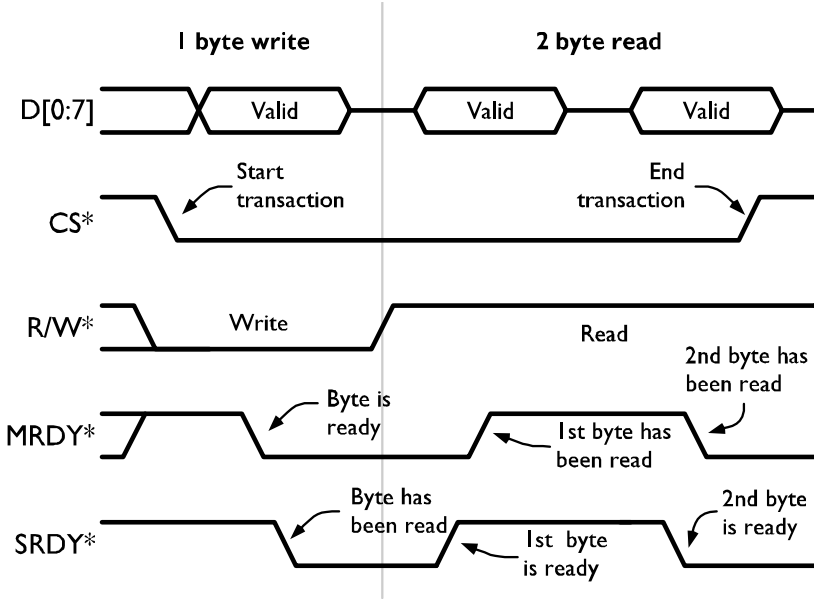
Parallel bus

This proprietary 8-bit data bus is used for communication between the CPU card and I/O cards.

A4–A11: ADD[0:7]. The address lines. ADD0–ADD3 are used to select a specific card. ADD4–ADD7 are not used.
A13. CLK (Clock). A 16 MHz clock signal used for the Atmel microcontrollers.
A15: RESET*. When pulled low, the Atmel microcontrollers on all I/O cards are reset, regardless of whether or not CS* is active. Used to upload firmware onto the microcontrollers.
B4–B11, C4–C11: D[0:15]. The data lines. Only D0–D7 are currently used.
C13: CS* (Card Select). Each I/O card has its own active-low select line. An address decoder on the backplane decodes a 4-bit address provided by the CPU and pulls the appropriate select line low. Addresses 0–5 select the I/O cards; 6 selects the front panel; 7 is not used; and addresses 8 and above select none. When low, the I/O card can send and receive messages from the CPU, during which time the card stops all other activity.
C14: SRDY* (Slave Ready). The I/O card inverts the state of this line after reading data or placing data on the bus. Each bus transaction starts with SRDY* in a high state.
C15: MRDY* (Master Ready). The CPU inverts the state of this line when it places data on the bus (in write mode) or after it has read data (in read mode). Each bus transaction starts with MRDY* in a high state.
C16: R/W* (Read/Write). If high, the selected I/O card takes control of the data lines. If the CPU holds the R/W* line high when CS* is pulled low, the I/O card immediately sends its most recent reading from each channel. Otherwise, the I/O card waits to receive data from the CPU.

C17: SIZ16* (Transfer size 16). Can be used to enable 16-bit data transfers. Currently not used.

C18: CONV* (Convert). A rising or falling edge on this line puts the I/O card into a "standby" state for 5 ms, during which the I/O card is inactive. The CPU card normally requests the I/O card's ADC readings during this period. 5 ms after the falling edge, the I/O card exits the standby state and begins an ADC conversion. If it does not receive the CONV* signal, the I/O card never performs any ADC conversions.



Parallel bus timing diagram. For simplicity only a 1-byte write and 2-byte read are shown, but reads and writes generally transfer at least 3 bytes each.

SPI bus

The SPI bus is used to reprogram the Atmel microcontrollers on the I/O cards. The card's Card Select (CS*) line must be pulled low for its SPI bus to be active.

C20: SCK (SPI Clock).
C21: MOSI (Master out, slave in).
C22: MISO (Master in, slave out).

UART

Connected to the PTC10's back-panel RS-232 port. The I/O cards do not use and are not connected to the backplane UART.

A19: CTS (Clear to Send).
A20: RTS (Request to Send).
A21: RXD (Receive Data).
A22: TXD (Transmit Data).

PTC231 front panel

The front panel connects to the same backplane bus as the I/O cards. An Atmel ATmega162 microcontroller on the front panel PCB detects touchscreen touches and button presses, controls the system fan, generates sounds, and manages the LCD power supplies.

All sounds are generated by the Atmel microcontroller and output as an 8-bit, 60 kHz PWM signal. The speaker driver amplifies this signal, providing 250 mW of power to drive the speaker.

Touchscreen and button presses are detected by touchscreen controller U201, which is connected to the microcontroller with an SPI interface. The Atmel microcontroller automatically plays "click" sounds and illuminates the front-panel LEDs (except for the Output Enable LED) when the buttons or touchscreen are pressed.

The LCD display is illuminated by three strings of built-in LEDs. The LCD backlight supply has three independent constant-current sources that each produce 62.5 mA of current to power one string of LEDs. The BACKLIGHT_ON* signal is driven by one of the Atmel microcontroller's PWM outputs. The LCD display can be dimmed by rapidly switching the backlight LEDs on and off.

The fan driver converts a PWM signal from the Atmel microcontroller into a constant-current output. The microcontroller can vary the fan speed by changing its PWM output. The front panel has provisions for a fan tachometer that are currently not used.

The RS-232 port is provided for debugging and is not used.

PTC240 GPIB card

The GPIB interface is based on a National Instruments TNT4882 GPIB chip. Since the GPIB chip uses a +5V supply, while the other CPU bus components use a +3.3V supply, 5V-tolerant transceivers are needed to interface the chip with the CPU bus. A glue logic chip, U160, resolves incompatibilities between the GPIB's data bus and the CPU bus.

I/O cards

All I/O cards include an Atmel ATmega microcontroller (U110). The microcontroller has onboard flash and SRAM, and is configured to use an external 16 MHz oscillator located on the PTC's backplane. The microcontroller controls the ADCs or DACs on each I/O card.

Each card has a status LED that mirrors the state of the backplane CONV* signal, toggling each time an ADC conversion occurs. If the status LED does not blink while the PTC is running, or does not blink at the same rate as the status LEDs on other I/O cards, the card has a hardware or software problem.

Each card is calibrated at the factory, and the microcontroller's built-in EEPROM holds the card's calibration data. Input cards produce calibrated readings in the "native units" of the sensor; for example, the RTD card provides calibrated resistance readings, while the thermocouple provides calibrated voltage readings. The CPU card converts these readings to temperatures using calibration data for the particular sensor. Output cards provide calibrated outputs in watts.

The microcontroller is interfaced to the backplane bus with a transceiver (U120). An RS-232 port is available but is only used for debugging. The backplane bus uses a proprietary synchronous communication protocol.

PTC320 1-channel thermistor/diode/RTD reader

The card measures the resistance of thermistors and RTDs by passing an excitation current through both the sensor and a reference resistor in series with the sensor. An ADC measures the ratio between the sensor and reference voltages.

Diodes are measured with a similar technique, except a standard 5V reference is used instead of the reference resistor.

Variable current source: generates the excitation current. A 10V reference (U610), resistor ladder, and 8:1 multiplexer (U620) produce one of eight voltages: 0 mV, 100 mV, 200 mV, 500 mV, 1 V, 2V, 5V, or 10V. Op amp U650A provides the excitation current, keeping the voltage across a sense resistor equal to the selected voltage. Multiplexer U630 selects one of three sense resistors (1 kΩ, 100kΩ, or 10MΩ). The voltage across the sense resistor is measured by a unity-gain instrumentation amplifier (U660, U670 U680).

Fixed 10 µA current source: generates a high-accuracy excitation current for diode sensors. Voltage reference LT1027 maintains a 5V potential across R642, thereby producing the 10 µA current. Op amp U650B provides a virtual ground for the reference; the virtual ground voltage is the same as the voltage at the bottom of R642. Zener diode D641 prevents this voltage from exceeding 5V, which is the maximum value that can be read by the ADCs.

Reference resistors: Mechanical relays are used to select one of eight reference resistors. Mechanical relays are needed because the input protection diodes of semiconductor switches would leak current between the signal and reference resistors, producing unacceptable errors.

When reading diode sensors, the excitation current still passes through a reference resistor, although the reference resistor voltage is not actually used. In this case, the lowest-resistance reference is selected.

Select current source and forward/reverse current: Multiplexer U230 controls the direction of current flow through both the temperature sensor and the reference resistor.

ADC input buffers: These FET-input op amps isolate the signal and reference resistors from the current produced or drawn by the ADC input pins. The buffers are equipped with RC networks that allow them to drive 1 µF capacitors.

Compensate for current direction: When reverse current is selected, a multiplexer ensures that the voltage at the ADC's REF+ pin is more positive than the voltage at the REF- pin. The multiplexer creates a significant voltage drop (because the ADC's REF+ and REF- pins draw a few microamps of current). To compensate for this voltage drop, the feedback network of each ADC input buffer is connected through the multiplexer to a point as close as possible to the actual ADC input pins.

ADC: a 24-bit, delta-sigma ADC, the LTC2440's input range is -0.5·Vref – +0.5·Vref, where Vref is the difference between the voltages at pins ref+ and ref–.

Heater driver: this feature is not used.

Ambient temperature sensor: this feature is not used.

PC board temperature sensor: used to compensate for thermal drift. Each PTC320 is calibrated at 25 and 35 °C. Based on the PC board temperature reading, the PTC320 interpolates between these two calibrations.

PTC321 4-channel RTD reader

The PTC321's analog components are powered by the backplane's +8, +20, and -20V analog supplies. These supplies are regulated to +5, +15, and -15V, respectively, with on-card regulators U650, U660, and U670.

The PTC321 has four identical input channels. Considering only channel 0, op amp U230A provides a 1 mA excitation current, while switch U251 controls the direction of the excitation current through the sensor.

The excitation current passes through switch U251, which is somewhat prone to static damage, then a lowpass "T" filter intended to prevent static damage and reduce high-frequency noise. The current passes through the sensor (connected to J200) and a precision reference resistor, R200. The current then passes through another "T" filter, through switch U251 again, and then to ground. Four voltages are provided to the ADC's inputs, one from each end of the sensor and one from each end of the reference resistor. Each voltage is passed through a "T" filter. Diodes D201-4 prevent excessive voltages from damaging op amps U260A-D (U251 is similarly protected by built-in diodes). The chopper-stabilized op amps U260A-D buffer the voltages, which is necessary to prevent ADC glitches and to prevent the ADC from injecting change between the RTD and reference resistor.

The ADC, U290, outputs a numeric value that indicates the ratio between the signal and reference resistances. Since the reference resistance is known, the signal resistance can be calculated. The accuracy of the PTC321 therefore depends on the stability of resistor R200.

To reduce noise, the analog section is isolated from the digital section with optoisolators ISO610, IOS611, and ISO630. SPI-to-parallel converter U640 has four outputs (ANA_CS0*–ANA_CS3*) that select one of the four ADCs for SPI communication, and four outputs that control the current direction of each channel. The BUSY signal of channel 0's ADC, which is high whenever an ADC conversion is occurring, is passed to the microcontroller through an optoisolator; without this signal, the microcontroller may freeze up.

An Atmel ATmega64 microcontroller receives data from the ADCs and applies a temperature-dependant, 4-coefficient polynomial calibration. Temperature sensor U720 monitors the temperature of transistor Q721, which indicates the approximate temperature of the circuit board. To compensate for thermal drift, the PTC321 is calibrated at circuit board temperatures of 25 and 35 degrees C. The microcontroller continuously monitors the circuit board temperature and interpolates between the two calibrations as necessary. The output of the PTC321 is an accurate resistance value; the PTC's main processor is responsible for converting that value to a temperature.

Since the excitation current can pass through the reference resistor in either direction, switch U252 is needed to ensure that the ADC always receives a positive reference voltage.

If R292 is removed, the ADC can be powered by a 5V reference located at U270, potentially reducing noise and drift. However, under most circumstances the reference does not make a noticeable difference, so R292 is normally installed (connecting the ADC to the analog +5V supply) and U270 is omitted.

A circuit to drive an on-board heater is provided but not used. The heater was intended to keep the card at a constant temperature and thereby minimize thermal drift. Temperature sensor U730 is part of the on-board heater system and is also not used. Currently, the speed of the system fan is modulated to accomplish this goal.

The card can usually detect disconnected inputs because they produce "out-of-range" ADC measurements. However, no pull-up or pull-down resistors are connected to the sensor inputs to ensure that this occurs, since such resistors would decrease the accuracy of the PTC321. Therefore, spurious readings may appear when no sensor is connected.

PTC330 thermocouple reader

Unlike the other input cards, the PTC330 does not use the PTC's analog power supplies. Instead, each channel has its own 8V isolated power supply. This allows the PTC330's four thermocouple inputs to float independently.

The PTC330's four channels are identical. Looking at channel 0, spark gaps GAP201-2, the T filter, and diodes D201-2 protect the inputs against electrostatic discharge and overvoltage. U210 produces the ADC's 1V reference voltage and, through resistor R201, sets the voltage of the positive thermocouple input to 1 V. Capacitor C203 filters the input to reduce high-frequency noise. R202 pulls the negative input to ground if no thermocouple is connected so that disconnected inputs can be detected.

The thermocouple cannot be directly connected to the ADC (U220) because the ADC produces a small amount of current between its input pins. If allowed to propagate through the thermocouple, this current creates an error proportional to the thermocouple's resistance. Therefore, the ADC inputs are buffered with op amps U200A-B. Capacitors C206-7 eliminate ADC glitches by absorbing the current transients produced by the ADC's internal switches, while RN205 and C205 allow the op amp to drive the large capacitance of C206-7 without oscillating.

Optoisolators ISO230A-B and ISO240 connect the ADC to the Atmel microcontroller's SPI bus.

The output voltage of the isolated power supply (measured at TP262 relative to the channel's floating ground) is proportional to the ratio of resistors R611 and R613, but R613 must be about 3k. The desired output is about 8 V, which linear regulator U260 reduces to 5V. Since the thermocouple ground is floating and is the output of a switching power supply, when inspected with an oscilloscope it appears as a 285 kHz square wave relative to system ground. The square wave on ground can be eliminated by installing a zero ohm resistor at R263, which connects the thermocouple ground to system ground and sets the thermocouple's potential to 1 V. In this case, the thermocouple can no longer be put into electrical contact with any objects that are not floating.

The card includes an ambient temperature sensor, U630. The system can adjust the speed of the front-panel fan to keep U630 at a constant temperature, thereby reducing thermal drift of the card. However, unlike the PTC321, the PTC330 is not calibrated at multiple temperatures and cannot compensate for changing temperatures by adjusting its on-board calibration data.

Cold junction temperature measurement is accomplished with an RTD and a circuit similar to the PTC321, except the direction of the excitation current cannot be reversed.

PTC420 AC output card

The PTC420 uses a solid-state relay, LS200, to switch AC line voltage to the user's heater (connected to J200) on and off. The solid-state relay only switches the "hot" line. Components RV200 and L200 are provided to prevent damage to the solid-state relay when inductive or capacitive loads are driven.

A mechanical relay, K260, disconnects both the hot and neutral lines when the PTC's "Output Enable" is off. The mechanical relay ensures that power can be shut off if the solid-state relay fails (solid-state relays usually fail in the "closed" position) and also protects the user from electric shocks if the hot and neutral lines are swapped within the PTC or within the user's laboratory.

The remainder of the analog circuitry monitors the current and voltage across the heater.

After passing through the heater, AC current passes through the current sense resistor, R200. The voltage at each end of this resistor is passed to op amps U220A and B. A high-value resistor (R211, R212) and a diode (D211, D212) protect the op amps from excessive voltage if the neutral line becomes hot. A peak detector circuit produces a DC voltage equal to the amplitude of the AC voltage across this resistor. The DC voltage is measured by a 10-bit ADC on-board the Atmel ATmega microcontroller. To provide higher resolution measurements of small currents, op amp U240B amplifies the DC voltage by a factor of 5 and provides the result to a second ADC input.

The heater voltage monitor is similar to the current monitor, but measures the voltage across the user's heater.

If the voltage on the AC neutral line exceeds 4V, op amps U220 A-D become saturated and the voltage and current measurement circuits do not work properly.

PTC430 50W DC output card

The PTC430 outputs 1 A of current with a compliance voltage of up to 50V. 50V power is generated on-card by a switching boost regulator, U210.

The PTC430 has four current sources, one for each of the three current ranges, plus one that increases output resolution by outputting a small dithered current. The four current sources differ mainly in the resistance of their current sense resistors. The microcontroller selects a current range by outputting a 2-bit address (IRANGE0, IRANGE1). Based on this address, address decoder U243 enables one of the current sources. In addition, switch U244 changes the maximum output of the dither current source to a value equal to one LSB of the main current source.

A 16-bit DAC, U240, sets the desired output current. The DAC outputs a value between 0.2 V (no output current) and 4.0 V (highest possible current for the selected range).

Considering the 2.0A circuit, current from the +50V supply flows through sense resistor R251, then through FET Q251, which throttles back the current to the desired level, then to the user's heater.

This high-side configuration is safer than the more common low-side current source, but requires a special high-side-sense IC, U290A. The output of this chip is a voltage proportional to the voltage across sense resistor R251. A 0.2V reference voltage offsets U233's output such that when no current is flowing through R251, the output of U233 is 0.2V, while when the maximum current is flowing (2A in this case), the output is 4.0 V.

Switch U290A enables or disables the 2A current source. When the control voltage at pin 1 is high, the switch output (pin 3) is connected to +5V and the current source is disabled. When the control voltage is low, pin 3 is connected to the output of U233 and the current source is enabled. The switch is somewhat sensitive to damage from static discharge.

While the current source is enabled, op amp U250A drives FET Q251 such that the output of U233 is equal to the output of the current control DAC, U240. FET Q233 is needed so that the gate of Q251 can be driven with a high voltage (up to +50V).

FET Q251 is attached to the large heatsink and dissipates up to 50 W of power. If it is not kept sufficiently cool, it may fail in the "on" position. Therefore a temperature sensor, U140, measures the temperature of the large heatsink. The sensor outputs a voltage of 1 mV/°F which is read by one of the microcontroller's ADC inputs. The microcontroller requests increasing cooling from the system fan as the heatsink temperature rises above 35°C. If the heatsink temperature exceeds 60°C, the microcontroller causes a pop-up window to appear on the PTC's front panel and disables the output.

An automatically-resetting fuse (F221) cuts off the output current if it exceeds 2 A. The current passes through a low-pass filter and then through the user's heater, which is connected to banana plug sockets J201 and J202. A second sense resistor, R208, is used to measure the return current. If the return current differs from the output current by more than 0.25A, the microcontroller requests that a "ground fault" popup window be displayed on the PTC's front panel.

A multiplexed 16-bit ADC, U280, monitors the heater current, the voltage across the heater, and the return current. The ADC has a range of 0–4V. The heater current is monitored by measuring the voltage across the sense resistor, which is 0.2V when no current is flowing and 4.0V when the maximum current for the selected range is flowing.

The dither current circuit is either fully on or fully off. The on/off state is controlled by one of the microcontroller's PWM outputs.

PTC431 100W DC output card

The PTC431 outputs 2 A of current with a compliance voltage of up to 50V.

+24V to +50V 2A boost regulator: a variable-voltage power supply. The output is labeled +50V, but in fact is always a few volts greater than the voltage across the heater, with a minimum of 24V and a maximum of 55V.

Regulator U210 adjusts the power supply output in order to keep the voltage at its feedback pin (FB, pin 3) equal to 1.26 V. The feedback pin voltage is produced by a voltage divider between the power supply output and op amp U220A. When the voltage across the heater (OUT+) is 55V, op amp U220A outputs 0V; when OUT+ is 24V, U220A outputs 1.23V. Diode D221 protects the feedback pin from an over-voltage condition during start-up. R214 sinks current when the op amp output is near its lower rail.

Constant-current heater driver: the card has three independent current-output heater driver circuits, one for each current range. The circuits are identical except for the sense resistor. The microcontroller selects a current range by pulling one of the three lines 2000MA_ONOFF, 200MA_ONOFF, or 20MA_ONOFF low.

A 16-bit DAC, U240, sets the desired output current. The DAC outputs a value between 0 V (no output current) and 4.0 V (highest possible current for the selected range).

Considering the 2.0A circuit, current from the +50V supply flows through sense resistor R251, then through FET Q251, which throttles back the current to the desired level, then to the user's heater.

This high-side configuration is safer than the more common low-side current source, but requires a special high-side-sense IC, U290A. The output of this chip is a voltage proportional to the voltage across sense resistor R251 multiplied by 20.1. When the maximum current is flowing (2A in this case), the output is 4.0 V.

Switch U290A enables or disables the 2A current source. When the control voltage at pin 1 is high, the switch output (pin 3) is connected to +5V and the current source is disabled. When the

control voltage is low, pin 3 is connected to the output of U233 and the current source is enabled. The switch is somewhat sensitive to damage from static discharge.

While the current source is enabled, op amp U250A drives FET Q251 such that the output of U233 is equal to the output of the current control DAC, U240. FET Q233 is needed so that the gate of Q251 can be driven with a high voltage (up to +50V).

FET Q251 can dissipate up to 10 W of power. If it is not kept sufficiently cool, it may fail in the "on" position. Therefore a temperature sensor, U140, measures the temperature of the heatsink. The sensor outputs a voltage of 1 mV/°F which is read by one of the microcontroller's ADC inputs. The microcontroller requests increasing cooling from the system fan as the heatsink temperature rises above 35°C. If the heatsink temperature exceeds 60°C, the microcontroller causes an error message to appear on the PTC's front panel and disables the output.

A pair of automatically-resetting fuses (F221, F222) cuts off the output current if it exceeds 2 A. The current passes through a noise filter and then through the user's heater, which is connected to banana plug sockets J201 and J202. A second sense resistor, R208, is used to measure the return current. If the return current differs from the output current by more than 0.25A, the microcontroller requests that a "ground fault" error window be displayed on the PTC's front panel.

Voltage and current monitor: a multiplexed 16-bit ADC, U280, monitors the heater current, the voltage across the heater, and the return current. The ADC has a range of 0–4V. The heater current is monitored by measuring the voltage across the sense resistor, which is 0.2V when no current is flowing and 4.0V when the maximum current for the selected range is flowing.

PTC440 TEC driver

Step-down regulator: a variable-voltage power supply for the current source, switching regulator U320 steps the PTC10's 24V supply from 24V down to 3, 6, 9, or 12V.

Current monitor: the 0.05 ohm current sense resistor R240 is used to monitor the current passing through the TEC. Precision amplifier U240 multiplies the voltage across this resistor by a factor of 10 and adds 2.5 V to the result; the output of this amplifier is 2.5 V if the TEC is receiving no current, 5 V at 5A of current, and 0V at –5A.

Current source: Op amp U210A drives FETs Q211 and Q212, providing current to the positive output terminal. The op amp tries to keep the average of the current monitor voltage and the current control DAC output at 2.5V. Resistor R205 limits the range of the current control DAC. Therefore, when the DAC output is 0 V, the current monitor voltage should be 4.773 V; when the DAC output is 5V, the current monitor voltage should be 0.227 V.

Op amp U210B drives FETs Q221 and Q222, providing current to the negative output terminal. This op amp tries to keep the average of the positive and negative terminal voltages at 7.5 V (a value determined by R225 and R226). Thus, as the current becomes more positive, the positive terminal rises above 7.5V and the negative terminal drops below 7.5 V. Since the PTC440's high-current supply is unipolar, at no time does the negative terminal actually have a negative voltage with respect to ground.

Current bypass: When the BYPASS* signal from the microprocessor is low, PhotoMOS relay U230A shorts out the positive and negative terminals. This feature is used when no TEC is attached to the PTC440; otherwise, small errors in the current monitor or DAC output would result in a 15V differential voltage across the TEC+ and TEC– terminals. With such a voltage present, the output filtering capacitors would produce a brief current spike of tens of amps when the TEC is plugged in, enough to destroy the TEC. The current bypass is also used whenever the output current is set to zero to reduce the current resulting from any small errors in the current monitor or DAC output.

The current bypass should not be activated while current is flowing. However, in case it is, resistor R231 protects the relay by preventing more than 0.15A of current from flowing through it.

Power shutoff: When the TEC_POWER signal from the microprocessor is low, FET Q202 shuts off power to the current source. This safety mechanism is engaged whenever the PTC's outputs are disabled with the Output Enable button. When the power is not shut off, even if the set current is zero, a 7.5 V voltage is present at the TEC+ and TEC– terminals and shorting these terminals to ground can cause the PTC440 to output its the maximum current.

ADC: U290 is a multiplexed ADC that can read eight single-ended inputs, four differential inputs, or any combination of the two. The current monitor, voltage monitor, and AD590 sensors are read as single-ended inputs; resistive temperature sensors are read as differential inputs. The ADC's multiplexer is not connected directly to the ADC, but is buffered by chopper-stabilized op amps U280A and B. An RC network (RN281, RN282, and C251) makes it possible for the op amps to drive the large capacitors (C282, C283) necessary for optimum ADC performance. Even though the OPA3333s are unipolar, they are design such that when equipped with pull-down resistors (R281 and R282), their output swing can extend below 0V.

Voltage monitor: measures the voltage across the voltage sense terminals. The voltage measurement is used to determine whether or not a TEC device is connected and also for auto-ranging.

Sensor excitation: provides 10, 100, or 1000 μA of current for reading RTDs or thermistors. Op amp U420A provides a virtual ground for 2.5V reference U400. The voltage across the 2.5 kΩ sense resistor R415 is set to 25 mV, 250 mV, or 2.5V by the resistor ladder R411–R414.

Sensor input: The sensor input circuit can read both the voltage and the current across the sensor (to measure resistance, the card's firmware divides the voltage by the current). The voltage across the sensor is directly read by the ADC assembly. The excitation current flows through reference resistor R441, entering the resistor at a voltage of 0V and exiting at a negative voltage. The negative voltage is inverted by U430 and becomes the current measurement.

PTC510 analog I/O card

The PTC510 has four channels that can be used as DAC outputs or ADC inputs. On-card regulators produce +5, +15, and -15V analog supply voltages.

A 4-channel DAC, U202, produces four 0–5V outputs, which are converted to ±10V by U203A-D. Switches U204A-D can disconnect any of the DAC outputs from the card's BNC connectors, changing the affected channels from DAC outputs to ADC inputs.

The outputs of the four switches are connected to the card's four BNC connectors. A self-resetting fuse, F301-4, temporarily shuts off the current if it exceeds 200 mA. The normal resistance of the fuse is about 1.5 ohms. D301 protects the card from electrostatic discharge and excessive voltages.

U206 multiplexes the four channels into a 24-bit ADC. Since the ADC has a 0–5V range while the inputs are specified for a ±10V range, the input voltage is divided by 4 and offset by 2.5V.

The microcontroller communicates with the analog section through an optoisolated SPI bus. A two-bit address (SPI_ADD0, SPI_ADD1) provided to an address decoder (U302) selects one of three chips on the bus: an SPI-to-parallel adapter (U340), the ADC, or the DAC. The SPI-to-parallel adapter controls the ADC's multiplexer and the direction (input or output) of each channel. The ADC's BUSY signal, which is high while the ADC is performing a conversion, is also connected to the microcontroller through an optoisolator; this signal tells the microcontroller when an ADC conversion is complete and without it the microcontroller freezes up.

PTC520 digital I/O card

The PTC's eight digital I/O (DIO) lines can be user-configured to serve as inputs or outputs. All eight lines must have the same direction.

The DIO lines are presented on a 25-pin D connector, J200. Resistors RN200 and RN201 terminate the lines. Capacitors C200–C207 provide ESD protection, while D200, D202, D204, and D206 provide overvoltage protection. The parallel-to-SPI converter, U210, reads the inputs, while the SPI-to-parallel converter U220 produces the outputs. When DOUT_EN* is high, the outputs of U210 are placed into a high-impedance state and the DIO lines serve as inputs. When DOUT_EN* is low, U210 is enabled and the DIO lines serve as outputs.

Since the digital I/O lines are optically isolated and have a floating ground, U210 and U220 are powered by an isolated 5V power supply.

The DIO card also includes four non-latching relays, K401–K404. Each relay is double throw Pins 2, 3, and 4 serve as a monitoring relay. If the monitoring relay fails to switch as expected, XOR gates U410 notify the microcontroller by pulling one of OUT1MON, OUT2MON, etc. high.

Parts List

PTC211 CPU board

BT101	0-01089-000	1065	Battery holder
BT101A	6-00789-612	CR2032 W/OUT PN	Battery
C 101	5-00334-569	.1U/T35	Cap, Tantalum, SMT (all case sizes)
C 102	5-00601-578	0.1UF - 16V X7R	SMT Ceramic Cap, all sizes
C 103	5-00471-569	10U/T16	Cap, Tantalum, SMT (all case sizes)
C 104	5-00609-578	1500P	SMT Ceramic Cap, all sizes
C 105	5-00609-578	1500P	SMT Ceramic Cap, all sizes
C 106	5-00609-578	1500P	SMT Ceramic Cap, all sizes
C 107	5-00609-578	1500P	SMT Ceramic Cap, all sizes
C 108	5-00609-578	1500P	SMT Ceramic Cap, all sizes
C 109	5-00609-578	1500P	SMT Ceramic Cap, all sizes
C 110	5-00609-578	1500P	SMT Ceramic Cap, all sizes
C 111	5-00609-578	1500P	SMT Ceramic Cap, all sizes
C 112	5-00609-578	1500P	SMT Ceramic Cap, all sizes
C 113	5-00609-578	1500P	SMT Ceramic Cap, all sizes
C 114	5-00609-578	1500P	SMT Ceramic Cap, all sizes
C 115	5-00609-578	1500P	SMT Ceramic Cap, all sizes
C 116	5-00609-578	1500P	SMT Ceramic Cap, all sizes
C 117	5-00609-578	1500P	SMT Ceramic Cap, all sizes
C 118	5-00609-578	1500P	SMT Ceramic Cap, all sizes
C 119	5-00609-578	1500P	SMT Ceramic Cap, all sizes
C 120	5-00609-578	1500P	SMT Ceramic Cap, all sizes
C 121	5-00609-578	1500P	SMT Ceramic Cap, all sizes
C 122	5-00609-578	1500P	SMT Ceramic Cap, all sizes
C 123	5-00609-578	1500P	SMT Ceramic Cap, all sizes
C 124	5-00609-578	1500P	SMT Ceramic Cap, all sizes
C 125	5-00609-578	1500P	SMT Ceramic Cap, all sizes
C 126	5-00609-578	1500P	SMT Ceramic Cap, all sizes
C 127	5-00609-578	1500P	SMT Ceramic Cap, all sizes
C 128	5-00609-578	1500P	SMT Ceramic Cap, all sizes
C 129	5-00609-578	1500P	SMT Ceramic Cap, all sizes
C 130	5-00609-578	1500P	SMT Ceramic Cap, all sizes
C 131	5-00609-578	1500P	SMT Ceramic Cap, all sizes
C 132	5-00609-578	1500P	SMT Ceramic Cap, all sizes
C 201	5-00601-578	0.1UF - 16V X7R	SMT Ceramic Cap, all sizes
C 202	5-00601-578	0.1UF - 16V X7R	SMT Ceramic Cap, all sizes
C 203	5-00601-578	0.1UF - 16V X7R	SMT Ceramic Cap, all sizes
C 204	5-00601-578	0.1UF - 16V X7R	SMT Ceramic Cap, all sizes
C 205	5-00601-578	0.1UF - 16V X7R	SMT Ceramic Cap, all sizes
C 206	5-00601-578	0.1UF - 16V X7R	SMT Ceramic Cap, all sizes
C 207	5-00601-578	0.1UF - 16V X7R	SMT Ceramic Cap, all sizes
C 208	5-00601-578	0.1UF - 16V X7R	SMT Ceramic Cap, all sizes
C 209	5-00601-578	0.1UF - 16V X7R	SMT Ceramic Cap, all sizes
C 210	5-00601-578	0.1UF - 16V X7R	SMT Ceramic Cap, all sizes
C 211	5-00601-578	0.1UF - 16V X7R	SMT Ceramic Cap, all sizes
C 212	5-00601-578	0.1UF - 16V X7R	SMT Ceramic Cap, all sizes
C 213	5-00601-578	0.1UF - 16V X7R	SMT Ceramic Cap, all sizes
C 215	5-00601-578	0.1UF - 16V X7R	SMT Ceramic Cap, all sizes
C 216	5-00601-578	0.1UF - 16V X7R	SMT Ceramic Cap, all sizes
C 218	5-00601-578	0.1UF - 16V X7R	SMT Ceramic Cap, all sizes
C 302	5-00601-578	0.1UF - 16V X7R	SMT Ceramic Cap, all sizes
C 303	5-00601-578	0.1UF - 16V X7R	SMT Ceramic Cap, all sizes
C 304	5-00601-578	0.1UF - 16V X7R	SMT Ceramic Cap, all sizes
C 305	5-00601-578	0.1UF - 16V X7R	SMT Ceramic Cap, all sizes
C 306	5-00601-578	0.1UF - 16V X7R	SMT Ceramic Cap, all sizes

C 307	5-00601-578	0.1UF - 16V X7R	SMT Ceramic Cap, all sizes
C 308	5-00601-578	0.1UF - 16V X7R	SMT Ceramic Cap, all sizes
C 309	5-00601-578	0.1UF - 16V X7R	SMT Ceramic Cap, all sizes
C 310	5-00601-578	0.1UF - 16V X7R	SMT Ceramic Cap, all sizes
C 401	5-00601-578	0.1UF - 16V X7R	SMT Ceramic Cap, all sizes
C 402	5-00601-578	0.1UF - 16V X7R	SMT Ceramic Cap, all sizes
C 403	5-00601-578	0.1UF - 16V X7R	SMT Ceramic Cap, all sizes
C 404	5-00601-578	0.1UF - 16V X7R	SMT Ceramic Cap, all sizes
C 405	5-00601-578	0.1UF - 16V X7R	SMT Ceramic Cap, all sizes
C 406	5-00601-578	0.1UF - 16V X7R	SMT Ceramic Cap, all sizes
C 407	5-00601-578	0.1UF - 16V X7R	SMT Ceramic Cap, all sizes
C 408	5-00601-578	0.1UF - 16V X7R	SMT Ceramic Cap, all sizes
C 409	5-00601-578	0.1UF - 16V X7R	SMT Ceramic Cap, all sizes
C 410	5-00601-578	0.1UF - 16V X7R	SMT Ceramic Cap, all sizes
C 431	5-00334-569	.1U/T35	Cap, Tantalum, SMT (all case sizes)
C 441	5-00604-578	0.01UF / 16V	SMT Ceramic Cap, all sizes
C 442	5-00604-578	0.01UF / 16V	SMT Ceramic Cap, all sizes
C 443	5-00604-578	0.01UF / 16V	SMT Ceramic Cap, all sizes
C 444	5-00604-578	0.01UF / 16V	SMT Ceramic Cap, all sizes
C 445	5-00604-578	0.01UF / 16V	SMT Ceramic Cap, all sizes
C 446	5-00604-578	0.01UF / 16V	SMT Ceramic Cap, all sizes
C 447	5-00604-578	0.01UF / 16V	SMT Ceramic Cap, all sizes
C 448	5-00604-578	0.01UF / 16V	SMT Ceramic Cap, all sizes
C 449	5-00471-569	10U/T16	Cap, Tantalum, SMT (all case sizes)
C 450	5-00601-578	0.1UF - 16V X7R	SMT Ceramic Cap, all sizes
C 451	5-00604-578	0.01UF / 16V	SMT Ceramic Cap, all sizes
C 452	5-00604-578	0.01UF / 16V	SMT Ceramic Cap, all sizes
C 453	5-00604-578	0.01UF / 16V	SMT Ceramic Cap, all sizes
C 454	5-00604-578	0.01UF / 16V	SMT Ceramic Cap, all sizes
C 455	5-00604-578	0.01UF / 16V	SMT Ceramic Cap, all sizes
C 456	5-00471-569	10U/T16	Cap, Tantalum, SMT (all case sizes)
C 457	5-00601-578	0.1UF - 16V X7R	SMT Ceramic Cap, all sizes
C 458	5-00471-569	10U/T16	Cap, Tantalum, SMT (all case sizes)
C 459	5-00601-578	0.1UF - 16V X7R	SMT Ceramic Cap, all sizes
C 460	5-00604-578	0.01UF / 16V	SMT Ceramic Cap, all sizes
C 461	5-00601-578	0.1UF - 16V X7R	SMT Ceramic Cap, all sizes
C 462	5-00369-552	33P	Capacitor, Chip (SMT1206), 50V, 5%, NPO
C 463	5-00369-552	33P	Capacitor, Chip (SMT1206), 50V, 5%, NPO
C 464	5-00604-578	0.01UF / 16V	SMT Ceramic Cap, all sizes
C 465	5-00601-578	0.1UF - 16V X7R	SMT Ceramic Cap, all sizes
C 466	5-00601-578	0.1UF - 16V X7R	SMT Ceramic Cap, all sizes
C 471	5-00601-578	0.1UF - 16V X7R	SMT Ceramic Cap, all sizes
C 472	5-00601-578	0.1UF - 16V X7R	SMT Ceramic Cap, all sizes
C 473	5-00601-578	0.1UF - 16V X7R	SMT Ceramic Cap, all sizes
C 521	5-00601-578	0.1UF - 16V X7R	SMT Ceramic Cap, all sizes
C 522	5-00601-578	0.1UF - 16V X7R	SMT Ceramic Cap, all sizes
C 523	5-00601-578	0.1UF - 16V X7R	SMT Ceramic Cap, all sizes
C 524	5-00601-578	0.1UF - 16V X7R	SMT Ceramic Cap, all sizes
C 531	5-00601-578	0.1UF - 16V X7R	SMT Ceramic Cap, all sizes
C 532	5-00601-578	0.1UF - 16V X7R	SMT Ceramic Cap, all sizes
C 533	5-00601-578	0.1UF - 16V X7R	SMT Ceramic Cap, all sizes
C 534	5-00601-578	0.1UF - 16V X7R	SMT Ceramic Cap, all sizes
C 541	5-00601-578	0.1UF - 16V X7R	SMT Ceramic Cap, all sizes
C 542	5-00601-578	0.1UF - 16V X7R	SMT Ceramic Cap, all sizes
C 543	5-00601-578	0.1UF - 16V X7R	SMT Ceramic Cap, all sizes
C 544	5-00601-578	0.1UF - 16V X7R	SMT Ceramic Cap, all sizes
C 601	5-00601-578	0.1UF - 16V X7R	SMT Ceramic Cap, all sizes
C 602	5-00601-578	0.1UF - 16V X7R	SMT Ceramic Cap, all sizes
C 603	5-00601-578	0.1UF - 16V X7R	SMT Ceramic Cap, all sizes
C 604	5-00601-578	0.1UF - 16V X7R	SMT Ceramic Cap, all sizes
C 605	5-00366-552	18P	Capacitor, Chip (SMT1206), 50V, 5%, NPO
C 606	5-00366-552	18P	Capacitor, Chip (SMT1206), 50V, 5%, NPO
C 621	5-00601-578	0.1UF - 16V X7R	SMT Ceramic Cap, all sizes
C 631	5-00299-568	.1U	Cap, Ceramic 50V SMT (1206), X7R

C 632	5-00371-552	47P	Capacitor, Chip (SMT1206), 50V, 5%, NPO
C 633	5-00371-552	47P	Capacitor, Chip (SMT1206), 50V, 5%, NPO
C 641	5-00031-520	220U	Capacitor, Electrolytic, 16V, 20%, Rad
C 642	5-00299-568	.1U	Cap, Ceramic 50V SMT (1206), X7R
C 643	5-00031-520	220U	Capacitor, Electrolytic, 16V, 20%, Rad
C 644	5-00299-568	.1U	Cap, Ceramic 50V SMT (1206), X7R
C 645	5-00371-552	47P	Capacitor, Chip (SMT1206), 50V, 5%, NPO
C 646	5-00371-552	47P	Capacitor, Chip (SMT1206), 50V, 5%, NPO
C 647	5-00371-552	47P	Capacitor, Chip (SMT1206), 50V, 5%, NPO
C 648	5-00371-552	47P	Capacitor, Chip (SMT1206), 50V, 5%, NPO
D 301	3-00575-311	GREEN MINI	LED, Subminiature
D 302	3-00575-311	GREEN MINI	LED, Subminiature
D 303	3-00575-311	GREEN MINI	LED, Subminiature
D 304	3-00575-311	GREEN MINI	LED, Subminiature
D 305	3-00575-311	GREEN MINI	LED, Subminiature
D 306	3-00575-311	GREEN MINI	LED, Subminiature
D 307	3-00575-311	GREEN MINI	LED, Subminiature
D 308	3-00575-311	GREEN MINI	LED, Subminiature
D 441	3-00575-311	GREEN MINI	LED, Subminiature
D 603	3-00010-303	GREEN	LED, T1 Package
D 645	3-01342-313	STZ5.6NT146	Diode, SMT
D 646	3-01342-313	STZ5.6NT146	Diode, SMT
J 101	1-01178-132	26 PIN	Header, DIP
J 201	1-00006-130	2 PIN DI	Connector, Male
J 202	1-01179-100	0536271275	Connector, Misc.
J 431	1-00485-165	9 PIN VERTICAL	Connector, D-Sub, Female
J 440	1-01075-100	J1012F21C	Connector, Misc.
J 470	1-00251-130	10 PIN DIL	Connector, Male
J 630	1-00350-150	4 PIN, USB	Socket, THRU-HOLE
J 640	1-01180-143	URA-1002	Connector, USB
JD301	1-00236-109	120 PIN RT ANGL DIN	Connector, Male
L 441	6-00236-631	FR47	Ferrite bead, SMT
L 442	6-00236-631	FR47	Ferrite bead, SMT
L 631	6-00236-631	FR47	Ferrite bead, SMT
L 641	6-00236-631	FR47	Ferrite bead, SMT
L 642	6-00236-631	FR47	Ferrite bead, SMT
L 643	6-00236-631	FR47	Ferrite bead, SMT
L 644	6-00236-631	FR47	Ferrite bead, SMT
PC1	7-01711-701	PTC, CPU	Printed Circuit Board
R 102	4-01722-400	47K / 0603	SMT Resistor, Misc.
R 103	4-01724-461	10K - SMT/0603	Thick Film, 5%, 200 ppm, Chip Resistor
R 104	4-01439-461	22	Thick Film, 5%, 200 ppm, Chip Resistor
R 105	4-01725-461	4.7K - SMT/0603	Thick Film, 5%, 200 ppm, Chip Resistor
R 106	4-01439-461	22	Thick Film, 5%, 200 ppm, Chip Resistor
R 107	4-01431-461	10	Thick Film, 5%, 200 ppm, Chip Resistor
R 201	4-01725-461	4.7K - SMT/0603	Thick Film, 5%, 200 ppm, Chip Resistor
R 202	4-01725-461	4.7K - SMT/0603	Thick Film, 5%, 200 ppm, Chip Resistor
R 301	4-01725-461	4.7K - SMT/0603	Thick Film, 5%, 200 ppm, Chip Resistor
R 302	4-01722-400	47K / 0603	SMT Resistor, Misc.
R 441	4-01725-461	4.7K - SMT/0603	Thick Film, 5%, 200 ppm, Chip Resistor
R 442	4-01242-462	20.0K	Thin Film, 1%, 50 ppm, MELF Resistor
R 443	4-01155-462	2.49K	Thin Film, 1%, 50 ppm, MELF Resistor
R 444	4-01251-462	24.9K	Thin Film, 1%, 50 ppm, MELF Resistor
R 446	4-01725-461	4.7K - SMT/0603	Thick Film, 5%, 200 ppm, Chip Resistor
R 447	4-01726-454	49.9 - SMT/0603	Thick Film, 1%, 100ppm, Chip Res.(SMT)
R 448	4-01726-454	49.9 - SMT/0603	Thick Film, 1%, 100ppm, Chip Res.(SMT)
R 449	4-01726-454	49.9 - SMT/0603	Thick Film, 1%, 100ppm, Chip Res.(SMT)
R 450	4-01726-454	49.9 - SMT/0603	Thick Film, 1%, 100ppm, Chip Res.(SMT)
R 543	4-01725-461	4.7K - SMT/0603	Thick Film, 5%, 200 ppm, Chip Resistor
R 603	4-01467-461	330	Thick Film, 5%, 200 ppm, Chip Resistor
R 631	4-01551-461	1.0M	Thick Film, 5%, 200 ppm, Chip Resistor
R 633	4-01551-461	1.0M	Thick Film, 5%, 200 ppm, Chip Resistor
R 634	4-01406-461	0	Thick Film, 5%, 200 ppm, Chip Resistor
R 642	4-01406-461	0	Thick Film, 5%, 200 ppm, Chip Resistor

R 643	4-01406-461	0	Thick Film, 5%, 200 ppm, Chip Resistor
RN101	4-00911-463	4.7KX4D	Resistor network, SMT, Leadless
RN102	4-00911-463	4.7KX4D	Resistor network, SMT, Leadless
RN103	4-01727-463	22X4	Resistor network, SMT, Leadless
RN104	4-01727-463	22X4	Resistor network, SMT, Leadless
RN105	4-01727-463	22X4	Resistor network, SMT, Leadless
RN106	4-00911-463	4.7KX4D	Resistor network, SMT, Leadless
RN107	4-00911-463	4.7KX4D	Resistor network, SMT, Leadless
RN108	4-00911-463	4.7KX4D	Resistor network, SMT, Leadless
RN301	4-00911-463	4.7KX4D	Resistor network, SMT, Leadless
RN302	4-00910-463	1.0KX4D	Resistor network, SMT, Leadless
RN303	4-00910-463	1.0KX4D	Resistor network, SMT, Leadless
RN441	4-00911-463	4.7KX4D	Resistor network, SMT, Leadless
RN442	4-00911-463	4.7KX4D	Resistor network, SMT, Leadless
RN443	4-00910-463	1.0KX4D	Resistor network, SMT, Leadless
RN601	4-00912-463	10KX4D	Resistor network, SMT, Leadless
RN602	4-00912-463	10KX4D	Resistor network, SMT, Leadless
RN632	4-01727-463	22X4	Resistor network, SMT, Leadless
RN641	4-01727-463	22X4	Resistor network, SMT, Leadless
S 101	2-00053-208	B3F-1052	Switch, Momentary Push Button, NO
U 101	3-01229-360	MAX6365LKA31	Integrated Circuit (Surface Mount Pkg)
U 102	3-01230-360	MCF5307FT90B	Integrated Circuit (Surface Mount Pkg)
U 201	3-01231-360	MT48LC4M32B2TG7	Integrated Circuit (Surface Mount Pkg)
U 202	3-01232-360	SST39VF3201-70	Integrated Circuit (Surface Mount Pkg)
U 204	3-01837-360	CY62146EV30LL-	Integrated Circuit (Surface Mount Pkg)
U 206	3-01233-360	DS1672S-33	Integrated Circuit (Surface Mount Pkg)
U 302	3-01235-360	74LCX04M	Integrated Circuit (Surface Mount Pkg)
U 303	3-01236-360	74LCX16245MTD	Integrated Circuit (Surface Mount Pkg)
U 304	3-01236-360	74LCX16245MTD	Integrated Circuit (Surface Mount Pkg)
U 401	3-01237-360	S1D13706F00A100	Integrated Circuit (Surface Mount Pkg)
U 403	3-01205-360	74LVC4245ADW	Integrated Circuit (Surface Mount Pkg)
U 430	3-01239-360	MAX3233ECWP	Integrated Circuit (Surface Mount Pkg)
U 440	3-01240-360	AX88796L	Integrated Circuit (Surface Mount Pkg)
U 470	3-01743-360	ISPGAL22V10AV	Integrated Circuit (Surface Mount Pkg)
U 520	3-01241-360	74VCX16245MTD	Integrated Circuit (Surface Mount Pkg)
U 530	3-01241-360	74VCX16245MTD	Integrated Circuit (Surface Mount Pkg)
U 540	3-01241-360	74VCX16245MTD	Integrated Circuit (Surface Mount Pkg)
U 600	3-01835-360	ISP1161A1BM	Integrated Circuit (Surface Mount Pkg)
U 610	3-00663-360	74HC08	Integrated Circuit (Surface Mount Pkg)
U 620	3-01836-360	TPS2042BD	Integrated Circuit (Surface Mount Pkg)
Y 101	6-00662-621	45MHZ - SMT	Crystal Oscillator
Y 201	6-00762-626	32.768KHZ - 6PF	Crystal, SMT
Y 440	6-00664-620	25MHZ	Crystal
Y 601	6-00772-620	6MHZ	Crystal
Z 0	0-00306-026	4-40X3/16PP	Screw, Black, All Types
Z 0	7-01773-720	BRACKET PTC10	Fabricated Part

PTC221 backplane

C 111	5-00601-578	0.1UF - 16V X7R	SMT Ceramic Cap, all sizes
C 121	5-00601-578	0.1UF - 16V X7R	SMT Ceramic Cap, all sizes
C 131	5-00601-578	0.1UF - 16V X7R	SMT Ceramic Cap, all sizes
C 141	5-00601-578	0.1UF - 16V X7R	SMT Ceramic Cap, all sizes
C 142	5-00601-578	0.1UF - 16V X7R	SMT Ceramic Cap, all sizes
C 143	5-00601-578	0.1UF - 16V X7R	SMT Ceramic Cap, all sizes
C 144	5-00601-578	0.1UF - 16V X7R	SMT Ceramic Cap, all sizes
C 151	5-00334-569	.1U/T35	Cap, Tantalum, SMT (all case sizes)
C 160	5-00023-529	.1U	Cap, Monolithic Ceramic, 50V, 20%, Z5U
C 201	5-00601-578	0.1UF - 16V X7R	SMT Ceramic Cap, all sizes
C 202	5-00601-578	0.1UF - 16V X7R	SMT Ceramic Cap, all sizes
C 211	5-00375-552	100P	Capacitor, Chip (SMT1206), 50V, 5%, NPO
C 212	5-00472-569	4.7U/T35	Cap, Tantalum, SMT (all case sizes)
C 213	5-00395-568	4700P -5%	Cap, Ceramic 50V SMT (1206), X7R
C 214	5-00299-568	.1U	Cap, Ceramic 50V SMT (1206), X7R
C 215	5-00299-568	.1U	Cap, Ceramic 50V SMT (1206), X7R
C 216	5-00329-526	120U	Capacitor, Electrolytic, 35V, 20%, Rad
C 217	5-00384-552	560P	Capacitor, Chip (SMT1206), 50V, 5%, NPO
C 218	5-00318-569	2.2U/T35	Cap, Tantalum, SMT (all case sizes)
C 221	5-00318-569	2.2U/T35	Cap, Tantalum, SMT (all case sizes)
C 222	5-00318-569	2.2U/T35	Cap, Tantalum, SMT (all case sizes)
C 223	5-00318-569	2.2U/T35	Cap, Tantalum, SMT (all case sizes)
C 224	5-00318-569	2.2U/T35	Cap, Tantalum, SMT (all case sizes)
C 225	5-00318-569	2.2U/T35	Cap, Tantalum, SMT (all case sizes)
C 226	5-00318-569	2.2U/T35	Cap, Tantalum, SMT (all case sizes)
C 227	5-00610-553	220U / 100V	SMT Capacitor, Electrolytic, 80V, +/-20%
C 228	5-00610-553	220U / 100V	SMT Capacitor, Electrolytic, 80V, +/-20%
C 229	5-00610-553	220U / 100V	SMT Capacitor, Electrolytic, 80V, +/-20%
C 241	5-00375-552	100P	Capacitor, Chip (SMT1206), 50V, 5%, NPO
C 242	5-00628-569	22U - 35V	Cap, Tantalum, SMT (all case sizes)
C 244	5-00399-568	.01U - 5%	Cap, Ceramic 50V SMT (1206), X7R
C 245	5-00640-569	100U - 10V	Cap, Tantalum, SMT (all case sizes)
C 246	5-00640-569	100U - 10V	Cap, Tantalum, SMT (all case sizes)
C 251	5-00375-552	100P	Capacitor, Chip (SMT1206), 50V, 5%, NPO
C 252	5-00628-569	22U - 35V	Cap, Tantalum, SMT (all case sizes)
C 253	5-00628-569	22U - 35V	Cap, Tantalum, SMT (all case sizes)
C 254	5-00399-568	.01U - 5%	Cap, Ceramic 50V SMT (1206), X7R
C 255	5-00640-569	100U - 10V	Cap, Tantalum, SMT (all case sizes)
C 256	5-00640-569	100U - 10V	Cap, Tantalum, SMT (all case sizes)
D 161	3-00204-301	1N5230	Diode
D 211	3-00380-301	1N5248	Diode
D 221	3-00479-301	MUR410	Diode
D 222	3-00479-301	MUR410	Diode
D 223	3-00479-301	MUR410	Diode
D 224	3-00479-301	MUR410	Diode
D 225	3-00479-301	MUR410	Diode
D 226	3-00479-301	MUR410	Diode
D 227	3-00479-301	MUR410	Diode
D 228	3-00479-301	MUR410	Diode
D 231	3-00012-306	GREEN	LED, Rectangular
D 232	3-00012-306	GREEN	LED, Rectangular
D 233	3-00012-306	GREEN	LED, Rectangular
D 234	3-00012-306	GREEN	LED, Rectangular
D 235	3-00012-306	GREEN	LED, Rectangular
D 236	3-00012-306	GREEN	LED, Rectangular
D 241	3-01859-360	B540C-13-F	Integrated Circuit (Surface Mount Pkg)
D 251	3-01859-360	B540C-13-F	Integrated Circuit (Surface Mount Pkg)
J 100	1-01181-132	431602103	Header, DIP
J 101	1-01184-132	4 PIN	Header, DIP
J 102	1-01184-132	4 PIN	Header, DIP
J 103	1-01184-132	4 PIN	Header, DIP
J 104	1-01184-132	4 PIN	Header, DIP

J 106	1-00166-130	60 PIN DIL	Connector, Male
J 150	1-00485-165	9 PIN VERTICAL	Connector, D-Sub, Female
J 160	1-00086-130	3 PIN SI	Connector, Male
J 201	1-00111-116	6 PIN WHITE	Header, Amp, MTA-156
J 203	1-00006-130	2 PIN DI	Connector, Male
J 211	1-00006-130	2 PIN DI	Connector, Male
J 241	1-00006-130	2 PIN DI	Connector, Male
J 251	1-00006-130	2 PIN DI	Connector, Male
JD100	1-00235-108	96 PIN VERTICAL	DIN Connector, Female
JD101	1-00235-108	96 PIN VERTICAL	DIN Connector, Female
JD102	1-00235-108	96 PIN VERTICAL	DIN Connector, Female
JD103	1-00235-108	96 PIN VERTICAL	DIN Connector, Female
JD104	1-00235-108	96 PIN VERTICAL	DIN Connector, Female
JD105	1-00235-108	96 PIN VERTICAL	DIN Connector, Female
JD107	1-00237-108	120 PIN VERTICA	DIN Connector, Female
JP203	1-00087-131	2 PIN JUMPER	Connector, Female
L 241	6-00691-600	22UH - SMT	Misc. Components
L 251	6-00691-600	22UH - SMT	Misc. Components
PC1	7-01712-701	PTC, BACKPLANE	Printed Circuit Board
Q 211	3-00283-340	IRF530/IRF532	Integrated Circuit (Thru-hole Pkg)
Q 212	3-00283-340	IRF530/IRF532	Integrated Circuit (Thru-hole Pkg)
R 111	4-01495-461	4.7K	Thick Film, 5%, 200 ppm, Chip Resistor
R 121	4-01439-461	22	Thick Film, 5%, 200 ppm, Chip Resistor
R 161	4-00082-401	470K	Resistor, Carbon Film, 1/4W, 5%
R 162	4-00138-407	10.0K	Resistor, Metal Film, 1/8W, 1%, 50PPM
R 163	4-00138-407	10.0K	Resistor, Metal Film, 1/8W, 1%, 50PPM
R 164	4-00130-407	1.00K	Resistor, Metal Film, 1/8W, 1%, 50PPM
R 165	4-00170-407	249K	Resistor, Metal Film, 1/8W, 1%, 50PPM
R 201	4-01439-461	22	Thick Film, 5%, 200 ppm, Chip Resistor
R 202	4-01406-461	0	Thick Film, 5%, 200 ppm, Chip Resistor
R 203	4-01406-461	0	Thick Film, 5%, 200 ppm, Chip Resistor
R 204	4-01406-461	0	Thick Film, 5%, 200 ppm, Chip Resistor
R 205	4-01406-461	0	Thick Film, 5%, 200 ppm, Chip Resistor
R 211	4-01479-461	1.0K	Thick Film, 5%, 200 ppm, Chip Resistor
R 212	4-01158-462	2.67K	Thin Film, 1%, 50 ppm, MELF Resistor
R 213	4-01455-461	100	Thick Film, 5%, 200 ppm, Chip Resistor
R 214	4-01455-461	100	Thick Film, 5%, 200 ppm, Chip Resistor
R 215	4-01021-462	100	Thin Film, 1%, 50 ppm, MELF Resistor
R 216	4-01021-462	100	Thin Film, 1%, 50 ppm, MELF Resistor
R 217	4-01001-462	61.9	Thin Film, 1%, 50 ppm, MELF Resistor
R 218	4-00436-409	.1	Resistor, Wire Wound
R 231	4-01458-461	130	Thick Film, 5%, 200 ppm, Chip Resistor
R 232	4-01466-461	300	Thick Film, 5%, 200 ppm, Chip Resistor
R 233	4-01472-461	510	Thick Film, 5%, 200 ppm, Chip Resistor
R 234	4-00029-401	1.8K	Resistor, Carbon Film, 1/4W, 5%
R 235	4-00029-401	1.8K	Resistor, Carbon Film, 1/4W, 5%
R 236	4-00048-401	2.2K	Resistor, Carbon Film, 1/4W, 5%
R 241	4-01479-461	1.0K	Thick Film, 5%, 200 ppm, Chip Resistor
R 251	4-01479-461	1.0K	Thick Film, 5%, 200 ppm, Chip Resistor
RN111	4-01727-463	22X4	Resistor network, SMT, Leadless
RN112	4-01727-463	22X4	Resistor network, SMT, Leadless
RN131	4-01727-463	22X4	Resistor network, SMT, Leadless
RN132	4-01727-463	22X4	Resistor network, SMT, Leadless
RN141	4-00905-463	82X4D	Resistor network, SMT, Leadless
RN142	4-00905-463	82X4D	Resistor network, SMT, Leadless
RN143	4-00905-463	82X4D	Resistor network, SMT, Leadless
RN144	4-00905-463	82X4D	Resistor network, SMT, Leadless
RN145	4-00905-463	82X4D	Resistor network, SMT, Leadless
RN146	4-00905-463	82X4D	Resistor network, SMT, Leadless
T 211	6-00774-610	PTC220	Transformer
U 110	3-01345-360	74ABT541CSC	Integrated Circuit (Surface Mount Pkg)
U 120	3-01346-360	74HC4040M	Integrated Circuit (Surface Mount Pkg)
U 130	3-00795-360	74AC138	Integrated Circuit (Surface Mount Pkg)
U 140	3-01498-360	74ABT16245CMTD	Integrated Circuit (Surface Mount Pkg)

U 150	3-01239-360	MAX3233ECWP	Integrated Circuit (Surface Mount Pkg)
U 160	3-00281-340	LM111	Integrated Circuit (Thru-hole Pkg)
U 201	3-00742-360	74HC74	Integrated Circuit (Surface Mount Pkg)
U 202	3-00782-360	74HC02	Integrated Circuit (Surface Mount Pkg)
U 210	3-00919-360	3525A	Integrated Circuit (Surface Mount Pkg)
U 240	3-01347-360	LM2670S-3.3	Integrated Circuit (Surface Mount Pkg)
U 250	3-01348-360	LM2670S-5	Integrated Circuit (Surface Mount Pkg)
Y 110	6-00692-621	16MHZ - SMT	Crystal Oscillator
Z 0	0-00128-053	4" #24	Wire #24 UL1007 Strip 1/4x1/4 Tin
Z 0	0-00267-052	6-1/2" #22 RED	Wire #22 UL1007
Z 0	0-00268-052	6-1/2" #22 BL	Wire #22 UL1007
Z 0	0-00390-024	1-72X1/4	Screw, Slotted
Z 0	0-00391-010	1-72X5/32X3/64	Nut, Hex
Z 0	0-01093-007	563002B00000	Heat Sinks
Z 0	1-00087-131	2 PIN JUMPER	Connector, Female

PTC231 front panel

C 101	5-00601-578	0.1UF - 16V X7R	SMT Ceramic Cap, all sizes
C 102	5-00601-578	0.1UF - 16V X7R	SMT Ceramic Cap, all sizes
C 103	5-00601-578	0.1UF - 16V X7R	SMT Ceramic Cap, all sizes
C 105	5-00601-578	0.1UF - 16V X7R	SMT Ceramic Cap, all sizes
C 106	5-00601-578	0.1UF - 16V X7R	SMT Ceramic Cap, all sizes
C 107	5-00601-578	0.1UF - 16V X7R	SMT Ceramic Cap, all sizes
C 108	5-00601-578	0.1UF - 16V X7R	SMT Ceramic Cap, all sizes
C 201	5-00601-578	0.1UF - 16V X7R	SMT Ceramic Cap, all sizes
C 202	5-00601-578	0.1UF - 16V X7R	SMT Ceramic Cap, all sizes
C 203	5-00601-578	0.1UF - 16V X7R	SMT Ceramic Cap, all sizes
C 205	5-00601-578	0.1UF - 16V X7R	SMT Ceramic Cap, all sizes
C 211	5-00604-578	0.01UF / 16V	SMT Ceramic Cap, all sizes
C 212	5-00604-578	0.01UF / 16V	SMT Ceramic Cap, all sizes
C 213	5-00604-578	0.01UF / 16V	SMT Ceramic Cap, all sizes
C 214	5-00604-578	0.01UF / 16V	SMT Ceramic Cap, all sizes
C 301	5-00519-569	.33U/T35	Cap, Tantalum, SMT (all case sizes)
C 302	5-00513-569	1U-16V A-CASE	Cap, Tantalum, SMT (all case sizes)
C 303	5-00513-569	1U-16V A-CASE	Cap, Tantalum, SMT (all case sizes)
C 305	5-00318-569	2.2U/T35	Cap, Tantalum, SMT (all case sizes)
C 306	5-00601-578	0.1UF - 16V X7R	SMT Ceramic Cap, all sizes
C 307	5-00518-569	15U/T35	Cap, Tantalum, SMT (all case sizes)
C 308	5-00299-568	.1U	Cap, Ceramic 50V SMT (1206), X7R
C 309	5-00375-552	100P	Capacitor, Chip (SMT1206), 50V, 5%, NPO
C 310	5-00601-578	0.1UF - 16V X7R	SMT Ceramic Cap, all sizes
C 311	5-00318-569	2.2U/T35	Cap, Tantalum, SMT (all case sizes)
C 312	5-00318-569	2.2U/T35	Cap, Tantalum, SMT (all case sizes)
C 321	5-00601-578	0.1UF - 16V X7R	SMT Ceramic Cap, all sizes
C 331	5-00407-568	.047U	Cap, Ceramic 50V SMT (1206), X7R
C 332	5-00395-568	4700P -5%	Cap, Ceramic 50V SMT (1206), X7R
C 341	5-00525-578	1U	SMT Ceramic Cap, all sizes
C 343	5-00601-578	0.1UF - 16V X7R	SMT Ceramic Cap, all sizes
C 350	5-00299-568	.1U	Cap, Ceramic 50V SMT (1206), X7R
D 101	3-00576-311	RED MINI	LED, Subminiature
D 201	3-00010-303	GREEN	LED, T1 Package
D 202	3-00010-303	GREEN	LED, T1 Package
D 203	3-00010-303	GREEN	LED, T1 Package
D 204	3-00010-303	GREEN	LED, T1 Package
D 205	3-00010-303	GREEN	LED, T1 Package
D 206	3-00010-303	GREEN	LED, T1 Package
D 301	3-00926-360	MBR0540T1	Integrated Circuit (Surface Mount Pkg)
D 302	3-00926-360	MBR0540T1	Integrated Circuit (Surface Mount Pkg)
D 341	3-00626-301	MUR1100E	Diode
IS350	3-00446-340	6N137	Integrated Circuit (Thru-hole Pkg)
J 101	1-00251-130	10 PIN DIL	Connector, Male
J 106	1-00166-130	60 PIN DIL	Connector, Male

J 201	1-00559-100	1.00MM FFC -SMT	Connector, Misc.
J 301	1-00006-130	2 PIN DI	Connector, Male
J 302	1-00363-130	4 PIN	Connector, Male
J 303	1-00573-130	1.25MM X 14PIN	Connector, Male
J 305	1-00515-130	2 PIN HEADER	Connector, Male
J 341	1-00599-114	3 PIN, WHITE	Header, Amp, MTA-100
JP304	1-00086-130	3 PIN SI	Connector, Male
L 301	6-00519-609	22UH - SMT	Inductor, Fixed, SMT
PC1	7-01713-701	PTC, F/P	Printed Circuit Board
Q 342	3-00629-329	IRF510	Voltage Reg., TO-220 (TAB) Package
R 104	4-01466-461	300	Thick Film, 5%, 200 ppm, Chip Resistor
R 105	4-01909-465	47K	Thick Film, 5%, 200ppm, 0603 Chip Res.
R 201	4-01909-465	47K	Thick Film, 5%, 200ppm, 0603 Chip Res.
R 202	4-01431-461	10	Thick Film, 5%, 200 ppm, Chip Resistor
R 203	4-01288-462	60.4K	Thin Film, 1%, 50 ppm, MELF Resistor
R 204	4-01213-462	10.0K	Thin Film, 1%, 50 ppm, MELF Resistor
R 301	4-01510-461	20K	Thick Film, 5%, 200 ppm, Chip Resistor
R 302	4-01510-461	20K	Thick Film, 5%, 200 ppm, Chip Resistor
R 304	4-01467-461	330	Thick Film, 5%, 200 ppm, Chip Resistor
R 306	4-01355-462	301K	Thin Film, 1%, 50 ppm, MELF Resistor
R 307	4-01551-461	1.0M	Thick Film, 5%, 200 ppm, Chip Resistor
R 308	4-01524-461	75K	Thick Film, 5%, 200 ppm, Chip Resistor
R 311	4-01414-461	2.0	Thick Film, 5%, 200 ppm, Chip Resistor
R 323	4-01575-461	10M	Thick Film, 5%, 200 ppm, Chip Resistor
R 324	4-01527-461	100K	Thick Film, 5%, 200 ppm, Chip Resistor
R 331	4-01479-461	1.0K	Thick Film, 5%, 200 ppm, Chip Resistor
R 332	4-01503-461	10K	Thick Film, 5%, 200 ppm, Chip Resistor
R 333	4-01495-461	4.7K	Thick Film, 5%, 200 ppm, Chip Resistor
R 334	4-01503-461	10K	Thick Film, 5%, 200 ppm, Chip Resistor
R 340	4-01406-461	0	Thick Film, 5%, 200 ppm, Chip Resistor
R 342	4-01517-461	39K	Thick Film, 5%, 200 ppm, Chip Resistor
R 343	4-01500-461	7.5K	Thick Film, 5%, 200 ppm, Chip Resistor
R 344	4-01503-461	10K	Thick Film, 5%, 200 ppm, Chip Resistor
R 349	4-01606-409	1.00	Resistor, Wire Wound
R 351	4-01471-461	470	Thick Film, 5%, 200 ppm, Chip Resistor
R 352	4-01471-461	470	Thick Film, 5%, 200 ppm, Chip Resistor
RN101	4-00910-463	1.0KX4D	Resistor network, SMT, Leadless
RN102	4-00905-463	82X4D	Resistor network, SMT, Leadless
RN103	4-00905-463	82X4D	Resistor network, SMT, Leadless
RN104	4-00905-463	82X4D	Resistor network, SMT, Leadless
RN105	4-01707-463	47KX4D	Resistor network, SMT, Leadless
RN201	4-01618-463	330X8D	Resistor network, SMT, Leadless
RN202	4-01707-463	47KX4D	Resistor network, SMT, Leadless
S 201	2-00065-201	12MM TACT SWITC	Switch, Momentary Push Button
S 201A	7-02036-735	BLK CAP	Injection Molded Plastic
S 202	2-00065-201	12MM TACT SWITC	Switch, Momentary Push Button
S 202A	7-02036-735	BLK CAP	Injection Molded Plastic
S 203	2-00065-201	12MM TACT SWITC	Switch, Momentary Push Button
S 203A	7-02036-735	BLK CAP	Injection Molded Plastic
S 204	2-00065-201	12MM TACT SWITC	Switch, Momentary Push Button
S 204A	7-02036-735	BLK CAP	Injection Molded Plastic
S 205	2-00065-201	12MM TACT SWITC	Switch, Momentary Push Button
S 205A	7-02036-735	BLK CAP	Injection Molded Plastic
S 206	2-00065-201	12MM TACT SWITC	Switch, Momentary Push Button
S 206A	7-02036-735	BLK CAP	Injection Molded Plastic
S 207	2-00065-201	12MM TACT SWITC	Switch, Momentary Push Button
S 207A	7-02036-735	BLK CAP	Injection Molded Plastic
S 208	2-00065-201	12MM TACT SWITC	Switch, Momentary Push Button
S 208A	7-02037-735	RED CAP	Injection Molded Plastic
U 101	3-01497-360	ATMEGA162-16AI	Integrated Circuit (Surface Mount Pkg)
U 102	3-01498-360	74ABT16245CMTD	Integrated Circuit (Surface Mount Pkg)
U 201	3-01215-360	MAX1234EGI	Integrated Circuit (Surface Mount Pkg)
U 202	3-00741-360	74HC04	Integrated Circuit (Surface Mount Pkg)
U 203	3-01216-360	HEF4794BTD	Integrated Circuit (Surface Mount Pkg)

U 301	3-01841-360	LM4871M	Integrated Circuit (Surface Mount Pkg)
U 302	8-00069-800	INVERTER 1000V	Miscellaneous
U 303	3-00966-360	IRF7103	Integrated Circuit (Surface Mount Pkg)
U 304	3-00959-360	MAX686EEE	Integrated Circuit (Surface Mount Pkg)
U 320	3-00663-360	74HC08	Integrated Circuit (Surface Mount Pkg)
U 340	3-00907-360	LM324A	Integrated Circuit (Surface Mount Pkg)
Z 0	1-00087-131	2 PIN JUMPER	Connector, Female

PTC240 GPIB option

C 111	5-00601-578	0.1UF - 16V X7R	SMT Ceramic Cap, all sizes
C 112	5-00601-578	0.1UF - 16V X7R	SMT Ceramic Cap, all sizes
C 113	5-00601-578	0.1UF - 16V X7R	SMT Ceramic Cap, all sizes
C 114	5-00601-578	0.1UF - 16V X7R	SMT Ceramic Cap, all sizes
C 121	5-00601-578	0.1UF - 16V X7R	SMT Ceramic Cap, all sizes
C 122	5-00601-578	0.1UF - 16V X7R	SMT Ceramic Cap, all sizes
C 123	5-00601-578	0.1UF - 16V X7R	SMT Ceramic Cap, all sizes
C 124	5-00601-578	0.1UF - 16V X7R	SMT Ceramic Cap, all sizes
C 131	5-00601-578	0.1UF - 16V X7R	SMT Ceramic Cap, all sizes
C 132	5-00601-578	0.1UF - 16V X7R	SMT Ceramic Cap, all sizes
C 133	5-00601-578	0.1UF - 16V X7R	SMT Ceramic Cap, all sizes
C 134	5-00601-578	0.1UF - 16V X7R	SMT Ceramic Cap, all sizes
C 135	5-00601-578	0.1UF - 16V X7R	SMT Ceramic Cap, all sizes
C 136	5-00601-578	0.1UF - 16V X7R	SMT Ceramic Cap, all sizes
C 137	5-00601-578	0.1UF - 16V X7R	SMT Ceramic Cap, all sizes
C 138	5-00601-578	0.1UF - 16V X7R	SMT Ceramic Cap, all sizes
C 139	5-00601-578	0.1UF - 16V X7R	SMT Ceramic Cap, all sizes
C 140	5-00601-578	0.1UF - 16V X7R	SMT Ceramic Cap, all sizes
C 150	5-00601-578	0.1UF - 16V X7R	SMT Ceramic Cap, all sizes
C 161	5-00601-578	0.1UF - 16V X7R	SMT Ceramic Cap, all sizes
C 162	5-00601-578	0.1UF - 16V X7R	SMT Ceramic Cap, all sizes
C 163	5-00601-578	0.1UF - 16V X7R	SMT Ceramic Cap, all sizes
J 100	1-01140-100	52837-1279	Connector, Misc.
J 140	1-00160-162	IEEE488/STAND.	Connector, IEEE488, Standard, R/A, Female
J 160	1-00251-130	10 PIN DIL	Connector, Male
PC1	7-01892-701	PTC240, GPIB	Printed Circuit Board
R 131	4-01406-461	0	Thick Film, 5%, 200 ppm, Chip Resistor
U 110	3-01236-360	74LCX16245MTD	Integrated Circuit (Surface Mount Pkg)
U 120	3-01236-360	74LCX16245MTD	Integrated Circuit (Surface Mount Pkg)
U 130	3-01019-360	TNT4882-BQ	Integrated Circuit (Surface Mount Pkg)
U 140	3-01742-360	74VCX245WM	Integrated Circuit (Surface Mount Pkg)
U 150	3-00741-360	74HC04	Integrated Circuit (Surface Mount Pkg)
U 160	3-01743-360	ISPGAL22V10AV	Integrated Circuit (Surface Mount Pkg)
Y 101	6-00756-621	40 MHZ	Crystal Oscillator
Z 0	0-00500-000	554043-1	Hardware, Misc.
Z 1	7-01736-720	PTC BRKT	Fabricated Part

PTC320 1-channel thermistor, diode, and RTD reader

C111	5-00601	0.1UF - 16V X7R	
C112	5-00601	0.1UF - 16V X7R	
C113	5-00601	0.1UF - 16V X7R	
C121	5-00601	0.1UF - 16V X7R	
C122	5-00601	0.1UF - 16V X7R	
C123	5-00601	0.1UF - 16V X7R	
C124	5-00601	0.1UF - 16V X7R	
C200	5-00752	10000P	Capacitor, Mono, 50V,+/-10%, X7R, 0603
C201	5-00752	10000P	Capacitor, Mono, 50V,+/-10%, X7R, 0603
C202	5-00752	10000P	Capacitor, Mono, 50V,+/-10%, X7R, 0603
C203	5-00752	10000P	Capacitor, Mono, 50V,+/-10%, X7R, 0603
C204	5-00752	10000P	Capacitor, Mono, 50V,+/-10%, X7R, 0603
C205	5-00752	10000P	Capacitor, Mono, 50V,+/-10%, X7R, 0603
C206	5-00752	10000P	Capacitor, Mono, 50V,+/-10%, X7R, 0603
C210	5-00601	0.1UF - 16V X7R	
C230	5-00601	0.1UF - 16V X7R	
C231	5-00601	0.1UF - 16V X7R	
C260	5-00601	0.1UF - 16V X7R	
C270	5-00601	0.1UF - 16V X7R	
C271	5-00526	22U-T16	SMD Tantalum, C-Case
C280	5-00601	0.1UF - 16V X7R	
C281	5-00601	0.1UF - 16V X7R	
C290	5-00513	1U-16V A-CASE	SMT Tantalum, 16V, A-case (1206, but NEEDS POLARITY mark)
C291	5-00525	1U	CAP 1UF 25V CERAMIC Y5V 1206 +80/ -20%
C292	5-00525	1U	CAP 1UF 25V CERAMIC Y5V 1206 +80/ -20%
C293	5-00525	1U	CAP 1UF 25V CERAMIC Y5V 1206 +80/ -20%
C294	5-00525	1U	CAP 1UF 25V CERAMIC Y5V 1206 +80/ -20%
C295	5-00654	.01UF X 4	
C300	5-00299	.1U	Capacitor, Mono, 50V, 10%, X7R, 1206
C310	5-00299	.1U	Capacitor, Mono, 50V, 10%, X7R, 1206
C311	5-00299	.1U	Capacitor, Mono, 50V, 10%, X7R, 1206
C330	5-00299	.1U	Capacitor, Mono, 50V, 10%, X7R, 1206
C340	5-00601	0.1UF - 16V X7R	
C345	5-00601	0.1UF - 16V X7R	
C351	5-00035	47U	Capacitor, Electrolytic, 25V, 20%, Rad
C352	5-00519	.33U/T35	SMD Tantalum, Y-Case
C353	5-00513	1U-16V A-CASE	SMT Tantalum, 16V, A-case (1206, but NEEDS POLARITY mark)
C361	5-00035	47U	Capacitor, Electrolytic, 25V, 20%, Rad
C362	5-00519	.33U/T35	SMD Tantalum, Y-Case
C363	5-00513	1U-16V A-CASE	SMT Tantalum, 16V, A-case (1206, but NEEDS POLARITY mark)
C371	5-00035	47U	Capacitor, Electrolytic, 25V, 20%, Rad
C372	5-00519	.33U/T35	SMD Tantalum, Y-Case
C373	5-00513	1U-16V A-CASE	SMT Tantalum, 16V, A-case (1206, but NEEDS POLARITY mark)
C411	5-00601	0.1UF - 16V X7R	
C421	5-00601	0.1UF - 16V X7R	
C521	5-00601	0.1UF - 16V X7R	
C522	5-00391	2200P	Capacitor, Mono, 50V, 5%, NPO, 1206
C531	5-00601	0.1UF - 16V X7R	
C611	5-00601	0.1UF - 16V X7R	
C612	5-00525	1U	CAP 1UF 25V CERAMIC Y5V 1206 +80/ -20%
C620	5-00601	0.1UF - 16V X7R	
C621	5-00601	0.1UF - 16V X7R	
C622	5-00601	0.1UF - 16V X7R	
C630	5-00601	0.1UF - 16V X7R	
C631	5-00601	0.1UF - 16V X7R	
C641	5-00740	1000P	Capacitor, Mono, 50V, ª0.25pF or 5%, NPO, 0603
C650	5-00601	0.1UF - 16V X7R	
C651	5-00601	0.1UF - 16V X7R	
C652	5-00752	10000P	Capacitor, Mono, 50V,+/-10%, X7R, 0603
C660	5-00601	0.1UF - 16V X7R	
C661	5-00601	0.1UF - 16V X7R	

C670	5-00601	0.1UF - 16V X7R	
C671	5-00601	0.1UF - 16V X7R	
C672	5-00601	0.1UF - 16V X7R	
C680	5-00601	0.1UF - 16V X7R	
C681	5-00601	0.1UF - 16V X7R	
C682	5-00740	1000P	Capacitor, Mono, 50V, ª0.25pF or 5%, NPO, 0603
D111	3-00011	RED	LED, T1 Package, 3mm diameter
D200	3-00945	BAT54S	Dual schottky diode, series connection
D201	3-01319	MMBD1503A	
D202	3-01319	MMBD1503A	
D203	3-01319	MMBD1503A	
D204	3-01319	MMBD1503A	
D641	3-01357	MMBZ5230	4.7V ZENER 5%
ISO310	3-01320	HCPL-2630	
ISO311	3-01320	HCPL-2630	
ISO330	3-01320	HCPL-2630	
J200	1-00281	10 PIN DI	Header, DIM
J260	1-01238	6 PIN	
JDR121	1-00234	96 PIN RT ANGLE	3 Row, Right Angle Mount
K430	3-01316	G6SK-2F-DC5	
K431	3-01316	G6SK-2F-DC5	
K432	3-01316	G6SK-2F-DC5	
K433	3-01316	G6SK-2F-DC5	
K434	3-01316	G6SK-2F-DC5	
K435	3-01316	G6SK-2F-DC5	
K436	3-01316	G6SK-2F-DC5	
K437	3-01316	G6SK-2F-DC5	
K438	3-01316	G6SK-2F-DC5	
K439	3-01316	G6SK-2F-DC5	
K440	3-01316	G6SK-2F-DC5	
K441	3-01316	G6SK-2F-DC5	
K442	3-01316	G6SK-2F-DC5	
K443	3-01316	G6SK-2F-DC5	
K444	3-01316	G6SK-2F-DC5	
K445	3-01316	G6SK-2F-DC5	
L351	6-00174	6611 TYPE 43	Ferite Bead, Thru-hole, Type 43
L352	6-00684	10UH	Inductor, SMD, Type R, 23MHz, 240mA, 10%, 1210
L361	6-00174	6611 TYPE 43	Ferite Bead, Thru-hole, Type 43
L362	6-00684	10UH	Inductor, SMD, Type R, 23MHz, 240mA, 10%, 1210
L371	6-00174	6611 TYPE 43	Ferite Bead, Thru-hole, Type 43
L372	6-00684	10UH	Inductor, SMD, Type R, 23MHz, 240mA, 10%, 1210
PCB	7-01705	PTC RTD/THERM	Printed circuit board
Q521	3-00601	MMBT3904LT1	MMBT3904LT1, 3904 NPN
R112	4-01466	300	Resistor, Thick Film, 5%, 200 ppm, SMT
R260	4-02253	10.0K	Resistor, Thin Film, 1%, 50 ppm, 1/16W 0603 Chip
R261	4-02253	10.0K	Resistor, Thin Film, 1%, 50 ppm, 1/16W 0603 Chip
R281	4-01948	2.0M	Resistor, Thick Film, 5%, 200 ppm, 1/16W, 0603 Chip
R282	4-01948	2.0M	Resistor, Thick Film, 5%, 200 ppm, 1/16W, 0603 Chip
R291	4-01519	47K	Resistor, Thick Film, 5%, 200 ppm, SMT
R391	4-01431	10	Resistor, Thick Film, 5%, 200 ppm, SMT
R392	4-01431	10	Resistor, Thick Film, 5%, 200 ppm, SMT
R393	4-01431	10	Resistor, Thick Film, 5%, 200 ppm, SMT
R394	4-01431	10	Resistor, Thick Film, 5%, 200 ppm, SMT
R430	4-02480	60 OHM	
R432	4-02481	200 OHM	
R434	4-01740	600 OHM	
R436	4-02482	2000 OHM	
R438	4-00678	6.040K	Resistor, Metal Film, 1/8W, 0.1%, 5ppm
R440	4-01742	PTF56-20K0-BT16	
R442	4-02483	60K	
R444	4-01743	PTF56-200K-BT16	
R611	4-01184	4.99K	Resistor, Thin Film, 1%, 50 ppm, MELF
R612	4-01146	2.00K	Resistor, Thin Film, 1%, 50 ppm, MELF
R613	4-01117	1.00K	Resistor, Thin Film, 1%, 50 ppm, MELF

R614	4-01117	1.00K	Resistor, Thin Film, 1%, 50 ppm, MELF
R615	4-01088	499	Resistor, Thin Film, 1%, 50 ppm, MELF
R616	4-01050	200	Resistor, Thin Film, 1%, 50 ppm, MELF
R617	4-01021	100	Resistor, Thin Film, 1%, 50 ppm, MELF
R618	4-01050	200	Resistor, Thin Film, 1%, 50 ppm, MELF
R631	4-01117	1.00K	Resistor, Thin Film, 1%, 50 ppm, MELF
R632	4-01309	100K	Resistor, Thin Film, 1%, 50 ppm, MELF
R633	4-00139	10.0M	Resistor, Metal Film, 1/8W, 1%, 50PPM
R641	4-00011	10K	Pot, Multi Turn, Top Adjust
R642	4-01655	500K - 2PPM	
R643	4-01869	1.0K	Resistor, Thick Film, 5%, 200 ppm, 1/16W, 0603 Chip
R644	4-01917	100K	Resistor, Thick Film, 5%, 200 ppm, 1/16W, 0603 Chip
R651	4-01869	1.0K	Resistor, Thick Film, 5%, 200 ppm, 1/16W, 0603 Chip
R652	4-02061	100	Resistor, Thin Film, 1%, 50 ppm, 1/16W 0603 Chip
R682	4-01917	100K	Resistor, Thick Film, 5%, 200 ppm, 1/16W, 0603 Chip
RN111	4-01707	47KX4D	
RN112	4-01707	47KX4D	
RN113	4-00910	1.0KX4D	Network, DIP, Isolated, 1/16W, 5%, Tiny
RN121	4-01707	47KX4D	
RN200	4-00916	47X4D	Network, DIP, Isolated, 1/16W, 5%, Tiny
RN201	4-00916	47X4D	Network, DIP, Isolated, 1/16W, 5%, Tiny
RN202	4-00916	47X4D	Network, DIP, Isolated, 1/16W, 5%, Tiny
RN203	4-00916	47X4D	Network, DIP, Isolated, 1/16W, 5%, Tiny
RN291	4-00911	4.7KX4D	Network, DIP, Isolated, 1/16W, 5%, Tiny
RN292	4-01764	10X4D	
RN310	4-00909	470X4D	Network, DIP, Isolated, 1/16W, 5%, Tiny
RN312	4-00911	4.7KX4D	Network, DIP, Isolated, 1/16W, 5%, Tiny
RN330	4-00909	470X4D	Network, DIP, Isolated, 1/16W, 5%, Tiny
RN332	4-00909	470X4D	Network, DIP, Isolated, 1/16W, 5%, Tiny
RN345	4-00911	4.7KX4D	Network, DIP, Isolated, 1/16W, 5%, Tiny
RN670	4-00910	1.0KX4D	Network, DIP, Isolated, 1/16W, 5%, Tiny
U110	3-01696	ATMEGA64-16AC	
U120	3-01498	74ABT16245CMTD	
U210	3-01940	MAX4644EUT-T	
U230	3-01941	MAX339CSE	
U260	3-01942	LTC6082CGN#PBF	
U270	3-01396	LT1027CCS8-5	LT1027C, Precision 5 V Reference, SO-8
U280	3-01963	MAX4674ESE+	
U281	3-01695	MAX4635EUB+	
U290	3-01500	LTC2440CGN	
U300	3-00663	74HC08	74HC08, Quad 2-Input AND Gate
U340	3-00787	74HC595	8 Bit Serial Input, Parallel Output Shift Register
U345	3-00787	74HC595	8 Bit Serial Input, Parallel Output Shift Register
U350	3-00814	78M05	
U360	3-01175	78M15	
U370	3-01176	79M15	
U410	3-01944	74HC238	
U420	3-01944	74HC238	
U430	3-01302	NUD3105DMT1	
U432	3-01302	NUD3105DMT1	
U434	3-01302	NUD3105DMT1	
U436	3-01302	NUD3105DMT1	
U438	3-01302	NUD3105DMT1	
U440	3-01302	NUD3105DMT1	
U442	3-01302	NUD3105DMT1	
U444	3-01302	NUD3105DMT1	
U520	3-01317	MAX6627MKA-T	
U610	3-00542	AD587JR	High precision 10 volt reference
U620	3-01386	DG408DY	Analog mux, 8-to-1, +/-15V okay, TTL compat.
U630	3-01941	MAX339CSE	
U640	3-01396	LT1027CCS8-5	LT1027C, Precision 5 V Reference, SO-8
U650	3-01398	OPA2131UJ	FET-input dual opamp, 4 MHz GBW
U660	3-01945	INA121UA	
U670	3-01945	INA121UA	

U680	3-01945	INA121UA
Z1	0-00306	4-40X3/16PP
Z2	0-00306	4-40X3/16PP
Z3	7-02096	PTC320 FLANGE

PTC321 4-channel RTD reader

C 111	5-00601-578	0.1UF - 16V X7R	SMT Ceramic Cap, all sizes
C 112	5-00601-578	0.1UF - 16V X7R	SMT Ceramic Cap, all sizes
C 113	5-00601-578	0.1UF - 16V X7R	SMT Ceramic Cap, all sizes
C 121	5-00601-578	0.1UF - 16V X7R	SMT Ceramic Cap, all sizes
C 122	5-00601-578	0.1UF - 16V X7R	SMT Ceramic Cap, all sizes
C 123	5-00601-578	0.1UF - 16V X7R	SMT Ceramic Cap, all sizes
C 124	5-00601-578	0.1UF - 16V X7R	SMT Ceramic Cap, all sizes
C 201	5-00399-568	.01U - 5%	Cap, Ceramic 50V SMT (1206), X7R
C 202	5-00399-568	.01U - 5%	Cap, Ceramic 50V SMT (1206), X7R
C 203	5-00399-568	.01U - 5%	Cap, Ceramic 50V SMT (1206), X7R
C 204	5-00399-568	.01U - 5%	Cap, Ceramic 50V SMT (1206), X7R
C 205	5-00399-568	.01U - 5%	Cap, Ceramic 50V SMT (1206), X7R
C 206	5-00399-568	.01U - 5%	Cap, Ceramic 50V SMT (1206), X7R
C 231	5-00299-568	.1U	Cap, Ceramic 50V SMT (1206), X7R
C 232	5-00299-568	.1U	Cap, Ceramic 50V SMT (1206), X7R
C 251	5-00299-568	.1U	Cap, Ceramic 50V SMT (1206), X7R
C 252	5-00299-568	.1U	Cap, Ceramic 50V SMT (1206), X7R
C 260	5-00299-568	.1U	Cap, Ceramic 50V SMT (1206), X7R
C 270	5-00299-568	.1U	Cap, Ceramic 50V SMT (1206), X7R
C 271	5-00526-569	22U-T16	Cap, Tantalum, SMT (all case sizes)
C 290	5-00513-569	1U-16V A-CASE	Cap, Tantalum, SMT (all case sizes)
C 291	5-00525-578	1U	SMT Ceramic Cap, all sizes
C 292	5-00525-578	1U	SMT Ceramic Cap, all sizes
C 293	5-00525-578	1U	SMT Ceramic Cap, all sizes
C 294	5-00525-578	1U	SMT Ceramic Cap, all sizes
C 295	5-00654-500	.01UF X 4	Capacitor, Misc.
C 301	5-00399-568	.01U - 5%	Cap, Ceramic 50V SMT (1206), X7R
C 302	5-00399-568	.01U - 5%	Cap, Ceramic 50V SMT (1206), X7R
C 303	5-00399-568	.01U - 5%	Cap, Ceramic 50V SMT (1206), X7R
C 304	5-00399-568	.01U - 5%	Cap, Ceramic 50V SMT (1206), X7R
C 305	5-00399-568	.01U - 5%	Cap, Ceramic 50V SMT (1206), X7R
C 306	5-00399-568	.01U - 5%	Cap, Ceramic 50V SMT (1206), X7R
C 351	5-00299-568	.1U	Cap, Ceramic 50V SMT (1206), X7R
C 352	5-00299-568	.1U	Cap, Ceramic 50V SMT (1206), X7R
C 360	5-00299-568	.1U	Cap, Ceramic 50V SMT (1206), X7R
C 370	5-00299-568	.1U	Cap, Ceramic 50V SMT (1206), X7R
C 371	5-00526-569	22U-T16	Cap, Tantalum, SMT (all case sizes)
C 390	5-00513-569	1U-16V A-CASE	Cap, Tantalum, SMT (all case sizes)
C 391	5-00525-578	1U	SMT Ceramic Cap, all sizes
C 392	5-00525-578	1U	SMT Ceramic Cap, all sizes
C 393	5-00525-578	1U	SMT Ceramic Cap, all sizes
C 394	5-00525-578	1U	SMT Ceramic Cap, all sizes
C 395	5-00654-500	.01UF X 4	Capacitor, Misc.
C 401	5-00399-568	.01U - 5%	Cap, Ceramic 50V SMT (1206), X7R
C 402	5-00399-568	.01U - 5%	Cap, Ceramic 50V SMT (1206), X7R
C 403	5-00399-568	.01U - 5%	Cap, Ceramic 50V SMT (1206), X7R
C 404	5-00399-568	.01U - 5%	Cap, Ceramic 50V SMT (1206), X7R
C 405	5-00399-568	.01U - 5%	Cap, Ceramic 50V SMT (1206), X7R
C 406	5-00399-568	.01U - 5%	Cap, Ceramic 50V SMT (1206), X7R
C 451	5-00299-568	.1U	Cap, Ceramic 50V SMT (1206), X7R
C 452	5-00299-568	.1U	Cap, Ceramic 50V SMT (1206), X7R
C 460	5-00299-568	.1U	Cap, Ceramic 50V SMT (1206), X7R
C 470	5-00299-568	.1U	Cap, Ceramic 50V SMT (1206), X7R
C 471	5-00526-569	22U-T16	Cap, Tantalum, SMT (all case sizes)
C 490	5-00513-569	1U-16V A-CASE	Cap, Tantalum, SMT (all case sizes)
C 491	5-00525-578	1U	SMT Ceramic Cap, all sizes

C 492	5-00525-578	1U	SMT Ceramic Cap, all sizes
C 493	5-00525-578	1U	SMT Ceramic Cap, all sizes
C 494	5-00525-578	1U	SMT Ceramic Cap, all sizes
C 495	5-00654-500	.01UF X 4	Capacitor, Misc.
C 501	5-00399-568	.01U - 5%	Cap, Ceramic 50V SMT (1206), X7R
C 502	5-00399-568	.01U - 5%	Cap, Ceramic 50V SMT (1206), X7R
C 503	5-00399-568	.01U - 5%	Cap, Ceramic 50V SMT (1206), X7R
C 504	5-00399-568	.01U - 5%	Cap, Ceramic 50V SMT (1206), X7R
C 505	5-00399-568	.01U - 5%	Cap, Ceramic 50V SMT (1206), X7R
C 506	5-00399-568	.01U - 5%	Cap, Ceramic 50V SMT (1206), X7R
C 551	5-00299-568	.1U	Cap, Ceramic 50V SMT (1206), X7R
C 552	5-00299-568	.1U	Cap, Ceramic 50V SMT (1206), X7R
C 560	5-00299-568	.1U	Cap, Ceramic 50V SMT (1206), X7R
C 570	5-00299-568	.1U	Cap, Ceramic 50V SMT (1206), X7R
C 571	5-00526-569	22U-T16	Cap, Tantalum, SMT (all case sizes)
C 590	5-00513-569	1U-16V A-CASE	Cap, Tantalum, SMT (all case sizes)
C 591	5-00525-578	1U	SMT Ceramic Cap, all sizes
C 592	5-00525-578	1U	SMT Ceramic Cap, all sizes
C 593	5-00525-578	1U	SMT Ceramic Cap, all sizes
C 594	5-00525-578	1U	SMT Ceramic Cap, all sizes
C 595	5-00654-500	.01UF X 4	Capacitor, Misc.
C 600	5-00299-568	.1U	Cap, Ceramic 50V SMT (1206), X7R
C 601	5-00299-568	.1U	Cap, Ceramic 50V SMT (1206), X7R
C 610	5-00299-568	.1U	Cap, Ceramic 50V SMT (1206), X7R
C 611	5-00299-568	.1U	Cap, Ceramic 50V SMT (1206), X7R
C 630	5-00299-568	.1U	Cap, Ceramic 50V SMT (1206), X7R
C 640	5-00299-568	.1U	Cap, Ceramic 50V SMT (1206), X7R
C 651	5-00035-521	47U	Capacitor, Electrolytic, 25V, 20%, Rad
C 652	5-00519-569	.33U/T35	Cap, Tantalum, SMT (all case sizes)
C 653	5-00513-569	1U-16V A-CASE	Cap, Tantalum, SMT (all case sizes)
C 661	5-00035-521	47U	Capacitor, Electrolytic, 25V, 20%, Rad
C 662	5-00519-569	.33U/T35	Cap, Tantalum, SMT (all case sizes)
C 663	5-00513-569	1U-16V A-CASE	Cap, Tantalum, SMT (all case sizes)
C 671	5-00035-521	47U	Capacitor, Electrolytic, 25V, 20%, Rad
C 672	5-00519-569	.33U/T35	Cap, Tantalum, SMT (all case sizes)
C 673	5-00513-569	1U-16V A-CASE	Cap, Tantalum, SMT (all case sizes)
C 681	5-00299-568	.1U	Cap, Ceramic 50V SMT (1206), X7R
C 682	5-00525-578	1U	SMT Ceramic Cap, all sizes
C 721	5-00299-568	.1U	Cap, Ceramic 50V SMT (1206), X7R
C 722	5-00391-552	2200P	Capacitor, Chip (SMT1206), 50V, 5%, NPO
D 111	3-00011-303	RED	LED, T1 Package
D 201	3-01319-360	MMBD1503A	Integrated Circuit (Surface Mount Pkg)
D 202	3-01319-360	MMBD1503A	Integrated Circuit (Surface Mount Pkg)
D 203	3-01319-360	MMBD1503A	Integrated Circuit (Surface Mount Pkg)
D 204	3-01319-360	MMBD1503A	Integrated Circuit (Surface Mount Pkg)
D 301	3-01319-360	MMBD1503A	Integrated Circuit (Surface Mount Pkg)
D 302	3-01319-360	MMBD1503A	Integrated Circuit (Surface Mount Pkg)
D 303	3-01319-360	MMBD1503A	Integrated Circuit (Surface Mount Pkg)
D 304	3-01319-360	MMBD1503A	Integrated Circuit (Surface Mount Pkg)
D 401	3-01319-360	MMBD1503A	Integrated Circuit (Surface Mount Pkg)
D 402	3-01319-360	MMBD1503A	Integrated Circuit (Surface Mount Pkg)
D 403	3-01319-360	MMBD1503A	Integrated Circuit (Surface Mount Pkg)
D 404	3-01319-360	MMBD1503A	Integrated Circuit (Surface Mount Pkg)
D 501	3-01319-360	MMBD1503A	Integrated Circuit (Surface Mount Pkg)
D 502	3-01319-360	MMBD1503A	Integrated Circuit (Surface Mount Pkg)
D 503	3-01319-360	MMBD1503A	Integrated Circuit (Surface Mount Pkg)
D 504	3-01319-360	MMBD1503A	Integrated Circuit (Surface Mount Pkg)
IS610	3-01320-340	HCPL-2630	Integrated Circuit (Thru-hole Pkg)
IS611	3-01320-340	HCPL-2630	Integrated Circuit (Thru-hole Pkg)
IS630	3-01320-340	HCPL-2630	Integrated Circuit (Thru-hole Pkg)
J 111	1-00251-130	10 PIN DIL	Connector, Male
J 200	1-01099-100	161417	Connector, Misc.
J 300	1-01099-100	161417	Connector, Misc.
J 400	1-01099-100	161417	Connector, Misc.

J 500	1-01099-100	161417	Connector, Misc.
JD121	1-00234-109	96 PIN RT ANGLE	DIN Connector, Male
L 651	6-00174-630	6611 TYPE 43	Ferrite Beads
L 652	6-00684-609	10UH	Inductor, Fixed, SMT
L 661	6-00174-630	6611 TYPE 43	Ferrite Beads
L 662	6-00684-609	10UH	Inductor, Fixed, SMT
L 671	6-00174-630	6611 TYPE 43	Ferrite Beads
L 672	6-00684-609	10UH	Inductor, Fixed, SMT
PC1	7-01811-701	PTC RTD READER	Printed Circuit Board
Q 231	3-01073-360	MMBTA64LT1	Integrated Circuit (Surface Mount Pkg)
Q 331	3-01073-360	MMBTA64LT1	Integrated Circuit (Surface Mount Pkg)
Q 431	3-01073-360	MMBTA64LT1	Integrated Circuit (Surface Mount Pkg)
Q 531	3-01073-360	MMBTA64LT1	Integrated Circuit (Surface Mount Pkg)
Q 721	3-00601-360	MMBT3904LT1	Integrated Circuit (Surface Mount Pkg)
R 112	4-01466-461	300	Thick Film, 5%, 200 ppm, Chip Resistor
R 200	4-01740-400	600 OHM / .1%	Resistor, Misc.
R 230	4-01184-462	4.99K	Thin Film, 1%, 50 ppm, MELF Resistor
R 291	4-01519-461	47K	Thick Film, 5%, 200 ppm, Chip Resistor
R 292	4-01431-461	10	Thick Film, 5%, 200 ppm, Chip Resistor
R 300	4-01740-400	600 OHM / .1%	Resistor, Misc.
R 330	4-01184-462	4.99K	Thin Film, 1%, 50 ppm, MELF Resistor
R 391	4-01519-461	47K	Thick Film, 5%, 200 ppm, Chip Resistor
R 392	4-01431-461	10	Thick Film, 5%, 200 ppm, Chip Resistor
R 400	4-01740-400	600 OHM / .1%	Resistor, Misc.
R 430	4-01184-462	4.99K	Thin Film, 1%, 50 ppm, MELF Resistor
R 491	4-01519-461	47K	Thick Film, 5%, 200 ppm, Chip Resistor
R 492	4-01431-461	10	Thick Film, 5%, 200 ppm, Chip Resistor
R 500	4-01740-400	600 OHM / .1%	Resistor, Misc.
R 530	4-01184-462	4.99K	Thin Film, 1%, 50 ppm, MELF Resistor
R 591	4-01519-461	47K	Thick Film, 5%, 200 ppm, Chip Resistor
R 592	4-01431-461	10	Thick Film, 5%, 200 ppm, Chip Resistor
R 681	4-01184-462	4.99K	Thin Film, 1%, 50 ppm, MELF Resistor
R 682	4-01184-462	4.99K	Thin Film, 1%, 50 ppm, MELF Resistor
RN111	4-01707-463	47KX4D	Resistor network, SMT, Leadless
RN112	4-01707-463	47KX4D	Resistor network, SMT, Leadless
RN113	4-00910-463	1.0KX4D	Resistor network, SMT, Leadless
RN121	4-01707-463	47KX4D	Resistor network, SMT, Leadless
RN201	4-00916-463	47X4D	Resistor network, SMT, Leadless
RN202	4-00916-463	47X4D	Resistor network, SMT, Leadless
RN203	4-00916-463	47X4D	Resistor network, SMT, Leadless
RN291	4-00911-463	4.7KX4D	Resistor network, SMT, Leadless
RN292	4-01764-463	10X4D	Resistor network, SMT, Leadless
RN301	4-00916-463	47X4D	Resistor network, SMT, Leadless
RN302	4-00916-463	47X4D	Resistor network, SMT, Leadless
RN303	4-00916-463	47X4D	Resistor network, SMT, Leadless
RN391	4-00911-463	4.7KX4D	Resistor network, SMT, Leadless
RN392	4-01764-463	10X4D	Resistor network, SMT, Leadless
RN401	4-00916-463	47X4D	Resistor network, SMT, Leadless
RN402	4-00916-463	47X4D	Resistor network, SMT, Leadless
RN403	4-00916-463	47X4D	Resistor network, SMT, Leadless
RN491	4-00911-463	4.7KX4D	Resistor network, SMT, Leadless
RN492	4-01764-463	10X4D	Resistor network, SMT, Leadless
RN501	4-00916-463	47X4D	Resistor network, SMT, Leadless
RN502	4-00916-463	47X4D	Resistor network, SMT, Leadless
RN503	4-00916-463	47X4D	Resistor network, SMT, Leadless
RN591	4-00911-463	4.7KX4D	Resistor network, SMT, Leadless
RN592	4-01764-463	10X4D	Resistor network, SMT, Leadless
RN610	4-00909-463	470X4D	Resistor network, SMT, Leadless
RN612	4-00909-463	470X4D	Resistor network, SMT, Leadless
RN630	4-00909-463	470X4D	Resistor network, SMT, Leadless
RN632	4-00909-463	470X4D	Resistor network, SMT, Leadless
U 110	3-01696-360	ATMEGA64-16AC	Integrated Circuit (Surface Mount Pkg)
U 120	3-01498-360	74ABT16245CMTD	Integrated Circuit (Surface Mount Pkg)
U 230	3-01364-360	OPA4277UA	Integrated Circuit (Surface Mount Pkg)

U 251	3-01695-360	MAX4635EUB+	Integrated Circuit (Surface Mount Pkg)
U 252	3-01695-360	MAX4635EUB+	Integrated Circuit (Surface Mount Pkg)
U 260	3-01822-360	LTC2052CS	Integrated Circuit (Surface Mount Pkg)
U 290	3-01500-360	LTC2440CGN	Integrated Circuit (Surface Mount Pkg)
U 351	3-01695-360	MAX4635EUB+	Integrated Circuit (Surface Mount Pkg)
U 352	3-01695-360	MAX4635EUB+	Integrated Circuit (Surface Mount Pkg)
U 360	3-01822-360	LTC2052CS	Integrated Circuit (Surface Mount Pkg)
U 390	3-01500-360	LTC2440CGN	Integrated Circuit (Surface Mount Pkg)
U 451	3-01695-360	MAX4635EUB+	Integrated Circuit (Surface Mount Pkg)
U 452	3-01695-360	MAX4635EUB+	Integrated Circuit (Surface Mount Pkg)
U 460	3-01822-360	LTC2052CS	Integrated Circuit (Surface Mount Pkg)
U 490	3-01500-360	LTC2440CGN	Integrated Circuit (Surface Mount Pkg)
U 551	3-01695-360	MAX4635EUB+	Integrated Circuit (Surface Mount Pkg)
U 552	3-01695-360	MAX4635EUB+	Integrated Circuit (Surface Mount Pkg)
U 560	3-01822-360	LTC2052CS	Integrated Circuit (Surface Mount Pkg)
U 590	3-01500-360	LTC2440CGN	Integrated Circuit (Surface Mount Pkg)
U 600	3-00663-360	74HC08	Integrated Circuit (Surface Mount Pkg)
U 601	3-00749-360	74HC541	Integrated Circuit (Surface Mount Pkg)
U 640	3-00787-360	74HC595	Integrated Circuit (Surface Mount Pkg)
U 650	3-00814-360	78M05	Integrated Circuit (Surface Mount Pkg)
U 660	3-01175-360	78M15	Integrated Circuit (Surface Mount Pkg)
U 670	3-01176-360	79M15	Integrated Circuit (Surface Mount Pkg)
U 680	3-00542-360	AD587JR	Integrated Circuit (Surface Mount Pkg)
U 720	3-01317-360	MAX6627MKA-T	Integrated Circuit (Surface Mount Pkg)
Z 0	0-00306-026	4-40X3/16PP	Screw, Black, All Types
Z 0	1-01106-100	1690450000	Connector, Misc.
Z 0	7-01888-720	PTC-BRACKET	Fabricated Part
Z 0	7-01920-720	PTC10	Fabricated Part

PTC330 thermocouple reader

C 111	5-00601-578	0.1UF - 16V X7R	SMT Ceramic Cap, all sizes
C 112	5-00601-578	0.1UF - 16V X7R	SMT Ceramic Cap, all sizes
C 113	5-00601-578	0.1UF - 16V X7R	SMT Ceramic Cap, all sizes
C 121	5-00601-578	0.1UF - 16V X7R	SMT Ceramic Cap, all sizes
C 122	5-00601-578	0.1UF - 16V X7R	SMT Ceramic Cap, all sizes
C 123	5-00601-578	0.1UF - 16V X7R	SMT Ceramic Cap, all sizes
C 124	5-00601-578	0.1UF - 16V X7R	SMT Ceramic Cap, all sizes
C 200	5-00299-568	.1U	Cap, Ceramic 50V SMT (1206), X7R
C 201	5-00389-552	1500P	Capacitor, Chip (SMT1206), 50V, 5%, NPO
C 202	5-00389-552	1500P	Capacitor, Chip (SMT1206), 50V, 5%, NPO
C 203	5-00528-568	2.2U	Cap, Ceramic 50V SMT (1206), X7R
C 205	5-00654-500	.01UF X 4	Capacitor, Misc.
C 206	5-00525-578	1U	SMT Ceramic Cap, all sizes
C 207	5-00525-578	1U	SMT Ceramic Cap, all sizes
C 208	5-00525-578	1U	SMT Ceramic Cap, all sizes
C 210	5-00299-568	.1U	Cap, Ceramic 50V SMT (1206), X7R
C 211	5-00513-569	1U-16V A-CASE	Cap, Tantalum, SMT (all case sizes)
C 220	5-00299-568	.1U	Cap, Ceramic 50V SMT (1206), X7R
C 230	5-00299-568	.1U	Cap, Ceramic 50V SMT (1206), X7R
C 240	5-00299-568	.1U	Cap, Ceramic 50V SMT (1206), X7R
C 250	5-00299-568	.1U	Cap, Ceramic 50V SMT (1206), X7R
C 260	5-00513-569	1U-16V A-CASE	Cap, Tantalum, SMT (all case sizes)
C 261	5-00519-569	.33U/T35	Cap, Tantalum, SMT (all case sizes)
C 262	5-00628-569	22U - 35V	Cap, Tantalum, SMT (all case sizes)
C 264	5-00381-552	330P	Capacitor, Chip (SMT1206), 50V, 5%, NPO
C 270	5-00299-568	.1U	Cap, Ceramic 50V SMT (1206), X7R
C 300	5-00299-568	.1U	Cap, Ceramic 50V SMT (1206), X7R
C 301	5-00389-552	1500P	Capacitor, Chip (SMT1206), 50V, 5%, NPO
C 302	5-00389-552	1500P	Capacitor, Chip (SMT1206), 50V, 5%, NPO
C 303	5-00528-568	2.2U	Cap, Ceramic 50V SMT (1206), X7R
C 305	5-00654-500	.01UF X 4	Capacitor, Misc.
C 306	5-00525-578	1U	SMT Ceramic Cap, all sizes

C 307	5-00525-578	1U	SMT Ceramic Cap, all sizes
C 308	5-00525-578	1U	SMT Ceramic Cap, all sizes
C 310	5-00299-568	.1U	Cap, Ceramic 50V SMT (1206), X7R
C 311	5-00513-569	1U-16V A-CASE	Cap, Tantalum, SMT (all case sizes)
C 320	5-00299-568	.1U	Cap, Ceramic 50V SMT (1206), X7R
C 330	5-00299-568	.1U	Cap, Ceramic 50V SMT (1206), X7R
C 340	5-00299-568	.1U	Cap, Ceramic 50V SMT (1206), X7R
C 360	5-00513-569	1U-16V A-CASE	Cap, Tantalum, SMT (all case sizes)
C 361	5-00519-569	.33U/T35	Cap, Tantalum, SMT (all case sizes)
C 362	5-00628-569	22U - 35V	Cap, Tantalum, SMT (all case sizes)
C 364	5-00381-552	330P	Capacitor, Chip (SMT1206), 50V, 5%, NPO
C 400	5-00299-568	.1U	Cap, Ceramic 50V SMT (1206), X7R
C 401	5-00389-552	1500P	Capacitor, Chip (SMT1206), 50V, 5%, NPO
C 402	5-00389-552	1500P	Capacitor, Chip (SMT1206), 50V, 5%, NPO
C 403	5-00528-568	2.2U	Cap, Ceramic 50V SMT (1206), X7R
C 405	5-00654-500	.01UF X 4	Capacitor, Misc.
C 406	5-00525-578	1U	SMT Ceramic Cap, all sizes
C 407	5-00525-578	1U	SMT Ceramic Cap, all sizes
C 408	5-00525-578	1U	SMT Ceramic Cap, all sizes
C 410	5-00299-568	.1U	Cap, Ceramic 50V SMT (1206), X7R
C 411	5-00513-569	1U-16V A-CASE	Cap, Tantalum, SMT (all case sizes)
C 420	5-00299-568	.1U	Cap, Ceramic 50V SMT (1206), X7R
C 430	5-00299-568	.1U	Cap, Ceramic 50V SMT (1206), X7R
C 440	5-00299-568	.1U	Cap, Ceramic 50V SMT (1206), X7R
C 450	5-00299-568	.1U	Cap, Ceramic 50V SMT (1206), X7R
C 460	5-00513-569	1U-16V A-CASE	Cap, Tantalum, SMT (all case sizes)
C 461	5-00519-569	.33U/T35	Cap, Tantalum, SMT (all case sizes)
C 462	5-00628-569	22U - 35V	Cap, Tantalum, SMT (all case sizes)
C 464	5-00381-552	330P	Capacitor, Chip (SMT1206), 50V, 5%, NPO
C 500	5-00299-568	.1U	Cap, Ceramic 50V SMT (1206), X7R
C 501	5-00389-552	1500P	Capacitor, Chip (SMT1206), 50V, 5%, NPO
C 502	5-00389-552	1500P	Capacitor, Chip (SMT1206), 50V, 5%, NPO
C 503	5-00528-568	2.2U	Cap, Ceramic 50V SMT (1206), X7R
C 505	5-00654-500	.01UF X 4	Capacitor, Misc.
C 506	5-00525-578	1U	SMT Ceramic Cap, all sizes
C 507	5-00525-578	1U	SMT Ceramic Cap, all sizes
C 508	5-00525-578	1U	SMT Ceramic Cap, all sizes
C 510	5-00299-568	.1U	Cap, Ceramic 50V SMT (1206), X7R
C 511	5-00513-569	1U-16V A-CASE	Cap, Tantalum, SMT (all case sizes)
C 520	5-00299-568	.1U	Cap, Ceramic 50V SMT (1206), X7R
C 530	5-00299-568	.1U	Cap, Ceramic 50V SMT (1206), X7R
C 540	5-00299-568	.1U	Cap, Ceramic 50V SMT (1206), X7R
C 560	5-00513-569	1U-16V A-CASE	Cap, Tantalum, SMT (all case sizes)
C 561	5-00519-569	.33U/T35	Cap, Tantalum, SMT (all case sizes)
C 562	5-00628-569	22U - 35V	Cap, Tantalum, SMT (all case sizes)
C 564	5-00381-552	330P	Capacitor, Chip (SMT1206), 50V, 5%, NPO
C 610	5-00299-568	.1U	Cap, Ceramic 50V SMT (1206), X7R
C 611	5-00319-569	10U/T35	Cap, Tantalum, SMT (all case sizes)
C 612	5-00387-552	1000P	Capacitor, Chip (SMT1206), 50V, 5%, NPO
C 613	5-00299-568	.1U	Cap, Ceramic 50V SMT (1206), X7R
C 614	5-00381-552	330P	Capacitor, Chip (SMT1206), 50V, 5%, NPO
C 616	5-00519-569	.33U/T35	Cap, Tantalum, SMT (all case sizes)
C 621	5-00329-526	120U	Capacitor, Electrolytic, 35V, 20%, Rad
C 630	5-00299-568	.1U	Cap, Ceramic 50V SMT (1206), X7R
C 701	5-00790-578	1UF - 0603	SMT Ceramic Cap, all sizes
C 702	5-00790-578	1UF - 0603	SMT Ceramic Cap, all sizes
C 710	5-00470-569	2.2U/T16	Cap, Tantalum, SMT (all case sizes)
C 711	5-00790-578	1UF - 0603	SMT Ceramic Cap, all sizes
C 720	5-00299-568	.1U	Cap, Ceramic 50V SMT (1206), X7R
C 720	5-00601-578	0.1UF - 16V X7R	SMT Ceramic Cap, all sizes
C 730	5-00299-568	.1U	Cap, Ceramic 50V SMT (1206), X7R
C 740	5-00299-568	.1U	Cap, Ceramic 50V SMT (1206), X7R
C 750	5-00299-568	.1U	Cap, Ceramic 50V SMT (1206), X7R
C 760	5-00513-569	1U-16V A-CASE	Cap, Tantalum, SMT (all case sizes)

C 761	5-00519-569	.33U/T35	Cap, Tantalum, SMT (all case sizes)
C 762	5-00035-521	47U	Capacitor, Electrolytic, 25V, 20%, Rad
C 770	5-00601-578	0.1UF - 16V X7R	SMT Ceramic Cap, all sizes
C 771	5-00654-500	.01UF X 4	Capacitor, Misc.
C 772	5-00790-578	1UF - 0603	SMT Ceramic Cap, all sizes
C 773	5-00790-578	1UF - 0603	SMT Ceramic Cap, all sizes
C 774	5-00790-578	1UF - 0603	SMT Ceramic Cap, all sizes
C 775	5-00790-578	1UF - 0603	SMT Ceramic Cap, all sizes
C 780	5-00601-578	0.1UF - 16V X7R	SMT Ceramic Cap, all sizes
D 111	3-00011-303	RED	LED, T1 Package
D 201	3-01319-360	MMBD1503A	Integrated Circuit (Surface Mount Pkg)
D 202	3-01319-360	MMBD1503A	Integrated Circuit (Surface Mount Pkg)
D 261	3-00010-303	GREEN	LED, T1 Package
D 262	3-01303-313	B340LA-13-F	Diode, SMT
D 301	3-01319-360	MMBD1503A	Integrated Circuit (Surface Mount Pkg)
D 302	3-01319-360	MMBD1503A	Integrated Circuit (Surface Mount Pkg)
D 361	3-00010-303	GREEN	LED, T1 Package
D 362	3-01303-313	B340LA-13-F	Diode, SMT
D 401	3-01319-360	MMBD1503A	Integrated Circuit (Surface Mount Pkg)
D 402	3-01319-360	MMBD1503A	Integrated Circuit (Surface Mount Pkg)
D 461	3-00010-303	GREEN	LED, T1 Package
D 462	3-01303-313	B340LA-13-F	Diode, SMT
D 501	3-01319-360	MMBD1503A	Integrated Circuit (Surface Mount Pkg)
D 502	3-01319-360	MMBD1503A	Integrated Circuit (Surface Mount Pkg)
D 561	3-00010-303	GREEN	LED, T1 Package
D 562	3-01303-313	B340LA-13-F	Diode, SMT
D 614	3-00380-301	1N5248	Diode
D 615	3-00926-360	MBR0540T1	Integrated Circuit (Surface Mount Pkg)
IS230	3-01320-340	HCPL-2630	Integrated Circuit (Thru-hole Pkg)
IS240	3-00446-340	6N137	Integrated Circuit (Thru-hole Pkg)
IS330	3-01320-340	HCPL-2630	Integrated Circuit (Thru-hole Pkg)
IS340	3-00446-340	6N137	Integrated Circuit (Thru-hole Pkg)
IS430	3-01320-340	HCPL-2630	Integrated Circuit (Thru-hole Pkg)
IS440	3-00446-340	6N137	Integrated Circuit (Thru-hole Pkg)
IS530	3-01320-340	HCPL-2630	Integrated Circuit (Thru-hole Pkg)
IS540	3-00446-340	6N137	Integrated Circuit (Thru-hole Pkg)
IS730	3-01320-340	HCPL-2630	Integrated Circuit (Thru-hole Pkg)
IS740	3-00446-340	6N137	Integrated Circuit (Thru-hole Pkg)
J 111	1-00251-130	10 PIN DIL	Connector, Male
J 201	1-00006-130	2 PIN DI	Connector, Male
J 301	1-00006-130	2 PIN DI	Connector, Male
J 401	1-00006-130	2 PIN DI	Connector, Male
J 501	1-00006-130	2 PIN DI	Connector, Male
JD121	1-00234-109	96 PIN RT ANGLE	DIN Connector, Male
L 621	6-00174-630	6611 TYPE 43	Ferrite Beads
L 622	6-00684-609	10UH	Inductor, Fixed, SMT
L 761	6-00174-630	6611 TYPE 43	Ferrite Beads
L 762	6-00684-609	10UH	Inductor, Fixed, SMT
PC1	7-01707-701	PTC, THRMCPL RD	Printed Circuit Board
Q 780	3-01073-360	MMBTA64LT1	Integrated Circuit (Surface Mount Pkg)
R 112	4-01466-461	300	Thick Film, 5%, 200 ppm, Chip Resistor
R 201	4-01431-461	10	Thick Film, 5%, 200 ppm, Chip Resistor
R 202	4-01575-461	10M	Thick Film, 5%, 200 ppm, Chip Resistor
R 261	4-01466-461	300	Thick Film, 5%, 200 ppm, Chip Resistor
R 262	4-01455-461	100	Thick Film, 5%, 200 ppm, Chip Resistor
R 301	4-01431-461	10	Thick Film, 5%, 200 ppm, Chip Resistor
R 302	4-01575-461	10M	Thick Film, 5%, 200 ppm, Chip Resistor
R 361	4-01466-461	300	Thick Film, 5%, 200 ppm, Chip Resistor
R 362	4-01455-461	100	Thick Film, 5%, 200 ppm, Chip Resistor
R 401	4-01431-461	10	Thick Film, 5%, 200 ppm, Chip Resistor
R 402	4-01575-461	10M	Thick Film, 5%, 200 ppm, Chip Resistor
R 461	4-01466-461	300	Thick Film, 5%, 200 ppm, Chip Resistor
R 462	4-01455-461	100	Thick Film, 5%, 200 ppm, Chip Resistor
R 501	4-01431-461	10	Thick Film, 5%, 200 ppm, Chip Resistor

R 502	4-01575-461	10M	Thick Film, 5%, 200 ppm, Chip Resistor
R 561	4-01466-461	300	Thick Film, 5%, 200 ppm, Chip Resistor
R 562	4-01455-461	100	Thick Film, 5%, 200 ppm, Chip Resistor
R 600	4-01406-461	0	Thick Film, 5%, 200 ppm, Chip Resistor
R 611	4-01270-462	39.2K	Thin Film, 1%, 50 ppm, MELF Resistor
R 612	4-01210-462	9.31K	Thin Film, 1%, 50 ppm, MELF Resistor
R 613	4-01163-462	3.01K	Thin Film, 1%, 50 ppm, MELF Resistor
R 614	4-01009-462	75.0	Thin Film, 1%, 50 ppm, MELF Resistor
R 701	4-01744-400	S102K-300R00-.1	Resistor, Misc.
R 702	4-02061-466	100	Thin Film, 1%, 50ppm, 0603 Chip Resistor
R 781	4-02195-466	2.49K	Thin Film, 1%, 50ppm, 0603 Chip Resistor
R 782	4-02224-466	4.99K	Thin Film, 1%, 50ppm, 0603 Chip Resistor
R 783	4-02224-466	4.99K	Thin Film, 1%, 50ppm, 0603 Chip Resistor
RN111	4-00911-463	4.7KX4D	Resistor network, SMT, Leadless
RN113	4-00910-463	1.0KX4D	Resistor network, SMT, Leadless
RN121	4-01707-463	47KX4D	Resistor network, SMT, Leadless
RN201	4-00916-463	47X4D	Resistor network, SMT, Leadless
RN205	4-00911-463	4.7KX4D	Resistor network, SMT, Leadless
RN206	4-01764-463	10X4D	Resistor network, SMT, Leadless
RN231	4-00909-463	470X4D	Resistor network, SMT, Leadless
RN232	4-00909-463	470X4D	Resistor network, SMT, Leadless
RN301	4-00916-463	47X4D	Resistor network, SMT, Leadless
RN305	4-00911-463	4.7KX4D	Resistor network, SMT, Leadless
RN306	4-01764-463	10X4D	Resistor network, SMT, Leadless
RN331	4-00909-463	470X4D	Resistor network, SMT, Leadless
RN332	4-00909-463	470X4D	Resistor network, SMT, Leadless
RN401	4-00916-463	47X4D	Resistor network, SMT, Leadless
RN405	4-00911-463	4.7KX4D	Resistor network, SMT, Leadless
RN406	4-01764-463	10X4D	Resistor network, SMT, Leadless
RN431	4-00909-463	470X4D	Resistor network, SMT, Leadless
RN501	4-00916-463	47X4D	Resistor network, SMT, Leadless
RN505	4-00911-463	4.7KX4D	Resistor network, SMT, Leadless
RN506	4-01764-463	10X4D	Resistor network, SMT, Leadless
RN531	4-00909-463	470X4D	Resistor network, SMT, Leadless
RN532	4-00909-463	470X4D	Resistor network, SMT, Leadless
RN700	4-01765-463	0KX4D	Resistor network, SMT, Leadless
RN731	4-00909-463	470X4D	Resistor network, SMT, Leadless
RN732	4-00909-463	470X4D	Resistor network, SMT, Leadless
RN771	4-00911-463	4.7KX4D	Resistor network, SMT, Leadless
RN772	4-01764-463	10X4D	Resistor network, SMT, Leadless
T 600	6-00683-610	VP1-0190	Transformer
U 110	3-01696-360	ATMEGA64-16AC	Integrated Circuit (Surface Mount Pkg)
U 120	3-01498-360	74ABT16245CMTD	Integrated Circuit (Surface Mount Pkg)
U 200	3-01697-360	LTC2051CS8#PBF	Integrated Circuit (Surface Mount Pkg)
U 210	3-01698-360	LM4140ACM-1.0	Integrated Circuit (Surface Mount Pkg)
U 220	3-01500-360	LTC2440CGN	Integrated Circuit (Surface Mount Pkg)
U 250	3-00663-360	74HC08	Integrated Circuit (Surface Mount Pkg)
U 260	3-00814-360	78M05	Integrated Circuit (Surface Mount Pkg)
U 270	3-00741-360	74HC04	Integrated Circuit (Surface Mount Pkg)
U 300	3-01697-360	LTC2051CS8#PBF	Integrated Circuit (Surface Mount Pkg)
U 310	3-01698-360	LM4140ACM-1.0	Integrated Circuit (Surface Mount Pkg)
U 320	3-01500-360	LTC2440CGN	Integrated Circuit (Surface Mount Pkg)
U 360	3-00814-360	78M05	Integrated Circuit (Surface Mount Pkg)
U 400	3-01697-360	LTC2051CS8#PBF	Integrated Circuit (Surface Mount Pkg)
U 410	3-01698-360	LM4140ACM-1.0	Integrated Circuit (Surface Mount Pkg)
U 420	3-01500-360	LTC2440CGN	Integrated Circuit (Surface Mount Pkg)
U 450	3-00663-360	74HC08	Integrated Circuit (Surface Mount Pkg)
U 460	3-00814-360	78M05	Integrated Circuit (Surface Mount Pkg)
U 500	3-01697-360	LTC2051CS8#PBF	Integrated Circuit (Surface Mount Pkg)
U 510	3-01698-360	LM4140ACM-1.0	Integrated Circuit (Surface Mount Pkg)
U 520	3-01500-360	LTC2440CGN	Integrated Circuit (Surface Mount Pkg)
U 560	3-00814-360	78M05	Integrated Circuit (Surface Mount Pkg)
U 610	3-01322-360	LT1425CS	Integrated Circuit (Surface Mount Pkg)
U 621	3-00114-329	7815	Voltage Reg., TO-220 (TAB) Package

U 630	3-01717-360	MAX6629MUT	Integrated Circuit (Surface Mount Pkg)
U 710	3-01469-360	MAX6250BCSA	Integrated Circuit (Surface Mount Pkg)
U 720	3-01500-360	LTC2440CGN	Integrated Circuit (Surface Mount Pkg)
U 750	3-00663-360	74HC08	Integrated Circuit (Surface Mount Pkg)
U 760	3-00814-360	78M05	Integrated Circuit (Surface Mount Pkg)
U 770	3-01822-360	LTC2052CS	Integrated Circuit (Surface Mount Pkg)
U 780	3-00659-360	OP284FS	Integrated Circuit (Surface Mount Pkg)
Z 0	0-00043-011	4-40 KEP	Nut, Kep
Z 0	0-00187-021	4-40X1/4PP	Screw, Panhead Phillips
Z 0	0-00306-026	4-40X3/16PP	Screw, Black, All Types
Z 0	0-00772-000	1.5" WIRE	Hardware, Misc.
Z 0	0-01093-007	563002B00000	Heat Sinks
Z 0	0-01116-062	92916A325	Washer, Other
Z 0	0-01117-000	92671A005	Hardware, Misc.
Z 0	0-01118-020	4-40X3/8"	Screw, Flathead Phillips
Z 0	0-01119-023	4-40X3/8"	Screw, Roundhead Phillips
Z 0	0-01120-049	TFCC-010-50	Thermocouple Wire
Z 0	0-01121-049	TFCH-010-50	Thermocouple Wire
Z 0	0-01159-062	92916A330	Washer, Other
Z 0	0-01160-049	TFCY-010-50	Thermocouple Wire
Z 0	0-01161-049	TFAL-010-50	Thermocouple Wire
Z 0	0-01209-049	TFIR-010-50	Thermocouple Wire
Z 0	0-01210-049	TFCI-010-50	Thermocouple Wire
Z 0	0-01211-049	TFCP-010-50	Thermocouple Wire
Z 0	1-01105-100	MPJ-K-F	Connector, Misc.
Z 0	1-01122-000	MPJ-E-F	Hardware, Misc.
Z 0	1-01193-000	MPJ-J-F	Hardware, Misc.
Z 0	1-01194-000	MPJ-T-F	Hardware, Misc.
Z 0	6-00735-600	S245PD12	Misc. Components
Z 0	7-01699-721	PTC BLOCK TP CV	Machined Part
Z 0	7-01700-721	PTC BLOCK STRIP	Machined Part
Z 0	7-01701-721	PTC BLOCK BT CV	Machined Part
Z 0	7-01735-720	PTC BRKT	Fabricated Part
Z 0	7-01992-720	PTC SIL PAD	Fabricated Part

PTC420 AC output card

C 111	5-00601-578	0.1UF - 16V X7R	SMT Ceramic Cap, all sizes
C 112	5-00601-578	0.1UF - 16V X7R	SMT Ceramic Cap, all sizes
C 113	5-00601-578	0.1UF - 16V X7R	SMT Ceramic Cap, all sizes
C 114	5-00601-578	0.1UF - 16V X7R	SMT Ceramic Cap, all sizes
C 121	5-00601-578	0.1UF - 16V X7R	SMT Ceramic Cap, all sizes
C 122	5-00601-578	0.1UF - 16V X7R	SMT Ceramic Cap, all sizes
C 123	5-00601-578	0.1UF - 16V X7R	SMT Ceramic Cap, all sizes
C 124	5-00601-578	0.1UF - 16V X7R	SMT Ceramic Cap, all sizes
C 211	5-00393-552	3300P	Capacitor, Chip (SMT1206), 50V, 5%, NPO
C 212	5-00393-552	3300P	Capacitor, Chip (SMT1206), 50V, 5%, NPO
C 213	5-00389-552	1500P	Capacitor, Chip (SMT1206), 50V, 5%, NPO
C 214	5-00389-552	1500P	Capacitor, Chip (SMT1206), 50V, 5%, NPO
C 220	5-00601-578	0.1UF - 16V X7R	SMT Ceramic Cap, all sizes
C 221	5-00601-578	0.1UF - 16V X7R	SMT Ceramic Cap, all sizes
C 230	5-00601-578	0.1UF - 16V X7R	SMT Ceramic Cap, all sizes
C 231	5-00601-578	0.1UF - 16V X7R	SMT Ceramic Cap, all sizes
C 234	5-00542-572	1.0U	SMT Film Capacitors, 50V, 5%, All Sizes
C 235	5-00542-572	1.0U	SMT Film Capacitors, 50V, 5%, All Sizes
C 240	5-00601-578	0.1UF - 16V X7R	SMT Ceramic Cap, all sizes
C 241	5-00601-578	0.1UF - 16V X7R	SMT Ceramic Cap, all sizes
C 250	5-00601-578	0.1UF - 16V X7R	SMT Ceramic Cap, all sizes
C 251	5-00522-569	47U/T10	Cap, Tantalum, SMT (all case sizes)
C 252	5-00522-569	47U/T10	Cap, Tantalum, SMT (all case sizes)
C 260	5-00299-568	.1U	Cap, Ceramic 50V SMT (1206), X7R
C 290	5-00471-569	10U/T16	Cap, Tantalum, SMT (all case sizes)
C 291	5-00299-568	.1U	Cap, Ceramic 50V SMT (1206), X7R

C 292	5-00471-569	10U/T16	Cap, Tantalum, SMT (all case sizes)
C 293	5-00299-568	.1U	Cap, Ceramic 50V SMT (1206), X7R
C 294	5-00298-568	.01U	Cap, Ceramic 50V SMT (1206), X7R
D 111	3-00011-303	RED	LED, T1 Package
D 112	3-00011-303	RED	LED, T1 Package
D 211	3-00896-301	BAV99	Diode
D 212	3-00896-301	BAV99	Diode
D 213	3-00896-301	BAV99	Diode
D 214	3-00896-301	BAV99	Diode
D 231	3-01400-313	BAV199	Diode, SMT
D 232	3-01400-313	BAV199	Diode, SMT
D 262	3-00806-360	BAV170LT1	Integrated Circuit (Surface Mount Pkg)
J 111	1-00251-130	10 PIN DIL	Connector, Male
J 201	1-01185-100	7690	Connector, Misc.
J 202	1-01052-130	4 POS IN	Connector, Male
JD121	1-00234-109	96 PIN RT ANGLE DIN	Connector, Male
K 260	3-01056-335	24VDC DPDT	Relay
L 200	6-00757-604	390UH	Inductor, Vertical Mount
L 290	6-00236-631	FR47	Ferrite bead, SMT
LS200	3-01739-335	AQ5A2ZP3/28VDC	Relay
PC1	7-01708-701	PTC, AC OUTPUT	Printed Circuit Board
Q 260	3-00601-360	MMBT3904LT1	Integrated Circuit (Surface Mount Pkg)
R 112	4-01466-461	300	Thick Film, 5%, 200 ppm, Chip Resistor
R 113	4-01466-461	300	Thick Film, 5%, 200 ppm, Chip Resistor
R 200	4-01783-400	0.1 OHM - 5W	Resistor, Misc.
R 211	4-01544-461	510K	Thick Film, 5%, 200 ppm, Chip Resistor
R 212	4-01544-461	510K	Thick Film, 5%, 200 ppm, Chip Resistor
R 213	4-01551-461	1.0M	Thick Film, 5%, 200 ppm, Chip Resistor
R 214	4-01496-461	5.1K	Thick Film, 5%, 200 ppm, Chip Resistor
R 215	4-01551-461	1.0M	Thick Film, 5%, 200 ppm, Chip Resistor
R 216	4-01496-461	5.1K	Thick Film, 5%, 200 ppm, Chip Resistor
R 231	4-01538-461	300K	Thick Film, 5%, 200 ppm, Chip Resistor
R 232	4-01538-461	300K	Thick Film, 5%, 200 ppm, Chip Resistor
R 233	4-00434-408	4.990K	Resistor, Metal Film, 1/8W, 0.1%, 25ppm
R 234	4-00218-408	10.00K	Resistor, Metal Film, 1/8W, 0.1%, 25ppm
R 235	4-00434-408	4.990K	Resistor, Metal Film, 1/8W, 0.1%, 25ppm
R 236	4-00218-408	10.00K	Resistor, Metal Film, 1/8W, 0.1%, 25ppm
R 242	4-01242-462	20.0K	Thin Film, 1%, 50 ppm, MELF Resistor
R 243	4-01242-462	20.0K	Thin Film, 1%, 50 ppm, MELF Resistor
R 261	4-01495-461	4.7K	Thick Film, 5%, 200 ppm, Chip Resistor
R 262	4-01495-461	4.7K	Thick Film, 5%, 200 ppm, Chip Resistor
RN111	4-01707-463	47KX4D	Resistor network, SMT, Leadless
RN113	4-00911-463	4.7KX4D	Resistor network, SMT, Leadless
RN121	4-01707-463	47KX4D	Resistor network, SMT, Leadless
RN231	4-00911-463	4.7KX4D	Resistor network, SMT, Leadless
RN232	4-00912-463	10KX4D	Resistor network, SMT, Leadless
RN233	4-00912-463	10KX4D	Resistor network, SMT, Leadless
RN241	4-00912-463	10KX4D	Resistor network, SMT, Leadless
RN242	4-01707-463	47KX4D	Resistor network, SMT, Leadless
RV200	4-01784-435	V250LA10	Varistor, Zinc Oxide Nonlinear Resistor
U 111	3-01740-360	ATMEGA16-16AC	Integrated Circuit (Surface Mount Pkg)
U 120	3-01498-360	74ABT16245CMTD	Integrated Circuit (Surface Mount Pkg)
U 220	3-01257-360	LMC6484AIM	Integrated Circuit (Surface Mount Pkg)
U 230	3-01257-360	LMC6484AIM	Integrated Circuit (Surface Mount Pkg)
U 240	3-01257-360	LMC6484AIM	Integrated Circuit (Surface Mount Pkg)
U 250	3-01741-360	MAX660M	Integrated Circuit (Surface Mount Pkg)
U 260	3-00741-360	74HC04	Integrated Circuit (Surface Mount Pkg)
Z 0	0-00306-026	4-40X3/16PP	Screw, Black, All Types
Z 0	0-00428-000	SLEEVE	Hardware, Misc.
Z 0	0-00541-052	#22GRN/YEL	Wire #22 UL1007
Z 0	0-00636-032	39-00-0047	FEM Termination
Z 0	0-01174-007	AQ-HS-5A	Heat Sinks
Z 0	0-01175-002	49-2BK	Power Entry Hardware
Z 0	0-01244-052	8 1/2" BROWN	Wire #22 UL1007

Z 0	0-01245-052	8 1/2" BLUE	Wire #22 UL1007
Z 0	1-01054-179	4POS, VERT SING	Connector Housing, Receptacle
Z 0	1-01216-172	PTC AC OUTPUT	Line Cord
Z 0	7-01737-720	PTC BRKT	Fabricated Part

PTC430 50W DC output card

C 111	5-00601-578	0.1UF - 16V X7R	SMT Ceramic Cap, all sizes
C 112	5-00601-578	0.1UF - 16V X7R	SMT Ceramic Cap, all sizes
C 113	5-00601-578	0.1UF - 16V X7R	SMT Ceramic Cap, all sizes
C 121	5-00601-578	0.1UF - 16V X7R	SMT Ceramic Cap, all sizes
C 122	5-00601-578	0.1UF - 16V X7R	SMT Ceramic Cap, all sizes
C 123	5-00601-578	0.1UF - 16V X7R	SMT Ceramic Cap, all sizes
C 124	5-00601-578	0.1UF - 16V X7R	SMT Ceramic Cap, all sizes
C 201	5-00389-552	1500P	Capacitor, Chip (SMT1206), 50V, 5%, NPO
C 202	5-00389-552	1500P	Capacitor, Chip (SMT1206), 50V, 5%, NPO
C 203	5-00606-578	1U / 100V	SMT Ceramic Cap, all sizes
C 204	5-00389-552	1500P	Capacitor, Chip (SMT1206), 50V, 5%, NPO
C 211	5-00607-553	10U / 50V SMT	Capacitor, Electrolytic, 80V, +/-20%
C 212	5-00607-553	10U / 50V SMT	Capacitor, Electrolytic, 80V, +/-20%
C 213	5-00607-553	10U / 50V SMT	Capacitor, Electrolytic, 80V, +/-20%
C 214	5-00608-553	100U /100V SMT	Capacitor, Electrolytic, 80V, +/-20%
C 215	5-00608-553	100U /100V SMT	Capacitor, Electrolytic, 80V, +/-20%
C 216	5-00605-578	.82UF / 25V	SMT Ceramic Cap, all sizes
C 230	5-00519-569	.33U/T35	Cap, Tantalum, SMT (all case sizes)
C 231	5-00513-569	1U-16V A-CASE	Cap, Tantalum, SMT (all case sizes)
C 232	5-00629-568	1000P X 4	Cap, Ceramic 50V SMT (1206), X7R
C 233	5-00299-568	.1U	Cap, Ceramic 50V SMT (1206), X7R
C 234	5-00299-568	.1U	Cap, Ceramic 50V SMT (1206), X7R
C 235	5-00299-568	.1U	Cap, Ceramic 50V SMT (1206), X7R
C 236	5-00299-568	.1U	Cap, Ceramic 50V SMT (1206), X7R
C 240	5-00299-568	.1U	Cap, Ceramic 50V SMT (1206), X7R
C 243	5-00299-568	.1U	Cap, Ceramic 50V SMT (1206), X7R
C 244	5-00299-568	.1U	Cap, Ceramic 50V SMT (1206), X7R
C 245	5-00627-578	0.1U X 4	SMT Ceramic Cap, all sizes
C 250	5-00299-568	.1U	Cap, Ceramic 50V SMT (1206), X7R
C 251	5-00319-569	10U/T35	Cap, Tantalum, SMT (all case sizes)
C 252	5-00299-568	.1U	Cap, Ceramic 50V SMT (1206), X7R
C 253	5-00319-569	10U/T35	Cap, Tantalum, SMT (all case sizes)
C 254	5-00299-568	.1U	Cap, Ceramic 50V SMT (1206), X7R
C 255	5-00298-568	.01U	Cap, Ceramic 50V SMT (1206), X7R
C 261	5-00299-568	.1U	Cap, Ceramic 50V SMT (1206), X7R
C 270	5-00299-568	.1U	Cap, Ceramic 50V SMT (1206), X7R
C 271	5-00798-568	2.2U	Cap, Ceramic 50V SMT (1206), X7R
C 272	5-00525-578	1U	SMT Ceramic Cap, all sizes
C 273	5-00513-569	1U-16V A-CASE	Cap, Tantalum, SMT (all case sizes)
C 274	5-00654-500	.01UF X 4	Capacitor, Misc.
C 275	5-00525-578	1U	SMT Ceramic Cap, all sizes
C 276	5-00525-578	1U	SMT Ceramic Cap, all sizes
C 277	5-00299-568	.1U	Cap, Ceramic 50V SMT (1206), X7R
C 281	5-00299-568	.1U	Cap, Ceramic 50V SMT (1206), X7R
C 290	5-00299-568	.1U	Cap, Ceramic 50V SMT (1206), X7R
C 300	5-00299-568	.1U	Cap, Ceramic 50V SMT (1206), X7R
C 310	5-00299-568	.1U	Cap, Ceramic 50V SMT (1206), X7R
C 311	5-00522-569	47U/T10	Cap, Tantalum, SMT (all case sizes)
C 312	5-00522-569	47U/T10	Cap, Tantalum, SMT (all case sizes)
D 111	3-00576-311	RED MINI	LED, Subminiature
D 211	3-00403-301	1N459A	Diode
D 212	3-01253-313	B270-13	Diode, SMT
D 214	3-00626-301	MUR1100E	Diode
F 221	6-00644-611	1A 60V	Fuse
J 111	1-00251-130	10 PIN DIL	Connector, Male
J 201	0-01097-035	571-0100	Banana jack

J 202	0-01096-035	571-0500	Banana jack
JD121	1-00234-109	96 PIN RT ANGLE	DIN Connector, Male
L 201	6-00512-631	2744045447	Ferrite bead, SMT
L 202	6-00512-631	2744045447	Ferrite bead, SMT
L 211	6-00645-609	330UH	Inductor, Fixed, SMT
L 251	6-00236-631	FR47	Ferrite bead, SMT
PC1	7-01706-701	PTC, DC OUTPUT	Printed Circuit Board
Q 233	3-01254-360	BSS123LT1	Integrated Circuit (Surface Mount Pkg)
Q 234	3-01254-360	BSS123LT1	Integrated Circuit (Surface Mount Pkg)
Q 235	3-01254-360	BSS123LT1	Integrated Circuit (Surface Mount Pkg)
Q 236	3-01254-360	BSS123LT1	Integrated Circuit (Surface Mount Pkg)
Q 251	3-01819-360	IRF6218PBF	Integrated Circuit (Surface Mount Pkg)
Q 252	3-01819-360	IRF6218PBF	Integrated Circuit (Surface Mount Pkg)
Q 253	3-01819-360	IRF6218PBF	Integrated Circuit (Surface Mount Pkg)
Q 254	3-01820-360	IRF9520NPBF	Integrated Circuit (Surface Mount Pkg)
R 112	4-01466-461	300	Thick Film, 5%, 200 ppm, Chip Resistor
R 201	4-01406-461	0	Thick Film, 5%, 200 ppm, Chip Resistor
R 202	4-01406-461	0	Thick Film, 5%, 200 ppm, Chip Resistor
R 203	4-01406-461	0	Thick Film, 5%, 200 ppm, Chip Resistor
R 204	4-01406-461	0	Thick Film, 5%, 200 ppm, Chip Resistor
R 205	4-01406-461	0	Thick Film, 5%, 200 ppm, Chip Resistor
R 206	4-01186-462	5.23K	Thin Film, 1%, 50 ppm, MELF Resistor
R 207	4-01309-462	100K	Thin Film, 1%, 50 ppm, MELF Resistor
R 208	4-00436-409	.1	Resistor, Wire Wound
R 211	4-01147-462	2.05K	Thin Film, 1%, 50 ppm, MELF Resistor
R 212	4-01292-462	66.5K	Thin Film, 1%, 50 ppm, MELF Resistor
R 213	4-01134-462	1.50K	Thin Film, 1%, 50 ppm, MELF Resistor
R 231	4-01173-462	3.83K	Thin Film, 1%, 50 ppm, MELF Resistor
R 232	4-01155-462	2.49K	Thin Film, 1%, 50 ppm, MELF Resistor
R 233	4-01117-462	1.00K	Thin Film, 1%, 50 ppm, MELF Resistor
R 234	4-01146-462	2.00K	Thin Film, 1%, 50 ppm, MELF Resistor
R 235	4-01173-462	3.83K	Thin Film, 1%, 50 ppm, MELF Resistor
R 236	4-01155-462	2.49K	Thin Film, 1%, 50 ppm, MELF Resistor
R 237	4-01117-462	1.00K	Thin Film, 1%, 50 ppm, MELF Resistor
R 238	4-01146-462	2.00K	Thin Film, 1%, 50 ppm, MELF Resistor
R 239	4-01173-462	3.83K	Thin Film, 1%, 50 ppm, MELF Resistor
R 240	4-01155-462	2.49K	Thin Film, 1%, 50 ppm, MELF Resistor
R 241	4-01117-462	1.00K	Thin Film, 1%, 50 ppm, MELF Resistor
R 242	4-01146-462	2.00K	Thin Film, 1%, 50 ppm, MELF Resistor
R 243	4-01173-462	3.83K	Thin Film, 1%, 50 ppm, MELF Resistor
R 244	4-01201-462	7.50K	Thin Film, 1%, 50 ppm, MELF Resistor
R 245	4-01146-462	2.00K	Thin Film, 1%, 50 ppm, MELF Resistor
R 246	4-01088-462	499	Thin Film, 1%, 50 ppm, MELF Resistor
R 247	4-01155-462	2.49K	Thin Film, 1%, 50 ppm, MELF Resistor
R 248	4-01117-462	1.00K	Thin Film, 1%, 50 ppm, MELF Resistor
R 249	4-01146-462	2.00K	Thin Film, 1%, 50 ppm, MELF Resistor
R 251	4-02456-400	1 OHM - 1%	Resistor, Misc.
R 252	4-01712-409	4.0 5W	Resistor, Wire Wound
R 253	4-01729-449	20.0 / 100PPM	Resistor, Metal Film 1/2W, 1%, 50ppm
R 254	4-01320-462	130K	Thin Film, 1%, 50 ppm, MELF Resistor
R 255	4-01146-462	2.00K	Thin Film, 1%, 50 ppm, MELF Resistor
R 256	4-01146-462	2.00K	Thin Film, 1%, 50 ppm, MELF Resistor
R 257	4-01146-462	2.00K	Thin Film, 1%, 50 ppm, MELF Resistor
R 263	4-01404-462	976K	Thin Film, 1%, 50 ppm, MELF Resistor
R 264	4-01296-462	73.2K	Thin Film, 1%, 50 ppm, MELF Resistor
R 273	4-01242-462	20.0K	Thin Film, 1%, 50 ppm, MELF Resistor
R 274	4-01117-462	1.00K	Thin Film, 1%, 50 ppm, MELF Resistor
RN111	4-01707-463	47KX4D	Resistor network, SMT, Leadless
RN112	4-01707-463	47KX4D	Resistor network, SMT, Leadless
RN113	4-00910-463	1.0KX4D	Resistor network, SMT, Leadless
RN121	4-01707-463	47KX4D	Resistor network, SMT, Leadless
RN271	4-00910-463	1.0KX4D	Resistor network, SMT, Leadless
RN272	4-01764-463	10X4D	Resistor network, SMT, Leadless
RN273	4-00911-463	4.7KX4D	Resistor network, SMT, Leadless

RN291	4-00910-463	1.0KX4D	Resistor network, SMT, Leadless
RN292	4-00911-463	4.7KX4D	Resistor network, SMT, Leadless
U 110	3-01696-360	ATMEGA64-16AC	Integrated Circuit (Surface Mount Pkg)
U 120	3-01498-360	74ABT16245CMTD	Integrated Circuit (Surface Mount Pkg)
U 140	3-00413-340	LM34DZ	Integrated Circuit (Thru-hole Pkg)
U 210	3-01255-360	LM2586T-ADJ	Integrated Circuit (Surface Mount Pkg)
U 230	3-00814-360	78M05	Integrated Circuit (Surface Mount Pkg)
U 233	3-01821-360	LTC6102HMS	Integrated Circuit (Surface Mount Pkg)
U 234	3-01821-360	LTC6102HMS	Integrated Circuit (Surface Mount Pkg)
U 235	3-01821-360	LTC6102HMS	Integrated Circuit (Surface Mount Pkg)
U 236	3-01821-360	LTC6102HMS	Integrated Circuit (Surface Mount Pkg)
U 240	3-00675-360	LTC1655	Integrated Circuit (Surface Mount Pkg)
U 243	3-00795-360	74AC138	Integrated Circuit (Surface Mount Pkg)
U 244	3-01256-360	MAX4634EUB	Integrated Circuit (Surface Mount Pkg)
U 250	3-01822-360	LTC2052CS	Integrated Circuit (Surface Mount Pkg)
U 260	3-01386-360	DG408DY	Integrated Circuit (Surface Mount Pkg)
U 270	3-01257-360	LMC6484AIM	Integrated Circuit (Surface Mount Pkg)
U 271	3-01186-360	MAX6241BCSA	Integrated Circuit (Surface Mount Pkg)
U 280	3-01258-360	LTC2433-1CMS	Integrated Circuit (Surface Mount Pkg)
U 290	3-01366-360	DG333ADW	Integrated Circuit (Surface Mount Pkg)
U 300	3-01717-360	MAX6629MUT	Integrated Circuit (Surface Mount Pkg)
U 310	3-01741-360	MAX660M	Integrated Circuit (Surface Mount Pkg)
Z 0	0-00187-021	4-40X1/4PP	Screw, Panhead Phillips
Z 0	0-00246-043	#8 X 1/16	Washer, nylon
Z 0	0-00306-026	4-40X3/16PP	Screw, Black, All Types
Z 0	0-01092-007	78060	Heat Sinks
Z 0	0-01093-007	563002B00000	Heat Sinks
Z 0	0-01094-067	MAX02	Pins & Clips
Z 0	0-01095-003	HF300P-.001-AC	Insulators
Z 0	7-01733-720	PTC BRACKET	Fabricated Part

PTC440 TEC driver

C110	5-00513	1U-16V A-CASE	SMT Tantalum, 16V, A-case (1206, but NEEDS POLARITY mark)
C111	5-00601	0.1UF - 16V X7R	
C112	5-00601	0.1UF - 16V X7R	
C113	5-00601	0.1UF - 16V X7R	
C121	5-00601	0.1UF - 16V X7R	
C122	5-00601	0.1UF - 16V X7R	
C123	5-00601	0.1UF - 16V X7R	
C124	5-00601	0.1UF - 16V X7R	
C200	5-00299	.1U	Capacitor, Mono, 50V, 10%, X7R, 1206
C202	5-00516	330U	Capacitor, Electrolytic, High Ripple, High Temp (-55/+105 DEG C)
C203	5-00520	4.7U/T35	SMD Tantalum, C-Case
C210	5-00299	.1U	Capacitor, Mono, 50V, 10%, X7R, 1206
C211	5-00299	.1U	Capacitor, Mono, 50V, 10%, X7R, 1206
C212	5-00399	.01U - 5%	Capacitor, Mono, 50V, 5%, X7R, 1206
C213	5-00388	1200P	Capacitor, Mono, 50V, 5%, NPO, 1206
C216	5-00526	22U-T16	SMD Tantalum, C-Case
C223	5-00388	1200P	Capacitor, Mono, 50V, 5%, NPO, 1206
C226	5-00299	.1U	Capacitor, Mono, 50V, 10%, X7R, 1206
C231	5-00299	.1U	Capacitor, Mono, 50V, 10%, X7R, 1206
C232	5-00299	.1U	Capacitor, Mono, 50V, 10%, X7R, 1206
C233	5-00299	.1U	Capacitor, Mono, 50V, 10%, X7R, 1206
C240	5-00299	.1U	Capacitor, Mono, 50V, 10%, X7R, 1206
C241	5-00299	.1U	Capacitor, Mono, 50V, 10%, X7R, 1206
C242	5-00299	.1U	Capacitor, Mono, 50V, 10%, X7R, 1206
C250	5-00299	.1U	Capacitor, Mono, 50V, 10%, X7R, 1206
C251	5-00299	.1U	Capacitor, Mono, 50V, 10%, X7R, 1206
C252	5-00299	.1U	Capacitor, Mono, 50V, 10%, X7R, 1206
C260	5-00526	22U-T16	SMD Tantalum, C-Case
C261	5-00299	.1U	Capacitor, Mono, 50V, 10%, X7R, 1206

C262	5-00299	.1U	Capacitor, Mono, 50V, 10%, X7R, 1206
C263	5-00526	22U-T16	SMD Tantalum, C-Case
C280	5-00299	.1U	Capacitor, Mono, 50V, 10%, X7R, 1206
C282	5-00299	.1U	Capacitor, Mono, 50V, 10%, X7R, 1206
C283	5-00299	.1U	Capacitor, Mono, 50V, 10%, X7R, 1206
C284	5-00299	.1U	Capacitor, Mono, 50V, 10%, X7R, 1206
C290	5-00299	.1U	Capacitor, Mono, 50V, 10%, X7R, 1206
C291	5-00470	2.2U/T16	SMD Tantalum, Y-Case
C292	5-00470	2.2U/T16	SMD Tantalum, Y-Case
C293	5-00525	1U	CAP 1UF 25V CERAMIC Y5V 1206 +80/ -20%
C300	5-00299	.1U	Capacitor, Mono, 50V, 10%, X7R, 1206
C302	5-00299	.1U	Capacitor, Mono, 50V, 10%, X7R, 1206
C310	5-00164	4.7UF - 1812	Capacitor, Ceramic, 50V, 10%, SL, Rad
C311	5-00399	.01U - 5%	Capacitor, Mono, 50V, 5%, X7R, 1206
C312	5-00119	22UF	Capacitor, Silver Mica, 500V, 5%, DM15
C320	5-00299	.1U	Capacitor, Mono, 50V, 10%, X7R, 1206
C321	5-00299	.1U	Capacitor, Mono, 50V, 10%, X7R, 1206
C330	5-00519	.33U/T35	SMD Tantalum, Y-Case
C331	5-00513	1U-16V A-CASE	SMT Tantalum, 16V, A-case (1206, but NEEDS POLARITY mark)
C340	5-00519	.33U/T35	SMD Tantalum, Y-Case
C341	5-00319	10U/T35	SMD Tantalum, D-Case
C342	5-00319	10U/T35	SMD Tantalum, D-Case
C360	5-00299	.1U	Capacitor, Mono, 50V, 10%, X7R, 1206
C400	5-00520	4.7U/T35	SMD Tantalum, C-Case
C401	5-00520	4.7U/T35	SMD Tantalum, C-Case
C402	5-00525	1U	CAP 1UF 25V CERAMIC Y5V 1206 +80/ -20%
C410	5-00299	.1U	Capacitor, Mono, 50V, 10%, X7R, 1206
C411	5-00525	1U	CAP 1UF 25V CERAMIC Y5V 1206 +80/ -20%
C420	5-00299	.1U	Capacitor, Mono, 50V, 10%, X7R, 1206
C421	5-00299	.1U	Capacitor, Mono, 50V, 10%, X7R, 1206
C430	5-00299	.1U	Capacitor, Mono, 50V, 10%, X7R, 1206
C431	5-00525	1U	CAP 1UF 25V CERAMIC Y5V 1206 +80/ -20%
C440	5-00299	.1U	Capacitor, Mono, 50V, 10%, X7R, 1206
C451	5-00525	1U	CAP 1UF 25V CERAMIC Y5V 1206 +80/ -20%
C452	5-00525	1U	CAP 1UF 25V CERAMIC Y5V 1206 +80/ -20%
C500	5-00299	.1U	Capacitor, Mono, 50V, 10%, X7R, 1206
C510	5-00299	.1U	Capacitor, Mono, 50V, 10%, X7R, 1206
C511	5-00299	.1U	Capacitor, Mono, 50V, 10%, X7R, 1206
C530	5-00299	.1U	Capacitor, Mono, 50V, 10%, X7R, 1206
C540	5-00299	.1U	Capacitor, Mono, 50V, 10%, X7R, 1206
C572	5-00519	.33U/T35	SMD Tantalum, Y-Case
C573	5-00513	1U-16V A-CASE	SMT Tantalum, 16V, A-case (1206, but NEEDS POLARITY mark)
D111	3-00576	RED MINI	LED, Subminiature, 1.8mm (T 3/4)
D234	3-00945	BAT54S	Dual schottky diode, series connection
D300	3-01400	BAV199	dual series switching diode, low leakage
D312	3-01936	PDS560-13	
D341	3-01400	BAV199	dual series switching diode, low leakage
D400	3-00198	1N5231B	1N5231B, 5.1V, 500mW, DO-35 ZENER DIODE
D402	3-01430	BAS40-05	Dual Schottky, Common Cathode
D451	3-00945	BAT54S	Dual schottky diode, series connection
ISO510	3-01320	HCPL-2630	
ISO511	3-01320	HCPL-2630	
ISO530	3-01320	HCPL-2630	
J230	1-00370	15 PIN D	DB Female, Right Angle, .318
JDR121	1-00234	96 PIN RT ANGLE	3 Row, Right Angle Mount
L231	6-00512	2744045447	Ferrite Bead, Common Mode, SMD, Type 44, 3312
L232	6-00512	2744045447	Ferrite Bead, Common Mode, SMD, Type 44, 3312
L312	6-00815	10UH	
PCB	7-02093	PTC440 PELTIER	
Q202	3-00944	IRF4905	P-channel Power MOSFET, ultra-low Ron
Q211	3-01678	IRF1010EZ	
Q212	3-00944	IRF4905	P-channel Power MOSFET, ultra-low Ron
Q221	3-01678	IRF1010EZ	

Q222	3-00944	IRF4905	P-channel Power MOSFET, ultra-low Ron
R112	4-01466	300	Resistor, Thick Film, 5%, 200 ppm, SMT
R204	4-01178	4.32K	Resistor, Thin Film, 1%, 50 ppm, MELF
R205	4-01406	0	Resistor, Thick Film, 5%, 300 ppm, SMT
R206	4-01213	10.0K	Resistor, Thin Film, 1%, 50 ppm, MELF
R207	4-01213	10.0K	Resistor, Thin Film, 1%, 50 ppm, MELF
R211	4-01213	10.0K	Resistor, Thin Film, 1%, 50 ppm, MELF
R212	4-01146	2.00K	Resistor, Thin Film, 1%, 50 ppm, MELF
R213	4-01146	2.00K	Resistor, Thin Film, 1%, 50 ppm, MELF
R216	4-01178	4.32K	Resistor, Thin Film, 1%, 50 ppm, MELF
R217	4-01146	2.00K	Resistor, Thin Film, 1%, 50 ppm, MELF
R218	4-01213	10.0K	Resistor, Thin Film, 1%, 50 ppm, MELF
R221	4-01213	10.0K	Resistor, Thin Film, 1%, 50 ppm, MELF
R222	4-01213	10.0K	Resistor, Thin Film, 1%, 50 ppm, MELF
R223	4-01213	10.0K	Resistor, Thin Film, 1%, 50 ppm, MELF
R224	4-01146	2.00K	Resistor, Thin Film, 1%, 50 ppm, MELF
R225	4-01213	10.0K	Resistor, Thin Film, 1%, 50 ppm, MELF
R226	4-01213	10.0K	Resistor, Thin Film, 1%, 50 ppm, MELF
R227	4-01146	2.00K	Resistor, Thin Film, 1%, 50 ppm, MELF
R228	4-01213	10.0K	Resistor, Thin Film, 1%, 50 ppm, MELF
R231	4-01021	100	Resistor, Thin Film, 1%, 50 ppm, MELF
R232	4-01050	200	Resistor, Thin Film, 1%, 50 ppm, MELF
R233	4-01050	200	Resistor, Thin Film, 1%, 50 ppm, MELF
R234	4-01117	1.00K	Resistor, Thin Film, 1%, 50 ppm, MELF
R240	4-01762	0.05	
R242	4-01213	10.0K	Resistor, Thin Film, 1%, 50 ppm, MELF
R252	4-01213	10.0K	Resistor, Thin Film, 1%, 50 ppm, MELF
R281	4-01213	10.0K	Resistor, Thin Film, 1%, 50 ppm, MELF
R282	4-01213	10.0K	Resistor, Thin Film, 1%, 50 ppm, MELF
R321	4-01205	8.25K	Resistor, Thin Film, 1%, 50 ppm, MELF
R322	4-01192	6.04K	Resistor, Thin Film, 1%, 50 ppm, MELF
R323	4-01171	3.65K	Resistor, Thin Film, 1%, 50 ppm, MELF
R324	4-01129	1.33K	Resistor, Thin Film, 1%, 50 ppm, MELF
R325	4-01117	1.00K	Resistor, Thin Film, 1%, 50 ppm, MELF
R340	4-01058	243	Resistor, Thin Film, 1%, 50 ppm, MELF
R341	4-01163	3.01K	Resistor, Thin Film, 1%, 50 ppm, MELF
R410	4-01213	10.0K	Resistor, Thin Film, 1%, 50 ppm, MELF
R411	4-01213	10.0K	Resistor, Thin Film, 1%, 50 ppm, MELF
R412	4-01117	1.00K	Resistor, Thin Film, 1%, 50 ppm, MELF
R413	4-01021	100	Resistor, Thin Film, 1%, 50 ppm, MELF
R414	4-00930	11.3	Resistor, Thin Film, 1%, 50 ppm, MELF
R415	4-01703	2.490K	
R421	4-01146	2.00K	Resistor, Thin Film, 1%, 50 ppm, MELF
R431	4-01213	10.0K	Resistor, Thin Film, 1%, 50 ppm, MELF
R432	4-01670	20K 1%	MPM Series Resistive Divider, Thin Film, 10.0K x 2, 0.1W, 1%
R441	4-01703	2.490K	
R442	4-01213	10.0K	Resistor, Thin Film, 1%, 50 ppm, MELF
R443	4-01146	2.00K	Resistor, Thin Film, 1%, 50 ppm, MELF
R444	4-01050	200	Resistor, Thin Film, 1%, 50 ppm, MELF
R451	4-01213	10.0K	Resistor, Thin Film, 1%, 50 ppm, MELF
R452	4-01213	10.0K	Resistor, Thin Film, 1%, 50 ppm, MELF
RN111	4-01707	47KX4D	
RN112	4-01707	47KX4D	
RN113	4-00910	1.0KX4D	Network, DIP, Isolated, 1/16W, 5%, Tiny
RN121	4-01707	47KX4D	
RN510	4-00909	470X4D	Network, DIP, Isolated, 1/16W, 5%, Tiny
RN512	4-00909	470X4D	Network, DIP, Isolated, 1/16W, 5%, Tiny
RN530	4-00909	470X4D	Network, DIP, Isolated, 1/16W, 5%, Tiny
RN532	4-00909	470X4D	Network, DIP, Isolated, 1/16W, 5%, Tiny
U110	3-01696	ATMEGA64-16AC	
U120	3-01498	74ABT16245CMTD	
U140	3-00413	LM34DZ	LM34 Precision Temperature Sensor, Fahrenheit
U200	3-00675	LTC1655	16 bit Rail-Rail DAC

U210	3-00581	AD822	AD822JR Dual JFET Single supply rail to rail op amp
U230	3-01443	AQW225NA	AQW225N, Dual PhotoMOS
U240	3-01685	LT1991IMS	
U250	3-01685	LT1991IMS	
U260	3-01451	ADR421AR	Low Noise, 2.048, 2.500 V reference
U280	3-01978	LT1368CS8/#PBF	
U290	3-01938	LTC2445CUHF	
U291	3-01469	MAX6250BCSA	+5V Reference
U300	3-00741	74HC04	74HC04, Hex Inverter
U310	3-01939	LM22678TJ-ADJ	
U320	3-00956	MAX4602CWE	2.5 OHM CMOS, QUAD SWT., 16 WIDE SO
U330	3-00814	78M05	78M05,
U340	3-01977	LM317MABDTG	
U360	3-01717	MAX6629MUT	
U400	3-01451	ADR421AR	Low Noise, 2.048, 2.500 V reference
U410	3-00643	DG211BDY-ROHS	DG211BDY, Quad Analog Switch
U420	3-01370	OPA277UA	OPA277A, Precision Op-Amp, 20 ªV typ., 1 MHz typ., SO-8
U430	3-01683	OPA333AIDBVT	
U440	3-01683	OPA333AIDBVT	
U500	3-00663	74HC08	74HC08, Quad 2-Input AND Gate
U540	3-00787	74HC595	74HC595, 8 Bit Serial Input, Parallel Output Shift Register
U570	3-01979	79M05CDT/RK	
Z1	0-00150	4-40X1/4PF	
Z10	0-01094	MAX02	
Z11	0-01094	MAX02	
Z12	0-01094	MAX02	
Z13	0-01095	HF300P-.001-AC	
Z14	7-02095	PTC440 FLANGE	
Z2	0-00150	4-40X1/4PF	
Z3	0-00246	#8 X 1/16	
Z4	0-00246	#8 X 1/16	
Z5	0-00306	4-40X3/16PP	
Z6	0-00306	4-40X3/16PP	
Z7	0-01092	78060	
Z8	0-01094	MAX02	
Z9	0-01094	MAX02	

PTC510 analog I/O card

C 101	5-00601-578	0.1UF - 16V X7R	SMT Ceramic Cap, all sizes
C 102	5-00601-578	0.1UF - 16V X7R	SMT Ceramic Cap, all sizes
C 103	5-00601-578	0.1UF - 16V X7R	SMT Ceramic Cap, all sizes
C 105	5-00601-578	0.1UF - 16V X7R	SMT Ceramic Cap, all sizes
C 106	5-00601-578	0.1UF - 16V X7R	SMT Ceramic Cap, all sizes
C 107	5-00601-578	0.1UF - 16V X7R	SMT Ceramic Cap, all sizes
C 108	5-00601-578	0.1UF - 16V X7R	SMT Ceramic Cap, all sizes
C 201	5-00470-569	2.2U/T16	Cap, Tantalum, SMT (all case sizes)
C 202	5-00525-578	1U	SMT Ceramic Cap, all sizes
C 203	5-00470-569	2.2U/T16	Cap, Tantalum, SMT (all case sizes)
C 204	5-00299-568	.1U	Cap, Ceramic 50V SMT (1206), X7R
C 205	5-00471-569	10U/T16	Cap, Tantalum, SMT (all case sizes)
C 206	5-00527-568	.47U	Cap, Ceramic 50V SMT (1206), X7R
C 207	5-00601-578	0.1UF - 16V X7R	SMT Ceramic Cap, all sizes
C 208	5-00601-578	0.1UF - 16V X7R	SMT Ceramic Cap, all sizes
C 209	5-00527-568	.47U	Cap, Ceramic 50V SMT (1206), X7R
C 210	5-00527-568	.47U	Cap, Ceramic 50V SMT (1206), X7R
C 211	5-00527-568	.47U	Cap, Ceramic 50V SMT (1206), X7R
C 212	5-00601-578	0.1UF - 16V X7R	SMT Ceramic Cap, all sizes
C 213	5-00601-578	0.1UF - 16V X7R	SMT Ceramic Cap, all sizes
C 214	5-00601-578	0.1UF - 16V X7R	SMT Ceramic Cap, all sizes
C 215	5-00601-578	0.1UF - 16V X7R	SMT Ceramic Cap, all sizes
C 216	5-00627-578	0.1U X 4	SMT Ceramic Cap, all sizes
C 217	5-00601-578	0.1UF - 16V X7R	SMT Ceramic Cap, all sizes

C 225	5-00601-578	0.1UF - 16V X7R	SMT Ceramic Cap, all sizes
C 226	5-00601-578	0.1UF - 16V X7R	SMT Ceramic Cap, all sizes
C 227	5-00381-552	330P	Capacitor, Chip (SMT1206), 50V, 5%, NPO
C 232	5-00299-568	.1U	Cap, Ceramic 50V SMT (1206), X7R
C 233	5-00471-569	10U/T16	Cap, Tantalum, SMT (all case sizes)
C 302	5-00601-578	0.1UF - 16V X7R	SMT Ceramic Cap, all sizes
C 310	5-00299-568	.1U	Cap, Ceramic 50V SMT (1206), X7R
C 311	5-00299-568	.1U	Cap, Ceramic 50V SMT (1206), X7R
C 330	5-00299-568	.1U	Cap, Ceramic 50V SMT (1206), X7R
C 331	5-00299-568	.1U	Cap, Ceramic 50V SMT (1206), X7R
C 340	5-00601-578	0.1UF - 16V X7R	SMT Ceramic Cap, all sizes
C 351	5-00035-521	47U	Capacitor, Electrolytic, 25V, 20%, Rad
C 352	5-00519-569	.33U/T35	Cap, Tantalum, SMT (all case sizes)
C 353	5-00513-569	1U-16V A-CASE	Cap, Tantalum, SMT (all case sizes)
C 361	5-00035-521	47U	Capacitor, Electrolytic, 25V, 20%, Rad
C 362	5-00519-569	.33U/T35	Cap, Tantalum, SMT (all case sizes)
C 363	5-00513-569	1U-16V A-CASE	Cap, Tantalum, SMT (all case sizes)
C 371	5-00035-521	47U	Capacitor, Electrolytic, 25V, 20%, Rad
C 372	5-00519-569	.33U/T35	Cap, Tantalum, SMT (all case sizes)
C 373	5-00513-569	1U-16V A-CASE	Cap, Tantalum, SMT (all case sizes)
D 101	3-00011-303	RED	LED, T1 Package
D 201	3-00544-360	BAV70LT1-ROHS	Integrated Circuit (Surface Mount Pkg)
D 202	3-00544-360	BAV70LT1-ROHS	Integrated Circuit (Surface Mount Pkg)
D 203	3-00544-360	BAV70LT1-ROHS	Integrated Circuit (Surface Mount Pkg)
D 204	3-00544-360	BAV70LT1-ROHS	Integrated Circuit (Surface Mount Pkg)
D 246	3-01384-301	MMBZ5232BLT1	Diode
D 301	3-01880-313	SMBJ12CA	Diode, SMT
D 302	3-01880-313	SMBJ12CA	Diode, SMT
D 303	3-01880-313	SMBJ12CA	Diode, SMT
D 304	3-01880-313	SMBJ12CA	Diode, SMT
D 341	3-00011-303	RED	LED, T1 Package
D 342	3-00011-303	RED	LED, T1 Package
D 343	3-00011-303	RED	LED, T1 Package
D 344	3-00011-303	RED	LED, T1 Package
F 301	6-00773-611	1206L020	Fuse
F 302	6-00773-611	1206L020	Fuse
F 303	6-00773-611	1206L020	Fuse
F 304	6-00773-611	1206L020	Fuse
IS310	3-01320-340	HCPL-2630	Integrated Circuit (Thru-hole Pkg)
IS311	3-01320-340	HCPL-2630	Integrated Circuit (Thru-hole Pkg)
IS330	3-01320-340	HCPL-2630	Integrated Circuit (Thru-hole Pkg)
J 101	1-00251-130	10 PIN DIL	Connector, Male
J 301	1-00233-120	RT ANGLE	Connector, BNC
J 302	1-00233-120	RT ANGLE	Connector, BNC
J 303	1-00233-120	RT ANGLE	Connector, BNC
J 304	1-00233-120	RT ANGLE	Connector, BNC
JD101	1-00234-109	96 PIN RT ANGLE	DIN Connector, Male
L 351	6-00174-630	6611 TYPE 43	Ferrite Beads
L 352	6-00684-609	10UH	Inductor, Fixed, SMT
L 361	6-00174-630	6611 TYPE 43	Ferrite Beads
L 362	6-00684-609	10UH	Inductor, Fixed, SMT
L 371	6-00174-630	6611 TYPE 43	Ferrite Beads
L 372	6-00684-609	10UH	Inductor, Fixed, SMT
PC1	7-01709-701	PTC	Printed Circuit Board
R 101	4-01466-461	300	Thick Film, 5%, 200 ppm, Chip Resistor
R 201	4-01230-462	15.0K	Thin Film, 1%, 50 ppm, MELF Resistor
R 202	4-01213-462	10.0K	Thin Film, 1%, 50 ppm, MELF Resistor
R 203	4-01213-462	10.0K	Thin Film, 1%, 50 ppm, MELF Resistor
R 204	4-01155-462	2.49K	Thin Film, 1%, 50 ppm, MELF Resistor
R 205	4-01213-462	10.0K	Thin Film, 1%, 50 ppm, MELF Resistor
R 206	4-01155-462	2.49K	Thin Film, 1%, 50 ppm, MELF Resistor
R 207	4-01213-462	10.0K	Thin Film, 1%, 50 ppm, MELF Resistor
R 208	4-01155-462	2.49K	Thin Film, 1%, 50 ppm, MELF Resistor
R 209	4-01213-462	10.0K	Thin Film, 1%, 50 ppm, MELF Resistor

R 210	4-01155-462	2.49K	Thin Film, 1%, 50 ppm, MELF Resistor
R 227	4-01163-462	3.01K	Thin Film, 1%, 50 ppm, MELF Resistor
R 228	4-01117-462	1.00K	Thin Film, 1%, 50 ppm, MELF Resistor
R 230	4-01139-462	1.69K	Thin Film, 1%, 50 ppm, MELF Resistor
R 231	4-01110-462	845	Thin Film, 1%, 50 ppm, MELF Resistor
R 234	4-01156-462	2.55K	Thin Film, 1%, 50 ppm, MELF Resistor
RN101	4-01704-463	100Kx4D 5%	Resistor network, SMT, Leadless
RN102	4-00911-463	4.7KX4D	Resistor network, SMT, Leadless
RN103	4-00910-463	1.0KX4D	Resistor network, SMT, Leadless
RN105	4-01707-463	47KX4D	Resistor network, SMT, Leadless
RN206	4-00910-463	1.0KX4D	Resistor network, SMT, Leadless
RN310	4-00909-463	470X4D	Resistor network, SMT, Leadless
RN312	4-00909-463	470X4D	Resistor network, SMT, Leadless
RN330	4-00909-463	470X4D	Resistor network, SMT, Leadless
RN332	4-00909-463	470X4D	Resistor network, SMT, Leadless
RN341	4-00908-463	270X4D	Resistor network, SMT, Leadless
U 101	3-01497-360	ATMEGA162-16AI	Integrated Circuit (Surface Mount Pkg)
U 102	3-01498-360	74ABT16245CMTD	Integrated Circuit (Surface Mount Pkg)
U 201	3-01469-360	MAX6250BCSA	Integrated Circuit (Surface Mount Pkg)
U 202	3-01499-360	DAC8534IPW	Integrated Circuit (Surface Mount Pkg)
U 203	3-01838-360	MC33079D	Integrated Circuit (Surface Mount Pkg)
U 204	3-01365-360	DG411DY	Integrated Circuit (Surface Mount Pkg)
U 205	3-01838-360	MC33079D	Integrated Circuit (Surface Mount Pkg)
U 206	3-01369-360	DG409DY	Integrated Circuit (Surface Mount Pkg)
U 209	3-01500-360	LTC2440CGN	Integrated Circuit (Surface Mount Pkg)
U 302	3-00743-360	74HC138D	Integrated Circuit (Surface Mount Pkg)
U 331	3-00749-360	74HC541	Integrated Circuit (Surface Mount Pkg)
U 340	3-00787-360	74HC595	Integrated Circuit (Surface Mount Pkg)
U 350	3-00814-360	78M05	Integrated Circuit (Surface Mount Pkg)
U 360	3-01175-360	78M15	Integrated Circuit (Surface Mount Pkg)
U 370	3-01176-360	79M15	Integrated Circuit (Surface Mount Pkg)
Z 0	0-00472-018	1-329631-2	Jam Nut
Z 0	7-01734-720	PTC ANL.IO BRKT	Fabricated Part
Z 1	0-00306-026	4-40X3/16PP	Screw, Black, All Types
Z 2	0-00306-026	4-40X3/16PP	Screw, Black, All Types

PTC520 digital I/O card

C 111	5-00601-578	0.1UF - 16V X7R	SMT Ceramic Cap, all sizes
C 112	5-00601-578	0.1UF - 16V X7R	SMT Ceramic Cap, all sizes
C 113	5-00601-578	0.1UF - 16V X7R	SMT Ceramic Cap, all sizes
C 121	5-00601-578	0.1UF - 16V X7R	SMT Ceramic Cap, all sizes
C 122	5-00601-578	0.1UF - 16V X7R	SMT Ceramic Cap, all sizes
C 123	5-00601-578	0.1UF - 16V X7R	SMT Ceramic Cap, all sizes
C 124	5-00601-578	0.1UF - 16V X7R	SMT Ceramic Cap, all sizes
C 200	5-00378-552	180P	Capacitor, Chip (SMT1206), 50V, 5%, NPO
C 201	5-00378-552	180P	Capacitor, Chip (SMT1206), 50V, 5%, NPO
C 202	5-00378-552	180P	Capacitor, Chip (SMT1206), 50V, 5%, NPO
C 203	5-00378-552	180P	Capacitor, Chip (SMT1206), 50V, 5%, NPO
C 204	5-00378-552	180P	Capacitor, Chip (SMT1206), 50V, 5%, NPO
C 205	5-00378-552	180P	Capacitor, Chip (SMT1206), 50V, 5%, NPO
C 206	5-00378-552	180P	Capacitor, Chip (SMT1206), 50V, 5%, NPO
C 207	5-00378-552	180P	Capacitor, Chip (SMT1206), 50V, 5%, NPO
C 210	5-00299-568	.1U	Cap, Ceramic 50V SMT (1206), X7R
C 220	5-00299-568	.1U	Cap, Ceramic 50V SMT (1206), X7R
C 230	5-00299-568	.1U	Cap, Ceramic 50V SMT (1206), X7R
C 240	5-00299-568	.1U	Cap, Ceramic 50V SMT (1206), X7R
C 250	5-00299-568	.1U	Cap, Ceramic 50V SMT (1206), X7R
C 260	5-00299-568	.1U	Cap, Ceramic 50V SMT (1206), X7R
C 310	5-00299-568	.1U	Cap, Ceramic 50V SMT (1206), X7R
C 311	5-00319-569	10U/T35	Cap, Tantalum, SMT (all case sizes)
C 312	5-00387-552	1000P	Capacitor, Chip (SMT1206), 50V, 5%, NPO
C 313	5-00299-568	.1U	Cap, Ceramic 50V SMT (1206), X7R

C 314	5-00381-552	330P	Capacitor, Chip (SMT1206), 50V, 5%, NPO
C 316	5-00519-569	.33U/T35	Cap, Tantalum, SMT (all case sizes)
C 360	5-00513-569	1U-16V A-CASE	Cap, Tantalum, SMT (all case sizes)
C 361	5-00519-569	.33U/T35	Cap, Tantalum, SMT (all case sizes)
C 362	5-00628-569	22U - 35V	Cap, Tantalum, SMT (all case sizes)
C 364	5-00381-552	330P	Capacitor, Chip (SMT1206), 50V, 5%, NPO
C 410	5-00299-568	.1U	Cap, Ceramic 50V SMT (1206), X7R
C 420	5-00299-568	.1U	Cap, Ceramic 50V SMT (1206), X7R
D 111	3-00576-311	RED MINI	LED, Subminiature
D 200	3-01342-313	STZ5.6NT146	Diode, SMT
D 202	3-01342-313	STZ5.6NT146	Diode, SMT
D 204	3-01342-313	STZ5.6NT146	Diode, SMT
D 206	3-01342-313	STZ5.6NT146	Diode, SMT
D 314	3-00380-301	1N5248	Diode
D 315	3-00926-360	MBR0540T1	Integrated Circuit (Surface Mount Pkg)
D 361	3-00010-303	GREEN	LED, T1 Package
D 362	3-01303-313	B340LA-13-F	Diode, SMT
D 401	3-00806-360	BAV170LT1	Integrated Circuit (Surface Mount Pkg)
D 403	3-00806-360	BAV170LT1	Integrated Circuit (Surface Mount Pkg)
D 421	3-00011-303	RED	LED, T1 Package
D 422	3-00011-303	RED	LED, T1 Package
D 423	3-00011-303	RED	LED, T1 Package
D 424	3-00011-303	RED	LED, T1 Package
IS230	3-01320-340	HCPL-2630	Integrated Circuit (Thru-hole Pkg)
IS240	3-00446-340	6N137	Integrated Circuit (Thru-hole Pkg)
IS250	3-01320-340	HCPL-2630	Integrated Circuit (Thru-hole Pkg)
IS260	3-00446-340	6N137	Integrated Circuit (Thru-hole Pkg)
J 111	1-00251-130	10 PIN DIL	Connector, Male
J 200	1-00371-160	25 PIN D RS232	Connector, D-Sub, Right Angle PC, Female
J 400	1-01090-115	1615490000	Header, Amp, MTA-100, Rt Angle
JD121	1-00234-109	96 PIN RT ANGLE	DIN Connector, Male
K 401	3-01056-335	24VDC DPDT	Relay
K 402	3-01056-335	24VDC DPDT	Relay
K 403	3-01056-335	24VDC DPDT	Relay
K 404	3-01056-335	24VDC DPDT	Relay
PC1	7-01710-701	PTC	Printed Circuit Board
Q 411	3-00601-360	MMBT3904LT1	Integrated Circuit (Surface Mount Pkg)
Q 412	3-00601-360	MMBT3904LT1	Integrated Circuit (Surface Mount Pkg)
Q 413	3-00601-360	MMBT3904LT1	Integrated Circuit (Surface Mount Pkg)
Q 414	3-00601-360	MMBT3904LT1	Integrated Circuit (Surface Mount Pkg)
R 112	4-01466-461	300	Thick Film, 5%, 200 ppm, Chip Resistor
R 311	4-01270-462	39.2K	Thin Film, 1%, 50 ppm, MELF Resistor
R 312	4-01210-462	9.31K	Thin Film, 1%, 50 ppm, MELF Resistor
R 313	4-01163-462	3.01K	Thin Film, 1%, 50 ppm, MELF Resistor
R 314	4-01009-462	75.0	Thin Film, 1%, 50 ppm, MELF Resistor
R 361	4-01466-461	300	Thick Film, 5%, 200 ppm, Chip Resistor
R 362	4-01455-461	100	Thick Film, 5%, 200 ppm, Chip Resistor
R 412	4-01406-461	0	Thick Film, 5%, 200 ppm, Chip Resistor
RN111	4-01707-463	47KX4D	Resistor network, SMT, Leadless
RN112	4-00911-463	4.7KX4D	Resistor network, SMT, Leadless
RN113	4-00910-463	1.0KX4D	Resistor network, SMT, Leadless
RN121	4-01707-463	47KX4D	Resistor network, SMT, Leadless
RN200	4-00916-463	47X4D	Resistor network, SMT, Leadless
RN201	4-00916-463	47X4D	Resistor network, SMT, Leadless
RN202	4-00911-463	4.7KX4D	Resistor network, SMT, Leadless
RN231	4-00909-463	470X4D	Resistor network, SMT, Leadless
RN232	4-00909-463	470X4D	Resistor network, SMT, Leadless
RN251	4-00909-463	470X4D	Resistor network, SMT, Leadless
RN252	4-00909-463	470X4D	Resistor network, SMT, Leadless
RN410	4-01707-463	47KX4D	Resistor network, SMT, Leadless
RN411	4-01707-463	47KX4D	Resistor network, SMT, Leadless
RN412	4-00911-463	4.7KX4D	Resistor network, SMT, Leadless
RN421	4-00908-463	270X4D	Resistor network, SMT, Leadless
T 300	6-00683-610	VP1-0190	Transformer

U 110	3-01497-360	ATMEGA162-16AI	Integrated Circuit (Surface Mount Pkg)
U 120	3-01498-360	74ABT16245CMTD	Integrated Circuit (Surface Mount Pkg)
U 210	3-01343-360	74HC166D	Integrated Circuit (Surface Mount Pkg)
U 220	3-00787-360	74HC595	Integrated Circuit (Surface Mount Pkg)
U 310	3-01322-360	LT1425CS	Integrated Circuit (Surface Mount Pkg)
U 321	3-01460-360	MC7815ACD2T	Integrated Circuit (Surface Mount Pkg)
U 360	3-00814-360	78M05	Integrated Circuit (Surface Mount Pkg)
U 410	3-01375-360	74HC86AD	Integrated Circuit (Surface Mount Pkg)
U 420	3-00741-360	74HC04	Integrated Circuit (Surface Mount Pkg)
Z 0	7-01738-720	PTC DIG.I/O BRK	Fabricated Part
Z 1	0-00306-026	4-40X3/16PP	Screw, Black, All Types
Z 2	0-00306-026	4-40X3/16PP	Screw, Black, All Types
Z 3	0-01093-007	563002B00000	Heat Sinks
Z 4	1-01186-131	1690520000	Connector, Female

Schematics

Circuit board	Page count
PTC211 CPU board	6
PTC221 Backplane	3
PTC231 Front panel	3
PTC240 GPIB card	1
PTC320 1-channel thermistor/diode/RTD reader	6
PTC321 4-channel RTD reader	6
PTC323 2-channel thermistor/diode/RTD reader	6
PTC330 4-channel thermocouple reader	7
PTC420 600W AC output card	2
PTC430 50W DC output card	3
PTC431 100W DC output card	4
PTC440 TEC driver	5
PTC510 Analog IO card	3
PTC520 Digital IO card	4