User Manual

CTC100

Cryogenic Temperature Controller

Version 1.5 (April 8, 2013)

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 CTC100 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 CTC100, provides connection to the power source and to a protective ground.

Power cord

The CTC100 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 CTC100. 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 CTC100 does not include any user serviceable parts inside. Refer service to a qualified technician.

Specifications

CTC100 temperature controller

Minimum sampling rate	1 Hz
Maximum sampling 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 color 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	8.5"× 5" × 16" (WHL)
Weight	13 lbs.
Warranty	One years parts and labor on defects in material and workmanship.

Thermistor, diode, and RTD inputs

Inputs	Four inputs for 2-wire or 4-wire thermistor, diode, or RTD
Connectors	Two 9-pin D-sub sockets
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	±1 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	±1 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

100W DC outputs

Output	Two unipolar DC current sources
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 bit
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, DC–10 Hz	5 µA (2 A range) 1.5 µA (0.6 A range) 0.5 µA (0.2 A range)

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 (at 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 25-pin D-sub socket

Relays

Outputs	4 independent SPDT relays
Connector	One 12-pin 3.5mm header
Maximum current	5 A
Maximum voltage	250 VAC

Introduction

The CTC100 is a high-performance cryogenic temperature controller that can monitor and control temperatures with millikelvin resolution. Its features include:

4 temperature sensor inputs

Each of the CTC100's four temperature inputs can read RTDs, thermistors, and diodes.

Each temperature input channel has its own 24-bit ADC with ten input ranges that can be automatically or manually selected. By default each sensor is read 10 times per second, but the rate can be set as low as 1 Hz or as high as the line frequency (50 or 60 Hz).

Each input has an independent excitation current source. The excitation current is automatically selected based on the input range. The direction in which the excitation current flows through the sensor can be reversed to detect EMF errors, and the CTC100 can automatically reverse the current direction at every ADC reading and display the average of forward and reverse current readings.

Standard calibration curves for a variety of sensors are included, and custom calibration curves of up to 200 points each can be entered by saving a text file on a USB memory stick and then plugging the memory stick into the CTC100. Calibrations can be adjusted by entering an offset and gain from the front panel.

Each sensor input has high and low level or rate-of-change alarms. Alarms can be latching or non-latching and when triggered, can shut off a heater output, trip a relay, and/or create one of four alarm sounds.

Sensor inputs can be lowpass-filtered to reduce noise and/or differenced with another channel. The rate of change of sensor inputs can be calculated.

In addition, any of the CTC100's four voltage I/O channels can be used to read pre-amplified sensor signals.

2 powered and 4 unpowered heater outputs

The CTC100 has two heater outputs, each capable of delivering up to 100W of power to a 25 ohm heater. In addition, four unpowered voltage I/O channels can be used to drive heaters with the help of an external amplifier.

Up to 6 feedback control loops

Each of the heater outputs can be controlled by a PID feedback loop. A feedback loop continually adjusts the heater power in order to keep a sensor at a constant temperature. Any of the CTC100's channels can be selected as the input for each feedback loop. Feedback time constants can be adjusted between about 200 ms and 10 hours. .

PID feedback parameters can be tuned manually or automatically. Depending on the amount of overshoot that is acceptable, aggressive, moderate, or conservative tuning goals can be selected.

Up to ten sets of PID parameters can be stored for each channel; each set of parameters can be assigned a temperature range and automatically recalled when the temperature falls within that range. The temperature sensor used for the feedback loop can also be selected based on the temperature.

Setpoints can be ramped at a fixed rate or, with a user program, set from an analog input.

Feedforward and cascade feedback are supported.

General-purpose analog I/O, digital I/O, relays, and virtual channels

The CTC100 has four general-purpose ±10V voltage I/O channels read by a 24-bit ADC. Custom calibration curves and/or offset/gain controls can be used to convert voltage readings to pressure, temperature, etc.

The CTC100 also has eight digital I/O channels that can interact with user programs. Four 5A relays can be used for process control. Three virtual channels not connect to any physical input allow calculated values (such as the difference between two channels, or a value calculated by a user program) to be displayed, graphed, and logged.

Graphical touchscreen display

The CTC100's color LCD display can show any combination of temperature measurements and heater outputs on graphs or numeric displays. Up to eight channels can be plotted, either on a single graph with a common Y axis or on separate graphs with independent Y axes.

Touchscreen operation makes the instrument versatile and easy to use.

Data logging to USB memory devices

Up to 4096 readings per channel can be logged to the CTC100's internal memory. For longer-term storage, data can be logged to standard USB memory sticks or hard drives. Readings can be logged at intervals as short as 0.1 s or as long as 1 hour. The log rate can be set independently for each channel, or a single global rate used.

Data logged to USB devices can be transferred to a computer by plugging the USB device into a PC and copying the log files. Windows applications are included to graph CTC100 log files and to convert them to various ASCII text formats.

Computer communications

Each of the CTC100's front-panel controls has a corresponding text command that can be sent over USB, Ethernet, and either RS-232 or an optional GPIB interface. When the USB interface is used, the CTC100 appears on the computer as a standard COM port and can be controlled by any software that is compatible with an RS-232 port.

Eight digital I/O lines are also provided; these can interact with user programs to control most aspects of the instrument's operation.

User programs

User programs (macros) consisting of one or more remote commands can be uploaded to the CTC100, either by sending them through one of the communications ports or by saving them as text files on a USB memory device and then plugging the device into the CTC100. Macros can be started or stopped, and their progress monitored, from the front panel. Macros can call other macros, and conditional statements and loops are supported. Using the CTC100's virtual channels, values calculated by macros can be plotted on-screen, saved to logs, and/or used as inputs for feedback loops. Up to 10 macros can run concurrently.

At a basic level, macros can be used to program temperature profiles or other sequences of events. Macros can also be employed in more advanced ways to tailor the behavior of the CTC100 for your experiment; for example, infinite-loop macros running as background tasks can take steps to address alarm conditions or automatically switch between sensor inputs (or heater outputs) depending the value of some input.

Connecting the inputs and outputs

The CTC100 has four temperature sensor inputs; two powered heater outputs; four ±10V analog I/O channels; four 5A relays; and eight digital I/O lines.

Temperature sensor inputs

The CTC100 has four multi-range inputs, each of which can read resistive sensors having resistances between 1 Ω and 2.5 MΩ, and diode sensors having voltage drops of up to 2.5V.

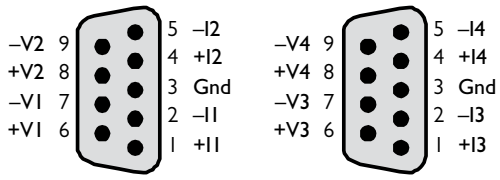
Standard calibration curves are included for the sensors shown in the following table. The "Range" column indicates the range of the standard calibration curve; if the sensor is outside this range, no reading appears. It may be possible to obtain a larger range by uploading a custom calibration curve.

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 kinds of resistive and diode sensors can be used, 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.

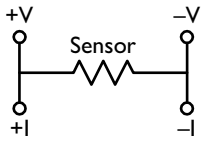
Connecting the sensor

The CTC100 has two 9-pin D-sub (DB9) sockets that mate with any standard DB9 plug, such as Amphenol L717SDE09P with backshell 17E-1657-09. Two plugs and backshells are provided with each CTC100.Here is the pinout of the two sockets, as they appear when looking at the CTC100's back panel:



Sensor In 1, for example, should be connected to pins +I1, –I1, +V1, and –V1 as described below. Cable shields should be connected to chassis ground at pin 3 of either connector.

The +I and –I pins provide an excitation current that should be routed to the temperature sensor through two wires, preferably a shielded twisted pair. The excitation current produces a voltage across the sensor that is measured with additional pins, +V and –V. 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. Because essentially no current flows through the V leads, they accurately transmit the sensor voltage to the CTC100.Using four wires instead of two ensures that the CTC100 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 the CTC100 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 the cathode is connected to –V and –I and the anode to +V and +I, the `Channel.Current` setting should be Forward. If the diode is connected in the opposite direction, the current should be set 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 put EMI filters not only the on the sensor leads but also on all other leads entering the dewar. The filters should be located at the point where the wires enter the dewar, and the dewar itself should be grounded. D-sub and circular connectors with built-in 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 to the dewar.

Excitation current

The excitation current is automatically determined by the CTC100 based on the type of sensor and the measurement range, as shown in the table below.

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 CTC100

The amount of power dissipated in an RTD is at most 400 µW at the 100Ω range, decreasing to 2.5 µW at the 2.5 MΩ range. The power dissipation in a thermistor is at most 10 µW at the 10Ω range, decreasing to 300 pW at the 300 kΩ range. Thermistor power dissipation decreases much more rapidly than RTDs as the measurement range is increased. Low power dissipation at high resistances is critical for thermistors used in cryogenic systems, since the resistance of the sensor increases and the heat conductivity of the surrounding medium decreases as the temperature approaches 0 K.

The direction of the excitation current can be set by the user to forward, reverse, or AC (switching between forward and reverse with each sample). AC current is recommended for resistive sensors to reduce noise and drift. AC current cannot be used with diode sensors. See the discussion of the Current setting on page 55.

100W heater outputs

The CTC100 has two outputs for resistive heaters. The output connectors are #6-32 wire clamp screws and will accept bare wire between 12 and 22 AWG. For the most reliable connection it is recommended to crimp a #6 insulated spade terminal (such as TE Connectivity 34080 for 16–22 AWG wires or 35559 for 14–16 AWG wires) to the end of each heater wire. A crimp tool such as TE Connectivity 58433-3 should be used for this purpose.

The CTC100 should always be switched off and unplugged when connecting the heater outputs.

Each output has two voltage ranges (50 V and 20 V) and three current ranges (2A, 0.6A, and 0.2A). Each output also has an auto-range setting that continuously adjusts the current and voltage ranges to the smallest values needed to reach the channel's Hi Lmt setting.

The 0.6A and 0.2A current ranges offer lower noise levels than the 2A range and are intended to be used when more precise control is needed. On the other hand, the 20V range is only included for safety reasons and it has essentially the same performance as the 50V range.

The maximum power that each output 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	4R
	25	100
	>25	2500/R
50 V 0.6 A	<75	0.4R
	75	33
	>75	2500/R
50 V 0.2 A	<250	0.04R
	250	10
	>250	2500/R

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

The heater outputs are generated on two printed circuit boards (PCBs). If the temperature of a PCB exceeds 60°C, the CTC100 automatically shuts off the corresponding 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. The PCB temperatures can be monitored by sending the remote command `(System.display.T(PCB)) = Show` and restarting the CTC100.

Hardware faults

The CTC100 can detect certain unsafe operating conditions. If such a condition occurs and persists for more than 2 seconds, the CTC100'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 CTC100's screen:

- **Measured heater current differs from desired value**: The CTC100's output is non-zero, and the current flowing out of the positive terminal differs from the desired current by more than 0.25A. This error can occur if the CTC100 is out of calibration. It can also mean that the CTC100 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 CTC100's output is non-zero, 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.
- **Output is off but heater current was detected**: The CTC100's output is set to zero, but current is flowing into the negative terminal. This error may indicate that the heater is shorted to a power source other than the CTC100. It can also indicate a failure of the CTC100's output circuit.
- **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 CTC100's chassis fan is not working. Try reducing the maximum output voltage or current, and make sure the front panel fan is running.

±10V analog I/O channels

Each of the four analog I/O channels has a BNC connector on the back panel of the CTC100. The outer shell of the connector is grounded.

Each analog I/O channel can be an input (±10V, 24-bit ADC) or an output (±10V, 16-bit DAC).

Although they aren't as accurate as the dedicated sensor inputs and heater outputs, the analog I/O channels can be used in a limited fashion to read temperature sensors and drive heaters. If used to drive a heater, each analog I/O channel can only supply up to 30 mA of current. Furthermore, because of their limited accuracy, when set to 0 V the analog outputs may still feed a small amount of power to the heater.This residual current can be eliminated by placing a diode in series with the heater and increasing the channel's Lo Lmt setting to about 0.5V (to prevent integral windup).

Relays, digital I/O, and virtual channels

The CTC100 has four relays, each rated for up to 5A of current. The connector for the relays is 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 CTC 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 CTC100 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 "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 CTC100 also has eight isolated TTL I/O lines on a 25-pin connector. The pinout of this connector is compatible with the standard PC parallel port. The TTL lines can be used as inputs or outputs, but all eight must have the same direction. The pinout follows (the pin numbers are embossed next to the pins on the D-sub connector):

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		

All 25 pins on this connector are electrically isolated from the rest of the CTC100 and are floating with respect to earth ground. Therefore, to use the digital I/O lines, at least one of the "Gnd" pins must be connected to ground. Alternatively, if the digital I/O lines are configured as inputs, the value of D0 to D7 can be set by shorting them either to a +5V pin or to a Gnd pin.

The status of the eight digital I/O lines is reported 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 is the sum of the values of all set bits. For example, if only bits D1 and D3 are set, the CTC100 shows a DIO value of 2 + 8 = 10.

By using background macros, the digital I/O lines can be associated with most functions of the CTC100. The remote interface provides bitwise operators to set and query the relays and digital I/O lines.

The DIO lines can also be used to pass a single, 8-bit value into or out of the CTC. The CTC 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, which by default are named V1, V2, and V3. These channels do not have physical inputs or outputs; instead, their values can be set by macros or remote commands, or they can automatically follow the value of another channel. Like other channels, the values of virtual channels can be monitored on the Display screen and logged to USB memory devices.

Also like other channels, virtual channels have an IO type that determines how the channel can be used. If the IO type is "Input", the virtual channel can follow the value of another channel (see the description of the Channel.Follow button in the Operation section), and the value can be modified by applying a lowpass filter, subtracting a difference channel, taking its derivative with respect to time, or applying offset and 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 a virtual channel's IO type is set to "Meas out", a PID feedback loop becomes available. The feedback loop can be used, for example, to implement cascade control; see the description of the Channel.PID.Casc button in the Operation section. Unlike other outputs, virtual outputs are not forced to zero when the CTC100's outputs are disabled with the Output Enable button. However, virtual PID feedback loops do stop running when the CTC100's outputs are disabled.

When the value of a virtual channel is changed by a macro or via 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

Before turning the power on, connect any sensors and heaters to the CTC100 as described in the previous section. Then, plug the CTC100 in and turn it on with the power switch on the back of the instrument. A logo should appear on-screen immediately and remain for about 30 seconds while the system boots. A second splash screen appears for an additional 15 seconds while the firmware is initialized.

If the CTC100 does not turn on, a fuse may have blown. The CTC100 has two internal fuses that can be accessed by unplugging the instrument and then removing its top cover.

Plot data

The CTC100 boots up with the "Select Channels" screen showing. This screen has one button for each input and output connector on the back panel of the instrument. The locations of the buttons on the screen roughly correspond to the locations of the connectors on the back panel. In addition there are buttons for three virtual channels, V1 – V3, that do not correspond to back-panel connectors.

To plot data:

1. On the Select screen, touch the buttons for the channels to be plotted. The buttons should change to a lighter color, indicating that the channels are selected. If any other channels are selected, touch their buttons to de-select them.
2. Press the Show Data key on the CTC100's front panel.

The Show Data screen has four blue tabs at the top that control the type of display:

- **Single**: all selected channels are plotted together on a single graph.
- **Multiple**: each selected channel is plotted in its own graph.
- **Ponytail**: all selected channels are plotted together on a single graph, and the traces are offset such that each channel starts at zero.
- **Custom**: selected channels are assigned to plots with the "Plot" button on the channel setup screen, described on page 62.
- **Numeric**: a numeric value is displayed for each selected channel.

To zoom in, touch anywhere within the right half of the plot. To zoom out, touch the left half of the plot (but not left of the Y axis). You can also drag the plot left or right to see older or newer data; the words "X lock" appear in the bottom-left corner of the screen to indicate that the graph is no longer automatically scrolling to show new data. Touch the "X lock" indicator to return to viewing real-time data.

Set the data logging rate

By default, the CTC100 records one data point per second to each channel's log. To change this rate for all channels, press the Setup key on the front panel and then touch the blue "System" tab. 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 ADC sampling or PID feedback performance.

Each channel can be assigned its own data logging rate; see the description of the Channel.Logging control on page 62.

Save data to and retrieve data from a USB memory device

If no USB memory stick or hard drive is present, the CTC100 only stores the most recent 4096 data points for each channel; older points are erased. Therefore, if the logging rate is 1 point per second, only the most recent hour of data can be displayed. In addition, all stored data is lost if the CTC100 is turned off.

A USB memory stick can be used to keep a much longer record of logged data that won't be lost if the CTC100 is turned off. Follow these steps to begin logging data to a USB storage device:

Save data to a USB device

1. Plug a USB memory stick into the port on the back of the instrument. The memory stick should be freshly-formatted and completely empty. If you use the memory stick that came with the CTC100, copy the files onto a computer and format the memory stick before using it to log data.
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, dark-blue 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 CTC100 is saving data to the USB device. If the CTC100 is unable to write to the device, the USB logging indicator will not turn white.
4. Before turning the instrument off or removing the USB device, touch the USB logging indicator again and wait for it to turn dark blue. This very important step is needed to prevent damage to the USB device. If this step is skipped (e.g. if a power failure occurs while logging), the USB device should be re-formatted with 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 CTC100 channel plus the extension ".ptc" (the files use the same format as the PTC10 temperature controller). 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 CTC100 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 "Setup" button on the CTC100's front panel and touching the blue "System" tab, has controls for setting up the CTC100's RS-232, GPIB, and Ethernet interfaces (under the "COM" and "IP" columns). The USB interface requires no setup on the CTC100 but may 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 CTC100 sometimes drops characters from the RS-232 messages that it receives, try using a USB-to-RS-232 adapter or use 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 CTC100 into the PC.
3. The New Hardware Found wizard appears on the PC. Tell the wizard not to search the web for the driver; choose 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 CTC100 should appear as a COM port on your computer, and your programs can use the USB connection in the same way that they use an RS-232 connection.

Read data from the CTC100

All RS-232, GPIB, USB, and Ethernet messages sent to the CTC100 must end with a linefeed (decimal 10 = hex 0x0a = '\n'). The CTC100 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. Omit any spaces from the channel's name. For example, to query the value of channel "Out 1", send the command `Out1?`. The CTC100 replies with a value such as "0.00000":

```
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?
29.98424, 25.86019, 27.49236, NaN, 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 in which the channels are listed, send a `getOutputNames` query:

```
getOutputNames?
In 1, In 3, In 2, In 4, Out 1, Out 2, AIO 1, AIO 2, AIO 3, AIO 4,
V1, V2, V3, DIO, Relays
```

Data can also be read with the `getLog` instruction, which returns logged data. Logged values are typically the average of ten ADC conversions and have less noise than the values returned by `getOutput` and *`channel`*`?`, both of which return the result from the single most recent ADC conversion only. In addition, `getLog` makes it easier to retrieve data at consistent time intervals. For example, begin by sending this command, which retrieves the last point in channel In 1's log:

```
getLog "In 1", last
27.53936
```

Next, send the following command:

```
getLog "In 1", next
27.57375
```

Each time this command is sent, the CTC100 sends the next data point in the log, if necessary waiting for a new point to be added.

Control a temperature

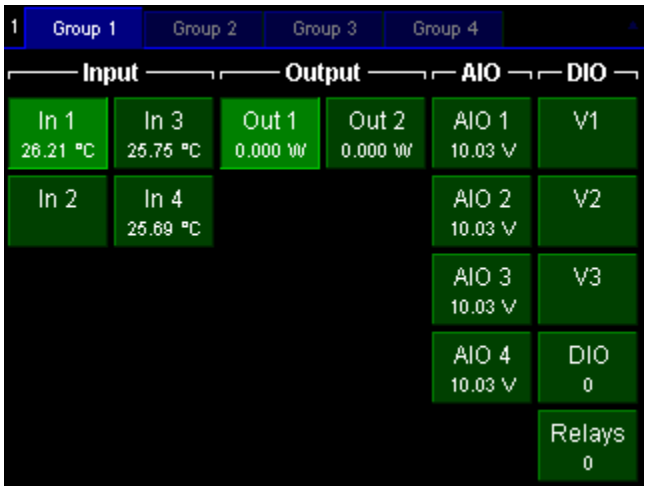
The CTC100 can control the temperature of one or more external devices with a resistive heater and a temperature sensor.

Each of the CTC100's output channels can use proportional-integral-differential (PID) feedback software to monitor a temperature sensor and determine how much power to send to the heater. The PID feedback has three adjustable gain factors that determine how much and how quickly the heater power is adjusted if the temperature deviates from its desired value. These gain factors must be properly set before the CTC100 can control the temperature of your system.

Start by plugging the heater and temperature sensor into the CTC100'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

The stability of the feedback loop can usually be dramatically improved by lowpass-filtering the temperature reading. To do this, first select the channel to be filtered by pressing the "Select Channels" key, then touching the relevant channel to highlight it. Although it's not necessary, you could also select the output channel at this point, since you will need to set it up next. If any other channels are highlighted, touch them to de-select them. In this example, we've selected temperature sensor "In 1" and heater "Out 1":



Now press the "Setup" key. At the top of the screen are three blue tabs: a "System" tab for configuring system-wide parameters like the RS-232 baud rate and the display brightness, and a tab for each of the channels you selected. Touch the tab labeled "In 1".

A list of options for temperature input "In 1" is displayed. The upper-left green button, for example, shows the name of the channel; the name can be changed by touching the button. The "Value" button shows the sensor reading, but since the sensor is an input, its value can't be changed from the front panel and therefore the button is greyed out.

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

In the Lopass menu, select the value that is closest to your heater's response time. By reducing noise, the filter improves the accuracy of the PID tuning process and the performance of the tuned PID feedback loop. The larger the lowpass value is, the less noise there will be; however, a value larger than the heater's response time will slow down the feedback

Configure the alarm

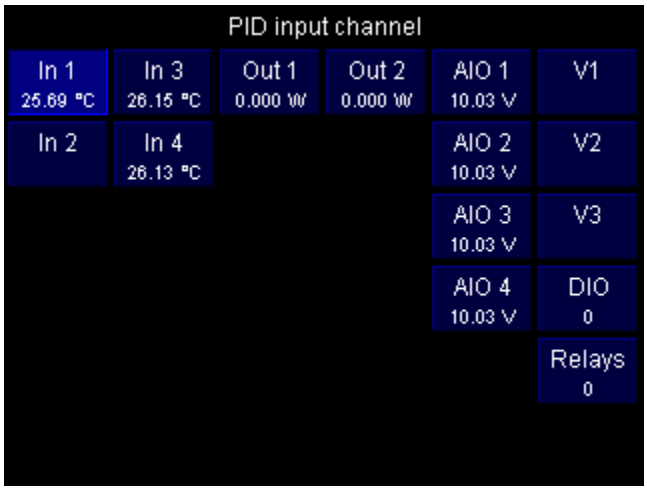
To protect your system from being damaged by excessive heater power (which can occur if, for example, the PID feedback is configured incorrectly or the sensor becomes disconnected), it's important to set up an alarm. The alarm automatically shuts off the heater whenever the temperature exceeds limits 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 channel In 1, under the Alarm heading, set the options as follows:

- **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.
- **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**: Should be set well below the lowest temperature that could normally be observed; the min setting should 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.

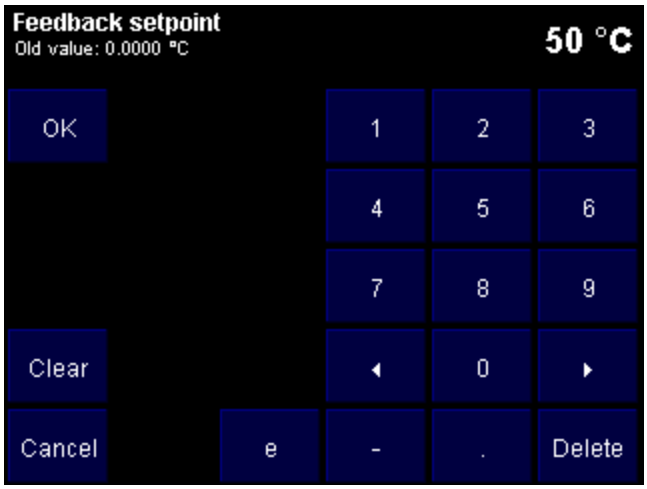
Configure the PID feedback loop

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. Touch the "Out 1" tab to bring up the setup screen for channel Out 1. In the first "PID" column, touch the "Input" button. Then, on the list of channels that appears, touch the temperature input channel "In 1". This tells the CTC100 that we want heater Out 1 to control the temperature of sensor In 1.



Next, touch the "Setpoint" button and enter the desired temperature. Touch "OK" once you've entered the setpoint. Since the feedback is still disabled, the CTC100 won't actually apply any power to the heater yet.



Configure the feedback autotuner

The feedback tuner works by changing the heater output and then measuring how much the temperature changes in response. Before this can be done, you need to determine how much the heater output should be changed by and indicate how long the CTC100 should wait for the temperature to change.

Make sure the "Channel" screen is showing, and the tab for the heater output channel is 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 faster but can also add noise. 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 feedback turned off and the heater stabilized at the ambient temperature. On the other hand, 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 starting at ambient temperature, ensure that the feedback is turned off before enabling the outputs: select the output channel on the "Select Channels" screen, then press the Setup key, select the tab for the output channel, and touch the "Off" button.

If the outputs are disabled, enable them by pressing the "Output Enable" key twice. The red Output Enable LED turns on and the CTC100 beeps (if pressed again, the Output Enable key immediately turns all the CTC100'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 CTC100 will not tune the feedback if it detects an excessive amount of thermal drift. As an example of how the drift is measured, assume that Step Y is set to 2 W and Lag is set to 45 seconds. These values might be appropriate if the CTC100 is heating a small object weighing about 100g. The CTC100 locks the heater output at its current value for one-third of the Lag time, in this case 15 seconds, and measures how much the temperature changes over this period. The CTC100 then increases the heater output by 2 W and waits for an additional 45 seconds to pass. If the temperature does not change by at least ten times the amount that it changed during the first 15

seconds, autotuning is automatically cancelled, the heater output is returned to its original value, and no changes are made to the feedback gains. In addition, if the Status window is showing, it displays a message that says "Tuning was cancelled because the response was less than 10 times the noise and drift". The cause of the problem may be one or more of the following:

- 2 W was not enough power to significantly increase the temperature, in which case Step Y should be increased;
- 45 seconds was not enough time for the heater temperature to increase, in which case the Lag should be increased; or
- the temperature was drifting up or down before the test was started, resulting in an excessively large baseline drift and noise measurement. In this case, allow the heater to stabilize at room temperature for at least 30–60 minutes (more if object you are heating is very large) before trying the test again.

It's OK to dismiss the status window or otherwise use the CTC100's controls during the tuning process; tuning will continue unless you cancel it by setting the tuning mode to off or by disabling the outputs with the Output Enable key. In fact, it's a good idea to display a graph of heater output and temperature while autotuning (select the two channels, press the "Show Data" key, and select the "Multiple" tab). To see the status message again, press the "Setup" key, select the tab for the output channel, and then touch the "Status" button in the bottom-right corner.

When tuning is finished, the CTC100 beeps and the PID feedback is automatically enabled. If the temperature is still below the setpoint, the CTC100 starts increasing power to the heater. The temperature may overshoot the setpoint, but should eventually stabilize at the setpoint.

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

Acquiring and logging data

Input filters

The CTC100 has several numeric filters for processing 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 value equal to another channel)
3. Offset/gain (multiplies a channel by a gain and adds an offset)
4. Difference (subtracts the value of another channel)
5. Lowpass (filters out noise)
6. Derivative (takes the derivative of the signal with respect to time)

The order affects how the filters 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 input or output channel, except for virtual channels. The custom calibration replaces the preloaded sensor calibration and is responsible for converting the raw sensor reading in ohms, volts, etc. to a temperature.

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 to be calibrated, plus the extension ".txt". Create a directory named "cal" within the top-level directory of a USB storage device, and copy the.txt file into the directory. Plug the storage device into the CTC100, and the CTC100 automatically loads the files. It is recommended that the storage device be left plugged into the CTC100 whenever the custom calibration curve is in use.

If you are using a calibrated Lake Shore sensor, the CTC100 will accept the .dat calibration file included with the sensor. Just change the name of the file to the name of the channel plus the extension ".txt" (for example, "In 1.txt"), copy the file into the cal directory of your USB stick, and plug the USB stick into the CTC100.

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 CTC100, the CTC100 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 CTC100 is switched off, all calibration tables in RAM are lost. Therefore, once a custom calibration table is loaded, 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 CTC100.
- 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 CTC100 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 CTC100 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.

Calibration table format

A calibration table is an ASCII text file containing a units declaration followed by pairs of numeric values. For example, here is a calibration table for a 100Ω platinum RTD:

```
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 following the first whitespace character on this line is ignored; therefore, the XY data must begin on the second line.

If the display units are "°C", "°F", "K", or "mK", the CTC100 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 deceleration 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 CTC100 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 CTC100 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 CTC100 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 (putting the measured value first, followed by the displayed value) 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 an 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 CTC100 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 CTC100 has three virtual channels that by default are named V1, V2, and V3. These channels are not connected to a physical input or output channel. Instead, they can mirror another channel or be assigned a value by a macro. 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, and their value can be graphed and saved to a log.

Virtual channels can be used to apply different sets of filters to a single channel. For example, channel 3A could show the temperature of an apparatus, while virtual channel V1 could show the rate of change of that temperature.

Since a virtual channel's value can be set by a macro, the channel can be used to reveal internal CTC parameters that cannot otherwise be graphed or saved to the log. For example, a virtual

channel show 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 a little over one hour of data. Older data points are deleted. The entire log is erased if the instrument is turned off or the logging rate is changed.

To create a permanent record of data, or to plot more than an hour of data, the CTC100 can store data on removable USB memory devices such as USB hard drives or flash memory keys. The back panel of the CTC has two plugs for such devices; the CTC logs data to the last USB device to be plugged in. When a USB device is plugged in, it takes the CTC100 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.

The USB memory device must be freshly-formatted and must not contain any files other than CTC100 calibration, log, and macro files.

A small white triangle appears in the upper-right corner of the screen whenever data is being logged to USB. If a USB device is present but data is not being stored on it, the triangle is dark blue, while if no USB device is present, the triangle disappears completely. To log data to a USB device, plug the device into the CTC, touch the greyed-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 CTC100 off while USB logging is enabled. Either of these actions causes loss of data and corruption of the device's file system. If the USB logging triangle is white, always touch it and wait for it to become greyed out before unplugging the USB device or turning the CTC100 off.

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

ADC sampling and logged data

The CTC100 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 analog-to-digital conversion or A/D rate controls how often a data point is acquired for each channel. All channels are read at the same rate, which by default is 100 ms (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.

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 rate is set to 100 ms, conversions occur every six cycles of the AC voltage if the CTC100 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 could still create a constant offset in the temperature readings, but the offset is usually too small to be of concern with thermocouples and can be removed from RTD readings using current reversal.

It is possible to uncouple A/D conversions from the line frequency by moving the "Trigger source" jumper on the motherboard to the "1 MHz clock" position (note that the jumper should only be moved while the system is switched off). In this case, the A/D rate can be set to any value between 10 and 1000 ms with a resolution of 1 µs. However, A/D conversions will no longer be perfectly synchronized with the AC line voltage, even if the 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 equal to the difference between the AC line frequency and the closest multiple of the A/C conversion rate (all expressed in Hertz). For example, if the A/D rate is 10.1 Hz and the AC line frequency is 60 Hz, a sine wave with a frequency of $60 - (6 \cdot 10.1) = 0.6$ 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 in the graphs but may produce a stairstep appearance, while a fast log rate produces graphs with more detail but also more noise.

Format of CTC100 log files

The CTC100 saves data in a compact binary format shared with the SRS PTC10. Because the log files cannot easily be read by other programs, a "PTCFileConverter" program is available from the SRS website. This program converts the binary files to various text formats readable by other programs. For users who want to create their own programs to read CTC100 log files, this section describes the native binary format.

Each CTC100 log file contains data from 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 CTC100's front-panel display.

A new record is created when the user does one of the following:

- enables USB logging;
- changes the log interval (the time between data points);
- sets the system time; or
- plugs in a sensor or heater after it has been unplugged for more than 100 log points (in which case, no data points are logged while the sensor is unplugged)

Not-a-number values (0x7fc00000 if the binary data is 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 log points, no values are recorded and a new record is created the next time a sensor or heater is plugged in.

By default, log files are given the name of the channel followed by the extension ".PTC", i.e. "Out 1.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. If numeric extension 999 is reached, data for the channel is no longer logged.

A description of the file and record structure 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, though, 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.

The data values begin immediately after the record header:

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. At the default 1 second log rate, this limit is reached in about 15 years.

The system fan

The CTC100's fan regulates the temperature of the heater output and sensor input circuits. Air enters through vents in the top and rear of the instrument and exits through the a vent in the bottom cover. The vents should always be left unobstructed, or the CTC100 may overheat and be damaged.

The heater output and sensor input circuits are contained on four I/O cards. At every A/D conversion, each I/O card reads an internal temperature sensor 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 sets the fan to the fastest requested speed .

For the heater output cards, the requested fan speed depends on the temperature of the card's heatsink, the amount of current being delivered, and the voltage drop across the heater. If the temperature of a heater card 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 CTC100's outputs), or by pressing the Channel.Off button.

For the sensor input cards, 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. The default PCB setting is 35°C.

It is possible to display and log the I/O card temperatures by setting the System.Display.T(PCB) control to Show. It's necessary to restart the CTC100 for any changes to this control to become effective.

The fan speed can be overridden with the System.Other.Fan remote command. This should only be done if it is certain that the heater output cards will not overheat, otherwise the CTC100 may be damaged.

Besides the main system fan, the CTC100 also has an internal fan that periodically turns on to keep the main power supply cool. This fan runs even when the CTC100 is in system standby mode.

Rack mounting the CTC100

A 19-inch rack mount tray, SRS part number O100CTRM, is available for the CTC100. The tray will accept either one or two CTC100s or other half-rack instruments. Note that although the CTC100 chassis is 3U high, the rack mount tray is 4U high.

Important: the CTC100's main vent is on the bottom of the chassis. When rack mounting the instrument, it is important to ensure that the vent is not blocked.

Using PID feedback

Basic concepts

To control a temperature, the CTC100 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 heating/cooling device, or a cooling-only device such as a fan.

The CTC100 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 CTC100'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 a 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 CTC100, 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 temperature approaches the setpoint, the rate of change of the integral output Y_i drops to zero.

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:

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

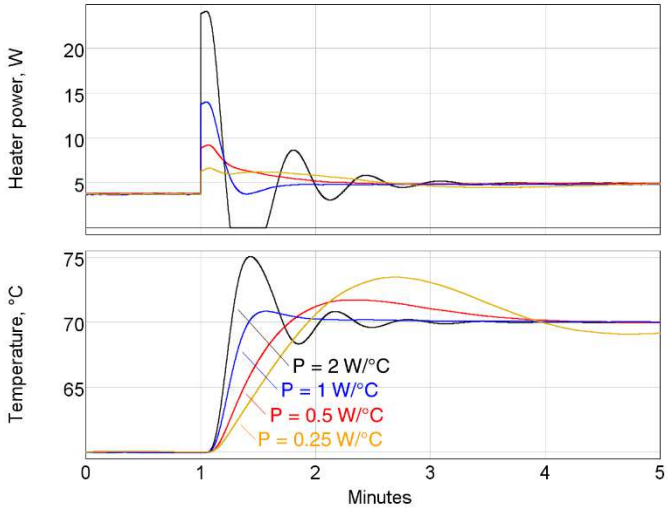
The key challenge to using a PID feedback loop is determining the best feedback gains. The constants *P*, *I*, and *D* are different for every apparatus and must be determined experimentally. As a general rule, if the gains are too low, the feedback won't respond enough to temperature

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.

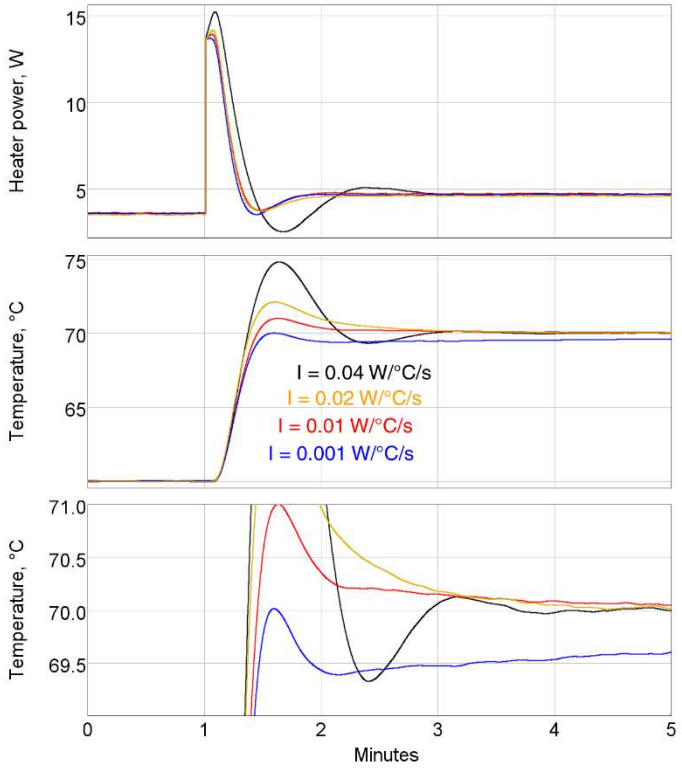
Proportional: the figure below illustrates the effect of changing the proportional gain *P*. The top graph shows the power being delivered to a heater by a PID feedback loop during four separate tests, while the bottom graph shows the temperature of the heater during the same tests. Each test is identical 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 temperature rises more slowly. 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.

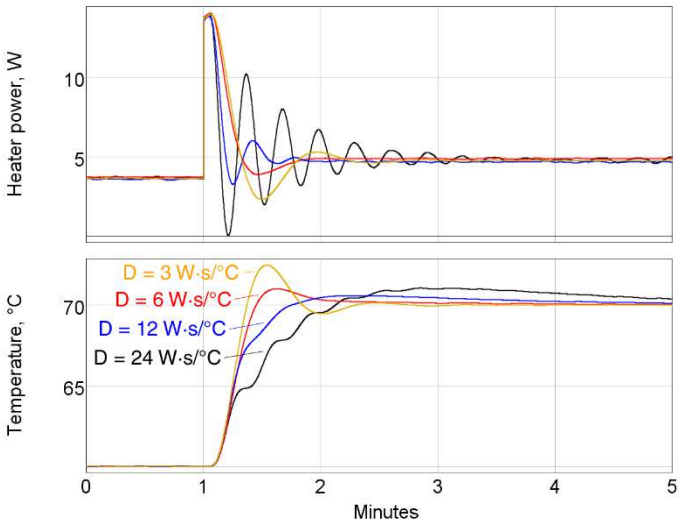
Integral: as with proportional gain, increasing the integral gain *I* also results in a larger heater response, but integral feedback doesn't respond as quickly. Integral feedback is slow because it works by adjusting its previous output, rather than re-calculating its output from scratch at each feedback 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 for a long period of time. 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.

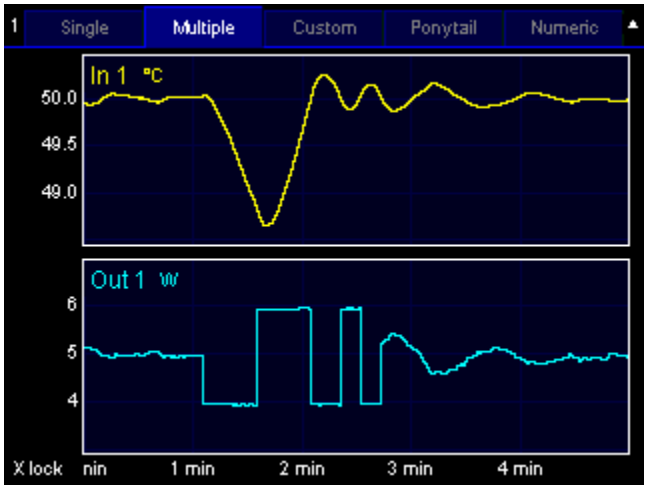


With the right amount of derivative feedback, we can increase *P* and *I* to levels that would otherwise cause oscillations, and thereby obtain faster, more responsive feedback control.

Automatic tuning algorithms

During automatic tuning, the CTC100 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 CTC100: the relay tuner and the step response tuner.

Relay tuner



Temperature (top) and heater power (bottom) during relay autotuning. Step Y is 2 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.

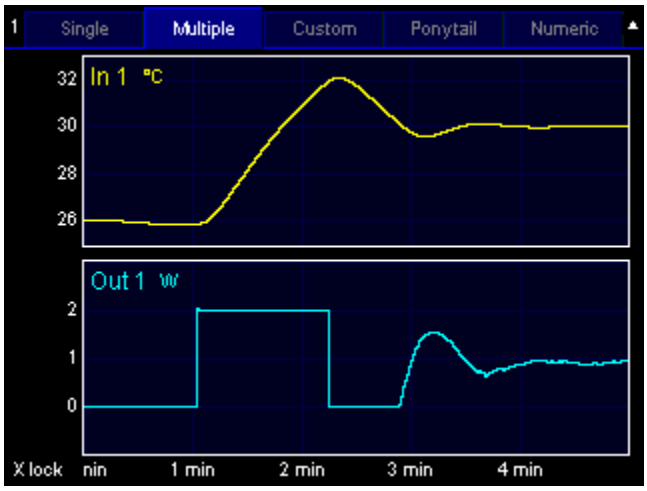
After the drift and noise measurement, the relay tuner sets the heater output to $\text{Output}_{\text{low}}$ for the Lag time to start the oscillation. If during this period the feedback input does not change by at least ten times the drift-and-noise value, an error message is displayed in the Status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



Temperature (top) and heater power (bottom) during step response autotuning. Step Y is 2 W, Lag is 30 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 30°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.

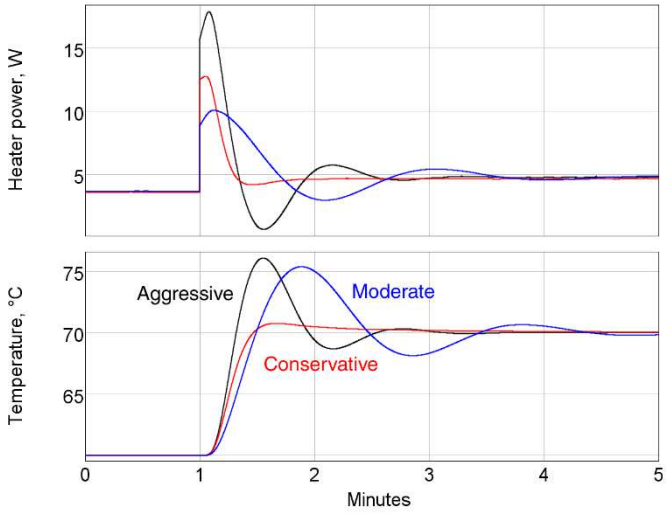
If the tuning mode is set to "Auto", the CTC100 selects the relay tuner if both its high and low outputs are within the heater's limits; otherwise, it selects the step response tuner. In particular, if

the output is off when autotuning is started, the step response tuner runs because the relay tuner would require a negative output.

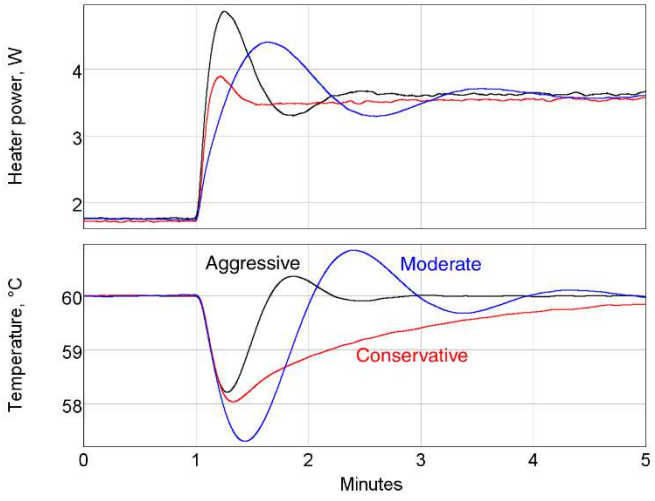
Aggressive, moderate, and conservative tuning

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 CTC100 to separate the effect of the heater from random temperature fluctuations. "Step Y" controls how much the CTC100 increases the heater output, and "Lag" controls how long the CTC100 waits for a response. If either value is too small, the CTC100 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.

Automatic tuner error messages

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

`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 noticable 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 PID mode was set to "Off"

The user turned off PID feedback while the tuner was 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" after autotuning started. The tuner is unable to run in this mode.

Autotuning was cancelled because the tuning mode was set to "Off"

Indicates that the user turned off autotuning while it was running.

Tuning was cancelled because the input was disconnected

No sensor signal was detected during the tuning process. 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 Ω or greater than 10 kΩ.

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 one of the following conditions occurs:

- The current at the + and – terminals is not equal
- Current was detected when the heater was supposed to be off
- The measured current differs from the expected current.
- The card's internal power supply is not at its specified voltage.

Make sure that the heater is not shorted to ground or to another power supply. In some cases, this error message may indicate that the output circuit has been damaged.

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

During step response tuning, the heater output is increased by the amount shown in the "Step Y" button. During relay tuning, the heater output is increased and then decreased by half of the Step Y

value. If the heater output is expected to exceed its maximum or minimum values, an error message appears. The message appears before the heater output is changed.

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.

Using alarms with PID feedback loops

By default, the PID heater output is frozen whenever the sensor becomes disconnected or goes out of range. In some cases this can lead to uncontrolled heating or cooling of the sample. For example, if the feedback setpoint is set to 200 degrees but the sensor can only measure temperatures as high as 100 degrees, the CTC100 will continue heating the sample indefinitely.

Each input channel has an alarm that can be used to prevent such runaway heating. When properly configured, alarms set the heater output to zero whenever the sensor is disconnected, out of range, or the temperature exceeds limits that you specify. Alarms should be set up whenever the heater is capable of providing enough heat to damage your system.

Front-panel controls

The front panel has four menu keys labeled "Select Channels", "Show Data", "Program", and "Setup". These keys can be pressed at any time to display one of the four main screens. 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 CTC100's outputs on and off.

Most front-panel controls have an equivalent remote command that performs the same function over RS-232, USB, GPIB, or Ethernet. For quick reference the equivalent remote command is listed after the name of each front-panel control. Parts of the command that are in italics should not be entered literally but should be replaced with an appropriate value. See the "Programming" section for more information on remote commands.

USB logging indicator

`System.log.logTo { RAM, USB, None }`

When the CTC100 is logging to a USB memory device, a small white triangle appears in the upper-right corner of all screens; when the CTC100 is not logging to USB, the triangle is a dark blue color (greyed out). The triangle confirms that the system is logging to USB and can also be used to start and stop USB logging. If the triangle is white, touch it to turn USB logging off (equivalent to pressing the System.Log.Log To button and selecting "RAM"). When it's dark blue, touch it 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 dark blue and not turn white.

Removing the USB memory device or powering down the CTC100 while USB logging is on 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

Command`.help`

The "Help" key displays a popup screen that provides more information about whatever is currently visible on the CTC100's display. Some screens that don't accept any user input may not have any Help information.

"Output Enable" key

`OutputEnable { on, off }`

Immediately after the CTC is turned on, its inputs function normally but its outputs are disabled. This safety feature gives you a chance to adjust the CTC100'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 CTC100's outputs. Re-enabling the outputs immediately returns all outputs to their previous values.

In certain cases it may be desirable to have the CTC100 power up with the outputs enabled to ensure that the feedback loops automatically resume after a power failure. Such behavior can be implemented 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 CTC100 or unplug the CTC100 from the wall.

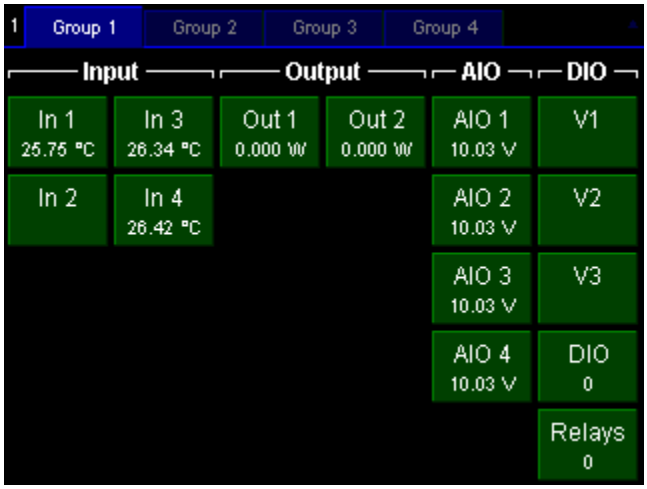
Press and hold the Output Enable key for 3 seconds to put the CTC100 into standby mode. In standby mode, the outputs are turned off, data acquisition and macros are paused, the front panel display and system fan are shut off, and the system does not respond to remote commands. RTD excitation currents are still on, and an internal cooling fan may switch on occasionally. Press the Output Enable key again to leave standby mode. There is no remote command for entering or exiting standby mode.

"Select Channels" screen

In 1, In 2, etc.

Channel.selected { on, off }

Each of the green buttons on the "Select Channels" screen represents one I/O channel. The buttons are arranged in roughly the same order as the connectors on the back of the CTC100. Each button shows the channel's name and current value. If no sensor or heater is connected, the value may be blank.



A small dot appears in the upper-right corner of a button whenever the channel's alarm is triggered. The upper-left corner of the button is clipped if the channel uses a custom calibration table.

Touch one or more buttons to select channels to view on the Show Data and Setup screens.

Group 1, Group 2, etc.

Group { 1, 2, 3, 4 }

The top of the Select Channels screen has four blue tabs that can be used to save and recall groups of selected channels. Touch one of these Group tabs to select the channels in the group (all other channels are de-selected). To modify the definition of a group, simply select or de-select channels while the group is selected.

The group number also appears in the top-left corner of the screen. Touch the group number to advance to the next group. Repeatedly pressing the "Select Channels" key also advances to the next group.

"Show Data" screen

This screen displays data from the selected channels as graphs or as numbers. The tabs at the top of the screen control how data is displayed. Press the "Show Data" key repeatedly to change the selection group. Each of the four groups remembers its display format (single, multiple, etc.) as

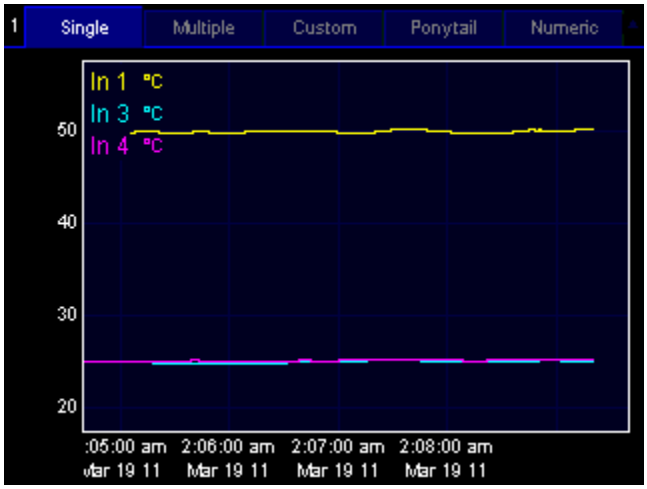
well as the plot's X and Y range. Therefore, when you change the selection group, the graph's range may also change.

Note that the graphs always show data recalled from the log. If data is deleted from the log, it no longer appears on the graph. In addition, if the log interval is sufficiently long, the graphs may have a "stairstep" appearance.

Single

`System.display.type single`

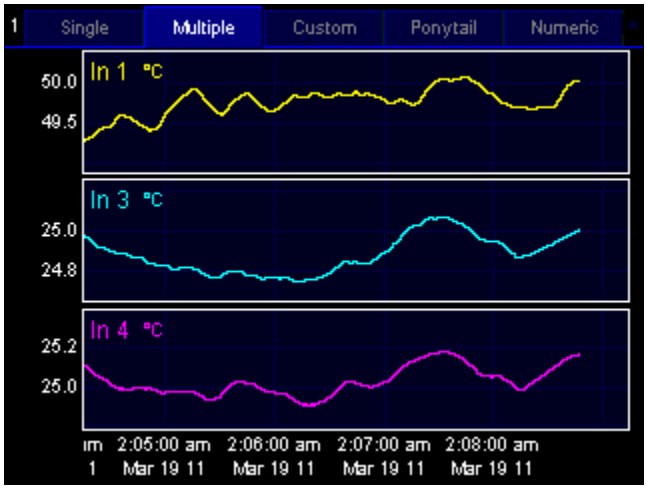
Touch the Single tab to see the selected channels plotted on a single graph with a common Y axis. Up to eight selected channels can be shown. If more than eight channels are selected, only the first eight are shown.



Multiple

`System.display.type multiple`

Touch the Multiple tab to see each selected channel plotted on its own graph. Each graph has its own Y axis scale. If more than eight channels are selected, only the first eight are shown.

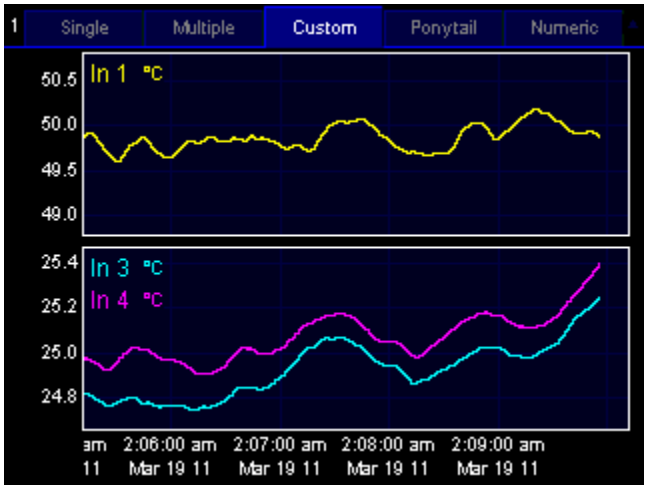


Custom

`System.display.type custom`

Touch the Custom tab to view a plot in which each channel can be assigned to one of up to eight graphs. To set the plot a particular channel appears in, display the Setup menu for that channel and touch the "Plot" button.

In the example below, channel "In 1" has been assigned to plot 1, while channels In 3 and 4 have both been assigned to plot 2.

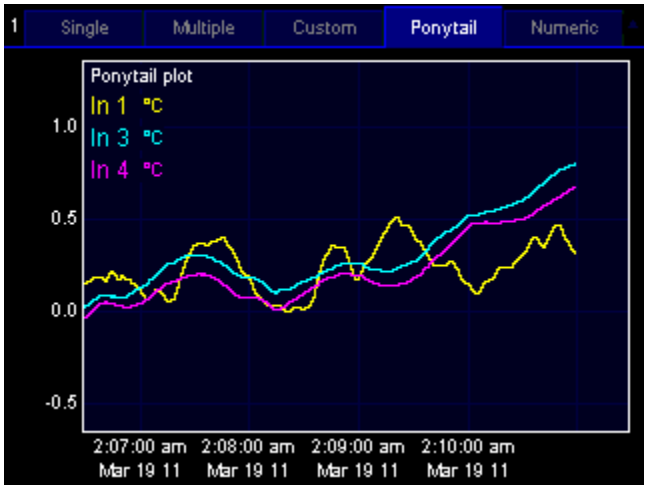


Ponytail

`System.display.type ponytail`

The Ponytail plot resembles the Single plot, except 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 CTC100's front panel, the offset is never recalculated.

Viewing the Ponytail plot does not cause offsets to be subtracted from logged data or feedback setpoints.



Numeric
`System.display.type numeric`

Touch the Numeric tab to see the current values of the selected channels as numbers. Up to 22 channels can be displayed. The more channels that are selected, the smaller the numbers are. If enough space is available, the type of sensor or output may be displayed, and an annunciator may appear that indicates whether the sensor or heater is disconnected ("N/A"), over range ("Hi"), under range ("Lo"), if Output Enable is off ("Off"), or if an internal error has occurred ("Err").

Touch one of the channels to go to its setup menu.

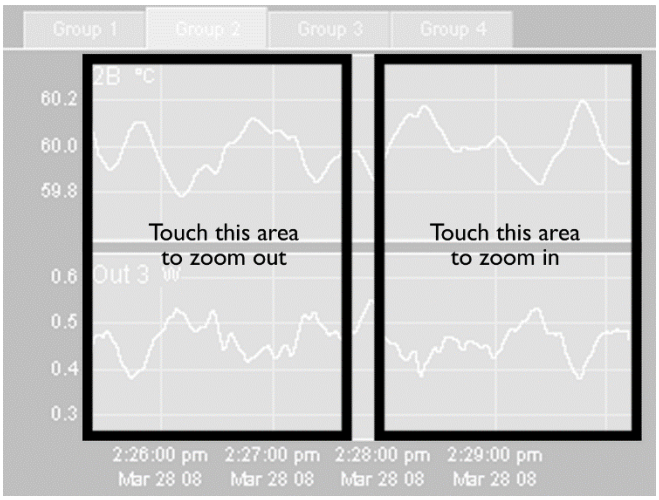
Zooming and panning

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

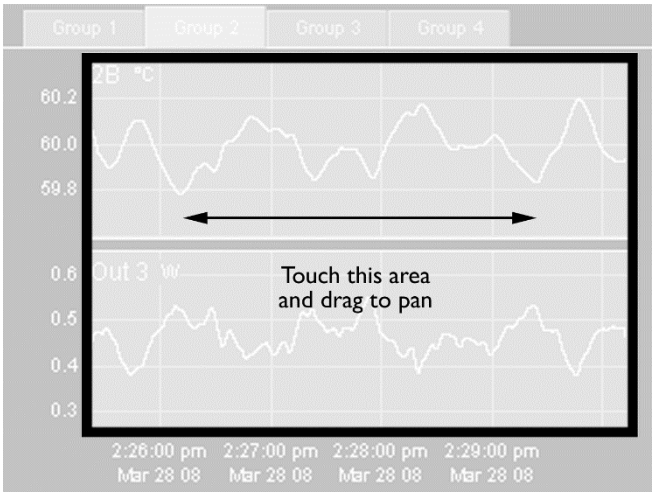
- Touch the right half of the plot to zoom in
- Touch the left half to zoom out
- Drag to pan.

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.



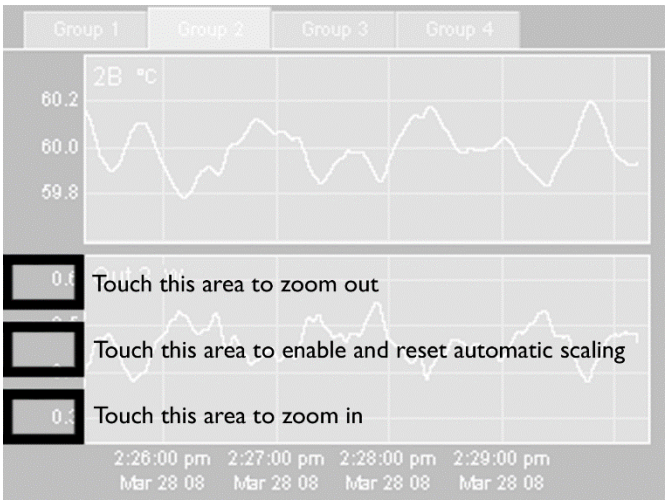
How to change the X axis scale



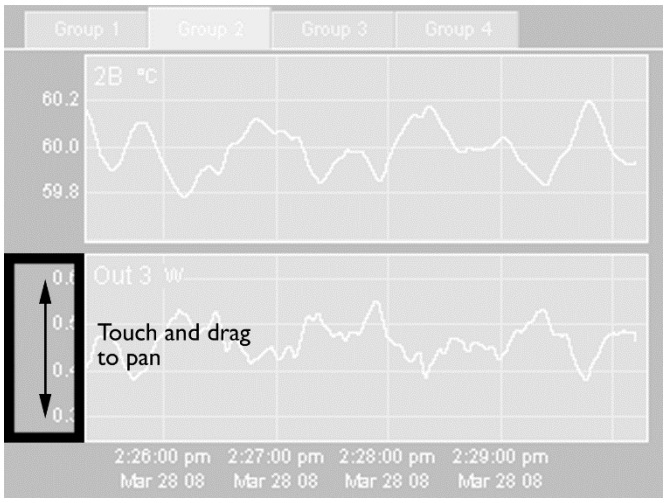
How to pan the graph horizontally

By default, the CTC100 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 remote instructions in ASCII text format. Programs can be sent over the RS-232, GPIB, USB, or Ethernet interface, input from the program screen, or transferred as text files on a USB memory device. Regardless of how a program was input, its progress can be monitored from the program screen. Up to 10 programs from any one interface and up to 20 programs total can run at once.

The Program screen has an Input window, which shows the program as it was received; a Messages window, which shows responses and error messages from the CTC100; and a Progress window, which shows the individual instructions in the program, one instruction per line.

If a program is not running, you can compose or modify it 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 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

`define` *`macroName macroContent`*

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 and then touching the name of the program. Saved programs can also be called by sending their name (like any other instruction) over one of the remote interfaces.

Delete

`delete` *`macroName`*

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. If the program is running, deleting it does not affect the running program.

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

Programs can be entered from any of the CTC100's communications ports: RS-232, USB, Ethernet (via Telnet), or the optional GPIB port. Each line of text sent to the CTC100 is run as a separate program (the entire program must be on a single line). If two or more lines are sent to the CTC100 in quick succession, the programs may run concurrently; the CTC100 may 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 necessary to run programs sequentially, begin each line with the *PHO (port holdoff) instruction.

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

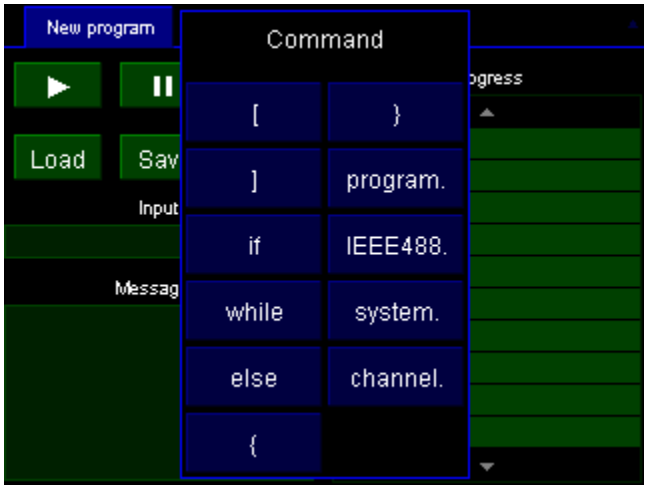
Preparing programs as files on USB memory devices

The CTC100 can also read programs that are stored as text files a USB memory device. This is the easiest way to import 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 CTC100. To verify that the program is available, look for its name in the Macros column of the System Setup screen. The program can be run just as if it were saved in the CTC100's memory; however, after the USB device is unplugged, the program is no longer available.

Programs that are prepared as files can contain up to 4096 characters. Unlike programs sent over communications ports, programs in the form of text files can have more than one line; all extra whitespace is ignored. The program can also contain comments; an apostrophe, i.e. a single quote mark, indicates that the rest of the line is a comment.

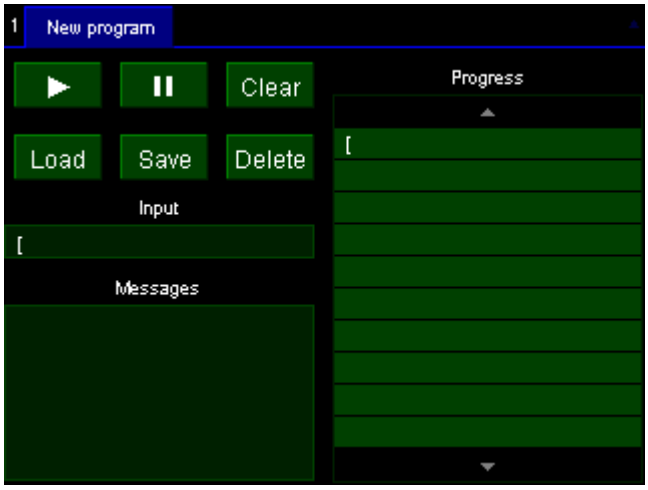
Preparing programs from the front panel



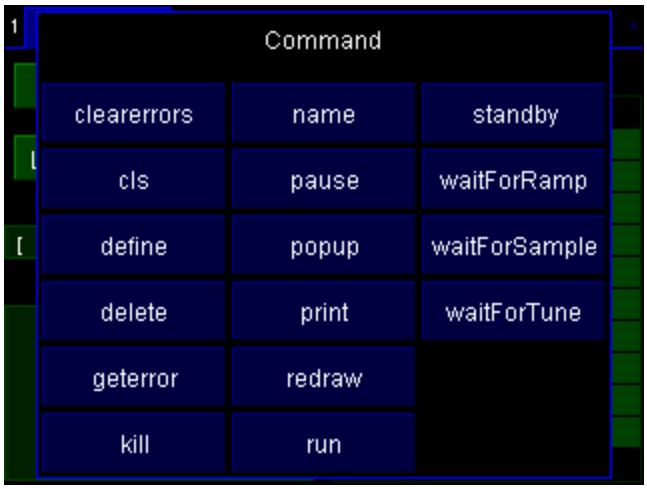
Simple programs, for example, a series of temperature ramps, can be entered from the front panel.

To enter a program from the front panel, first press the "program" key to show the Program screen. Touch the Progress window and a list of available top-level commands appears. A dot at the end of a command means that touching that button will bring up a sub-menu of instructions. For example, the command to change the feedback setpoint (channel.PID.setpoint) is accessed by first touching the "channel." button. See the "Programming" section of this manual for a full list of commands.

Touch the left square bracket (the button in the upper-left corner). Square brackets surround blocks of code to be repeated. The menu of instructions closes, and the first line in the "Progress" window is now a left square bracket.

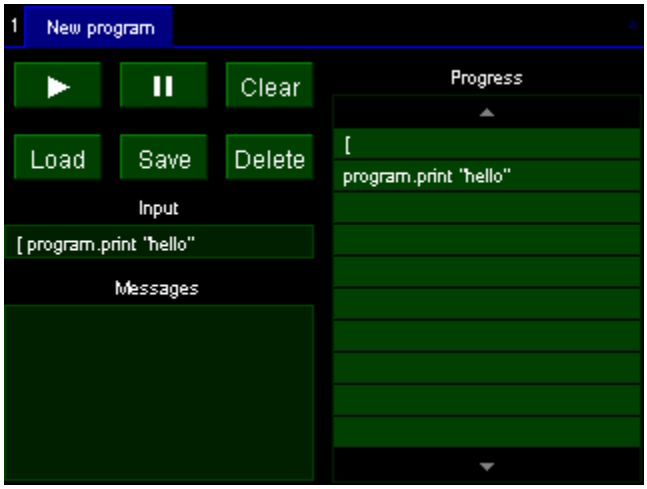


Touch the Progress window again, anywhere beneath the first line. The list of possible instructions appears again. Select "program." from the list. The sub-menu that appears contains a list of instructions that affect the program. For example, "cls" clears the Messages window; "name" assigns a name to 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”.

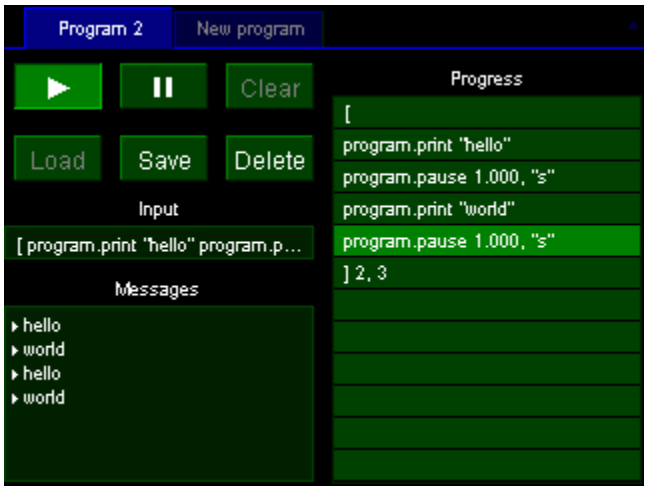
Touch the OK button. The Program screen re-appears and the instruction “program.print “hello”” appears in the second line of the Progress window.



Next, enter the instruction: “program.pause 1 s”. The pause instruction has two arguments that must be entered separately. First a numeric input screen appears where you can type “1”. Touch “OK” and a second menu appears where you can select 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 number of repetitions remaining appears next to the right square bracket. In addition, while the program is running, a 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 has finished it’s possible to 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

A macro can run for a long period of time or even indefinitely. Therefore, 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 CTC can run up to ten concurrent macros started from the front panel. If an eleventh macro is started, a “Too many macros” assembly error is generated and the macro does not run.

When the CTC100 is turned on, it looks for a macro named “startup” and, if it exists, runs the macro. Any other macros that might have been running when the CTC100 was switched off are not re-started.

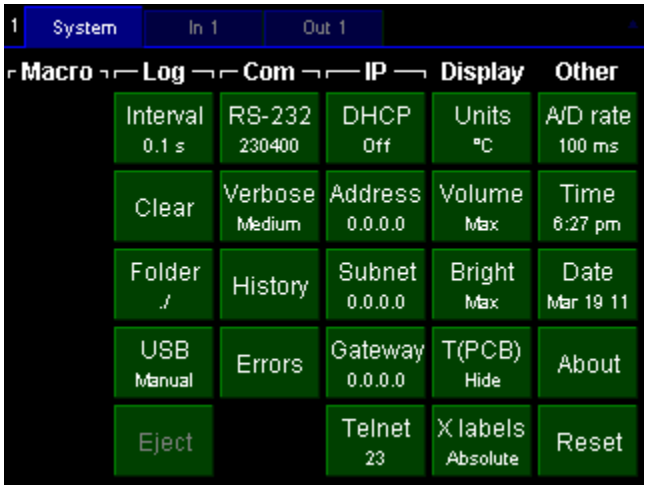
“Setup” screen

Press the “Setup” key to configure the CTC100. The Setup screen has between 1 and 5 blue tabs at the top, depending on how many channels are selected. Touch the “System” tab to configure parameters that affect the entire instrument, like the RS-232 baud rate, the display brightness, and

the time and date. The Setup screen also has one tab for each selected channel. Touch one of these tabs to set up a particular channel.

Repeatedly pressing the "Setup" button, or touching the group indicator in the top-left corner, cycles through the four selection groups.

"Setup" screen: System tab



The System setup screen includes controls for all settings that affect the entire instrument, including time and date, Ethernet and GPIB, and data logging parameters.

"Setup" screen: System tab: Macro column

MacroName

If any macros have been defined, buttons with their names appear in the left-hand column of the System setup screen. If more than five macros have been defined, buttons for only the first five appear. Touching one of these macro buttons runs the corresponding macro, and the button remains selected (i.e., highlighted) as long as the macro continues to run.

More generally, a macro button appears to be selected whenever a macro with the name shown on the button is running, whether the macro was started by touching the button, with a remote command, or from the Program screen. Touching a selected macro button stops all currently-running macros with that name, regardless of how the macros were started. See the Macro Names topic in the Remote Programming section for more information on how macro names are assigned.

"Setup" screen: System tab: Log column

Interval

`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 time between log points. If the interval is set, for example, to 1 s, the CTC saves a data point once per second, and each point represents the average reading over one second period.

Note that each channel has its own log interval setting (`Channel.Logging`) that can override the default interval.

Clear
`System.Log.clear { yes, no }`
Press this button and select 'yes' to erase all data from the current log folder on the USB device. The CTC100's RAM is also cleared. After clearing the log, the plot will be blank until new data is acquired.

Folder
`System.Log.folder "FolderName"`
Sets the USB device folder into which data is logged. If the folder does not exist, it is created. If the folder does exist and already contains log files, data is appended to the existing files. Only data from the current folder appears on the plot screen. The default folder name is "./", which is the root directory of the USB device.

Log to
`System.Log.LogTo { RAM, USB, None }`
USB: Data is logged to the USB device and also in the CTC100's internal memory. If the USB device is unplugged, the setting automatically changes to RAM.
RAM: Data is only stored in the CTC100's internal memory. There is enough memory to store about an hour of data at the default 1 second log rate. Therefore, the Plot screen only shows the previous hour of data.
None: the CTC100 does not store any data at all, and the plots on the Plot screen are always empty.

USB
`System.Log.USB { auto, manual }`
This setting determines whether or not the CTC automatically starts logging to USB memory devices when they are plugged in.
Auto: when a USB storage device is plugged into the instrument, the CTC immediately starts logging data to it.
Manual: when a USB storage device is plugged into the instrument, you must touch the blue triangle in the upper-right corner of the screen to begin logging. If you unplug the device and plug it back in, data will no longer be logged to the device.

"Setup" screen: System tab: COM column

RS-232
`System.COM.RS-232 { 2400, 4800, 9600, 19200, 38400, 57600, 115200, 230400 }`
Sets the RS-232 baud rate. The RS-232 interface always has 8 bits, 1 stop bit, and no parity.

GPIB
`System.COM.GPIB { 1, 2, 3,…30 }`
Sets the primary GPIB address. The address must be a value between 0 and 30, inclusive, but in most GPIB systems 0 is reserved for the controller-in-charge and should not be used.

Verbose
`System.COM.Verbose { Low, Medium, High }`
Determines how the CTC100 responds to RS-232, USB, GPIB, and Telnet messages.
Low: the CTC100 only sends messages in response to queries. This mode should be selected for IEEE488.2 compatibility.
Medium: the CTC100 also sends error messages whenever a command could not be understood. Error messages always begin with the word "Error".

High: the CTC100 also sends messages whenever a parameter is set. Messages include the name of the parameter that was set or queried

Example responses are shown in the table below.

Verbose level	Response to instruction… 2A?	**xyz** (invalid instruction)	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

`System.COM.History`

Pressing 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

`System.COM.Errors`

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

"Setup" screen: System tab: IP column

DHCP

`System.IP.DHCP { On, Off }`

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 greyed out.

Address

`System.IP.Address` *`address`*

Sets the IP address in dot-decimal notation.

Subnet

`System.IP.Subnet` *`subnet`*

Sets the subnet mask.

Gateway

`System.IP.Gateway` *`gateway`*

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

Telnet

`System.IP.Telnet` *`portNumber`*

Sets the telnet port for Ethernet communications. Remote commands can be sent to the CTC 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.

"Setup" screen: System tab: Display column

Units

`System.Display.Units { °C, K, mK, °F, Sensor }`

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.

Five options are available: °C, K, mK, °F, and Sensor. If the Sensor option is selected, sensor measurements are not converted to temperature and appear in the native units of the sensor, i.e. millivolts for thermocouples, volts for diode sensors, and ohms for resistive sensors. When Sensor units are selected, the Units button is blank and `System.display.units?` returns an empty string.

When the system temperature units are changed, other variables that are expressed in temperature units need to be manually updated by the user. These variables are not automatically updated because in some cases it is inappropriate to update them (for example, when inputs are set up to reflect temperature differences rather than absolute temperatures). The following settings may need to be updated:

`Channel.PID.Setpoint`
`Channel.PID.Ramp`
`Channel.PID.P`
`Channel.PID.I`
`Channel.PID.D`
`Channel.Alarm.Min`
`Channel.Alarm.Max`
`Channel.Cal.Offset`
All Zone Min, P, I, and D settings

Volume

`System.Display.Volume { Off, 1, 2, 3, 4, 5, 6, 7, Max }`

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

Bright

`System.Display.Bright { Min, 2, 3, 4, 5, 6, Max }`

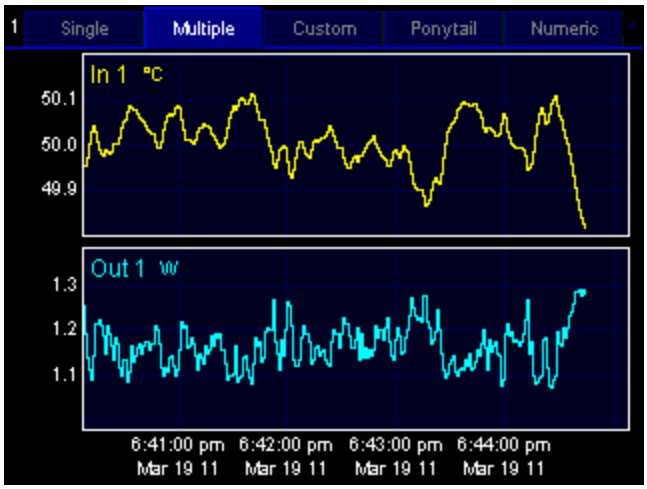
Sets the backlight brightness.

X labels

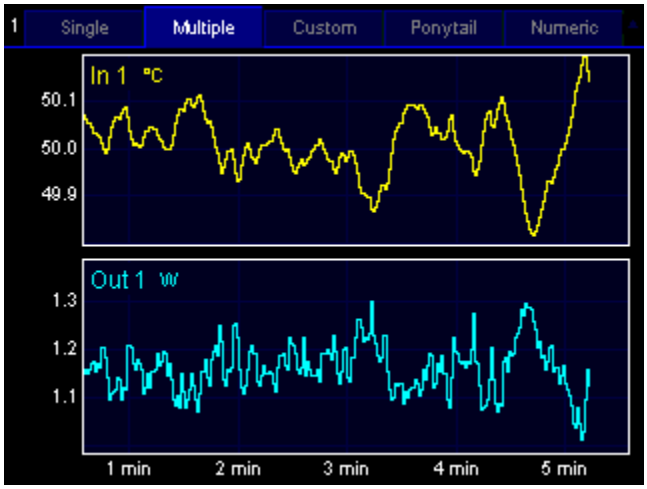
`System.Display.XLabels { Absolute, Elapsed }`

Absolute: the labels at the bottom of each graph show the full time and date.

Elapsed: the labels only indicate the amount of time between grid lines. The elapsed time labels do not actually reflect the amount of time elapsed since any particular event and reset to zero once per minute, hour, or day, depending on the X range of the graph.



Absolute X labels



Elapsed X labels

Figures

`System.Display.Figures { 0, 1, 2, 3, 4, 5, 6 }`

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.

"Setup" screen: System tab: Other column

A/D rate

```
System.Other.A/DRate { 16.7 ms, 33.3 ms, 50 ms, 66.7 ms, 83.3 ms, 100 ms,
150 ms, 200 ms, 250 ms, 300 ms, 350 ms, 400 ms, 500 ms, 600 ms, 700 ms,
800 ms, 900 ms, 1000 ms }
```

Determines how often ADC readings are taken. If ADC readings are synchronized to the line frequency (which is the default configuration), the A/D rate must be a multiple of the line period. ADC readings can be decoupled from the line frequency by moving the "Trigger source" jumper on the motherboard to the "1 MHz clock" position, in which case the A/D rate can be set to any value

between 10 and 1000 ms. The trigger source jumper should only be moved when the CTC100 is switched off.

Faster A/D rates may improve the performance of the PID feedback loop when used with fast-responding heaters and sensors. Slower A/D rates reduce the amount of sensor noise.

Time

`System.Other.Time "time"`

Sets the time of day. Does not affect the time stamps of previously-acquired data points. For example, 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 erased from the USB log; it just doesn't appear on the plot.

Date

`System.Other.Date "date"`

Sets the date. Does not affect time stamps on previously-acquired data points.

About

`System.Other.About`

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

Reset

```
System.Other.Reset { "Running macros", "Saved macros", Display, Ports,
"Port settings", Channels, Log, All }
```

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 the internal temperature display, T(PCB).

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.

Setup screen for channels In 1 – In 4

Except for the "PCB" setting, all the settings on this screen apply only to the channel in the highlighted tab and will not affect any other channels. When using the remote commands the word *Channel*, where it appears in italics, should be replaced with the channel name with spaces omitted. For example, the remote command to change the name of channel In 1 to "Sample A" would be:

```
In1.name = "Sample A"
```

Name
Channel.Name = "*New channel name*"
Touch this button to change the name of the channel. The name must have 10 or fewer characters.

Value
Channel.Value?
Channel?
This button shows the most recent sensor reading. The reading can't be changed by typing in a new value, so the button is greyed out.

Sensor
Channel.Sensor { Diode, ROX, RTD, Therm }
Touch this button to select a sensor class. Four options are available: diode, ROX (ruthenium oxide), RTD, and thermistor.

This setting controls how the sensor input hardware reads the input signal. It determines the excitation current, whether the CTC100 reads the sensor voltage or resistance, and the list of calibration options available in the Cal column. The Diode option sets the sensor excitation current to 10 µA and causes the hardware to read the voltage across the sensor. The ROX, Thermistor, or RTD option causes the hardware to read the sensor resistance. The ROX and thermistor modes are identical, except for the list of calibration options. The RTD mode results in a larger sensor excitation current (and therefore lower noise) and places an RTD-specific list of calibration options in the Cal column.

Range
Channel.Range { 10ê, 30ê, 100ê, 300ê, 1kê, 3kê, 10kê, 30kê, 100kê, 300kê, 2.5V, Auto }
Sets the sensor measurement range. The default range is Auto. In general, a lower range results in a larger excitation current, less noise, and more accurate measurements. The range should be

manually set if it is critical to limit sensor self-heating; otherwise the CTC100 may change the range and excitation current at unexpected times.

The CTC100 uses ASCII character 234 for the Ohms symbol. To type this character on a Windows computer, hold down the alt key and type 0234 on the number pad. On Windows computers the character appears as a letter "e" with a circumflex accent.

Units

Channel.Units?

This button shows the native units in which the sensor is read. It reads "volts" if the sensor type is "diode", or "ohms" if any other sensor type is selected. The units cannot be changed directly, but they change automatically if the sensor type is changed.

Plot

Channel.Plot { 1, 2, 3, 4, 5, 6, 7, 8 }

Indicates which plot this channel will appear in when the "Plot" screen is showing, the plot type is "Custom" (see the "Plot Screen" section above), and this 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. Empty plots won't appear on the "Plot" screen; for example, if all the selected channels have been assigned to plot 4, only one plot appears on the Custom plot screen.

Logging

Channel.Logging { 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", Default }

By default, readings from all channels are saved to the log at the global log rate, which is set on the System Setup screen (System.Log.Interval). However, exceptions can be made for individual channels by setting a different rate with the Logging button. To return the channel to the global log rate, set Logging to "Default".

Current

Channel.Current { Forward, Reverse, AC, Off }

Forward: the polarity of the Sense and Excitation pins are as shown in the connector diagram.

Reverse: the polarities of the pins are switched and the sense current flows in the opposite direction through the sensor.Can be used to compensate for diodes that have been connected backwards.

AC: the current switches polarity with every reading. The measured resistance is the average of the last two readings. Recommended for resistive temperature sensors such as RTDs and thermistors, since it cancels out thermal EMFs, significantly improves accuracy, and reduces noise.

Off: disables the excitation current. The sensor cannot be read in this state and no sensor reading will appear.Prevents the CTC100 from "hunting" for the correct range when no sensor is connected, a process that generates audible clicks.

If two diodes are connected in parallel but with opposing polarities to a single pair of leads, one diode can be read with the forward current setting, the other with the reverse current setting, and their average with the AC setting. This technique reduces the number of leads and therefore the amount of heat transfer.

PCB

Channel.PCB *0.0*

Sets the maximum printed circuit board (PCB) temperature. Since channels In 1 and In 3 are located on a single printed circuit board, their PCB setting is always the same. Likewise, channels In 2 and In 4 also share the same PCB value.

If the card's temperature exceeds the maximum and System.Other.Fan is set to "Auto", the CTC100 increases the fan speed to reduce the card's temperature.

The PCB temperature is always in °C, regardless of the System.Display.Units setting. The default setting is 35°C.

Reducing the maximum PCB temperature results in tighter regulation of the selected card's temperature, at the expense of the other cards and more fan noise.

The fan speed is also determined by the cooling needs of the DC outputs.

Diff

PositiveChannel.Diff "*Negative channel*"

This button lets you display the difference between two channels. Touching this button displays a list of available channels. Touch a channel and its value is then continuously subtracted from the channel indicated by the blue tab at the top of the Setup screen. If, for example, the Setup menu for channel In 1 is showing, and you touch the "Diff" button and select channel "In 2" from the list, channel In 1's value becomes In 1 – In 2. The raw value of channel In 1 can no longer be seen.

To turn the difference feature off, touch "Diff", then touch whatever channel is currently selected. The "Diff" button then shows an empty value.

Difference readings 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

Channel.Lopass { Off, "1 s", "3 s", "10 s", "30 s", "100 s", "300 s" }

The lowpass option smoothes the input signal with a 6th-order RC filter, reducing noise but also slowing down the sensor response. If, for example, the 10 s lowpass filter is selected, noise spikes less than 10 seconds long are removed, but it would also take the signal at least 10 seconds to respond to any sudden temperature changes.

The filter's time constant should ideally be just below the response time of your hardware. That is, the 10 second lowpass filter should only be used if you wouldn't expect to see temperature spikes shorter than 10 seconds anyway. In that case the lowpass filter only eliminates noise and doesn't slow down the system.

The lowpass filter should usually be enabled on the temperature inputs of PID control loops. This is especially true when using step response PID tuning or when derivative feedback is enabled (i.e., when 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.

When a sensor is disconnected and then reconnected to a lowpass-filtered channel, the CTC 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.

d/dt

Channel.d/dt { Off, On }

When this control is set to "On" the value of the selected channel is replaced with its rate of change, i.e. the difference between the previous ADC reading and the current reading divided by the time between the two readings. Since the derivative is normally somewhat noisy, the lowpass filter should be enabled when the derivative filter is used.

Setup screen for channels In 1 – In 4: 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 CTC100's relays and the relay associated with the alarm. Without such a safety mechanism, it's possible for the CTC100 to enter a "runaway feedback" condition if a sensor becomes unplugged or malfunctions, or if the PID feedback is incorrectly set up.

Status

Channel.Alarm.Status { Off, On }

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

Channel.Alarm.Mode { Off, Level, "Rate /s" }

Off: the alarm never sounds.

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

Latch

Channel.Alarm.Latch { Yes, No }

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

Channel.Alarm.Mute { On, Off }

Temporarily silences the alarm sound without affecting the associated relays or output channels. Once this button is touched, the alarm stays muted until the alarm condition goes away or until the button is touched again.

Sound

Channel.Alarm.Sound { None, "1 beep", "2 beeps", "3 beeps", "4 beeps" }

Controls which sound plays when the alarm goes off.

Output
Channel.Alarm.Output "*Output name*"
The alarm, when triggered, can shut off one of the CTC100'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
Channel.Alarm.Relay { None, A, B, C, D }
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
Channel.Alarm.Min *0.0*
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
Channel.Alarm.Max *0.0*
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
Channel.Alarm.Lag *0.0*
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.

Setup screen for channels In 1 – In 4: Cal column

The CTC100 offers four different ways to calibrate sensor readings:

- **Built-in calibration tables**: the easiest but least accurate way to calibrate your sensors. You select a sensor type and the CTC100 uses built-in calibration data that describes a typical sensor of that type. No experimental data is needed.
- **Calibration coefficients**: potentially more accurate. You enter 3–4 coefficients for an equation that is specific to your sensor type (the Callendar–van Dusen equation for RTDs, the Steinhart–Hart equation for thermistors, or a polynomial fit for diodes). The coefficients are typically provided by the sensor manufacturer or can be derived from several measurements at known temperatures.
- **Calibration tables**: you enter a table containing about 100–200 sensor readings over the entire working temperature range. This method can produce the most accurate results of all but also requires the most experimental data. The CTC100 can directly read the calibration tables provided by some sensor manufacturers. See the "Custom calibration tables" topic on page 20 for more information.

- **Offset/gain**: the temperature values produced by any of the above calibrations can be multiplied by a constant and then added to a second constant.

Type

Channel.Cal.Type { DT-470, DT-670, Si410, Si430, Si440, S700, S800, S900, Custom } (if Sensor = Diode)
Channel.Cal.Type { RX-102A, RX-103A, RX-202A, RO600, R400, R500 } (if Sensor = ROX)
Channel.Cal.Type { ITS-90, US, Custom } (if Sensor = RTD)
Channel.Cal.Type { "100 ê", "300 ê", "1000 ê", "2252 ê", "3000 ê", "5000 ê", "6000 ê", "10000 ê B", "10000 ê H", "30 kê", "100 kê", "300 kê", "1 Mê", Custom } (if Sensor = Therm)
Channel.Cal.Type { File, Standard } (if a custom calibration table is loaded)

The Calibration Type control determines which of the CTC100's preloaded calibration tables is used to convert raw sensor readings to temperature values. If a diode, RTD, or thermistor is in use, the Type setting also has an option to produce a custom calibration table from user-entered calibration coefficients.

Changing the sensor type has no effect on how the raw sensor reading is acquired; for example, it does not affect the channel's input range or excitation current.

If the selected channel uses a custom calibration table that was loaded from a file on a USB device, its calibration type reads "File". 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. To return to using the calibration file, unplug the USB device with the file (if it is still plugged in) and then plug the device in again.

The available calibration types depend on the sensor type.

Diodes: Choose from the list of commercial cryogenic diodes. See the table on page 3 for more information on standard diode calibrations.

ROX: Choose from the list of commercial ruthenium oxide sensors. See the table on page 3 for more information on standard ROX calibrations.

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.

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 there are no international standards for thermistors. Therefore, thermistors from different companies may not be compatible with each other or with the CTC100's built-in calibrations even though they have the correct resistance at 25°C.

The CTC100 uses ASCII character 234 for the Ohms symbol. To type this character on a Windows computer, hold down the alt key and type 0234 on the number pad. On Windows computers the character appears as a letter "e" with a circumflex accent.

A (Sensor = RTD, thermistor, and diode only)
B (Sensor = RTD, thermistor, and diode only)
C (Sensor = RTD, thermistor, and diode only)
R0 (Sensor = RTD only)
Channel.Cal.A *0.0*
Channel.Cal.B *0.0*
Channel.Cal.C *0.0*
Channel.Cal.R0 *0.0*

These settings allow you to enter Steinhart–Hart, Callendar–van Dusen, or polynomial fit coefficients for your RTD, thermistor, or diode sensor, respectively. The settings are only available if the Sensor control is set to one of these three sensor types and the Cal Type control is set to "Custom".

The use of calibration coefficients can result in more accurate measurements than the preloaded calibration tables. In many cases, commercial sensors come with these coefficients.

. 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. The temperature t is calculated from the RTD resistance R_t based on the following equation:

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

R_0 is the resistance of the RTD at 0°C, expressed in ohms; t is the temperature in °C.

When the calibration type is set to IEC751 or US, the A, B, and C settings are automatically changed to the values for that particular calibration, and the A, B, and C controls are greyed out and cannot be modified (to modify these values, select the "Custom" calibration type). The value of R0, however, is not preset and can still 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 are calibrating your own sensor and the calibration points are separated by less than about 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) based on 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 are automatically changed to show the 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 CTC100 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 20.

Offset
Gain
Channel.Cal.Offset *0.0*
Channel.Cal.Gain *1.0*

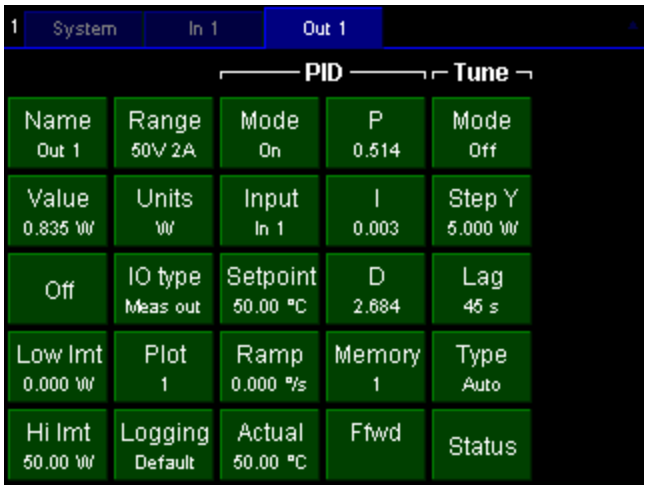
The offset/gain filter modifies the value of an input channel as follows:

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

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 difference, lowpass, and derivative filters.

Setup screen for channels Out 1 and Out 2



Name
Channel.Name = "*NewName*"

Touch this button to change the name of the channel. The name must have 10 or fewer characters.

Value
Channel.Value *0.0*

This button can be used to manually set the heater output. If the outputs have not enabled by pressing the Output Enable key, the channel value button is greyed out and its value can't be changed. If the outputs are enabled but the channel's PID feedback is turned on, changing the heater output will have no effect.

Off
Channel.Off

Pressing this button immediately sets the PID feedback mode to Off, cancels PID tuning, and sets the channel's output to zero or the "Low lmt" value, whichever is higher. Unlike the Output Enable key, which turns all of the CTC100's outputs off, the Off button only affects one channel.

Low lmt
Channel.LowLmt *0.0*
Touch this button to place a lower limit on the output. 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. If the output units are changed, the limits are not automatically converted to the new units and must be updated by the user.

Hi lmt
Channel.HiLmt *0.0*
Touch this button to set an upper limit on the output, for example 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
Channel.Range { "50V 2A", "50V .6A", "50V .2A", "20V 2A", "20V .6A", "20V .2A", Auto }
Using this control, the maximum heater voltage can be set to 50 or 20V, and the maximum heater current can be set to 2, 0.6, or 0.2 A. For safety the voltage should ideally be set to 20V if the full 50V is not needed, however, doing so does not improve the performance of the output. On the other hand, selecting a smaller current range does reduce the output noise and improve the accuracy. In the Auto setting, the range is selected based on the heater resistance and the Hi Lmt value.

Units
Channel.Units { W, A, V }
Determines whether the heater output is specified in W (watts), A (amps), or V (volts). The "W" setting generally works the best with resistive heaters, since the temperature of such heaters is roughly a linear function of the power supplied to the heater. If the output is connected to a fan or a thermoelectric cooler, the "A" setting is preferable. The default setting is "W".

IO type
Channel.IOType { "Meas out", "Set out" }
Each output channel has a DAC that produces the output and an ADC that measures it. The "IO type" setting determines whether the value displayed on the CTC100's screen is the one measured by the ADC ("Meas out") or the one that was sent to the DAC ("Set out"). The measured output can differ from the set output if, for example, the heater has become disconnected, or the output's compliance voltage has been exceeded. The default setting is "Meas out".

Plot
Channel.Plot { 1, 2, 3, 4, 5, 6, 7, 8 }
Indicates which plot this 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, plot 4 will occupy the entire Custom plot screen.

Logging
Channel.Logging { 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", Default }
By default, each channel's value is written to the log at a global log rate that is set from the System Setup screen (System.Log.Interval). The Logging button makes it possible to override the global log rate for individual channels.

Setup screen for channels Out 1 and Out 2: PID column

Input
Channel.PID.Input "*Input channel*"

This setting determines which the temperature sensor the PID feedback loop tries to regulate. It's possible to use one temperature sensor as the input for more than one PID loop.

Mode
Channel.PID.Mode { Off, On, Follow }

Off: PID feedback is inactive and the output can be controlled with the "Value" button.

On: PID feedback actively controls the heater output, ideally maintaining the input channel at the setpoint.

Follow: the output mirrors the input channel. A gain and offset can be applied; see "Zero pt" and "Gain", below. There is no PID feedback in follow mode.

Setpoint
Channel.PID.Setpoint *0.0*

The Setpoint is the temperature at which the PID feedback tries to keep the input channel. The setpoint is expressed in the same units as the input channel.

Zero pt (Follow mode only)
Gain (Follow mode only)
Channel.PID.ZeroPt *0.0*
Channel.PID.Gain *0.0*

These controls are only available when the PID Mode is set to "Follow".

In "follow" mode, heater power is directly controlled by one of the CTC100's inputs, rather than by a feedback loop or from the front panel. The Zero Point and Gain settings allow the user to scale the output. The heater output is given by the following equation:

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

Note that the output is zero when the input is equal to the zero point.

Ramp
Channel.PID.Ramp *0.0*

This button is used to set the ramp rate in degrees per second,controlling how quickly the CTC100 heats or cools your system.

When the user changes the setpoint, the CTC100 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 cryogenic hardware 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 CTC100 heats or cools your system at the maximum possible rate.

Ramp T
Channel.PID.RampT *0.0*

The temperature that the PID feedback is trying to maintain. This is an internally-generated value that depends on the setpoint and the ramp rate.

During times when the feedback is disabled, Ramp T automatically tracks the sensor temperature. When the feedback is enabled, Ramp T gradually increases or decreases at the ramp rate until the setpoint is reached. This ensures that the temperature smoothly ramps from its initial value to the setpoint at a user-determined rate. If this behavior is undesirable (for example, if the

ramp rate has been set to a small value but it's preferable to reach the setpoint quickly), Ramp T can be manually set to another value, typically the setpoint.

Once it reaches the setpoint, Ramp T remains there until the setpoint is changed or the feedback is disabled. If 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 track the sensor temperature.

The Ramp T button can be used to monitor the progress of temperature ramps. Although the sensor temperature could also be used for this purpose, it's subject to noise, external disturbances, and other artifacts that in some cases could make it difficult to determine the intended temperature.

P
I
D
Channel.PID.P *0.0*
Channel.PID.I *0.0*
Channel.PID.D *0.0*

Sets the proportional, integral, and derivative gain factors for PID feedback. The PID equation is:

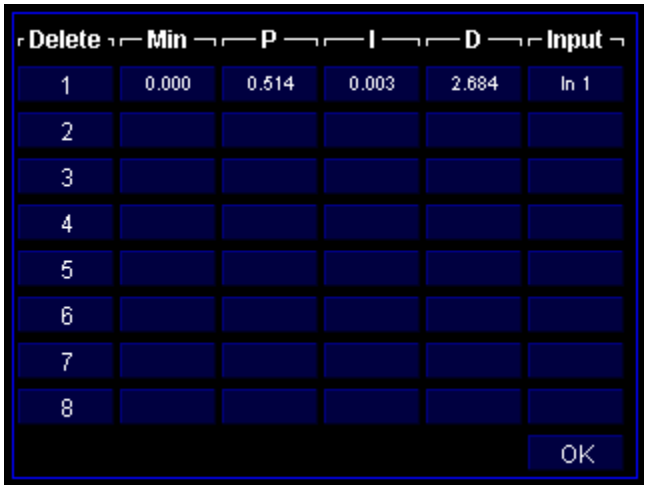
$$\text{Output}_t = Pe_t + 0.5IT((e_0 + e_1) + (e_1 + e_2) + \ldots (e_{t-2} + e_{t-1}) + (e_{t-1} + e_t)) + (D/T)(e_t - e_{t-1})$$

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. Negative values of P, I, and D should be used if the output drives a fan or other device that cools the sample.

Zone
Channel.PID.Zone { 1, 2, 3, 4, 5, 6, 7, 8, Auto }

The Zone setting stores up to eight sets of feedback parameters. Each set can be associated with a temperature range and automatically recalled when the temperature of your experimental system 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, the P, I, and D feedback gains, and the input channel. 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 memory 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. In either case, if any feedback parameters are subsequently changed (for example, if the feedback is tuned), the selected zone is automatically updated with the new values.

To have the CTC100 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
Channel.PID.Ffwd "*Input channel*"

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 input channel typically must be scaled using offset/gain factors (in the input channel's "cal" menu) or a custom calibration table.

Setup screen for channels Out 1 and Out 2: Tune column

This column is used to configure the PID autotuner. See the "Automatic PID Tuning" section for more details.

Step Y
Channel.Tune.StepY *0.0*

This setting determines how much the autotuner changes the heater power. 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, autotuning will fail or may succeed but produce inaccurate feedback parameters. If Step Y is too large, the heater may become unacceptably hot.

If autotuning is in progress when Step Y is changed, the old value of Step Y is used.

Lag
Channel.Tune.Lag *0.0*

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.

Changes to the Lag setting doesn't affect any autotuning algorithms that are currently in progress.

Status
Channel.Tune.Status?

Touch this button to view the progress of the autotuner.

Type
Channel.Tune.Type { Cons, Moderate, Aggr, Auto }

Controls the PID tuning rules used by the auto-tuner.

Cons (conservative): results in minimal overshoot (ideally, zero overshoot) but very slow response.

Aggr (aggressive): results in much faster feedback response but typically ~25% overshoot.

Moderate: provides intermediate results.

Auto: uses the conservative setting for step response tuning and aggressive for relay tuning. 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.

Regardless of the tuning type, the relay tuner always tunes more aggressively than the step response tuner. See "Aggressive, moderate, and conservative tuning" on page 32 for more information.

Setup screen for analog I/O and digital I/O channels

Depending on their "IO type" setting, the general-purpose analog and digital I/O channels have the same front-panel settings as either the sensor input or the heater output channels. These settings have been described above.

The general-purpose channels don't offer built-in sensor calibration curves, but they do accept custom calibration tables.

IO type
Channel.IOType { Input, "Set out", "Meas out" }

The analog and digital I/O channels can be inputs or outputs. Two output types are available: if "Set out" is selected, the desired output is shown, while if "Meas out" is selected, the actual output is measured and the measured value is reported.

PID feedback functionality is only available if the channel is an output, while alarm and calibration functions are only available if the channel is an input.

Setup screen for virtual channels

Depending on their "IO type" setting, the virtual channels V1, V2, and V3 have the same front-panel settings as either the sensor input or the heater output channels. These settings have been described above.

Virtual channels don't offer built-in sensor calibration curves, but they do accept custom calibration tables. When configured as an output, virtual channels also offer a cascade control setting.

IO type
Channel.IOType { Input, "Meas out" }

Virtual channels can be inputs or outputs. In either case, it is possible to set the channel's value from the front panel or by sending a remote command. However, PID feedback functionality is only available if the channel is an output, while alarm and calibration functions are only available if the channel is an input.

Casc
Channel.PID.Casc "*Output channel*"

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 CTC100'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". You should see a list of output channels. If a channel is selected from this list, its PID setpoint will continuously 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.

Firmware updates

The CTC100's firmware can be updated by copying a firmware file onto a USB stick, plugging the USB stick into the CTC100, and issuing a remote command. Besides the CPU firmware, each of the six I/O cards and the front panel has its own firmware that can be upgraded.

In most cases, firmware updates do not affect your settings or I/O card calibration data. However, if the functionality of a particular setting has changed in the new firmware, that particular setting may revert to its default value.

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 CTC100 and wait until a window that says "Opening USB drive" appears and then disappears.
3. Press the System key on the CTC100's front panel. If less than five other macros are defined, there should be a button labeled "Update" in the leftmost column. Press the "Update" button.
4. The CTC100 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 CTC100 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 firmware files with names that end in ".hex", plus macro files 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 CTC100 and wait until a window that says "Opening USB drive" appears and then disappears.
3. Press the System key on the CTC100's front panel. If there aren't too many other macros defined, there should be buttons labeled "U1", "U2", etc. in the leftmost column. If the buttons are not visible because other macros are occupying the 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 CTC100 should be turned off and back on again to ensure that the I/O card is properly initialized.

Replacing the memory backup battery

The CTC100 has a CR2032 battery which 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 CTC100 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 by the following procedure:

1. Unplug the CTC100 from the wall. This is important since otherwise live AC voltages may be present inside the chassis even if the CTC100 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 CTC100, the battery should be clearly visible. It is a 20 mm diameter coin cell located on the left side of the instrument 8 inches behind the front panel. The CTC100 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 CTC100's lid.
7. After turning the CTC100 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 CTC100 has three I/O ports that can be used for computer control: USB, Ethernet, and either GPIB or RS-232. All three ports accept the same text commands. All three ports are always active; it is not necessary to enable or select the port that you want to use. Likewise, the front panel controls are always enabled; the CTC100 does not have separate "remote" and "local" modes.

Each line of text transmitted to the CTC100 should be terminated in one of the following ways:

- 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').

Each line of text that the CTC100 transmits is terminated with a carriage return followed by a newline.

Each line of text transmitted to the CTC100 may consist of one or more instructions. The series of instructions, known as a "macro", starts running as soon as the terminating linefeed character is received. If it takes long enough to complete, its progress can be monitored on the Program screen. Meanwhile, as the macro is running, it's possible to send additional macros to the CTC100. Up to 10 macros can run concurrently, although only the first four are visible on the Program screen.

Any macro sent to the CTC100 over an I/O port must be written on a single line, otherwise it will be interpreted as several macros to be run concurrently. Each macro can have a maximum of 1024 characters, while each argument 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 also be stored as text files on a USB memory device. When the USB device is plugged into the CTC100, 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.

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.

Most macro instructions correspond directly to buttons on the Setup 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" tab of the Setup screen, in the "COM" column, and is named "RS-232".

Connecting to the CTC100

RS-232

The CTC100's RS-232 port is a 9-pin female D-sub connector. The connector is not present if the GPIB option is installed. The CTC100 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	CTC100 data out
3	CTC100 data in
4	Not connected
5	Signal ground
6	Not connected
7	RTS (Request to Send; CTC flow control in)
8	CTS (Clear to Send; CTC 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 CTC100 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 CTC100 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 CTC100 stops sending data whenever the PC pulls pin 7 low.

Of the PC serial ports tested at 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 CTC100, may stop transmitting data after several characters, or may never stop transmitting data, in which case the CTC100 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 CTC100. USB-to-serial converters based on the Prolific PL-2303 chip are also compatible.

The RS-232 interface has no parity, 8 bits, and 1 stop bit. The baud rate can be selected from the System Setup menu.

USB device port

The CTC100 has a single USB 1.1 device interface that can be connected to a PC with a standard USB A-to-B cable. The CTC100 appears on the PC as a COM port, and any software that can communicate with an RS-232 port can be used to send remote commands to the CTC100. 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 CTC100's USB interface, the PC may display a "New Hardware Found" dialog. In this case, the USB driver 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 USB driver. No additional setup is needed.

If the PC does not recognize the presence of the CTC100 when the USB connection is made, unplug the USB cable and plug it back in. In addition, if the CTC100 is turned off and back on again while the PC application is running, the application may no longer be able to communicate with the CTC100 until it is closed and re-opened.

When using LabView to communicate with the CTC100 over USB, ensure that the National Instruments VISA driver is version 4.0 or later. Older versions of the driver cannot communicate with the CTC100. The latest version can be downloaded for free from the National Instruments website.

USB host port

Macros can be imported from a USB hard drives or flash key. Save the macro as a text file (its name must end with ".txt") and copy it to a folder named "macros" in the topmost directory of the

USB device. When the device is plugged into the CTC100, up to six buttons with the names of the text files appear in the System.Macro menu. A macro can then be run by touching the button with its file name. If the USB device is unplugged, the corresponding macro buttons disappear but any running macros continue to run.

In addition, one macro can be saved in the topmost directory of the USB device under the name "autorun.txt". This macro automatically runs each time the USB device is plugged into the CTC100.

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 can affect the CTC100's performance.

GPIB

CTC100 units can be ordered with or without a GPIB port. If GPIB is requested, it replaces the RS-232 port. Although any standard GPIB cable can be used, due to space restrictions a single-ended cable (such as a National Instruments X5 cable) is recommended.

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 CTC100's Ethernet interface via telnet port 23. The IP address and subnet mask must 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 CTC100 can be connected directly to your 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 CTC100 to your computer with a standard Cat5 Ethernet cable.
2. Enter a suitable IP address into the CTC100's System menu. If you're using a direct connection (nothing else is connected to the network), the IP address should be within your computer's subnet; 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 should 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 CTC100's screen.
6. Type `Description` and press Enter. The CTC100 should return an instrument description string.

Various serial port redirectors are available that convert a telnet connection into a COM port, allowing any software that can communicate over RS-232 to communicate with the CTC100 over Ethernet. 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 may introduce a 150 ms delay after receiving the first character of each message from the CTC100, limiting the speed of the Ethernet connection. Windows Vista and Linux computers do not have this issue.

Troubleshooting communications problems

If the remote interface does not respond at all, try the following:

- If using RS-232, make sure the baud rate is set correctly.
- Make sure that each line of text sent to the CTC100 ends with a linefeed character (decimal 10 = hex 0x0a = '\n').
- Try viewing the System.COM.History window. This will tell you if the CTC100 is receiving anything at all.
- Try sending the command "popup hello". This command produces a response that is easy to see (a popup window appears) and only requires that the interface work in one direction. Next, send the command "description", which should generate a response.

Communication, assembly, and run-time errors

If the CTC100 is unable to receive a macro due to a problem with the I/O port, a communication error may be generated and the macro does not run.

If the macro is successfully received, the CTC analyzes it and any macros that it calls to ensure that:

- Each instruction is valid, and
- 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 at this time to see if they fall within acceptable limits, since those limits may change as the macro runs.

If the macro fails one of these tests, it doesn't run and an assembly error is reported. If the System.COM.Verbose setting is Medium or High, the CTC100 reports the error 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.

At this point, the macro is displayed on the Program screen and starts to run. As each instruction is executed, errors can occur if:

- 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

Because macros can run for a long period of time or even indefinitely, when the CTC100 receives a macro over an I/O port, it may start running before the previous macro has finished. In addition, it's possible to run multiple instances of a saved macro simultaneously.

The CTC can run up to 10 concurrent macros received over any one I/O port and up to 20 concurrent macros from all sources combined (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 CTC is turned off and turned back on again, macros that were running when the CTC100 was turned off are not restarted.

When a macro is sent to the CTC over an I/O port, at least one instruction is executed before any later macros sent on 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 CTC may execute them concurrently and replies may not be received in the expected order.

Macro names

Each running macro has a name that can be used by the `kill` instruction to stop the macro and also appears in a tab on the Program screen. It is possible to have two or more macros with the same name running.

If a macro is started by a remote command with 32 or fewer characters, the macro name is the same as the remote command. If the command has more than 32 characters, the CTC100 assigns the name "Program XY", where XY is a two-digit number.

If a macro is started from the Program screen, its name is the text in the Input field. If the Input field contains more than 32 characters, the macro name is "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 text on the macro button. If the name is too long for the button and has been truncated on screen, the full name of the macro is used.

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

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

Command syntax

instruction = argument
instruction += argument
instruction?

Many instructions must be followed by some sort of value. The value must be 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.

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

If a question mark follows the instruction, no argument should be provided, and the CTC100 replies with the current value of the setting. The reply also appears on the Program screen if the appropriate tab is selected.

For example,

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

sets the value of channel "Out 1" to 5 watts. The equals sign is optional and everything is case-insensitive. Since the channel name "Out 1" has a space, the instruction has to be in quotes or it will be interpreted as two separate instructions. The argument must be outside the quotes.

To reduce the need for quotes, spaces can be omitted from instructions. For example:

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

is equivalent to:

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

Spaces cannot be omitted from arguments.

The command:

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

increases the value of channel "Out 1" by 1 watt. The equals sign and the spaces before and after the + are optional. This command:

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

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

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

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

```
In1.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 would be "10 s" after the above remote command was issued.

(*instruction*) (argument)
"*instruction*" "argument"

Instructions and arguments are normally separated by spaces. If an instruction contains spaces, the spaces can just be omitted, but if an argument contains spaces, the argument must be enclosed in parentheses or quotation marks.

Parentheses can be nested, but quotation marks cannot. Two quotation marks in a row before an instruction results in an "empty instruction" assembly error.

These two instructions are equivalent:

```
popup "Hello world!"
popup(Hello world!)
```

If an argument doesn't contain any spaces, it doesn't have to be enclosed in quotes or parentheses.

```
popup Hello!
```

Whitespace can be included before or after parentheses or quotes but is not necessary.

[*instructions*]*1*

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
***menu*.list**
***instruction*.list**

`List` prints a list of top-level menus. If the `.list` suffix is appended to the name of any menu (System, Channel, System.COM, Channel.PID, etc.), the CTC100 lists the available instructions for the menu or submenu. If appended to an instruction, the `.list` suffix returns a list of arguments required for the instruction. 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.

In the examples that follow, the first line is the remote command, while the remaining lines are the CTC100's reply.

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

In this case, the reply is a list of arguments that can be appended to the instruction `Out1`. The dot at the end of `pid.` indicates that `Out1.pid.` is another menu, not a complete instruction.

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

Since `Out1.pid` is a menu, the reply lists the instructions available in the menu.

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

`Out1.pid.setpoint` is an instruction, so 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, `Out1.value` takes a single floating-point instruction in the range 0 – 1200. 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 a variable. The help suffix is not available for program flow instructions such as if, while, abort, and kill.

if (*condition*) { *instructions* }
while (*condition*) { *instructions* }
else { *instructions* }

Conditional statements consist of an `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 causes a macro to wait until temperature In1 is between 39 and 41 degrees:

```
while (In1 < 39 || In1 > 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.

When the name of a channel is used within 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 (or any other conditional term) can be preceded by a dollar ($) sign to ensure that it is treated as a string, or by a pound (#) sign to ensure that it is treated as a query. For example:

```
if (Out1.PID.Input==$In1) { Out1.PID.Input = In2 }
```

In this example, the dollar sign ensures that the PID input channel is compared with the string "`In1`", not the numeric value of channel In1. 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 hash (#) to force the CTC100 to treat it as a query. Since conditional terms are treated as queries by default, the pound sign is only 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.

#variable 0.0

The hash character 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 hash (#) 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. The equals sign is optional.

Variables can be used by the macro in which they are defined; by any macros called by that macro; and by the macro that called it. A macro 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 CTC 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.

The CTC100 has three virtual channels that behave like much like variables. However, while a variable can only be used by 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).

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<3) { #x+=1 Out1=#x pause 1 s }
```

cycles through the "while" loop three times, setting channel "Out 1" to 1, then a second later to 2, and another second later to 3.

The CTC100's macro system does not support equations. For example, a statement of the form "#x = #y + #z" is not allowed. More generally, each CTC100 argument can only contain a single term.

#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 CTC100 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 variables that have been defined within the macro.

"Macro name"

Macros can be defined with the `define` instruction; by saving a macro from the Program screen; or by plugging in a USB drive containing macros in the form of text files. 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 macro 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 to the CTC100:

```
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, while the instruction takes precedence if it is called with a lower-case first letter.

Errors: If the child macro contains any invalid instructions, an assembly-time error occurs and neither macro runs.

A macro cannot be both defined and called by another macro; either an assembly-time "not a valid instruction" error will occur, or an older version of the macro will be called instead of the new one.

Remote instructions

In the following listing, words in `Courier` font represent text that may be sent to or received from the CTC100 over RS-232, USB, GPIB, or Telnet, or via a text file on a USB memory device. Words in *`italicized Courier`* are placeholders that should be replaced with other names or values; for example, when the word *`Channel`* appears it should be replaced with the name of a data channel like `In1`. If an argument is enclosed in quotation marks and contains spaces, it must be enclosed in quotes or parentheses. If the argument doesn't contain any spaces, the quotes can be omitted.

Miscellaneous instructions

`abort`
Stops the macro. This instruction only affects its parent macro. Use the `kill` instruction to stop other, concurrently-running macros.

`description`
Writes a string similar to the following to the I/O port:

```
CTC100 Cryogenic 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 second 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.
- **`first`** to get the oldest point in the log.
- **`last`** to get the most recent point in the log.
- **`next`** to get the point after the one that `getLog` last fetched from the channel. If the next point has not been acquired yet, the CTC100 waits for it to be acquired. If `getLog` has not been used on this channel since the CTC100 was turned on or since `getLog.reset` 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 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 "In 1", next }
```

transmits the value of channel In 1 each time a new value is logged.

"`getLog?` *`channel`*" returns the number of data points that can be read with "`getLog` *`channel`*`, next`" before the end of the log is reached. For example, to read all logged data for channel 3A, first issue the following instructions:

```
getLog "In 1", first   getLog? "In 1"
```

Then, send the instruction "`getLog "In 1", 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. The values are always reported in the same order, which can be determined with the getOutput.names instruction.

`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`
Changes the channel selection group. The group must be a number between 1 and 4, inclusive.

`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 CTC was turned on, the return value indicates how many seconds have elapsed since the CTC100 finished booting.

`menu { Select Channels, Show Data, Program, Setup, Help, Output Enable }`
`menu 1`
Makes the CTC100 behave as if one of the front-panel buttons has been pressed. The argument can be the name of a front-panel button or a numeric value between 1 and 6, inclusive (1 for "Select Channels", 2 for "Show Data", etc). "Menu += 1" advances the CTC100 to the next menu; issuing the "Menu += 1" instruction while the Setup menu is showing brings up the Select Channels 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 "month day year hours:minutes"`
`systemtime.dmy day/month/year`
`systemtime.hms hours:minutes:seconds`
`systemtime.mdy month/day/year`
`systemtime.ms 0`
`systemtime.smh seconds minutes hours day month year`
The `systemtime` instruction is similar to `System.Other.Time` and `System.Other.Date`, except that it 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 2011 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**" sets the time as the number of milliseconds since midnight on January 1, 1970 UTC.
- "**Systemtime.smh**" sets 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 CTC100'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` ***`0`***
`*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 Alarm Status Register is a 32-bit integer that indicates which alarms were triggered since the last time the `*ASR?` command was issued. Each of the CTC100'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 CTC100's local memory. Note that the macro content, like all instruction arguments, must be 256 or fewer characters in length.

`*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 are enabled and returns either 0 (macros disabled) or 1 (macros enabled). Since the state of `*EMC` does not persist when the CTC100 is rebooted, macros are always enabled when the CTC100 is turned on.

ESE *0
***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 I/O port that received the command) the text of a macro.

***IDN?**

Returns an identification string with the following format:

Manufacturer, Model number, serial number, version

where *serial number* is the instrument's five-digit 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 CTC100 operations have finished, then sets the Operation Complete bit in the Event Status register. `*OPC` is intended to indicate that all previous instructions in the macro have been completed.

`*OPC` is not generally required because most CTC100 instructions are fully processed before the next instruction in the macro is begun. The exceptions are PID autotuning (i.e., *`channel`*`.tune.mode`) and ramp-to-setpoint (*`channel`*`.setpoint`, if *`channel`*`.ramp` is nonzero). It's also possible to overlap instructions by sending a macro before the previous macro has finished.

`*OPC` 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, `*OPC` 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 macros that contain `*WAI?`, `*OPC?`, or `*OPC` instructions, the result is a deadlock and both macros pause indefinitely. A deadlock does not

occur if the two macros were received on different I/O ports or if one was started from the front panel.

While *OPC is waiting, new commands received over the source port are held in the input buffer. The commands are not processed until *OPC has finished waiting.

***OPC?**

Identical to *OPC, 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 *PHO 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**

*RST 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.
- All log data is stored in the CTC100's RAM is erased. Logs on USB devices are not affected. Unless data is being logged to a USB storage device, all graphs on the Plot screen are empty after a *RST command.

SRE *0
***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 CTC100 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 CTC100 stops automatically acquiring data. The inputs are only read, and PID feedback loops only update their outputs, when a *TRG command or a GET message is received. PID feedback outputs will not function properly unless the CTC 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 System.other.A/D rate. For example,

```
"System.other.A/D rate" = 100
```

sets the CTC100 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 times ADC data has been dropped because of timing issues, 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 CTC100'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 received on the same port, all PID tuning processes (regardless of how they were started), and all setpoint ramps have finished. Identical to *OPC, but doesn't provide any explicit indication to the I/O port when the wait is complete.

The `program.` prefix can be used but is not necessary for these instructions.

`abortMacro "`*`Macro content`*`"`

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 Setup 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 reached; therefore, this instruction should usually be at the beginning of the macro. 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. Calls to submacros are replaced with the full text of the submacro before the macro starts to run, but the define instruction doesn't actually define the macro until run time.

Example:

```
define Hello([print "Hello world!" pause 1 second]3)
```

The macro "Hello" can now be run by issuing the remote command:

```
Hello
```

Like all instruction arguments, the macro content must be 256 or fewer characters in length. To define a macro longer than 256 characters, instead of using the `define` instruction, save the macro on a USB memory device. First, use a text editor on a PC to compose the macro, and save it as a text file. The name of the text file should be the name of the macro plus the extension ".txt". Copy the text file to a folder named "macros" in the root directory of a USB memory device, and then plug the USB device into the CTC100. The macro should now be available for use as long as the USB device is plugged in.

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. "`define`" does not check the contents of the macro for syntax errors.

delete "*Macro name*"
delete.all

Deletes a saved macro. "Delete.all" deletes all macros saved in the CTC100's internal memory, 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 is received from 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 "*Macro name*"
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.

kill.all stops all currently-running macros regardless of name or which port started the macro.

There is no kill? query.

name "*Macro name*"

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.

The name instruction does not affect the file name that a macro is defined under.

Errors**:** If the runtime name is more than 32 characters long, it is truncated to 32 characters.

pause *0.0* { 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 "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 "*Popup text*"
popup.close

Produces a popup window on the CTC100'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 message 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.

Popup.close closes any popup or help window currently visible, regardless of how the window was created.

If a popup window is visible on-screen, popup? returns the content of the popup window; otherwise, it 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.

print "*message*"
Prints the indicated message. The message can be any alphanumeric string up to 128 characters long. If the program's tab 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 CTC.

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 content*"
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.

`run` should only be used when a child macro needs to run concurrently with 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 CTC100 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 chassis cooling fan may switch on occasionally. Press the "Output Enable" key to exit standby. There is no remote command to exit 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.rampT) { pause 1 s }
```

waitForSample
Pauses the macro 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 setup

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 }

Determines how the CTC100 replies when a remote instruction is processed.

Low: the CTC100 only replies when a query is processed.
Medium: messages are also produced whenever an error occurs.
High: messages are also sent whenever an instruction sets a parameter, and the messages include the names of parameters that are 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.display.Bright { Min, 2, 3, 4, 5, 6, Max }

Sets the brightness of the front-panel display backlight.

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 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 *channel*.stats) is shown next to the channel name. Ponytail plots do not show the average and standard deviation, but instead show the offset of each channel, if stats display has been enabled.

"system.display.T(PCB)" { Hide, Show }

If set to Show, the temperature of each I/O card that has a printed circuit board (PCB) temperature sensor is collected, stored, and shown on the Select screen. The system must be restarted before any changes are effective.

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, mK, °F, "" }

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, graphs and logs will appear to show that a value of 22°F was recorded. If the units are set to an empty string, thermocouple readings are shown in millivolts and RTD and thermistor readings are shown in

ohms, even if the sensors have a custom calibration curve with declared units (see the "Custom calibration" section).

system.display.Volume { off, 1, 2, 3, 4, 5, 6, 7, max }
Controls the volume of all tones and alarm sounds played through the CTC100's speaker.

system.display.XLabels { 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.XRange *0*
Sets the X range of the plot in milliseconds. 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.IP.Address *0.0.0.0*
Sets the CTC100'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 *0.0.0.0*
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 CTC100 firmware.
Errors: The gateway cannot be changed if `system.IP.DHCP` is set to `on`.

system.IP.MAC *00:00:00:00:00:00*
Sets or queries the media access control address. This value is set at the factory and should not generally be changed unless the CTC100'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 *0.0.0.0*
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 `on`.

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

system.log.clear { yes, no }
Erases log files from the USB device.

- 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 the CTC100's logged data. If the folder does not exist, it is created. If the folder does exist and it already contains CTC100 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 "RAM".

system.log.USB { Auto, Manual }
If set to Auto, any time a memory device is plugged into one of the CTC100's USB ports, the CTC automatically begins logging to it. If set to Manual, the user must touch the USB logging triangle in the upper-right corner of the screen to begin logging.

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 0.0 (1 MHz trigger source)
Sets the A/D conversion time and 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 CTC100'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. Settings other than auto can reduce the accuracy of temperature measurements and cause the DC outputs to overheat and shut down.

system.other.date "*month day year*"
system.other.time "*hours:minutes*"
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 some or all user settings. 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 the CTC100's internal memory, but 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 (global) value, 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.

Channel setup

Channel 0.0

To change the value of an output channel, send the channel's name followed by a floating-point value. Regardless of the channel's direction, *channel*? returns the current value of the channel. This instruction is identical to "*channel*.value". For example,

```
Out1 = 2.5
```

sets the value of channel Out 1 to 2.5 W (if Output Enable is on).

```
Out1?
```

Queries the value of channel Out1.

Errors: a run-time error occurs if this instruction is used to set the value of an input channel. If the a channel has an enabled feedback loop, its value cannot be changed but no error message is produced.

Channel.Average

If statistics collection is enabled for the indicated channel (*channel*.Stats = on), this query returns the average over the most recent *n* A/D samples, where *n* is set with *channel*.Points.

Channel.Current { Forward, Reverse, AC, off } (Temperature input channels only)

Selects the direction of the excitation current. 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. The excitation current can also be switched off entirely to control sensor self-heating; the sensor cannot be read while the excitation current is off.

Channel.d/dt { On, Off } (Input channels only)

Enables or disables the derivative filter. If set to "On", the value of the channel is replaced with its rate of change expressed in units such as degrees/second, Watts/second, etc. Since the

derivative is normally somewhat noisy, the lowpass filter should be enabled when the derivative filter is used.

Channels that have their derivative filter enabled can be used as inputs for PID feedback loops, in which case the feedback maintains a constant rate of temperature change rather than a constant absolute temperature.

***ChannelA*.Diff "*Channel B*"** (Input channels only)

Enables or disables the difference filter. If channel B is valid, 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:

```
In1.diff(In 2)
```

Replaces the output of channel In 1 with the value (In 1 – In 2). Channel In 2 is unaffected.

```
In1.diff()
```

Removes the differencing function from channel In 1.

Channels that have their difference filter enabled 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.

***ChannelA*.Follow "*Channel B*"** (Virtual channels only)

This instruction is only available for virtual channels (channels V1, V2, and V3) with an IO type of Input. If Channel B is a valid channel name, the value of the virtual channel is updated with the value of Channel B each time an ADC conversion occurs. To exit follow mode, issue the *Channel*.Follow() instruction with an empty argument.

***Channel*.IOtype { Input, "Set out", "Meas out" }** (Output channels only)

This instruction, which is only available for output channels, determines the channel's direction. Not all options are available for every output channel.

If the IO type is set to "Input", the channel measures whatever value is present and does not produce an output; it becomes a high-impedance input.

If the IO type is "Set out" or "Meas out", the channel outputs either voltage, current, or power, depending on the *Channel*.Units setting. If "Set out" is selected, the CTC100 just displays whatever output was most recently requested by the PID feedback loop, remote interface, or front panel. If "Meas out" is selected, the displayed value is an ADC reading of the output.

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" }**

(Input channels only)

Sets the time constant for the lowpass filter. Input channels can be filtered with a 6th-order lowpass RC filter to remove noise. If enabled, the filter removes noise spikes and other transient

signals that last for less than the selected time constant. The disadvantage is that the response speed of the sensor is also limited; that is, if your sensor can respond to temperature changes within 1 second and you select a 10 second lowpass filter, the sensor will now take 10 seconds to respond to temperature changes.

Errors: attempting to use the ***Channel*.Lopass** instruction on an output channel results in a compile-time "unrecognized instruction" error.

Channel*.LowLmt *0.0 (Output channels only)
Channel*.HiLmt *0.0 (Output channels only)

Constrains the minimum or maximum value of an output channel. These instructions can be used to prevent the PID loop, remote commands, or the front-panel controls 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 set again when the output units are changed, since the limits are not converted to the new units.

If the lower limit is greater than zero, it does not apply when the CTC100's outputs are disabled with the "Output Enable" key or the **OutputEnable off** instruction.

Errors: attempting to use one of these instructions on an input channel results in a compile-time "unrecognized instruction" error.

***Channel*.Name "*New channel name*"**

Changes the name of this channel. Once the name of a channel has been changed, the default channel name (In 1, In 2, Out 1, etc.) can no longer be used and all remote commands must address the channel by its new name.

To determine the current names of the CTC100's channels, use the **getOutput.names** instruction.

Errors: If a macro changes a channel's name, any attempts to address that channel again within the same macro will produce an "unrecognized instruction" error.

***Channel*.Off** (Output channels only)

Turns the selected channel off. The instruction 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.

Errors: attempting to use this instruction on an input channel results in a compile-time "unrecognized instruction" error.

Channel*.PCB *0.0 (Temperature input channels only)

Sets the maximum allowable temperature of the input circuit (e.g., the printed circuit board or PCB). If the temperature of the circuit exceeds this value and **System.Other.Fan** is **Auto**, the CTC100 increases the fan speed to cool the air inside the chassis. 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 }**

Indicates which plot the channel should appear in when the Plot screen is showing and the Custom plot tab is selected. Plot 1 is the topmost plot. If no channels are assigned to a plot, that plot does not appear.

Channel*.Points *0

Controls the maximum number of ADC readings used to calculate the average and standard deviation. The value 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*.Range { 10ê, 30ê, 100ê, 300ê, 1kê, 3kê, 10kê, 30kê, 100kê, 300kê, 2.5V, Auto }** (Temperature input channels only)

Sets the sensor measurement range. The default range is Auto. In general, a lower range results in a larger excitation current, less noise, and more accurate measurements.

The CTC100 uses ASCII character 234 for the Ohms symbol. To type this character on a Windows computer, hold down the alt key and type 0234 on the number pad. On Windows computers the character appears as a letter "e" with a circumflex accent.

Errors**:** If this command is used with a channel that is not a sensor input channel, a "not a valid instruction" error is produced.

***Channel*.SD**

If statistics collection is enabled for this channel (with *channel*.Stats), this instruction returns 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:

```
In1.selected(on)
```

adds channel In 1 to the current selection group, if it hasn't already been added.

```
In1.selected = off
```

removes channel In 1 from the current selection group.

***Channel*.Sensor { RTD, Thermistor, Diode, ROX }** (Temperature input channels only)

Selects the sensor type for a channel. Select ROX for a ruthenium oxide sensor, Thermistor for other NTC resistive sensors, RTD for PTC resistive sensors, and Diode for cryogenic diode sensors.

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 or ROX and load a custom calibration table (see "Custom Calibration Tables" in the Introduction of this manual).

Changing the sensor type may affect how the CTC hardware acquires data from the sensor. In particular, if the sensor type is changed from Thermistor to Diode, the CTC acquires voltage instead of resistance readings and a special high-accuracy excitation current source is used. Also, the RTD setting results in larger excitation currents than the other settings.

The sensor type also affects which instructions are available in the *channel*.Cal menu. For example, if the sensor type is 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.

***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, A, V }** (Heater output channels only)

By default, the outputs of the heater driver cards are measured in watts. Using the Units instruction, the output units of the 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 *0.0

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:

```
Out1.value = 1.0
```

Sets channel Out 1 to output 1 watt of power. Note that spaces in the channel's name should be omitted.

```
In1.value?
```

Queries the output of channel In1. The response is a numeric value such as

```
37.4722
```

if System.Com.Verbose is set to Low or Medium, or

```
In1.value = 37.4722
```

if System.Com.Verbose is set to High. If sensor In1 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 CTC100 is the most recent ADC reading with the sensor calibration and lowpass, difference, etc. filters applied. 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.

Errors: attempting to set its value of an input channel results in a "locked parameter" error.

Channel.alarm submenu

All *channel*.alarm instructions can only be applied to input channels. Issuing any of the following instructions for an output channel results in an assembly-time "unrecognized instruction" error.

Channel*.alarm.lag *0

A non-zero lag prevents the alarm from triggering until the signal has continuously exceeded the alarm limits for the indicated number of seconds.

***Channel*.alarm.latch { No, Yes }**

Selecting `No` makes the channel's alarm momentary; `Yes` makes the alarm latching. A momentary alarm only sounds while the input signal exceeds the alarm limits; a latching alarm, once triggered, continues to sound until the status or mode is set to off.

Channel*.alarm.min *0.0
Channel*.alarm.max *0.0

These instructions set the alarm thresholds. The alarm is triggered whenever the signal exceeds these values. The thresholds 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 that indicates which bit in the Alarm Status Register this alarm sets whenever it is tripped; for example, a mask value of 1 indicates that bit 0 is set; 2 indicates that bit 1 is set; 4 indicates that bit 2 is set; and so on. 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 or disables the alarm. The alarm can be programmed to trigger either when the level of the signal or its rate of change exceeds the thresholds. The rate of change is calculated over two successive A/D conversions and is therefore susceptible to noise; if necessary, use the channel's lowpass filter to reduce 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; that is, 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.:

```
In1.alarm.output()
```

***Channel*.alarm.relay { None, A, B, C, D }**

An alarm can trigger one of the CTC100's four relays. The `alarm.relay` instruction determines which, if any, of the four relays is triggered.

***Channel*.alarm.sound { None, 1 beep, 2 beeps, 3 beeps, 4 beeps }**

Controls which sound plays when 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 _0.0_

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 59 for more information.

Errors: If `cal.Type` is not set to `Custom`, attempting to set `cal.A`, `cal.B`, or `cal.C` produces a run-time "locked parameter" error. Attempting to use any of these instructions on a channel that is not a sensor input produces an assembly-time "unrecognized instruction" error.

Channel.cal.Gain _0.0_
Channel.cal.Offset _0.0_

These commands can be used to adjust a channel's calibration. 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 the offset or 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 { 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 58 for more information.

Channel.PID submenu

All `_channel_.PID` instructions are only available 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, all PID settings are locked except for `channel.PID.input`. 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 _0.0_
Channel.PID.I _0.0_
Channel.PID.P _0.0_

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. Attempting to set P 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 *0.0
Channel*.PID.ZeroPt *0.0

These instructions set the offset and gain for Follow mode. They are only available when the PID mode of *Channel* is set to Follow. In Follow mode, the value of an output channel follows the value of another channel with offset and gain applied:

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

Note that "Input" can be either an input or an output channel. Also note that 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*"**

Determines which temperature 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 disabled.

***Channel*.PID.Mode { Off, On, Follow }**

Enables or 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 value of the channel selected with the input instruction, adjusted by the Zero pt and Gain factors.

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 *0.0

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 CTC 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 *0.0

Ramp temperature. The ramp temperature is an internally-generated setpoint for the PID feedback loop; it is the temperature that the CTC100 is trying to maintain at the present moment. If the feedback is not running, the ramp temperature always equals the sensor temperature, since the CTC100 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 CTC100 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 *0.0

Determines 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.TMin *0.0

Each of the eight PID memory locations can be assigned a temperature range for zoned feedback. If zoned feedback is enabled by setting *Channel*.PID.Zone to Auto, any given memory location is automatically recalled whenever the PID input temperature enters its temperature range.

The *Channel*.PID.TMin instruction determines that temperature range. It assigns a lower temperature bound to whichever memory location is currently selected. There is no TMax instruction; the upper end of the temperature range is the next-highest TMin value in the memory table.

Errors: Attempting to set the minimum zone temperature when no PID input channel is selected produces a run-time "locked parameter" error.

***Channel*.PID.Zone { 1, 2, 3, 4, 5, 6, 7, 8, Auto }**

Sets the PID temperature zone. A set of PID gains, an input sensor, and a minimum temperature can be assigned to each of eight temperature zones. If the zone is set to Auto, a set of stored feedback parameters is automatically recalled whenever the ramp temperature (*Channel*.PID.RampT, which is usually the same as the feedback setpoint) enters one of the temperature zones. Any changes to P, I, D, or the input sensor are automatically reflected in the zone definition for the current zone.

Errors: Attempting to change the memory location 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 *0.0
Channel*.Tune.StepY *0.0

These parameters provide the PID autotuners with initial guesses of the system's response magnitude and time. *Channel*.Tune.StepY controls the height of the step response or relay disturbance, while *Channel*.Tune.Lag determines how long the tuner waits before it first evaluates the effect of the disturbance. If either value is too small, the autotuning algorithm will be susceptible to noise. The Y step size should be high enough to produce a temperature rise of several degrees, and the 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 results in a run-time "locked parameter" error.

***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 CTC100 begins a step response if the PID output is less than half of *Channel*.Tune.StepY; otherwise it begins the relay tuning procedure. 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

The CTC100 reports an error code if it encounters an error in a macro and System.COM.Verbose is set to High. The error code appears in the error message sent to the communications port that initiated the macro, and is accompanied by an explanation of the error and which instruction caused the error. For example, if you send the word Hello to the CTC100 over the RS-232 port when System.COM.Verbose is set to High, the CTC100 replies with the following message:

```
Error: "hello" is not a valid instruction (assembly error -113)
```

-100 – -199: assembly errors

Assembly errors are produced before the macro starts to run. If an assembly error is reported, the macro was cancelled before it began running.

-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 on 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

Runtime errors are 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 greyed 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 macros

To make a macro run automatically whenever the CTC100 boots up, enclose the macro in the following statement:

```
define Startup(macro)
```

where *macro* is the text of the macro to be run. Send this line over a serial port or run it from a USB stick. The macro doesn't run when the define statement is issued, but subsequently, it will run each time the CTC100 boots up. Note that the macro must be less than 256 characters long and must not call any macros stored on USB devices.

For example, the following remote command defines a startup macro that displays a message each time the CTC boots up:

```
define Startup(popup "Power has cycled")
```

If the Startup macro contains any errors, the macro won't run and no error messages will appear. Therefore, it's a good idea to test startup macros by running them normally, i.e. by sending the remote command `Startup` or using the Program screen to start the macro.

Similar functionality can be obtained by saving a macro as a file called "autorun.txt" in the root directory (not the macros directory) of a USB device and keeping the device plugged in to the CTC100. This macro will automatically run each time the USB device is plugged into the CTC100 and each time the CTC100 is turned on with the USB device plugged in. Autorun macros are not limited to 256 characters and can call other macros stored on the same USB device.

Sample macros

This section presents several sample macros to illustrate the capabilities of the CTC100. The macros are shown on multiple lines for clarity and can only be run as shown if they are input with a USB memory stick, 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 CTC100.
3. Press the CTC100'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.

If the sample macros are sent to the CTC100 via the RS-232, GPIB, USB device, or Ethernet port, each macro must be formatted as a single line with the comments removed, otherwise each line will be treated as a separate macro, and the lines will all run at the same time instead of sequentially.

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):

```
Out1.PID.ramp = 1        ' set the ramp rate to 1 degree/s
Out1.PID.setpoint = 100  ' start a ramp to 100 degrees
waitForRamp              ' wait for the ramp to finish
pause 1 min              ' wait for 1 minute
Out1.PID.setpoint = 80
waitForRamp
pause 1 min
Out1.PID.ramp = 0        ' disable ramping
Out1.PID.setpoint = 0
```

The equals signs are optional and are shown for clarity. If this macro is entered from the "Program" screen, the "channel." and "program." prefixes must be included:

```
channel.Out1.PID.ramp 1
channel.Out1.PID.setpoint 100
program.waitForRamp
program.pause 1 min
channel.Out1.PID.setpoint 80
program.waitForRamp
program.pause 1 min
channel.Out1.PID.ramp 0
channel.Out1.PID.setpoint 0
```

This is the most straightforward way to implement a temperature profile. However, it doesn't work if two or more PID feedback loops are ramping at the same time, because `waitForRamp` actually waits for all setpoint ramps to end, whether or not they were started by the macro.

A more elaborate version eliminates this issue by comparing the current value of the ramp (`Out1.PID.rampT`) with the endpoint of the ramp (`Out1.PID.setpoint`):

```
Out1.PID.ramp = 1
Out1.PID.setpoint = 100
while (Out1.PID.rampT!=Out1.PID.setpoint) { pause 1 s }
pause 1 min
Out1.PID.setpoint = 80
while (Out1.PID.rampT!=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 endpoint of the ramp:

```
Out1.PID.ramp = 1
Out1.PID.setpoint = 100
while (In1 < 99.5 && In1 > 100.5) { pause 1 s }
pause 1 min
Out1.PID.setpoint = 80
while (In1 > 80) { pause 1 s }
pause 1 min
Out1.PID.ramp = 0
Out1.PID.setpoint = 0
```

The `pause 1 s` instructions are not strictly necessary, but reduce the load on the CPU.

Control a feedback setpoint with an analog input

Using the following macro, it's possible to control the setpoint of channel Out 1 with the voltage at analog input A. The macro converts the ±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` 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 = #AIOA
    #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.

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
```

Show the PID setpoint in a virtual channel

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 also be made to echo any CTC100 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.rampT]-1
```

Each time an ADC conversion occurs, this macro sets channel V1 to the setpoint of channel "Out 1" (if the setpoint is ramping toward a given value, Out1.PID.rampT returns the current value of the ramp, while Out1.PID.setpoint returns the endpoint of the ramp). Because the macro is contained within a `[…]-1` statement it repeats indefinitely, running as a background task.

Using the "diff" function of 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 CTC100 can deliver, the CTC100'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 CTC100'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. As a result, you may notice 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 20 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 such as 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 A to "Set out" or "Meas out" and disable channel AIO A's PID feedback loop. Next, run the following macro, which sets AIO A to the square root of channel V1 each time an ADC conversion occurs.

```
[
  waitForSample
  #x = #V1
  #x^=0.5
  AIOA = #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 In 1,
  ' set the PID input channel to In 1
  if (#x==0 && Out1.PID.input!=$In 1) { Out1.PID.input=(In 1) }

  ' if bit 1 is set and the PID input channel is not In 2,
  ' set the PID input channel to In 2
  if (#x==2 && Out1.PID.input!=$In 2) { Out1.PID.input=(In 2) }

  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 In 1, rather than to the string "In 1".

PC applications

SRS offers a package of PC applications for displaying CTC100 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 CTC100 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 CTC log files into a single text file that can be imported by other programs. 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 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 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 log files or files that are not 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 all cases, 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) the user stopped and then restarted logging, for example by touching the USB logging indicator.

If the "Binary" output format is selected, the output files are written in the CTC 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, 2000 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 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 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.

The resample feature is useful for reducing the number of data points in the output file. Log files with a large number of data points can be cumbersome to display and often cannot be imported into application programs. In addition, different CTC channels can be logged at different 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 CTC100 log files.

To plot a file, either drag a 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 CTC100 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 PTCFileConverter to downsample the file before opening it with FileGrapher.

File menu

Open

Opens a directory for plotting. All log 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 PTCFileConverter 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 mark**s: 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 average 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 is subsequently subtracted from all displayed data until "Clear baseline" is selected. Selecting this option does not change the actual data that's stored in the program; it just changes how 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 stored in the program, 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 emulating an analog RC lowpass filter. Similar to the CTC100's lowpass filter, except 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 menu contains macros that each consist of some combination of operations from the other menus. The list of macros is defined in the file Resource\SpecialMenu.rsc, and the individual macros are defined by files 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)
clearAllMarks	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 "dateTime" (date and time), "elapsedTime" (elapsed time), or "off" (none)
yLabel "*text*"	Label the Y axis of the graph with the indicated text

Circuit description

Each of the six I/O cards (two sensor input, two heater output, analog I/O, and digital I/O) includes an Atmel ATmega microcontroller (U110). The microcontroller has onboard flash and SRAM. Its clock signal comes from an external 16 MHz oscillator located on the CTC100's backplane. The microcontroller controls the ADCs or DACs on each I/O card.

Each I/O card has a status LED that turns on or off each time an ADC conversion occurs; that is, if 10 ADC conversions are occurring each second, the LED blinks 5 times per second. If the status LED does not blink while the CTC100 is running, or does not blink at the same rate as the status LEDs on the other I/O cards, the card has a hardware or software problem.

I/O cards are 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 only used for debugging. The backplane bus uses a proprietary synchronous communication protocol.

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 CTC100'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 erased, the card must be reprogrammed at the factory.

The LCD controller (U401) contains the CTC's video memory and generates drive waveforms for the LCD display. Nearby 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 CTC is switched off) and transceivers that interface the ColdFire to the backplane bus. The EEPROM, battery monitor, and RS-232 transceiver circuits are not populated (if populated, the RS-232 transceiver on the CPU card provides a Linux terminal for debugging purposes). The RS-232 transceiver for user communications is on the backplane board.

Backplane

The backplane uses a proprietary parallel bus to connect the CPU card to the six I/O cards and the front panel. The bus has six I/O card slots. All six slots are equivalent; only the chassis cutouts constrain which cards are plugged into which slots.

The backplane also includes +5V and +3.3V switching power supplies for the CTC100's digital components, and +10, +20, and -20V switching supplies for the 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 CTC420 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 CTC100 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 CTC100 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 CTC100'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.

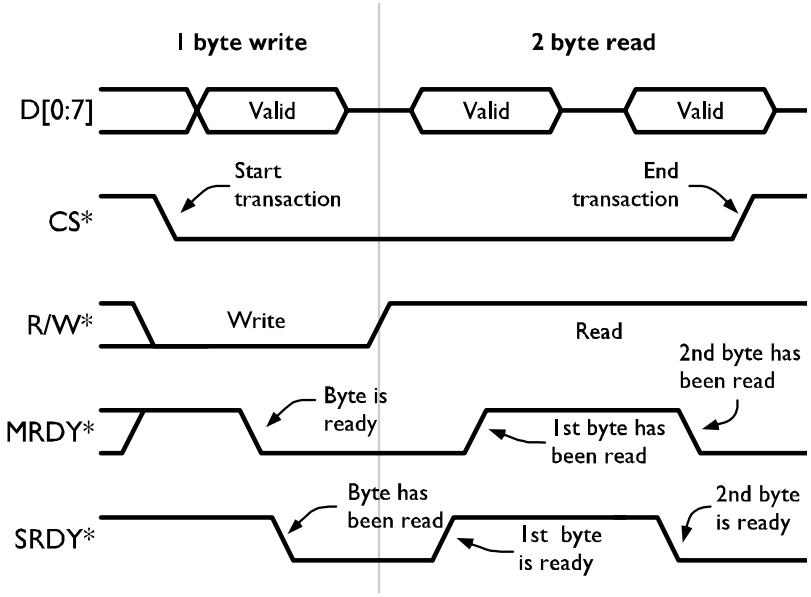
C14: SRDY* (Slave Ready). The I/O card inverts the state of this line after reading data or placing data on the bus. Each bus transaction starts with SRDY* in a high state.

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 become active.

C20: SCK (SPI Clock).

C21: MOSI (Master out, slave in).

C22: MISO (Master in, slave out).

UART

Connected to the CTC100'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).

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.

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.

Sensor input cards

Each of the two sensor input cards has two input channels. The cards measure 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.

Diode sensor voltages are measured with a similar technique, except a 5V voltage reference is used instead of the reference resistor.

Because each card has two independent channels, it has two copies of each of the following analog circuits. Part references are given for one circuit only.

Variable current source: generates the excitation current. A 10V reference (U610), resistor ladder, and 8:1 multiplexer (U620) produce one of eight voltages: 200 mV, 300 mV, 500 mV, 1 V, 2V, 3V, 5V, or 10V. Op amp U650A provides the excitation current, keeping the voltage across a sense resistor equal to the selected voltage. Multiplexers U630 and U670 select 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).

Fixed 10 µA current source: generates a high-accuracy excitation current for diode sensors. Voltage reference U640 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 four reference resistors. Mechanical relays are needed because the input protection diodes of semiconductor switches would leak current and produce 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. The current bypass, U210, is engaged while switching between different excitation current values and when the excitation current is set to "off". It keeps the excitation circuit from developing a large voltage (which could be damaging to diode sensors) when it is disconnected.

Multiplexer U210 shunts the excitation current through either D200 or U233. D200 adds a 300 mV offset, ensuring that the voltages at the inputs of op amps U260A–D are above the minimum value. Current is shunted through U233 when the 30x gain circuit is enabled; it adds a 2.5V offset.

ADC input buffers: These 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. Multiplexers U250A–B activate a 30x gain circuit used when necessary to keep the reference voltage above the 100 mV minimum required by the ADC. The gain applies to both the signal and the reference voltage.

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 it has a 4 ohm resistance and 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–.

Temperature sensor: U140 reports the temperature of the board's analog section and is used to regulate the CTC100's fan speed. The sensor is read by a built-in ADC on the microprocessor.

Heater driver cards

Each heater driver card outputs 2 A of current with a compliance voltage of up to 55V.

+24V to +50V 2A boost regulator: this switching regular boosts the power supply voltage to the level required by the constant-current heater driver. Although the output of the regulator is labeled "+50V" on the schematics, in fact it can be adjusted to any value between 28 and 55V, or it can be disabled, in which case the heater drivers receive a +23.8V supply. The card's microcontroller sets the regulator output via a PWM signal such that it is always slightly above the heater voltage.

Switching regulator U210 regulates the supply such that the voltage at its feedback pin (FB, pin 3) is 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 op amp U220A outputs 0V, the voltage across the heater (OUT+) is 55V; when U220A outputs 0.8V, OUT+ is 24V. 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.

If 50VSHDN is low, regulator U210 is shut down and the heater voltage is limited to 23.8V.

A 10W 120 ohm internal load resistor, R331, is connected between the +50V supply and ground. The microcontroller can switch the current through this resistor on or off to keep the power supply voltage from oscillating at low output voltages and/or currents.

Constant-current heater driver: the card has three independent current-output heater driver circuits which output 1.333A, 0.465A, and 0.200A. If the user has selected a 2A range, all three circuits operate in parallel. If a 0.6A range is selected, the 1.333A circuit is disabled. If a 0.2A range is selected, only the 0.2A circuit is enabled. The three circuits are identical except for the sense resistor. The microcontroller enables each circuit 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 given the 55V range, it 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. When the maximum current is flowing (2A in this case), the output is 4.0 V.

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 CTC'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 the user's heater, which is connected to J200. 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 an error message be displayed on the CTC'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.

Analog I/O card

The analog I/O card 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.

Digital I/O card

The CTC'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

Chassis

0-00048	6-32 KEP	Kep nuts for fan
0-00079	4-40X3/16 M/F	Black hex head screws for RS-232 and DIO connectors
0-00120	16 #18	Wire
0-00149	4-40X1/4PF	Mounting screws for front panel and power supply
0-00159	FAN GUARD	
0-00167	6-32X1/2RP	Mounting screws for backplane bracket
0-00179	RIGHT FOOT	
0-00180	LEFT FOOT	
0-00185	6-32X3/8PP	Screws for front feet
0-00204	REAR FOOT	
0-00238	6-32X1/4PF	Backplane mounting screws
0-00288	7 #24	Wire
0-00315	6-32X7/16 PP	Screws for rear feet
0-00328	8 #18 RED	Wire
0-00329	8 #18 BLACK	Wire
0-00371	4-40X3/16PF	Bezel mounting screws
0-00457	6-32X1/4PP/LW	Speaker and backplane mounting screws
0-00517	BINDING POST	Ground lug
0-00525	8-1/4 #18	Wire
0-00901	0.25	Ring terminal for ground lug
0-00978	M4 X 6MM	Power supply mounting screws
0-01013	18GREEN W/YELL	Wire
0-01014	4GREEN W/YELL	Wire
0-01212	6-32X1/4 BLACK	Wire
0-01226	16 BROWN	Wire
0-01227	36151	"PIDG ring terminal, 22-18 guage"
0-01228	696366-1	Blue faston terminal 0.25 in
0-01246	51864	"PIDG ring terminal, 16-14 AWG, #6, for ground wire"
0-01320	37CFM / 24V	Fan
0-01323	74-IFH5	Fuse holder
0-01324	10EAS1	AC power inlet
0-01325	#4-40	I/O card support screws
0-01327	3-520412-2	0.188 inch faston terminal
0-01329	10-32 x 1/4 TR	Black Phillips screws for top and bottom covers
1-00340	10 COND DIL 13	10 PIN DIL CNCTR to 9 PIN D-SUB
1-00472	"2 PIN, 24AWG/WH"	Plug for 24V board-to-board wiring
1-00496	6 POS 18GA ORNG	Plug for 24V supply-to-board wiring
1-01093	"3 PIN, 640441-3"	3 pin white plug for fan
1-01182	3 PIN	AC power plug for motherboard
1-01183	43375-0001	Crimp contacts for AC power plug
1-01187	60 COND.	Front panel ribbon cable
1-01252	050R33-075B	White LCD display cable
2-00068	RC1083BBLKBLKFF	Power switch
6-00076	2 SPKR	2 inch speaker
6-01012	24V / 240W	Main switching power supply
6-01013	5TT 4-R	4A 120V slow blow fuse
6-01014	34.312	2A 250V slow blow fuse
7-00122	BAIL	Stand
7-01002	IGC BEZEL	Plastic bezel for front panel
7-01286	"IGC, RCK SHELF"	Rack mount tray
7-02180	CTC100 CHASSIS	Chassis metal
7-02181	CTC100 F/P	Front panel
7-02182	CTC100 LEXAN	Plastic front panel overlay
7-02184	CTC100 M/B BRKT	Motherboard bracket
7-02185	CTC100 BRKT P/S	Power supply mounting bracket

	7-02186	CTC100 BOT COVE	Bottom cover
	7-02187	CTC100 CPU BRKT	CPU card angle bracket
	7-02201	CTC100 DISPLAY	Paper spacer; goes between LCD display and front panel PCB
	7-02206	CTC100 TOP COVE	Top cover
	7-02225	CTC100 COVER	Cover for GPIB cutout, with RS-232 connector mount
	8-00021	TOUCH PANEL	Touch-sensitive overlay for LCD display
	8-00098	LCD DISPLAY	QVGA display
	9-00267	GENERIC	Serial number label

CPU card

BT101	0-01089	1065	Battery
BT101A	6-00789	CR2032 W/OUT PN	Battery holder
C101	5-00334	.1U/T35	SMD TANTALUM, A-Case, NOTE NEEDS POLARITY!
C102	5-00601	0.1UF - 16V X7R	
C103	5-00471	10U/T16	SMD TANTALUM, C-Case
C104	5-00609	1500P	
C105	5-00609	1500P	
C106	5-00609	1500P	
C107	5-00609	1500P	
C108	5-00609	1500P	
C109	5-00609	1500P	
C110	5-00609	1500P	
C111	5-00609	1500P	
C112	5-00609	1500P	
C113	5-00609	1500P	
C114	5-00609	1500P	
C115	5-00609	1500P	
C116	5-00609	1500P	
C117	5-00609	1500P	
C118	5-00609	1500P	
C119	5-00609	1500P	
C120	5-00609	1500P	
C121	5-00609	1500P	
C122	5-00609	1500P	
C123	5-00609	1500P	
C124	5-00609	1500P	
C125	5-00609	1500P	
C126	5-00609	1500P	
C127	5-00609	1500P	
C128	5-00609	1500P	
C129	5-00609	1500P	
C130	5-00609	1500P	
C131	5-00609	1500P	
C132	5-00609	1500P	
C201	5-00601	0.1UF - 16V X7R	
C202	5-00601	0.1UF - 16V X7R	
C203	5-00601	0.1UF - 16V X7R	
C204	5-00601	0.1UF - 16V X7R	
C205	5-00601	0.1UF - 16V X7R	
C206	5-00601	0.1UF - 16V X7R	
C207	5-00601	0.1UF - 16V X7R	
C208	5-00601	0.1UF - 16V X7R	
C209	5-00601	0.1UF - 16V X7R	
C210	5-00601	0.1UF - 16V X7R	
C211	5-00601	0.1UF - 16V X7R	
C212	5-00601	0.1UF - 16V X7R	
C213	5-00601	0.1UF - 16V X7R	
C215	5-00601	0.1UF - 16V X7R	
C216	5-00601	0.1UF - 16V X7R	
C218	5-00601	0.1UF - 16V X7R	
C302	5-00601	0.1UF - 16V X7R	
C303	5-00601	0.1UF - 16V X7R	

C304	5-00601	0.1UF - 16V X7R	
C305	5-00601	0.1UF - 16V X7R	
C306	5-00601	0.1UF - 16V X7R	
C307	5-00601	0.1UF - 16V X7R	
C308	5-00601	0.1UF - 16V X7R	
C309	5-00601	0.1UF - 16V X7R	
C310	5-00601	0.1UF - 16V X7R	
C401	5-00601	0.1UF - 16V X7R	
C402	5-00601	0.1UF - 16V X7R	
C403	5-00601	0.1UF - 16V X7R	
C404	5-00601	0.1UF - 16V X7R	
C405	5-00601	0.1UF - 16V X7R	
C406	5-00601	0.1UF - 16V X7R	
C407	5-00601	0.1UF - 16V X7R	
C408	5-00601	0.1UF - 16V X7R	
C441	5-00604	0.01UF / 16V	
C442	5-00604	0.01UF / 16V	
C443	5-00604	0.01UF / 16V	
C444	5-00604	0.01UF / 16V	
C445	5-00604	0.01UF / 16V	
C446	5-00604	0.01UF / 16V	
C447	5-00604	0.01UF / 16V	
C448	5-00604	0.01UF / 16V	
C449	5-00471	10U/T16	SMD TANTALUM, C-Case
C450	5-00601	0.1UF - 16V X7R	
C451	5-00604	0.01UF / 16V	
C452	5-00604	0.01UF / 16V	
C453	5-00604	0.01UF / 16V	
C454	5-00604	0.01UF / 16V	
C455	5-00604	0.01UF / 16V	
C456	5-00471	10U/T16	SMD TANTALUM, C-Case
C457	5-00601	0.1UF - 16V X7R	
C458	5-00471	10U/T16	SMD TANTALUM, C-Case
C459	5-00601	0.1UF - 16V X7R	
C460	5-00604	0.01UF / 16V	
C461	5-00601	0.1UF - 16V X7R	
C462	5-00369	33P	Capacitor, Mono, 50V, 5%, NPO, 1206
C463	5-00369	33P	Capacitor, Mono, 50V, 5%, NPO, 1206
C464	5-00604	0.01UF / 16V	
C465	5-00601	0.1UF - 16V X7R	
C466	5-00601	0.1UF - 16V X7R	
C471	5-00601	0.1UF - 16V X7R	
C472	5-00601	0.1UF - 16V X7R	
C473	5-00601	0.1UF - 16V X7R	
C521	5-00601	0.1UF - 16V X7R	
C522	5-00601	0.1UF - 16V X7R	
C523	5-00601	0.1UF - 16V X7R	
C524	5-00601	0.1UF - 16V X7R	
C531	5-00601	0.1UF - 16V X7R	
C532	5-00601	0.1UF - 16V X7R	
C533	5-00601	0.1UF - 16V X7R	
C534	5-00601	0.1UF - 16V X7R	
C541	5-00601	0.1UF - 16V X7R	
C542	5-00601	0.1UF - 16V X7R	
C543	5-00601	0.1UF - 16V X7R	
C544	5-00601	0.1UF - 16V X7R	
C601	5-00601	0.1UF - 16V X7R	
C602	5-00601	0.1UF - 16V X7R	
C603	5-00601	0.1UF - 16V X7R	
C604	5-00601	0.1UF - 16V X7R	
C605	5-00366	18P	Capacitor, Mono, 50V, 5%, NPO, 1206
C606	5-00366	18P	Capacitor, Mono, 50V, 5%, NPO, 1206
C621	5-00601	0.1UF - 16V X7R	
C631	5-00299	.1U	Capacitor, Mono, 50V, 10%, X7R, 1206

C632	5-00371	47P	Capacitor, Mono, 50V, 5%, NPO, 1206
C633	5-00371	47P	Capacitor, Mono, 50V, 5%, NPO, 1206
C641	5-00031	220U	Capacitor, Electrolytic, 16V, 20%, Rad
C642	5-00299	.1U	Capacitor, Mono, 50V, 10%, X7R, 1206
C643	5-00031	220U	Capacitor, Electrolytic, 16V, 20%, Rad
C644	5-00299	.1U	Capacitor, Mono, 50V, 10%, X7R, 1206
C645	5-00371	47P	Capacitor, Mono, 50V, 5%, NPO, 1206
C646	5-00371	47P	Capacitor, Mono, 50V, 5%, NPO, 1206
C647	5-00371	47P	Capacitor, Mono, 50V, 5%, NPO, 1206
C648	5-00371	47P	Capacitor, Mono, 50V, 5%, NPO, 1206
D301	3-00575	GREEN MINI	LED, Subminiature, 1.8mm (T-3/4)
D302	3-00575	GREEN MINI	LED, Subminiature, 1.8mm (T-3/4)
D303	3-00575	GREEN MINI	LED, Subminiature, 1.8mm (T-3/4)
D304	3-00575	GREEN MINI	LED, Subminiature, 1.8mm (T-3/4)
D305	3-00575	GREEN MINI	LED, Subminiature, 1.8mm (T-3/4)
D306	3-00575	GREEN MINI	LED, Subminiature, 1.8mm (T-3/4)
D307	3-00575	GREEN MINI	LED, Subminiature, 1.8mm (T-3/4)
D308	3-00575	GREEN MINI	LED, Subminiature, 1.8mm (T-3/4)
D441	3-00575	GREEN MINI	LED, Subminiature, 1.8mm (T-3/4)
D603	3-00010	GREEN	LED, T1 Package, 3mm diameter
D645	3-01342	STZ5.6NT146	
D646	3-01342	STZ5.6NT146	
J101	1-01178	26 PIN	
J201	1-00006	2 PIN DI	Header, SIM
J202	1-01290	40 PIN	
J440	1-01075	J1012F21C	
J470	1-00251	10 PIN DIL	Header, DIM, Locking Clips
J630	1-00350	4 PIN, USB	
J640	1-01180	URA-1002	
JD301	1-00236	120 PIN RT ANGL	3 Row, Right Angle Mount
L441	6-00236	FR47	Ferrite Bead, SMD, Type 43/44, 1812
L442	6-00236	FR47	Ferrite Bead, SMD, Type 43/44, 1812
L631	6-00236	FR47	Ferrite Bead, SMD, Type 43/44, 1812
L641	6-00236	FR47	Ferrite Bead, SMD, Type 43/44, 1812
L642	6-00236	FR47	Ferrite Bead, SMD, Type 43/44, 1812
L643	6-00236	FR47	Ferrite Bead, SMD, Type 43/44, 1812
L644	6-00236	FR47	Ferrite Bead, SMD, Type 43/44, 1812
PC1	7-02143	PTC100 CPU PCB	
R102	4-01722	47K / 0603 SMT	
R103	4-01724	10K - SMT/0603	
R104	4-01439	22	Resistor, Thick Film, 5%, 200 ppm, SMT
R105	4-01725	4.7K - SMT/0603	
R106	4-01439	22	Resistor, Thick Film, 5%, 200 ppm, SMT
R107	4-01431	10	Resistor, Thick Film, 5%, 200 ppm, SMT
R201	4-01725	4.7K - SMT/0603	
R202	4-01725	4.7K - SMT/0603	
R301	4-01725	4.7K - SMT/0603	
R441	4-01725	4.7K - SMT/0603	
R442	4-01242	20.0K	Resistor, Thin Film, 1%, 50 ppm, MELF
R443	4-01155	2.49K	Resistor, Thin Film, 1%, 50 ppm, MELF
R444	4-01251	24.9K	Resistor, Thin Film, 1%, 50 ppm, MELF
R446	4-01725	4.7K - SMT/0603	
R447	4-01726	49.9 - SMT/0603	
R448	4-01726	49.9 - SMT/0603	
R449	4-01726	49.9 - SMT/0603	
R450	4-01726	49.9 - SMT/0603	
R543	4-01725	4.7K - SMT/0603	
R603	4-01467	330	Resistor, Thick Film, 5%, 200 ppm, SMT
R631	4-01551	1.0M	Resistor, Thick Film, 5%, 200 ppm, SMT
R633	4-01551	1.0M	Resistor, Thick Film, 5%, 200 ppm, SMT
R634	4-01406	0	Resistor, Thick Film, 5%, 300 ppm, SMT
R642	4-01406	0	Resistor, Thick Film, 5%, 300 ppm, SMT
R643	4-01406	0	Resistor, Thick Film, 5%, 300 ppm, SMT
RN101	4-00911	4.7KX4D	Network, DIP, Isolated, 1/16W, 5%, Tiny

RN102	4-00911	4.7KX4D	Network, DIP, Isolated, 1/16W, 5%, Tiny
RN103	4-01727	22X4	
RN104	4-01727	22X4	
RN105	4-01727	22X4	
RN106	4-00911	4.7KX4D	Network, DIP, Isolated, 1/16W, 5%, Tiny
RN107	4-00911	4.7KX4D	Network, DIP, Isolated, 1/16W, 5%, Tiny
RN108	4-00911	4.7KX4D	Network, DIP, Isolated, 1/16W, 5%, Tiny
RN301	4-00911	4.7KX4D	Network, DIP, Isolated, 1/16W, 5%, Tiny
RN302	4-00910	1.0KX4D	Network, DIP, Isolated, 1/16W, 5%, Tiny
RN303	4-00910	1.0KX4D	Network, DIP, Isolated, 1/16W, 5%, Tiny
RN401	4-00905	82X4D	Network, DIP, Isolated, 1/16W, 5%, Tiny
RN402	4-00905	82X4D	Network, DIP, Isolated, 1/16W, 5%, Tiny
RN403	4-00905	82X4D	Network, DIP, Isolated, 1/16W, 5%, Tiny
RN404	4-00905	82X4D	Network, DIP, Isolated, 1/16W, 5%, Tiny
RN405	4-00905	82X4D	Network, DIP, Isolated, 1/16W, 5%, Tiny
RN406	4-00905	82X4D	Network, DIP, Isolated, 1/16W, 5%, Tiny
RN441	4-00911	4.7KX4D	Network, DIP, Isolated, 1/16W, 5%, Tiny
RN442	4-00911	4.7KX4D	Network, DIP, Isolated, 1/16W, 5%, Tiny
RN443	4-00910	1.0KX4D	Network, DIP, Isolated, 1/16W, 5%, Tiny
RN601	4-00912	10KX4D	Network, DIP, Isolated, 1/16W, 5%, Tiny
RN602	4-00912	10KX4D	Network, DIP, Isolated, 1/16W, 5%, Tiny
RN632	4-01727	22X4	
RN641	4-01727	22X4	
S101	2-00053	B3F-1052	Push button switch (order key cap separately, eg 0-996)
U101	3-01229	MAX6365LKA31	
U102	3-01230	MCF5307AI90B	
U201	3-01231	MT48LC4M32B2TG7	
U202	3-01232	SST39VF3201-70	
U204	3-01837	CY62146EV30LL-	
U206	3-01233	DS1672S-33	
U302	3-01235	74LCX04M	
U303	3-01236	74LCX16245MTD	
U304	3-01236	74LCX16245MTD	
U401	3-01237	S1D13706F00A100	
U440	3-01240	AX88796L	
U470	3-01743	ISPGAL22V10AV	
U520	3-01241	74VCX16245MTD	
U530	3-01241	74VCX16245MTD	
U540	3-01241	74VCX16245MTD	
U600	3-01835	ISP1161A1BM	
U610	3-00663	74HC08	74HC08, Quad 2-Input AND Gate
U620	3-01836	TPS2042BD	
Y101	6-00662	45MHZ - SMT	
Y201	6-00762	32.768KHZ - 6PF	
Y440	6-00664	25MHZ	
Y601	6-00772	6MHZ	
Z0	0-00187	4-40X1/4PP	
Z1	7-01773	BRACKET PTC10	Non-GPIB version

Backplane

C111	5-00601	0.1UF - 16V X7R	
C121	5-00601	0.1UF - 16V X7R	
C131	5-00601	0.1UF - 16V X7R	
C141	5-00601	0.1UF - 16V X7R	
C142	5-00601	0.1UF - 16V X7R	
C143	5-00601	0.1UF - 16V X7R	
C144	5-00601	0.1UF - 16V X7R	
C150	5-00601	0.1UF - 16V X7R	
C160	5-00299	.1U	Capacitor, Mono, 50V, 10%, X7R, 1206
C161	5-00393	3300P	Capacitor, Mono, 50V, 5%, NPO, 1206
C201	5-00601	0.1UF - 16V X7R	
C202	5-00601	0.1UF - 16V X7R	

C211	5-00375	100P	Capacitor, Mono, 50V, 5%, NPO, 1206
C212	5-00472	4.7U/T35	SMD TANTALUM, D-Case
C213	5-00395	4700P -5%	Capacitor, Mono, 50V, 5%, X7R, 1206
C214	5-00299	.1U	Capacitor, Mono, 50V, 10%, X7R, 1206
C215	5-00299	.1U	Capacitor, Mono, 50V, 10%, X7R, 1206
C216	5-00329	120U	Capacitor, Electrolytic, 35V, 20%, Rad
C217	5-00384	560P	Capacitor, Mono, 50V, 5%, NPO, 1206
C218	5-00318	2.2U/T35	SMD TANTALUM, C-Case
C221	5-00318	2.2U/T35	SMD TANTALUM, C-Case
C223	5-00318	2.2U/T35	SMD TANTALUM, C-Case
C224	5-00318	2.2U/T35	SMD TANTALUM, C-Case
C227	5-00041	220U	Capacitor, Electrolytic, 50V, 20%, Rad
C228	5-00041	220U	Capacitor, Electrolytic, 50V, 20%, Rad
C229	5-00041	220U	Capacitor, Electrolytic, 50V, 20%, Rad
C241	5-00375	100P	Capacitor, Mono, 50V, 5%, NPO, 1206
C242	5-00628	22U - 35V	
C244	5-00399	.01U - 5%	Capacitor, Mono, 50V, 5%, X7R, 1206
C245	5-00640	100U - 10V	
C246	5-00640	100U - 10V	
C251	5-00375	100P	Capacitor, Mono, 50V, 5%, NPO, 1206
C252	5-00628	22U - 35V	
C253	5-00628	22U - 35V	
C254	5-00399	.01U - 5%	Capacitor, Mono, 50V, 5%, X7R, 1206
C255	5-00640	100U - 10V	
C256	5-00640	100U - 10V	
D161	3-00204	1N5230	1N5230, 4.7V, 500mW DO-35 ZENER DIODE
D211	3-00380	1N5248	1N5248, 18V, 500mW, DO-35 ZENER DIODE
D221	3-00479	MUR410	MUR410, 100V, 4A ULTRA FAST DIODE
D222	3-00479	MUR410	MUR410, 100V, 4A ULTRA FAST DIODE
D223	3-00479	MUR410	MUR410, 100V, 4A ULTRA FAST DIODE
D224	3-00479	MUR410	MUR410, 100V, 4A ULTRA FAST DIODE
D225	3-00479	MUR410	MUR410, 100V, 4A ULTRA FAST DIODE
D226	3-00479	MUR410	MUR410, 100V, 4A ULTRA FAST DIODE
D227	3-00479	MUR410	MUR410, 100V, 4A ULTRA FAST DIODE
D228	3-00479	MUR410	MUR410, 100V, 4A ULTRA FAST DIODE
D231	3-00012	GREEN	LED, Rectangular, 0.1÷ x 0.3÷
D232	3-00012	GREEN	LED, Rectangular, 0.1÷ x 0.3÷
D233	3-00012	GREEN	LED, Rectangular, 0.1÷ x 0.3÷
D234	3-00012	GREEN	LED, Rectangular, 0.1÷ x 0.3÷
D235	3-00012	GREEN	LED, Rectangular, 0.1÷ x 0.3÷
D236	3-00012	GREEN	LED, Rectangular, 0.1÷ x 0.3÷
D241	3-01859	B540C-13-F	
D251	3-01859	B540C-13-F	
J100	1-01181	431602103	
J106	1-00166	60 PIN DIL	Header, DIM, Latching Clips
J150	1-00251	10 PIN DIL	Header, DIM, Locking Clips
J160	1-00086	3 PIN SI	Header, SIM
J201	1-00111	6 PIN WHITE	Header, SIM, Polarized
J205	1-00260	4 PIN, WHITE	Header, SIM, Polarized
J206	1-00250	2 PIN, WHITE	Header, SIM, Polarized
J207	1-00471	4 PIN, WHITE	Header, SIM, Polarized
J208	1-00471	4 PIN, WHITE	Header, SIM, Polarized
J209	1-00250	2 PIN, WHITE	Header, SIM, Polarized
J211	1-00006	2 PIN DI	Header, SIM
J241	1-00006	2 PIN DI	Header, SIM
J251	1-00006	2 PIN DI	Header, SIM
JD100	1-00235	96 PIN VERTICAL	3 Row, Vertical
JD101	1-00235	96 PIN VERTICAL	3 Row, Vertical
JD102	1-00235	96 PIN VERTICAL	3 Row, Vertical
JD103	1-00235	96 PIN VERTICAL	3 Row, Vertical
JD104	1-00235	96 PIN VERTICAL	3 Row, Vertical
JD105	1-00235	96 PIN VERTICAL	3 Row, Vertical
JD107	1-00237	120 PIN VERTICA	3 Row, Vertical Mount
L241	6-00691	22UH - SMT	

L251	6-00691	22UH - SMT	
PC1	7-02178	CTC100 BACKPLAN	
Q211	3-00283	IRF530/IRF532	100V,14A, N Channel MOSFET, R(DS)on = 0.140 ohms
Q212	3-00283	IRF530/IRF532	100V,14A, N Channel MOSFET, R(DS)on = 0.140 ohms
R121	4-01439	22	Resistor, Thick Film, 5%, 200 ppm, SMT
R160	4-00082	470K	Resistor, Carbon Film, 1/4W, 5%
R161	4-00082	470K	Resistor, Carbon Film, 1/4W, 5%
R162	4-01510	20K	Resistor, Thick Film, 5%, 200 ppm, SMT
R163	4-01503	10K	Resistor, Thick Film, 5%, 200 ppm, SMT
R164	4-01459	150	Resistor, Thick Film, 5%, 200 ppm, SMT
R165	4-01510	20K	Resistor, Thick Film, 5%, 200 ppm, SMT
R166	4-01448	51	Resistor, Thick Film, 5%, 200 ppm, SMT
R201	4-01439	22	Resistor, Thick Film, 5%, 200 ppm, SMT
R202	4-01406	0	Resistor, Thick Film, 5%, 300 ppm, SMT
R203	4-01406	0	Resistor, Thick Film, 5%, 300 ppm, SMT
R204	4-01406	0	Resistor, Thick Film, 5%, 300 ppm, SMT
R205	4-01406	0	Resistor, Thick Film, 5%, 300 ppm, SMT
R206	4-01406	0	Resistor, Thick Film, 5%, 300 ppm, SMT
R207	4-01406	0	Resistor, Thick Film, 5%, 300 ppm, SMT
R211	4-01479	1.0K	Resistor, Thick Film, 5%, 200 ppm, SMT
R212	4-01158	2.67K	Resistor, Thin Film, 1%, 50 ppm, MELF
R213	4-01455	100	Resistor, Thick Film, 5%, 200 ppm, SMT
R214	4-01455	100	Resistor, Thick Film, 5%, 200 ppm, SMT
R215	4-01021	100	Resistor, Thin Film, 1%, 50 ppm, MELF
R216	4-01021	100	Resistor, Thin Film, 1%, 50 ppm, MELF
R217	4-01001	61.9	Resistor, Thin Film, 1%, 50 ppm, MELF
R218	4-00436	0.1	Resistor, Wire-wound
R231	4-01458	130	Resistor, Thick Film, 5%, 200 ppm, SMT
R232	4-01466	300	Resistor, Thick Film, 5%, 200 ppm, SMT
R233	4-01472	510	Resistor, Thick Film, 5%, 200 ppm, SMT
R234	4-00029	1.8K	Resistor, Carbon Film, 1/4W, 5%
R235	4-00029	1.8K	Resistor, Carbon Film, 1/4W, 5%
R236	4-00048	2.2K	Resistor, Carbon Film, 1/4W, 5%
R241	4-01479	1.0K	Resistor, Thick Film, 5%, 200 ppm, SMT
R251	4-01479	1.0K	Resistor, Thick Film, 5%, 200 ppm, SMT
RN111	4-01727	22X4	
RN112	4-01727	22X4	
RN131	4-01727	22X4	
RN132	4-01727	22X4	
RN143	4-00905	82X4D	Network, DIP, Isolated, 1/16W, 5%, Tiny
RN144	4-00905	82X4D	Network, DIP, Isolated, 1/16W, 5%, Tiny
RN145	4-00905	82X4D	Network, DIP, Isolated, 1/16W, 5%, Tiny
RN146	4-00905	82X4D	Network, DIP, Isolated, 1/16W, 5%, Tiny
T211	6-00774	PTC220	
U110	3-01345	74ABT541CSC	
U120	3-01346	74HC4040M	
U130	3-00795	74AC138	74AC138, 3-to-8 Line Decoder
U140	3-01498	74ABT16245CMTD	
U150	3-01239	MAX3233ECWP	
U160	3-00094	LM311	LM311 Voltage Comparator
U201	3-00742	74HC74	74HC74, Dual D-Type Flip-Flop With Clear and Preset, SO-14
U202	3-00782	74HC02	74HC02, Quad 2-Input NOR Gate
U210	3-00919	3525A	3525A, POWER SUPPLY CONTROLLER
U240	3-01347	LM2670S-3.3	
U250	3-01348	LM2670S-5	
Y110	6-00692	16MHZ - SMT	
Z0	1-00470	4 PIN, 24AWG/WH	Non board mount, Female, 24 AWG
Z1	1-00087	2 PIN JUMPER	2 PIN JUMPER ON J160 & J203
Z2	1-00254	2 PIN, 22AWG/RD	Non board mount, Female, Seperate wire, 22 AWG
Z3	1-00259	4 PIN, 18AWG/OR	Non board mount, Female, Seperate wire, 18 AWG
Z4	0-00043	4-40 KEP	
Z5	0-00129	5 #24	
Z6	0-00187	4-40X1/4PP	
Z7	0-00390	1-72X1/4	TO HOLD CNCTRS. DOWN

Z8	0-00391	1-72X5/32X3/64	TO HOLD CNCTRS. DOWN
Z9	0-01015	11RED #18	
Z10	0-01016	11 BLK #18	
Z11	0-01093	563002B00000	

Front panel

C101	5-00601	0.1UF - 16V X7R	
C102	5-00601	0.1UF - 16V X7R	
C103	5-00601	0.1UF - 16V X7R	
C105	5-00601	0.1UF - 16V X7R	
C106	5-00601	0.1UF - 16V X7R	
C107	5-00601	0.1UF - 16V X7R	
C108	5-00601	0.1UF - 16V X7R	
C201	5-00601	0.1UF - 16V X7R	
C202	5-00601	0.1UF - 16V X7R	
C203	5-00601	0.1UF - 16V X7R	
C205	5-00601	0.1UF - 16V X7R	
C211	5-00604	0.01UF / 16V	
C212	5-00604	0.01UF / 16V	
C213	5-00604	0.01UF / 16V	
C214	5-00604	0.01UF / 16V	
C301	5-00519	.33U/T35	SMD TANTALUM, Y-Case
C302	5-00513	1U-16V A-CASE	SMT Tantalum, 16V, A-case (1206, but NEEDS POLARITY mark)
C303	5-00513	1U-16V A-CASE	SMT Tantalum, 16V, A-case (1206, but NEEDS POLARITY mark)
C304	5-00389	1500P	Capacitor, Mono, 50V, 5%, NPO, 1206
C331	5-00407	.047U	Capacitor, Mono, 50V, 10%, X7R, 1206
C360	5-00519	.33U/T35	SMD TANTALUM, Y-Case
C361	5-00519	.33U/T35	SMD TANTALUM, Y-Case
C362	5-00519	.33U/T35	SMD TANTALUM, Y-Case
C370	5-00601	0.1UF - 16V X7R	
D101	3-00576	RED MINI	LED, Subminiature, 1.8mm (T 3/4)
D201	3-00010	GREEN	LED, T1 Package, 3mm diameter
D202	3-00010	GREEN	LED, T1 Package, 3mm diameter
D203	3-00010	GREEN	LED, T1 Package, 3mm diameter
D204	3-00010	GREEN	LED, T1 Package, 3mm diameter
D205	3-00009	YELLOW	LED, T1 Package, 3mm diameter
D206	3-00011	RED	LED, T1 Package, 3mm diameter
D341	3-01253	B270-13	
ISO350	3-01414	MOC213-M	MOC213, Transistor Output Optocoupler, CTR = 100% min, SO-8
J106	1-01253	60 PIN DIL	
J201	1-00559	1.00MM FFC -SMT	
J301	1-00473	2 PIN, WHITE	Header, SIM, Polarized
J341	1-00045	3 PIN STRAIGHT	Header, SIM, w/ Friction Lock
J360	1-01250	SM06B-SHLS-TF	
J370	1-01251	XF2M-3315-1A	
PC1	7-02183	CTC100 F/P PCB	
Q342	3-01989	IRFR3410	
Q360	3-01989	IRFR3410	
Q361	3-01989	IRFR3410	
Q362	3-01989	IRFR3410	
R104	4-01466	300	Resistor, Thick Film, 5%, 200 ppm, SMT
R105	4-01519	47K	Resistor, Thick Film, 5%, 200 ppm, SMT
R201	4-01519	47K	Resistor, Thick Film, 5%, 200 ppm, SMT
R202	4-01431	10	Resistor, Thick Film, 5%, 200 ppm, SMT
R301	4-01510	20K	Resistor, Thick Film, 5%, 200 ppm, SMT
R302	4-01514	30K	Resistor, Thick Film, 5%, 200 ppm, SMT
R331	4-01479	1.0K	Resistor, Thick Film, 5%, 200 ppm, SMT
R360	4-00954	20	Resistor, Thin Film, 1%, 50 ppm, MELF
R361	4-00954	20	Resistor, Thin Film, 1%, 50 ppm, MELF
R362	4-00954	20	Resistor, Thin Film, 1%, 50 ppm, MELF
R363	4-01423	4.7	Resistor, Thick Film, 5%, 300 ppm, SMT
R364	4-01423	4.7	Resistor, Thick Film, 5%, 300 ppm, SMT

R365	4-01423	4.7	Resistor, Thick Film, 5%, 300 ppm, SMT
R371	4-01495	4.7K	Resistor, Thick Film, 5%, 200 ppm, SMT
R374	4-01495	4.7K	Resistor, Thick Film, 5%, 200 ppm, SMT
RN101	4-00911	4.7KX4D	Network, DIP, Isolated, 1/16W, 5%, Tiny
RN102	4-00905	82X4D	Network, DIP, Isolated, 1/16W, 5%, Tiny
RN103	4-00905	82X4D	Network, DIP, Isolated, 1/16W, 5%, Tiny
RN104	4-00905	82X4D	Network, DIP, Isolated, 1/16W, 5%, Tiny
RN105	4-01707	47KX4D	
RN202	4-01707	47KX4D	
RN204	4-00908	270X4D	Network, DIP, Isolated, 1/16W, 5%, Tiny
RN205	4-00908	270X4D	Network, DIP, Isolated, 1/16W, 5%, Tiny
S201	2-00065	12MM TACT SWITC	
S202	2-00065	12MM TACT SWITC	
S203	2-00065	12MM TACT SWITC	
S204	2-00065	12MM TACT SWITC	
S205	2-00065	12MM TACT SWITC	
S206	2-00065	12MM TACT SWITC	
U101	3-01497	ATMEGA162-16AI	
U102	3-01498	74ABT16245CMTD	
U201	3-01215	MAX1234EGI	
U202	3-00741	74HC04	74HC04, Hex Inverter
U203	3-01216	HEF4794BTD	
U301	3-00939	LM4882M	LM4882M, AUDIO POWER AMP
U360	3-01977	LM317MABDTG	
U361	3-01977	LM317MABDTG	
U362	3-01977	LM317MABDTG	
U370	3-01235	74LCX04M	
Z0	7-02036	BLK CAP	
Z1	7-02037	RED CAP	
Z2	1-01252	050R33-075B	

GPIB option

C111	5-00601	0.1UF - 16V X7R	
C112	5-00601	0.1UF - 16V X7R	
C113	5-00601	0.1UF - 16V X7R	
C114	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	
C131	5-00601	0.1UF - 16V X7R	
C132	5-00601	0.1UF - 16V X7R	
C133	5-00601	0.1UF - 16V X7R	
C134	5-00601	0.1UF - 16V X7R	
C135	5-00601	0.1UF - 16V X7R	
C136	5-00601	0.1UF - 16V X7R	
C137	5-00601	0.1UF - 16V X7R	
C138	5-00601	0.1UF - 16V X7R	
C139	5-00601	0.1UF - 16V X7R	
C140	5-00601	0.1UF - 16V X7R	
C150	5-00601	0.1UF - 16V X7R	
C161	5-00601	0.1UF - 16V X7R	
C162	5-00601	0.1UF - 16V X7R	
C163	5-00601	0.1UF - 16V X7R	
J140	1-00160	IEEE488/STAND.	Connector, IEEE488, Standard, R/A, Female
J160	1-00251	10 PIN DIL	Header, DIM, Locking Clips
J202	1-01291	40 PIN	
PC1	7-01892	PTC240, GPIB	
R131	4-01406	0	Resistor, Thick Film, 5%, 300 ppm, SMT
U110	3-01236	74LCX16245MTD	
U120	3-01236	74LCX16245MTD	
U130	3-01019	TNT4882-BQ	GPIB

U140	3-01742	74VCX245WM	
U150	3-00741	74HC04	74HC04, Hex Inverter
U160	3-01743	ISPGAL22V10AV	
Y101	6-00756	40 MHZ	
Z0	0-00500	554043-1	
Z1	7-01736	PTC BRKT	

2-channel thermistor/RTD/diode reader

Z0	0-00079	4-40X3/16 M/F	
Z1	0-00089	4	
J300	1-00071	8 PIN, WHITE	Header, SIM, Polarized
JDR121	1-00234	96 PIN RT ANGLE	3 Row, Right Angle Mount
J200	1-00281	10 PIN DI	Header, DIM
J500	1-00281	10 PIN DI	Header, DIM
Z2	1-00468	8 PIN, 24AWG/WH	Non board mount, Female, 24 AWG
Z3	1-01067	9 PIN	
Z4	1-01068	9 PIN	
J260	1-01331	1201-066	
D111	3-00011	RED	LED, T1 Package, 3mm diameter
D351	3-00489	1N5232	1N5232, 5.6V, 500 mW, DO-35 ZENER DIODE
U610	3-00542	AD587JR	High precision 10 volt reference
U140	3-00656	LM34DM	LM34DM, TEMP SENSOR
U300	3-00663	74HC08	74HC08, Quad 2-Input AND Gate
U302	3-00743	74HC138D	74HC138, 3-to-8 line decoder/demultiplexer; inverting
U340	3-00787	74HC595	74HC595, 8 Bit Serial Input, Parallel Output Shift Register
U341	3-00787	74HC595	74HC595, 8 Bit Serial Input, Parallel Output Shift Register
U342	3-00787	74HC595	74HC595, 8 Bit Serial Input, Parallel Output Shift Register
U345	3-00787	74HC595	74HC595, 8 Bit Serial Input, Parallel Output Shift Register
U350	3-00814	78M05	78M05
U233	3-01133	TL431CD5	TL431C, Adjustable Shunt Voltage Regulator, 100 mA, SOT23-5
U380	3-01133	TL431CD5	TL431C, Adjustable Shunt Voltage Regulator, 100 mA, SOT23-5
U385	3-01133	TL431CD5	TL431C, Adjustable Shunt Voltage Regulator, 100 mA, SOT23-5
U533	3-01133	TL431CD5	TL431C, Adjustable Shunt Voltage Regulator, 100 mA, SOT23-5
U360	3-01175	78M15	
U370	3-01176	79M15	
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	
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	
D205	3-01319	MMBD1503A	
D206	3-01319	MMBD1503A	
D207	3-01319	MMBD1503A	

D208	3-01319	MMBD1503A	
D501	3-01319	MMBD1503A	
D502	3-01319	MMBD1503A	
D503	3-01319	MMBD1503A	
D504	3-01319	MMBD1503A	
D505	3-01319	MMBD1503A	
D506	3-01319	MMBD1503A	
D507	3-01319	MMBD1503A	
D508	3-01319	MMBD1503A	
ISO310	3-01320	HCPL-2630	
ISO311	3-01320	HCPL-2630	
ISO330	3-01320	HCPL-2630	
D641	3-01357	MMBZ5230	4.7V ZENER 5%
D741	3-01357	MMBZ5230	4.7V ZENER 5%
U620	3-01386	DG408DY	Analog mux, 8-to-1, +/-15V okay, TTL compat.
U720	3-01386	DG408DY	Analog mux, 8-to-1, +/-15V okay, TTL compat.
U650	3-01398	OPA2131UJ	FET-input dual opamp, 4 MHz GBW,
U750	3-01398	OPA2131UJ	FET-input dual opamp, 4 MHz GBW,
U270	3-01469	MAX6250BCSA	+5V Reference
U640	3-01469	MAX6250BCSA	+5V Reference
U740	3-01469	MAX6250BCSA	+5V Reference
U120	3-01498	74ABT16245CMTD	
U290	3-01500	LTC2440CGN	
U590	3-01500	LTC2440CGN	
U210	3-01695	MAX4635EUB+	
U250	3-01695	MAX4635EUB+	
U281	3-01695	MAX4635EUB+	
U510	3-01695	MAX4635EUB+	
U550	3-01695	MAX4635EUB+	
U581	3-01695	MAX4635EUB+	
U110	3-01696	ATMEGA64-16AC	
U260	3-01900	LT6012ACS#PBF	Quad unity-stable opamp, rail/rail output
U560	3-01900	LT6012ACS#PBF	Quad unity-stable opamp, rail/rail output
U230	3-01941	MAX339CSE	
U530	3-01941	MAX339CSE	
U630	3-01941	MAX339CSE	
U670	3-01941	MAX339CSE	
U730	3-01941	MAX339CSE	
U770	3-01941	MAX339CSE	
U410	3-01944	74HC238	
U420	3-01944	74HC238	
U660	3-01945	INA121UA	
U760	3-01945	INA121UA	
U280	3-01963	MAX4674ESE+	
U580	3-01963	MAX4674ESE+	
R641	4-00016	10K	Pot, Multi Turn, Side Adjust
R741	4-00016	10K	Pot, Multi Turn, Side Adjust
R633	4-00139	10.0M	Resistor, Metal Film, 1/8W, 1%, 50PPM
R733	4-00139	10.0M	Resistor, Metal Film, 1/8W, 1%, 50PPM
RN292	4-00442	1.2K 1206 MINI	Network, scalloped edge 1206,
RN592	4-00442	1.2K 1206 MINI	Network, scalloped edge 1206,
R432	4-00678	6.040K	Resistor, Metal Film, 1/8W, 0.1%, 5ppm
R440	4-00678	6.040K	Resistor, Metal Film, 1/8W, 0.1%, 5ppm
RN310	4-00909	470X4D	Network, DIP, Isolated, 1/16W, 5%, Tiny
RN312	4-00909	470X4D	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
RN670	4-00910	1.0KX4D	Network, DIP, Isolated, 1/16W, 5%, Tiny
RN770	4-00910	1.0KX4D	Network, DIP, Isolated, 1/16W, 5%, Tiny
RN291	4-00911	4.7KX4D	Network, DIP, Isolated, 1/16W, 5%, Tiny
RN345	4-00911	4.7KX4D	Network, DIP, Isolated, 1/16W, 5%, Tiny
RN591	4-00911	4.7KX4D	Network, DIP, Isolated, 1/16W, 5%, Tiny
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
RN500	4-00916	47X4D	Network, DIP, Isolated, 1/16W, 5%, Tiny
RN501	4-00916	47X4D	Network, DIP, Isolated, 1/16W, 5%, Tiny
RN502	4-00916	47X4D	Network, DIP, Isolated, 1/16W, 5%, Tiny
RN503	4-00916	47X4D	Network, DIP, Isolated, 1/16W, 5%, Tiny
R631	4-01117	1.00K	Resistor, Thin Film, 1%, 50 ppm, MELF
R731	4-01117	1.00K	Resistor, Thin Film, 1%, 50 ppm, MELF
R632	4-01309	100K	Resistor, Thin Film, 1%, 50 ppm, MELF
R732	4-01309	100K	Resistor, Thin Film, 1%, 50 ppm, MELF
R112	4-01466	300	Resistor, Thick Film, 5%, 200 ppm, SMT
RN111	4-01707	47KX4D	
RN112	4-01707	47KX4D	
RN121	4-01707	47KX4D	
R430	4-01733	604	Resistor, Metal Film, 1/8W, 0.1%, 5ppm
R438	4-01733	604	Resistor, Metal Film, 1/8W, 0.1%, 5ppm
R113	4-01869	1.0K	Resistor, Thick Film, 5%, 200 ppm, 1/16W, 0603 Chip
R643	4-01869	1.0K	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
R743	4-01869	1.0K	Resistor, Thick Film, 5%, 200 ppm, 1/16W, 0603 Chip
R751	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
R682	4-01917	100K	Resistor, Thick Film, 5%, 200 ppm, 1/16W, 0603 Chip
R744	4-01917	100K	Resistor, Thick Film, 5%, 200 ppm, 1/16W, 0603 Chip
R782	4-01917	100K	Resistor, Thick Film, 5%, 200 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
R581	4-01948	2.0M	Resistor, Thick Film, 5%, 200 ppm, 1/16W, 0603 Chip
R582	4-01948	2.0M	Resistor, Thick Film, 5%, 200 ppm, 1/16W, 0603 Chip
R617	4-02061	100	Resistor, Thin Film, 1%, 50 ppm, 1/16W 0603 Chip
R652	4-02061	100	Resistor, Thin Film, 1%, 50 ppm, 1/16W 0603 Chip
R717	4-02061	100	Resistor, Thin Film, 1%, 50 ppm, 1/16W 0603 Chip
R752	4-02061	100	Resistor, Thin Film, 1%, 50 ppm, 1/16W 0603 Chip
R616	4-02090	200	Resistor, Thin Film, 1%, 50 ppm, 1/16W 0603 Chip
R618	4-02090	200	Resistor, Thin Film, 1%, 50 ppm, 1/16W 0603 Chip
R716	4-02090	200	Resistor, Thin Film, 1%, 50 ppm, 1/16W 0603 Chip
R718	4-02090	200	Resistor, Thin Film, 1%, 50 ppm, 1/16W 0603 Chip
R383	4-02107	301	Resistor, Thin Film, 1%, 50 ppm, 1/16W 0603 Chip
R385	4-02107	301	Resistor, Thin Film, 1%, 50 ppm, 1/16W 0603 Chip
R615	4-02128	499	Resistor, Thin Film, 1%, 50 ppm, 1/16W 0603 Chip
R715	4-02128	499	Resistor, Thin Film, 1%, 50 ppm, 1/16W 0603 Chip
R613	4-02157	1.00K	Resistor, Thin Film, 1%, 50 ppm, 1/16W 0603 Chip
R614	4-02157	1.00K	Resistor, Thin Film, 1%, 50 ppm, 1/16W 0603 Chip
R713	4-02157	1.00K	Resistor, Thin Film, 1%, 50 ppm, 1/16W 0603 Chip
R714	4-02157	1.00K	Resistor, Thin Film, 1%, 50 ppm, 1/16W 0603 Chip
R612	4-02186	2.00K	Resistor, Thin Film, 1%, 50 ppm, 1/16W 0603 Chip
R712	4-02186	2.00K	Resistor, Thin Film, 1%, 50 ppm, 1/16W 0603 Chip
R233	4-02195	2.49K	Resistor, Thin Film, 1%, 50 ppm, 1/16W 0603 Chip
R533	4-02195	2.49K	Resistor, Thin Film, 1%, 50 ppm, 1/16W 0603 Chip
R381	4-02217	4.22K	Resistor, Thin Film, 1%, 50 ppm, 1/16W 0603 Chip
R386	4-02217	4.22K	Resistor, Thin Film, 1%, 50 ppm, 1/16W 0603 Chip
R382	4-02224	4.99K	Resistor, Thin Film, 1%, 50 ppm, 1/16W 0603 Chip
R387	4-02224	4.99K	Resistor, Thin Film, 1%, 50 ppm, 1/16W 0603 Chip
R611	4-02224	4.99K	Resistor, Thin Film, 1%, 50 ppm, 1/16W 0603 Chip
R711	4-02224	4.99K	Resistor, Thin Film, 1%, 50 ppm, 1/16W 0603 Chip
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
R560	4-02253	10.0K	Resistor, Thin Film, 1%, 50 ppm, 1/16W 0603 Chip
R561	4-02253	10.0K	Resistor, Thin Film, 1%, 50 ppm, 1/16W 0603 Chip
R434	4-02483	60K	
R442	4-02483	60K	
R250	4-02519	MAX5491WC30000	
R251	4-02519	MAX5491WC30000	
R550	4-02519	MAX5491WC30000	

R551	4-02519	MAX5491WC30000	
R436	4-02520	634K / 5PPM	
R444	4-02520	634K / 5PPM	
R642	4-02524	500K / 0.1%	
R742	4-02524	500K / 0.1%	
C352	5-00525	1U	CAP 1UF 25V CERAMIC Y5V 1206 +80/ -20%
C353	5-00525	1U	CAP 1UF 25V CERAMIC Y5V 1206 +80/ -20%
C362	5-00525	1U	CAP 1UF 25V CERAMIC Y5V 1206 +80/ -20%
C363	5-00525	1U	CAP 1UF 25V CERAMIC Y5V 1206 +80/ -20%
C372	5-00525	1U	CAP 1UF 25V CERAMIC Y5V 1206 +80/ -20%
C373	5-00525	1U	CAP 1UF 25V CERAMIC Y5V 1206 +80/ -20%
C612	5-00525	1U	CAP 1UF 25V CERAMIC Y5V 1206 +80/ -20%
C271	5-00526	22U-T16	SMD TANTALUM, C-Case
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	
C210	5-00601	0.1UF - 16V X7R	
C230	5-00601	0.1UF - 16V X7R	
C231	5-00601	0.1UF - 16V X7R	
C250	5-00601	0.1UF - 16V X7R	
C260	5-00601	0.1UF - 16V X7R	
C261	5-00601	0.1UF - 16V X7R	
C270	5-00601	0.1UF - 16V X7R	
C280	5-00601	0.1UF - 16V X7R	
C281	5-00601	0.1UF - 16V X7R	
C300	5-00601	0.1UF - 16V X7R	
C302	5-00601	0.1UF - 16V X7R	
C310	5-00601	0.1UF - 16V X7R	
C311	5-00601	0.1UF - 16V X7R	
C330	5-00601	0.1UF - 16V X7R	
C331	5-00601	0.1UF - 16V X7R	
C332	5-00601	0.1UF - 16V X7R	
C340	5-00601	0.1UF - 16V X7R	
C341	5-00601	0.1UF - 16V X7R	
C342	5-00601	0.1UF - 16V X7R	
C345	5-00601	0.1UF - 16V X7R	
C411	5-00601	0.1UF - 16V X7R	
C421	5-00601	0.1UF - 16V X7R	
C510	5-00601	0.1UF - 16V X7R	
C530	5-00601	0.1UF - 16V X7R	
C531	5-00601	0.1UF - 16V X7R	
C550	5-00601	0.1UF - 16V X7R	
C560	5-00601	0.1UF - 16V X7R	
C561	5-00601	0.1UF - 16V X7R	
C580	5-00601	0.1UF - 16V X7R	
C581	5-00601	0.1UF - 16V X7R	
C611	5-00601	0.1UF - 16V X7R	
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	
C640	5-00601	0.1UF - 16V X7R	
C650	5-00601	0.1UF - 16V X7R	
C651	5-00601	0.1UF - 16V X7R	
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	

C682	5-00601	0.1UF - 16V X7R	
C720	5-00601	0.1UF - 16V X7R	
C721	5-00601	0.1UF - 16V X7R	
C722	5-00601	0.1UF - 16V X7R	
C730	5-00601	0.1UF - 16V X7R	
C731	5-00601	0.1UF - 16V X7R	
C740	5-00601	0.1UF - 16V X7R	
C750	5-00601	0.1UF - 16V X7R	
C751	5-00601	0.1UF - 16V X7R	
C760	5-00601	0.1UF - 16V X7R	
C761	5-00601	0.1UF - 16V X7R	
C770	5-00601	0.1UF - 16V X7R	
C771	5-00601	0.1UF - 16V X7R	
C772	5-00601	0.1UF - 16V X7R	
C782	5-00601	0.1UF - 16V X7R	
C295	5-00654	.01UF X 4	
C595	5-00654	.01UF X 4	
C305	5-00716	100P	Capacitor, Mono, 50V, 0.25pF or 5%, NPO, 0603
C306	5-00716	100P	Capacitor, Mono, 50V, 0.25pF or 5%, NPO, 0603
C307	5-00716	100P	Capacitor, Mono, 50V, 0.25pF or 5%, NPO, 0603
C200	5-00740	1000P	Capacitor, Mono, 50V, 0.25pF or 5%, NPO, 0603
C201	5-00740	1000P	Capacitor, Mono, 50V, 0.25pF or 5%, NPO, 0603
C202	5-00740	1000P	Capacitor, Mono, 50V, 0.25pF or 5%, NPO, 0603
C203	5-00740	1000P	Capacitor, Mono, 50V, 0.25pF or 5%, NPO, 0603
C204	5-00740	1000P	Capacitor, Mono, 50V, 0.25pF or 5%, NPO, 0603
C205	5-00740	1000P	Capacitor, Mono, 50V, 0.25pF or 5%, NPO, 0603
C206	5-00740	1000P	Capacitor, Mono, 50V, 0.25pF or 5%, NPO, 0603
C500	5-00740	1000P	Capacitor, Mono, 50V, 0.25pF or 5%, NPO, 0603
C501	5-00740	1000P	Capacitor, Mono, 50V, 0.25pF or 5%, NPO, 0603
C502	5-00740	1000P	Capacitor, Mono, 50V, 0.25pF or 5%, NPO, 0603
C503	5-00740	1000P	Capacitor, Mono, 50V, 0.25pF or 5%, NPO, 0603
C504	5-00740	1000P	Capacitor, Mono, 50V, 0.25pF or 5%, NPO, 0603
C505	5-00740	1000P	Capacitor, Mono, 50V, 0.25pF or 5%, NPO, 0603
C506	5-00740	1000P	Capacitor, Mono, 50V, 0.25pF or 5%, NPO, 0603
C641	5-00740	1000P	Capacitor, Mono, 50V, 0.25pF or 5%, NPO, 0603
C741	5-00740	1000P	Capacitor, Mono, 50V, 0.25pF or 5%, NPO, 0603
C652	5-00752	10000P	Capacitor, Mono, 50V,+/-10%, X7R, 0603
C752	5-00752	10000P	Capacitor, Mono, 50V,+/-10%, X7R, 0603
C272	5-00841	1UF/16V/ X5R	
C290	5-00841	1UF/16V/ X5R	
C291	5-00841	1UF/16V/ X5R	
C292	5-00841	1UF/16V/ X5R	
C293	5-00841	1UF/16V/ X5R	
C294	5-00841	1UF/16V/ X5R	
C590	5-00841	1UF/16V/ X5R	
C591	5-00841	1UF/16V/ X5R	
C592	5-00841	1UF/16V/ X5R	
C593	5-00841	1UF/16V/ X5R	
C594	5-00841	1UF/16V/ X5R	
C642	5-00841	1UF/16V/ X5R	
C742	5-00841	1UF/16V/ X5R	
L300	6-01030	FT-87-W	
PCB	7-02172	PTC100 PCB	
PCB	7-02172	PTC100 PCB	

100W DC output card

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	
C203	5-00606	1U / 100V	
C204	5-00389	1500P	Capacitor, Mono, 50V, 5%, NPO, 1206
C205	5-00850	0.33U PEN 16V	
C211	5-00607	10U / 50V SMT	
C212	5-00299	.1U	Capacitor, Mono, 50V, 10%, X7R, 1206
C213	5-00840	10 UF / X7S	
C214	5-00840	10 UF / X7S	
C216	5-00525	1U	CAP 1UF 25V CERAMIC Y5V 1206 +80/ -20%
C217	5-00298	.01U	Capacitor, Mono, 50V, 10%, X7R, 1206
C220	5-00299	.1U	Capacitor, Mono, 50V, 10%, X7R, 1206
C222	5-00525	1U	CAP 1UF 25V CERAMIC Y5V 1206 +80/ -20%
C223	5-00525	1U	CAP 1UF 25V CERAMIC Y5V 1206 +80/ -20%
C232	5-00629	1000P X 4	
C233	5-00299	.1U	Capacitor, Mono, 50V, 10%, X7R, 1206
C234	5-00299	.1U	Capacitor, Mono, 50V, 10%, X7R, 1206
C235	5-00299	.1U	Capacitor, Mono, 50V, 10%, X7R, 1206
C240	5-00299	.1U	Capacitor, Mono, 50V, 10%, X7R, 1206
C245	5-00627	0.1U X 4	
C250	5-00299	.1U	Capacitor, Mono, 50V, 10%, X7R, 1206
C251	5-00299	.1U	Capacitor, Mono, 50V, 10%, X7R, 1206
C261	5-00299	.1U	Capacitor, Mono, 50V, 10%, X7R, 1206
C270	5-00299	.1U	Capacitor, Mono, 50V, 10%, X7R, 1206
C271	5-00798	2.2U	
C272	5-00525	1U	CAP 1UF 25V CERAMIC Y5V 1206 +80/ -20%
C273	5-00525	1U	CAP 1UF 25V CERAMIC Y5V 1206 +80/ -20%
C274	5-00654	.01UF X 4	
C275	5-00525	1U	CAP 1UF 25V CERAMIC Y5V 1206 +80/ -20%
C276	5-00525	1U	CAP 1UF 25V CERAMIC Y5V 1206 +80/ -20%
C277	5-00299	.1U	Capacitor, Mono, 50V, 10%, X7R, 1206
C281	5-00299	.1U	Capacitor, Mono, 50V, 10%, X7R, 1206
C290	5-00299	.1U	Capacitor, Mono, 50V, 10%, X7R, 1206
C311	5-00035	47U	Capacitor, Electrolytic, 25V, 20%, Rad
C312	5-00525	1U	CAP 1UF 25V CERAMIC Y5V 1206 +80/ -20%
C313	5-00525	1U	CAP 1UF 25V CERAMIC Y5V 1206 +80/ -20%
C320	5-00525	1U	CAP 1UF 25V CERAMIC Y5V 1206 +80/ -20%
C321	5-00035	47U	Capacitor, Electrolytic, 25V, 20%, Rad
C323	5-00525	1U	CAP 1UF 25V CERAMIC Y5V 1206 +80/ -20%
C331	5-00525	1U	CAP 1UF 25V CERAMIC Y5V 1206 +80/ -20%
C500	5-00299	.1U	Capacitor, Mono, 50V, 10%, X7R, 1206
C501	5-00601	0.1UF - 16V X7R	
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
C550	5-00299	.1U	Capacitor, Mono, 50V, 10%, X7R, 1206
D111	3-00011	RED	LED, T1 Package, 3mm diameter
D211	3-00403	1N459A	1N459A, 175V, 0.5A, LOW LEAKAGE DIODE
D212	3-02066	12CWQ10FNPBF	
D214	3-00626	MUR1100E	MUR1100E, 1000V, 1A ULTRA FAST DIODE
D221	3-00896	BAV99	BAV99, DUAL SERIES DIODE, 70V BREAKDOWN
D251	3-00457	1N5241B	1N5241B, 11V, 500mW, DO-35 ZENER DIODE
D252	3-00457	1N5241B	1N5241B, 11V, 500mW, DO-35 ZENER DIODE
D253	3-00457	1N5241B	1N5241B, 11V, 500mW, DO-35 ZENER DIODE
F221	6-00644	1A 60V	
F222	6-00644	1A 60V	
ISO500	3-00446	6N137	Hi Speed Optocoupler
ISO510	3-01320	HCPL-2630	
ISO511	3-01320	HCPL-2630	
ISO530	3-01320	HCPL-2630	
J111	1-00251	10 PIN DIL	Header, DIM, Locking Clips
JDR121	1-00234	96 PIN RT ANGLE	3 Row, Right Angle Mount
L211	6-01005	22 UH	
L310	6-00684	10UH	Inductor, SMD, Type R, 23MHz, 240mA, 10%, 1210

L311	0-00000	UNDECIDED PART	
L320	6-00684	10UH	Inductor, SMD, Type R, 23MHz, 240mA, 10%, 1210
L321	6-00174	6611 TYPE 43	Ferite Bead, Thru-hole, Type 43
L351	6-00174	6611 TYPE 43	Ferite Bead, Thru-hole, Type 43
PCB1	7-02177	PTC431 2A DC OU	
Q210	3-02065	IRLR3110ZPBF	
Q220	3-01254	BSS123LT1	
Q233	3-01254	BSS123LT1	
Q234	3-01254	BSS123LT1	
Q235	3-01254	BSS123LT1	
Q251	3-02075	IRF6218S	
Q252	3-02075	IRF6218S	
Q253	3-02075	IRF6218S	
Q330	3-02065	IRLR3110ZPBF	
R112	4-01466	300	Resistor, Thick Film, 5%, 200 ppm, SMT
R202	4-01186	5.23K	Resistor, Thin Film, 1%, 50 ppm, MELF
R203	4-01309	100K	Resistor, Thin Film, 1%, 50 ppm, MELF
R206	4-01186	5.23K	Resistor, Thin Film, 1%, 50 ppm, MELF
R207	4-01309	100K	Resistor, Thin Film, 1%, 50 ppm, MELF
R208	4-00436	0.1	Resistor, Wire-wound
R211	4-01157	2.61K	Resistor, Thin Film, 1%, 50 ppm, MELF
R212	4-01292	66.5K	Resistor, Thin Film, 1%, 50 ppm, MELF
R213	4-01130	1.37K	Resistor, Thin Film, 1%, 50 ppm, MELF
R214	4-01029	121	Resistor, Thin Film, 1%, 50 ppm, MELF
R215	4-01285	56.2K	Resistor, Thin Film, 1%, 50 ppm, MELF
R216	4-01096	604	Resistor, Thin Film, 1%, 50 ppm, MELF
R217	4-02546	0.01 ohm	
R222	4-00645	4.7K	Resistor, Thick Film, 1/8W, 5%, 1206
R223	4-00645	4.7K	Resistor, Thick Film, 1/8W, 5%, 1206
R224	4-00645	4.7K	Resistor, Thick Film, 1/8W, 5%, 1206
R225	4-00645	4.7K	Resistor, Thick Film, 1/8W, 5%, 1206
R226	4-01151	2.26K	Resistor, Thin Film, 1%, 50 ppm, MELF
R231	4-01175	4.02K	Resistor, Thin Film, 1%, 50 ppm, MELF
R232	4-01155	2.49K	Resistor, Thin Film, 1%, 50 ppm, MELF
R233	4-01117	1.00K	Resistor, Thin Film, 1%, 50 ppm, MELF
R234	4-01050	200	Resistor, Thin Film, 1%, 50 ppm, MELF
R235	4-01175	4.02K	Resistor, Thin Film, 1%, 50 ppm, MELF
R236	4-01155	2.49K	Resistor, Thin Film, 1%, 50 ppm, MELF
R237	4-01117	1.00K	Resistor, Thin Film, 1%, 50 ppm, MELF
R238	4-01050	200	Resistor, Thin Film, 1%, 50 ppm, MELF
R239	4-01175	4.02K	Resistor, Thin Film, 1%, 50 ppm, MELF
R240	4-01155	2.49K	Resistor, Thin Film, 1%, 50 ppm, MELF
R241	4-01117	1.00K	Resistor, Thin Film, 1%, 50 ppm, MELF
R242	4-01050	200	Resistor, Thin Film, 1%, 50 ppm, MELF
R251	4-02525	0.1 ohm	
R252	4-02526	1 ohm	
R253	4-00925	10	Resistor, Thin Film, 1%, 50 ppm, MELF
R255	4-01050	200	Resistor, Thin Film, 1%, 50 ppm, MELF
R256	4-01050	200	Resistor, Thin Film, 1%, 50 ppm, MELF
R257	4-01050	200	Resistor, Thin Film, 1%, 50 ppm, MELF
R263	4-01404	976K	Resistor, Thin Film, 1%, 50 ppm, MELF
R264	4-01296	73.2K	Resistor, Thin Film, 1%, 50 ppm, MELF
R271	4-01670	20K 1%	Divider, Thin Film, 10.0K x 2, 0.1W, 1%, 2ppm ratio, SOT23
R273	4-01242	20.0K	Resistor, Thin Film, 1%, 50 ppm, MELF
R274	4-01117	1.00K	Resistor, Thin Film, 1%, 50 ppm, MELF
R331	4-02547	120 OHM / 10W	
R332	4-00645	4.7K	Resistor, Thick Film, 1/8W, 5%, 1206
R501	4-01471	470	Resistor, Thick Film, 5%, 200 ppm, SMT
R502	4-01471	470	Resistor, Thick Film, 5%, 200 ppm, SMT
RN111	4-01707	47KX4D	
RN112	4-01707	47KX4D	
RN113	4-00910	1.0KX4D	Network, DIP, Isolated, 1/16W, 5%, Tiny
RN121	4-01707	47KX4D	
RN272	4-01764	10X4D	

RN273	4-00911	4.7KX4D	Network, DIP, Isolated, 1/16W, 5%, Tiny
RN291	4-00912	10KX4D	Network, DIP, Isolated, 1/16W, 5%, Tiny
RN292	4-00911	4.7KX4D	Network, DIP, Isolated, 1/16W, 5%, Tiny
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	
U200	3-00656	LM34DM	LM34DM, TEMP SENSOR
U210	3-02064	LM3478MM/NOPB	
U220	3-00773	LM358	LM358 Dual low power 1 MHz GBW op amp
U221	3-01133	TL431CD5	TL431C, Adjustable Shunt Voltage Regulator, 100 mA, SOT23-5
U233	3-01821	LTC6102HMS	
U234	3-01821	LTC6102HMS	
U235	3-01821	LTC6102HMS	
U240	3-00675	LTC1655	16 bit Rail-Rail DAC
U250	3-01257	LMC6484AIM	
U260	3-01386	DG408DY	Analog mux, 8-to-1, +/-15V okay, TTL compat.
U270	3-01257	LMC6484AIM	
U271	3-01186	MAX6241BCSA	
U280	3-01258	LTC2433-1CMS	
U290	3-01366	DG333ADW	Quad SPDT 175nsec, 25ohms-ONres
U310	3-00814	78M05	78M05,
U320	3-01979	79M05CDT/RK	
U500	3-00663	74HC08	74HC08, Quad 2-Input AND Gate
U540	3-00787	74HC595	74HC595, 8 Bit Serial Input, Parallel Output Shift Register
U550	3-00743	74HC138D	74HC138, 3-to-8 line decoder/demultiplexer; inverting
Z0	0-00772	1.5 WIRE	
Z1	0-01318	7109DG	
Z2	0-01349	8-32 X 5/8 PP	

Analog I/O card

C101	5-00601	0.1UF - 16V X7R	
C102	5-00601	0.1UF - 16V X7R	
C103	5-00601	0.1UF - 16V X7R	
C105	5-00601	0.1UF - 16V X7R	
C106	5-00601	0.1UF - 16V X7R	
C107	5-00601	0.1UF - 16V X7R	
C108	5-00601	0.1UF - 16V X7R	
C201	5-00470	2.2U/T16	SMD TANTALUM, Y-Case
C202	5-00525	1U	CAP 1UF 25V CERAMIC Y5V 1206 +80/ -20%
C203	5-00470	2.2U/T16	SMD TANTALUM, Y-Case
C204	5-00299	.1U	Capacitor, Mono, 50V, 10%, X7R, 1206
C205	5-00471	10U/T16	SMD TANTALUM, C-Case
C206	5-00527	.47U	CAP .47UF 16V CERAMIC X7R 1206
C207	5-00601	0.1UF - 16V X7R	
C208	5-00601	0.1UF - 16V X7R	
C209	5-00527	.47U	CAP .47UF 16V CERAMIC X7R 1206
C210	5-00527	.47U	CAP .47UF 16V CERAMIC X7R 1206
C211	5-00527	.47U	CAP .47UF 16V CERAMIC X7R 1206
C212	5-00601	0.1UF - 16V X7R	
C213	5-00601	0.1UF - 16V X7R	
C214	5-00601	0.1UF - 16V X7R	
C215	5-00601	0.1UF - 16V X7R	
C216	5-00627	0.1U X 4	
C217	5-00601	0.1UF - 16V X7R	
C225	5-00601	0.1UF - 16V X7R	
C226	5-00601	0.1UF - 16V X7R	
C227	5-00381	330P	Capacitor, Mono, 50V, 5%, NPO, 1206
C232	5-00299	.1U	Capacitor, Mono, 50V, 10%, X7R, 1206
C233	5-00471	10U/T16	SMD TANTALUM, C-Case

C302	5-00601	0.1UF - 16V X7R	
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
C331	5-00299	.1U	Capacitor, Mono, 50V, 10%, X7R, 1206
C340	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)
D101	3-00011	RED	LED, T1 Package, 3mm diameter
D201	3-00544	BAV70LT1-ROHS	BAV70LT1
D202	3-00544	BAV70LT1-ROHS	BAV70LT1
D203	3-00544	BAV70LT1-ROHS	BAV70LT1
D204	3-00544	BAV70LT1-ROHS	BAV70LT1
D246	3-01384	MMBZ5232BLT1	5.6V Zener
D301	3-01880	SMBJ12CA	
D302	3-01880	SMBJ12CA	
D303	3-01880	SMBJ12CA	
D304	3-01880	SMBJ12CA	
D341	3-00011	RED	LED, T1 Package, 3mm diameter
D342	3-00011	RED	LED, T1 Package, 3mm diameter
D343	3-00011	RED	LED, T1 Package, 3mm diameter
D344	3-00011	RED	LED, T1 Package, 3mm diameter
F301	6-00773	1206L020	
F302	6-00773	1206L020	
F303	6-00773	1206L020	
F304	6-00773	1206L020	
IS310	3-01320	HCPL-2630	
IS311	3-01320	HCPL-2630	
IS330	3-01320	HCPL-2630	
J101	1-00251	10 PIN DIL	Header, DIM, Locking Clips
J301	1-00233	RT ANGLE	BNC, PCB Panel Mount, Right Angle, Isolated
J302	1-00233	RT ANGLE	BNC, PCB Panel Mount, Right Angle, Isolated
J303	1-00233	RT ANGLE	BNC, PCB Panel Mount, Right Angle, Isolated
J304	1-00233	RT ANGLE	BNC, PCB Panel Mount, Right Angle, Isolated
JD101	1-00234	96 PIN RT ANGLE	3 Row, Right Angle Mount
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
PC1	7-01709	PTC	
R101	4-01466	300	Resistor, Thick Film, 5%, 200 ppm, SMT
R201	4-01230	15.0K	Resistor, Thin Film, 1%, 50 ppm, MELF
R202	4-01213	10.0K	Resistor, Thin Film, 1%, 50 ppm, MELF
R203	4-01213	10.0K	Resistor, Thin Film, 1%, 50 ppm, MELF
R204	4-01155	2.49K	Resistor, Thin Film, 1%, 50 ppm, MELF
R205	4-01213	10.0K	Resistor, Thin Film, 1%, 50 ppm, MELF
R206	4-01155	2.49K	Resistor, Thin Film, 1%, 50 ppm, MELF
R207	4-01213	10.0K	Resistor, Thin Film, 1%, 50 ppm, MELF
R208	4-01155	2.49K	Resistor, Thin Film, 1%, 50 ppm, MELF
R209	4-01213	10.0K	Resistor, Thin Film, 1%, 50 ppm, MELF
R210	4-01155	2.49K	Resistor, Thin Film, 1%, 50 ppm, MELF
R227	4-01163	3.01K	Resistor, Thin Film, 1%, 50 ppm, MELF
R228	4-01117	1.00K	Resistor, Thin Film, 1%, 50 ppm, MELF
R230	4-01139	1.69K	Resistor, Thin Film, 1%, 50 ppm, MELF
R231	4-01110	845	Resistor, Thin Film, 1%, 50 ppm, MELF

R234	4-01156	2.55K	Resistor, Thin Film, 1%, 50 ppm, MELF
RN101	4-01704	100Kx4D 5%	Network, DIP, Isolated, 1/16W, 5%, Tiny
RN102	4-00911	4.7KX4D	Network, DIP, Isolated, 1/16W, 5%, Tiny
RN103	4-00910	1.0KX4D	Network, DIP, Isolated, 1/16W, 5%, Tiny
RN105	4-01707	47KX4D	
RN206	4-00910	1.0KX4D	Network, DIP, Isolated, 1/16W, 5%, Tiny
RN310	4-00909	470X4D	Network, DIP, Isolated, 1/16W, 5%, Tiny
RN312	4-00909	470X4D	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
RN341	4-00908	270X4D	Network, DIP, Isolated, 1/16W, 5%, Tiny
U101	3-01497	ATMEGA162-16AI	
U102	3-01498	74ABT16245CMTD	
U201	3-01469	MAX6250BCSA	+5V Reference
U202	3-01499	DAC8534IPW	
U203	3-01838	MC33079D	
U204	3-01365	DG411DY	Quad SPST 25ohms-ONRes
U205	3-01838	MC33079D	
U206	3-01369	DG409DY	Diff Analog MUX 4-ch
U209	3-01500	LTC2440CGN	
U302	3-00743	74HC138D	74HC138, 3-to-8 line decoder/demultiplexer; inverting
U331	3-00749	74HC541	74HC541, Octal 3-State Buffer / Line Driver/Receiver
U340	3-00787	74HC595	74HC595, 8 Bit Shift Register w Latched 3-state Outputs
U350	3-00814	78M05	78M05
U360	3-01175	78M15	
U370	3-01176	79M15	
Z0	0-00472	1-329631-2	Jam nut for BNC connectors
Z1	0-00306	4-40X3/16PP	
Z1	0-00772	1.5 WIRE	
Z2	0-00306	4-40X3/16PP	
Z2	7-01734	PTC ANALOG.IO BRKT	

Digital I/O card

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	5-00378	180P	Capacitor, Mono, 50V, 5%, NPO, 1206
C201	5-00378	180P	Capacitor, Mono, 50V, 5%, NPO, 1206
C202	5-00378	180P	Capacitor, Mono, 50V, 5%, NPO, 1206
C203	5-00378	180P	Capacitor, Mono, 50V, 5%, NPO, 1206
C204	5-00378	180P	Capacitor, Mono, 50V, 5%, NPO, 1206
C205	5-00378	180P	Capacitor, Mono, 50V, 5%, NPO, 1206
C206	5-00378	180P	Capacitor, Mono, 50V, 5%, NPO, 1206
C207	5-00378	180P	Capacitor, Mono, 50V, 5%, NPO, 1206
C210	5-00299	.1U	Capacitor, Mono, 50V, 10%, X7R, 1206
C220	5-00299	.1U	Capacitor, Mono, 50V, 10%, X7R, 1206
C230	5-00299	.1U	Capacitor, Mono, 50V, 10%, X7R, 1206
C240	5-00299	.1U	Capacitor, Mono, 50V, 10%, X7R, 1206
C250	5-00299	.1U	Capacitor, Mono, 50V, 10%, X7R, 1206
C260	5-00299	.1U	Capacitor, Mono, 50V, 10%, X7R, 1206
C270	5-00299	.1U	Capacitor, Mono, 50V, 10%, X7R, 1206
C310	5-00299	.1U	Capacitor, Mono, 50V, 10%, X7R, 1206
C311	5-00319	10U/T35	SMD TANTALUM, D-Case
C312	5-00387	1000P	Capacitor, Mono, 50V, 5%, NPO, 1206
C313	5-00299	.1U	Capacitor, Mono, 50V, 10%, X7R, 1206
C314	5-00381	330P	Capacitor, Mono, 50V, 5%, NPO, 1206
C316	5-00519	.33U/T35	SMD TANTALUM, Y-Case
C360	5-00513	1U-16V A-CASE	SMT Tantalum, 16V, A-case (1206, but NEEDS POLARITY mark)

C361	5-00519	.33U/T35	SMD TANTALUM, Y-Case
C362	5-00628	22U - 35V	
C364	5-00381	330P	Capacitor, Mono, 50V, 5%, NPO, 1206
C410	5-00299	.1U	Capacitor, Mono, 50V, 10%, X7R, 1206
C420	5-00299	.1U	Capacitor, Mono, 50V, 10%, X7R, 1206
D111	3-00576	RED MINI	LED, Subminiature, 1.8mm (T 3/4)
D200	3-01342	STZ5.6NT146	
D202	3-01342	STZ5.6NT146	
D204	3-01342	STZ5.6NT146	
D206	3-01342	STZ5.6NT146	
D314	3-00380	1N5248	1N5248, 18V, 500mW, DO-35 ZENER DIODE
D315	3-00926	MBR0540T1	MBR0540T1, Power Rectifier
D361	3-00010	GREEN	LED, T1 Package, 3mm diameter
D362	3-01303	B340LA-13-F	
D401	3-00806	BAV170LT1	BAV170LT1, DUAL DIODE COMMON CATHODE
D403	3-00806	BAV170LT1	BAV170LT1, DUAL DIODE COMMON CATHODE
D421	3-00011	RED	LED, T1 Package, 3mm diameter
D422	3-00011	RED	LED, T1 Package, 3mm diameter
D423	3-00011	RED	LED, T1 Package, 3mm diameter
D424	3-00011	RED	LED, T1 Package, 3mm diameter
IS230	3-01320	HCPL-2630	
IS240	3-00446	6N137	Hi Speed Optocoupler
IS250	3-01320	HCPL-2630	
IS260	3-00446	6N137	Hi Speed Optocoupler
J111	1-00251	10 PIN DIL	Header, DIM, Locking Clips
J200	1-00371	25 PIN D RS232	DB Female, Right Angle, .318
J400	1-01090	1615490000	
JD121	1-00234	96 PIN RT ANGLE	3 Row, Right Angle Mount
K401	3-01056	24VDC DPDT	
K402	3-01056	24VDC DPDT	
K403	3-01056	24VDC DPDT	
K404	3-01056	24VDC DPDT	
PC1	7-01710	PTC	
Q411	3-00601	MMBT3904LT1	MMBT3904LT1, 3904 NPN
Q412	3-00601	MMBT3904LT1	MMBT3904LT1, 3904 NPN
Q413	3-00601	MMBT3904LT1	MMBT3904LT1, 3904 NPN
Q414	3-00601	MMBT3904LT1	MMBT3904LT1, 3904 NPN
R112	4-01466	300	Resistor, Thick Film, 5%, 200 ppm, SMT
R311	4-01270	39.2K	Resistor, Thin Film, 1%, 50 ppm, MELF
R312	4-01210	9.31K	Resistor, Thin Film, 1%, 50 ppm, MELF
R313	4-01163	3.01K	Resistor, Thin Film, 1%, 50 ppm, MELF
R314	4-01009	75	Resistor, Thin Film, 1%, 50 ppm, MELF
R361	4-01466	300	Resistor, Thick Film, 5%, 200 ppm, SMT
R362	4-01455	100	Resistor, Thick Film, 5%, 200 ppm, SMT
R412	4-01406	0	Resistor, Thick Film, 5%, 300 ppm, SMT
RN111	4-01707	47KX4D	
RN112	4-00911	4.7KX4D	Network, DIP, Isolated, 1/16W, 5%, Tiny
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	4-01765	0KX4D	
RN231	4-00909	470X4D	Network, DIP, Isolated, 1/16W, 5%, Tiny
RN232	4-00909	470X4D	Network, DIP, Isolated, 1/16W, 5%, Tiny
RN251	4-00909	470X4D	Network, DIP, Isolated, 1/16W, 5%, Tiny
RN252	4-00909	470X4D	Network, DIP, Isolated, 1/16W, 5%, Tiny
RN410	4-01707	47KX4D	
RN411	4-01707	47KX4D	
RN412	4-00911	4.7KX4D	Network, DIP, Isolated, 1/16W, 5%, Tiny
RN421	4-00908	270X4D	Network, DIP, Isolated, 1/16W, 5%, Tiny
T300	6-00683	VP1-0190	
U110	3-01497	ATMEGA162-16AI	
U120	3-01498	74ABT16245CMTD	
U210	3-01343	74HC166D	

U220	3-00787	74HC595	74HC595, 8 Bit Shift Register w Latched 3-state Outputs
U270	3-00749	74HC541	74HC541, Octal 3-State Buffer / Line Driver/Receiver
U310	3-01322	LT1425CS	
U321	3-01460	MC7815ACD2T	7815, 3 Terminal, 15V, 1A Regulator
U360	3-00814	78M05	78M05,
U410	3-01375	74HC86AD	Quad XOR gate
U420	3-00741	74HC04	74HC04, Hex Inverter
Z0	7-01738	PTC DIG.I/O BRK	
Z1	0-00306	4-40X3/16PP	
Z2	0-00306	4-40X3/16PP	
Z3	0-01093	563002B00000	Heat sink
Z4	1-01186	1690520000	Relay connector

Schematics

Circuit board	Page count
PTC211 CPU board	6
PTC222 Backplane	3
PTC232 Front panel	3
PTC240 GPIB card	1
PTC323 2-channel thermistor/diode/RTD reader	6
PTC431 100W DC output card	3
PTC510 Analog IO card	3
PTC520 Digital IO card	4