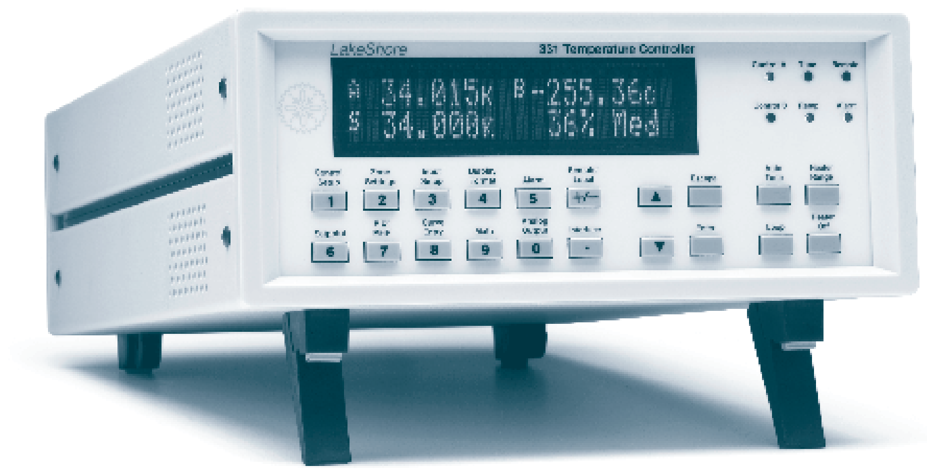
Model 331 Temperature Controller



331S Features

- Operates down to 1.2 K with appropriate sensors
- Two sensor inputs
- Supports diode, RTD, and thermocouple sensors
- Sensor excitation current reversal eliminates thermal EMF errors in resistance sensors
- Two autotuning control loops: 50 W and 1 W
- IEEE-488 and RS-232C interfaces, analog outputs, and alarm relays

331E Features

- Same as 331S, except IEEE-488 interface, relays, analog output, and a second control loop are not included

Product Description

The Model 331 Temperature Controller combines the easy operation and unsurpassed reliability of the Model 330 with improved sensor input and interface flexibility, including compatibility with negative temperature coefficient (NTC) resistance temperature detectors (RTDs). Backed by the Lake Shore tradition of excellence in cryogenic sensors and instrumentation, the Model 331 Temperature Controller sets the standard for mid-price range temperature control instruments.

The Model 331 Temperature Controller is available in two versions. The Model 331S is fully equipped for interface and control flexibility. The Model 331E shares measurement and display capability with the Model 331S, but does not include the IEEE-488 interface, relays, analog voltage output, or a second control loop.

Sensor Inputs

The Model 331 Temperature Controller is designed for high performance over a wide operating temperature range and in difficult sensing conditions. The Model 331 features two inputs, with a high-resolution 24-bit analog-to-digital converter and separate current source for each input. Sensors are optically isolated from other instrument functions for quiet and repeatable sensor measurements. Sensor data from each input can be read up to ten times per second, with display updates twice each second. The Model 331 uses current reversal to eliminate thermal EMF errors in resistance sensors.

Standard temperature response curves for silicon diodes, platinum RTDs, and many thermocouples are included. Up to twenty 200-point CalCurves™ for Lake Shore calibrated sensors or user curves can be loaded into non-volatile memory via a computer interface or the instrument front panel. A built-in SoftCal™[1] algorithm can also be used to generate curves for silicon diodes and platinum RTDs, for storage as user curves.

[1] The Lake Shore SoftCal™ algorithm for silicon diode and platinum RTD sensors is a good solution for applications requiring more accuracy than a standard sensor curve but not in need of traditional calibration. SoftCal uses the predictability of a standard curve to improve the accuracy of an individual sensor around a few known temperature reference points. Both versions of the Model 331 can generate SoftCal curves.

Sensor inputs for both versions of the Model 331 are factory configured and compatible with either diode/RTDs or thermocouple sensors. The purchaser's choice of two diode/RTD inputs, one diode/RTD input and one thermocouple input, or two thermocouple inputs must be specified at time of order and cannot be reconfigured in the field. Software selects appropriate excitation current and signal gain levels when sensor type is entered via the instrument front panel.

Temperature Control

The Model 331E offers one and the Model 331S offers two proportional-integral-derivative (PID) control loops. A PID control algorithm calculates control output based on temperature setpoint and feedback from the control sensor. Wide tuning parameters accommodate most cryogenic cooling systems and many small high-temperature ovens. Control output is generated by a high-resolution digital-to-analog converter for smooth continuous control. The user can set the PID values or the Autotuning feature of the Model 331 can automate the tuning process.

Heater output for Model 331S and Model 331E is a well-regulated variable DC current source. Heater output is optically isolated from other circuits to reduce interference and ground loops. Heater output can provide up to 50 W of continuous power to a resistive heater load, and includes two lower ranges for systems with less cooling power. Heater output is short-circuit protected to prevent instrument damage if the heater load is accidentally shorted.

The setpoint ramp feature allows smooth continuous changes in setpoint and can also make the approach to a setpoint temperature more predictable. The zone feature can automatically change control parameter values for operation over a large temperature range. Values for ten different temperature zones can be loaded into the instrument, which will select the next appropriate value on setpoint change.

Interface

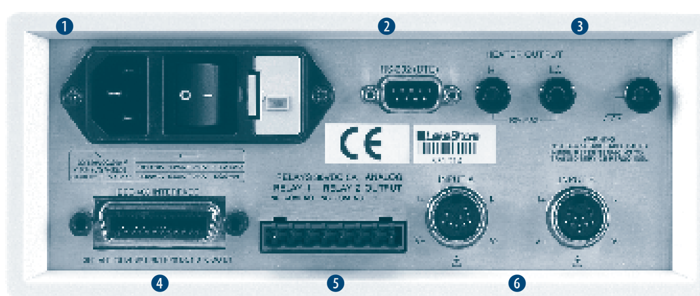
The Model 331 is available with both parallel (IEEE-488, 331S only) and serial (RS-232C) computer interfaces. In addition to data gathering, nearly every function of the instrument can be controlled via computer interface. Also included is a Model 330 command emulation mode that makes the Model 331 interchangeable with the older Model 330 in software controlled systems.

Each input has a high and low alarm which offer latching and non-latching operation. The two relays on the Model 331S can be used in conjunction with the alarms to alert the operator of a fault condition or perform simple on-off control. Relays can be assigned independently to any alarm or be operated manually.

When not being used for temperature control, the loop 2 control output can be used as an analog voltage output. It can be configured to send a voltage proportional to temperature to a strip-chart recorder or data acquisition system. The user may select the scale and data sent to the output, including temperature, sensor units, or linear equation results. Under manual control, the analog voltage output can also serve as a voltage source for other applications.

Interface Features of Model 331S and Model 331E

Feature	*331S*	*331E*
Numeric keypad	■	■
Front panel curve entry	■	■
Alarms	■	■
RS-232C interface	■	■
IEEE-488 interface	■	
Second control loop	■	
Analog voltage output	■	
Two relays	■	

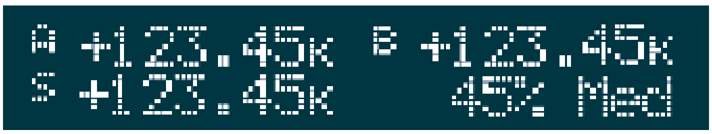


Model 331S Rear Panel Connections

❶ *Line input assembly*
❷ *Serial (RS-232C) I/O (DTE)*
❸ *Heater output*
❹ *IEEE-488 interface*
❺ *Terminal block (for relays and analog output)*
❻ *Sensor input connectors*

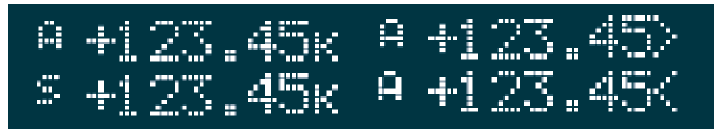
Configurable Display

Both versions of the Model 331 include a bright vacuum fluorescent display that simultaneously displays up to four readings. Display data includes input and source annunciators for each reading. All four display locations can be configured by the user. Data from either input may be assigned to any of the four locations; the user's choice of temperature, sensor units, maximum, minimum, or linear equation results can be displayed. Heater range and control output as current or power can also be continuously displayed for immediate feedback on control operation.



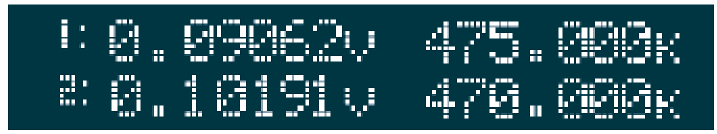
Normal (Default) Display Configuration

The display provides four reading locations. Readings from each input and the control setpoint can be expressed in any combination of temperature or sensor units, with heater output expressed as a percent of full scale current or power.



Flexible Configuration

Reading locations can be configured by the user to meet application needs. The character preceding the reading indicates input A or B or setpoint S. The character following the reading indicates measurement units or the math function in use.



Curve Entry

The Model 331 display offers the flexibility to support curve, SoftCal™, and zone entry. Curve entry may be performed accurately and to full resolution via the display and keypad as well as computer interface.

Sensor Selection

Sensor Temperature Range (sensors sold separately)

		Model	Useful Range	Magnetic Field Use
Diodes	**Silicon Diode**	DT-670-SD	1.4 K to 500 K	T ≥ 60 K & B ≤ 3 T
	Silicon Diode	DT-670E-BR	30 K to 500 K	T ≥ 60 K & B ≤ 3 T
	Silicon Diode	DT-414	1.4 K to 375 K	T ≥ 60 K & B ≤ 3 T
	Silicon Diode	DT-421	1.4 K to 325 K	T ≥ 60 K & B ≤ 3 T
	Silicon Diode	DT-470-SD	1.4 K to 500 K	T ≥ 60 K & B ≤ 3 T
	Silicon Diode	DT-471-SD	10 K to 500 K	T ≥ 60 K & B ≤ 3 T
	GaAlAs Diode	TG-120-P	1.4 K to 325 K	T > 4.2 K & B ≤ 5 T
	GaAlAs Diode	TG-120-PL	1.4 K to 325 K	T > 4.2 K & B ≤ 5 T
	GaAlAs Diode	TG-120-SD	1.4 K to 500 K	T > 4.2 K & B ≤ 5 T
Positive Temperature Coefficient RTDs	**100 Ω Platinum**	PT-102/3	14 K to 873 K	T > 40 K & B ≤ 2.5 T
	100 Ω Platinum	PT-111	14 K to 673 K	T > 40 K & B ≤ 2.5 T
	Rhodium-Iron	RF-800-4	1.4 K to 500 K	T > 77 K & B ≤ 8 T
	Rhodium-Iron	RF-100T/U	1.4 K to 325 K	T > 77 K & B ≤ 8 T
Negative Temperature Coefficient RTDs[2]	**Cernox™**	CX-1010	2 K to 325 K[5]	T > 2 K & B ≤ 19 T
	Cernox™	CX-1030-HT	3.5 K to 420 K[3,6]	T > 2 K & B ≤ 19 T
	Cernox™	CX-1050-HT	4 K to 420 K[3,6]	T > 2 K & B ≤ 19 T
	Cernox™	CX-1070-HT	15 K to 420 K[3]	T > 2 K & B ≤ 19 T
	Cernox™	CX-1080-HT	50 K to 420 K[3]	T > 2 K & B ≤ 19 T
	Germanium	GR-200A/B-1000	2.2 K to 100 K[4]	Not Recommended
	Germanium	GR-200A/B-1500	2.6 K to 100 K[4]	Not Recommended
	Germanium	GR-200A/B-2500	3.1 K to 100 K[4]	Not Recommended
	Carbon-Glass	CGR-1-500	4 K to 325 K[5]	T > 2 K & B ≤ 19 T
	Carbon-Glass	CGR-1-1000	5 K to 325 K[5]	T > 2 K & B ≤ 19 T
	Carbon-Glass	CGR-1-2000	6 K to 325 K[5]	T > 2 K & B ≤ 19 T
	Rox™	RX-102A	1.4 K to 40 K[5]	T > 2 K & B ≤ 10 T
Thermocouples	**Type K**	9006-006	3.2 K to 1505 K	Not Recommended
	Type E	9006-004	3.2 K to 934 K	Not Recommended
	Chromel-AuFe 0.07%	9006-002	1.2 K to 610 K	Not Recommended

[2] Single excitation current may limit the low temperature range of NTC resistors
[3] Non-HT version maximum temperature: 325 K
[4] Low temperature limited by input resistance range
[5] Low temperature specified with self-heating error: ≤ 5 mK
[6] Low temperature specified with self-heating error: ≤ 12 mK

Silicon diodes are the best choice for general cryogenic use from 1.4 K to above room temperature. Diodes are economical to use because they follow a standard curve and are interchangeable in many applications. They are not suitable for use in ionizing radiation or magnetic fields.

Cernox™ thin-film RTDs offer high sensitivity and low magnetic field-induced errors over the 2 K to 420 K temperature range. Cernox sensors require calibration.

Platinum RTDs offer high uniform sensitivity from 30 K to over 800 K. With excellent reproducibility, they are useful as thermometry standards. They follow a standard curve above 70 K and are interchangeable in many applications.

Typical Sensor Performance – *see Appendix F for sample calculations of typical sensor performance*

	Example Lake Shore Sensor	Temp	Nominal Resistance/ Voltage	Typical Sensor Sensitivity[7]	Measurement Resolution: Temperature Equivalents	Electronic Accuracy: Temperature Equivalents	Temperature Accuracy including Electronic Accuracy, CalCurve™, and Calibrated Sensor	Electronic Control Stability[8]: Temperature Equivalents
Silicon Diode	DT-670-SD-13	1.4 K	1.644 V	-12.49 mV/K	0.8 mK	±13 mK	±25 mK	±1.6 mK
	with 1.4H	77 K	1.028 V	-1.73 mV/K	5.8 mK	±76 mK	±98 mK	±11.6 mK
	calibration	300 K	0.5597 V	-2.3 mV/K	4.4 mK	±47 mK	±79 mK	±8.8 mK
		500 K	0.0907 V	-2.12 mV/K	4.8 mK	±40 mK	±90 mK	±9.6 mK
Silicon Diode	DT-470-SD-13	1.4 K	1.6981 V	-13.1 mV/K	0.8 mK	±13 mK	±25 mK	±1.6 mK
	with 1.4H	77 K	1.0203 V	-1.92 mV/K	5.2 mK	±69 mK	±91 mK	±10.4 mK
	calibration	300 K	0.5189 V	-2.4 mV/K	4.2 mK	±45 mK	±77 mK	±8.4 mK
		475 K	0.0906 V	-2.22 mV/K	4.6 mK	±39 mK	±89 mK	±9.2 mK
GaAlAs Diode	TG-120-SD	1.4 K	5.391 V	-97.5 mV/K	0.2 mK	±7 mK	±19 mK	±0.4 mK
	with 1.4H	77 K	1.422 V	-1.24 mV/K	16.2 mK	±180 mK	±202 mK	±32.4 mK
	calibration	300 K	0.8978 V	-2.85 mV/K	7 mK	±60 mK	±92 mK	±14 mK
		475 K	0.3778 V	-3.15 mV/K	6.4 mK	±38 mK	±88 mK	±12.8 mK
100 Ω Platinum RTD 500 Ω Full Scale	PT-103	30 K	3.660 Ω	0.191 Ω/K	10.5 mK	±23 mK	±33 mK	±21 mK
	with 1.4J	77 K	20.38 Ω	0.423 Ω/K	4.8 mK	±15 mK	±27 mK	±9.6 mK
	calibration	300 K	110.35 Ω	0.387 Ω/K	5.2 mK	±39 mK	±62 mK	±10.4 mK
		500 K	185.668 Ω	0.378 Ω/K	5.3 mK	±60 mK	±106 mK	±10.6 mK
Cernox™	CX-1050-SD-HT[9]	4.2 K	3507.2 Ω	-1120.8 Ω/K	36 μK	±1.4 mK	±6.4 mK	±72 μK
	with 4M	77 K	205.67 Ω	-2.4116 Ω/K	16.6 mK	±76 mK	±92 mK	±33.2 mK
	calibration	300 K	59.467 Ω	-0.1727 Ω/K	232 mK	±717 mK	±757 mK	±464 mK
		420 K	45.030 Ω	-0.0829 Ω/K	483 mK	±1.42 K	±1.49 K	±966 mK
Germanium	GR-200A-1000	2 K	6674 Ω	-9930 Ω/K	4 μK	±0.3 mK	±4.3 mK	±8 μK
	with 1.4D	4.2 K	1054 Ω	-526 Ω/K	76 μK	±1 mK	±5 mK	±152 μK
	calibration	10 K	170.9 Ω	-38.4 Ω/K	1 mK	±4.4 mK	±9.4 mK	±2 mK
		100 K	2.257 Ω	-0.018 Ω/K	2.22 K	±5.61 K	±5.626 K	±4.44 K
Carbon-Glass	CGR-1-2000	4.2 K	2260 Ω	-2060 Ω/K	20 μK	±0.5 mK	±4.5 mK	±40 μK
	with 4L	77 K	21.65 Ω	-0.157 Ω/K	255 mK	±692 mK	±717 mK	±510 mK
	calibration	300 K	11.99 Ω	-0.015 Ω/K	2.667 K	±7 K	±7.1 K	±5.334 K
Thermocouple 50 mV	Type K	75 K	-5862.9 μV	15.6 μV/K	26 mK	±0.25 K[10]	Calibration not available from Lake Shore	±52 mK
		300 K	1075.3 μV	40.6 μV/K	10 mK	±0.038 K[10]		±20 mK
		600 K	13325 μV	41.7 μV/K	10 mK	±0.184 K[10]		±20 mK
		1505 K	49998.3 μV	36.006 μV/K	12 mK	±0.73 K[10]		±24 mK

[7] *Typical sensor sensitivities were taken from representative calibrations for the sensor listed*
[8] *Control stability of the electronics only, in an ideal thermal system*
[9] *Non-HT version maximum temperature: 325 K*
[10] *Accuracy specification does not include errors from room temperature compensation*

Specifications

Input Specifications

	Sensor Temperature Coefficient	Input Range	Excitation Current	Display Resolution	Measurement Resolution	Electronic Accuracy	Electronic Control Stability[11]
Diode	negative	0 V to 2.5 V	10 μA $\pm$0.05%[12, 13]	100 μV	10 μV	$\pm$80 μV $\pm$0.005% of rdg	$\pm$20 μV
	negative	0 V to 7.5 V	10 μA $\pm$0.05%[12, 13]	100 μV	20 μV	$\pm$80 μV $\pm$0.01% of rdg	$\pm$40 μV
PTC RTD	positive	0 Ω to 500 Ω	1 mA[14]	10 mΩ	2 mΩ	$\pm$0.004 Ω $\pm$0.01% of rdg	$\pm$4 mΩ
	positive	0 Ω to 5000 Ω	1 mA[14]	100 mΩ	20 mΩ	$\pm$0.04 Ω $\pm$0.02% of rdg	$\pm$40 mΩ
NTC RTD	negative	0 Ω to 7500 Ω	10 μA $\pm$0.05%[14]	100 mΩ	40 mΩ	$\pm$0.1 Ω $\pm$0.04% of rdg	$\pm$80 mΩ
Thermocouple	positive	$\pm$25 mV	NA	1 μV	0.4 μV	$\pm$1 μV $\pm$0.05% of rdg[15]	$\pm$0.8 μV
	positive	$\pm$50 mV	NA	1 μV	0.4 μV	$\pm$1 μV $\pm$0.05% of rdg[15]	$\pm$0.8 μV

[11] Control stability of the electronics only, in an ideal thermal system
[12] Current source error has negligible effect on measurement accuracy
[13] Diode input excitation current can be set to 1 mA – refer to the Model 331 user manual for details
[14] Current source error is removed during calibration
[15] Accuracy specification does not include errors from room temperature compensation

Thermometry

Number of inputs	2
Input configuration	Each input is factory configured for either diode/RTD or thermocouples
Isolation	Sensor inputs optically isolated from other circuits but not each other
A/D resolution	24-bit
Input accuracy	Sensor dependent – refer to Input Specifications table
Measurement resolution	Sensor dependent – refer to Input Specifications table
Maximum update rate	10 readings/s on each input (except 5 readings/s on input A when configured as thermocouple)
User curves	Room for twenty 200-point CalCurves™ or user curves
SoftCal™	Improves accuracy of DT-470 diode to $\pm$0.25 K from 30 K to 375 K; improves accuracy of Platinum RTDs to $\pm$0.25 K from 70 K to 325 K – stored as user curves
Math	Maximum, Minimum, and Linear Equation (Mx + B) or M(x+B)
Filter	Averages 2 to 64 input readings

Control

Control loops	Two on 331S, one on 331E
Control type	Closed loop digital PID with manual heater output, or open loop
Tuning	Autotune (one loop at a time), PID, PID zones
Control stability	Sensor dependent – to 2× measurement resolution (in an ideal thermal system)

PID control parameters	
Proportional (gain)	0 to 1000 with 0.1 setting resolution
Integral (reset)	1 to 1000 (1000/s) with 0.1 setting resolution
Derivative (rate)	1 to 200% with 1% resolution
Manual output	0 to 100% with 0.01% setting resolution
Zone control	10 temperature zones with P, I, D, manual heater out, and heater range
Setpoint ramping	0.1 K/min to 100 K/min
Safety limits	Curve temperature, power up heater off, short circuit protection

Sensor Input Configuration

	Diode/RTD	Thermocouple
Measurement type	4-lead differential	2-lead, room temperature compensated
Excitation	Constant current with current reversal for RTDs	NA
Supported sensors	Diodes: Silicon, GaAlAs RTDs: 100 Ω Platinum, 1000 Ω Platinum, Germanium, Carbon-Glass, Cernox™, and Rox™	Most thermocouple types
Standard curves	DT-470, DT-500D, DT-670, PT-100, PT-1000, RX-102A, RX-202A	Type E, Type K, Type T, AuFe 0.07% vs. Cr, AuFe 0.03% vs. Cr
Input connector	6-pin DIN	Ceramic isothermal block

Heater Output

	Loop 1	Loop 2
Heater output type	Variable DC current source	Variable DC voltage source
Heater output D/A resolution	18-bit	16-bit
Max heater power	50 W	1 W
Max heater output current	1 A	0.1 A
Heater output compliance	50 V	10 V
Heater output ranges	3 decade steps in power	1
Heater load type	Resistive	Resistive
Heater load range	10 Ω to 100 Ω recommended	100 Ω minimum
Heater load for max power	50 Ω	100 Ω
Heater noise (<1 kHz) RMS	50 μV + 0.01% of output voltage	<0.3 mV
Isolation	Optical isolation between output and other circuits	None
Heater connector	Dual banana	Detachable terminal block

Loop 1 Full Scale Heater Power at Typical Resistance

Heater Resistance	Heater Range	Heater Power
10 Ω	Low Med High	100 mW 1 W 10 W
25 Ω	Low Med High	250 mW 2.5 W 25 W
50 Ω	Low Med High	500 mW 5 W 50 W

Front Panel

Display	2 line by 20 character, 9 mm character height, vacuum fluorescent display
Number of reading displays	1 to 4
Display units	K, °C, V, mV, Ω
Reading source	Temperature, sensor units, max, min, and linear equation
Display update rate	All readings twice per s
Temp display resolution	0.001° from 0° to 99.999°, 0.01° from 100° to 999.99°, 0.1° above 1000°
Sensor units display resolution	Sensor dependent to 5 digits
Other displays	Setpoint, Heater Range, and Heater Output (user selected)
Setpoint setting resolution	Same as display resolution (actual resolution is sensor dependent)
Heater output display	Numeric display in percent of full scale for power or current
Heater output resolution	1%
Display annunciators	Control Input, Remote, Alarm, Tuning, Ramp, Max, Min, Linear
Keypad	20 full travel keys, numeric and specific functions
Front panel features	Front panel curve entry, display brightness control, keypad lock-out

Interface

IEEE-488 interface (331S)	
Features	SH1, AH1, T5, L4, SR1, RL1, PP0, DC1, DT0, C0, E1
Reading rate	To 10 readings per s on each input
Software support	LabVIEW™ driver (consult factory for availability)
Serial interface	
Electrical format	RS-232C
Max baud rate	9600 baud
Connector	9-pin D-sub
Reading rate	To 10 readings/s on each input (at 9600 baud)
Special interface features	Model 330 command emulation mode
Alarms	
Number	4, high and low for each input
Data source	Temperature, Sensor Units, Linear Equation
Settings	Source, High Setpoint, Low Setpoint, Deadband, Latching or Non-Latching, Audible On/Off
Actuators	Display annunciator, beeper, relays
Relays (331S)	
Number	2
Contacts	Normally Open (NO), Normally Closed (NC), and Common (C)
Contact rating	30 VDC at 5 A
Operation	Activate relays on high, low, or both alarms for either input or manual
Connector	Detachable terminal block
Analog voltage output (331S)	
Scale	User selected
Update rate	10 readings per s
Data source	Temperature, Sensor Units, Linear Equation
Settings	Input, source, top of scale, bottom of scale, or manual
Range	±10 V
Resolution	0.3 mV
Accuracy	±2.5 mV
Min load resistance	100 Ω (short circuit protected)

General

Ambient temperature	15 °C to 35 °C at rated accuracy, 10 °C to 40 °C at reduced accuracy
Power requirement	100, 120, 220, 240 VAC, (+6%, -10%), 50 or 60 Hz, 120 VA
Size	216 mm W × 89 mm H × 368 mm D (8.5 in × 3.5 in × 14.5 in), half rack
Weight	4.8 kg (10.5 lb)
Approval	CE mark

Ordering Information

Part number	Description
Standard temperature controllers – *all features included*	
331S	Two diode/resistor inputs
331S-T1	One diode/resistor input, one thermocouple input
331S-T2	Two thermocouple inputs
Economy temperature controllers – *all features of the 331S are included except IEEE-488 interface, relays, analog voltage output, and a second control loop*	
331E	Two diode/resistor inputs
331E-T1	One diode/resistor input, one thermocouple input
331E-T2	Two thermocouple inputs
Select a power configuration*:	
VAC-100	Instrument configured for 100 VAC with U.S. power cord
VAC-120	Instrument configured for 120 VAC with U.S. power cord
VAC-120-ALL	Instrument configured for 120 VAC with U.S. power cord and universal Euro line cord and fuses for 220/240 VAC setting
VAC-220	Instrument configured for 220 VAC with universal Euro line cord
VAC-240	Instrument configured for 240 VAC with universal Euro line cord
**Other country line cords available, consult Lake Shore*	
Accessories included	
106-009	Heater output connector (dual banana jack)
106-233	Sensor input mating connector (6-pin DIN plugs)
106-739	Terminal block, 8-pin
——	Calibration certificate
MAN-331	Model 331 user manual
Options and accessories	
4005	1 m (3.3 ft long) IEEE-488 (GPIB) computer interface cable assembly – includes extender required for simultaneous use of IEEE cable and relay terminal block
8001-331	CalCurve™, factory installed – the breakpoint table from a calibrated sensor stored in the instrument (extra charge for additional sensor curves)
8002-05-331	CalCurve™, field installed – the breakpoint table from a calibrated sensor loaded into a nonvolatile memory for customer installation
CAL-331-CERT	Instrument recalibration with certificate
CAL-331-DATA	Instrument recalibration with certificate and data
RM-½	Kit for mounting one ½ rack temperature controller in a 482.6 mm (19 in) rack, 90 mm (3.5 in) high
RM-2	Kit for mounting two ½ rack temperature controllers in a 482.6 mm (19 in) rack, 135 mm (5.25 in) high

USD