User's Manual

Model 372

AC Resistance Bridge and Temperature Controller

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Electromagnetic Compatibility (EMC) for the Model 372 AC Resistance Bridge and Temperature Controller

Electromagnetic Compatibility (EMC) of electronic equipment is a growing concern worldwide. Emissions of and immunity to electromagnetic interference is now part of the design and manufacture of most electronics. To qualify for the CE Mark, the Model 372 meets or exceeds the requirements of the European EMC Directive 89/372/EEC as a CLASS A product. A Class A product is allowed to radiate more RF than a Class B product and must include the following warning:

WARNING: This is a Class A product. In a domestic environment, this product may cause radio interference in which case the user may be required to take adequate measures.

The instrument was tested under normal operating conditions with sensor and interface cables attached. If the installation and operating instructions in the User's Manual are followed, there should be no degradation in EMC performance.

This instrument is not intended for use in close proximity to RF Transmitters such as two-way radios and cell phones. Exposure to RF interference greater than that found in a typical laboratory environment may disturb the sensitive measurement circuitry of the instrument.

Pay special attention to instrument cabling. Improperly installed cabling may defeat even the best EMC protection. For the best performance from any precision instrument, follow the grounding and shielding instructions in the User's Manual. In addition, the installer of the Model 372 should consider the following:

- Shield measurement and computer interface cables.
- Leave no unused or unterminated cables attached to the instrument.
- Make cable runs as short and direct as possible. Higher radiated emissions are possible with long cables.
- Do not tightly bundle cables that carry different types of signals.

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Chapter 1: Introduction

FIGURE 1-1 ***Model 372 front view***

1.1 Model 372 Features

- Patented noise rejection technology
- Highly versatile and reliable measurement input
- Ability to increase the number of measurement channels to a maximum of 16 with optional 3726 scanner
- Dedicated input for ultra-low temperature control
- Powerful impedance measurement capabilities such as quadrature measurements
- Multiple PID controllable outputs with up to 10 W of heater power available
- Latest generation front panel for ease of use
- 3-year standard warranty

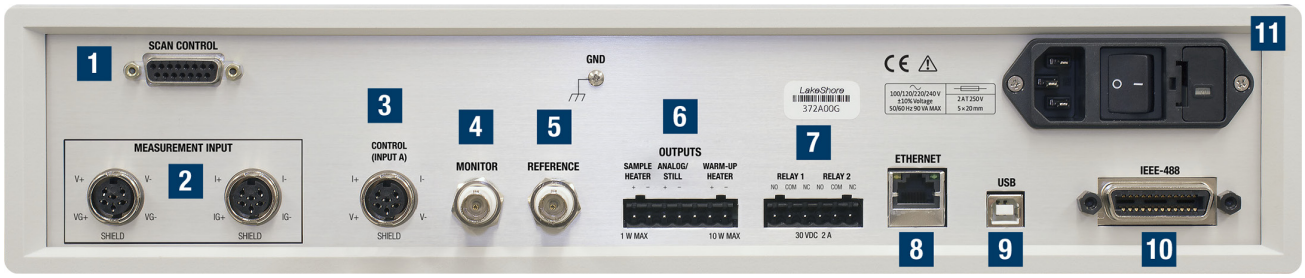


FIGURE 1-2 ***Model 372 rear panel***

1. Scanner control input (DA-15)
2. Sensor voltage/current input (6-pin DIN)
3. Secondary control input (6-pin DIN)
4. Monitor output (BNC)
5. Reference output (BNC)
6. Sample heater output, warm-up heater output, and still heater output (terminal block)
7. Relay 1 and 2 (terminal block)
8. Ethernet interface (RJ-45)
9. USB interface (USB type B)
10. IEE-488.2 interface
11. Line power/fuse assembly

1.2 Introduction

The Model 372 AC resistance bridge and temperature controller builds on the solid foundation provided by the original Lake Shore AC resistance bridge. The Model 372 provides the best possible temperature measurement and control capabilities for dilution refrigerators (DRs) that are intended to be operated below 100 mK. The Model 372 makes it easy to perform multiple tasks that were once very difficult to perform reliably at ultra-low temperatures:

- Temperature measurement
- Automatic or manual temperature control
- Device or sample impedance measurements

1.3 Targeted Applications

See section 1.3.1 through section 1.3.7 for descriptions of the targeted applications for the Model 372.

1.3.1 Ultra-low Temperature Measurement

Making measurements below 100 mK is far from a trivial exercise, with even the smallest amounts of added energy leading to self-heating and unwanted temperature shifts. Every design decision made on the Model 372 aims to minimize the amount of energy needed to take measurements.

1.3.2 Noise Rejection

Externally generated electronic noise can be a major cause of self-heating if it is allowed to couple into the device under test. Multiple noise-rejection strategies have been implemented to reduce this effect substantially:

- Our patented* balanced noise-rejecting current source ensures that external signals have no path to ground through the measurement circuit, effectively making the Model 372 unaltered by these noise sources.
- The measurement signal cables use a driven guard that reduces parasitic capacitance in the cables that connect a scanner to the Model 372. This helps to further balance the measurement network and bolster the integrity of the noise rejection circuitry.
- All measurement circuitry is isolated from other instrument components, limiting the impact of any small electrical disturbances.
- The AC frequency options used for the measurement signal are selected to be naturally resilient to line voltage frequencies (50 and 60 Hz).

**U. S. Patent #6,501,255, Dec., 2002, "Differential current source with active common mode reduction," Lake Shore Cryotronics, Inc.*

1.3.3 AC Measurement Signals

By using alternating current (AC) measurement in tandem with a specially designed internal lock-in amplifier, the Model 372 is able to extract very small measurement signals from background noise. This allows for much lower excitation levels to be used when compared to traditional direct current (DC) system, minimizing the amount of energy that is dissipated into the device under test.

These AC excitation levels can be set to as low as 10 pA, while still maintaining accuracy of better than 1% over quite a wide range of resistances. This enables impedance and temperature measurements to be made while adding power levels so small that they are measured in the attowatt range (10^{-18} W). These features are vital in allowing accurate measurement to be made while minimizing the negative effects of self-heating.

1.3.4 Low Noise Signal Recovery

Due to the very low excitation level used for measurement, the resulting voltage levels must first be boosted to allow those signals to be measured. The internal lock-in amplifier in the Model 372 has been specifically designed to minimize the amount of noise added to the signal. This results in an input noise figure that is less than 10 nV/√Hz, thereby increasing the resolution of measurements and limiting the amount of post-measurement filtering that needs to be applied.

1.3.5 Temperature Measurement

Extremely accurate and reliable ultra-low temperature measurements can be achieved by combining the Model 372 with a negative temperature coefficient (NTC) resistive temperature device (RTD), such as the Lake Shore Cernox®, Rox™ or germanium temperature sensors. Multiple calibration curves can easily be uploaded to the Model 372, allowing highly-accurate conversion of sensor resistance to equivalent temperature, using cubic spine interpolation (an improved interpolation technique compared to older instruments).

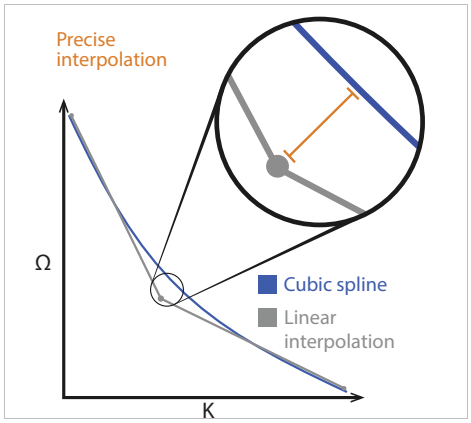


FIGURE 1-3 ***Cubic spline vs. linear interpolation***

User-generated calibration curves can also be created and loaded into the Model 372, allowing great flexibility in the type of resistive sensors that are used. A maximum of 39 calibration curves can be stored on the instrument, and when used with a 3726 scanner, up to 17 sensors can be connected simultaneously, each with their own curve.

1.3.6 Measure a Wide Range of Resistive Devices

With up to 21 different current (I) excitation levels available, the Model 372 is able to perform accurate impedance measurements from several microohms($10^{-6}\Omega$) to many megohms ($10^{6}\Omega$), all while keeping power dissipation levels to an absolute minimum.

The addition of full quadrature measurements mean that both the resistive and reactive components of an impedance can now be measured. This enables much better characterization of the device under test by allowing capacitive or inductive components to be measured.

1.3.7 Expandability

For situations where temperature measurements must be taken at multiple locations, the 3726 scanner and preamp can be paired with the Model 372 to provide up to 16 connections for 4-wire resistance measurements. The Model 372 can switch measurement to any one of these connections as required, removing the need to physically switch cables on the instrument to look at different sensors. The measurement signal is also boosted by a pre-amp circuit in the 3726 scanner, preserving the signal-to-noise ratio between the sensor and measurement circuitry of the Model 372. This allows connection cables of up to 10 m to be used between the Model 372 and the 3726.

FIGURE 1-4 ***The new 3726 scanner option***

In cases where measurements are required at multiple locations simultaneously within an experiment space, additional Model 372 units may be used together. Five different AC excitation frequencies are available for this purpose, ensuring that up to five simultaneous measurements can be performed without the risk of co-channel interference.

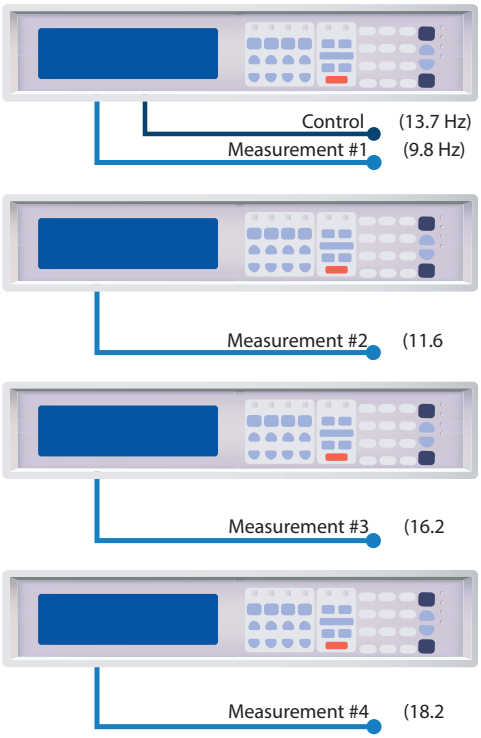


FIGURE 1-5 ***Multi-instrument setup***

1.4 Dilution Refrigerator Temperature Control

Accurate measurement at ultra-low temperatures are no easy feat, especially when working in the ranges seen by modern dilution refrigerators. The Model 372 has many features specifically developed for dilution refrigerator applications.

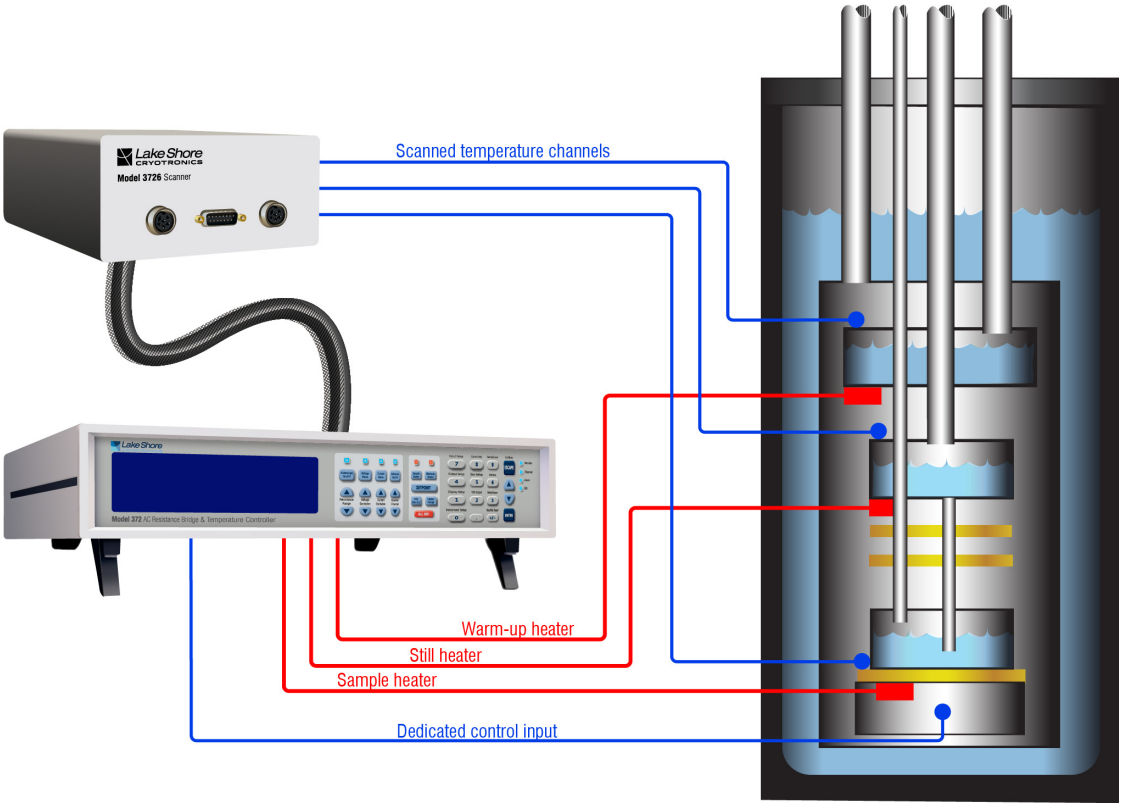


FIGURE 1-6 ***A Model 372 and 3726 used to control a dilution refrigerator***

1.4.1 Dedicated Temperature Control Input

Taking measurements at ultra-low temperatures deserves uninterrupted attention from measurement devices. The Model 372 uses a dedicated temperature control input that is designed specifically for connection to a negative temperature coefficient resistive sensor. This input is designed to continuously monitor the temperature of the dilution refrigerator sample holder, while the measurement input scans through the multiple other temperature sensors placed throughout the dilution refrigerator.

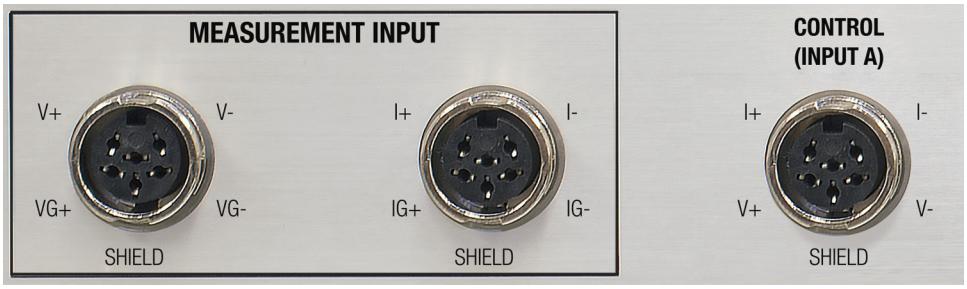


FIGURE 1-7 ***The dedicated control input ensures uninterrupted dilution refrigerator temperature control***

1.4.2 Multiple Heater Options

Three separate heater outputs are available on the Model 372:

- *Sample heater*—for fine control of the sample stage at ultra-low temperatures with up to 1 W of power available.
- *Warm-up heater*—supplying up to 10 W of power and featuring a warm-up mode specifically for the purpose of bringing the system temperature up to allow work to be performed on the sample stage.
- *Still heater*—an additional 1 W heater is available for the purpose of controlling the temperature of a dilution refrigerator's still. Alternatively, this output can provide an analog out signal to other devices if required.

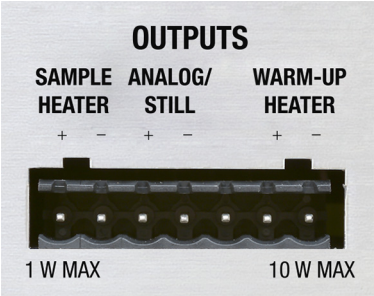


FIGURE 1-8 ***Physical heater connections***

The sample and warm-up heaters have many powerful control options, including PID control that allows both the setting of fixed temperature setpoints as well as ramp rates.

1.4.3 Stable Temperature Control

When operating at ultra-low temperatures, even small amounts of added energy can cause unwanted spikes in system temperature. The Model 372 heater outputs implement several protection mechanisms to reduce or eliminate this potential:

- The circuitry for the sample and still heaters are electrically isolated from other instrument sections
- Multiple power range settings allow extremely fine or coarse power transitions, depending on the need
- Heater outputs are shunted during power up and power range changes, eliminating the potential for unwanted power surges
- Terminal connections allow twisted pair cabling to be easily used for heater wiring; additional shielding of these wires can also be added to further reduce the potential of injecting noise into a system via the heater cabling

1.4.4 Temperature Zone Control

Thermal response characteristics of a dilution refrigerator system can change quite dramatically over the useful range of operation, particularly down towards the lower temperature limit of a system, where cooling power is reduced. To accommodate these system variations, different PID values can be set for different temperature ranges (zones). This allows for more aggressive transition settings to be used at higher temperatures where system response is faster, and less reactive settings at low temperatures when temperature overshoots result in long recovery times.

1.4.5 Heater Fail-Safes

The Model 372 has several features that will protect your system and experiment from accidental deviations in planned temperature settings:

- Temperature thresholds can be set for all heater outputs, meaning the heaters will automatically shut down if it is detected that the system is being overheated.
- An easy-to-access "ALL OFF" button is provided that shuts all heaters down instantly. This eliminates the terrible experience of having to hurriedly search through menu options while your experiment continues to heat.

FIGURE 1-9 ***ALL OFF button***

1.5 Low-Power Impedance Characterization: the 3708 Scanner

FIGURE 1-10 ***The 3708 scanner***

Many material characterization experiments require cryogenic temperature environments to perform measurements. This can be because the material behavior changes in interesting ways at these temperatures, or because background thermal noise must be minimized for useful measurement data to be extracted. The standard inputs of the Model 372 accurately measure higher-impedance devices such as temperature sensors, but begin to lose resolution and accuracy when extremely low impedances are encountered such as in Hall effect or superconducting material measurements. However, by adding a 3708 preamp and scanner to the Model 372, these materials can be characterized with the same accuracy and stability as when measuring higher-impedance devices.

To accomplish this, the 3708 produces higher levels of DC bias current than both the Model 372 and the 3726 scanner and preamp. This means the 3708 would cause self-heating in a temperature sensor used at ultra-low temperatures. The new dedicated control input resolves this issue by providing the ability to make highly-reliable measurements of a temperature control sensor.

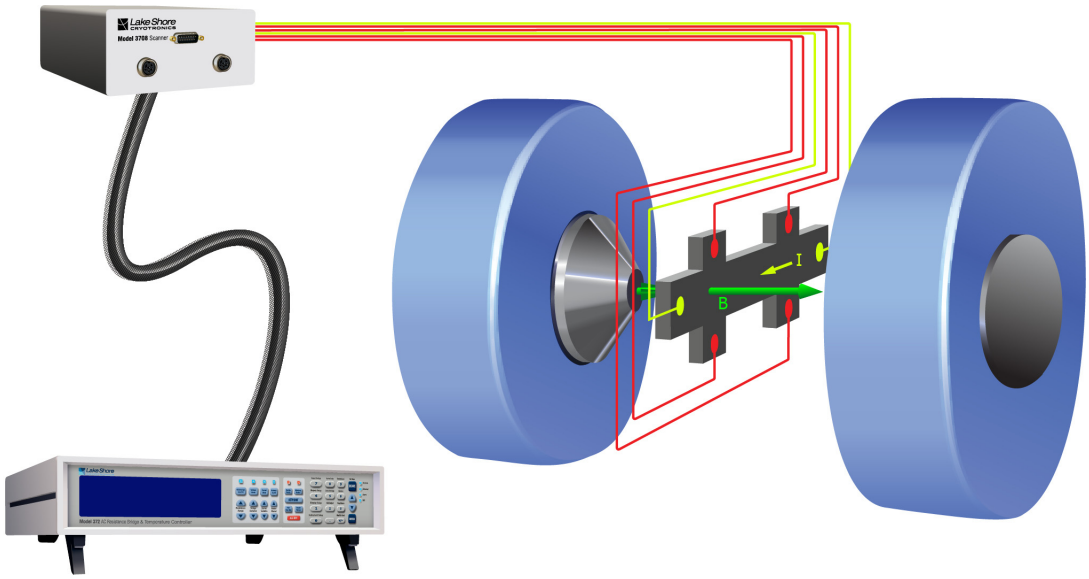


FIGURE 1-11 ***A model 372 and 3708 used in a Hall measurement application***

1.5.1 Lower Input Voltage Noise

The limiting factor for making extremely low-impedance measurements directly with the Model 372 is the input voltage noise figure of 10 nV/√Hz. The preamp in the 3708 reduces this by a factor of 5 to an impressive 2 nV/√Hz. By reducing the amount of input noise, even smaller return signals can be recovered with excellent accuracy. When combined with the ability of the Model 372 to smooth measurement values with user-settable filters ranging from 1 to 200 s, the 3708 preamp and scanner provides the best solution to measuring low impedance devices at cryogenic temperatures. The 3708 scanner and preamp allows up to eight simultaneous connections to be made, with the scanner feature enabling measurement to be switched between those connections. Unlike the 3726 scanner, all connections that are not actively being measured are left open, allowing the 3708 to be connected to Hall bar devices.

1.5.2 Overcoming Cable Length

With such small resultant voltages needing to be measured, it can be very helpful to have these signals amplified slightly as close as possible to the source of these signals. The compact size of the 3708 scanner and preamp allows it be mounted close to the device or sample being measured, thereby maintaining signal-to-noise ratio for the measurement signal between the sample and the Model 372 that will ultimately perform the measurements. Cable lengths of up to 10 m are supported by the 3708, allowing the Model 372 to be located away from the experiment area if needed.

1.6 Connectivity and Usability—Communication Options

1.6.1 Physical connectivity

Various methods for communicating with the Model 372 are made available:

- Ethernet: allows full control and reporting throughout an IP network.
- USB: provides direct serial communication by emulating a standard RS-232 connection.
- IEE-488.2: allows connection to GPIB systems.

FIGURE 1-12 ***Ethernet, USB and IEEE-488 connections on the Model 372***

1.6.2 Available Functions

Multiple actions can be performed when connected to the Model 372 through one of its various remote access options:

- Send any command to the instrument that could be entered via the front panel
- Read and store measurement data that is generated by the instrument
- Live graphical viewing of data using the Lake Shore Cryotronics Chart Recorder software
- Load new calibration curves for use with new temperature sensors
- Upload new firmware if required

1.6.3 Backwards Compatibility

The Model 372 is designed for trouble-free integration with existing equipment and software that has been built around the previous generation Model 370.

- Emulation mode on the Model 372 is designed to imitate all important communication functions of the Model 370. In most cases, programming that was previously written for the Model 370 can be used to interact with the Model 372.
- A convenient heater connector adapter (117-071) can also be purchased that replicates the BNC heater connections that were available on the Model 370, allowing connection swapping between the Model 372 and Model 370 without the need to rewire experiment cabling.

1.7 Sensor Performance

Excitation ranges in sensor tables were selected to minimize sensor self-heating.
Excitation power = actual current^2 × sensor resistance

1.7.1 Measurement Resolution

Measurement resolution comes from electronic instrumentation and sensor thermal noises. Measurement resolution is given by:
Resolution (Ω) = ((instrument noise at RT)^2 + (sensor thermal noise)^2)$^{0.5}$
Electronic instrumentation is taken at ambient temperature, while sensor thermal noise is taken at the temperature specified in the following tables.

$$\text{Resolution (K)} = \frac{\text{Resolution } (\Omega)}{(dR/dT)}$$

1.7.2 Electronic Accuracy

Electronic accuracy is influenced by the measurement range used and sensor resistance value. Electronic accuracy is given by:
Electronic accuracy (Ω) = Accuracy(%) × sensor resistance + 0.005% of resistance range
Where: Accuracy (%) is given in the instrument performance table (FIGURE 1-16 and FIGURE 1-17) at the selected current and voltage range.

$$\text{Electronic accuracy (K)} = \frac{\text{Electronic accuracy } (\Omega)}{(dR/dT)}$$

1.7.3 Self-heating errors

Self-heating errors are measurement errors due to power dissipation in the sensor causing unwanted temperature rises. Self-heating error is given by:
Self heating error = thermal resistance × power
Thermal resistances specified are typical values resulting from minimal heat sinking. Improved values can be achieved with permanent installation.

1.7.4 Calibration accuracies

Calibration accuracies are based on Lake Shore sensor calibration uncertainty and repeatability values—see Appendices B, D & E of the Temperature Measurement and Control Catalog for more information.

1.7.5 Interpolation errors

Interpolation errors are due to the linear interpolation method used by the Model 372 to convert resistance values to temperatures when using a temperature sensor. These errors are not present when resistance is measured directly.

1.7.6 Overall accuracy

Overall accuracy is a combination of all listed sources of potential error and is given by:
Overall accuracy = (measurement resolution^2 + electronic accuracy^2 + self heating errors^2 + calibration accuracy^2 + interpolation error^2)$^{0.5}$

1.7.7 Lake Shore Rox™-102B-CB with 0.02 to 40 K Calibration

Values given are for measurement input. If the value is different for the control input, it is shown in blue.

Sensor properties				Excitation and instrumentation				Instrument performance		Overall performance			
Temperature	Nominal resistance	Typical sensor sensitivity	Thermal resistance	Resistance range	Excitation voltage limit	Excitation current	Power	Measurement resolution	Electronic accuracy	Calibration accuracy	Self-heating errors	Interpolation error	Overall accuracy
20 mK	7.3 kΩ	-171 kΩ/K	17.2 K/nW	20 kΩ 632 kΩ	6.32 μV 200 μV	316 pA	730 aW	7.3 Ω (42.7 μK) 33.9 Ω (198 μK)	8.3 Ω (48.5 μK) 35.3 Ω (206 μK)	±2 mK	12.6 μK	±0.2 mK	2 mK
30 mK	6.0 kΩ	-100 kΩ/K	8.2 K/nW	6.32 kΩ 200 kΩ	6.32 μV 200 μV	1 nA	6 fW	485 mΩ (4.9 μK) 7.3 Ω (73 μK)	6.3 Ω (63 μK) 13.0 Ω (130 μK)	±4 mK	49.2 μK	±0.2 mK	4 mK
40 mK	5.2 kΩ	-62 kΩ/K	635.8 mK/nW	6.32 kΩ 63.2 kΩ	20 μV 200 μV	3.16 nA	52 fW	502 mΩ (8.1 μK) 1.5 Ω (24.2 μK)	2.9 Ω (46.8 μK) 4.7 Ω (75.8 μK)	±4 mK	33.1 μK	±0.2 mK	4 mK
50 mK	4.7 kΩ	-41 kΩ/K	415.1 mK/nW	6.32 kΩ 63.2 kΩ	20 μV 200 μV	3.16 nA	47 fW	502 mΩ (12.2 μK) 1.5 Ω (36.6 μK)	2.7 Ω (65.9 μK) 4.6 Ω (112 μK)	±4 mK	19.5 μK	±0.2 mK	4 mK
100 mK	3.5 kΩ	-13 kΩ/K	33.2 mK/nW	6.32 kΩ 20 kΩ	63.2 μV 200 μV	10 nA	350 fW	48.6 mΩ (3.7 μK) 338 mΩ (26 μK)	2.1 Ω (162 μK)	±4 mK	11.6 μK	±0.2 mK	4 mK
300 mK	2.5 kΩ	-2.4 kΩ/K	2.8 mK/nW	6.32 kΩ	200 μV	31.6 nA	2.5 pW	50.2 mΩ (20.9 μK) 87 mΩ (36.3 μK)	1.1 Ω (458 μK)	±4 mK	7.0 μK	±0.2 mK	4 mK
1 K	1.9 kΩ	-351 Ω/K	609.6 μK/nW	6.32 kΩ	200 μV	31.6 nA	1.9 pW	50.2 mΩ (143 μK) 87 mΩ (248 μK)	0.9 Ω (2.6 mK)	±4 mK	1.2 μK	±0.2 mK	4.7 mK

FIGURE 1-13 ***Sensor performance for Lake Shore Rox™-102B-CB with 0.02 to 40 K calibration***

1.7.8 Lake Shore GR-50-AA with 0.05 to 6 K Calibration

Values given are for measurement input. If the value is different for the control input, it is shown in blue.

Sensor properties				Excitation and instrumentation				Instrument performance		Overall performance			
Temperature	Nominal resistance	Typical sensor sensitivity	Thermal resistance	Resistance range	Excitation voltage limit	Excitation current	Power	Measurement resolution	Electronic accuracy	Calibration accuracy	Self-heating errors	Interpolation error	Overall accuracy
50 mK	35 kΩ	-3.6 MΩ/K	200 mK/nW	63.2 kΩ 200 kΩ	63.2 μV 200 μV	1 nA	35 fW	3.4 Ω (944 nK) 7.3 Ω (2 μK)	20.7 Ω (5.8 μK) 27.5 Ω (7.6 μK)	±4 mK	7.0 μK	±0.2 mK	4 mK
100 mK	2317 Ω	-72 kΩ/K	20 mK/nW	6.32 kΩ 20 kΩ	63.2 μV 200 μV	10 nA	232 fW	48.5 mΩ (674 nK) 338 mΩ (4.7 μK)	1.5 Ω (20.8 μK) 1.7 Ω (23.6 μK)	±4 mK	4.6 μK	±0.2 mK	4 mK
300 mK	164 Ω	-964 Ω/K	4 mK/nW	632 Ω 2 kΩ	200 μV	316 nA 100 nA	16 pW 1.6 pW	3.6 mΩ (3.7 μK) 29 mΩ (30.1 μK)	81 mΩ (84 μK) 149 mΩ (155 μK)	±4 mK	66 μK 6.6 μK	±0.2 mK	4 mK
500 mK	73.8 Ω	-202.9 Ω/K	1.2 mK/nW	632 Ω 2 kΩ	200 μV	316 nA 100 nA	7.4 pW 738 fW	3.6 mΩ (17.7 μK) 29 mΩ (143 μK)	54 mΩ (266 μK) 122 mΩ (601 μK)	±4 mK	8.9 μK 886 nK	±0.2 mK	4 mK 4.1 mK
1 K	34 Ω	-31 Ω/K	100 μK/nW	200 Ω 2 kΩ	200 μV	1 μA 100 nA	34 pW 340 fW	1.2 mΩ (38.7 μK) 29 mΩ (935 μK)	20 mΩ (645 μK) 110 mΩ (3.5 mK)	±4 mK	3.4 μK 34 nK	±0.2 mK	4.1 mK 5.4 mK
1.4 K	24.7 Ω	-13.15 Ω/K	75 μK/nW	200 Ω 2 kΩ	200 μV	1 μA 100 nA	25 pW 247 fW	1.2 mΩ (91.3 μK) 29 mΩ (2.2 mK)	17 mΩ (1.3 mK) 107 mΩ (8.1 mK)	±5 mK	1.9 μK 19 nK	±0.2 mK	5.2 mK 9.8 mK
4.2 K	13.7 Ω	-1.036 Ω/K	25 μK/nW	20 Ω 2 kΩ	200 μV	10 μA 100 nA	1.4 nW 137 fW	120 μΩ (116 μK) 29 mΩ (28 mK)	5.1 mΩ (4.9 mK) 104 mΩ (100 mK)	±5 mK	3.5 μK 3.4 nK	±0.2 mK	7 mK 104 mK

FIGURE 1-14 ***Sensor performance for Lake Shore GR-50-AA with 0.05 to 6 K calibration***

1.7.9 Lake Shore CX-1010-SD with 0.01 to 325 K Calibration

Values given are for measurement input. If the value is different for the control input, it is shown in blue.

Sensor properties				Excitation and instrumentation				Instrument performance		Overall performance			
Temperature	Nominal resistance	Typical sensor sensitivity	Thermal resistance	Resistance range	Excitation voltage limit	Excitation current	Power	Measurement resolution	Electronic accuracy	Calibration accuracy	Self-heating errors	Interpolation error	Overall accuracy
100 mK	21.389 kΩ	-558 kΩ/K	1.4 K/nW	63.2 kΩ 200 kΩ	63.2 µV 200 µV	1 nA	21 fW	3.4 Ω (6.1 µK) 7.4 Ω (13.3 µK)	13.9 Ω (24.9 µK) 20.7 Ω (37.1 µK)	±4 mK	30 µK	±0.2 mK	4 mK
300 mK	2.3224 kΩ	-10.8 kΩ/K	26.8 mK/nW	6.32 kΩ	200 µV	31.6 nA	2.3 pW	50.2 mΩ (4.6 µK) 87.0 mΩ (8.1 µK)	1.0 Ω (92.6 µK) 1.0 Ω (93.8 µK)	±4 mK	62 µK	±0.2 mK	4 mK
500 mK	1.2482 kΩ	-2.7 kΩ/K	4.3 mK/nW	2 kΩ	200 µV	100 nA	12.5 pW	14.5 mΩ (5.4 µK) 29.2 mΩ (10.8 µK)	475 mΩ (176 µK) 474 mΩ (176 µK)	±4 mK	54 µK	±0.2 mK	4 mK
4.2 K	277.32 Ω	-32.2 Ω/K	2 µK/nW	632 Ω 2 kΩ	6.32 mV 200 µV	10 µA 100 nA	28 nW 2.8 pW	1.3 mΩ (40.4 µK) 29.2 mΩ (907 µK)	115 mΩ (3.6 mK) 183 mΩ (5.7 mK)	±4 mK	56 µK 5.6 nK	±0.2 mK	5.4 mK 7 mK
300 K	30.392 Ω	-65.4 mΩ/K	426 fK/nW	63.2 Ω 2 kΩ	6.32 mV 200 µV	100 µA 100 nA	304 nW 304 fW	130 µΩ (2.0 mK) 29.2 mΩ (446 mK)	12.3 mΩ (188 mK) 109 mΩ (1.7 K)	±78 mK	130 pK 129 aK	±0.2 mK	203 mK 1.7 K

FIGURE 1-15 ***Sensor performance for Lake Shore CX-1010-SD with 0.01 to 325 K calibration***

1.7.10 372/3726 Performance Specification Table

The values below apply to the measurement input. The control input operates over a reduced range indicated by the black bordered cells. These cells contain bracketed numbers to indicate the resolution that applies to the control input

Current excitation	Voltage range: 632 mV	200 mV	63.2 mV	20 mV	6.32 mV	2 mV	632 µV	200 µV	63.2 µV	20 µV	6.32 µV	2 µV
31.6 mA	20 Ω 20 µΩ 10 mW	6.32 Ω 6.3 µΩ 3.2 mW	2 Ω 2 µΩ 1 mW	632 mΩ 1.3 µΩ 320 µW	200 mΩ 400 nΩ 100 µW	63.2 mΩ 95 nΩ 32 µW	20 mΩ 36 nΩ 10 µW	6.32 mΩ 35 nΩ 3.2 µW	2 mΩ 40 nΩ 1 µW	* * *	* * *	* * *
10 mA	63.2 Ω 63 µΩ 3.2 mW	20 Ω 20 µΩ 1 mW	6.32 Ω 6.3 µΩ 320 µW	2 Ω 4 µΩ 100 µW	632 mΩ 1.3 µΩ 32 µW	200 mΩ 300 nΩ 10 µW	63.2 mΩ 120 nΩ 3.2 µW	20 mΩ 120 nΩ 1 µW	6.32 mΩ 130 nΩ 320 nW	2 mΩ 120 nΩ 100 nW	* * *	* * *
3.16 mA	200 Ω 200 µΩ 1 mW	63.2 Ω 63 µΩ 320 µW	20 Ω 20 µΩ 100 µW	6.32 Ω 13 µΩ 32 µW	2 Ω 4 µΩ 10 µW	632 mΩ 950 nΩ 3.2 µW	200 mΩ 390 nΩ 1 µW	63.2 mΩ 370 nΩ 320 nW	20 mΩ 400 nΩ 100 nW	6.32 mΩ 380 nΩ 32 nW	2 mΩ 400 nΩ 10 nW	* * *
1 mA	632 Ω 630 µΩ 3.2E-04	200 Ω 200 µΩ 100 µW	63.2 Ω 63 µΩ 32 µW	20 Ω 40 µΩ 10 µW	6.32 Ω 13 µΩ 3.2 µW	2 Ω 3 µΩ 1 µW	632 mΩ 1 µΩ 320 nW	200 mΩ 1 µΩ 100 nW	63.2 mΩ 1.3 µΩ 32 nW	20 mΩ 1.2 µΩ 10 nW	6.32 mΩ 1.3 µΩ 3.2 nW	2 mΩ 1 µΩ 1 nW
316 µA	2 kΩ 2 mΩ 100 µW	632 Ω 630 µΩ 32 µW	200 Ω 200 µΩ 10 µW	63.2 Ω 130 µΩ 3.2 µW	20 Ω 40 µΩ 1 µW	6.32 Ω 9.5 µΩ 320 nW	2 Ω 3.8 µΩ 100 nW	632 mΩ 3.7 µΩ 32 nW	200 mΩ 4 µΩ 10 nW	63.2 mΩ 3.8 µΩ 3.2 nW	20 mΩ 4 µΩ 1 nW	6.32 mΩ 3.7 µΩ 320 pW
100 µA	6.32 kΩ 6.3 mΩ 32 µW	2 kΩ 2 mΩ 10 µW	632 Ω 630 µΩ 3.2 µW	200 Ω 400 µΩ 1 µW	63.2 Ω 130 µΩ 320 nW	20 Ω 30 µΩ 100 nW	6.32 Ω 12 µΩ 32 nW	2 Ω 12 µΩ 10 nW	632 mΩ 13 µΩ 3.2 nW	200 mΩ 12 µΩ 1 nW	63.2 mΩ 13 µΩ 320 pW	20 mΩ 12 µΩ 100 pW
31.6 µA	20 kΩ 20 mΩ 10 µW	6.32 kΩ 6.3 mΩ 3.2 µW	2 kΩ 2 mΩ 1 µW	632 Ω 1.3 mΩ 320 nW	200 Ω 400 µΩ 100 nW	63.2 Ω 95 µΩ 32 nW	20 Ω 37 µΩ 10 nW	6.32 Ω 37 µΩ 3.2 nW	2 Ω 40 µΩ 1 nW	632 mΩ 38 µΩ 320 pW	200 mΩ 40 µΩ 100 pW	63.2 mΩ 37 µΩ 32 pW
10 µA	63.2 kΩ 63 mΩ 3.2 µW	20 kΩ 20 mΩ 1 µW	6.32 kΩ 6.3 mΩ 320 nW	2 kΩ 4 mΩ 100 nW	632 Ω 1.3 mΩ 32 nW	200 Ω 300 µΩ 10 nW	63.2 Ω 120 µΩ 3.2 nW	20 Ω 120 µΩ 1 nW	6.32 Ω 130 µΩ 320 pW	2 Ω 120 µΩ 100 pW	632 mΩ 130 µΩ 32 pW	200 mΩ 120 µΩ 10 pW
3.16 µA	200 kΩ 200 mΩ 1 µW	63.2 kΩ 63 mΩ 320 nW	20 kΩ 20 mΩ 100 nW	6.32 kΩ 13 mΩ 32 nW	2 kΩ 4 mΩ 10 nW	632 Ω 950 µΩ 3.2 nW	200 Ω 370 µΩ 1 nW	63.2 Ω 370 µΩ 320 pW	20 Ω 400 µΩ 100 pW	6.32 Ω 380 µΩ 32 pW	2 Ω 400 µΩ 10 pW	632 mΩ 370 µΩ 3.2 pW
1 µA	632 kΩ 630 mΩ 320 nW	200 kΩ 200 mΩ 100 nW	63.2 kΩ 63 mΩ 32 nW	20 kΩ 40 mΩ 10 nW	6.32 kΩ 13 mΩ 3.2 nW	2 kΩ 3 mΩ 1 nW	632 Ω 1.2 mΩ 320 pW	200 Ω 1.2 mΩ 100 pW	63.2 Ω 1.3 mΩ 32 pW	20 Ω 1.2 mΩ 10 pW	6.32 Ω 1.3 mΩ 3.2 pW	2 Ω 1.2 mΩ 1 pW
316 nA	2 MΩ 2 Ω 100 nW	632 kΩ 630 mΩ 32 nW	200 kΩ 200 mΩ 10 nW	63.2 kΩ 130 mΩ 3.2 nW	20 kΩ 40 mΩ 1 nW	6.32 kΩ 13 mΩ 320 pW	2 kΩ 4 mΩ 100 pW	632 Ω 3.8 mΩ 32 pW	200 Ω 4 mΩ 10 pW	63.2 Ω 3.8 mΩ 3.2 pW	20 Ω 4 mΩ 1 pW	6.32 Ω 3.8 mΩ 320 fW
100 nA	6.32 MΩ ** 32 nW	2 MΩ 2 Ω 10 nW	632 kΩ 630 mΩ 3.2 nW	200 kΩ 400 mΩ 1 nW	63.2 kΩ 130 mΩ 320 pW	20 kΩ 30 mΩ 100 pW	6.32 kΩ 13 mΩ 32 pW	2 kΩ 16 [30] mΩ 10 pW	632 Ω 13 mΩ 3.2 pW	200 Ω 12 mΩ 1 pW	63.2 Ω 13 mΩ 320 fW	20 Ω 12 mΩ 100 fW
31.6 nA	20 MΩ ** 10 nW	6.32 MΩ ** 3.2 nW	2 MΩ 2 Ω 1 nW	632 kΩ 1.3 Ω 320 pW	200 kΩ 300 mΩ 100 pW	63.2 kΩ 160 mΩ 32 pW	20 kΩ 100 mΩ 10 pW	6.32 kΩ 63 [95] mΩ 3.2 pW	2 kΩ 40 mΩ 1 pW	632 Ω 38 mΩ 320 fW	200 Ω 40 mΩ 100 fW	63.2 Ω 38 mΩ 32 fW
10 nA	63.2 MΩ ** 3.2 nW	20 MΩ ** 1 nW	6.32 MΩ ** 320 pW	2 MΩ 3 Ω 100 pW	632 kΩ 1.6 Ω 32 pW	200 kΩ 600 mΩ 10 pW	63.2 kΩ 470 mΩ 3.2 pW	20 kΩ 300 [400] mΩ 1 pW	6.32 kΩ 130 mΩ 320 fW	2 kΩ 160 mΩ 100 fW	632 Ω 130 mΩ 32 fW	200 Ω 120 mΩ 10 fW
3.16 nA	* * *	63.2 MΩ ** 320 pW	20 MΩ ** 100 pW	6.32 MΩ ** 32 pW	2 MΩ 9 Ω 10 pW	632 kΩ 4.7 Ω 3.2 pW	200 kΩ 3 Ω 1 pW	63.2 kΩ 1.6 [1.9] Ω 320 fW	20 kΩ 1 Ω 100 fW	6.32 kΩ 630 mΩ 32 fW	2 kΩ 500 mΩ 10 fW	632 Ω 380 mΩ 3.2 fW
1 nA	* * *	* * *	63.2 MΩ ** 32 pW	20 MΩ ** 10 pW	6.32 MΩ ** 3.2 pW	2 MΩ 30 Ω 1 pW	632 kΩ 16 Ω 320 fW	200 kΩ 6 [10] Ω 100 fW	63.2 kΩ 5.1 Ω 32 fW	20 kΩ 3 Ω 10 fW	6.32 kΩ 1.3 Ω 3.2 fW	2 kΩ 1.6 Ω 1 fW
316 pA	*	*	*	63.2 MΩ ** 3.2 pW	20 MΩ ** 1 pW	6.32 MΩ ** 320 fW	2 MΩ 90 Ω 100 fW	632 kΩ 47 [51] Ω 32 fW	200 kΩ 30 Ω 10 fW	63.2 kΩ 16 Ω 3.2 fW	20 kΩ 10 Ω 1 fW	6.32 kΩ 6.3 Ω 320 aW
100 pA				* * *	63.2 MΩ ** 320 fW	20 MΩ ** 100 fW	6.32 MΩ ** 32 fW	2 MΩ 300 Ω 10 fW	632 kΩ 160 Ω 3.2 fW	200 kΩ 100 Ω 1 fW	63.2 kΩ 51 Ω 320 aW	20 kΩ 30 Ω 100 aW
31.6 pA				*	*	63.2 MΩ ** 32 fW	20 MΩ ** 10 fW	6.32 MΩ ** 3.2 fW	2 MΩ 900 Ω 1 fW	632 kΩ 470 Ω 320 aW	200 kΩ 300 Ω 100 aW	63.2 kΩ 160 Ω 32 aW
10 pA						* * *	63.2 MΩ ** 3.2 fW	20 MΩ ** 1 fW	6.32 MΩ ** 320 aW	2 MΩ 3 kΩ 100 aW	632 kΩ 1.6 kΩ 32 aW	200 kΩ 1 kΩ 10 aW
3.16 pA						* * *	* * *	63.2 MΩ ** 320 aW	20 MΩ ** 100 aW	6.32 MΩ ** 32 aW	2 MΩ 9 kΩ 10 aW	632 kΩ 4.7 kΩ 3.2 aW
1 pA						* * *	* * *	* * *	63.2 MΩ ** 32 aW	20 MΩ ** 10 aW	6.32 MΩ ** 3.2 aW	2 MΩ 30 kΩ 1 aW

200 kΩ — resistance range
100 Ω [150 Ω] — measurement resolution [control resolution]
1.0 fW — power

Resistance range: Full scale resistance range, nominal 20% over range.
Resolution: RMS noise with 18 s filter settling time (approximates 3 s analog time constant). Noise specified at ½ full scale resistance at room temperature.
Power: Excitation power at one-half full scale resistance.
Precision: Dominated by measurement temperature coefficient (±0.0015% of reading ±0.0002% of range)/°C

Accuracy
- ±0.03% + 0.005% of range
- ±0.05% + 0.008% of range
- ±0.1% + 0.015% of range
- ±0.3% + 0.05% of range
- ±0.5% + 0.08% of range
- ±1.0% + 0.15% of range

* *Range not available*
** *Range available, not specified*

FIGURE 1-16 ***372/3726 performance specification table***

1.7.11 372/3708 Performance Specification Table

Current excitation \ Voltage range	6.32 mV	2.0 mV	632 µV	200 µV	63.2 µV	20 µV	6.32 µV	2.0 µV
31.6 mA	200 mΩ 200 nΩ 100 µW	63.2 mΩ 63 nΩ 32 µW	20 mΩ 40 nΩ 10 µW	6.32 mΩ 13 nΩ 3.2 µW	2.0 mΩ 10 nΩ 1.0 µW	* * *	* * *	* * *
10 mA	632 mΩ 630 nΩ 32 µW	200 mΩ 200 nΩ 10 µW	63.2 mΩ 130 nΩ 3.2 µW	20 mΩ 40 nΩ 1.0 µW	6.32 mΩ 32 nΩ 320 nW	2.0 mΩ 32 nΩ 100 nW	* * *	* * *
3.16 mA	2.0 Ω 2.0 µΩ 10 µW	632 mΩ 630 nΩ 3.2 µW	200 mΩ 400 nΩ 1.0 µW	63.2 mΩ 130 nΩ 320 nW	20 mΩ 100 nΩ 100 nW	6.32 mΩ 100 nΩ 32 nW	2.0 mΩ 100 nΩ 10 nW	* * *
1 mA	6.32 Ω 6.3 µΩ 3.2 µW	2.0 Ω 2.0 µΩ 1.0 µW	632 mΩ 1.3 µΩ 320 nW	200 mΩ 400 nΩ 100 nW	63.2 mΩ 320 nΩ 32 nW	20 mΩ 320 nΩ 10 nW	6.32 mΩ 320 nΩ 3.2 nW	2.0 mΩ 320 nΩ 1.0 nW
316 µA	20 Ω 20 µΩ 1.0 µW	6.32 Ω 6.3 µΩ 320 nW	2.0 Ω 4.0 µΩ 100 nW	632 mΩ 1.3 µΩ 32 nW	200 mΩ 1.0 µΩ 10 nW	63.2 mΩ 1.0 µΩ 3.2 nW	20 mΩ 1.0 µΩ 1.0 nW	6.32 mΩ 1.0 µΩ 320 pW
100 µA	63.2 Ω 63 µΩ 320 nW	20 Ω 20 µΩ 100 nW	6.32 Ω 13 µΩ 32 nW	2.0 Ω 4.0 µΩ 10 nW	632 mΩ 3.2 µΩ 3.2 nW	200 mΩ 3.2 µΩ 1.0 nW	63.2 mΩ 3.2 mΩ 320 pW	20 mΩ 3.2 µΩ 100 pW
31.6 µA	200 Ω 200 µΩ 100 nW	63.2 Ω 63 µΩ 32 nW	20 Ω 40 µΩ 10 nW	6.32 Ω 13 µΩ 3.2 nW	2.0 Ω 10 µΩ 1.0 nW	632 mΩ 10 µΩ 320 pW	200 mΩ 10 µΩ 100 pW	63.2 mΩ 10 µΩ 32 pW
10 µA	632 Ω 630 µΩ 32 nW	200 Ω 200 µΩ 10 nW	63.2 Ω 130 µΩ 3.2 nW	20 Ω 40 µΩ 1.0 nW	6.32 Ω 32 µΩ 320 pW	2.0 Ω 32 µΩ 100 pW	632 mΩ 32 µΩ 32 pW	200 mΩ 32 µΩ 10 pW
3.16 µA	2.0 kΩ 2.0 mΩ 10 nW	632 Ω 630 µΩ 3.2 nW	200 Ω 400 µΩ 1.0 nW	63.2 Ω 130 µΩ 320 pW	20 Ω 100 µΩ 100 pW	6.32 Ω 100 µΩ 32 pW	2.0 Ω 100 µΩ 10 pW	632 mΩ 100 µΩ 3.2 pW
1 µA	6.32 kΩ 6.3 mΩ 3.2 nW	2.0 kΩ 2.0 mΩ 1.0 nW	632 Ω 1.3 mΩ 320 pW	200 Ω 400 µΩ 100 pW	63.2 Ω 320 µΩ 32 pW	20 Ω 320 µΩ 10 pW	6.32 Ω 320 µΩ 3.2 pW	2.0 Ω 320 µΩ 1.0 pW
316 nA	20 kΩ 20 mΩ 1.0 nW	6.32 kΩ 6.3 mΩ 320 pW	2.0 kΩ 4.0 mΩ 100 pW	632 Ω 1.3 mΩ 32 pW	200 Ω 1.0 mΩ 10 pW	63.2 Ω 1.0 mΩ 3.2 pW	20 Ω 1.0 mΩ 1.0 pW	6.32 Ω 1.0 mΩ 320 fW
100 nA	63.2 kΩ 63 mΩ 320 pW	20 kΩ 40 mΩ 100 pW	6.32 kΩ 13 mΩ 32 pW	2.0 kΩ 6.0 mΩ 10 pW	632 Ω 3.2 mΩ 3.2 pW	200 Ω 3.2 mΩ 1.0 pW	63.2 Ω 3.2 mΩ 320 fW	20 Ω 3.2 mΩ 100 fW
31.6 nA	200 kΩ 400 mΩ 100 pW	63.2 kΩ 130 mΩ 32 pW	20 kΩ 60 mΩ 10 pW	6.32 kΩ 20 mΩ 3.2 pW	2.0 kΩ 20 mΩ 1.0 pW	632 Ω 10 mΩ 320 fW	200 Ω 10 mΩ 100 fW	63.2 Ω 10 mΩ 32 fW
10 nA	632 kΩ 1.9 Ω 32 pW	200 kΩ 600 mΩ 10 pW	63.2 kΩ 200 mΩ 3.2 pW	20 kΩ 200 mΩ 1.0 pW	6.32 kΩ 63 mΩ 320 fW	2.0 kΩ 63 mΩ 100 fW	632 Ω 32 Ω 32 fW	200 Ω 32 mΩ 10 fW
3.16 nA	2.0 MΩ 6.0 Ω 10 pW	632 kΩ 2.0 Ω 3.2 pW	200 kΩ 2.0 Ω 1.0 pW	63.2 kΩ 630 mΩ 320 fW	20 kΩ 600 mΩ 100 fW	6.32 kΩ 200 mΩ 32 fW	2.0 kΩ 200 mΩ 10 fW	632 Ω 100 mΩ 3.2 fW
1 nA	6.32 MΩ ** 3.2 pW	2.0 MΩ 20 Ω 1.0 pW	632 kΩ 6.3 Ω 320 fW	200 kΩ 6.0 Ω 100 fW	63.2 kΩ 3.2 Ω 32 fW	20 kΩ 2.0 Ω 10 fW	6.32 kΩ 630 mΩ 3.2 fW	2.0 kΩ 1.0 Ω 1.0 fW
316 pA	* * *	6.32 MΩ ** 320 fW	2.0 MΩ 60 Ω 100 fW	632 kΩ 19 Ω 32 fW	200 kΩ 20 Ω 10 fW	63.2 kΩ 6.3 Ω 3.2 fW	20 kΩ 3.0 Ω 1.0 fW	6.32 kΩ 3.2 Ω 320 aW
100 pA	* * *	* * *	6.32 MΩ ** 32 fW	2.0 MΩ 200 Ω 10 fW	632 kΩ 63 Ω 3.2 fW	200 kΩ 60 Ω 1.0 fW	63.2 kΩ 32 Ω 320 aW	20 kΩ 20 Ω 100 aW
31.6 pA	* * *	* * *	* * *	6.32 MΩ ** 3.2 fW	2.0 MΩ 600 Ω 1.0 fW	632 kΩ 190 Ω 320 aW	200 kΩ 200 Ω 100 aW	63.2 kΩ 63 Ω 32 aW
10 pA	* * *	* * *	* * *	* * *	6.32 MΩ ** 320 aW	2.0 MΩ 2.0 kΩ 100 aW	632 kΩ 630 Ω 32 aW	200 kΩ 600 Ω 10 aW
3.16 pA	* * *	* * *	* * *	* * *	* * *	6.32 MΩ ** 32 aW	2.0 MΩ 6.0 kΩ 10 aW	632 kΩ 1.9 kΩ 3.2 aW

200 kΩ — resistance range
100 Ω — measurement resolution
1.0 fW — power

Resistance range: Full scale resistance range, nominal 20% over range.
Resolution: RMS noise with 18 s filter settling time (approximates 3 s analog time constant). Noise specified at ½ full scale resistance at room temperature.
Power: Excitation power at one-half full scale resistance.
Precision: Dominated by measurement temperature coefficient (±0.0015% of reading ±0.0002% of range)/°C.

Accuracy
- ±0.03% + 0.005% of range
- ±0.05% + 0.008% of range
- ±0.1% + 0.015% of range
- ±0.3% + 0.05% of range
- ±0.5% + 0.08% of range
- ±1.0% + 0.15% of range

* *Range not available*
** *Range available, not specified*

FIGURE 1-17 ***372/3708 performance specification table***

1.8 Specifications

Full specifications about the Model 372 are provided on our website. Please see the Technical Specifications page at https://www.lakeshore.com/372.

Feature	Description
Power requirement	100, 120, 220, 240 VAC, ±10%, 50 or 60 Hz, 90 VA
Size	435 mm wide × 89 mm high × 368 mm deep (17 in × 3.5 in × 14.5 in), full rack
Weight	6.8 kg (15 lb)
Approvals	See https://www.lakeshore.com/compliance/.
Operating conditions	
Rated accuracy	15 °C to 35 °C
Reduced accuracy	5 °C to 40 °C

TABLE 1-1 ***Key specifications***

1.9 Safety Summary and Symbols

Observe these general safety precautions during all phases of instrument operation, service, and repair. Failure to comply with these precautions or with specific warnings elsewhere in this manual violates safety standards of design, manufacture, and intended instrument use. Lake Shore Cryotronics, Inc. assumes no liability for Customer failure to comply with these requirements.

The Model 372 protects the operator and surrounding area from electric shock or burn, mechanical hazards, excessive temperature, and spread of fire from the instrument. Environmental conditions outside of the conditions below may pose a hazard to the operator and surrounding area.

- Indoor use
- Altitude to 2000 m
- Temperature for safe operation: 5 °C to 40 °C
- Maximum relative humidity: 80% for temperature up to 31 °C decreasing linearly to 50% at 40 °C
- Power supply voltage fluctuations not to exceed ±10% of the nominal voltage
- Overvoltage category II
- Pollution degree 2

Ground the Instrument
To minimize shock hazard, the instrument is equipped with a 3-conductor AC power cable. Plug the power cable into an approved 3-contact electrical outlet or use a 3-contact adapter with the grounding wire (green) firmly connected to an electrical ground (safety ground) at the power outlet. The power jack and mating plug of the power cable meet Underwriters Laboratories (UL) and International Electrotechnical Commission (IEC) safety standards.

Ventilation
The instrument has ventilation holes in its top and side covers. Do not block these holes when the instrument is operating.

Do Not Operate in an Explosive Atmosphere
Do not operate the instrument in the presence of flammable gases or fumes. Operation of any electrical instrument in such an environment constitutes a definite safety hazard.

Keep Away from Live Circuits
Operating personnel must not remove instrument covers. Refer component replacement and internal adjustments to qualified maintenance personnel. Do not replace components with power cable connected. To avoid injuries, always disconnect power and discharge circuits before touching them.

Do Not Substitute Parts or Modify Instrument
Do not install substitute parts or perform any unauthorized modification to the instrument. Return the instrument to an authorized Lake Shore Cryotronics, Inc. representative for service and repair to ensure that safety features are maintained.

Cleaning
Do not submerge instrument. Clean only with a damp cloth and mild detergent. Exterior only.

Desktop Installation
When installing the instrument in a desktop environment, ensure it is mounted on a flat, level surface.

Improper Use
If the instrument is used in a manner that is not specified by Lake Shore, the safety protections provided by the instrument are no longer guaranteed, and may be impaired.

Direct current (power line)

Alternating current (power line)

Alternating or direct current (power line)

3~ Three-phase alternating current (power line)

Earth (ground) terminal

Protective conductor terminal

Frame or chassis terminal

On (supply)

Off (supply)

Equipment protected throughout by double insulation or reinforces insulation (equivalent to Class II of IEC 536—see Annex H)

CAUTION: High voltages; danger of electric shock; background color: yellow; symbol and outline: black

CAUTION or WARNING: See instrument documentation; background color: yellow; symbol and outline: black

FIGURE 1-18 ***Safety symbols***

Chapter 2: Cooling System Design and Temperature Control

2.1 General

This chapter provides background information related to the Model 372 AC Resistance Bridge and bridge measurements in general. It is intended to give the user insight into the benefits and limitations of the instrument and help apply the features of the Model 372 to a variety of experimental challenges. For information on how to install the Model 372 refer to Chapter 3. Instrument operation information is contained in Chapter 4.

2.2 Useful Temperature Range

The Model 372 is not an ordinary temperature controller. As described throughout this manual, every effort has been made to measure resistance with as little power as possible entering the resistor. The need for such careful attention is most evident at low temperatures, particularly below 1 K. The instrument is not limited to those applications and is useful in applications above 1 K when excitation power is critical. When excitation power is not critical, however, alternatives may be available that provide faster readings or lower cost.

The lowest temperature at which the Model 372 can make useful resistance measurements is difficult to define. In a practical sense, the instrument is limited by its need for four electrically conductive leads to be attached to a resistor and that resistor attached to a cold surface. Heat conduction and noise pick-up in the resistor leads limit the lowest temperature that can be achieved in this environment, even before an instrument is attached. The diminishing thermal contact between the resistor and cold surface at lower and lower temperatures only exaggerate the problem. In general, resistance bridge measurements are considered routine down to 100 mK in a capable cryogenic cooling system. With careful installation of a high quality bridge like the Model 372 it is not difficult to achieve 50 mK. Below that, each detail of the overall system has to be optimized to a low end of between 5 and 20 mK.

2.3 Temperature Scales

The goal of a temperature scale is to provide a measured value that is thermodynamically consistent with the physical laws of nature. As technology has advanced requiring better accuracy and consistency, so has the definition of the temperature scale. The currently internationally accepted temperature scale is the International Temperature Scale of 1990 (ITS-90). ITS-90 is defined from 0.65 K to the highest temperature realizable in terms of the Planck radiation law. The detailed definition relies on primary thermometers, fixed points, and interpolating instruments. The full realization of the temperature scale as defined is generally only done by national metrology institutes such as the U.S. National Institute of Standards (NIST). The practical propagation of the scale is typically done using secondary standards calibrated by a national metrology institute.

For temperatures below the range of ITS-90, the Comite International des Poids et Mesures (CIPM) adopted the Provisional Low Temperature Scale from 0.9 mK to 1 K (PLTS-2000). This temperature scale is based on noise and magnetic thermometry and defined using a ^{3}He melting curve thermometer.

Lake Shore calibrations are traceable to the above two scales, ITS-90 and PLTS-2000. Further details on these scales can be found in the information provided on the website for the Bureau International des Poids et Mesures (BIPM).

2.4 Cryogenic Cooling System Terminology

There are many different cryogenic cooling systems used in laboratories today and it would be impossible to describe them all in this manual. This section briefly illustrates the three most common cooling systems capable of reaching temperatures below 1 K. This is an attempt to demonstrate how the Model 372 can be integrated into these systems for resistance measurement, temperature measurement and temperature control. It is hoped that from these examples, those knowledgeable in cryogenic techniques will become familiar with the terminology used throughout this manual and the intended operation of many of the instrument features.

2.4.1 Dilution Refrigerator Terminology

Dilution refrigerators remain the workhorse of low temperature research down to approximately 5–10 mK. So many variations of factory and home built units exist that it is unlikely that any two are identical (FIGURE 2-1) illustrates only the most basic features.

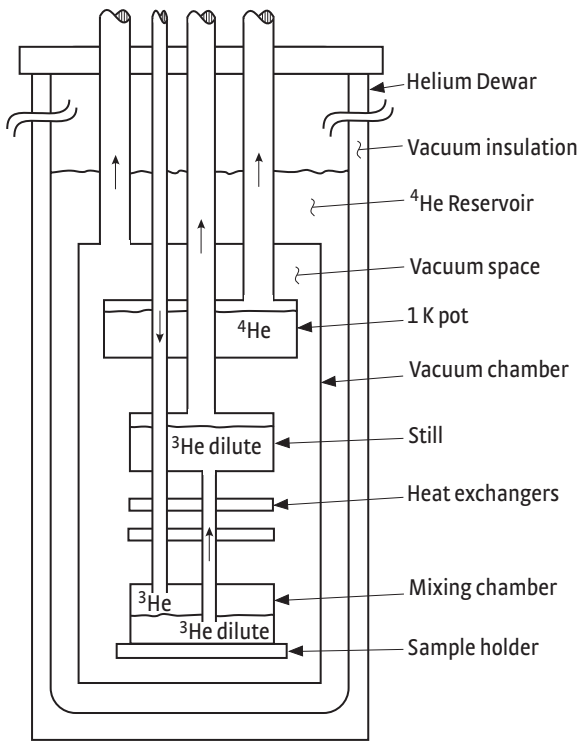


FIGURE 2-1 ***Dilution refrigerator block diagram***

- **Helium Dewar:** a vacuum insulated Dewar that is large enough to contain the following components. The Dewar sometimes includes a nitrogen outer jacket to improve efficiency or a superconducting magnet coil when needed.
- **^{4}He reservoir:** a reservoir of liquid ^{4}He at atmospheric pressure that provides bulk cooling down to 4.2 K. The reservoir precools gas entering the vacuum space, and it acts as a radiation shield for refrigeration components.
- **Vacuum space:** the vacuum space insulates the refrigeration components and provides a clear workspace.
- **1 K pot (^{4}He evaporator):** this is a pumped reservoir of ^{4}He maintained at 1 K. It is used in the process of condensing ^{3}He-rich gas returning from the pumping system. It is also used as a heat sink for measurement leads. The 1 K pot is a good temperature sensor location for cool down monitoring and troubleshooting.
- **Still heat exchanger:** this is the chamber used to evaporate ^{3}He out of a dilute ^{3}He mix (liquid ^{4}He containing some ^{3}He-sometimes called mash). It is the first stage below 1 K, and it is also used to liquefy returning ^{3}He. The still requires a

few milliwatts of heat from a resistive heater to sustain evaporation. The Model 372 still output can drive the still heater. This is a good location for a diagnostic temperature sensor.

- **Heat exchangers:** one or more heat exchangers serve to cool returning ^{3}He rich liquid to near the temperature of the mixing chamber. They are also used to heat sink measurement leads.
- **Mixing chamber:** this is the chamber where the cooling action takes place. It holds both ^{3}He rich liquid and dilute ^{3}He separated by a phase boundary. When ^{3}He is depleted from the mix by the still, more crosses the phase boundary to maintain equilibrium. In doing so, it is expanded into (diluted by) the ^{4}He creating cooling of the chamber. The mixing chamber is the best location for a temperature control sensor and resistive heater. The Model 372 sample heater output can control temperature by driving the heater under closed loop PID control or open loop control.
- **Load (sample holder):** this is located at the end of the mixing chamber where experiments can take place. It may either be part of or attached to the mixing chamber and it is often designed for a unique purpose. This will require a separate temperature sensor if its temperature is different from the mixing chamber.

2.4.2 ^{3}He Cryostat

^{3}He cryostats are the least complex systems capable of reaching temperatures down to 300 mK. Even at such relatively warm temperatures, the benefits of a well-designed resistance bridge must be considered when selecting instrumentation. FIGURE 2-2 illustrates the basic features.

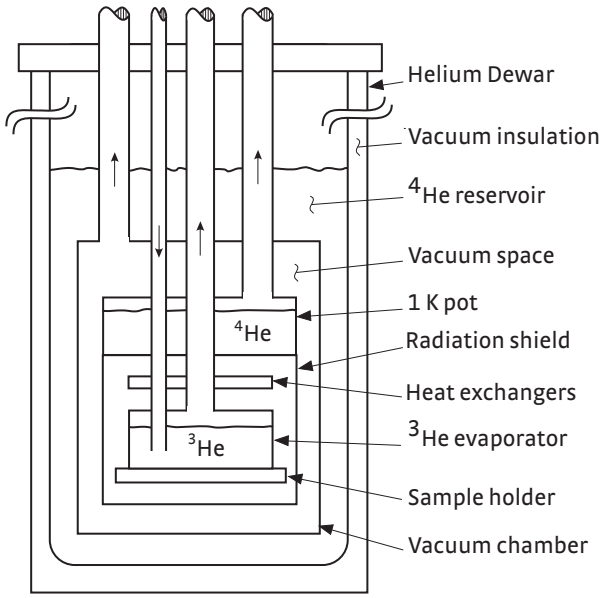


FIGURE 2-2 ***^{3}He cryostat block diagram***

- **Helium Dewar:** a vacuum insulated Dewar that is large enough to contain the following components. The Dewar sometimes includes a nitrogen outer jacket to improve efficiency.
- **^{4}He reservoir:** a reservoir of liquid ^{4}He at atmospheric pressure that provides bulk cooling down to 4.2 K. The reservoir precools gas entering the vacuum space, and it acts as a radiation shield for refrigeration components.
- **Vacuum space:** the vacuum space insulates the refrigeration components and provides a clear workspace.

- **1 K pot (^{4}He evaporator):** this is a pumped reservoir of ^{4}He maintained at 1 K. It is used in the process of condensing ^{3}He-rich gas returning from the pumping system. It is also used as a heat sink for measurement leads. The 1 K pot is a good temperature sensor location for cool down monitoring and troubleshooting.
- **Heat exchangers:** one or more heat exchangers serve to cool returning ^{3}He rich liquid to near the temperature of the ^{3}He evaporator. They are also used to heat sink measurement leads.
- **^{3}He evaporator:** this is the chamber where the cooling action takes place. Liquid ^{3}He is pumped under vacuum to reduce its boiling point to approximately 300 mK. The ^{3}He evaporator is the best location for a temperature control sensor and resistive heater. The Model 372 sample heater output can control temperature by driving the heater under closed loop PID control or open loop control.
- **Load (sample holder):** this is located at the end of the ^{3}He evaporator where experiments can take place. It may either be part of or attached to the evaporator and it is often designed for a unique purpose. This will require a separate temperature sensor if its temperature is different from the ^{3}He evaporator.

2.4.3 Adiabatic Demagnetization Refrigerator (ADR)

The principals of ADR have been known for some time and many very capable systems have been built over the years. There has recently been growing interest in the technology and it is finding its way into many new applications. The Model 372 has many features that can help automate and control these systems in temperature ranges where leaded resistance measurement is practical. FIGURE 2-3 illustrates a typical first stage of an ADR but other stages can be added.

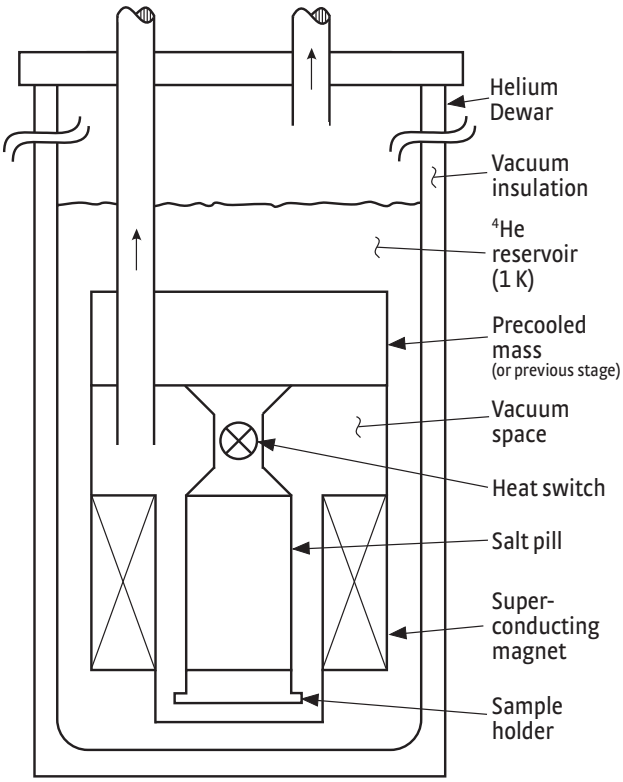


FIGURE 2-3 ***Single-stage ADR block diagram***

- **Helium Dewar:** a vacuum insulated Dewar that is large enough to contain the following components. The Dewar sometimes includes a nitrogen outer jacket to improve efficiency. It contains a superconducting magnet if the first magnetic cooling stage has a large mass.

- **^{4}He reservoir:** a reservoir of liquid ^{4}He at atmospheric pressure that provides bulk cooling down to 4.2 K. The reservoir precools leads entering the vacuum space, and it acts as a radiation shield for refrigeration components.
- **Precooling stage:** the precooling stage brings the system to a low enough temperature for magnetic cooling to become practical. It also acts as a heat sink for the first magnetic cooling stage. This can be a cryogenic refrigerator, ^{4}He bath, pumped ^{4}He cryostat or pumped ^{3}He cryostat. This is a good location for a temperature sensor for cool down monitoring and troubleshooting.
- **Vacuum space:** the vacuum space insulates the refrigeration components and provides a clear workspace.
- **Heat switch:** this allows thermal contact between the precooling stage and salt pill during magnetization then provides thermal isolation during demagnetization (cooling). The construction of the switch varies depending on temperature but could be superconducting, exchange gas (gas-gap) or mechanical. Several types of heat switches can be controlled by the Model 372 still heater or analog output.
- **Salt pill:** this is a mass of paramagnetic salt that acts as the refrigerant. It is magnetized while in thermal contact with the precooling stage so the heat of magnetization is removed and entropy is reduced. Then it is demagnetized while it is thermally isolated and as field is decreased, the salt must decrease in temperature to maintain constant entropy. This is the best location for a temperature control sensor. The Model 372 sample heater output can control temperature by trimming current in the magnet with its heater output current source. Resistive heating is not desirable.
- **Superconducting magnet:** the superconducting magnet magnetizes the salt pill while in thermal contact with the precooling stage then demagnetizes it when thermally isolated. The magnet power supply can be programmed by the Model 372 analog output and controlled via computer interface.
- **Load (sample holder):** this is located at the end of the ^{3}He evaporator where experiments can take place. This will require a separate temperature sensor if its temperature is different from the ^{3}He evaporator.

2.5 Model 372 Theory of Operation

This section describes the theory for operation of the Model 372.

2.5.1 Why is the Model 372 Called a Bridge?

Historically precision resistance measurements were made using one of several bridge configurations that are a combination of known reference resistors and the unknown being measured. Normally in a bridge, one of the known resistors is trimmed until a null appears at the measurement point of the circuit and at that time the unknown resistance can be calculated. The technique is preferred because it relies only on resistance ratios and a null measurement, which eliminates many of the errors normally associated with amplifiers, voltage references and current sources. As electronic circuits improve, fewer and fewer applications require the complexity of a bridge measurement.

Some applications benefit so much from the bridge configuration that they may never be replaced. One example is strain gauge measurements that integrate both measurement and temperature compensation into the bridge. Another application, often seen in physics laboratories, is low-noise resistance measurement where the reference resistors and unknown are all cooled to reduce thermal noise.

The Model 372 does not use a bridge configuration for resistance measurement. Its measurement technique is described in the next paragraph. Side-by-side testing demonstrated that the precision circuits in the Model 372 would not benefit from a bridge configuration unless the reference resistors were cooled. This path was not chosen because installation is more complicated than most applications require. The name "bridge" was retained to reflect the instrument's heritage of precision resistance measurements.

2.5.2 Resistance Measurement

The Model 372 uses a four lead, AC sine wave measurement technique to achieve the best possible accuracy with the lowest possible excitation. Similar circuits are used extensively in small signal measurement because they are flexible and can extract small signals from relatively noisy environments.

The Model 372 uses current excitation because controlled current is very stable and predictable. Current can also be scaled easily, which is necessary to achieve low excitation. The Model 372 has 21 current settings down to 3.16 pA for the measurement input and 6 current settings down to 316 pA for the control input. These currents have low noise and almost no DC component to self heat the measured resistor. For the measurement input, two excitation modes are available to best utilize the features of the current source in different applications. One lower current setting, 1 pA, is available but not specified because leakage and bias currents in the measurement circuits can be a large percentage of the excitation current. The 1 pA current setting should be used for relative measurements only.

Precision resistance measurements use a four lead method to eliminate the effect of nominal lead resistance. Excitation current is driven on one pair of leads while the resulting signal voltage is measured on the second pair. Measurement errors from lead resistance are proportional to current flowing in the voltage leads. Instrument voltage inputs are expected to have high impedance to prevent the unwanted current from flowing. The Model 372 has very high input impedance to both normal mode voltages (created by current source excitation) and common mode voltages (created by induced noise on the leads).

Offset voltages occur in every electronic circuit both in signal amplifiers and in lead wire connections that create thermal EMF voltages. Offset voltages affect accuracy more when the excitation is small because they are a larger percentage of the measured voltage. AC measurements allow AC filters that greatly reduce amplifier offsets at each stage, allowing higher amplifier gain and greater sensitivity than DC techniques. The AC technique is also naturally bipolar allowing any remaining thermal EMF or offset voltages to be averaged out of the resistance measurement. A relatively low frequency of excitation, 13.7 Hz, was chosen to reduce the effects of lead capacitance on the measurement. In a typical cryostat, lead heat sink requirements and limited space make it difficult to reduce capacitance enough to operate at significantly higher frequency.

Environmental noise can limit the resolution of low excitation measurement. Well-designed filtering is necessary to reclaim the desired signal from the noise. The Model 372 takes advantage of the AC filtering technique called phase sensitive detection that is used in lock-in amplifiers. This technique has no DC equivalent. Even with phase sensitive detection it is still necessary to shield these leads from environmental noise. The Model 372 facilitates appropriate shielding techniques in addition to offering more active noise reduction circuits.

2.5.3 Reactance Measurement

In practice, no measurement of a resistive load is purely resistive. There are likely capacitive and inductive components that must be taken into consideration to fully characterize the load being measured. The complex number formed by adding the resistive component (real) and the capacitive/inductive reactive component (imaginary) is called impedance.

The Model 372 uses an on-board digital signal processor to digitally synthesize the excitation current used for measurements. In addition, the Model 372 has the capability to measure both the resistive, in-phase voltage and the reactive, out of phase voltage measured across the load. The out-of-phase voltage measured across the load is comprised of both capacitive and inductive elements, causing the measured AC voltage to be 90 degrees out-of-phase, or "in quadrature" with the excitation current. A reactance reading that is dominated by capacitance will be negative while a reactance reading dominated by inductance will be positive.

Impedance (Z) is generally represented as Z = R + jX, where R is resistance in ohms, j is the imaginary component and X is reactance, also in ohms. This is represented slightly differently in the Model 372 and is shown below in FIGURE 2-4.

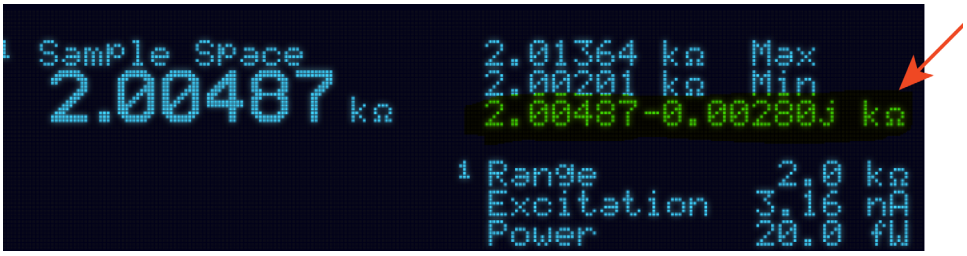


FIGURE 2-4 ***Display showing impedance measurement***

Keep in mind, the Model 372 impedance measurement assumes the load is modeled as a series RLC circuit. There are many applications, such as determining parasitic cable capacitance, where it is desired to measure the reactance parallel to the resistive load. In those cases, the resistive and reactive readings can be input into the following simple formulas to determine the equivalent parallel loads.

$$Resistance_{parallel} = \frac{Resistance^2_{series} + Reactance^2_{series}}{Resistance_{series}}$$

$$Reactance_{parallel} = \frac{Resistance^2_{series} + Reactance^2_{series}}{Reactance_{series}}$$

2.5.4 Excitation Modes

The Model 372 uses current source excitation for resistance measurements. Current excitation mode is the most fundamental measurement mode because operation is tied directly to hardware function. For the measurement input only, the instrument firmware is also able to simulate voltage excitation of the measured resistor to create a second operating mode. Some users prefer voltage excitation mode because it matches the operation of other bridges and permits convenient limiting of excitation power. Resistance range selection is different in these two modes as described below. Autorange is available for both modes.

2.5.4.1 Voltage Excitation Mode—Measurement Input Only

The user specifies an input voltage range that is a "not to exceed" setting for the instrument. The instrument selects the appropriate current setting that keeps the voltage across the resistor as high as possible without exceeding the voltage range setting. Current is changed when the resistance range changes to maintain the voltage limit. This mode is preferred when measuring negative temperature coefficient materials common in cryogenic temperature sensors. With voltage limited, excitation power in the resistor reduces with lowering temperature ($P = V^2/R$) limiting the effect of self-heating.

2.5.4.2 Current Excitation Mode

The user specifies a fixed excitation current. The instrument selects the appropriate voltage gain for the selected resistance range. The instrument changes gain when the resistance range changes. In this mode it is easier to calculate the actual power in the measured resistor ($P = I^2 \times R$) because the true current is displayed. In voltage excitation mode the voltage range displayed is the maximum not the actual voltage.

2.5.5 Resistance Ranges

2.5.5.1 Measurement Input

The Model 372 measurement input has full-scale resistance ranges from 2 mΩ to 2 MΩ. Many ranges are available, but with several different excitation levels, it makes resistance range selection somewhat more involved than it initially appears. The goal is to use enough excitation to maintain reasonable accuracy, resolution and settling time without putting too much heat into the resistor. Higher resistance ranges from 6.32 MΩ to 63.2 MΩ, are available but not specified because the effects of lead capacitance cannot be eliminated at such high resistances. These ranges should be used for relative measurements only.

The selected resistance range and excitation are always shown on the instrument display. Refer to FIGURE 1-13 through FIGURE 1-15 for resistance and excitation ranges. As shown in the figures, not every combination of excitation and resistance range is possible. Unusable combinations of range and excitation are automatically locked out. The Model 372 also continuously calculates and displays the excitation power being dissipated in the resistor as additional feedback to the operator. The excitation current source is shorted inside the instrument to minimize transients during range changes.

Manual operation allows the user to choose both the excitation and resistance range. The instrument does not change ranges automatically. If the input resistance is too large for the range an overload condition will be indicated. This mode is used when the system is very sensitive to excitation changes or if changes in input resistance are too fast for the auto range algorithms.

The Model 372 has an autorange feature that will increase the resistance range any time the measured resistance is greater than full scale for the range and decrease the range any time the measured resistance is below 20% of full scale. The ranges have an approximate 20% over range capability so in most cases the instrument will increase range before an overload appears. Autorange works with either voltage or current excitation. It will not change the excitation setting in order to reach a resistance range that is not available for the present selection.

2.5.5.2 Control Input

The Model 372 control input has full-scale resistance ranges from 2 kΩ up to 632 kΩ. Unlike the measurement input, the excitation current is a function of the selected resistance range. The resistance range is selectable from the Control Input (Input A) menu. Also, when in the Control Input display mode, the selected resistance range and current excitation are displayed.

The control input allows the user to manually choose the either the excitation current or resistance range. By default, the instrument does not change ranges automatically. If the input resistance is too large for the range an overload condition will be indicated. This mode is used when the system is very sensitive to excitation changes or if changes in input resistance are too fast for the auto range algorithms.

In addition to the standard autorange routine that is similar to the measurement input, the Model 372 control input comes equipped with a specialized autorange routine that is tailored to the ROX™-RX102B sensor. While still trying to maintain the best signal to noise ratio, the ROX™-RX102B autorange algorithm takes into consideration sensor-self heating and accuracy.

2.5.6 Measurement Circuit

The idea that small signal measurement instruments require special consideration during installation is expressed frequently in this manual. The following paragraphs illustrate how to treat the instrument and its environment as a "measurement circuit" and in general how to integrate instruments like the Model 372. The circuit analogy is appropriate because almost anything electrical or electronic in a laboratory has the potential to induce electric field (E-field) or magnetic field (H-field) noise on the measurement.

Since electrical noise is everywhere it is better to begin each installation with a good instrumentation strategy than try to deal with noise after measurements are compromised. Most parts of a good strategy are obvious, some are not and even the best plans do not work all the time. The Model 372 offers several features that help control noise and maintain signal integrity. The ideas and instrument features described in this manual often have to be tried in different combination to get the best results. Specific recommendations on installation and lead wiring are given in Chapter 3.

2.5.6.1 Shielding and Grounding Theory

Begin any installation by separating noise sources from their targets. Sources of E-field and H-field noise can be just about anything, but the targets are most often signal leads and other wires and cables. H-field coupling can be dramatically reduced with an inch or less of separation. E-field noise requires more separation but is also more easily shielded. Noise can also travel easily on the power lines. If clean power lines are not available for instrumentation, place line filters on noisy electrical or electronic devices. The line filter in the instrument can help, but noise is always better reduced at its source.

The best defense against E-field noise is a conductive shield around the measurement. The more complete the shield the better. Ideally it should extend from the instrument measurement circuits, through the cables, and down to the measured resistor. This ideal approach is impractical in all but a few cryogenic systems. The practical approach is to connect the shield from the measurement circuits, through the room temperature cables, to the conductive Dewar or vacuum chamber. This creates a faraday shield around the entire measurement circuit.

The shield can only divert noise energy away from measurement leads if that energy has a place to go. Connecting the shield to measurement common (shield pin in the connector) is a good starting point, but may not be the final answer. The Model 372's measurement common is isolated from earth ground and has, by design, a relatively low capacitive "mass". Most noise sources are referenced to earth ground and, if they are large enough, can swing the entire measurement, shield and all. The shield may require a low impedance connection to earth ground to effectively divert noise energy, but connecting to earth ground can cause new problems.

If the shield or any other part of the measurement circuit is connected to earth ground, it is necessary to prevent ground loops that couple line frequency noise into the measurement. A ground loop is created when measurement common is tied to earth ground at more than one point. The isolation of the instrument breaks the loop between the instrument power cord and the measurement common. No loop is formed if measurement common is tied to earth ground at only one point.

Loops are also the primary means of coupling H-field noise. Conductive shields do not reduce the effects of H-fields. Two ways to minimize H-field coupling are to reduce the loop area or break the loop (as described with ground loops). Loop area can be minimized by tightly twisting lead pairs, both voltage and current, within the shielded cables. This not only reduces the loop area, but also guarantees that both leads are exposed to the same common mode effects which are rejected by the Model 372 measurement input.

2.5.6.2 Shields

Shields provide a low impedance path to measurement common to block E-field noise from getting to the signal leads. Shield pins are provided in the input connectors as attachment points for the shield conductors in lead cables. Shielding individual leads inside a cryostat is difficult because of limited space and the potential for heat leak. Cable shields are usually connected to the experimental Dewar to create a faraday shield around the measurement.

2.5.6.3 Electrical Isolation

The precision analog front end of the Model 372 is electrically isolated from digital circuitry and chassis of the instrument by opto-couplers. This can improve measurements in two ways. First, isolation makes it more difficult for digital noise from control circuits and computer interfaces to affect the measurement leads. Second, isolation breaks ground loops. It is often desirable to extend shielding from the measurement leads to the experimental Dewar. If the instrument shield and the Dewar both have low impedance to earth ground, a ground loop will be created. Isolation separates the instrument measurement from earth ground to break the loop.

2.5.6.4 Driven Guards—Measurement Input Only

For installations where lead length is greater than 3m (10 ft) or measured resistance is greater than 100 kΩ, four separate driven guards are provided. The driven guards follow the signal voltage on each lead to maintain the lowest possible voltage difference between the signal lead and its immediate shield. This technique reduces the undesired effect of cable capacitance. Without the guards, cable capacitance and measured resistance act together as a low-pass filter and can attenuate the desired measurement signal. Cables between the instrument and cryostat can be guarded even if it is impractical to continue guarding inside the cryostat. Driven guards are not available for scanned inputs, but they are recommended for cables that run between the Model 372 and optional scanners.

2.5.6.5 Active Common Mode Reduction—Measurement Input Only

It is common for precision measurement equipment to use a differential input as the first stage of signal conditioning. The differential input offers high impedance on both input voltage terminals to reduce the effect of common mode voltage (voltage that acts on both leads at the same time). Common mode voltage can come from many sources including external noise coupling into the lead wires and the instrument's own current source.

To reduce the effect of common mode voltage further, the Model 372 includes an active common mode reduction circuit. This circuit dynamically adjusts the operation point of the current source output to minimize the common mode voltage seen at the measurement input. Active common mode reduction allows the system to operate in environments that would otherwise saturate the instrument's differential input amplifiers. The effect of active common mode reduction is most evident when excitation current is 1 μA or greater, but it should be left on most of the time. Active common mode reduction should be turned off any time a measurement lead is tied to measurement common (shield). The reduction circuit will not operate properly in this configuration because the symmetry of the measurement is lost. Measurements can be made with one lead grounded if the active common mode reduction feature is turned off.

2.5.6.6 Matched Impedance Current Source

The Model 372 takes the idea of a differential input one step further with a unique feature in its current source. The two current source output terminals have the same source impedance, similar to the voltage input terminals of a differential input that have the same input impedance. The resistor being measured and all noise sources in the environment "see" the same impedance on both current source leads when looking back into the instrument.

The circuit improves the measurement in two ways. First, the differential input remains truly differential and performs well measuring any value of resistor. Traditional current sources with different impedance on each lead (one lead grounded) can lessen the common mode rejection of a differential input especially when measuring large resistors. Second, common mode noise sources have the same effect on both sides of the resistor being measured ensuring that common mode voltages are not turned into normal mode voltages (voltages are present between measurement leads). Common mode voltage is rejected by the differential input, but normal mode error voltage is measured along with the desired signal.

2.5.7 Measurement Speed and Filtering

The Model 372 has a built-in firmware low-pass filter with a time constant of 200 ms. This minimum filtering is sufficient to measure small resistance values with large excitation, but that is not the true purpose of the AC bridge. As resistance increases and excitation decreases, additional filtering and longer time constants are necessary to maintain good resolution.

Additional filtering is done in the instrument firmware as a linear average. Linear averaging requires more memory than exponential filter algorithms, but it gives the best possible settling time. Exponential filters implemented in firmware can take several times as long to settle for the same number of filter points. Unfortunately, linear filters do not have a well behaved frequency response. The frequency response of a linear filter has the shape of a damped sine wave rather than the sloped roll-off of a first order low pass. This can create problems when trying to filter periodic noise that has a frequency lower than the excitation frequency.

The input hardware settles about 1 s after a large resistance change if no range change is required. When the firmware filter is turned on, that filter settling time must be added to the hardware settling time to approximate overall settling. Firmware filter settling time settings are available 1 s to 200 s. Please remember that filtering does not reduce the electrical noise that reaches the resistor and therefore will not reduce self-heating from noise.

Range change requires additional settling because the internal circuits need time to reestablish their operating point. The hardware settles in 2 to 3 s after range change. Settling may take a little longer especially if resistance is very large or excitation is very low. A change pause can be programmed into the instrument to allow for settling without disturbing other instrument firmware features. During the pause period, features including filter, max/min capture, analog voltage output calculations and temperature control and error testing are suspended. The pause time can be set from 3 to 60 s and must be added to the filter settling time to approximate overall settling after range change. Scan channel change is similar to range change except the new channel may autorange after a channel change creating a further delay.

The instruments A/D sampling (update) rate is 10 readings/s and all readings are available over computer interface with an efficiently written program. This rate allows the A/D to capture any resistance changes that are able to pass through the input hardware. The temperature control loop, analog voltage outputs and max/min capture are updated with each A/D reading. The display is updated at 2 readings/s.

2.6 Noise Sources

The effect of electrical noise is usually small and can be ignored when making routine measurements, but all noise matters when signals fall to the microvolt level. The following paragraphs describe the most common noise source encountered with small signal measurements and some techniques that can help reduce their effect. More specific installation instructions are given in Chapter 3. The Model 372 offers a diagnostic monitor voltage output that can be helpful in diagnosing noise related problems. The instrument will also display a message if noise overloads the measurement electronics. Refer to Chapter 7 for more information on diagnosing noise problems.

2.6.1 Induced Electrical Noise

Noise from the environment is typically classified as either electric field (E-field) or magnetic field (H-field). E-field noise capacitively couples into measurement leads or the resistor being measured. Voltage is induced on the leads as if the noise source and lead are two halves of a capacitor. The amount of coupling is related to the voltage change at the source, the common area between source and receiver (length of lead) and dielectric between them (distance in air). A cable shield is the first line of defense against E-field noise. No measurement cable of any length should be run from the Model 372 without a shield. The shield provides a low impedance path to measurement common that prevents the voltage change at the source from being seen at the measurement leads.

H-field noise inductively couples into measurement leads or other conductive loops. Current is induced in the lead as if the noise source and lead are two halves of a transformer. The amount of coupling is related to the field change from the source and the loop area. Tightly twisted leads inside the shielded cable reduce the total loop area and minimize the effect of H-field noise. It is also effective to move the instrument and leads away from noise sources because field strength reduces by the inverse cube of distance.

Even with proper installation it is difficult to reduce induced noise below 1 to 10 μV. High resistance ranges are affected more because the leads create a more efficient antenna when they are terminated at a high resistance.

2.6.2 Ground Loop Noise

Ground loops produce noise that acts similar to induced noise but the cause of the noise is different. Current is generated in any conductive circuit or loop when that loop contains changing current or magnetic field. In measurements this problem is commonly referred to as a ground loop and generally results when improperly grounded instruments are exposed to AC line current. Isolation reduces ground loop

noise by breaking the loop or circuit. The Model 372 has a well-designed power supply and uses galvanic isolation between the instrument chassis and measurement circuits. Careful installation is necessary to take advantage of the isolation. Ground loop noise can be kept as low as a few microvolts and usually appears as line frequency or one of its low harmonics.

2.6.3 Analog Circuit Noise

The current source and amplifiers inside the Model 372 make a contribution to measurement noise. Circuits were carefully chosen to maintain good noise performance over a wide resistance range without generating high leakage currents that could self heat resistors. Leakage current limits the practical current excitation range of the Model 372 to a few picoamps. Most analog circuit noise is distributed over a broad frequency band. It is often referred to as 1/f noise because there is equal noise power in each decade of frequency. Instrument noise, specified in Table 1-1, is dominated by amplifier noise for low resistances and by resistor thermal noise for high resistances. Noise from both sources can be further reduced with longer filter settling time.

2.6.4 Digital Circuit Noise

All digitally controlled instruments emit some high-frequency noise both through the air and on their leads. Emission from a Model 372 is very low and will not affect resistance measurements or heat measured resistors if the instrument is installed properly. The high frequency noise can interfere with very sensitive measurements being made in the same Dewar. Interference can be minimized by separating the instruments and their leads outside the Dewar and placing ferrite beads on the Model 372 measurement leads, near the Dewar, to stop the noise from getting inside. Wrapping leads through the large beads more than one time improves their attenuation of unwanted signals. A more common source of digital noise than the instrument itself is digital computers used for data acquisition. Computers with their high clock seeds generate a wide spectrum of noise and transmit it through line cords and interface cables. Isolation in the Model 372 separates the measurement circuits from interface circuits but computers must still be treated carefully during installation of a system.

2.6.5 Resistor Thermal Noise

Thermal noise or Johnson noise is the most common noise associated with resistors. This noise is present in all resistors, is independent of excitation, and has a flat frequency spectrum. The equation for Johnson noise is often expressed as:
$V_{noise} = (4kTR\Delta f)^{1/2}$, where V_{noise} is the RMS noise voltage, k is Boltzmann's constant (1.38×10^{-23} J/K), T is temperature in Kelvin and Δf is the noise bandwidth in Hz.

Some considerations when using the equation: peak-to-peak noise will be within 5 times RMS noise more than 99% of the time, f can be calculated several ways and a common method is $(\pi/2)\ f_{3db}$ where f_{3db} is the 3 dB bandwidth of the dominant low-pass filter in the measuring circuit. As a practical example, the noise voltage of a 100 kΩ resistor at room temperature using a 1 s filter is approximately 16 nV RMS or 80 nV PP which is 8% of a measurement made at 1 µV. This must be kept in mind when trying to characterize the measurement noise of the Model 372. The published noise specifications in Chapter 1 assume the resistive load is at room temperature. When the resistor is cooled, the thermal noise drops accordingly.

Please note that thermal noise is normally the biggest noise source in resistors being measured but not the only one. Metallic conductors approach the theoretical limit for thermal noise, but other materials have additional noise, sometimes referred to as flicker noise, that has a 1/f spectrum. Flicker noise is different for every material, is proportional to current and can change with construction techniques including lead attachment. Shot noise, which is a product of the discrete nature of electron flowing through resistive materials, is insignificant in most measurement, but can become measurable when current drops into the picoamp range.

2.6.6 Interference Between Two Model 372s

The digital phase sensitive detectors in the Model 372 effectively cancel noise from external sources, but they do have some difficulty canceling noise at or very near their own measurement frequencies. An odd operating frequency was intentionally chosen to minimize the possibility that outside noise sources would be the same frequency as the instrument. One source of noise that can be very close to the measurement frequency of a Model 372 is another Model 372. When two or more instruments are operated with leads closely coupled in the same Dewar it is possible for them to beat against each other and cause small oscillations. If this happens, the measurement frequency of one instrument can be changed slightly to avoid interference. Because of this, it is also recommended to keep the control input and measurement input excitation frequencies set to different values when being used simultaneously.

2.6.7 Vibration Noise

Noise can be generated in lead cables when they are moved or vibrated. This noise can be related to the triboelectric effect or changes in capacitance between conductors in the cable. A sudden movement of measurement lead cables can overload the instrument momentarily when it is on the most sensitive ranges. Cables carrying small signals should be fastened down without putting strain on the connections. For similar reasons, physical vibration of the Model 372 during sensitive measurements should be avoided.

2.7 Measurement Error

This section discusses measurement error.

2.7.1 Warm Up and Temperature Drift

When the Model 372 is first turned on it should be allowed to warm up for at least 30 min before use to allow its internal temperature to stabilize. Warm up is an exaggerated form of temperature drift because the temperature change inside the enclosure is larger and faster than would be experienced in a laboratory setting. Temperature drift, change in reading with change in ambient temperature, is small in the Model 372 and seldom a significant factor in absolute accuracy. Measurement repeatability is often dominated by temperature drift and temperature change should be considered if the instrument is being installed in a rack. If possible, precision measurement instruments should not be placed in the same rack with large power supplies or other equipment that can change the rack temperature quickly. Instrument racks should be well ventilated to prevent the build up of heat.

2.7.2 Resistor Installation

Installation is an important part of resistor measurements at cryogenic temperatures. The measured resistor must be at the temperature of its surroundings for the measurement to be valid. Some installation suggestions for temperature sensors are given in section 2.9. These suggestions are applicable to any resistor.

2.7.3 Resistor Self-Heating and Thermal Resistance

A resistor self heats when the electrical power being put into the measured resistor is large enough to warm the resistor above the temperature of its surroundings. Electrical power gets into the resistor from both the necessary excitation current and undesirable noise (section 2.6). Errors from self-heating are dangerous because they can easily go undetected. One strategy for detecting these errors is to understand the thermal resistance of the resistor and predict its reaction to excitation and noise.

Self-heating (ΔT_{sh}) is a product of the resistor's thermal resistance (R_t) expressed in kelvin per watt (K/W), and excitation power (P_s) expressed in watts.

$\Delta T_{sh} = R_t P_s$; P_s can be calculated as excitation current squared, times measured resistance ($P_s = I^2R$).

A familiar form of self-heating is sensor self-heating in resistive temperature detectors (RTDs), but the same principles apply to any resistor being measured. Specifications for the Model 372 include typical sensor characteristics for a Germanium RTD that estimates the thermal resistance of the sensor. This example demonstrates how excitation current must be reduced to compensate for the increase in thermal resistance at lower temperature. Otherwise self-heating would become a significant part of the overall accuracy. Calculations like this are difficult to do for two reasons, first, manufactures do not always publish specifications on thermal resistance and second, the actual thermal resistance is very dependent on installation. An explanation of how to calculate thermal resistance of a temperature sensor is given in the Lake Shore Temperature Measurement and Control Catalog, Appendix A.

With an estimate of thermal resistance, the effect of increased excitation current can be predicted. If self-heating behavior does not match the prediction, noise power may be high enough to heat the resistor.

2.7.4 Lead Resistance

Measurement leads in cryogenic systems routinely have resistance of tens or even hundreds of ohms. Lead wire is chosen for its thermal properties first and electrical resistance is a secondary consideration. The Model 372 measurement circuits can tolerate significant lead resistance without measurement error. A lead resistance specification of 100 Ω plus 10% of resistance range (for each of the four leads) is given for most excitation currents. This lead resistance will give a measurement error that is small compared to the specified accuracy on the resistance range, and in most cases the error is not measurable. The lead resistance specification is reduced to 10 Ω plus 10% of resistance range for the highest current excitations. At the higher currents, lead resistance of 100 Ω can create drops of several volts in each lead. These large voltage swings will measurably affect the millvolt and microvolt resistor measurements. If lead resistance exceeds the specified values, the instrument will measure with reduced accuracy until the compliance voltage of approximately 7 V RMS is reached. Keep the resistance in all of the leads similar whenever possible to maintain measurement balance.

2.7.5 Current Leakage

Lead wiring cannot be taken for granted when determining accuracy of cryogenic resistance measurements. Cryostats are notorious for having bundles of long, thinly insulated leads tightly wrapped around every available heat sink area. Shorts are inevitable. Lead wires should be “ohmed out” on a regular basis to test for short circuits that develop over time and thermal cycling.

2.7.6 Cable Capacitance

Cable capacitance and measured resistance act together as a low-pass filter to attenuate the desired measurement signal and shift its phase. Low excitation frequencies were chosen for the Model 372 to minimize this effect but capacitance can still contribute to measurement error when resistance is high. Driven guards should be used when measuring resistance above 100 kΩ, but they often cannot be used inside of the cryostat and are not available for scanner input leads.

2.7.6.1 Parasitic Capacitance Resistance Compensation

While the driven guards provide an excellent means of compensating for cable capacitance, they do not eliminate it. That, combined with the inability to guard the lines from the scanner to the resistive load in the cryostat means a parasitic capacitance, will still be present. This parasitic capacitance siphons current intended for the resistor, and results in a lower voltage being measured across the resistor. The end result is an artificially low resistance reading.

The Model 372 provides a complex sensor reading to allow the user to differentiate between the resistive (real) component and the reactive (imaginary) component of its

load. In this case, the reactive component of interest is parasitic capacitance. For an introduction to the reactance reading, refer to section 2.5.3.

It is possible to calculate the parallel resistance value based on the measured impedance, and therefore arrive at a corrected resistance value that removes the effect of the parasitic capacitance. Given an impedance measurement of: $R_{measured} + jX_{measured}$, the following equation can be used:

$$R_{corrected} = R_{measured} + \frac{{X_{measured}}^2}{R_{measured}}$$

As an example, if the Model 372 is displaying the a complex impedance reading of: 66.50 – j15.30 kΩ

Because of the large negative reactive component, it is concluded that there is a large parasitic capacitance in the test setup. The equivalent parallel resistance can be calculated to determine the approximate value of the actual DUT (assuming it is purely resistive):

$$R_{corrected} = 66.50\ k\Omega + \frac{(-15.30\ k\Omega)^2}{66.50\ k\Omega} = 70.02\ k\Omega$$

Lead inductance can create similar effects, but typical installation techniques will not produce large enough inductance to cause measurable attenuation. Inductance should be considered if inductive noise reduction filters are placed in series with leads.

2.7.6.2 Parasitic Capacitance Temperature Compensation

When making temperature measurements with a resistive sensor, the effects of parasitic capacitance that create an offset in measured resistance will result in a corresponding offset in measured temperature. This temperature reading can also be corrected using the measured real and imaginary components of the measurement:

$$T_{corrected} = T_{measured} + \frac{{X_{measured}}^2}{R_{measured} \times Sensor\ Sensitivity\ (\Omega/K)}$$

Keep in mind that most cryogenic temperature sensors are NTC (negative temperature coefficient) devices, which means sensor sensitivity will be a negative value. Therefore, the corrected temperature value will always be less than the measured temperature value. This temperature calculation may be useful in scenarios where it is not feasible to entirely remove the parasitic cable capacitance.

As an example, consider the previous case, where the impedance measurement was 66.50 – j15.30 kΩ. If this was a Rox RX-102A sensors and the temperature reading was being displayed as 55 mK, then the corrected temperature would be (assuming sensitivity is 5.09 kΩ/mK):

$$T_{corrected} = 55.0\ mK + \frac{(-15.30\ k\Omega)^2}{66.50\ k\Omega \times -5.09\ k\Omega/mK} = 54.3\ mK$$

This corrected calculation can be very useful in determining whether the reactance measured by the Model 372 is affecting the reported temperature in either a significant or tolerable way.

2.7.7 Instrument Operation

There are several features of the Model 372 intended to improve accuracy and repeatability that can have the opposite effect when used improperly. This paragraph provides a brief summary of operating features that may contribute to measurement uncertainty.

Use of the Model 372 with the 3726 scanner can improve or degrade measurement performance depending on application. The scanner can be calibrated in the field to eliminate gain error, but the addition of a large number of lead wires is always unpredictable. More information on the 3726 scanner is given in section 2.9.

Measurement uncertainty increases significantly if the instrument hardware and firmware filters are not allowed to settle completely. Information on settling time is given in section 2.5.7.

The common mode reduction feature can significantly reduce common mode voltage on the measurement input leads when used as described in section 2.5.6.5. Be sure that all four measurement leads remain isolated from measurement common (shield) when using the feature.

If one lead is grounded the instrument is able to make resistance measurements as long as the common mode reduction feature is turned off. This is not a recommended operating mode and accuracy is reduced. Increase in measurement error will not exceed 0.1% in a typical installation.

The Model 372 is calibrated and specified at its default measurement frequency of 13.7 Hz. An additional calibration is done at each of the four alternate measurement frequencies to compensate for the frequency response of the hardware filters. This calibration eliminates instrument errors only and will not account for attenuation caused by lead capacitance that is different at each frequency.

The autorange algorithm includes a hysteresis band to prevent instability when the measured resistor is at a range boundary. It is possible for the instrument to choose a different excitation current when approaching a value from below than it chooses when approaching from above. Autorange should not be used when a specific excitation current is critical.

2.8 Operating Tradeoffs

Any measurement must be optimized to provide the best practical result, and trade-offs must be made to favor the most important measurement characteristics. Some of the common trade-offs of low temperature resistance measurement are described below.

2.8.1 Resistor Self-heating vs. Excitation

Even after leads are properly heat sunk and noise is effectively shielded, there can be a temperature error in resistance measurements that comes from within. Self-heating will occur when the power from excitation current is large enough to warm the resistor above the temperature of its surroundings. The effect is most noticeable at low temperatures because the thermal conduction at material boundaries (thermal boundary resistance) becomes very poor. Proper attachment of the resistor to the cooling source is critical but cannot eliminate the problem entirely.

If noise is not suspected as a potential problem, it may be easier to measure the effect of self-heating using the many current ranges available in the Model 372 than to try to calculate thermal resistance.

1. Begin by cooling the resistor to the desired temperature and measure its value using current excitation; select a current in the middle of the available choices.

2. Step the current down a range, approximately a decade in power, and measure resistance again. A change in measured value indicates self-heating was present on the higher range.
3. Continue reducing current until the change is no longer significant to the measurement.
4. If the first step down did not indicate self-heating, step current up to improve resolution.
5. Thermal resistance changes with temperature so this process must be repeated at several temperatures.

2.8.2 Excitation vs. Signal-to-Noise

Since excitation power has such a dramatic effect on self-heating, why doesn't everyone use the lowest excitation range? The answer is noise, or more appropriately signal-to-noise. Noise from a variety of sources affects the small signals used to make bridge measurements. Lowering excitation makes the signals even smaller, but unfortunately doesn't decrease the noise. The noise sources described in section 2.6 are a fact of life. Even with careful installation, their effects cannot be reduced below a few microvolts. That is why the Model 372 does not have voltage excitation below 2 μV. The goal of most experiments is to choose an excitation that is the best compromise between self-heating and signal to noise. The monitor output (section 3.7) can be used to view the amplified signal coming into the input of the Model 372. Seeing the amplitude and frequency of noise at this point can help identify its sources as an aid in troubleshooting.

2.8.3 Signal-to-Noise vs. Measurement Bandwidth

The noise sources described in section 2.6 combine to reduce the resolution of small signal measurements. There are some common themes in the way noise interacts with measurements: noise effects worsen when signal size decreases, when resistance increases and when bandwidth increases. Excitation is limited by self-heating and cannot always be increased to create larger signals. Resistance can seldom be changed because it is the quantity being measured.

That leaves bandwidth to overcome signal-to-noise and improve resolution. If noise cannot be reduced at its source, it has to be averaged out. Reducing measurement bandwidth can help with nearly every continuous noise source including induced noise at discrete frequencies, 1/f circuit noise and broadband thermal noise. Unfortunately there is a trade-off, and it is time.

All small signal measurement instruments include some type of bandwidth limiting to improve resolution. The band limiting capabilities are so closely tied to instrument performance that most resolution specifications are given at a specified time constant or bandwidth. The Model 372 uses a combination of analog band pass with digital low-pass filters and averaging. The digital phase sensitive detector (PSD) in the Model 372 is a very narrow band pass filter. The output of the PSD is run through a digital low-pass filter with 200 ms time constant to give an equivalent, sampled DC voltage. The user cannot change these two filters, making 200 ms the widest bandwidth possible on the Model 372. Once the input signal has been digitally rectified and filtered using the 200 ms low-pass filter, the user can choose additional digital averaging to reduce bandwidth further and increase resolution.

Unfortunately, reducing bandwidth increases time constant and settling time slows the instrument response to real changes in resistance; because those changes are averaged along with the noise. Probably the most frustrating aspect of using a resistance bridge is realizing that when noise can be as large as the signal being measured, it takes a lot of time averaging to separate the two. Returning to the thermal noise

example above: if the noise voltage of a 100 kΩ resistor at room temperature, using a 1 s filter is approximately 80 nV PP, reducing it by a decade to 8 nV PP would require increasing the time constant 100 s (bandwidth to 10 ms). This reality is unappealing to most investigators because actual changes in resistance that take less than a few hundred seconds could easily be missed.

2.9 3726 and 3708 Scanner

The 3726 scanner expands the input capability of the Model 372 from 1 to 16 channels. The 3708 expands the input capability of the Model 372 from 1 to 8 channels and provides an even lower noise, low resistance measurement. Refer to section 1.2 for details on the differences between the available scanners.

The scanners are made up of relay switches for current and voltage signals of each channel, a times 100 amplifier for the voltage signals going back to the Model 372 and necessary control circuits. The scanner is housed in a separate shielded enclosure so that it can be placed near the test Dewar. Power for the scanner is taken directly from the regulated DC power supplies of the Model 372. Mounting bracket and 3m (10 ft) cables to join the Model 372 are included with the scanner. Mating connectors are supplied for the scanner inputs.

All scanner circuits including its power supplies and enclosure are referenced to the isolated measurement common in the instrument. This arrangement protects low level measurement signals from noise. All inactive input leads are shorted to common to minimize noise pickup. Special care must be taken during installation to maintain low noise operation. Refer to section 3.6 for scanner installation.

The Model 372 can read any of the 16 scanner channels, one at a time. Channel change can be done manually or with the autoscan feature. The instrument stores input setup information for each channel and will use the appropriate setup for each channel when selected. Refer to section 4.9 for scanner operation.

2.9.1 Scanner Performance

Up to 16 resistors with up to 64 leads can be attached to the 3726 scanner. Up to 8 resistors with up to 32 leads can be attached to the 3708 scanner. The large number and potential length of lead wires provide an excellent path for noise to couple into the measurement system. Proper installation combined with the noise reduction features built into both the Model 372, and 3726 and 3708 scanners can minimize the effects, but a fully loaded scanner may never be as quiet as a single guarded and shielded resistance input. A measurable increase in noise is most likely when measuring large resistance of more than 100 kΩ. Large resistances pose an additional problem because the guards available for a single resistance input end at the scanner enclosure. Scanner and lead capacitance after that point can attenuate measurement signals for large resistors.

On the other hand, the times 100 amplifier in the scanner can actually reduce measurement noise in installations that require the Model 372 to be a significant distance from the test Dewar. The built-in amplifier in the scanner may improve measurements any time long input leads are required, even if only one channel is being used.

Accuracy is not as big a concern as noise when using the 3726 and 3708 scanners. The Model 372 AC measurement eliminates any voltage offsets that may be present in the scanner's relays or amplifier. The amplifier gain is calibrated at the factory and can be recalibrated in the field to keep scanner gain error well below overall measurement uncertainty.

Settling time is a concern any time multiple inputs are multiplexed and must be scanned. The channel change settling time of the 3726 and 3708 scanners are virtually the same as the range change settling time of the Model 372. Additional time may be required for the instrument to autorange if that feature is enabled and the resistance on the new channel changes significantly between scans.

2.10 Temperature Measurement

Temperature measurement is a popular use of resistance bridges because most of the temperature sensors that can operate at low temperatures are negative temperature coefficient resistive temperature detectors (NTC RTDs) and need the flexibility of a bridge. Resistive temperature sensors must be treated with the same care as any other resistor being measured at low temperatures. The Model 372 is well equipped to measure and control temperature using these devices.

2.10.1 Sensor Selection

Lake Shore offers a full line of cryogenic temperature sensors including several models that are well suited for low temperature work to 50 mK and below. Two of the most popular are germanium and ruthenium oxide RTDs. The Lake Shore Temperature Measurement and Control catalog gives detailed specifications of these sensors and should be consulted as a reference when choosing temperature sensors. The Model 372 will work with resistive temperature sensors from Lake Shore or any other manufacture. A few important selection criteria are discussed below.

2.10.1.1 Sensitivity

Sensitivity is often the most important criteria when selecting a temperature sensor because it dictates many of the other specifications including range, resolution and accuracy. Many NTC resistive materials like germanium have a beneficial characteristic of temperature sensitivity that makes them particularly useful at low temperatures. The resistance and sensitivity of these materials increase exponentially as temperature decreases. The sensitivity of the sensors is best at the lowest temperatures where signal to noise is worst, making them more useful at lower temperatures than a linear device of the same resistance.

2.10.1.2 Temperature Range

Every type of sensor has an upper and lower limit to its temperature range. The upper limit of an NTC resistor is normally the point at which sensitivity falls so low that the sensor is no longer useful. The exact temperature where this happens is determined by the sensor itself, instrumentation capabilities and required resolution. Sensors that have a few micro kelvin resolution at 50 mK may have a resolution of several kelvin at room temperature. The sensor may be useful to monitor warm up and cool down but has little experimental value.

The lower limit of an NTC resistor is the temperature at which self-heating makes the measurement impractical. As temperature decreases the thermal resistance between sensor and load increases and eventually the heat of excitation can no longer be dissipated into the load. A nice feature of NTC resistors is that resistance increases as temperature decreases and, if the voltage across the sensor is limited, excitation power in the sensor decreases to offset the increase in thermal resistance. Unfortunately there is always a temperature at which self-heating wins and it is usually between 10 mK and 50 mK. The exact temperature depends on the sensor construction, mounting and instrumentation used for readout.

2.10.1.3 Temperature Resolution

Temperature measurement resolution is controlled to a large extent by sensor sensitivity when using a resistance bridge. The temperature example given in the instrument specifications shows the sensitivity of a typical germanium RTD changing from 3.5 MΩ /K at 50 mK to 36Ω /K at 1 K. An associated change in resolution is also shown as 1.7 µK at 50 mK to 83 µK at 1 K. The reason that the drop in resolution is not as severe as the drop in sensitivity is that excitation current is increased approximately 1,000 times by the Model 372 to maintain practical measurement parameters. Sensitivity (and therefore resolution) of most sensors changes with temperature so it is important to choose a sensor with high sensitivity in the most critical temperature range. Two or more sensors may be necessary to cover a large range of temperature with high resolution.

2.10.1.4 Accuracy

Resistive thermometers serve well as secondary standards and are much easier to use than most primary thermometers. Accuracy of a resistive temperature sensor depends on how closely it is compared to a primary standard, how the temperature scale is interpreted, how much the sensor drifts over time and how well the conditions used in calibration are duplicated when the sensor is being used. General rules to achieve best accuracy are to choose a sensor with good stability and high sensitivity in the most critical temperature range, calibrate it carefully or purchase a calibration from a reputable company, install the sensor according to manufacturer recommendations and use the same excitation that was used during calibration. Do not forget to include instrumentation errors when determining overall accuracy and recalibrate both sensors and instruments on a regular basis. If the pieces are put together properly, accuracy of a few millikelvin is possible at low temperatures.

2.10.1.5 Packaging

Sensor packaging is important for two main reasons. First, the package creates sensor contact with its environment playing a key role in the overall thermal resistance. Second, the package protects the resistive element from stress that is normally caused by thermal contraction as the load cools. When choosing a pre-packaged sensor watch for a specification of thermal resistance or a recommended maximum excitation to make sure it is compatible with the experiment and measuring instruments. Also

make sure the package is "strain free" or makes some accommodation to reduce stress on the resistive element during thermal cycling. Many sensors are also offered without packaging for applications that require smaller size or lower mass than packaged sensors provide. These must be installed with the greatest care and all manufacture recommendations should be followed.

2.10.1.6 Environment

All cryogenic temperature sensors have to contend with high vacuum and drastic temperature changes but some experiments create an even more hostile environment by adding high magnetic fields, ionizing radiation and more. These additional requirements make sensor selection more difficult because they can limit the useful range of many sensors. The Lake Shore Temperature Measurement and Control catalog includes magnetic field dependence for most temperature sensors. Other specific data on environmental factors is included when available. Lake Shore Cernox® RTDs are an excellent choice for many of these critical applications.

2.10.2 Sensor Calibration

The Model 372 can convert the resistance of a sensor to temperature, using either linear or cubic spline interpolation methods, if a temperature response curve is loaded into the instrument. Most curves are generated from an individual sensor calibration because few sensors follow a standard curve at low temperatures. The instrument can use curve options, called CalCurves, available with Lake Shore calibrated sensors or curves generated by the user. The Lake Shore Temperature Measurement and Control catalog gives complete specifications for calibrated sensors and gives the calibration range available for each sensor.

The Model 372 uses either linear or cubic spline interpolation to convert sensor resistance to temperature. Linear interpolation tends to be simpler to implement and more predictable. However, this advantage is a tradeoff to the loss of accuracy along non-linear regions of the temperature curve.

Cubic spline interpolation offers a smoother curve fit, due to the continuous nature of the first and second derivatives, and tends to be more accurate than linear interpolation methods. In addition, it does not suffer from oscillations and instabilities on certain regions of the curve that higher order polynomials tend to exhibit.

NOTE

Cubic spline curves can only be loaded and modified over the remote computer interface.

If you wish to calibrate your sensors in house, Lake Shore recommends using the linear interpolation method. If you wish to use a cubic spline curve with your existing Lake Shore sensor, please contact Lake Shore.

When calibrating sensors in house, remember to account for errors caused by linear interpolation between curve breakpoints. The Model 372 allows curves with up to 200 breakpoints. If linear interpolation errors are larger than desired in a specific temperature range, more breakpoints can be added to reduce the error. NTC resistor breakpoints are entered as Log Ω vs. K which acts to linearize temperature response data.

2.10.2.1 Sensors Using Standard Curves

Some types of sensors behave in a very predictable manner and a standard temperature response curve can be created for them. Standard curves are a convenient and inexpensive way to get reasonable temperature accuracy. Sensors that have a standard curve are often used when interchangeability is important. Some individual sensors are selected for their ability to match a published standard curve, but in general these sensors do not provide the accuracy of a calibrated sensor. For convenience, the Model 372 has several standard curves included in firmware.

2.10.2.2 Curve Handler™

Lake Shore provides a software application, called Curve Handler™, which makes loading temperature curves into the Model 372 a very simple process. The program can copy curves from properly formatted files into the Model 372 user curve locations. You can also use it to read curves from the Model 372 and save them to files.

There are two versions of the Curve Handler™ application. The fully featured version is a 32-bit Microsoft Windows™ application that must be installed on a Windows™ PC. This version works with the IEEE-488, Ethernet, and USB computer interfaces on the Model 372, and allows you to manipulate the temperature curves directly in the program window. This version is compatible with the older format .340 curves and the newer .CURVE format that is needed to load cubic spline curves. This version will also work with all existing Lake Shore temperature controller and temperature monitor instruments. The Windows™ version of the Curve Handler™ application is available, free of charge, from the Lake Shore website at www.lakeshore.com.

The second version of Curve Handler™ is written in the Java™ programming language and is available through the Ethernet web interface on the Model 372. This version allows you to copy curves from files to the Model 372, and vice versa, but it does not allow manipulation of curve data, does not support the newer .CURVE format (needed to read/write cubic spline curves), and only works using the Ethernet interface. Refer to section 6.4.4 for details on connecting to the web interface and opening the embedded Curve Handler™ application.

2.10.3 Sensor Installation

This section highlights some of the important elements of proper temperature sensor installation. Information on installing temperature sensors applies equally well to other resistance measurements. For more detailed information, Lake Shore sensors are shipped with installation instructions covering that specific sensor type and package. The Lake Shore Temperature Measurement and Control Catalog includes an installation section as well. Lake Shore also offers a line of Cryogenic Accessories. Many of the materials discussed here are available through Lake Shore and can be ordered with sensors or instruments.

2.10.3.1 Mounting Materials

Choosing appropriate mounting materials is very important in a cryogenic environment. The high vacuum used to insulate cryostats is one source of problems. Materials used in these applications should have a low vapor pressure so they do not evaporate or out-gas and spoil the vacuum insulation. Metals and ceramics do not have this problem, but greases and varnishes must be checked. Another source of problems is the wide extremes in temperature that most sensors are exposed to. The linear expansion coefficient of a material becomes important when temperature changes are so large. Never try to permanently bond materials with linear expansion coefficients that differ by more than three. A flexible mounting scheme should be

used or the parts will break apart, potentially damaging them. The thermal expansion or contraction of rigid clamps or holders could crush fragile samples or sensors that do not have the same coefficient. Thermal conductivity is a property of materials that can change with temperature. Do not assume that materials that work well at room temperature will do the same job at low temperatures.

2.10.3.2 Sensor Location

Finding a good place to mount a sensor in an already crowded cryostat is never easy. There are fewer problems if the entire load and sample holder are at the same temperature, unfortunately, this not the case in many systems. Temperature gradients (differences in temperature) exist because there is seldom perfect balance between the cooling source and heat sources. Even in a well-controlled system, unwanted heat sources like thermal radiation and heat conducting through mounting structures can cause gradients. For best accuracy, sensors should be positioned near the sample, so that little or no heat flows between the sample and sensor. This may not, however, be the best location for temperature control as discussed below.

2.10.3.3 Thermal Conductivity

The ability of heat to flow through a material is called thermal conductivity. Good thermal conductivity is important in any part of a cryogenic system that is intended to be the same temperature. Copper and aluminum are examples of metals that have good thermal conductivity, while stainless steel does not. Metals that super conduct tend to be better thermal conductors than normal and poor thermal conductors below their transition temperature. Non-metallic, electrically insulating materials like alumina oxide and similar ceramics have good thermal conductivity, while G-10 epoxy-impregnated fiberglass does not. Sensor leads should have poor thermal conductivity. Sensor packages, cooling loads, and sample holders should have good thermal conductivity to reduce temperature gradients. Surprisingly, the connections between thermally conductive mounting surfaces often have very poor thermal conductivity.

2.10.3.4 Contact Area

Thermal contact area greatly affects thermal conduction because a larger area has more opportunity to transfer heat. Even when the size of a sensor package is fixed, thermal contact area can be improved with the use of a gasket material. A soft gasket material forms into the rough mating surface to increase the area of the two surfaces that are in contact. Good gasket materials are soft, thin, and have good thermal conductivity. They must also withstand the environmental extremes. Indium foil (when not super conducting) and cryogenic grease are good examples.

2.10.3.5 Contact Pressure

When sensors are permanently mounted, the solder or epoxy used to hold the sensor act as both gasket and adhesive. Permanent mounting is not a good solution for everyone because it limits flexibility and can potentially damage sensors. Much care should be taken not to overheat or mechanically stress sensor packages. Less permanent mountings require some pressure to hold the sensor to its mounting surface. Pressure greatly improves the thermal resistance of joints and reduces thermal gradients. A spring clamp is recommended so that different rates of thermal expansion do not increase or decrease pressure with temperature change.

2.10.3.6 Lead Wire

Different types of sensors come with different types and lengths of electrical leads. In general a significant length of lead wire must be added to the sensor for proper heat sinking and connecting to a bulk head connector at the vacuum boundary. The lead wire must be an electrical conductor, but should not be a good thermal conductor, or heat will transfer down the leads and change the temperature reading of the sensor.

Small 30 to 40 AWG wire made of an alloy like Manganin or phosphor bronze is much better than copper wire. Super conducting wire is a good choice if wire temperature remains below the transition temperature. Thin wire insulation is preferred for better heat sinking. Twisted wire is recommended if electrical noise is present. The wire used on the room temperature side of the vacuum boundary is not critical so shielded copper cable is normally used.

2.10.3.7 Lead Soldering

When additional wire is soldered to short sensor leads, care must be taken not to overheat the sensor. A heat sink such as a metal wire clamp or alligator clip will heat sink the leads and protect the sensor. Lead wires should be tinned before bonding to reduce the time that heat is applied to the sensor lead. Solder flux should be cleaned after soldering to prevent corrosion.

2.10.3.8 Heat Sinking Leads

Sensor leads can be a significant source of error if they are not properly heat sunk. Heat will transfer down even small leads and alter the sensor reading. The goal of heat sinking is to cool the leads to a temperature as close to the sensor as possible. This can be accomplished by putting a significant length of lead wire in thermal contact with every cooled surface between room temperature and the sensor. Lead wires can be adhered to cold surfaces with varnish over a thin electrical insulator like cigarette paper. They can also be wound onto a bobbin that is firmly attached to the cold surface. Some sensor packages include a heat sink bobbin and wrapped lead wires to simplify heat sinking.

2.10.3.9 Thermal Radiation

Thermal (black body) radiation is one of the ways heat is transferred. Warm surfaces radiate heat to cold surfaces even through a vacuum. The difference in temperature between the surfaces is one thing that determines how much heat is transferred. Thermal radiation causes thermal gradients and reduces measurement accuracy. Many cooling systems include a radiation shield. The purpose of the shield is to surround the load, sample, and sensor with a surface that is at or near their temperature to minimize radiation. The shield is exposed to the room temperature surface of the vacuum shroud on its outer surface, so some cooling power must be directed to the shield to keep it near the load temperature. If the cooling system does not include an integrated radiation shield (or one cannot be easily made), one alternative is to wrap several layers of super-insulation (aluminized Mylar) loosely between the vacuum shroud and load. This reduces radiation transfer to the sample space.

2.11 Temperature Control

The Model 372 includes a dedicated control input to perform closed-loop temperature control in a dilution refrigerator or other low power cryogenic cooling system. The load must be equipped with a temperature sensor for feedback and a resistive heater to add heating power into the system. The instrument, sensor, and heater play important roles in establishing stable temperature control.

2.11.1 Considerations For Good Control

Most of the techniques discussed above to improve cryogenic temperature measurement apply to control as well. There is an obvious exception in sensor location and a compromise is suggested in section 2.11.3.

2.11.1.1 Thermal Conductivity

Good thermal conductivity is important in any part of a cryogenic system that is intended to be at the same temperature. Most systems begin with materials that have good conductivity themselves, but as sensors, heaters, sample holders, etc., are added to an ever more crowded space, the junctions between parts are often overlooked. In order for control to work well, junctions between the elements of the control loop must be in close thermal contact and have good thermal conductivity. Gasket materials should always be used along with reasonable pressure.

2.11.1.2 Thermal Lag

Poor thermal conductivity causes thermal gradients that reduce accuracy and also causes thermal lag that make it difficult for controllers to do their job. Thermal lag is the time it takes for a change in heating or cooling power to propagate through the load and get to the feedback sensor. Because the feedback sensor is the only thing that lets the controller know what is happening in the system, slow information to the sensor slows the response time. For example, if the temperature at the load drops slightly below the setpoint, the controller gradually increases heating power. If the feedback information is slow, the controller puts too much heat into the system before it is told to reduce heat. The excess heat causes a temperature overshoot, which degrades control stability. The best way to improve thermal lag is to pay close attention to thermal conductivity both in the parts used and their junctions.

2.11.1.3 Two-Sensor Approach

There is a conflict between the best sensor location for measurement accuracy and the best sensor location for control. For measurement accuracy the sensor should be very near the sample being measured, which is away from the heating and cooling sources to reduce heat flow across the sample and therefore thermal gradients. The best control stability is achieved when the feedback sensor is near both the heater and cooling source to reduce thermal lag. If both control stability and measurement accuracy are critical it may be necessary to use two sensors, one for each function.

Another reason to use a separate control sensor is that a dedicated control sensor can be run with higher excitation power. The additional power will reduce the accuracy of the feedback sensor but create a larger signal for better control stability. Accuracy of the control sensor is not important if the temperature sample is measured with a different sensor.

2.11.1.4 Thermal Mass

Cryogenic designers understandably want to keep the thermal mass of the load as small as possible. Small mass can have the advantage of reduced thermal gradients but controlling a very small mass is difficult because there is no buffer to adsorb changes in cooling power. Without buffering, small disturbances can very quickly create large temperature changes. In some systems it is necessary to add a small amount of thermal mass in order to improve control stability.

2.11.1.5 System Nonlinearity

Because of nonlinearities in the control system, a system controlling well at one temperature may not control well at another temperature. While nonlinearities exist in all temperature control systems, they are most evident at cryogenic temperatures. When the operating temperature changes the behavior of the control loop, the controller must be returned. As an example, a thermal mass acts differently at different temperatures. The specific heat of the load material is a major factor in thermal mass and the specific heat of materials like copper change as much as three orders of magnitude when cooled from 100 K to 10 K. Changes in cooling power and sensor sensitivity are also sources of nonlinearity.

The cooling power of most cooling sources also changes with load temperature. This is very important when operating at temperatures near the highest or lowest temperature that a system can reach. Nonlinearities very close to these high and low temperatures make it very difficult to configure them for stable control. If difficulty is encountered, it is recommended to gain experience with the system at temperatures further away from the limit and gradually approach it in small steps.

Keep an eye on temperature sensor sensitivity. Sensitivity not only affects control stability but it also contributes to the overall control system gain. The large changes in sensitivity that make some sensors so useful may make it necessary to retune the control loop more often.

2.11.2 Closed Loop PID Control

Closed loop PID control, often called feedback control, is the control mode most often associated with temperature controllers. In this mode the controller attempts to keep the load at exactly the user entered setpoint that can be entered in resistance or temperature. To do this, it uses feedback from the control sensor to calculate and actively adjust the control (heater) output. The Model 372 uses a control algorithm called PID that refers to the three terms used to tune the controller for each unique system.

The PID control equation has three variable terms: proportional (P), integral (I), and derivative (D) (FIGURE 2-4). Changing these variables for best control of a system is called tuning. The PID equation in the Model 372 is:

$$HeaterOutput = P\left[e + {}^{1}/_{I}\int(e)dt + D\frac{de}{dt}\right]$$

where the error (e) is defined as: e = Setpoint – Feedback Reading.

2.11.2.1 Proportional (P)

The Proportional term, also called gain, must have a value greater than zero for the control loop to operate. The value of the proportional term is multiplied by the error (e) which is defined as the difference between the setpoint and feedback temperatures, to generate the proportional contribution to the output: Output (P) = Pe. If proportional is acting alone, with no integral, there must always be an error or the output will go to zero. A great deal must be known about the load, sensor, and controller to compute a proportional setting (P). Most often, the proportional setting is determined by trial and error. The proportional setting is part of the overall control loop gain, and so are the heater range and cooling power. The proportional setting will need to change if either of these change.

2.11.2.2 Integral (I)

In the control loop, the integral term, also called reset, looks at error over time to build the integral contribution to the output:

$$Output(I) = P \cdot {}^{1}/_{I} \int (e)dt$$

By adding the integral to proportional contributions, the error that is necessary in a proportional only system can be eliminated. When the error is at zero, controlling at the setpoint, the output is held constant by the integral contribution. The integral setting (I) is more predictable than the proportional setting. It is related to the dominant time constant of the load. As discussed in section 2.8.3, measuring this time constant allows a reasonable calculation of the integral setting. In the Model 372, the integral term is set in seconds and a smaller setting creates a more active integrator.

2.11.2.3 Derivative (D)

The derivative term, also called rate, acts on the change in error with time to make its contribution to the output:

$$Output(D) = PD\frac{de}{dt}$$

By reacting to a fast changing error signal, the derivative can work to boost the output when the setpoint changes quickly, reducing the time it takes for temperature to reach the setpoint. It can also see the error decreasing rapidly when the temperature nears the setpoint and reduce the output for less overshoot. The derivative term can be useful in fast changing systems, but it is often turned off during steady state control because it reacts too strongly to small disturbances or noise. The derivative setting (D) is related to the dominant time constant of the load similar to the integral (I) and is also set in seconds but a smaller setting creates a less active derivative.

2.11.2.4 Manual Output

The Model 372 has a control parameter that is not a normal part of a PID control loop. Manual output can be used for open loop control, meaning feedback is ignored and the heater output stays at the user's manual setting. This is a good way to put constant heating power into a load when needed. The manual output term can also be added to the PID output. Some users prefer to set an output value near that necessary to control at a setpoint and let the closed loop make up the small difference.

NOTE

Manual Output should be set to 0 when not in use.

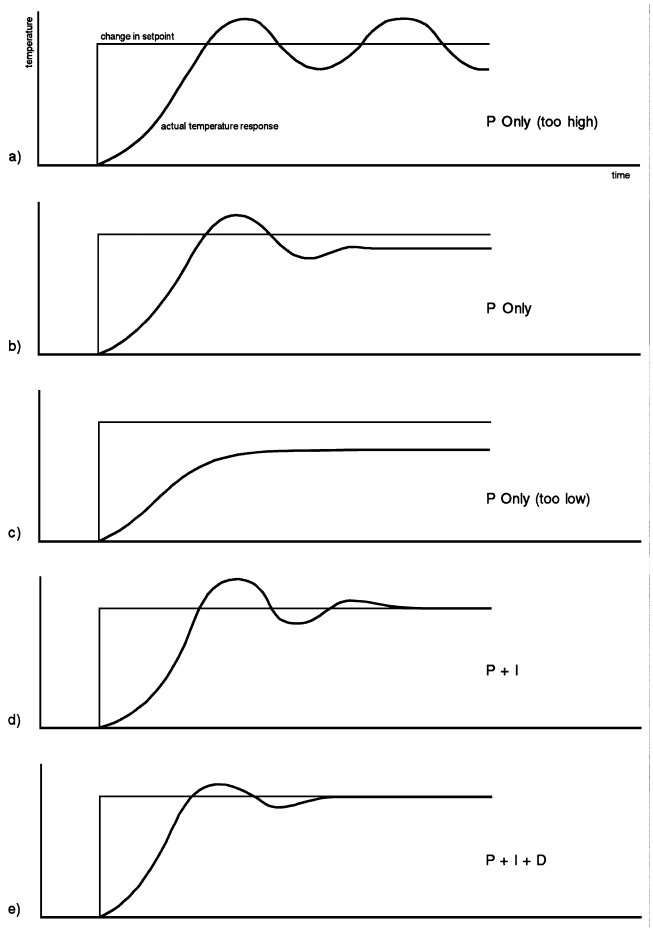


FIGURE 2-5 ***Examples of PID control***

2.11.3 Tuning a Closed Loop PID Controller

There has been a lot written about tuning closed loop control systems and specifically PID control loops. This section does not attempt to compete with control theory experts. It describes a few basic rules of thumb to help less experienced users get started. This technique will not solve every problem, but it has worked for many others in the field. This section assumes the user has worked through the operation sections of this manual and has a stable temperature reading from the control sensor. It is also a good idea to begin at the center of the temperature range of the cooling system (not close to its highest or lowest temperature).

2.11.3.1 Setting Heater Range

Setting an appropriate heater output range is an important first part of the tuning process. The heater range should allow enough heater power to comfortably overcome the cooling power of the cooling system. If the heater range will not provide enough power, the load will not be able to reach the setpoint temperature. If the range is set too high, the load may have very large temperature changes that take a long time to settle out. Delicate loads can even be damaged by too much power.

Often there is little information on the cooling power of the cooling system at the desired setpoint. If this is the case, try the following: Allow the load to cool completely with the heater off. Set manual heater output to 50% while in Open Loop control mode. Turn the heater to the lowest range and write down the temperature rise (if any). Select the next highest heater range and continue the process until the load warms up through its operating range. Do not leave the system unattended; the heater may have to be turned off manually to prevent overheating. If the load never reaches the top of its operating range, some adjustment may be needed in heater resistance or an external power supply may be necessary to boost the output power of the instrument.

The list of heater range versus load temperature is a good reference for selection the proper heater range. It is common for systems to require two or more heater ranges for good control over their full temperature. Lower heater ranges are normally needed for lower temperature. The Model 372 is of no use controlling at or below the temperature reached when the heater was off.

2.11.3.2 Tuning Proportional

The proportional setting is so closely tied to heater range that they can be thought of as fine and course adjustments of the same setting. An appropriate heater range must be known before moving on to the proportional setting.

Begin this part of the tuning process by letting the cooling system cool and stabilize with the heater off. Place the Model 372 in closed loop PID control mode, then turn integral, derivative and manual output settings off. Enter a setpoint above the cooling systems lowest temperature. Enter a low proportional setting of approximately 5 or 10 and then enter the appropriate heater range as described above. The heater display should show a value greater than zero and less than 100% when temperature stabilizes. The load temperature should stabilize at a temperature below the setpoint. If the load temperature and heater display swing rapidly, the heater range or proportional value may be set too high and should be reduced. Very slow changes in load temperature that could be described as drifting are an indication of a proportional setting that is too low (which is addressed in the next step).

Gradually increase the proportional setting by doubling it each time. At each new setting, allow time for the temperature of the load to stabilize. As the proportional setting is increased, there should be a setting in which the load temperature begins a sustained and predictable oscillation rising and falling in a consistent period of time (FIGURE 2-5). The goal is to find the proportional value in which the oscillation begins, do not turn the setting so high that temperature and heater output changes become violent. In many systems it is difficult to differentiate oscillation and noise. Operating the control sensor at higher than normal excitation power can help.

Record the proportional setting and the amount of time it takes for the load change from one temperature peak to the next. The time is called the oscillation period of the load. It helps describe the dominant time constant of the load, which is used in setting integral. If all has gone well, the appropriate proportional setting is one half of the value required for sustained oscillation (FIGURE 2-5).

If the load does not oscillate in a controlled manner, the heater range could be set too low. A constant heater reading of 100% on the display would be an indication of a low range setting. The heater range could also be too high, indicated by rapid changes in the load temperature or heater output less than 10% when temperature is stable. There are a few systems that will stabilize and not oscillate with a very high proportional setting and a proper heater range setting. For these systems, setting a proportional setting of one half of the highest setting is the best choice.

2.11.3.3 Tuning Integral

When the proportional setting is chosen and the integral is set to zero (off), the Model 372 controls the load temperature below the setpoint. Setting the integral allows the Model 372 control algorithm to gradually eliminate the difference in temperature by integrating the error over time (FIGURE 2-5). An integral setting that is too high causes the load to take too long to reach the setpoint. An integral setting that is too low can create instability and cause the load temperature to oscillate.

Begin this part of the tuning process with the system controlling in proportional only mode. Use the oscillation period of the load that was measured above in seconds as the integral setting. Enter the integral setting into the Model 372 and watch the load temperature approach the setpoint. If the temperature does not stabilize and begins to oscillate around the setpoint, the integral setting is too low and should be doubled. If the temperature is stable, but never reaches the setpoint, the integral setting is too high and should be decreased by half.

To verify the integral setting make a few small (2 to 5 degree) changes in setpoint and watch the load temperature react. Trial and error can help improve the integral setting by optimizing for experimental needs. Faster integrals, for example, get to the setpoint more quickly at the expense of greater overshoot. In most systems, setpoint changes that raise the temperature act differently than changes that lower the temperature.

If it was not possible to measure the oscillation period of the load during proportional setting, start with an integral setting of 50. If the load becomes unstable double the setting. If the load is stable make a series of small setpoint changes and watch the load react. Continue to decrease the integral setting until the desired response is achieved.

2.11.3.4 Tuning Derivative

If an experiment requires frequent changes in setpoint or data taking between changes in the setpoint, derivative should be considered (FIGURE 2-5). A derivative setting of zero, off, is recommended when the control system is seldom changed and data is taken when the load is at steady state.

The derivative setting is entered into the Model 372 in seconds and a good starting point is one fourth the integral setting in seconds.

Again, do not be afraid to make some small setpoint changes, halving or doubling this setting to watch the affect. Expect positive setpoint changes to react differently from negative setpoint changes.

Chapter 3: Installation

3.1 General

This chapter provides general installation instructions for the Model 372 AC resistance bridge and temperature controller. Please read this entire chapter before installing the instrument and powering it on to ensure the best possible performance and maintain operator safety. For instrument operating instructions refer to Chapter 4 and Chapter 5. For computer interface installation and operation refer to Chapter 6.

3.2 Inspection and Unpacking

Inspect shipping containers for external damage before opening them. Photograph any container that has significant damage before opening it. Inspect all items for both visible and hidden damage that occurred during shipment. If there is visible damage to the contents of the container, contact the shipping company and Lake Shore immediately, preferably within five days of receipt of goods, for instructions on how to file a proper insurance claim. Lake Shore products are insured against damage during shipment, but a timely claim must be filed before Lake Shore will take further action. Procedures vary slightly with shipping companies. Keep all damaged shipping materials and contents until instructed to either return or discard them.

Open the shipping container and keep the container and shipping materials until all contents have been accounted for. Check off each item on the packing list as it is unpacked. Instruments themselves may be shipped as several parts. The items included with the Model 372 are listed below. Contact Lake Shore immediately if there is a shortage of parts or accessories. Lake Shore is not responsible for any missing items if not notified within 60 days of shipment.

If the instrument must be returned for recalibration, replacement or repair, a Return Authorization (RMA) number must be obtained from a factory representative before it is returned. Refer to section 8.12.2 for the Lake Shore RMA procedure.

Items included with the Model 372 AC resistance bridge and temperature controller:

- Model 372 instrument
- Model 372 user's manual
- Line power cord
- 3 sensor input mating connectors, 6-pin DIN
- Terminal block mating connector, 6-pin terminal block, for relays 1 and 2
- Terminal block mating connector, 7-pin terminal block, for heater and analog outputs

Items included with the 3726 and 3708 scanner

- 1 3726 or 3708 scanner
- 1 scanner output to measurement input and control cable, 3m (10 ft)
- 1 ground strap for scanner enclosure
- 4 scanner input mating connectors
- 1 scanner mounting bracket

3.3 Rear Panel Definition

This section provides a description of the Model 372 rear panel connections. The rear panel consists of the measurement input connectors (#2 in FIGURE 3-1), scanner control connector (1), control input connector (3), diagnostic monitor output connector (4), reference output connector (5), sample heater, warm-up heater and analog output terminal block connector (6), relays 1 and 2 terminal block connector (7), RJ-45 Ethernet interface (8), USB type-B port (9), IEEE-488 interface (10), and the line input assembly (11). Refer to section 8.10 for rear panel connector pin-out details.

CAUTION **Always turn off the instrument before making any rear panel connections. This is especially critical when making sensor to instrument connections.**

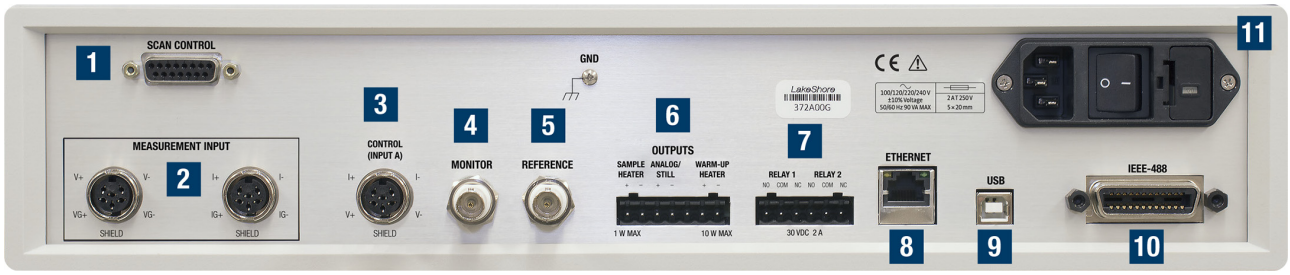


FIGURE 3-1 ***Model 372 rear panel***

3.4 Line Input Assembly

This section describes how to properly connect the Model 372 to line power. Please follow these instructions carefully to ensure proper operation of the instrument and the safety of operators.

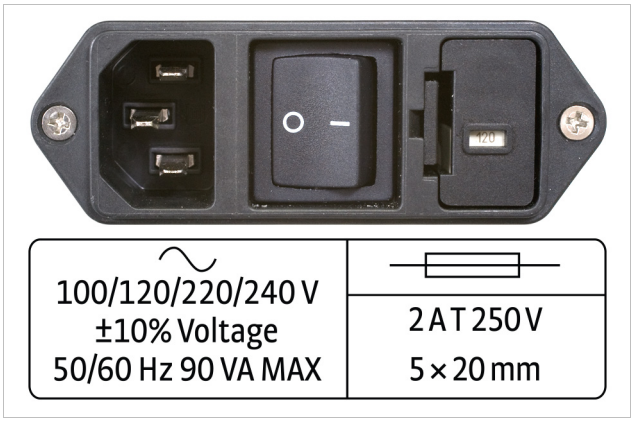


FIGURE 3-2 ***Line input assembly***

3.4.1 Line Voltage

The Model 372 has four different AC line voltage configurations so that it can be operated from line power anywhere in the world. The nominal voltage and voltage range of each configuration is shown below. (The recommended setting for 230 V operation is 240 V.)

Nominal	Minimum	Maximum
100 V	90 V	110 V
120 V	108 V	132 V
220 V	198 V	242 V
240 V	216 V	264 V

TABLE 3-1 ***Line voltage***

CAUTION

AC line voltage is set at Lake Shore, but it is good to verify that the AC line voltage indicator in the fuse drawer window is appropriate before turning the instrument on. The instrument may be damaged if turned on with the wrong voltage selected. Also remove and verify that the proper fuse is installed before plugging in and turning on the instrument. Refer to section 8.5 for instructions on changing the line voltage configuration.

3.4.2 Line Fuse and Fuse Holder

The line fuse is an important safety feature of the Model 372. If a fuse ever fails, it is important to replace it with the value and type indicated on the rear panel for the line voltage setting. The letter T on the fuse rating indicates that the instrument requires a time-delay or slow-blow fuse. Refer to section 8.6 for instructions for changing and verifying a line fuse.

3.4.3 Power Cord

The Model 372 includes a 3-conductor power cord that mates with the IEC 320-C14 line cord receptacle. Line voltage is present on the two outside conductors and the center conductor is a safety ground. The safety ground attaches to the instrument chassis and protects the user in case of a component failure. A CE approved power cord is included with instruments shipped to Europe; a domestic power cord is included with all other instruments (unless otherwise specified when ordered).

WARNING

Always plug the power cord into a properly grounded receptacle to ensure safe instrument operation.

WARNING

Position the Model 372 in such a way to enable easy access to the disconnecting device. Failure to comply could result in death or injury to personnel.

NOTE

If the power supply cord is damaged or lost, it must be replaced. Contact Lake Shore for a replacement to ensure proper voltage, current and type of cord. The power supply cord must not exceed 3 m (10 ft) in length.

The delicate nature of the measurements being taken with this instrument may necessitate additional grounding including ground strapping of the instrument chassis. In these cases the operator's safety should remain the highest priority and low impedance from the instrument chassis to safety ground should always be maintained.

3.4.4 Power Switch

The power switch is part of the line input assembly on the rear panel of the Model 372 and turns line power to the instrument on and off. When the circle symbol is depressed, power is off. When the line symbol is depressed, power is on.

3.5 Resistor Input Connection and Cabling

Signals being measured by the Model 372 are so small that the measurement environment must be taken into account when connecting resistors to the instrument input. This section describes how to attach a resistive sensor to the Model 372, and suggests ways to manage measurement noise. Understanding the information given in this section before installing the Model 372 can save hours of troubleshooting. Additional information on installing the 3726 scanner is given in section 3.6.

3.5.1 Measurement Input Connector Definition

Two 6-pin (240°) circular DIN 45322 receptacles are used for the resistive measurement input. One connector provides voltage source excitation connections (V) and the other provides current measurement connections (I). Both mate with 6-pin circular DIN plugs included with the instrument (Lake Shore P/N G-106-233). Examples of lead arrangements are shown in FIGURE 3-3. Refer to section 4.4 to configure the measurement input.

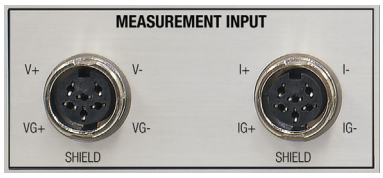


FIGURE 3-3 ***Measurement input connectors***

	Input V		Input I	
Pin	**Symbol**	**Description**	**Symbol**	**Description**
1	V–	Measurement voltage lead V–	I–	Measurement current lead I–
2	VG–	Guard or shield for voltage lead V–	IG–	Guard or shield for current lead I–
3	Shield	Shield tied to measurement common	Shield	Shield tied to measurement common
4	VG+	Guard or shield for voltage lead V+	IG+	Guard or shield for current lead I+
5	V+	Measurement voltage lead V+	I+	Measurement current lead I+
6	—	Shield tied to measurement common	—	Shield tied to measurement common
Body	—	Tied to measurement common	—	Tied to measurement common

The Model 372 makes an AC resistance measurement; therefore, the + and – signs are to aid in proper lead arrangement and not indicate signal polarity.

TABLE 3-2 ***Diode/resistor input connector details***

3.5.2 Control Input Connector Definition

One 6-pin (240°) circular DIN 45322 receptacle is used for the resistive control input. One connector provides both voltage source excitation connections (V) and the current measurement connections (I). The control input mates with one of the 6-pin Circular DIN plugs included with instrument (Lake Shore P/N G-106-233). The control input sensor connector pins are defined in FIGURE 3-4 and TABLE 3-3. Refer to section 4.4 to configure the control input.

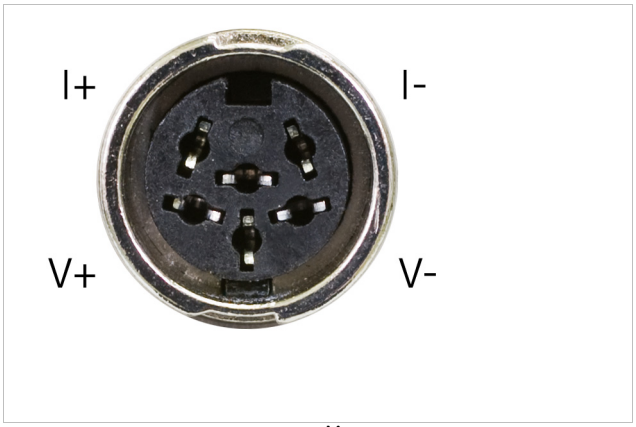


FIGURE 3-4 ***Control input connector***

Pin	Symbol	Description
1	I–	–Current
2	V–	–Voltage
3	None	Shield
4	V+	+Voltage
5	I+	+Current
6	None	Shield

TABLE 3-3 ***Standard input connector details***

3.5.3 Sensor Lead Cable

The sensor lead cable used outside the cooling system can be much different from what is used inside. Between the instrument and vacuum shroud, heat leak is not a concern. In this case, choose cabling to minimize error and noise pick up. Larger conductor, 22 AWG to 28 AWG stranded copper wire is recommended because it has low resistance yet remains flexible when several wires are bundled in a cable.

The arrangement of wires in a cable is also important. For the best results when interfacing to the control input, the voltage leads, V+ and V- should be twisted together and current leads I+ and I- should be twisted together. The twisted pairs of voltage and current leads should then be covered with a braided or foil shield that is connected to the shield pin of the instrument. This type of cable is available through local electronics suppliers. Instrument specifications are given assuming 3 m (10 ft) of sensor cable.

While the above control input cabling description is also applicable for the minimum cable configuration of the measurement input, it is recommended that the measurement input voltage and current pairs be individually shielded. However, for maximum performance, especially when measuring resistance above 100 kΩ, it is recommended to use the driven guard configuration as described in section 3.5.4. FIGURE 3-5 shows the recommended measurement input cable configuration.

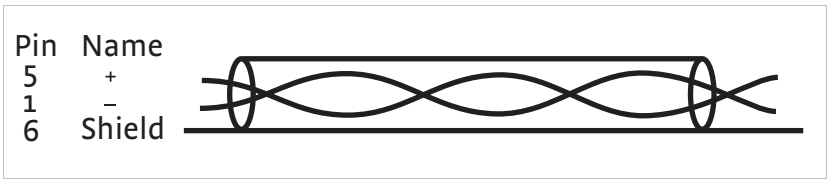


FIGURE 3-5 ***Twisted shield cables (typical for measurement input current and voltage leads)***

3.5.4 Driven Guards

A configuration of guarded and shielded cables is shown below and is recommended for long cables or when measuring large resistances. Variations may be necessary depending on the configuration of available triaxial cable. Guards are tied only to the guard pins on the measurement input connectors and should never be tied together, tied to shields or terminated in any other way. They should always be left unattached at the resistor end of the cable. The cable shield is tied to the shield pins on the measurement input connectors. Section 3.5.6 explains how the shield can be extended to the experimental Dewar without creating ground loops. The guards themselves provide some shielding, but they are not as effective as shields at reducing induced noise. The driven guards are only available for the measurement input and are always active. If you do not wish to use guarding, ensure that the guard conductors of the cable are not connected to the Model 372 guard pins.

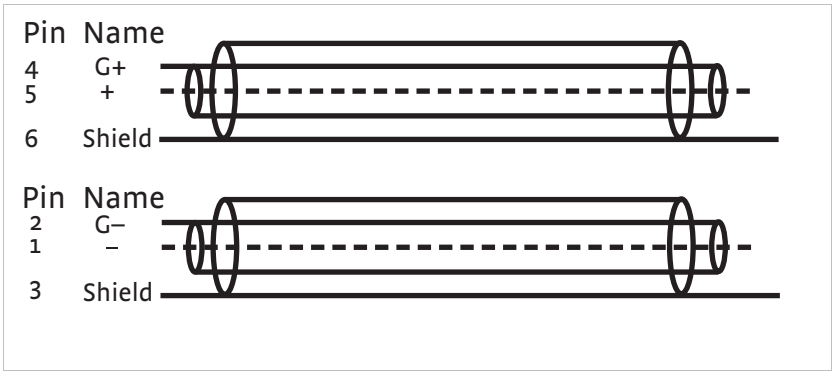


FIGURE 3-6 ***Measurement input guarded shielded cables (typical for current and voltage leads)***

3.5.5 Isolation and Grounding

The Model 372 has three distinct circuit areas that have different grounding needs: the chassis grounded circuits, the isolated measurement circuits, and the isolated sample heater and analog output circuits. Chassis grounded circuits include the instrument chassis, digital control, computer interface and warm-up heater output. Measurement circuits include the measurement input current and voltage leads with their associated guards and shield, the control input current and voltage leads with their associated shield, the diagnostic monitor output voltage, the reference output voltage and the scanner control lines. Proper installation of the instrument can enhance the benefits of both isolation and shielding. Improper installation can defeat both. Some trial and error may be required to determine the best configuration. A typical grounding scheme is shown in FIGURE 3-7.

Chassis grounded circuits should have a low impedance path to earth ground for both performance and safety. This is achieved by using a 3-conductor power cord in a properly grounded outlet. All instrumentation that is connected to the warm-up heater output, relays, or computer interface (or use earth ground as measurement common) should have similar low impedance to the same ground. Good grounding of all chassis in a group of instruments prevents voltage differences between their chassis (usually at line frequency) from inducing noise on the measurement. If good quality earth ground is not available, the chassis of line powered instruments should be strapped together with heavy gauge copper wire or ground strap. Signal leads in communication cables should not be relied on for ground strapping.

Measurement circuits should be as well isolated from earth ground as possible with one important exception. Measurement leads outside the Dewar should be shielded and in general protected from contact with earth ground. Inside, care must be taken to prevent electrical shorts between leads and conductive parts of the cooling system. During installation it is important to check for these shorts as well as shorts between the leads themselves. Measurement input guards should be terminated at the instrument end of cables only and not at the resistor end. Monitor and reference voltage outputs and scanner control lines should be treated as part of the measurement circuit and connected to isolated or differential measurement inputs. The only unanswered question is: where should cable shields be terminated?

Shield termination is the exception to the rule that isolated measurement circuits should be isolated from earth ground. In an ideal installation, the shield of the instrument can be joined with the natural shielding of a metal test Dewar to shield all internal measurement leads from external noise. (Obviously this will not shield noise generated within the Dewar.)

In many installations the best noise performance of the Model 372 can be achieved when the cable shield is tied directly to the Dewar or other large conductive mass surrounding the experimental space. The problem is that most test Dewars are connected to earth ground either directly or through the many vacuum and transfer lines running in and out. It would be very difficult to isolate a Dewar that was not specifically designed that way; therefore, the isolation of the instrument must be relied upon to prevent ground loops in this configuration. When the cable shield is connected to a Dewar and therefore earth ground, it should be the only connection between the measurement circuits and the earth.

Any additional connection between measurement circuits and ground will defeat the isolation built into the Model 372 and allow ground loops to form.

NOTE

In the unusual circumstance that one measurement lead is shorted to the cable shield (measurement common) the Model 372 can still make resistance measurements but the active CMR feature must be turned off.

3.5.6 Dressing Cables

Cable dressing is often overlooked in crowded laboratories, but even neatness can matter when making small signal measurements. Consider the following ideas for long cable runs outside of the experimental Dewar.

- Cables with signals sharing the same ground or common should be routed together to reduce ground loop area.
- Cables with signals that differ in ground or signal size should be routed separately to reduce induced noise.
- Cables should be kept away from noise generators like fluorescent lights and vacuum pump motors.
- Cables should be supported to minimize stress on connectors and terminations. Cable support should also limit movement and vibration of the cables during measurements because cable motion can generate electrical noise.
- Shielded cables should be used with the shields connected at both the scanner and Dewar connectors.

NOTE

Resistor leads from non-selected channels are shorted to measurement common to control noise in the 3726 scanner. In the 3708 scanners, these are left open. Please take this into account when installing the Dewar wiring.

NOTE

Model 372 scanner and measurement circuitry is isolated from the earth ground. Therefore, connecting shields at both the scanner and Dewar does not result in a "ground loop."

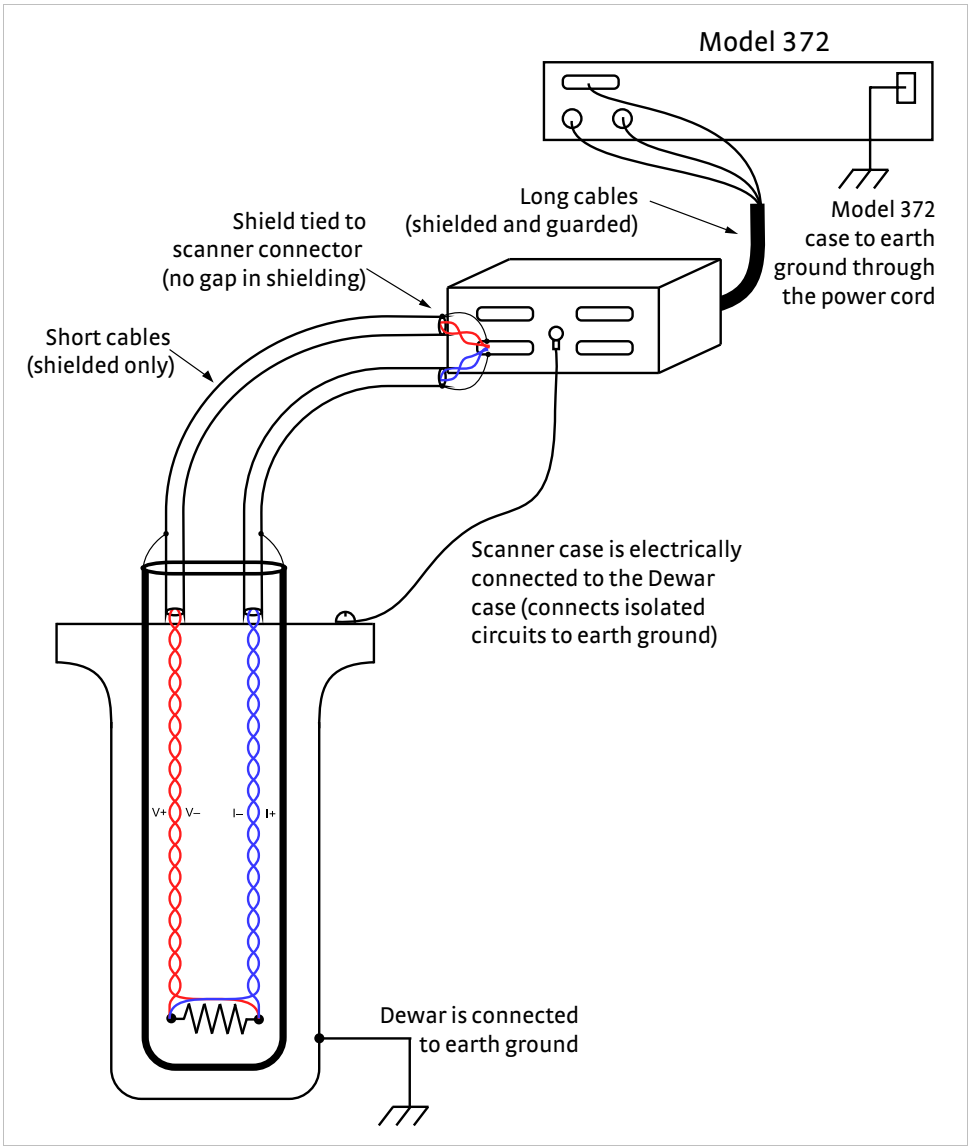


FIGURE 3-7 ***Example of instrument grounding***

3.5.7 Temperature Sensors

Resistive temperature sensors should be treated as any other resistor being measured. One difference is that four lead devices are normally calibrated with a specific arrangement of current and voltage leads. Follow all manufacturer recommendations on installation, including lead arrangement, or errors in temperature measurement will result.

3.6 Optional Scanner Installation

The 3726 and 3708 scanners expand the input capability of the Model 372 and increase the number of input channels to 16 (3726) or 8 (3708). It is an extension of the isolated measurement circuitry of the Model 372 so its installation should follow the guidelines described in section 3.5 as well as this paragraph. Cables between the scanner and Dewar should be as short as possible because they carry the smallest signals. Cables between the scanner and instruments can be longer.

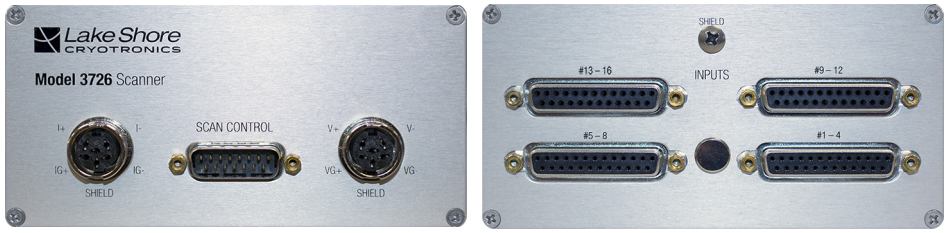


FIGURE 3-8 ***3726 scanner front and rear panels***

3.6.1 Grounding the Scanner

The enclosures of the 3726 and 3708 scanners are connected to the input cable shield, and therefore, are tied to measurement common (not the chassis) of the Model 372. In most installations the shield screw on the enclosure should be ground strapped to the test Dewar creating the single connection between measurement circuits and the earth. If a different shield to earth connection is preferred, the scanner enclosure must be electrically insulated from its surroundings.

3.6.2 Scanner Resistor Input Connector Definition

With the 3726 scanner, four 25-pin D-sub-miniature receptacles hold connections for up to sixteen 4-lead resistor inputs in four sets of four. With the 3708 scanner, two 25-pin DIN receptacles hold connections for up to eight 4-lead resistor inputs. They mate with 25-pin D-sub-miniature plugs included with the scanner (Lake Shore P/N 106-253). Unused inputs can either be left open or all four measurement pins can be shorted together. Pin connections for channels 1 through 4 are shown in FIGURE 3-9, channels 5 through 8, 9 through 12, and 13 through 16 are wired the same way.

3.6.3 Scanner Resistor Input Cabling

The cable between scanner and Dewar should be kept as short as possible without causing strain on the cable or connections (FIGURE 3-7). Short cables can improve the measurement in several ways. They minimize the potential for induced noise on the smallest voltage signals, limit cable capacitance that cannot be guarded because the guards are not carried through the scanner, and reduce the potential for ground loops if shield lines accidentally touch the Dewar.

Individually shielded, twisted pair cable is recommended for wiring the resistor inputs. Cable containing up to eight shielded pairs of wire is available from electronics distributors so one cable can provide enough wires to connect the four channels of one input connector. If multiple smaller cables are used they should be wrapped together to minimize ground loops. The two current leads of a measurement input channel should be twisted and the two voltage leads should be twisted. The input connectors provide several shield pins so that individual shields can be connected separately at the scanner end of the cable.

If the shield-screw on the scanner enclosure is strapped the test Dewar, the cable shield can be left unterminated at the Dewar end. If the scanner enclosure is not connected to the Dewar, the shields of the cable should be terminated at the bulk head connection or other conductive point on the Dewar.

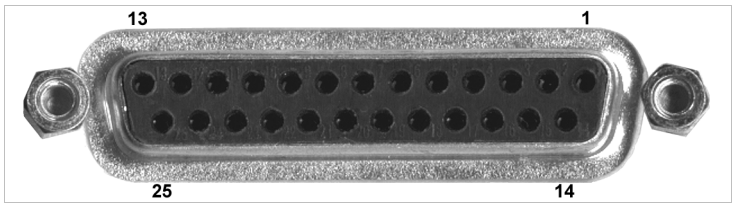


FIGURE 3-9 ***Scanner input connector***

Pin	Symbol	Pin	Symbol
1	Shield	**14**	Shield
2	Shield	**15**	1 I–
3	1 I+	**16**	1 V–
4	1 V+	**17**	Shield
5	Shield	**18**	2 I–
6	2 I+	**19**	2 V–
7	2 V+	**20**	Shield
8	Shield	**21**	3 I–
9	3 I+	**22**	3 V–
10	3 V+	**23**	Shield
11	Shield	**24**	4 I–
12	4 I+	**25**	4V–
13	4 V+		
Body	Shield		

Guards are not carried through the scanner. Shields are connected to isolated measurement common.

TABLE 3-4 ***Scanner input connector details***

3.6.4 Scanner Output Connector Definition

Two 6-pin (240°) circular DIN 45322 receptacles are used for the resistance measurement output from the scanner. These are identical to the connectors used on the measurement input of the Model 372. The cables included with the scanner are adequate for most installations. In the event that you must make a cable for a special application, connector pin definition on the scanner is identical to the input connector definition given in section 3.5.1. Guard pins are not connected inside the scanner but guards can be carried through the cable making them reversible. Connectors mate with 6-pin circular DIN plug (Lake Shore P/N G-106-233).

CAUTION

To avoid damaging the sensitive scanner circuitry, do not connect the scanner to a powered Model 372. Ensure that the instrument is not powered on when making the connection to the scanner.

3.6.5 Scanner Output Cabling

A scanner to instrument cable (Lake Shore P/N G-112-374) is included with the 3726 and 3708 scanners. The figure below illustrates the cable wiring. This configuration is recommended when making cables for the scanner. Shielded twisted pair cables, as described in section 3.5.3, can be used instead of dual triaxial cables for less demanding applications. Cable shields should always be tied to connector shield pins on both ends of this cable.

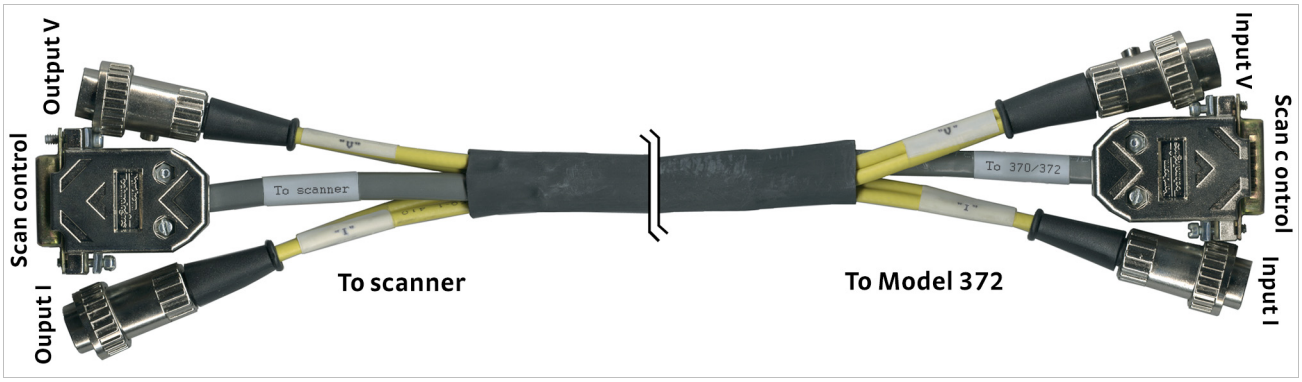


FIGURE 3-10 ***Scanner to instrument measurement cable***

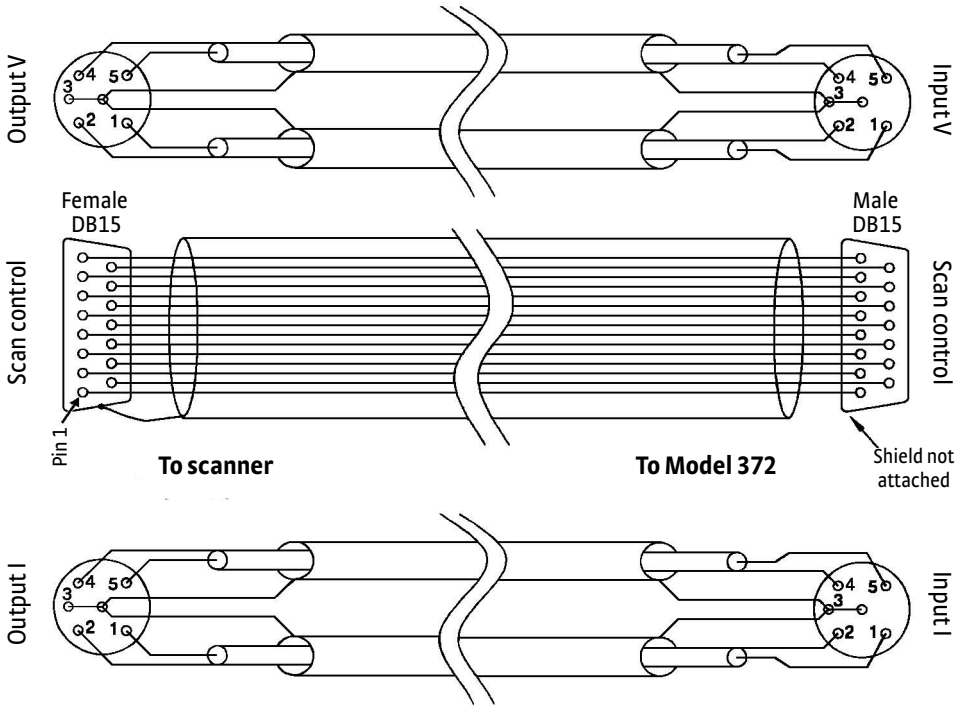


FIGURE 3-11 ***Scanner to instrument measurement cable***

3.6.6 Scanner Control Connector Definition

A 15-pin D-sub-miniature plug provides power supply and digital control input connections to the 3726 and 3708 scanners. The scanner control cable included with the scanner is adequate for most installations. A connector pin definition is provided in case a cable must be made for a special application. Both instrument and scanner have the same pin numbering, but the instrument has a connector receptacle and the scanner has a connector plug.

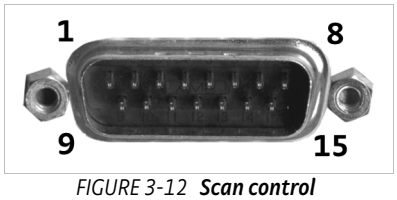


FIGURE 3-12 ***Scan control***

Pin	Name	Description
1	Scan present	Signal to Model 370 that a scanner is installed
2	Digital common	Common or ground for digital control signals
3	Digital common	
4	Unused	—
5	Analog common	Common or ground for analog signals
6	Analog common	
7	Analog common	
8	-15 V	-15 V referenced to scanner analog common
9	Scan 1	Scan channel select line 1
10	Scan 2	Scan channel select line 2
11	Scan 3	Scan channel select line 3
12	Scan 4	Scan channel select line 4
13	Scan gain	Selects scanner gain of 1 or 100
14	+5 V	+5 V referenced to scanner digital common
15	+15 V	+15 V referenced to scanner analog common
Body	Chassis	(Do not use)

Both scanner analog and scanner digital common are tied to isolated measurement circuits inside the instrument and must remain isolated from the instrument chassis and earth ground. The connector body should not be used for shielding the scan control cable because the chassis of the instrument is at earth ground, and the chassis of the scanner is at isolated measurement common.

TABLE 3-5 ***Scanner to scan control connector***

3.6.7 Scanner Control Cabling

A scanner control cable is included with the 3726 and 3708 scanners. Commercial 15-pin extension cables should not be used because the shield is tied to the body of the connector that is at chassis ground on the instrument. Longer cables can be constructed with shield tied to the scanner analog common. The cable must have one connector plug end to mate with the instrument, and one connector receptacle end to mate with the scanner.

3.6.8 Using the Scan Control Signals without a Scanner

If an optional scanner is not installed, some of the scan control lines are available for other uses. These signals remain part of the isolated measurement circuitry and should be treated like part of the resistance measurement. They should only be used to drive isolated or differential inputs. Scan channel select lines can be controlled by the computer interface command DOUT. The power supplies can also be used, but external circuits must guarantee that current is limited or performance of the instrument may be degraded.

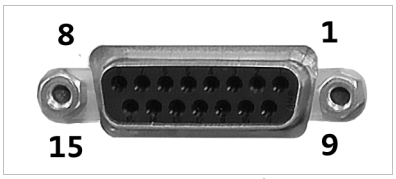


FIGURE 3-13 Scan control connector

Pin	Name	Description
2	Digital common	Common or ground +5 V
3	Digital common	
5	Analog common	Common or ground for ±15 V
6	Analog common	
7	Analog common	
8	-15 V	-15 V at 25 mA
9	Scan 1	TTL digital output 1
10	Scan 2	TTL digital output 2
11	Scan 3	TTL digital output 3
12	Scan 4	TTL digital output 4
13	Scan gain	TTL digital output 5
14	+5 V	+5 V at 50 mA
15	+15 V	+15 V at 25 mA

TABLE 3-6 ***Scan control: signals without a scanner***

3.6.9 Scanner Mounting Bracket

A scanner mounting bracket is included with the 3726 and 3708 scanners so that it can be mounted on or very near the test Dewar. Rigidly mounting the scanner will prevent unnecessary cable movement and help maintain a uniform shield connection over time. The hole pattern for the bracket is shown below, but the bracket is made of soft aluminum, and additional holes can be added easily. No mounting screws are included.

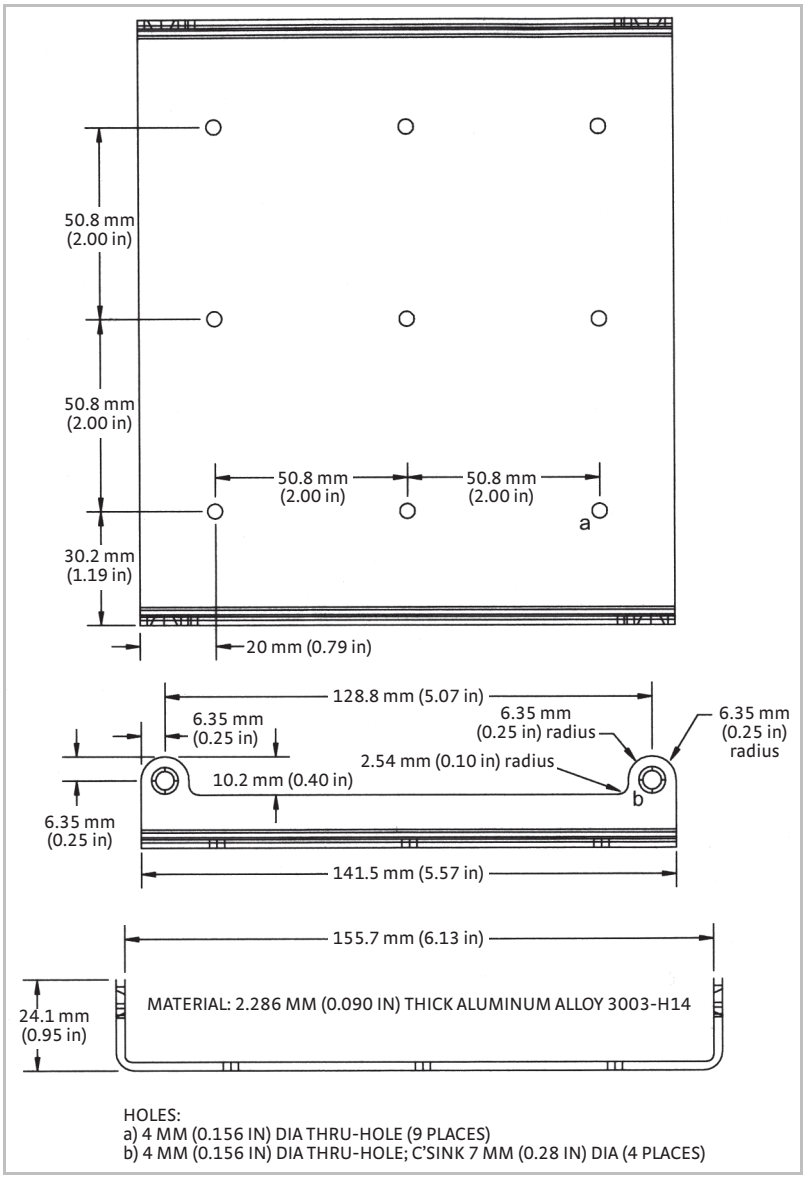


FIGURE 3-14 ***Scanner mounting bracket with a sample hole pattern***

3.7 Heater Output Setup

The following section covers the heater wiring from the vacuum shroud to the instrument for both heater outputs. Specifications are detailed in section 1.3.

3.7.1 Heater Output Description

This section describes the sample heater and the warm-up heater.

3.7.1.1 Sample Heater

The sample heater output is a controlled DC current source capable of generating a maximum of 1 W of power into a resistive heater that is attached to the cooled load. During control, the heater output is adjusted, either manually or through a closed loop PID control algorithm, to balance the continuous cooling power of the refrigeration system and maintain steady load temperature.

The sample heater on the Model 372 has eight current ranges scaled in approximate one-third steps. Each range will source one-tenth the power of the next largest range with the highest range being 1 W. The current source voltage compliance is 10 V and limits the heater resistance to 100 Ω when operating at full power. The restriction on heater resistance is not as severe on lower power ranges and higher heater resistance is often preferred. Heater output can be displayed either as percent of full scale current for a range or as power in watts. Power calculation requires an accurate heater resistance be entered into the instrument.

Some examples of heater resistance and output range are given in TABLE 3-7. Maximum power for a range is the lower of the two; $P = I^2R$ and $P = V^2/R$ where P is heater power in watts, I is the maximum current for the range and V is the compliance voltage of 10 V. Heater output resolution is lost any time the compliance voltage limits the power.

If a permanently installed heater has a very high resistance value, a resistor may have to be put in parallel with it on the outside of the Dewar to increase the number of useful output ranges and maintain good control resolution.

		Heater Resistance			
		10 Ω	100 Ω	1000 Ω	5000 Ω
Output range	100 mA	100 mW	1 W*	100 mW†	20 mW†
	31.6 mA	10 mW	100 mW	100 mW†	20 mW†
	10 mA	1 mW	10 mW	100 mW	20 mW†
	3.16 mA	100 µW	1 mW	10 mW	20 mW†
	1 mA	10 µW	100 µW	1 mW	5 mW
	316 A	1 µW	10 µW	100 µW	500 µW
	100 µA	100 nW	1 µW	10 µW	50 µW
	31.6 µA	10 nW	100 nW	1 µW	5 µW

**Indicates maximum power range and resistance*

† Indicates power limited by compliance voltage

TABLE 3-7 ***Sample heater resistance***

3.7.1.2 Warm-Up Heater

The warm-up heater is a traditional control output for a cryogenic temperature controller. It is a DC current source with software settable ranges and limits. It is designed for higher power than the sample heater (up to 10 W), providing control at higher temperatures, and more specifically, fast warm-up capability. The warm-up heater is configurable for optimization using either a 25 Ω or a 50 Ω heater resistance. At the

50 Ω setting, it is limited to a maximum output current of 0.45 A, and at the 25 Ω setting, the maximum heater output current is 0.63 A. The compliance voltage is 23 V minimum, but can reach as high as 28 V if the heater resistance is higher than the nominal setting. Refer to TABLE 3-8 for the maximum current and power ratings into different heater resistances.

		Heater resistance (Ω)					
		10	25	30	40	50	100
Maximum current	0.63 A	4 W	**10 W**	12 W	—	—	—
	0.5 A (user)	3 W	6 W	8 W	10 W	—	—
	0.45 A	2 W	5 W	6 W	8W	**10 W**	

Shaded black: maximum current too high for these resistances due to voltage compliance limit
Bold: discrete options available for 25) and 50) heaters under the maximum current setting

TABLE 3-8 ***Warm-up heater resistance***

3.7.2 Heater Output Connectors

A 7-pin detachable terminal block is used to connect the sample and warm-up heaters to the Model 372. One 7-pin terminal block is included in the connector kit shipped with the Model 372. This is a common connector, and additional mating connectors can be purchased from electronics suppliers, or from Lake Shore as P/N 106-765. Both the sample and warm-up heaters are connected between their respective + and - terminals.

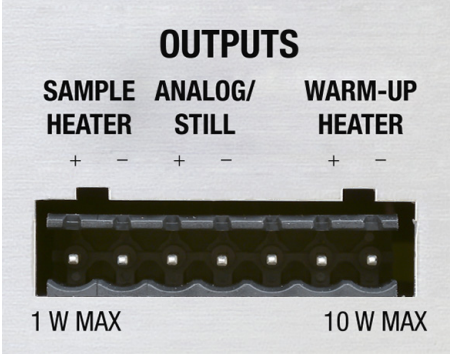


FIGURE 3-15 ***Rear panel output terminals (without block attached)***

3.7.3 Heater Output Wiring

Heater output current is what determines the size (gauge) of wire needed to connect the heater. The maximum current that can be sourced from sample heater output is 100 mA, while the warm-up heater can source up to 0.63 A. When less current is needed to power a cooling system, the sample heater can be limited with range settings while the warm-up heater can be limited by maximum current settings.
When setting up a temperature control system, the lead wire for the heater must be capable of carrying a continuous current that is greater than the maximum current. Wire manufacturers recommend 30 AWG or larger wire to carry 0.63 A of current, but there is little advantage in using wire smaller than 20 AWG to 22 AWG outside the cryostat. Inside the cryostat, smaller gauge wire is often desirable.

It is recommended to use twisted heater leads. Large changes in heater current can induce noise in measurement leads and twisting reduces the effect. It is also recommended to run heater leads in a separate shielded cable from the measurement leads to further reduce interaction.

For best noise performance, do not connect the resistive heater or its leads to chassis ground. Also avoid connecting heater leads to sensor leads or any other instrument inputs or outputs.

3.7.4 Heater Output Isolation

The sample heater output circuitry, as well as the analog/still output, is independently isolated from both chassis ground and measurement circuits. This isolation is intended to reduce noise from coupling into the heater output from digital circuits inside the instrument and to eliminate ground loop problems. The sample heater output should not be left completely floating during operation. It is recommended to tie the negative return lead of the sample heater output to the Dewar, allowing the sample heater output signal to follow the moving reference (Dewar case), thus taking advantage of the isolation. Similar to the isolated measurement circuit shield, the sample heater cable shield should only be connected to the test Dewar at a single point. Other noise reduction techniques used for the resistor input apply to the heater as well.

When on, the warm-up heater is referenced to the chassis ground. When turned off, the warm-up heater outputs are shorted together, and the heater terminals are isolated from the chassis ground. Because of this, it is recommended t keep the warm-up heater off when performing control and measurement at ultra-low temperatures, to avoid ground loops. Unlike the sample heater, it is not recommended to tie the negative lead of the warm-up heater to the Dewar. However, like the sample heater, it is recommended to connect the warm-up heater cable shield to the test Dewar at a single point.

3.7.5 Heater Output Noise

The warm-up heater output circuitry in the Model 372 is capable of sourcing 10 W of power. This type of circuitry can generate some electrical noise. The Model 372 is designed to generate as little noise as possible, but even noise that is a small percentage of the output voltage or current can be too much when sensitive measurements are being made nearby. Heater output noise can be most detrimental when controlling at very low temperatures. The sample heater uses a fully linear power supply to minimize heater noise. The switching power supply used for the warm-up heater is turned completely off when the warm-up heater is off. For best results use the sample heater for control, and ensure the warm-up heater is off when controlling at very low temperatures.

3.8 Analog/Still Output

The Model 372 has one analog voltage output. It includes additional firmware features that makes it useful as a still heater output for a dilution refrigerator.

3.8.1 Analog/Still Output Connection

The analog/still output pins are located on the same 7-pin detachable terminal block as the heater outputs. As seen in FIGURE 3-15, the analog/still output label and polarity are indicated on the silkscreen. The analog/still signal output is referenced to the same isolated ground as the sample heater. Because of this, it is also recommended to tie the negative lead of the analog/still output to the Dewar. This will allow the analog/still output signal to follow of the moving reference (Dewar case), thus taking advantage of the isolation. In addition, similar to the sample heater, the analog/still cable shield should only be tied to one point on the Dewar.

3.8.2 Calculating Still Heater Power

The heating power sourced by the analog output can be calculated as $P = V^2/R$ where P is power in watts, V is the output in volts and R is the heater resistance in ohms. Output voltage ranges from 0 to 10 V and is capable of driving a resistance of 100 Ω or greater. The maximum power output of 0 to 1 W can be achieved with a 100 Ω heater. Most stills do not require the maximum power. Using a larger resistor will reduce the range of power and improve setting resolution. For example a 1000 Ω resistor will produce a 0 to 100 mW power range with full setting resolution. If a small resistive heater is permanently installed in the cooling system, lower power can be created by adding a series resistor in a heater lead outside the Dewar.

3.8.3 Calculating Still Heater Current

The current sourced by an analog output can be calculated as I = V/R where I is current in amps, V is the output in volts and R is the heater resistance in ohms. Output voltage ranges from 0 to 10 V and is capable of driving a resistance of 100 Ω or greater. The maximum current output of 0 to 100 mA can be achieved with a 100 Ω heater. Most stills do not require the maximum current. Using a larger resistor will reduce the full scale current and maintain good setting resolution. For example, a 1000 Ω resistor will produce a 0 to 10 mA current range with full setting resolution. If a small resistive heater is permanently installed in the cooling system, lower current can be created by adding a series resistor in a heater lead outside the Dewar.

3.9 Monitor and Reference Outputs

The diagnostic monitor and reference voltage outputs are included to aid in troubleshooting, especially identification of ground loops and other noise sources during instrument installation. Both signal outputs and their common connections are part of the isolated measurement circuitry and should be treated like part of the resistance measurement. They should only be used to drive isolated or differential inputs. Please note that most line powered oscilloscopes are earth ground referenced and can create the exact problems that they are being used to diagnose.

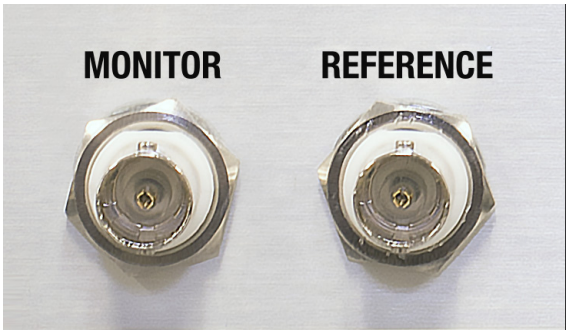


FIGURE 3-16 ***Monitor and reference connectors***

3.10 Diagnostic Monitor Voltage Output

A BNC receptacle provides the connection for the diagnostic monitor voltage output. Signal is carried on the center conductor and isolated measurement common is on the outer conductor. The signal can be switched internally to one of several diagnostic voltage test points. It has a maximum voltage range of ±15 V and should be used to source no more than 1 mA of current. The mating connector is not included. See section 8.12 for more information on how to configure and use this output.

3.11 Reference Voltage Output

A BNC receptacle provides the connection for the reference output. The signal is carried on the center conductor and isolated measurement common is on the outer conductor. The signal is a TTL level digital square-wave voltage synchronized to the measurement or control input frequency that can be used for synchronous (lock-in) detection of AC measurement signals. The output maintains TTL logic voltage levels when driving no more than 2 TTL loads. The mating connector is not included.

The signal that is presented here is dependent on the diagnostic monitor output configuration. For example, if the diagnostic monitor output is configured for a measurement input signal, reference output will produce the measurement input reference frequency. If the diagnostic monitor output is configured for the control input ADC signal, the reference output will produce the control input reference frequency. Section 8.12 provides more information on how to configure and use this output.

Chapter 4: Operation

4.1 General

This chapter provides instructions for the general operating features of the Model 372 AC resistance bridge and temperature controller. Advanced operation is in Chapter 5. Computer interface instructions are in Chapter 6.

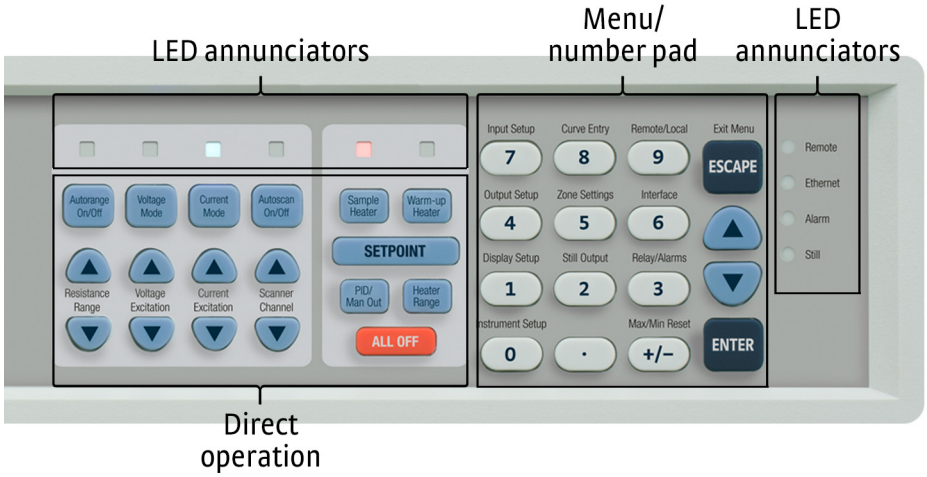


FIGURE 4-1 ***Model 372 front panel***

4.1.1 Understanding Menu Navigation

Each feature that is discussed in this chapter will include a menu navigation section. This section is intended to be a quick guide through the necessary key presses to arrive at and set the desired features. See FIGURE 4-2 and TABLE 4-1 for an explanation of the conventions used in the menu navigation.

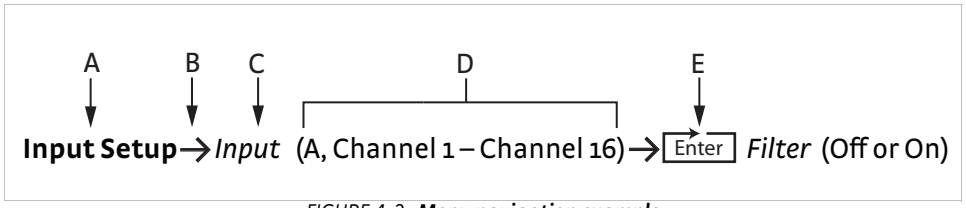


FIGURE 4-2 ***Menu navigation example***

Item	Convention	Explanation
A	**Bold**	Typically, the first word in the menu navigation is in bold type, which indicates the first key you will need to press.
B	→	The arrow indicates that the screen is advancing to the next screen. In the menu navigation, the item that follows the arrow is the next item you would see on the screen or the next action that you will need to perform.
C	*Italic type*	Often, the words that follow the arrow are in italic type. The italic type indicates that there is a setting that needs to be selected.
D	(Parentheses)	The items that follow the italicized word and which are in parentheses, are the available selections to which you can set the desired feature.
E	Enter	Press Enter on the keypad.

TABLE 4-1 ***Menu navigation key***

4.2 Front Panel Description

This section provides a description of the front panel controls and indicators for the Model 372.

4.2.1 Keypad Definitions

The keypad is divided into two sections. The direct operation section includes all keys to the left of the number pad, and the menu/number pad section includes the standard 12 number pad keys and the **Up**, **Down**, **Escape**, and **Enter** keys (FIGURE 4-1). The direct operation keys provide one touch access to the most often used functions of the Model 372. The number pad keys, with the exception of the decimal point key, are dual function keys. If the instrument is in the number entry mode, the keys are used to enter numbers. If it is in normal operating mode, the number keys provide menu entry points. An abbreviated description of each key is provided as follows. A more detailed description of each function is provided starting in section 4.3 and through section 4.6.

4.2.1.1 Direct Operation Keys

Key	Function	Refer to section:
Autorange On/Off	Turns Autorange on or off for resistance range	4.4.3
Resistance Range up/ down	Manually increase or decrease resistance range	4.4.2
Voltage Mode	Enables Voltage Excitation Mode	4.4.1.1
Voltage Excitation up/ down	Increase or decrease voltage excitation	4.4.1.1
Current Mode	Enable current excitation mode	4.4.1.2
Current Excitation up/ down	Increase or decrease current excitation	4.4.1.2
Autoscan On/Off	Turn Autoscan on or off if a scanner is installed	4.4.4.2
Scanner Channel up/ down	Manually increment or decrement scanner channel	4.4.4.1
Sample Heater	Displays the control loop information for Sample Heater	4.3.1.2
Warm-up Heater	Displays the control loop information for Warm-up Heater	4.6.1.2
Setpoint	Press this key to enter the control setpoint for the currently displayed loop, if applicable	4.6.1.5.6
PID/Man Out	Displays menu allowing for manual adjustment of P,I,D and manual output values	4.6.1.4.1
Heater Range	Selects a sample heater current source output range for temperature control or turns the warm-up heater on or off, depending on the presently displayed control loop.	4.6.1.5.9
ALL OFF	Press this key to set the range for all outputs to Off (not applicable to Monitor Out mode)	4.6.1.5.12

TABLE 4-2 ***Direct operation keys***

4.2.1.2 Menu/Number Pad Keys

Key	Function	Refer to section
Input Setup	Press this key to configure features related to the inputs.	4.4
Output Setup	Press this key to configure features related to the outputs, including configuration of control loops.	4.6
Display Setup	Press this key to configure the display.	4.3
Instrument Setup	Press this key to configure instrument parameters common to all channels	4.5
Curve Entry	Press this key to view, edit, copy, and erase temperature curves.	4.4.12
Zone Settings	Press this key to enter user-specified control parameters for up to ten temperature zones.	4.6.1.4.2
Still Output	Press this key to change the still heater output value if the analog output is configured for Still mode.	4.6.2.2
Remote/Local	Press this key to toggle the IEEE-488 Remote mode.	4.7.3.1
Interface	Press this key to configure the USB, Ethernet, and IEEE-488 interfaces.	4.7
Relays/Alarms	Press this key to configure the two rear-panel relays and the alarm feature.	5.5
Max/Min Reset	Press this key to reset the maximum and minimum readings for all inputs.	NA

TABLE 4-3 ***Menu/number pad keys***

Key	Function	Refer to section
▲	Press this key to navigate menus, and to select parameters.In addition, this key will allow the user to navigate to a temporary display screen to view scan channels/inputs that aren't presently displayed.[1]	4.2.3
▼	Press this key to navigate menus, and to select parameters.In addition, this key will allow the user to navigate to a temporary display screen to view scan channels/inputs that aren't presently displayed.[1]	4.2.3
ESCAPE (Exit Menu)	Press this key to cancel a number entry, or parameter selection. You can also use this key to navigate up one level in a setting menu, which exits the menu if at the top level. Press and hold for 3 s to reset instrument parameters to factory default values.	4.2.3
ENTER	Press this key to accept a number entry, or a parameter selection. You can also use it to navigate deeper into a menu setting screen. Press and hold for 3 s to lock or unlock the keypad.	4.2.3
0 through **9, +/-,.**	Press these keys to enter numeric data. This includes a key to toggle plus (+) or minus (-), and a key for entry of a decimal point.	4.2.3

TABLE 4-3 ***Menu/number pad keys***

1. Available in a future firmware release.

4.2.2 Annunciators

LED annunciators: the eight blue and two red LED annunciators are included to provide visual feedback of the operations listed in TABLE 4-4.

LED	Function	Refer to section
Autorange On/Off	On when autorange is enabled for resistance range.	4.4.3
Voltage Mode	On when Voltage Excitation mode is enabled.	4.4.1.1
Current Mode	On when Current Excitation mode is enabled.	4.4.1.2
Autoscan On/Off	On when autoscanning the scanner channels.	4.4.4.2
Remote	On steady when the instrument is in the Remote mode (may be controlled via the IEEE-488 interface). If the LED is not illuminated, the instrument is in Local mode.	4.7.3.1
Ethernet	On steady when the Ethernet is connected and properly configured. Blinks at a slow pace when attempting to acquire an IP address. Blinks rapidly when in an error state.	4.7.2
Alarm	On steady when the alarm feature for any sensor input is turned on and the input's visual parameter is set to On. Blinks when any input sensor alarm is in the alarming state and the alarming input's visual parameter is set to On.	5.5.1
Still	On steady when the analog output is configured in Still mode and the output is in the On state.	4.6.2.2

TABLE 4-4 ***LED annunciators***

Display annunciators: include symbols for sensor inputs and their respective temperatures and units.

Annunciator	Function	Annunciator	Function
1	Measurement input, channel 1	A	Control input
2	Measurement input, channel 2	K	Temperature in kelvin
3	Measurement input, channel 3	mK	Temperature in millikelvin
4	Measurement input, channel 4	mΩ	Sensor units of milliohms
5	Measurement input, channel 5	Ω	Sensor units of ohms
6	Measurement input, channel 6	kΩ	Sensor units of kilohms
7	Measurement input, channel 7	MΩ	Sensor units of megohms
8	Measurement input, channel 8	j	Imaginary sensor units (quadrature)
9	Measurement input, channel 9	mW	Sensor power, milliwatts
10	Measurement input, channel 10	µW	Sensor power, microwatts
11	Measurement input, channel 11	nW	Sensor power, nanowatts
12	Measurement input, channel 12	pW	Sensor power, picowatts
13	Measurement input, channel 13	fW	Sensor power, femtowatts
14	Measurement input, channel 14	aW	Sensor power attowatts
15	Measurement input, channel 15	—	—
16	Measurement input, channel 16	—	—

TABLE 4-5 ***Display annunciators***

4.2.3 General Keypad Operation

There are five basic keypad operations: direct operation, menu navigation, number entry, alpha-numeric entry and setting selection.

- *Direct operation:* the key function occurs as soon as you press the key; these include the **Autorange On/Off**, **Voltage Mode, Current Mode**, **Autoscan On/Off** (and their corresponding up and down arrows). In addition, this includes the **Sample Heater**, **Warm-up Heater**, **Setpoint**, **PID/Man Out**, **Heater Range** and **All Off** keys.
- *Menu navigation:* each menu has a list of configurable parameters. Menus that apply to multiple entities (for example, Input Setup could apply to Measurement input channels 1 through 16) have a first level selection to determine which entity to configure (for instance, Channel 6). Once the first level selection is made, the list of menu parameters is displayed. The parameter labels are displayed on the left, and the current value of each parameter is displayed on the right. In this screen, use the ▲ and ▼ keys to move the highlight up or down, respectively. Press **Enter** to enter the setting mode for the highlighted parameter. The type of setting mode depends on the type of parameter highlighted. The possible setting modes are: number entry, alpha-numeric entry, and setting selection. Refer to the respective entry mode descriptions below. During menu navigation, press **Escape** (Exit Menu) to perform the Exit Menu function; this will not cancel any setting changes already made by the setting modes listed below.
- *Number entry:* allows you to enter number data using the number pad keys. Number pad keys include the numbers **0** through **9**, **+/-**, and the decimal point. The proportional control parameter is an example of a parameter that requires number entry. During a number entry sequence use the number entry keys to enter the number value, press **Enter** to accept the new data. Press **Escape** once to clear the entry, and twice to return to the menu navigation mode.
- *Alpha-numeric entry:* allows you to enter character data using the number pad keys, and the ▲ and ▼ keys. The input sensor name is an example of a parameter that requires alpha-numeric entry. Press ▲ or ▼ to cycle through the upper and lower case English alphabet, numerals 0 through 9, and a small selection of common symbols. Press **Enter** to advance the cursor to the next position, or to save the string and return from alpha-numeric entry mode if in the last position. Press **Escape** to move the cursor back one position, or to cancel all changes and return from alpha-numeric entry mode if at the first position. Press any of the number pad keys, except for **+/-**, to enter that character into the string and advance the cursor to the next position automatically, or to save the string and return to menu navigation mode if in the last position. Use the **+/-** key to enter the whitespace character.
- *Setting selection:* allows you to select from a list of values. During a selection sequence, use the ▲ or ▼ keys to select a parameter value. To select the highlighted parameter as the new setting, press **Enter**; the setting is saved and the mode returns to menu navigation. Press **Escape** at any time while the parameter list is displayed to cancel any changes and return to menu navigation mode.

4.3 Display Setup

The intuitive front panel layout and keypad logic, bright, graphic display, and LED indicators enhance the user-friendly front panel interface of the Model 372. The Model 372 offers a bright, graphic, vacuum fluorescent, (VF) display that can simultaneously display up to eight readings at once.

4.3.1 Display Overview

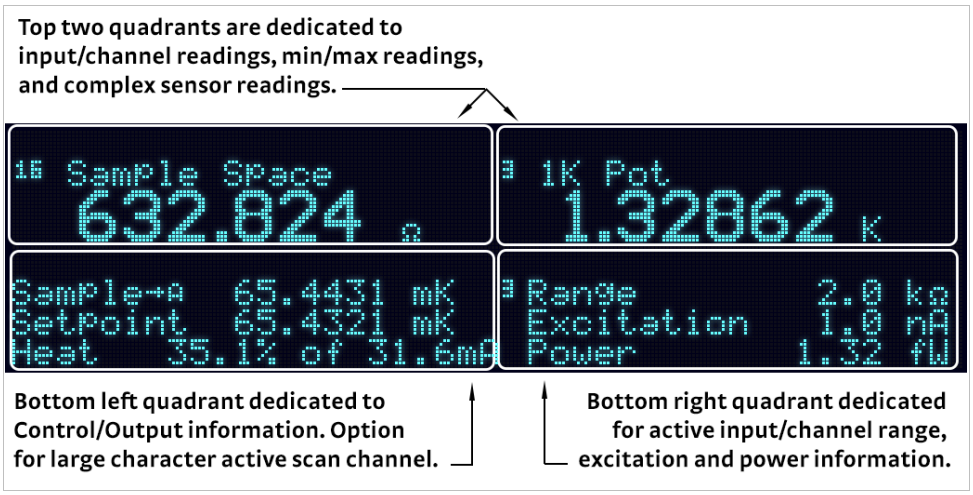


FIGURE 4-3 ***Display quadrant breakdown***

4.3.1.1 Range, Excitation and Power Information

When configured for measurement input or custom display modes, the lower right quadrant of the display provides feedback from the active measurement channel resistance measurement, and it is continually updated for both autorange and scanner operation. When configured for control input display mode, the range, excitation and power information is fixed to the control input, independent of the active measurement input scan channel. The active resistance range is shown first followed by the chosen excitation. Excitation is displayed in volts if the voltage mode is active and amps if current mode is active. Excitation power is shown on the bottom display line. Power is continuously calculated using the instruments nominal current source excitation and the resistance measurement after each update. Power from stray noise sources is not included in the calculation.

4.3.1.2 Control Loop and Scan Information

The lower left quadrant of the display shows relevant control loop information for either the sample heater or warm-up heater, independent of display mode. In addition, it can be configured to display the active measurement input scan channel (section 4.3.3).

4.3.1.3 Temporary Reading Display Mode[1]

Independent of the configured display mode, the Model 372 provides the capability to enter into a temporary display mode using the ▲ and ▼ keys. This allows the user to scroll through the latest enabled measurement input channel readings and the control input reading. After the ▲ or ▼ key is pressed, the respective input/channel display becomes active for approximately 10 s before returning to the configured display mode. This provides quick access to readings and information that may not be presently displayed.

1. Available in a future firmware release.

Press **Escape** to manually return the display to the configured display mode.

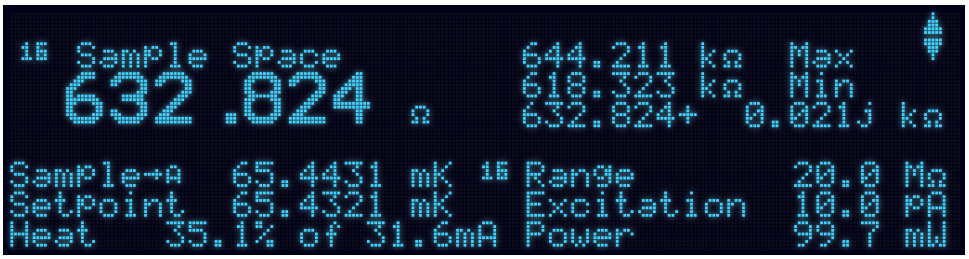


FIGURE 4-4 ***Temporary reading display***

4.3.1.4 Display Update Indicator

The annunciators for the respective inputs (A for the control input and 1 through 16 for the measurement input channels) also act as indicators of the settling status of that input's reading.

- The indicator remains on continuously to indicate hardware settling after a range change. Hardware settling also includes the user specified pause time.
- The indicator blinking with the on-time equal to the off-time indicates that the reading is unsettled due to the firmware filtering.
- The display update indicator blinks on 90% and off 10% when the instrument is reporting a stable reading and all features are active.

During the first two settling states, autorange, max/min, alarm, analog output and temperature control functions are frozen so they are not affected by transitional data.

Interface command: **`RDGSTL?`**

4.3.2 Display Modes

The Model 372 provides several display modes designed to accommodate different instrument configurations and user preferences. The measurement input display mode provides detailed information about the active measurement input channel sensor. The control input display mode provides detailed information about the control input. Finally, the custom display mode provides the ability to customize the displayed front panel information to your preference.

Menu navigation:
Display Setup →*Display Mode* (Measurement Input, Control Input, Custom)
Default: Measurement input
Interface command: **`DISPLAY`**

4.3.2.1 Measurement Input Display Mode

The measurement input display mode provides detailed information relevant to the active measurement input channel. If no scanner is attached, this mode will display only the single measurement input reading. When a scanner is attached, this mode will display information related to the active scan channel.

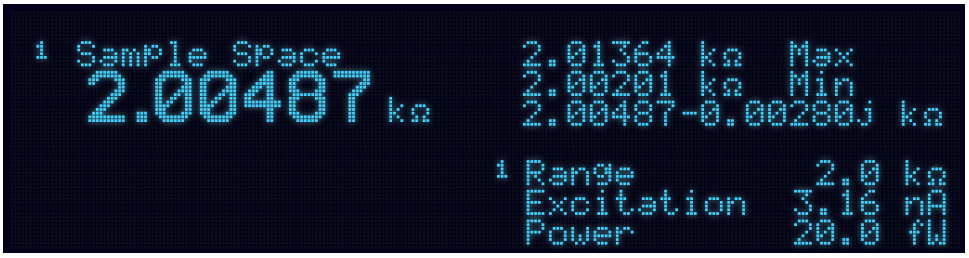


FIGURE 4-5 ***Measurement input display mode***

The top half of the display provides information related to the sensor input. The input channel number is displayed, followed by the user-assignable input name. The sensor reading is displayed in large character format, using the units assigned to the respective input's preferred units parameter. The top half of the display also shows the maximum and the minimum sensor reading since the last max/min reset. In addition, the complex sensor reading (real and imaginary values) are always displayed here.

The lower right quadrant describes the range, excitation, and power for the given channel as described in section 4.3.1.1.

Menu navigation:
Display Setup→*Display Mode*→Measurement Input
Interface command: **DISPLAY**

4.3.2.2 Control Input Display Mode

Similar to the measurement input display mode, the control input display mode provides detailed information relevant to control input.

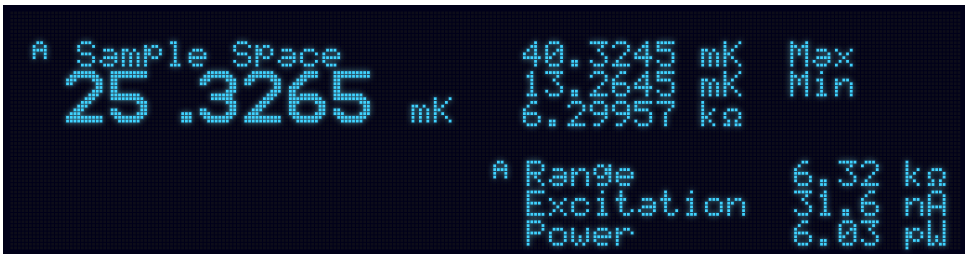


FIGURE 4-6 ***Control input display mode***

The top half of the display provides information related to the sensor input. The input channel number is displayed, followed by the user-assignable input name. The sensor reading is displayed in large character format, using the units assigned to the respective input's preferred units parameter. The top half of the display also shows the maximum and the minimum sensor reading since the last Max/Min reset.

The lower right quadrant describes the range, excitation, and power for the given channel as described in section 4.3.1.1.

Menu navigation:
Display Setup→*Display Mode*→Control Input
Interface command: **DISPLAY**

4.3.2.3 Custom Display Mode

The custom display mode provides the ability to customize the front panel information to your preference. As with the input display modes, the custom display mode shows sensor input information in the top half of the screen, and control loop information or the active measurement input scan channel in the bottom left half of the screen. The sensor input information can be customized to display two large character sensor readings with names, four large character sensor readings without names, or eight small character format sensor readings without names. Each displayed reading can use any sensor as the input, and can be displayed in units of kelvin, sensor, min, max, input name, and quadrature (measurement input only).

Menu navigation:
Display Setup→*Display Mode*→Custom
Interface command: **DISPLAY**

- *Locations:* depending on the number of displays parameter, there can be anywhere from two to eight display locations for displaying sensor readings. The placement of a given display location on the front panel display depends on the number of displays setting.

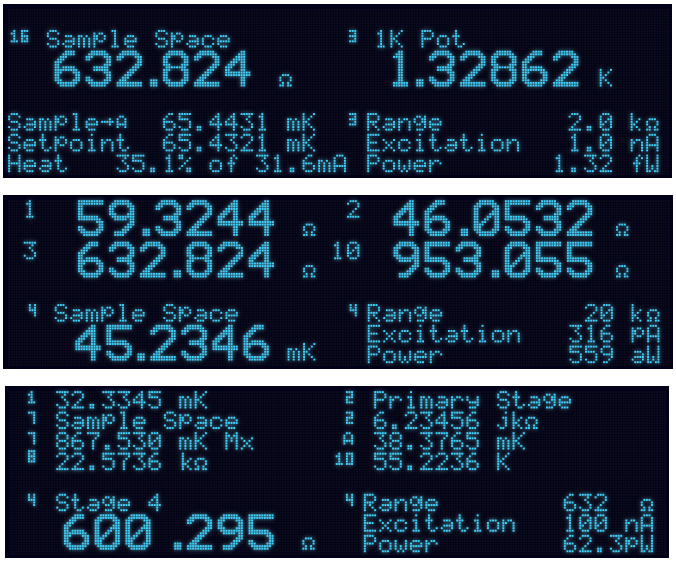


FIGURE 4-7 ***Model 372 screen images showing 2 (top), 4 (middle) and 8 (bottom) display locations***

- *Number of custom display locations:* the number of displays parameter determines how many sensor readings are displayed, as well as the character size of the displayed readings. If "2 (Large)" is selected, then two large character readings are displayed, along with sensor names. If "4 (Large)" is selected, then four large character readings are displayed, without sensor names. If "8 (Small)" is selected, then eight small character readings are displayed, without sensor names.

  Menu navigation:
  Display Setup→*Number of Locations* (2 Large, 4 Large, 8 Small)

- *Input and units:* each available display location has an associated Input, and Units setting. The input parameter determines which sensor will be used as the input of the displayed data. The input can be the control input, measurement input (and corresponding channels if a scanner is attached), or none. If none is selected, then the display location will be blank. The units parameter determines which units to display the reading in.

  Menu navigation:
  Display Setup→*Location* (1, 2, 3, 4, 5, 6, 7, 8) → Input (None, Input A, 1-16)
  Display Setup→*Location* (1, 2, 3, 4, 5, 6, 7, 8) → Units (Kelvin, Ohms, Quadrature [Measurement Input only], Min, Max, Sensor Name)
  Interface command: **`DISPFLD`**

4.3.3 Control and Scan Information Display Quadrant

Independent of the display mode, the lower left quadrant of the display shows relevant control loop information for either the sample heater or warm-up heater, independent of display mode. In addition, it can be configured to display the active measurement input scan channel.

When this display quadrant is configured to active scan channel mode, the channel designator and channel name are displayed in small characters while the reading is displayed in large characters. The following figure shows the active measurement channel displayed in the lower left quadrant. In this example, the display happens to be configured in the custom, 4 large reading mode.

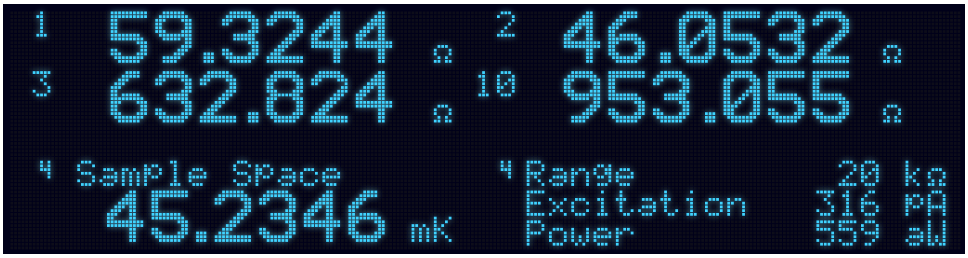


FIGURE 4-8 ***Display showing the active measurement channel displayed in the lower left quadrant***

When this display quadrant is configured to display either sample heater or warm-up heater, the information displayed is dependent on how the respective heater output is configured. If an input is assigned to the heater, an arrow pointing to the input annunciator will appear indicating that the input is tied to the heater output. In addition, the input's reading will be displayed to the right of the annunciator. If the heater is configured for zone or closed loop PID mode, the setpoint will appear on the line below the heater name. Finally, if applicable, the heater output percentage and range will be displayed on the last line.

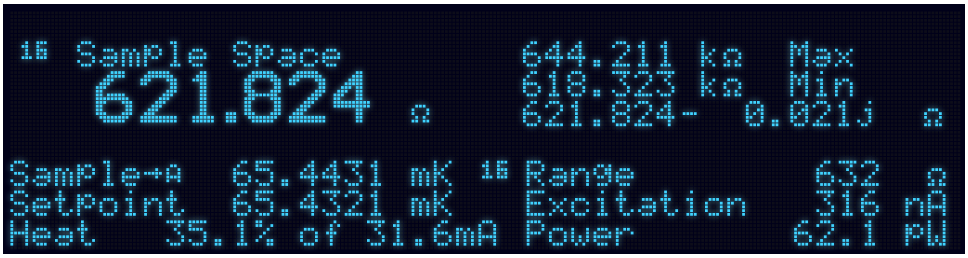


FIGURE 4-9 ***Control/scan information display quadrant configured to display sample heater A***

The sample heater and warm-up heater direct operation key functionality are related to the heater control information displayed in this lower left quadrant. After one of these keys are pressed, independent of display mode or what information is currently displayed in the lower left quadrant, the respective heater control loop information will be displayed for approximately 10 s before returning to the configured control/scan info display. This provides quick access to each heater output and associated control loop information for gathering information or changing control loop parameters. Press **Escape** to manually return the display to the configured control/scan info mode. Press and hold a direct operation heater key until an audible beep is heard (about 3 s) to cause the configured control/scan information display quadrant to change the display configuration to the heater associated with that key.

Menu navigation:
Display Setup→*Control/Scan Info* (None, Sample Heater, Warm Up Heater, Active Scan Channel)

4.3.4 Display Brightness

The front panel VF display brightness can be adjusted for optimal viewing. The default value should work well in most standard room temperature environments, but deviations in room temperature and extreme viewing angles can cause the display brightness to require adjustment for optimal viewing.
Menu navigation:
Display Setup→*Brightness* (25%, 50%, 75%, 100%)
Default: 50%
Interface command: **`BRIGT`**

4.4 Input Setup

With no scanner attached, the Model 372 input setup menu will display only the control input (A) and the measurement input (1) as available for configuration. If an optional 8-channel 3708 or 16-channel 3726 scanner is attached, the input setup menu will expand the measurement input to display measurement input channels 1 through 8 or 1 through 16.

Menu navigation:
Input Setup→*Input* (A, 1-16)→ Input Enabled (Disabled, Enabled)
Default: Enabled
Interface command: **`INSET`**

4.4.1 Excitation Mode Selection

By default, the Model 372 uses current source excitation to measure resistance. The instrument firmware is also able to simulate voltage excitation of the measured resistor to create a second operating mode. These parameter selections can be different for every scanner channel if a scanner is installed. The instrument remembers how each measurement channel is configured and will return to that configuration whenever the channel is chosen.

The control input has a fixed voltage range. Therefore, only current excitation mode is available for the control input.

4.4.1.1 Voltage Excitation Mode (Measurement Input Only)

In voltage excitation mode the excitation selection in volts is treated as a "not to exceed" value. The instrument assigns an excitation current to each resistance range that keeps the measurement voltage as large as possible without exceeding the selected excitation voltage. Current is changed to accommodate resistance range or voltage excitation parameter changes.

To use voltage excitation mode press **Voltage Mode**. The LED annunciator above that key will light to indicate the excitation mode. The excitation display line in the lower right corner of the display will also change to indicate the maximum excitation in volts. Current excitation arrow keys are locked out.

To change the voltage excitation use the Voltage Excitation ▲ and ▼ keys. Available ranges are listed in Chapter 1. As the table indicates, not every combination of voltage excitation and resistance range is possible. The following messages are displayed in the excitation display to indicate limits.

- *Maximum*: maximum voltage excitation has already been chosen
- *Minimum*: minimum voltage excitation has already been chosen
- *Increase resistance*: resistance range must be increased before changing voltage excitation
- *Decrease resistance*: resistance range must be decreased before changing voltage excitation

4.4.1.2 Current Excitation Mode (Measurement and Control Input)

In current excitation mode, one of the instrument current source selections is chosen directly as excitation. Gain of the measurement and control inputs are changed to accommodate different resistance ranges.

To use current excitation mode press **Current Mode**. The LED annunciator above that key will light to indicate the excitation mode. The excitation display line in the lower right corner of the display will also change to indicate the current excitation in amps. Voltage excitation arrow keys are locked out.

To change the current excitation, use the Current Excitation ▲ and ▼ keys. Available ranges are listed in Chapter 1. As the range table indicates, not every combination of current excitation and resistance range is possible. The following messages are displayed in the excitation display to indicate limits.

- *Maximum:* maximum current excitation has already been chosen
- *Minimum:* minimum current excitation has already been chosen
- *Decrease resistance:* resistance range must be decreased before changing current excitation
- *Increase resistance:* resistance range must be increased before changing current excitation

In addition to using the Current Excitation▲ and ▼ keys, the control input current excitation can be configured from the input setup menu. Please note, unlike the measurement input, the control current excitation cannot be set independently of the resistance range. For example, setting the control input current excitation to 10 nA will inherently configure the control input to the 20 kΩ resistance range.

Menu navigation:
Input Setup→ *Input* (A) → Current Excitation (OFF, 316pA, 1nA, 3.16nA, 10nA, 31.6nA, 100nA)
Default: 10 nA
Interface command: **`INTYPE`**

4.4.2 Resistance Range Selection

Resistance ranges have approximately 20% over range, but the range should be increased when the reading is at full scale so that the range guarantees enough overhead to account for noise voltages. When the reading is below 20% of full scale, better measurement resolution can be achieved by decreasing the resistance range.

To change the resistance range, press the Resistance Range ▲ and ▼ keys. Available ranges are listed in Chapter 1. The following messages are displayed to indicate range limits.

- *Maximum*: maximum resistance range has already been chosen
- *Minimum:* minimum resistance range has already been chosen
- *Increase excitation:* voltage/current excitation must be increased before changing resistance range
- *Decrease excitation:* voltage/current excitation must be decreased before changing resistance range

In addition to using the Resistance Range ▲ and ▼ direct operation keys, the control input resistance range can be configured from the input setup menu. Please note, unlike the measurement input, the control resistance range cannot be set independently of the excitation current. For example, setting the control input current excitation to 20 kΩ will inherently configure the control input to an excitation current of 10 nA.

Menu navigation:
Input Setup→*Input* (A)→*Resistance Range*→ (632 kΩ, 200 kΩ, 63.2 kΩ, 20 kΩ, 6 kΩ, 2kΩ)
Default: 10 nA
Interface command: **`INTYPE`**

4.4.2.1 Turning Excitation Off

The Model 372 offers many excitation levels with the lowest being very low in power. It is still sometimes necessary to turn excitation off. Excitation should be turned off any time the current source leads are open-circuited and then attached to a cold resistor with the instrument turned on. This condition may occur when the input is scanned or multiplexed externally. Excitation is turned off automatically for channel changes when a scanner is being used.

When excitation is turned off, the instrument ramps its current source to the lowest output possible and then shunts across the output with a mechanical relay. The relay provides a low resistance path for any remaining leakage current, and then it prevents the current source from climbing to its compliance voltage. When excitation is turned back on, the process is reversed to prevent transients from heating the measured resistor.

To turn excitation off press **Voltage Mode** and **Current Mode** at the same time for one second. Both excitation mode LED annunciators will turn off, and the excitation display location will show Off.

To restore excitation press any of the range or excitation keys. In addition, the control input excitation can be turned off via the input setup menu as described in section 4.4.1.2.

4.4.3 Autorange

The Model 372 is equipped with an autoranging feature that will automatically select the appropriate resistance range for the connected resistive temperature device. The instrument will increase the resistance range if the measurement reaches full scale. Normally, over-range errors are not created because of the approximate 20% over-range capability of each of the inputs.

Over-range errors are possible when resistance changes very quickly or when resistance increases beyond the limit of the current excitation selection. The autorange algorithm will not change the excitation setting to accommodate larger resistances. The instrument will decrease the resistance range if the measurement drops below 20% of full scale. Autorange is not recommended when resistance changes are very fast, measurements are very noisy or when data acquisition cannot tolerate a range change delay in the middle of a data set.

To turn autorange on or off for the presently displayed input channel, press **Autorange**. The LED annunciator above the key lights to indicate autorange is on.

Menu navigation:
Input Setup→ *Input* (A, 1 to 16)→ *Autorange*→(Off or On)
Default: Off
Interface command: **`INTYPE`**

4.4.3.1 Control Input Rox™ RX-102B Auto Range Feature

In addition to the standard autorange feature, the Model 372 dedicated control input includes an autorange routine that is optimized for the Lake Shore RX-102B sensor. The primary objective of the standard autorange routine is to automatically adjust the resistance range to maintain the best possible signal to noise ratio. The RX-102B autorange routine, while factoring in signal-to-noise, also routinely takes into account sensor self-heating and accuracy. As with the standard autorange routine, the RX-102B autorange algorithm includes a hysteresis band to prevent instability when the sensor resistance is at a range boundary.

Menu navigation:
Input Setup→ *Input* (A) → *Autorange* (RX-102B)
Default: Off
Interface command: **INTYPE**

4.4.4 Optional Scanner Setup

The Model 372 automatically identifies the 3708 or 3726 scanner when it is powered up with the scanner attached. When the scanner is attached, operation related to the measurement input changes slightly. This section summarizes scanner operation although most of the operation is addressed in the individual feature paragraphs.

4.4.4.1 Manual Scanner Channel Selection

To change the active scanner channel manually, use the Scan Channel ▲ and ▼ keys. If the Model 372 is configured to display the active measurement channel, the channel annunciator will update immediately, but it can take several seconds for a valid reading to appear on the display. The first valid reading will be ready after the hardware settling time, change pause time and filter settling. The hardware settling time is fixed, but the change pause (section 4.4.6) and the filter settling time (section 4.4.7.1) can be set by the user.

4.4.4.2 Automatic Scanning

The Model 372 has an autoscan feature that will sequence through all enabled scanner channels. In addition to setting an appropriate change pause time and filter time constant, the user must set the scan dwell time for each channel as described in section 4.4.5. The scan dwell time is the length of time the instrument will take valid readings on the active channel before moving on to the next channel. The scan dwell time takes place after the hardware settling time and change pause time. If a measurement channel is used to control temperature and while autoscanning is enabled, the firmware will use the pause and dwell times as specified. More information about controlling while scanning can be found in section 4.6.1.6.

To turn on the autoscan feature press **Autoscan**. The LED annunciator above that key will light to indicate autoscan is on. To turn off the autoscan feature press **Autoscan** again.

4.4.5 Scanner Dwell Time

The scanner dwell time parameter allows the user to select how long the measurement input will dwell on any channel when the autoscan feature is on. Each channel can have a different dwell time from 1 to 200 s. Scan dwell time begins after both the change pause time and firmware filter is settled. Dwell time will be interrupted if temperature control using a scanned measurement input channel and Autoscan are active at the same time.

Menu navigation:
Input Setup→ *Input* (1-16)→ Scanner Dwell Time (1 to 200)
Default: 10 s
Interface command: **INSET**

4.4.6 Change Pause

The input change pause parameter allows the user to select how long the instrument waits after a resistance range or channel change before it begins using readings for autorange, max/min, alarm, analog output and temperature control functions. The default of 3 s is recommended for typical applications but the pause time should be increased for large resistances or very low excitations.
Menu navigation:
Input Setup→ *Input* (1-16) → *Change Pause* (3 to 200)
Default: 3 s
Interface command: **INSET**

4.4.7 Filter

The firmware filter is an integral part of the Model 372 resistance measurement. It is directly related to measurement resolution and frequency response. The instrument calculates readings 10 times per second no matter how the filter is configured. The filter algorithm takes a running, linear average of 10 to 2000 readings depending on settling time value. A new filtered reading is available over the interface ten times a second and displayed at the normal display update rate. The linear average filter gives faster settling times than other filter methods, but it has a poor frequency response.

NOTE

If you are tracking periodic changes in resistance, be aware that using this filter at its maximum settle time could mask those periodic changes.

When the firmware filter is disabled, the 200 ms time constant digital filter that is used to generate unfiltered readings remains active.

Menu navigation:
Input Setup→ *Input* (A, 1-16) → *Filter* (Off or On)
Default: Off
Interface command: **`FILTER`**

4.4.7.1 Filter Settle Time

Settling time is a filter setting that drives the filter noise attenuation performance. Filter settling time can be set from 1 to 200 s. TABLE 4-6 shows how the settling time is related to the number of readings averaged and nominal noise attenuation. Filter settling time begins after the pause time finishes on range or channel change. Because the Model 372 uses a linear average, the measurement bandwidth is not a simple function of frequency.

Settling times	Number of readings	Attenuation of noise
6 s	60	–10 dB
12 s	120	–16 dB
25 s	250	–22 dB
50 s	500	–28 dB
100 s	1000	–34 dB
200 s	2000	–40 dB

TABLE 4-6 ***Example of settling time as it relates to the number of readings and attenuation of noise***

The settle time can be set between 0 s and 200 s. When the filter is on and the settle time is zero, the instrument continues to calculate the filtered reading, despite the unfiltered readings being displayed. This feature allows the user to quickly toggle between 0 s and the desired settle time to observe the filtering effects on the reading. Previously on the Model 370, the only way to do this was to turn the filter off then on. This required the filter to re-populate with enough readings to meet the settle time requirement before a settled reading was presented.

The Model 372 also contains a new feature that allows the filter settle time to be adjusted without having to reset the filter. For example, if the reading is settled and the settle time is changed from 60 s to 30 s, the newly configured filtered reading is instantly provided. This is also applicable when increasing the settle time, assuming enough time has elapsed from the time the reading originally settled to account for the increase in settle time.

Menu navigation:
Input Setup → *Input* (A, 1 – 16) → *Filter Settle Time* → (0 – 200)

Default: 18 s
Interface command: **FILTER**

4.4.7.2 Filter Window

Filter window is an extra feature of the filter algorithm. If a single reading is different from the filtered value by more than the window limit, the algorithm will assume the change was intentional and restart the filter. The filter window is set in percent of full scale resistance range.

Menu navigation:
Input Setup → *Input* (A, 1 – 16) → *Filter Window* → (1% to 80%)
Default: 10%
Interface command: **FILTER**

4.4.8 Temperature Coefficient

If an RTD is used for temperature control and does not have a temperature response curve, the user must indicate the temperature coefficient of the device so that the control equation can be calculated correctly. This setting sequence will be skipped if a curve is selected for a given input. Platinum and Rhodium Iron RTDs are positive temperature coefficient and most thermistors and semiconductor RTDs like Cernox® and Germanium are negative temperature coefficient.

Menu navigation:
Input Setup → *Input* (A, 1 – 16) → *Temp Co* → (Negative or Positive)
Default: Negative
Interface command: **INSET**

4.4.9 Input Name

To increase usability and reduce confusion, the Model 372 provides a means of assigning a name to each of the inputs as well as each scanner channel if a scanner is attached. The designated input name is used on the front panel display whenever possible to indicate which sensor reading is being displayed. Refer to section 4.2.3 for alpha-numeric entry.

Menu navigation:
Input Setup→ *Input* (A, 1 – 16) → *Input Name* (15 Character String)
Default: Input A, Channel 01... Channel 16
Interface command: **INNAME**

4.4.10 Temperature Limit

The temperature limit parameter provides a means of protecting your equipment from damage by shutting down all control outputs when the assigned temperature limit is exceeded on any sensor input. The parameter is available for both the control input and each of the measurement channels. A temperature limit of 0 K (default value) turns this feature off.

Menu navigation:
Input Setup→ *Input* (A, 1 – 16) → *Temperature Limit* (0 K to 2999 K)
Default: 0.0000 K
Interface command: **TLIMIT**

4.4.11 Preferred Units

The preferred units parameter determines which units are used to display setpoint and max/min parameters whenever these parameters are displayed in any display mode. The sensor reading is also displayed in preferred units in all display modes except for the custom display mode, where each sensor location can be assigned specific display units.

The Model 370 allowed for the sensor units to be set independently for the alarms, setpoint, display, and min/max readings. In order to simplify user operation, the Model 372 adheres to the preferred units design as described above.

Menu navigation:
Input Setup→ *Input* (A, 1 – 16) → *Preferred Units* → (Kelvin or Sensor)
Interface command: **`INTYPE`**

4.4.12 Curve Selection

The Model 372 supports a variety of resistive temperature sensors manufactured by Lake Shore and other manufacturers. After the respective input/channel is selected (section 4.4), an appropriate curve may be selected. The Model 372 can use curves from several sources. Standard curves are preloaded with every instrument and numbered 1 to 20. User curves, numbered 21 to 59, can be used when a sensor does not match a standard curve. In addition, you can enter your own curves from the front panel (section 5.7) or computer interface (section 6.2). The complete list of sensor curves preloaded in the Model 372 is provided in TABLE 4-8. The standard sensor curve data points can be found on the Lake Shore website.

NOTE

Cubic spline curves can only be entered over the computer interface.

The Model 370 did not include standard curves. All Model 370 curves were considered user curves and were allocated to locations 1 to 20. In order for existing 370 control software to read and write curves from locations 1 to 20, the Model 372 must be placed into emulation mode (section 5.8). When in emulation mode, the firmware will translate the 370 curve locations received over the remote interface to adhere to the new curve location numbering scheme. Independent of emulation mode, the front panel curve menus will always show the curve locations using the newer number scheme. The following table illustrates how the curve numbers are interpreted over the remote interface as function of emulation mode.

	Normal mode	Emulation mode
Standard curve location	1 to 20	None
User curves location	21 to 59	1 to 20

TABLE 4-7 ***Sensor curves preloaded in the Model 372***

NOTE

The sensor reading of the instrument can always be displayed in sensor units. If a temperature response curve is selected for an input, its readings may also be displayed in temperature.

Curve number	Curve name	Sensor type	Model number	Temperature range*	Interpolation method
01	Reserved	—	—	—	—
02	Reserved	—	—	—	—
03	Reserved	—	—	—	—
04	Reserved	—	—	—	—
05	Reserved	—	—	—	—
06	PT-100	PTC RTD	PT-100	30 to 800 K	linear
07	Reserved	—	—	—	—
08	RX-102A-AA	NTC RTD	Rox™ RX-102A	0.05 to 40 K	linear
09	RX-202A-AA	NTC RTD	Rox™ RX-202A	0.05 to 40 K	linear
10	RX-103-AA	NTC RTD	Rox™ RX-103A	1.4 to 40 K	linear
11	Reserved	—	—	—	—
12	Reserved	—	—	—	—
13	Reserved	—	—	—	—
14	Reserved	—	—	—	—

TABLE 4-8 ***Sensor curves***

Curve number	Curve name	Sensor type	Model number	Temperature range*	Interpolation method
15	Reserved	—	—	—	—
16	Reserved	—	—	—	—
17	Reserved	—	—	—	—
18	Reserved	—	—	—	—
19	Reserved	—	—	—	—
20	Reserved	—	—	—	—
21 to 59	User curves	—	—	—	linear or cubic spline

**Instrument may not support the sensor over its entire range*

TABLE 4-8 ***Sensor curves***

Once the input is configured (section 4.4), you may choose a temperature curve. Any standard or user curve that matches the format of the sensor type configured for a given input will be available under the curve parameter in the Input Setup menu for that input. You are also given the choice of "none." When set to "none," front panel readings configured for kelvin will display the NOCURV message and the interface will report 0 K for KRDG queries.

Menu navigation:
Input Setup → *Input* (A, 1-16) → *Curve* (Any curve of RTD type)

4.5 Instrument Setup

The parameters grouped under Instrument Setup apply to all input channels whether or not a scanner is installed.

4.5.1 Frequency Selection

The Model 372 AC measurement input runs at a nominal excitation frequency of 13.7 Hz. This frequency was chosen so that it and its harmonics are separated from both 50 Hz and 60 Hz line frequency. It was also chosen to balance the effects of settling time and cable capacitance. It may be necessary to change the frequency to avoid interaction between this instrument and other measurements. This is sometimes necessary when two or more bridges are used in the same system. The Model 372 offers four alternate nominal frequencies of 9.8 Hz, 11.6Hz, 16.2 Hz, and 18.2 Hz, with the control input by default being assigned 16.2 Hz. Frequency can be changed through firmware without turning the instrument off; however, the hardware must be allowed to settle before new readings are valid.

While running the measurement input and control input in parallel, we recommend using different excitation frequencies for each input. This is to avoid an offset that will occur in the reading as a result of the two inputs coupling together. The offset becomes significant when the current levels between the two input excitations differ by a factor of 100 or more (i.e., the control input set to 1 nA and the measurement input is set to 100 nA).

NOTE

A frequency "beating" will occur when the two inputs are set to different frequencies. However, this "beating" is easily removed by filtering the respective readings.

Menu navigation:
Instrument Setup→ *Measurement Input* (9.8 Hz, 11.6 Hz, 13.7 Hz, 16.2 Hz, 18.2 Hz)
Default: 13.7 Hz
Interface command: `INTYPE`

Menu navigation:
Instrument Setup→ *Control Input* (9.8 Hz, 11.6 Hz, 13.7 Hz, 16.2 Hz, 18.2 Hz)
Default: 16.2 Hz
Interface command: `INTYPE`

4.5.2 Active Common Mode Reduction

Active common mode reduction is a special feature of the Model 372 that can reduce noise on the measurement input leads. It is most useful when the excitation current is 1 µA or less, but it should be left on unless one resistor lead is shorted to measurement common (section 3.5.5).

Menu navigation:
Instrument Setup → *CM Reduction* (On, Off)
Default: On
Interface command: **CMR**

4.5.3 Monitor Output Selection

The monitor output on the Model 372 is a tool to help the user diagnose measurement problems. The output can be set to monitor test voltages from several points inside the instrument. The monitor voltages are often used with the reference output. The signal presented at the reference output is a function of the monitor point selected. An explanation of these monitor voltages is given with other troubleshooting information in Chapter 8.

Monitor point	Description	Reference source
Off	Output grounded to measurement common	Measurement
CS NEG	AC voltage driving negative side of current source programming resistor	Measurement
CS POS	AC voltage driving positive side of current source programming resistor	Measurement
VCM NEG	AC voltage on the negative side of the differential input amplifier	Measurement
VCM POS	AC voltage on the positive side of the differential input amplifier	Measurement
VDIFF	AC voltage output of the differential input amplifier	Measurement
Measurement A/D	AC voltage into the measurement input AD converter	Measurement
Control	AC voltage into the control input AD converter	Control

TABLE 4-9 ***Monitor output voltages***

4.6 Output Control Setup

Once the sensor inputs have been configured (section 4.4), the outputs can be configured. The Output Setup menu is used to create control loops for controlling temperature, whether using feedback (closed loop) or manually setting the output (open loop). This section describes how to operate the output and control features, and how to set control parameters. Each control parameter should be considered before turning on a control loop output or the instrument may not be able to perform the most simple control functions. A good starting point is deciding which control loop to use, whether to operate in open or closed control mode and which tuning mode is best for the application. Other parameters fall into place once these have been chosen. Section 2.11.2 of this manual describes the principles of closed loop proportional, integral, and derivative (PID) control.

4.6.1 Heater Outputs

The Mode 372 comes equipped with two heaters. The sample heater is designed for control at very low temperatures, and can provide up to 1 W. The warm-up heater is designed for bulk heating and control at higher temperatures, and can provide up to 10 W. They each include a large set of hardware and software features, making them very flexible and easy to use. The heater outputs are well-regulated DC outputs. This provides quiet, stable control for a broad range of temperature control systems in a fully integrated package.

4.6.1.1 Sample Heater Resistance

The Model 372 does not need to know heater resistance to perform its control functions. Heater resistance is only required to accurately display the heater output and manual output in power. The instrument does not measure heater resistance so one must be entered for these display values to be meaningful. A 100 Ω heater is required for maximum power output, but other values can be used. If a heater resistance is not known, the heater output display should be configured for the current.

Menu navigation:
Output Setup → Sample Heater → *Heater Resistance* → (1 to 2000)
Default: 100 Ω
Interface command: **HTRSET**

4.6.1.2 Warm-up Heater Max Current and Heater Resistance

The Model 372 warm-up heater output is designed to work optimally into a 25 Ω or 50 Ω heater. The Heater Resistance and Max Current parameters work together to limit the maximum available power into the heater. This is useful for preventing heater damage or limiting the maximum heater power into the system. When using a 25 Ω or 50 Ω heater, set the Heater Resistance parameter accordingly. The Max Current setting will then provide a discrete current limit value that corresponds to the 10 W warm-up heater power rating. These current limits keep the output operating within the voltage compliance limit to ensure the best possible resolution. These parameters work with the heater range parameter (section 4.6.1.5.9) to provide safety and flexibility.

If you are not using a standard heater resistance, set the Heater Resistance setting to 25 Ω for any resistance less than 50 Ω, or to 50 Ω for any higher heater resistance. The user max current setting is useful when using a non-standard heater resistance value. Refer to section 4.6.1.2.1 for more information on Max User Current. TABLE 4-10 provides examples of different heater resistances and max current settings, and the resulting maximum heater power. The maximum heater powers in bold represent the discrete current limits available under the Max Current setting for 25 Ω and 50 Ω heaters.

Menu navigation:
Output Setup → Warm-up Heater → *Heater Resistance* → (25 Ω or 50 Ω)
Output Setup → Warm-up Heater → *Max Current* → (User, 0.45 A, 0.63 A)
Default:
Heater Resistance-> 25 Ω
Output 1 → Max Current → 0.63 A
Interface command: **HTRSET**

4.6.1.2.1 Max User Current

When using a heater that is not 25 Ω/10 W or 50 Ω/10 W, the provided discrete current limits may not be appropriate. The User Max Current setting is available for this case. The optimal maximum current value should be calculated based on the heater's power rating, or the maximum desired heater output power, whichever is lower. The 23 V heater output compliance voltage should also be taken into account in order to maximize heater setting resolution. This calculated current limit can then be entered using the User Max Current setting.

To calculate the Max Current setting based on a heater or load power limit, calculate current, I, using both of the following equations: I = Sqrt (P/R) and I = 23 V/ R where P is the maximum allowable power, R is the heater resistance. The load power limit and voltage compliance limit of the heater output (23 V) are in place at the same time, so the lower calculated current is the correct Max Current setting.

Example 1: a 25 Ω/5 W heater is connected to the warm-up heater.

Power Limit	**Voltage Compliance Limit**
I = Sqrt(P/R)	I = 23 V/R
I = Sqrt(5 W/25 Ω)	I = (23 V/25 Ω)
I = 0.48 A	I = 0.92 A

User Max Current should be set to the smaller of the two or 0.48 A. In this example, the desired 5 W of power is available to the heater.

Example 2: a 75 Ω/25 W heater is connected to the warm-up heater.

Power limit	**Voltage compliance limit**
I = Sqrt(P/R)	I = 23 V/R
I = Sqrt(25 W/75 Ω)	I = (23 V/75 Ω)
I = 0.58 A	I = 0.31 A

User Max Current should be set to the smaller of the two, or 0.31 A. In this example, only 7 W of the desired 25 W of power is available to the heater.

To enter a User Max Current, first set the Heater Resistance setting to 25 Ω for any resistance less than 50 Ω, or to 50 Ω for any higher heater resistance. Set the Max Current setting to User. The User Max Current setting now becomes available in the warm-up heater Output Setup menu. Enter the calculated current limit value in the User Max Current parameter.

Max current	Heater resistance (Ω)					
0.63	10	25	30	40	50	100
	4	**10**	12			
0.5 (user)	3	6	8	10		
0.45	2	5	6	8	**10**	

Shaded black: max current is too high for these resistances due to the voltage compliance limit.
Bold font: discrete options that are available for 25 Ω and 50 Ω heaters are under the max current setting.

TABLE 4-10 ***Warm-up heater user max currents***

4.6.1.3 Heater Output Display

The warm-up heater output can be displayed in units of percent of full scale current or percent of full scale power.

The sample heater output can also be configured to display the output range as its full scale current and the output as a percent of that current. However, unlike the warm-up heater, the sample heater can also be configured to display the output range by its full scale power and the output as power in watts. This configuration is better for predicting the power entering the load, but it relies on an accurate heater resistance being entered into the instrument (section 4.6.1.1).

With both heaters, the heater output display on the front panel is displayed in these units, and the Manual Output parameter is set in these units. Available full scale current and power are determined by the heater resistance, max current setting, and heater range.

NOTE

The heater output display is a calculated value intended to aid in system setup and tuning. It is not a measured value, and may not accurately represent actual power in the heater.

Menu navigation:
Output Setup → Sample Heater or Warm Up Heater → Heater Out Display → (Current, Power)
Default: Current
Interface command: **HTRSET**

4.6.1.4 Output Modes

Both heater outputs can be configured in one of four output modes: Off, Closed Loop PID, Zone, or Open Loop. In addition, the warm-up heater can be configured into a warm-up mode. The Off mode prevents current from being sourced to the given output. Closed Loop PID is the mode most often used for controlling temperature. Zone mode builds on the Closed Loop mode by providing automatic changing of control parameters at up to ten different temperature zones. Open Loop mode provides a means of applying a constant current to the output. Warm-up mode is intended to help bring a system to room temperature in order to change samples. Refer to section 5.3 for more information regarding warm up mode operation.

Menu navigation:
Output Setup → *Sample Heater* → *Output Mode* → (Off, Closed Loop PID, Zone, Open Loop)
Output Setup → *Warm Up Heater* → *Output Mode* → (Off, Closed Loop PID, Zone, Open Loop, Warm Up)
Default: Off
Interface command: **OUTMODE**

4.6.1.4.1 Closed Loop PID Mode

The Closed Loop PID mode is the most commonly used closed loop control mode for tightly controlling temperature using the heater outputs of the Model 372. In this mode, the controller attempts to keep the load at exactly the user-entered setpoint temperature. To do this, it uses feedback from the control input sensor to calculate and actively adjust the control output setting.

The Model 372 uses a control algorithm called PID that refers to the three terms used to tune the control. Refer to section 4.6.1.5.1 for details on assigning a control input for the closed loop feedback. Refer to section 2.11.2 and section 2.11.3 for a detailed discussion of PID control and manual tuning.

In Closed Loop PID mode, the controller will accept user-entered proportional, integral, and derivative parameters to provide 3-term PID control. Manual output can be used during closed loop control to add to the calculated PID control output.

Menu navigation:
Output Setup → *Sample Heater* or *Warm Up Heater* → *Output Mode* → Closed Loop PID

4.6.1.4.2 Zone Mode

Optimal control parameter values are often different at different temperatures within a system. Once control parameter values have been chosen for each temperature range (or zone), the instrument will update the control settings each time the setpoint crosses into a new zone.

NOTE

If desired, the control parameters can be changed manually (identical to Closed Loop PID mode), but they will be automatically updated once the setpoint crosses a zone boundary.

The control algorithm used for each zone is identical to that used in Closed Loop PID mode. The Zone feature is useful by itself, but it is even more powerful when used with other features. We recommend using zone mode with setpoint ramping (section 4.6.1.5.7). Section 5.2 provides details on setting up zones and section 2.11.2 provides a detailed explanation of PID control.

Menu navigation:
Output Setup → *Sample Heater* or *Warm Up Heater* → *Output Mode* → Zone

4.6.1.4.3 Open Loop Mode

Open Loop Output mode allows you to directly set the output using only the Manual Output and Range parameters. This guarantees constant current to the load, but it does not actively control temperature. Any change in the characteristics of the load will cause a change in temperature.

You can configure any output to Open Loop mode. When an output is configured in this mode, the Manual Output and Heater Range parameters become available in the Output Setup menu for setting the output. For convenience, the Control Input parameter can be used to assign a sensor input, which then allows the output to be displayed on the front panel when the output is configured to be displayed in the control/scan information display quadrant. When the output is displayed on the front panel, the **Manual Output** and **Heater Range** direct operation keys can be used for direct access to these settings. Refer to section 4.3.2 for details on configuring display modes.

CAUTION

Since there is no sensor feedback in Open Loop mode, there is nothing to prevent the system from being overheated. We recommend using the temperature limit feature to help protect the system from overheating (section 4.4.10).

Menu navigation:
Output Setup → *Sample Heater* or *Warm Up Heater* → *Output Mode* → Zone

4.6.1.4.4 Warm Up Mode (Warm-up Heater Only)

Warm Up mode is designed for driving a resistive heater load that is used for rapidly increasing the temperature in the controlled system, for example, to bring a system to room temperature in order to change samples. Refer to section 5.3 for more information on warm up operation.

Menu navigation:
Output Setup → Warm Up Heater → *Output Mode* → Warm Up

4.6.1.5 Control Parameters

Once the output mode is chosen, the control parameters can be used to begin controlling temperature. Control Input is used to create a control loop. The P, I, and D parameters provide fine tuning of the control algorithm. Manual Output provides a baseline output power about which to control. Setpoint is used to set the desired target temperature, and Heater Range is used to turn on the control output, as well as to set the power range of the output. These parameters are described in detail in section 4.6.1.5.1 to section 4.6.1.5.12.

4.6.1.5.1 Control Input

For closed loop control (Closed Loop PID, Zone, Warm Up Supply) a control loop must be created. A control loop consists of a control output for controlling the temperature, and an input for feedback into the control algorithm. Use the Control Input parameter to assign the control input sensor to the desired output.

In the Monitor Out mode the control input parameter is used to determine the source of the output voltage.

A special case exists when a scanner is attached, autoscanning is enabled, and a measurement input channel is selected as an output's control input. Details regarding the change to the control algorithm as a result of this special case are described in section 4.6.1.6.1.

NOTE **An input can only be assigned to one output at a time. If an input is assigned to a new output, the previous output will have an input setting of "none."**

NOTE **If the measurement input control channel is manually changed during control, the instrument will attempt to minimize disturbance to the load by choosing the reading value from the new channel as the setpoint when controlling in ohms.**

NOTE **If there is not a curve assigned to the control input, the appropriate temperature coefficient must be selected in the input setup menu (section 4.4.8) or the PID control algorithm will not operate properly.**

Menu navigation:
Output Setup (Sample Heater, Warm Up Heater, or Analog/Still) → Control Input→ (None, Input A, 1-16)
Default:
Sample Heater: Input A
Warm Up Heater: Off
Analog/Still: Off
Interface command: `OUTMODE`

4.6.1.5.2 Proportional (P)

The proportional parameter (also called gain) is the P part of the PID control equation. It has a range of 0.001 to 1000 with a resolution of 0.001. The default value is 10.

To set P, first configure the output mode of the desired heater to Closed Loop PID mode (section 4.6.1.4). Then press **Sample Heater** or **Warm-Up Heater** to display the respective control loop information if it is not already displayed. Then press **PID/Man Out**. This will cause a temporary Control Setup menu to be displayed allowing the P value to be set.

Menu navigation:
Sample Heater or **Warm-Up Heater** → PID/Man Out → Proportional (P) → (0.001 to 1000)
Default: 10
Interface command: `PID`

4.6.1.5.3 Integral (I)

The integral parameter (also called reset) is the I part of the PID equation. It has a setting range of 1 to 10,000 s. A setting of zero turns I off. The default value is 20 s.

To set I, first configure the output mode of the desired heater to Closed Loop PID mode (section 4.6.1.4). Then press **Sample Heater** or **Warm-Up Heater** to display the respective control loop information if it is not already displayed. Then press **PID/Man Out**. This will cause a temporary Control Setup menu to be displayed allowing the I value to be set.

Menu navigation:
Sample Heater or **Warm-Up Heater** → PID/Man Out → Integral (I) → (1 to 10,000)

Default: 20 s
Interface command: `PID`

4.6.1.5.4 Derivative (D)

The derivative parameter (also called rate) is the D part of the PID equation. It has a setting range of 1 to 2500 s. A setting of zero turns D off. The default value for D is zero (off).

To set D, first configure the output mode of the desired heater to Closed Loop PID mode (section 4.6.1.4). Then press **Sample Heater** or **Warm-Up Heater** to display the respective control loop information if it is not already displayed. Then press **PID/Man Out**. This will cause a temporary Control Setup menu to be displayed allowing the D value to be set.

Menu navigation:
Sample Heater or **Warm-Up Heater** → PID/Man Out → Derivative (D) → (1 to 2,500)
Default: 0 s
Interface command: `PID`

4.6.1.5.5 Manual Output

Manual Output is a manual setting of the control output. It can function in two different ways depending on control mode. In open loop control mode, the Manual Output is the only output to the load. You can directly set the control output from the front panel or over the computer interface. In closed loop control mode, Manual Output is added directly to the output of the PID control equation. In effect, the control equation operates about the Manual Output setting.

Manual output units follow the heater output display units of current or power. Refer to section 4.6.1.3 to set the Heater Out display units. When heater display units are configured as current, the manual output parameter is set in percent of full scale current for the selected heater range for both the warm-up heater and the sample heater. The Manual Output setting range is 0% to 100% with a resolution of 0.01%.

When the heater output display is configured for power, the warm-up heater manual output is a percentage of full scale power. The Manual Output current setting range is 0% to 100% with a resolution of 0.01%. However, when configured for power, the sample heater manual output parameter is set in watts, not percentage. An accurate heater resistance must be entered under the sample heater output setup menu for the power calculation to be accurate. The setting range is from 0 to full scale power for the selected heater range with a setting resolution of six digits. The actual resolution is limited to the 0.01% resolution of the heater output current source.

Available full scale current and power are determined by the heater resistance, Max Current setting, and Heater Range.

To set Manual Output, press **Sample Heater** or **Warm-Up Heater** to display the respective control loop information if it is not already displayed, then press **PID/Man Out** button. This will cause a temporary Control Setup menu to be displayed allowing the I value to be set.

In addition, when an output is configured for Open Loop mode, the Manual Output setting is available in the Output Setup menu.

Menu navigation:
Sample Heater or **Warm-Up Heater** → PID/Man Out → Manual Output →
(0% to 100%)

Default: 0%
Interface command: **MOUT**

4.6.1.5.6 Setpoint

Use the setpoint parameter to set the desired load temperature for a control loop. Before entering a setpoint, a control loop must be created by configuring an input sensor and assigning it to a control output using the control input parameter. The setpoint can be entered in either temperature units or sensor units, based on the sensor input's Preferred Units setting. The setpoint ramping feature is available when controlling in temperature units to provide smooth, continuous control from one temperature to the next. Refer to section 4.4 for details on Input Setup. Refer to section 4.6.1.5.1 for details on assigning a control input. Refer to section 4.6.1.5.7 for details on the setpoint ramping feature.

Most applications require control in units of temperature. To control in units of temperature, set the preferred units parameter of the control input sensor to kelvin (section 4.4.11). When controlling in temperature, the available setting range of the setpoint is limited by the setpoint limit parameter of the assigned temperature curve. Refer to section 5.6.1 for details on setting a curve setpoint limit.

NOTE

The setpoint limit feature only limits the setpoint entry. For even greater protection, the temperature limit feature can be used to turn off all heater outputs if a sensor reading above the specified temperature is observed (section 4.4.10).

There are some instances when temperature control in ohms may be desired, for example when a temperature curve is not available. For these applications the Model 372 can control temperature in ohms. To control in ohms, set the preferred units parameter to ohms. When controlling in ohms, the setpoint resolution matches the display resolution for the sensor input type given in the specifications (section 1.6.1).

NOTE

Temperature control in sensor units can be unpredictable since most resistive temperature sensors do not have a linear response to temperature, and therefore, can have different sensitivity in different temperature ranges.

If you change the preferred units from ohms to temperature (kelvin), or from temperature to ohms, the Model 372 uses the assigned temperature curve to convert the setpoint to the new control units. This provides minimal disruption in the control output if you change the preferred units parameter while the control loop is active.

To change the setpoint, first configure the output mode of the desired heater to Closed Loop PID mode (section 4.6.1.4). Then press **Sample Heater** or **Warm-Up Heater** to display the respective control loop information if it is not already displayed. Then press **Setpoint**.

Menu navigation:
Setpoint → (See note below)
Default: 0.0000 K
Interface command: **SETP**

NOTE

When controlling in temperature, setpoint is limited by the control input temperature curve's setpoint limit. When controlling in sensor units, setpoint is limited by the limits of the configured control sensor.

4.6.1.5.7 Setpoint Ramping

The Model 372 can generate a smooth setpoint ramp when the preferred units are expressed in temperature. You can set a ramp rate in degrees kelvin per minute with a range of 0 to 100 and a resolution of 0.001. Once the ramping feature is turned on, its action is initiated by a setpoint change. When you enter a new setpoint the instrument changes the setpoint temperature from the old value to the new value at the ramp rate. A positive ramp rate is always entered; it is used by the instrument to ramp either up or down in temperature. When you enter a ramp rate of zero, the setpoint change will be instantaneous, despite the setpoint ramping feature remaining on. This is most useful in zone control mode, when you desire ramping to be enabled for a particular output, but not necessarily for all zones.

Always use the ramping feature to minimize temperature overshoot and undershoot. When ramping is not used, a setpoint change can cause the error used by the PID equation to become very large, which causes the integral contribution of the control output equation to become larger the longer the error exists. This will result in a large overshoot or undershoot once the setpoint temperature is reached, since the integral contribution will only decrease when the error polarity is reversed. Use a ramp rate that keeps the control output from reaching the extremes of 100% or 0% while ramping for optimal results

The ramping feature is useful by itself, but it is even more powerful when used with other features. Setpoint ramps are often used with zone control mode. As temperature is ramped through different temperature zones, control parameters are automatically selected for best control. Ramps can be initiated and status read back using a computer interface. During computer-controlled experiments, the instrument generates the setpoint ramp while the computer is busy taking necessary data.

NOTE **When an incomplete ramp is shut off, the setpoint will remain on the most current setting (the reading will not jump to the end of the ramp).**

NOTE **If the input type or input curve is changed while a ramp is in progress, both ramping and the heater are turned off.**

NOTE **If Ramp is on and the setpoint is set to sensor units, the ramping function will remain on but when another setpoint is entered, the setpoint goes directly to the new setpoint value.**

NOTE **To bypass ramping and load the setpoint with the current temperature, with the control loop displayed, press and hold the Setpoint button for 3 s.**

Menu navigation:
Output Setup → *Sample Heater* or *Warm Up Heater* → *Setpoint Ramping* →
(Off or On)
Default: Off
Interface command: **`RAMP`**

To stop a ramp, when the desired control loop is displayed, press **Setpoint**, then immediately press **Enter**. This stops the ramp at the current setpoint, but leaves the ramping function activated. To continue the ramp, enter a new setpoint. Refer to section 4.6.1.5.6 for details on setting the setpoint parameter.

4.6.1.5.8 Setpoint Change Pause Time (Measurement Input Only)

Temperature control loops need time to settle after any setpoint change. If one of the measurement input channels is assigned to an output for temperature control while actively scanning, the loop may not get enough time to settle into the new setpoint before the scanner moves away from the control channel. The Model 372 can be forced to read only the specified measurement input control channel for a period of time after any setpoint change to guarantee settling. This time period is set with the setpoint change pause parameter. The setpoint change pause time parameter is selectable from 1 to 255 s with a resolution of 1 s. Manually changing scanner channel will override the pause and force a reading.

Menu navigation:
Output Setup → *Sample Heater* or *Warm Up Heater* → *Setpoint Chng Pause* → (1 to 255)
Default: Off
Interface command: **`RANGE`**

4.6.1.5.9 Heater Range

The Heater Range setting is used for turning a control output on, as well as setting the output power range for the heater outputs. All three outputs provide an Off setting for turning the output off.

The warm up heater and analog/still outputs do not have multiple output ranges, and only provide an On setting for enabling the respective output.

The sample heater provides eight ranges of settings which provide decade steps in power, based on the maximum output power available to the connected heater. The 100 mA range provides the maximum power, and each successive lower range provides 10 times less power than the last. Lower sample heater ranges are provided to allow good control resolution at lower temperatures where cooling power diminishes. Heater range is an integral part of the closed loop control system so re-tuning may be required when heater range is changed.

The sample heater output range follows the heater output display units of current or power. An appropriate heater resistance must be entered under the output setup menu for the power calculation to be meaningful. The maximum current or power is used on the display to indicate the selected range. Some examples of heater power versus heater resistance are given in section 3.7.1.1.

While controlling temperature, the following will cause the heater range to automatically turn off:

- Exceeding the temperature limit setting
- Setup changes to the control input
- Power loss with the power up enable feature turned off
- Input errors such as T. Over, T. Under, S. Over, and S. Under

NOTE

Available full scale current and power for the heater outputs are determined by the heater resistance, Max Current setting, and Heater Range.

Specifications of the heater outputs are provided in Chapter 1. Heater theory of operation is provided in section 2.5. Various heater installation considerations are provided in section 3.7.

To set the sample heater range, press **Sample Heater** to configure the front panel display to show the desired control loop information. Then press **Heater Range**. In addition, the heater range can be selected from the output setup menu.

The following menu navigation example illustrates the available heater ranges when the heater output display units are configured for current. If configured for power, the available ranges would be listed in power.

Menu navigation:
Heater Range → (Off, On, 31.6 µA, 100 µA, 316 µA, 1 mA, 3.16 mA, 10 mA, 31.6 mA, 100 mA)
Default: Off
Interface command: **RANGE**

4.6.1.5.10 Polarity (Sample Heater only)

When the sample heater output is used in a traditional manner (to drive a resistive load) the heater output needs to be unipolar since reversing the current will still heat the load. There may be some rare circumstances when the heater output is not connected to a resistive load and bipolar control is desired. The heater output can be set to control the current to plus and minus the full-scale range by setting the heater polarity to bipolar mode. For the majority of applications and any application where the heater output is connected to a resistive load, the unipolar mode should be chosen.

Menu navigation:
Output Setup → Sample Heater → Polarity → (Unipolar, Bipolar)
Default: Unipolar
Interface command: **OUTMODE**

4.6.1.5.11 Control Filter

During normal operation, the PID control algorithm uses the unfiltered input readings from the control channel as its feedback. This method offers the best control stability and some noise immunity because of the natural averaging that takes place in the integral (I) part of the control equation. The control algorithm can be configured to use filtered readings instead of unfiltered readings. This configuration can improve noise rejection but it is sometimes at the expense of more difficult tuning or even control instability. The filter creates time lag that destabilizes the control loop. When control filtering is enabled, the firmware uses the same filter parameters set for the control input channel. Any control application should be tuned first with the control filter off. Filter action should be added gradually, starting with a very short settling time, and adjustments to P and I made be required along the way (most often P will decrease and I will increase). The filter time constant should always remain shorter than the I setting in seconds.

Menu navigation:
Output Setup → *Sample Heater or Warm up Heater* → *Control Filter* → (Off,On)
Default: Off
Interface command: **OUTMODE**

4.6.1.5.12 ALL OFF

The **ALL OFF** key is provided as a means of shutting down all control outputs with one key. It is equivalent to setting the heater range parameter of all outputs to Off. This function is always active even if the keypad is locked or when it is in remote mode.

4.6.1.6 Controlling and Scanning

While use of the dedicated control input is the preferred method of temperature control, the Model 372 and 3726 scanner allow both temperature control and data collection at the same time using just the scanner without the dedicated control input. When autoscan is enabled, firmware in the Model 372 manages switching between the measurement input control channels and the enabled measurement input scan channels and will maintain the control heater output when the control channel is not active. Scanning during closed loop temperature control will never be as stable as using the dedicated control input, but with proper setup acceptable performance can be achieved for many applications.

4.6.1.6.1 Reading Sequence

The instrument takes control of the reading sequence when controlling temperature with one scanner channel and measuring on another. When autoscan is enabled, the Model 372 will alternate between the control channels and enabled scan channels using the scan dwell and change pause times as configured for the enabled measurement channels. In the case where two measurement input channels are used for control (for example one channel tied to the sample heater and one channel tied to the warm-up heater), the firmware will scan to the sample heater control channel, then to the warm-up heater control channel before scanning back to non-control channels. TABLE 4-11 and FIGURE 4-10 illustrate this sequence.

Measurement channel	Used for control?	Assigned output	Change pause time (s)	Scan dwell time (s)
1	No	NA	3	2
2	No	NA	3	2
4	Yes	Sample heater	5	20
5	Yes	Warm-up heater	5	15

TABLE 4-11 ***Reading sequence when two measurement input channels are used for control***

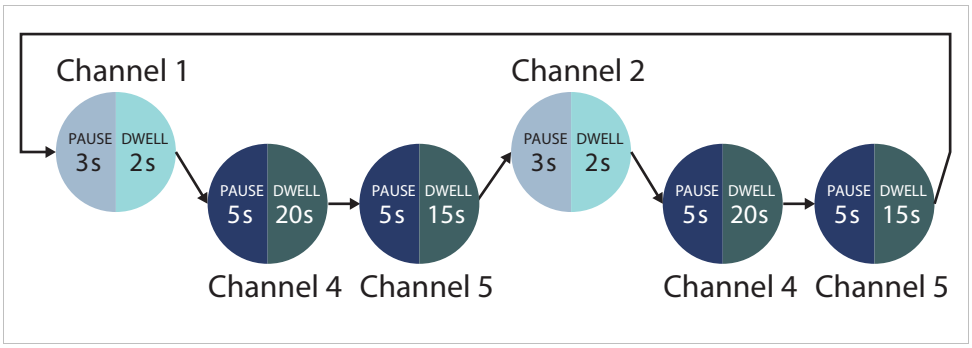


FIGURE 4-10 ***Reading sequence when two measurement input channels are used for control***

As an additional example, Table 4-11 and Figure 4-11 illustrate the case where only one measurement input channel is used for controlling an output. In this scenario, the firmware will alternate scanning between each non-controlling measurement input channel and the control channel assigned to the sample heater.

Measurement channel	Used for control?	Assigned output	Change pause time (s)	Scan dwell time (s)
1	No	NA	3	2
2	No	NA	3	2
3	No	NA	3	2
4	Yes	Sample heater	5	20

TABLE 4-12 ***Reading sequence when one measurement input channel is used for control***

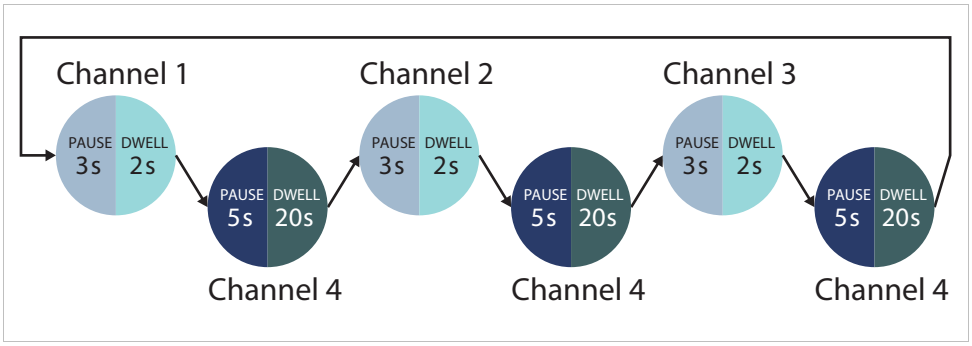


FIGURE 4-11 ***Reading sequence when one measurement input channel is used for control***

When using a measurement input channel as a controlling input it is particularly important to configure the dwell and change times properly to ensure stable control. Too short of a dwell time on a measurement input control channel may cause unacceptable control performance. See section 4.4.5 to configure the scanner dwell time. See section 4.4.6 for information regarding configuring change pause time.

The filter settling time for each channel is very important when alternating between a measurement input control channel and other readings. Longer settling times suspend active control for longer periods of time, increasing instability. The change pause must be set appropriately for each active channel and the control channel filter should have as short a settling time as possible.

4.6.2 Analog Output

The analog output is variable DC voltage sources that have a range from -10 V to + 10 V. The voltage is generated by a 16-bit D/A converter with resolution of 0.3 mV or 0.003% of full scale. This output can be configured to Open Loop (section 4.6.1.4.3), Monitor Output, or Still Output mode. The Open Loop mode can be used to set the output to a specific, constant value. The Monitor Out mode uses the output to provide a voltage proportional to an input sensor reading to be used by an external device such as a data logger. The Still Output mode is described in section 4.6.2.2.

The voltage output is designed to provide up to 1 W into a 100 Ω heater. The output current is limited to slightly over 100 mA, and therefore, a heater value less than 100 Ω can drive the output into current limit. This condition will not damage the output, but it can result in discontinuous temperature control.

4.6.2.1 Monitor Out

Refer to section 5.4 for more information on Monitor Out mode.

4.6.2.2 Still Output Mode

The Model 372 can provide the small amount of power required to drive the still heater of a dilution refrigerator with the analog output. None of the analog output hardware changes when it is configured for still operation. Section 3.8.2 describes how to estimate the full scale current sourced to a resistive heater. When the analog output is in still mode, the **Still** direct operation key gives direct access to the still output parameter, which is used to set a percentage of the full scale current. The still output parameter is the same as the manual output parameter in open loop mode, but the setting can be made without sequencing through the analog output menu. Unipolar operation is recommended for this application.

Menu navigation:
Output Setup → Analog/Still → Output Mode → (Still)
Interface command: `OUTMODE`

Menu navigation:
Still → Still Output → (–100% to 100%)
Interface command: `STILL`

4.6.3 Power Up Enable

All configuration parameters of the Model 372 can be retained through a power cycle. Some systems require that the heater range or analog output is turned off when power is restored. The power up enable feature allows you to choose whether or not the heater range or analog output is turned off each time the instrument power is cycled. Set the power up enable parameter to off to ensure that the heater range or analog output is turned off on power up. Set it to on to return the heater range or analog output to its previous setting when power is restored.

Menu navigation:
Output Setup → *Sample Heater, Warm Up Heater,* or *Analog/Still* →
Power Up Enable → (Off or On)
Default: Off
Interface command: `OUTMODE`

4.7 Interface

The Model 372 has three computer interfaces: IEEE-488, USB, and Ethernet. Only one of these interfaces can be active at one time. Use the Interface menu to configure which interface is active, and to configure the parameters related to the selected interface.

Menu navigation:
Interface → *Enabled* → (USB, Ethernet, IEEE-488)
Default: USB

4.7.1 USB

The USB interface is provided as a convenient way to connect to most modern computers, as a USB interface is provided on nearly all new PCs as of the writing of this manual. The Model 372 USB driver, which must be installed before using the interface (section 6.3.3), creates a virtual serial com port, which can be used in the same way as a traditional serial com port. Refer to Chapter 6 for details on computer interface operation.

Menu navigation:
Interface → Enabled → USB

4.7.2 Ethernet

The Ethernet interface is provided to allow the Model 372 to connect to a computer network. A direct connection to a PC can also be achieved using a cross-over Ethernet cable. The advantages of using the Ethernet interface include the ability to communicate directly with the Model 372 from any PC on the same local network, and even from around the world via the Internet. Refer to section 6.4.1 for details on Ethernet configuration.

Menu navigation:
Interface → Enabled → Ethernet

4.7.3 IEEE-488

An IEEE-488 (GPIB) interface is provided for compatibility with legacy systems. Refer to Chapter 6 for details on computer interface operation.

Menu navigation:
Interface→Enabled→IEEE-488

4.7.3.1 Remote/Local

Local refers to operating the Model 372 from the front panel. Remote refers to operating the controller via the IEEE-488 Interface. The keypad is disabled during remote operation, except for the **Remote/Local** key and the **ALL OFF** key. When in remote mode, the Remote front panel LED will be illuminated. When in local mode, the Remote LED will not be illuminated.

Menu navigation:
Remote/Local (LED On = Remote mode, LED Off = Local mode)

4.8 Locking and Unlocking the Keypad

The keypad lock feature prevents accidental changes to parameter values. When the keypad is locked, some parameter values may be viewed, but most cannot be changed from the front panel. **ALL OFF** is the only keypad function that remains active when the keypad is locked.

A three-digit keypad lock code locks and unlocks the keypad. The factory default code is 123. The code can be changed only through the computer interface. If instrument parameters are reset to default values, the lock code resets also. The instrument cannot reset from the front panel with the keypad locked.

To lock the keypad, press and hold **Enter** for 5 s. Use the numeric keypad to enter the three-digit lock code. If the lock code is accepted, *** Keypad Locked *** will be displayed for 3 s, and the display will return to normal. Changes attempted to any parameters result in a brief display of the *** Keypad Locked *** message.

To unlock the keypad, press and hold **Enter** for 5 s. Use the numeric keypad to enter the three-digit lock code. If the lock code is accepted, *** Keypad Unlocked *** will be displayed for 3 s and the display will return to normal. All Model 372 parameters are now accessible.

Chapter 5: Advanced Operation

5.1 General

This chapter provides information on the advanced operation of the Model 372 AC resistance bridge and temperature controller.

5.2 Zone Settings

The Model 372 allows you to establish up to ten custom contiguous temperature zones where the controller will automatically use pre-programmed values for PID, heater range, manual output, ramp rate, and relay 1 and 2 states. Zone control can be active for both control loops at the same time. Configure the zones using 1 as the lowest to 10 as the highest zone. Zone boundaries are always specified in kelvin (K). The bottom of the first zone is always 0 K; therefore, only the upper limit is required for all subsequent zones. Make a copy of FIGURE 5-1 to plan your zones.

To use the programmed zones, the output mode must be set to Zone (refer to section 4.6.1.4.2 to set up Zone mode). In Zone mode, the instrument will update the control settings each time the setpoint crosses into a new zone. If you change the settings manually, the controller will use the new setting while it is in the same zone, and will update to the programmed zone table settings when the setpoint crosses into a new zone.

To illustrate how the control parameters are updated in Zone mode, consider the zone settings in TABLE 5-1. Starting from room temperature (about 300 K), and setting a setpoint of 2 K (with Setpoint Ramping turned on), the setpoint will begin ramping at the current setpoint ramp rate, then once the setpoint crosses 100 K, the control parameters from Zone 8 will be used. The setpoint ramp will then continue toward 2 K at a rate of 20 K/min until crossing 50 K, when the control parameters from Zone 7 are loaded. This pattern will continue until the final setpoint value of 2 K is reached, or another setpoint is entered. In this example, the sample heater is used as the output.

Zone	Lower boundary (implied)	Upper boundary	P	I	D	Manual output	Range	Ramp rate
10	—	0 K	50	20	0	0.0%	Off	0.1 K/min
9	—	0 K	50	20	0	0.0%	Off	0.1 K/min
8	100.001 K	500 K	200	20	0	0.0%	100 mA	30 K/min
7	50.001 K	100 K	185	25	0	0.0%	31.6 mA	20 K/min
6	25.001 K	50 K	150	30	0	0.0%	10 mA	10 K/min
5	15.001 K	25 K	100	30	0	0.0%	3.16 mA	5 K/min
4	10.001 K	15 K	85	35	0	0.0%	1 mA	2 K/min
3	7.001K	10 K	85	35	0	0.0%	316 µA	0.9 K/min
2	4.001 K	7 K	70	40	0	0.0%	100 µA	0.7 K/min
1	0 K	4 K	50	50	0	0.0 %	31.6 µA	0.5 K/min

TABLE 5-1 ***Zone settings example***

	Proportional (0.0–1,000)	Integral (0–10,000)	Derivative (0–2,500)	Manual output (0–100%)	Heater Range	Upper boundary: K	Relay 1 ☐On ☐Off	Relay 2 ☐On ☐Off	Ramp Rate (0.001–100 K/min)
Zone 10									
Zone 09									
Zone 08									
Zone 07									
Zone 06									
Zone 05									
Zone 04									
Zone 03									
Zone 02									
Zone 01									

0 K

FIGURE 5-1 ***Record of zone settings***

Menu navigation:
Zone Settings → *Sample Heater* or *Warm-up Heater* → *Zones* → (1 to 10)

5.3 Warm Up Mode

The warm-up heater comes with a selectable warm-up mode that is designed to drive a heater to rapidly increase the temperature in a controlled system, for example, to bring a system to room temperature in order to change samples.

The control input parameter determines which sensor is used for feedback in the warm-up mode. Refer to section 4.6.1.5.1 for details on the control input parameter.

Once the warm-up heater is configured for warm-up mode, press **Warm-up Heater** button to display the warm-up heater control information on the display screen. Next, press **Setpoint** and set the desired temperature, then press **Heater Range** and set the range to on to activate the output.

NOTE

The Power Up Enable feature determines if the output will remain on after power is cycled. Refer to section 4.6.3 for details on the Power Up Enable feature.

Menu navigation:
Output Setup→ *Warm-up Heater* → *Output Mode* → Warm Up
Interface command: `OUTMODE`

5.3.1 Warm Up Percentage

The Warm Up Percentage parameter is used to determine the amount of current to apply to the heater when the warm-up heater is configured for warm-up mode.

The current applied will be the full scale output times the warm-up percentage. The full scale current output is dependent on the heater resistance and maximum current setting. For example, if a 25 Ω heater is attached to the warm-up heater, the maximum current provided to the heater will be 0.63 A. Therefore, if the Warm Up Percentage is set to 50%, the current supplied to the heater will be 50% of 0.63 A, or 0.32 A, when the output is on. For more information regarding the warm-up heater resistance and current settings, see section 4.6.1.2.

Menu navigation:
Output Setup→*Warm Up Heater* → *Warm Up Percentage*→(0% to 100%)
Default: 0.00%
Interface command: `WARMUP`

5.3.2 Warm Up Control

The Warm Up Control parameter determines what happens when the control input temperature reaches the setpoint. The options are:

- **Auto-Off**: once the Heater Range is set to on, the Warm Up Percentage current is applied to the output (section 5.3.1) and the output stays on until the control input temperature reaches the control setpoint. The output will then be turned off, and the Heater Range setting will automatically be set to Off, effectively turning off all temperature control for the control loop. If the Heater Range is again manually set to on, the cycle will begin again, and the output will turn on and stay on until the control input temperature reaches the setpoint again.
  Menu navigation:
  Output Setup → *Warm Up Heater* → *Warmup Mode* → Auto-Off
- **Continuous**: this mode implements what is often referred to as On/Off control. Once the Heater Range is set to on, the Warm Up Percentage current is applied to the output until the control input temperature reaches the setpoint. Then the output will turn off (0 V) until the temperature falls 1 K below the setpoint, at which point the Warm Up Percentage current is again applied to the output. The Heater Range will never be automatically set to Off in this mode.
  Menu navigation:

Output Setup→ *Warm Up Heater* →*Warm Up Control*→ Continuous
Default: Continuous
Interface command: **WARMUP**

5.4 Monitor Out

In Monitor Out mode, the unpowered analog/still output will track the assigned control input according to the scaling parameters you enter. A common use for this function would be to send a voltage proportional to temperature to a data acquisition system.

The Control Input parameter setting determines which sensor input is tracked by the output. The remaining parameters detailed in this section dictate how the output value is determined.

NOTE

When a scanned measurement input channel is selected as the control input and that channel is not active at a given time, the analog/still output will continue to output a voltage proportional to the last known valid reading.

NOTE

An output configured to Monitor Out mode is not affected by the ALL OFF key, as it does not have a Heater Range setting, and by design is always enabled.

Menu navigation:
Output Setup → *Analog/Still* → *Output Mode* → Monitor Out
Output Setup → *Analog Still* → *Control Input* → (None, A, 1-16)
Default: Control Input → None
Interface command: **OUTMODE**

5.4.1 Monitor Units

The Monitor Units parameter determines the units of the Control Input sensor to use for creating the proportional voltage output. The Monitor Out scaling parameter settings are entered using the units chosen for this parameter.

Menu navigation:
Output Setup → *Analog/Still* → *Monitor Out Units* → (Kelvin or Sensor)
Default: kelvin
Interface command: **ANALOG**

5.4.1.1 Polarity and Monitor Out Scaling Parameters

In the Monitor Out and Open Loop modes, the analog/still output can be configured as either unipolar (0 V to +10 V) or bipolar (-10 V to +10 V) outputs. In bipolar mode, the Monitor Out -10 V setting determines the temperature or sensor value at which the output should be -10 V. In unipolar mode, the Monitor Out 0 V setting determines the temperature or sensor value at which the output should be 0 V. The Monitor Out +10 V setting determines the temperature or sensor value at which the output should be +10 V in either unipolar or bipolar modes.

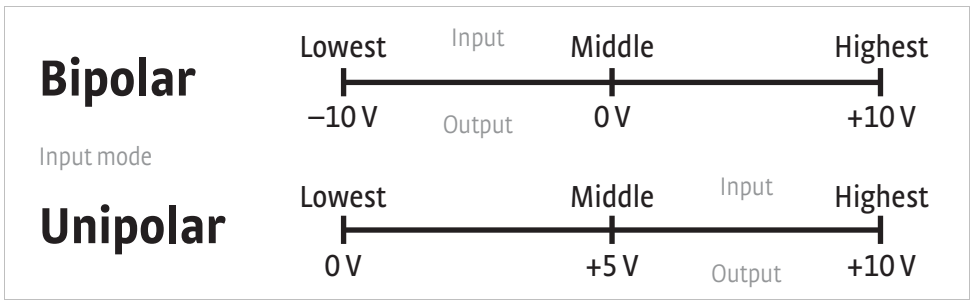


FIGURE 5-2 ***Unipolar and bipolar mode***

For example, if Polarity is set to Bipolar, then setting the Monitor Out –10 V parameter to 0 K and the Monitor Out +10 V parameter to 100 K will cause the analog output to correspond to the input temperature as shown in FIGURE 5-3. In this case if the actual reading was 50 K, then the output would be at 0 V (middle of the scale).

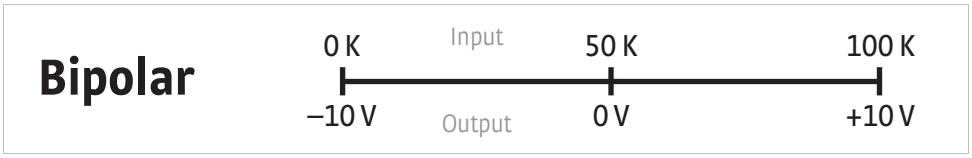


FIGURE 5-3 ***Analog output with polarity set to bipolar***

If we set the Polarity parameter to Unipolar, the output would be as shown in FIGURE 5-4. In this case if the actual reading was 50 K, the analog output would be +5 V (middle of the scale).

FIGURE 5-4 ***Output with polarity parameter set to unipolar***

Menu navigation:
Output Setup → *Analog/Still* → *Polarity* → (Unipolar or Bipolar)
Output Setup → *Analog/Still* → *Monitor Out* -10 V → (See note below)
Output Setup → *Analog/Still* → *Monitor Out* 0 V → (See note below)
Output Setup → *Analog/Still* → *Monitor Out* +10 V → (See note below)

NOTE

Monitor Out -10 V, 0 V, and +10 V settings depend on the Monitor Units selected, and are limited to the acceptable values of the selected units.

Default: *Polarity*→Unipolar
Monitor Out -10 V→0.0000 K
Monitor Out 0 V→0.0000 K
Monitor Out +10 V→1000 K
Interface command: **ANALOG**

5.5 Alarms and Relays

5.5.1 Alarms

Each input of the Model 372 has high and low alarm capability. Input reading data from any source can be compared to the alarm setpoint values. A reading higher than the high alarm setpoint triggers the high alarm for that input. A reading lower than the low alarm setpoint triggers the low alarm for that input.

Menu navigation:
Relays/Alarms → *Alarm Setup* → *Input* (*A, 1–16*)
Relays/Alarms → *Alarm Setup* → *Input* (*A, 1–16*)→*Low Setpoint* → (see note below)
Relays/Alarms → *Alarm Setup* → *Input* (*A, 1–16*)→*High Setpoint* → (see note below)

NOTE

Low and High Setpoint limits are determined by the Preferred Units of the associated sensor input.

Defaults: *Alarm* → Off
Low Setpoint→0.0000 K
High Setpoint→1000 K
Interface command: **`ALARM`**

5.5.1.1 Alarm Annunciators

The Alarm LED annunciator steadily displays when any alarm that is enabled also has the Visible parameter enabled. The annunciator flashes when any alarm that has the Visible parameter enabled activates. An input need not be displayed for the system Alarm annunciator to indicate input alarm status, but if the input is displayed on the front panel, then the reading will alternate between the alarm status message and the actual reading. If the Audible parameter is set to On for an enabled alarm, then the beeper inside the instrument will sound when the alarm activates. The two relays on the Model 372 can also be tied to alarm functions as described in section 5.5.2.

You may want to set the Visible parameter to Off if there is no need for showing the alarm state on the front panel, for instance, if you are using the alarm function to trigger a relay. The Audible parameter can be set to Off as well to keep the audible alarm from sounding when an alarm is triggered.

Menu navigation:
Relays/Alarms → *Alarm Setup* → *Input* (*A, 1–16*)→*Visible*→(Off, On)
Relays/Alarms → *Alarm Setup* → *Input* (*A, 1–16*)→*Audible*→(Off, On)
Default: *Visible* → On
Audible → Off
Interface command: **`ALARM`**

5.5.1.2 Alarm Latching

- *Latching Alarms*: often used to detect faults in a system or experiment that requires operator intervention. The alarm state remains visible to the operator for diagnostics even if the alarm condition is removed. Relays often signal remote monitors, or for added safety take critical equipment off line. You can clear a latched alarm by pressing **Alarm** and selecting Yes to the Reset Alarm prompt. Select No to the Reset Alarm prompt to enter the Alarm Setup menu.
- *Non-Latching Alarms*: often tied to relay operation to control part of a system or experiment. The alarm state follows the reading value. The dead band parameter can prevent relays from turning on and off repeatedly when the sensor input reading is near an alarm setpoint.
  FIGURE 5-5 illustrates the interaction between alarm setpoint and dead band in

non-latching operation. With the high alarm setpoint at 100 K and the dead band at 5 K, the high alarm triggers when sensor input temperature increases to 100 K, and it will not deactivate until temperature drops to 95 K. In addition, the same 5 K dead band is applied to the low alarm setpoint as well.

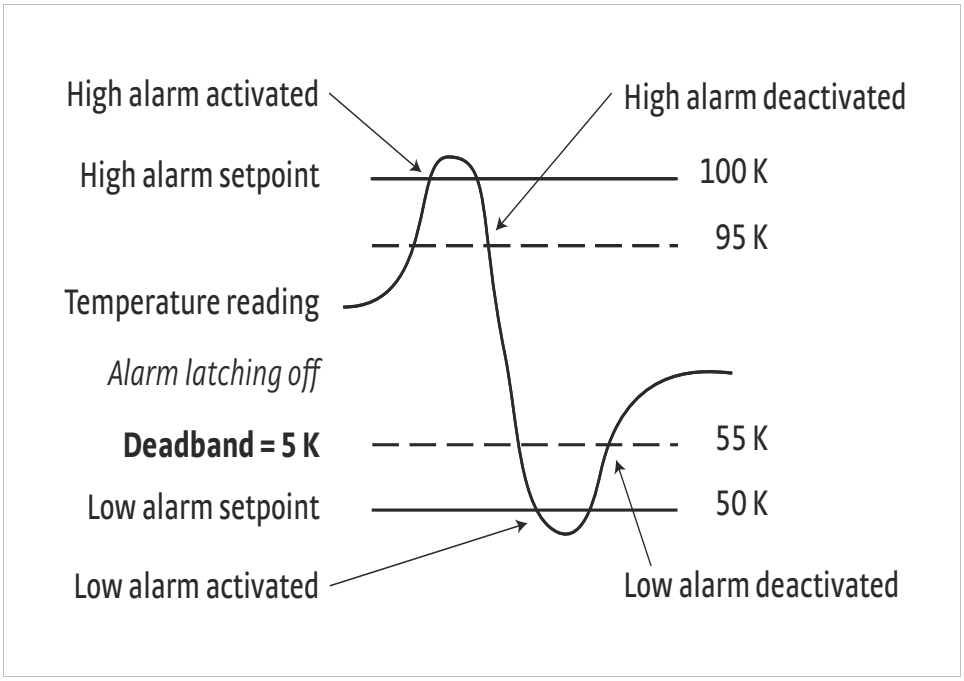


FIGURE 5-5 ***Dead band example***

To set up an alarm, enter the Alarm Setup menu by pressing the **Alarm** key. If a latching alarm has been activated, you will be prompted with a Reset Alarm? message. Select No to enter the Alarm Setup menu.

Menu navigation:
Relays/Alarms → *Alarm Setup* → *Input* (*A, 1–16*)→*Latching*→(Off, On)
Relays/Alarms → *Alarm Setup* → *Input* (*A, 1–16*)→*Deadband*→(see note below)

NOTE

Low and High Setpoint limits are determined by the Preferred Units of the associated sensor input.

Default: *Latching* → Off
Deadband → 1.0000 K
Interface command: **`ALARM`**

5.5.2 Relays

There are two relays on the Model 372, numbered 1 and 2. They are most commonly thought of as alarm relays, but they may also be manually controlled. Two relays can be used with one sensor input for independent high and low operation, or each can be assigned to a different input.

When using relays with alarm operation, set up alarms first. The relays are rated for 30 VDC and 2 A. Their terminals are in the detachable terminal block on the Model 372 rear panel.

In the Off mode, the relay is un-energized, leaving the normally open (NO) contacts open and the normally closed (NC) contacts closed. In the On mode, the relay is energized, so the NO contacts will be closed and the NC contacts will be open. In the Alarm mode the relay will activate based on the state of the configured Alarm Input sensor.

When the Alarm to Follow parameter is set to Low, the relay will energize if the configured Alarm Input sensor goes into a low alarm state. If it is set to High, the relay will energize if the configured Alarm Input sensor goes into a high alarm state. If the Alarm to Follow parameter is set to Both, the relay will energize if the configured Alarm Input sensor goes into either a low alarm or a high alarm state.

In the zone mode, each relay can be configured to an on or off state that is dependent on the current zone. Because the zones are a function of an output, the Output to Follow parameter lets the Model 372 determine which output zone settings the relays will follow. The relay 1 and 2 zone states can be configured in the zone settings menu for the respective control output.

Menu navigation:
Relays/Alarms → Relay Setup → (*Relay 1, Relay 2*)→*Mode*→(Off, On, Alarm, Zone (Sample), Zone (Warm up))
Relays/Alarms → Relay Setup → (*Relay 1, Relay 2*)→*Alarm Input* → Input (A, 1–16)
Relays/Alarms → Relay Setup → (*Relay 1, Relay 2*)→*Alarm to Follow* → (Low, High, Both)
Default: *Mode*→Off
Alarm Input→Channel 1
Alarm to Follow→Both

Interface command: **`RELAY`**

5.6 Curve Numbers and Storage

The Model 372 has 20 standard curve locations, numbered 1 through 20. At present, not all locations are occupied by curves; the others are reserved for future updates. If a standard curve location is in use, the curve can be viewed using the view operation. Standard curves cannot be changed by the user, and reserved locations are not available for user curves.

The Model 372 has 39 user curve locations, numbered 21 through 59. Each location can hold from 2 to 200 data pairs (breakpoints), including a value in ohms, a corresponding value in kelvin, and a corresponding curvature value that is only used for cubic spline curves. If a linear curve is loaded, the curvature value is set to zero. Using fewer than 200 breakpoints will not increase the number of available curve locations.

5.6.1 Curve Header Parameters

Each curve has parameters that are used for identification and to allow the instrument to use the curve effectively. The parameters must be set correctly before a curve can be used for temperature conversion or temperature control.

- *Curve number:* 1 to 59.
- *Name:* defaults to the name "User Curve" for front panel entry. A curve name of up to fifteen characters can be entered from either the front panel or from the computer interface. Refer to section 4.2.3 for alpha-numeric entry.
- *Serial number:* a sensor serial number of up to ten characters (letters or numbers) can be entered from either the front panel or from the computer interface. Refer to section 4.2.3 for alpha-numeric entry. The default is blank.
- *Format:* the format parameter tells the instrument what breakpoint data format to expect. Different sensor types require different formats. Formats for Lake Shore sensors are described in TABLE 5-2.

Format	Interpolation method	Description	Sensor units full scale range	Sensor units maximum resolution
Ω/K	Linear	Resistance vs. kelvin for platinum RTD sensors	10 MΩ	0.00001 Ω
Log Ω/K	Linear	Log resistance vs. kelvin for NTC resistive sensors	10 log Ω	0.00001 log Ω
Ω/K	Cubic spline	Resistance vs. kelvin for all RTD sensors	10 MΩ	0.00001 Ω

TABLE 5-2 ***Curve header parameter***

- *Setpoint limit:* limits the control setpoint to values less than or equal to this setting. A setpoint limit can be included with every curve. The default is 375 K. Enter a setting of 9999 K if no limit is needed.
- *Temperature coefficient:* the temperature coefficient is derived by the Model 372 from the first two breakpoints. The user does not enter this setting. If it is not correct, check for proper entry of the first two breakpoints. A positive coefficient indicates that the sensor signal increases with increasing temperature. A negative coefficient indicates that the sensor signal decreases with increasing temperature.

5.6.2 Curve Breakpoints

Temperature response data of a calibrated sensor must be reduced to a table of breakpoints before entering it into the instrument. A curve consists of 2 to 200 breakpoints and each breakpoint consists of one value in sensor units, one temperature value in kelvin, and one curvature value scale factor used for cubic spline interpolation. The Model 372 uses either linear or cubic spline interpolation to calculate temperature between breakpoints, depending on the format of the curve. The instrument will show T.OVER or T.UNDER on the display if the sensor reading is outside the range of the breakpoints. Sensor units are defined by the format setting in TABLE 5-2. Breakpoint setting resolution is six digits in temperature. Most temperature values are entered with 0.001 resolution. Temperature values of 1000 K and greater can be entered to 0.01 resolution. Temperature values below 10 K can be entered with 0.0001 resolution. Temperature range for curve entry is 0 K to 9999.99 K.

Sensor type	Typical Lake Shore model	Format	Limit (K)	Temperature coefficient	Typical sensor resolution
Platinum 100	PT-100	Ω/K	800	Positive	0.001 Ω
Platinum 1000	—*	Ω/K	800	Positive	0.01 Ω
Rhodium-iron	RF-800	Ω/K	325	Positive	0.001 Ω
Carbon-glass	CGR-1-1000	log Ω/K	325	Negative	0.00001 log Ω
Cernox®	CX-1050	log Ω/K	325	Negative	0.00001 log Ω
Germanium	GR-200A-100	log Ω/K	325	Negative	0.00001 log Ω
Rox™	RX-102A	log Ω/K	40	Negative	0.00001 log Ω

**Not offered by Lake Shore*

TABLE 5-3 ***Typical curve parameters***

Setting resolution is also six digits in sensor units. The curve format parameter defines the range and resolution in sensor units as shown in TABLE 5-2. The sensor type determines the practical setting resolution. TABLE 5-3 lists recommended sensor units resolutions.

Enter the breakpoints with the sensor units value increasing as point number increases. There should not be any breakpoint locations left blank in the middle of a curve. The search routine in the Model 372 interprets a blank breakpoint as the end of the curve.

The curvature parameter is always six digits in resolution. It is a scale factor that is used to calculate the four coefficients of the cubic spline polynomial. When loading a curve of a linear format, this value is automatically set to zero by the Model 372.

5.7 Front Panel Curve Entry Operations

There are four operations associated with front panel curve entry: Edit curve, View Curve, Erase Curve, and Copy Curve; as detailed below.

Operation	Description	Refer to section:
Edit Curve	Edit Curve allows you to edit curves at any user curve location. Standard curves cannot be changed.	5.7.1
View Curve	View Curve allows you to view any curve at any curve location. No curves can be changed.	5.7.2
Erase Curve	Erase Curve allows you to delete a curve from any user curve location. Standard curves cannot be erased.	5.7.3
Copy Curve	Copy Curve allows you to copy a curve from any location to any user curve location. Curves cannot be copied into standard curve locations.	5.7.4

TABLE 5-4 ***Front panel curve entry operations***

Menu navigation:
Curve Entry→(*Edit Curve, View Curve, Erase Curve, Copy Curve*)

NOTE

The edit curve operation only works with linear curves, therefore, you can only edit cubic spline curves from the computer interface. In addition, cubic spline curves can be viewed from the front panel. However, the curvature values will not be displayed. The Erase Curve and Copy Curve operations work in the same manner for both linear and cubic spline curves.

5.7.1 Edit Curve

Use the Edit Curve operation to enter a new curve or edit an existing user curve. Only user curves (21 to 59) can be edited. Entering the identification parameters associated with the curve is as important as entering the breakpoints. Curve header parameters are listed in TABLE 5-2. Typical curve parameters for common sensors are listed in TABLE 5-3. Read this section completely and gather all necessary data before beginning the process.

NOTE

If the curve you wish to enter has similar parameters as an existing curve, first copy the similar curve (as described in section 5.7.4) to a new location, then edit the curve to the desired parameters.

To perform the Edit Curve operation, follow this procedure.

1. Press **Curve Entry.**
2. Scroll to Edit Curve, and press **Enter**.
3. Scroll to the desired curve and press **Enter** again.
4. Edit the curve header parameters using the standard keypad operation methods described in section 4.2.3. The curve breakpoints are entered in a slightly different way than other menu parameters.
5. To access the breakpoint data, highlight Curve Points in the Curve Edit menu screen and press **Enter** to enter the Curve Point entry screen.

The Curve Point entry screen contains a scrollable list of all curve breakpoint pairs in the selected curve. There are three columns in the list. From left to right the columns are: breakpoint number, breakpoint sensor value, breakpoint temperature value. Initially the highlight is on the first breakpoint number.

Menu navigation:
Curve Entry →Edit Curve
Interface command: `CRVHDR`

5.7.1.1 Edit a Breakpoint Pair

To edit a breakpoint pair, follow this procedure.

1. Select a breakpoint pair to edit. Do this by scrolling to the desired breakpoint number and press **Enter**. The highlight moves to the sensor value of the selected pair.

2. Use the Number Entry method to edit the value. Refer to section 4.2.1.1 for details on the Number Entry method.
3. Once the new sensor value is entered, press **Enter** to highlight the temperature value.
4. Use the Number Entry method to enter the new temperature value.
5. Press **Enter** at this point to store the new breakpoint pair.
6. Press **Escape** at any time when a sensor or temperature value is highlighted to cancel any changes to either of the values and return the highlight to the breakpoint number.

If the sensor value entered is not between the previous breakpoint sensor value and the following breakpoint sensor value, then the new breakpoint pair will be moved to the position in the curve that bounds the sensor value of the new breakpoint pair. If the pair is moved, a message will be displayed to indicate to the location to which the breakpoint pair was moved.

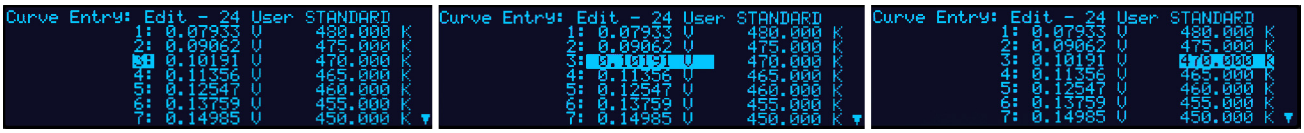


FIGURE 5-6 ***Left: Scroll to highlight a breakpoint number; Middle: Press the enter key to highlight the sensor value of the selected pair; Right: Press the enter key again, and the temperature value is highlighted***

Menu navigation:
Curve Entry →*Edit Curve*→ (*21–59*)→*Curve Points* →(*1–200*)
Interface command: **CRVPT**

5.7.1.2 Add a New Breakpoint Pair

The last breakpoint of a curve is signified by the first pair that contains a 0 value for both the temperature and sensor portions. Curves are limited to 200 breakpoint pairs, so if 200 pairs already exist, then the 200th pair will be the last pair in the list. To add a new breakpoint pair to a curve that has less than 200 pairs, scroll to the end of the list and edit the 0 value pair by following the procedure for editing a breakpoint pair in section 5.7.1.1. If the curve still contains less than 200 pairs, a new 0 value breakpoint will be added to the end of the list for entering another new breakpoint pair.
Menu navigation:
Curve Entry →Edit Curve → (*21–59*)→Curve Points→ (1–200)
Interface command: CRVPT

5.7.1.3 Delete a Breakpoint Pair

To delete a breakpoint pair, scroll to the desired breakpoint number, then enter a 0 value for both the sensor and temperature values by following the procedure for editing a breakpoint pair in section 5.7.1.1.

NOTE

If you are not entering 0 for both sensor and temperature values, then entering new values over an existing breakpoint pair will replace that pair with the new value when you press Enter.

After editing, adding, or deleting all desired breakpoint pairs, press **Escape** (Exit Menu) while the highlight is on a breakpoint number. All breakpoint pair changes, additions, and deletions will be saved when exiting the menu.

When curve entry is complete, you must assign the new curve to an input. The Model 72 does not automatically assign the new curve to any input. Refer to section 4.4.12 for details on assigning a curve to a sensor input.

Menu navigation:
Curve Entry→*Edit Curve*→ (*21–59*)→*Curve Points*→(*1– 200*)
Interface command: **CRVPT**

5.7.2 View Curve

The View Curve operation provides read-only access to all standard and user curves.

To perform the View Curve operation follow this procedure.

1. Press **Curve Entry**, scroll to View Curve, then press **Enter**.
2. Scroll to the desired curve and press **Enter** again to view the curve header information.
3. To view the curve breakpoints, highlight the Curve Points parameter and press **Enter**. The list of breakpoint pairs is scrollable, but data cannot be edited.
4. Press **Escape** (Exit Menu) to return to the curve header parameter list.
5. Press **Escape** (Exit Menu) again to exit the Curve Entry menu and return to normal operation.

Menu navigation:
Curve Entry→*View Curve*
Interface command: **CRVHDR, CRVPT**

5.7.3 Erase Curve

You can erase user curves that are no longer needed. Erase Curve sets all identification parameters to default and blanks all breakpoint values.

To perform the Erase Curve operation follow this procedure.

1. Press **Curve Entry**, scroll to Erase Curve, then press **Enter**.
2. Scroll to the desired curve and press **Enter**.
3. Choose Yes at the confirmation message to finalize the operation.
4. To cancel the operation, either choose No to the confirmation message, or press **Escape**.

Menu navigation:
Curve Entry→*Erase Curve* → (*21–59*)
Interface command: **CRVDEL**

5.7.4 Copy Curve

Temperature curves can be copied from one location in the Model 372 to another. This is a good way to make small changes to an existing curve. Curve copy may also be necessary if you need the same curve with two different temperature limits or if you need to extend the range of a standard curve. The curve that is copied from is always preserved.

NOTE

The copy routine allows you to overwrite an existing user curve. Please ensure the curve number you are writing to is correct before proceeding with the copy curve operation.

1. To perform the Copy Curve operation press **Curve Entry**, scroll to Copy Curve, then press **Enter**.
2. Scroll to the desired curve to copy, and press **Enter**. A list of user curves is displayed.
3. Scroll to the desired user curve location to copy to, and press **Enter**.
4. Choose Yes at the confirmation message to finalize the operation.
5. To cancel the operation, either choose No to the confirmation message, or press **Escape**.

Menu navigation:
Curve Entry →*Copy Curve* → (*1–59*) → (*21–59*)

Interface command: (No interface command directly corresponds to the copy curve operation. You can use the CRVHDR and CRVPT commands to read curve information from one curve location and write that information to another curve location.)

5.8 Emulation Mode

To provide compatibility with pre-existing software that was written to work with a Model 370, the Model 372 can be configured to emulate the remote interface of the Model 370. The emulation mode allows a Model 372 to replace a Model 370 in a software controlled system with very little effort, and very little downtime.

5.8.1 Unsupported Commands

Some commands are not supported in the Model 372, regardless of the emulation mode, as the associated functions are no longer included. Although these commands are unsupported, a properly formatted reply will be sent when these queries are received to prevent locking up or crashing software that was written to query this information. These unsupported commands are:

- LDAT
- LINEAR
- MNMX

Except for the unsupported commands above, when the Model 372 is in emulation mode, it will interpret all Model 370 commands. Each command will either be interpreted directly, or it will be translated to the most appropriate Model 372 setting, for full compatibility with the Model 370.

5.8.2 Command Interpretation

As a reference, the following commands are interpreted differently if Emulation mode is on:

- ANALOG
- DISPLAY
- ZONE
- CRVPT
- CRVHDR
- CRVDEL
- BAUD
- INSET
- INCRV

The Model 372 must be in Emulation mode in order for the commands to be interpreted as a Model 370.

5.8.3 Curve Location Numbering

As with the Model 370, the Model 372 has the ability to load and use temperature curves in order to read and control in units kelvin. One significant difference is that the Model 372 curve location structure is modeled after newer Lake Shore temperature controllers, and it consists of read-only standard curves and modifiable user curves.

TABLE 5-6 shows the differences in how curve numbers are assigned as a function of emulation mode.

	Normal mode	370 emulation mode
Standard curve locations	1-20	None
User curves locations	21-59	1-20

TABLE 5-6 ***Assignment of curve numbers***

In order for existing Model 370 control software to read and write curves from locations 1 to 20, the Model 372 must be placed into Emulation mode. When in Emulation mode, the firmware will translate the Model 370 curve locations received over the remote interface to the new curve location numbering scheme.

The new numbering scheme is necessary because, unlike the Model 370, standard temperature curves will be loaded into the Model 372 prior to shipment.

5.8.4 Controlling While Scanning Differences

When a measurement input channel is assigned to an output for controlling, the Model 370 automatically takes control of the reading sequence. It forces the scan dwell time to 5 s for the channel used for controlling, and one second for other reading channels, independent of autoscan being turned on or off. When autoscan is enabled, the Model 370 automatically scans back to the channel used for control in between the scanning of the non-control channels, using the previously mentioned dwell times. When autoscan is disabled, the Model 370 automatically scans to the channel used for controlling and dwell for 5 s, the scan back to the manually selected reading channel and dwell for one second.

After re-evaluating the autoscanning requirements, we decided to get rid of this forced autoscanning behavior and put the power back to you, the user. What this means is that when autoscanning is enabled, the Model 372 will still scan back to the control channel(s) in-between each reading, however it will not use forced dwell times of 1 and 5 s. Instead, it will use your user-specified scan dwell, pause, and filter settings. While this provides greater flexibility, care must be taken to ensure, for example, that the dwell times are not too long on non-controlling channels to maintain stable PID control.

When autoscanning is disabled, the Model 372 will not automatically switch back to the channel used for controlling if a non-control channel is manually selected. However, if this behavior is desired, autoscan can be enabled with a dwell time of 5 s being assigned to the channel used for control and 1 s for the non-reading channel.

5.8.5 Hardware Differences

One of the most significant hardware differences between the Model 370 and Model 372, besides the dedicated control input, is that the analog 1 voltage output of the Model 370 has been replaced with a warm-up heater current source. The Model 370 provides a ±10 V voltage source output with 100 mA maximum current, providing 1 W into a 100 Ω heater. The Model 372 provides a +630 mA current source, providing up to 10 W into a 25 Ω or 50 Ω load.

If you require the warm-up heater to function as a voltage source, then a resistor must be added across the warm-up heater output terminals to convert the current source to a voltage source. In addition, the warm-up heater maximum current must be set appropriately so that 100% current output equates to 10 V measured across the conversion resistor.

The following example shows how to calculate the conversion resistor value when the user load is of a high impedance. The warm-up heater resistance is set to the 25 Ω setting in order to maximize the current output (0.63 A) and subsequently, maintain maximum resolution.

R = V / I
R = 10 V / 0.63 A
R = 15.87 Ω

16 Ω is a common resistor value that would bring the full scale voltage to 10.08 V. In addition, the resistor must have a power rating high enough to handle the amount of current.

P = I * V
P = 10 V * 0.63 A
P = 6.3 W

Therefore, a 16 Ω/10 W resistor would be an acceptable solution in this scenario.

Keep in mind that higher resistance conversion resistors can be used in combination with lower warm-up heater current settings to minimize power loss; however, this comes with a cost of lost resolution. For example, a 100 Ω current conversion resistor can be used with a maximum current of 100 mA to attain 10 V across the 100 Ω resistor. However three bits of resolution loss occur as a result of this, decreasing the resolution from 0.003% of range to 0.02% of range.

To accommodate scenarios where your load resistance is small (on the order of 100 Ω), the current-to-voltage conversion resistor must be adjusted to maintain 10 V across it. For example, if the load resistor is 100 Ω, an added parallel resistor must be sized appropriately to maintain an equivalent resistance of 15.8 Ω in order to maintain 10 V at full scale output, assuming the maximum current is still set to 0.63 A.

$1/(100\ \Omega)+1/X = 1/(15.8\ \Omega)$
$1/X = 0.05329\ \Omega$
$X = 18.76\ \Omega$

Series and parallel combinations can be used with standard resistor values to reach the desired equivalent resistance.

Menu navigation:
Interface → Emulation Mode (*None, Model 370*)
Interface command: **`EMUL`**

Chapter 6: Computer Interface Operation

6.1 General

This chapter provides operational instructions for the computer interface for the Lake Shore Model 372 AC resistance bridge and temperature controller. Each of the three computer interfaces provided with the Model 372 permit remote operation. The first is the IEEE-488 interface described in section 6.2. The second is the USB interface described in section 6.3. The third is the Ethernet interface described in section 6.4. The three interfaces share a common set of commands detailed in section 6.6. Only one of the interfaces can be used at a time.

6.2 IEEE-488 Interface

The IEEE-488 interface is an instrumentation bus with hardware and programming standards that simplify instrument interfacing. The Model 372 IEEE-488 interface complies with the IEEE-488.2 standard and incorporates its functional, electrical, and mechanical specifications unless otherwise specified in this manual.

All instruments on the interface bus perform one or more of the interface functions of Talker, Listener, or Bus Controller. A Talker transmits data onto the bus to other devices. A Listener receives data from other devices through the bus. The Bus Controller designates to the devices on the bus which function to perform. The Model 372 performs the functions of Talker and Listener, but it cannot be a Bus Controller. The Bus Controller is the digital computer that tells the Model 372 which functions to perform.

TABLE 6-1 defines the IEEE-488 capabilities and subsets for the Model 372:

Subset	Capabilities
SH1:	Source handshake capability
RL1:	Complete remote/local capability
DC1:	Full device clear capability
DT0:	No device trigger capability
C0:	No system controller capability
T5:	Basic Talker, serial poll capability, talk only, unaddressed to talk if addressed to listen
L4:	Basic Listener, unaddressed to listen if addressed to talk
SR1:	Service request capability
AH1:	Acceptor handshake capability
PP0:	No parallel poll capability
E1:	Open collector electronics

TABLE 6-1 ***Model 372 IEEE-488 interface capabilities and their subsets***

Instruments are connected to the IEEE-488 bus by a 24-conductor connector cable as specified by the standard (section 8.10.1). Cables can be ordered from Lake Shore as IEEE-488 cable kit (P/N 4005), or they can be purchased from other electronic suppliers.

Cable lengths are limited to 2 m (6.6 ft) for each device and 20 m (66 ft) for the entire bus. The Model 372 can drive a bus with up to ten loads. If more instruments or cable length is required, a bus expander must be used.

6.2.1 Changing IEEE-488 Interface Parameters

The IEEE-488 address must be set from the front panel before communication with the instrument can be established.

Menu navigation:
Interface→Enabled→IEEE-488
Interface→IEEE-488 Address →(1 to 31)
Default: 12

6.2.2 Remote/Local Operation

Normal operations from the keypad are referred to as local operations. The Model 372 can also be configured for remote operations via the IEEE-488 interface or the **Remote/Local** key. The **Remote/Local** key will toggle between remote and local operation. During remote operations, the remote annunciator LED will be illuminated, and operations from the keypad will be disabled.

6.2.3 IEEE-488.2 Command Structure

The Model 372 supports several command types. These commands are divided into four groups.

1. Bus Control (section 6.2.3.1).
    a. Universal
        - Uniline
        - Multiline
    b. Addressed bus control
2. Common (section 6.2.3.2).
3. Device Specific (section 6.2.3.3).
4. Message Strings (section 6.2.3.4).

6.2.3.1 Bus Control Commands

A bus control command can either be a universal or an addressed bus control. A universal command addresses all devices on the bus. Universal commands include uniline and multiline commands. A uniline command (message) asserts only a single signal line. The Model 372 recognizes two of these messages from the Bus Controller: Remote (REN) and Interface Clear (IFC). The Model 372 sends one uniline command: Service Request (SRQ).

- REN (Remote): puts the Model 372 into remote mode
- IFC (Interface Clear): stops current operation on the bus
- SRQ (Service Request): tells the bus controller that the Model 372 needs interface service

A multiline command asserts a group of signal lines. All devices equipped to implement such commands do so simultaneously upon command transmission. These commands transmit with the Attention (ATN) line asserted low. The Model 372 recognizes two multiline commands:

- LLO (Local Lockout): prevents the use of instrument front panel controls
- DCL (Device Clear): clears Model 372 interface activity and puts it into a bus idle state

Finally, addressed bus control commands are multiline commands that must include the Model 372 listen address before the instrument responds. Only the addressed device responds to these commands. The Model 372 recognizes three of the addressed bus control commands:

- SDC (Selective Device Clear): the SDC command performs essentially the same function as the DCL command, except that only the addressed device responds
- GTL (Go To Local): the GTL command is used to remove instruments from the remote mode. With some instruments, GTL also unlocks front panel controls if they were previously locked out with the LLO command.

- SPE (Serial Poll Enable) and SPD (Serial Poll Disable): serial polling accesses the service request status byte register. This status register contains important operational information from the unit requesting service. The SPD command ends the polling sequence.

6.2.3.2 Common Commands

Common commands are addressed commands that create commonality between instruments on the bus. All instruments that comply with the IEEE-488 standard share these commands and their format. Common commands all begin with an asterisk. They generally relate to bus and instrument status and identification. Common query commands end with a question mark (?). Model 372 common commands are detailed in section 6.6.1 and summarized in TABLE 6-6.

6.2.3.3 Device Specific Commands

Device specific commands are addressed commands. The Model 372 supports a variety of device specific commands to program instruments remotely from a digital computer and to transfer measurements to the computer. Most device specific commands also work if performed from the front panel. Model 372 device specific commands are detailed in section 6.6.1 and summarized in TABLE 6-6.

6.2.3.4 Message Strings

A message string is a group of characters assembled to perform an interface function. There are three types of message strings: commands, queries and responses. The computer issues command and query strings through user programs, and the instrument issues responses. Two or more command strings or queries can be chained together in one communication, but they must be separated by a semi-colon (;). The total communication string must not exceed 255 characters in length.

A command string is issued by the computer and instructs the instrument to perform a function or change a parameter setting. When a command is issued, the computer is acting as talker and the instrument as listener. The format is:

```
<command mnemonic><space><parameter data><terminator>.
```

Command mnemonics and parameter data necessary for each one is described in section 6.6.1. A terminator must be sent with every message string.

A query string is issued by the computer and instructs the instrument which response to send. Queries are issued similar to commands with the computer acting as talker and the instrument as listener. The query format is:

```
<query mnemonic><?><space><parameter data><terminator>.
```

Query mnemonics are often the same as commands with the addition of a question mark. Parameter data is often unnecessary when sending queries. Query mnemonics and parameter data if necessary is described in section 6.6.1. A terminator must be sent with every message string. Issuing a query does not initiate a response from the instrument.

A response string is sent by the instrument only when it is addressed as a talker and the computer becomes the listener. The instrument will respond only to the last query it receives. The response can be a reading value, status report or the present value of a parameter. Response data formats are listed along with the associated queries in section 6.6.1.

6.2.4 Status System Overview

The Model 372 implements a status system compliant with the IEEE-488.2 standard. The status system provides a method of recording and reporting instrument information and is typically used to control the Service Request (SRQ) interrupt line. A diagram of the status system is shown in FIGURE 6-1. The status system is made up of status register sets, the status byte register, and the service request enable register. Each register set consists of two types of registers: event and enable.

6.2.4.1 Event Registers

Each register set includes an event register as shown in FIGURE 6-1. Bits in the event register correspond to various system events and latch when the event occurs. When an event bit is set, subsequent events corresponding to that bit are ignored. Set bits remain latched until the register is cleared by a query command (such as *ESR?) or a *CLS command. The register is read-only.

6.2.4.2 Enable Registers

Each register set includes an enable register as shown in FIGURE 6-1. An enable register determines which bits in the corresponding event register will set the summary bit for the register set in the status byte. You may write to or read from an enable register. Each event register bit is logically ANDed to the corresponding enable bit of the enable register. When you set an enable register bit, and the corresponding bit is set in the event register, the output (summary) of the register will be set, which in turn sets the summary bit of the status byte register.

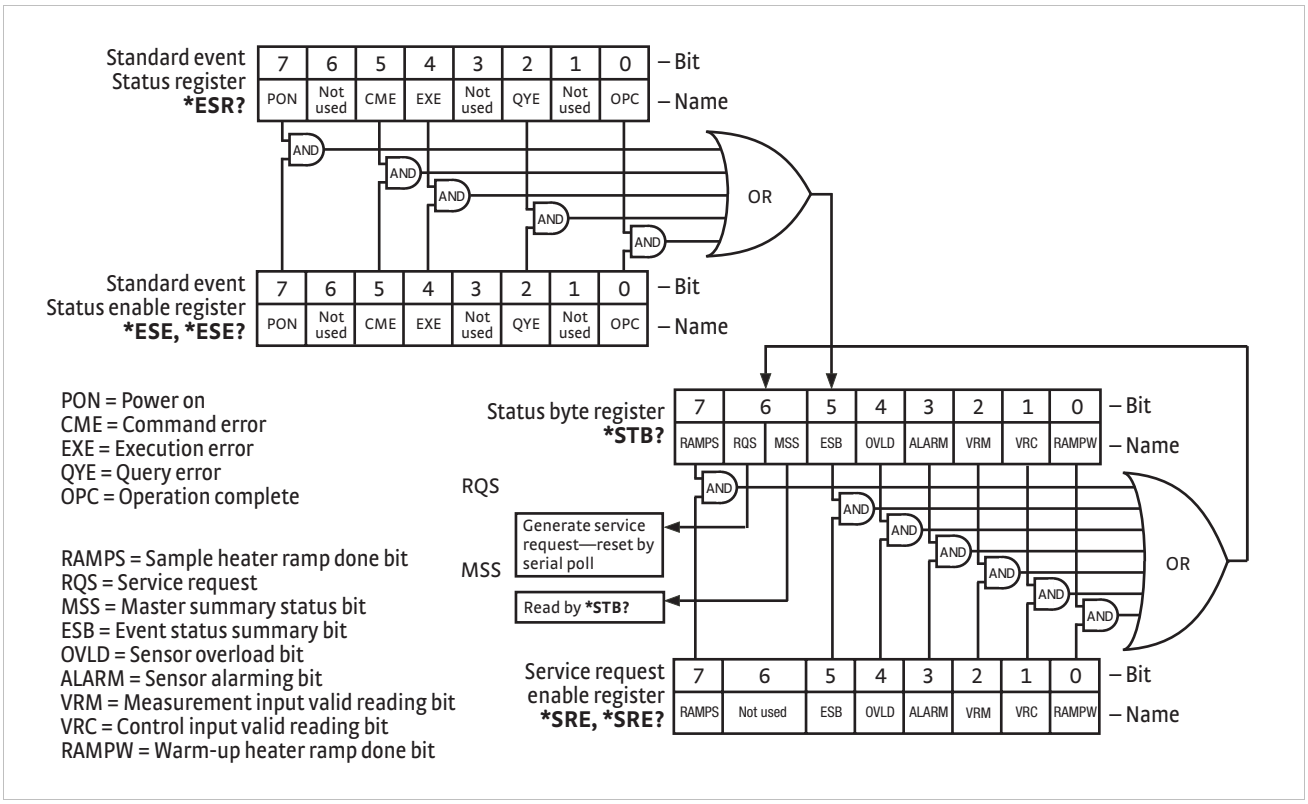


FIGURE 6-1 ***Model 372 status system***

6.2.4.3 Status Byte Register

The status byte register, typically referred to as the status byte, is a non-latching, read-only register that contains all of the summary bits from the register sets. The status of the summary bits are controlled from the register sets as explained in section 6.2.4.1 to section 6.2.4.2. The status byte also contains the Request for Service (RQS)/Master Summary Status (MSS) bit. This bit is used to control the service request hardware line on the bus and to report if any of the summary bits are set via the *STB? command. The status of the RQS/MSS bit is controlled by the summary bits and the service request enable register.

6.2.4.4 Service Request Enable Register

The service request enable register determines which summary bits in the status byte will set the RQS/MSS bit of the status byte. You may write to or read from the service request enable register. Each status byte summary bit is logically ANDed to the corresponding enable bit of the service request enable register. When you set a service request enable register bit, and the corresponding summary bit is set in the status byte, the RQS/MSS bit of the status byte will be set, which in turn sets the service request hardware line on the bus.

6.2.4.5 Reading Registers

You can read any register in the status system using the appropriate query command. Some registers clear when read, others do not (section 6.2.4.7). The response to a query will be a decimal value that corresponds to the binary-weighted sum of all bits in the register (TABLE 6-2). The actual query commands are described later throughout section 6.2.4.

Position	B7	B6	B5	B4	B3	B2	B1	B0
Decimal	128	64	32	16	8	4	2	1
Weighting	2^7	2^6	2^5	2^4	2^3	2^2	2^1	2^0

Example: If bits 0, 2, and 4 are set, a query of the register will return a decimal value of 21 (1+4+16).

TABLE 6-2 ***Binary weighting of an 8-bit register***

6.2.4.6 Programming Registers

The only registers that may be programmed by the user are the enable registers. All other registers in the status system are read-only registers. To program an enable register, send a decimal value that corresponds to the desired binary-weighted sum of all bits in the register (TABLE 6-2). The actual commands are described throughout (section 6.2.4).

6.2.4.7 Clearing Registers

The methods to clear each register are detailed in TABLE 6-3.

Register	Method	Example
Condition registers	None. Registers are not latched	—
Event register: **Standard event status register**	Query the event register	*ESR? (clears register)
	Send *CLS	*CLS (clears register)
	Power on instrument	—
Enable registers: **Standard Event Status Enable Register** **Service Request Enable Register**	Write 0 to the enable register	*ESE 0 (clears standard event status enable register)
	Power on instrument	—
Status byte	There are no commands that directly clear the status byte as the bits are non-latching; to clear individual summary bits clear the event register that corresponds to the summary bit—sending *CLS will clear all event registers which in turn clears the status byte	If bit 5 (ESB) of the status byte is set, send *ESR? to read the standard event status register and bit 5 will clear
	Power on instrument	—

TABLE 6-3 ***Register clear methods***

6.2.5 Status System Detail: Status Register Sets

As shown in FIGURE 6-1, there is one register in the status system of the Model 372: the standard event status register.

6.2.5.1 Standard Event Status Register Set

The standard event status register reports the following interface related instrument events: power on detected, command syntax errors, command execution errors, query errors, operation complete. Any or all of these events may be reported in the standard event summary bit through the enable register (FIGURE 6-2). The Standard Event Status Enable command (*ESE) programs the enable register and the query command (*ESE?) reads it. *ESR? reads and clears the standard event status register. The used bits of the Standard Event Register are described as follows:

- Power On (PON), Bit (7): this bit is set to indicate an instrument off-on transition.
- Command Error (CME), Bit (5): this bit is set if a command error has been detected since the last reading. This means that the instrument could not interpret the command due to a syntax error, an unrecognized header, unrecognized terminators, or an unsupported command.
- Execution Error (EXE), Bit (4): this bit is set if an execution error has been detected. This occurs when the instrument is instructed to do something not within its capabilities.
- Query Error (QYE), Bit (2): this bit indicates a query error. It occurs rarely and involves loss of data because the output queue is full.
- Operation Complete (OPC), Bit (0): when *OPC is sent, this bit will be set when the instrument has completed all pending operations. The operation of this bit is not related to the *OPC? command, which is a separate interface feature (section 6.2.6.5).

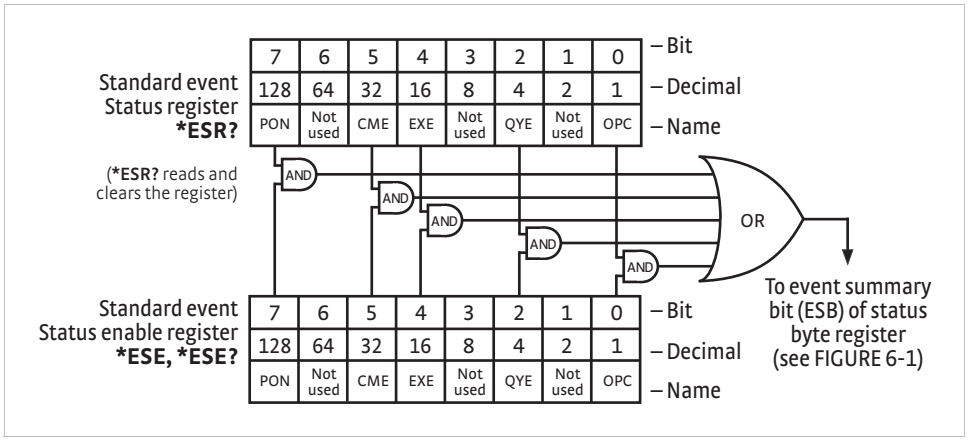


FIGURE 6-2 ***Standard event status register***

6.2.6 Status System Detail: Status Byte Register and Service Request

As shown in FIGURE 6-1, the status byte register receives the summary bits from the standard event status register. The status byte is used to generate a service request (SRQ). The selection of summary bits that generates an SRQ is controlled by the service request enable register.

6.2.6.1 Status Byte Register

The summary messages from the standard event status register set or clear the summary bits of the status byte register (FIGURE 6-3). These summary bits are not latched. Clearing the standard event status register will clear the corresponding summary bit in the status byte register. The bits of the status byte register are described as follows:

- Ramp Done—Sample Heater (RAMPS) Bit (7): this bit is set when the sample heater setpoint ramp is completed.
- Request Service (RQS)/Master Summary Status (MSS), Bit (6): this bit is set when a summary bit and the summary bit's corresponding enable bit in the service request enable register are set. Once set, the user may read and clear the bit in two different ways, which is why it is referred to as both the RQS and the MSS bit. When this bit goes from low to high, the service request hardware line on the bus is set; this is the RQS function of the bit (section 6.2.6.3). In addition, the status of the bit may be read with the *STB? query, which returns the binary weighted sum of all bits in the status byte; this is the MSS function of the bit.

Performing a serial poll will automatically clear the RQS function, but it will not clear the MSS function. A *STB? will read the status of the MSS bit (along with all of the summary bits), but also will not clear it. To clear the MSS bit, either clear the event register that set the summary bit or disable the summary bit in the service request enable register.

- Event Summary (ESB), Bit (5): this bit is set when an enabled standard event has occurred.
- Sensor Overload (OVLD), Bit (4): this bit is set when there is a sensor overload condition on either input. The following errors can trigger this bit to be set: CS OVL, VCM OVL, VDIF OVL, VMIX OVL, R. OVER, R. UNDER, T. OVER, T. UNDER.
- Alarming (ALARM), Bit (3): this bit is set when an input is in an alarming state, and the Alarm Visible parameter is on.
- Valid Reading— measurement input (VRM), Bit (2): this bit is set when the hardware and firmware filters are settled and a valid active measurement channel input reading can be taken.

- Valid Reading—Control Input (VRC), Bit (1): this bit is set when the hardware and firmware filters are settled and a valid control input reading can be taken.
- Ramp Done—Warm-up Heater (RAMPW), Bit (0): this bit is set when the warm-up heater setpoint ramp is completed.

6.2.6.2 Service Request Enable Register

The service request enable register is programmed by the user and determines which summary bits of the status byte may set bit 6 (RQS/MSS) to generate a service request. Enable bits are logically ANDed with the corresponding summary bits (FIGURE 6-3). Whenever a summary bit is set by an event register and its corresponding enable bit is set by the user, bit 6 will set to generate a service request. The Service Request Enable command (*SRE) programs the service request enable register and the query command (*SRE?) reads it.

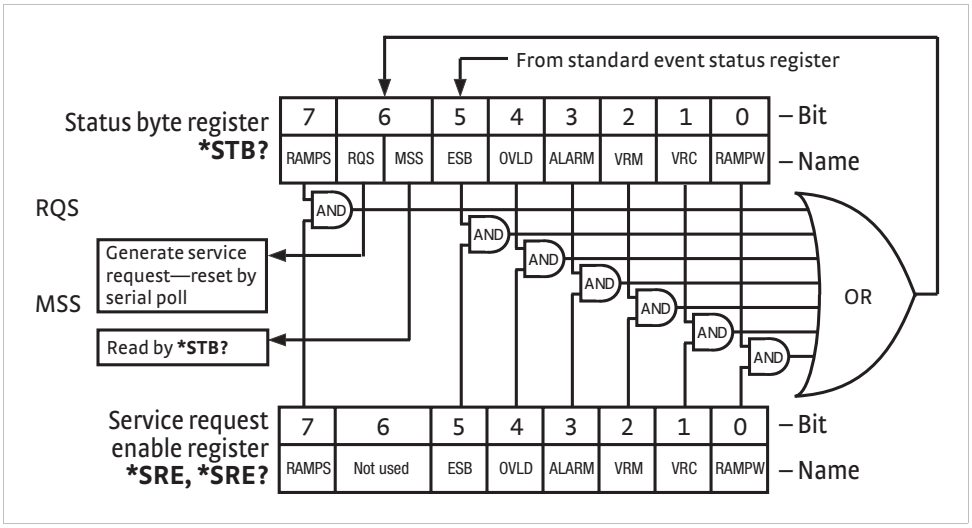


FIGURE 6-3 ***Status byte register and service request enable register***

6.2.6.3 Using Service Request (SRQ) and Serial Poll

When a status byte summary bit is enabled by the service request enable register and goes from 0 to 1, bit 6 (RQS/MSS) of the status byte will be set. This will send a service request (SRQ) interrupt message to the bus controller. The user program may then direct the bus controller to serial poll the instruments on the bus to identify which one requested service (the one with bit 6 set in its status byte).

Serial polling will automatically clear RQS of the status byte register. This allows subsequent serial polls to monitor bit 6 for an SRQ occurrence generated by other event types. After a serial poll, the same event or any event that uses the same status byte summary bit, will not cause another SRQ unless the event register that caused the first SRQ has been cleared, typically by a query of the event register.

The serial poll does not clear MSS. The MSS bit stays set until all enabled status byte summary bits are cleared, typically by a query of the associated event register (section 6.2.6.4).

The programming example in TABLE 6-4 initiates an SRQ when a command error is detected by the instrument.

Command or operation	Description
***ESR?**	Read and clear the standard event status register
***ESE 32**	Enable the Command Error (CME) bit in the standard event status register
***SRE 32**	Enable the Event Summary Bit (ESB) to set the RQS
***ABC**	Send improper command to instrument to generate a command error
Monitor bus	Monitor the bus until the service request interrupt (SRQ) is sent.
Initiate serial poll	Serial poll the bus to determine which instrument sent the interrupt and clear the RQS bit in the status byte.
***ESR?**	Read and clear the standard event status register allowing an SRQ to be generated on another command error.

TABLE 6-4 ***Programming example to generate an SRQ***

6.2.6.4 Using Status Byte Query (*STB?)

The Status Byte Query (*STB?) command is similar to a serial poll except it is processed like any other instrument command. The *STB? command returns the same result as a serial poll except that the status byte bit 6 (RQS/MSS) is not cleared. In this case, bit 6 is considered the MSS bit. Using the *STB? command does not clear any bits in the status byte register.

6.2.6.5 Using Operation Complete (*OPC) and Operation Complete Query (*OPC?)

The Operation Complete (*OPC) and Operation Complete Query (*OPC?) are both used to indicate when pending device operations complete. However, the commands operate with two distinct methods.

The *OPC command is used in conjunction with bit 0 (OPC) of the standard event status register. If *OPC is sent as the last command in a command sequence, bit 0 will be set when the instrument completes the operation that was initiated by the command sequence. Additional commands may be sent between the instrument and the bus controller while waiting for the initial pending operation to complete. A typical use of this function would be to enable the OPC bit to generate an SRQ and include the *OPC command when programming the instrument. The bus controller could then be instructed to look for an SRQ allowing additional communication with the instrument while the initial process executes.

The *OPC? query has no interaction with bit 0 (OPC) of the standard event status register. If the *OPC? query is sent at the end of a command sequence, the bus will be held until the instrument completes the operation that was initiated by the command sequence. Additional commands (except *RST) should not be sent until the operation is complete, as erratic operation will occur. Once the sequence is complete a 1 will be placed in the output buffer. This function is typically used to signal a completed operation without monitoring the SRQ. It is also used when it is important to prevent any additional communication on the bus during a pending operation.

6.3 USB Interface

The Model 372 USB interface provides a convenient way to connect to most modern computers, as a USB interface is provided on nearly all new PCs as of the writing of this manual. The USB interface is implemented as a virtual serial com port connection. This implementation provides a simple migration path for modifying existing RS-232 based remote interface software. It also provides a simpler means of communicating than a standard USB implementation.

6.3.1 Physical Connection

The Model 372 has a B-type USB connector on the rear panel. This is the standard connector used on USB peripheral devices, and it allows the common USB A-type to B-type cable to be used to connect the Model 372 to a host PC. The pin assignments for A-type and B-type connectors are shown in section 8.10. The maximum length of a USB cable, as defined by the USB 2.0 standard, is 5 m (16.4 ft). This length can be extended using USB hubs every 5 m (16.4 ft) up to five times, for a maximum total length of 30 m (98.4 ft).

6.3.2 Hardware Support

The USB interface emulates an RS-232 serial port at a default baud rate of 57,600, but with the physical connections of a USB. Baud rates of 300, 1200, and 9600 are also available for selection. This programming interface requires a certain configuration to communicate properly with the Model 372. The proper configuration parameters are listed in TABLE 6-5.

Baud rate	57,600
Data bits	7
Start bits	1
Stop bits	1
Parity	Odd
Flow control	None
Handshaking	None

TABLE 6-5 ***Host com port configuration***

The USB hardware connection uses the full speed (12,000,000 bits/s) profile of the USB 2.0 standard; however, since the interface uses a virtual serial com port at a fixed data rate, the data throughput is still limited to a baud rate of 57,600 bits/s.

6.3.3 Installing the USB Driver

The Model 372 USB driver has been made available through Windows® Update. This is the recommended method for installing the driver, as it will ensure that you always have the latest version of the driver installed. If you are unable to install the driver from Windows® Update, it may be downloaded from: https://www.lakeshore.com/resources/software/drivers.

6.3.4 Communication

Communicating via the USB interface is done using message strings. The message strings should be carefully formulated by the user program according to some simple rules to establish effective message flow control.

6.3.4.1 Character Format

A character is the smallest piece of information that can be transmitted by the interface. Each character is ten bits long and contains data bits, bits for character timing, and an error detection bit. The instrument uses seven bits for data in the American Standard Code for Information Interchange (ASCII) format. One start bit and one stop bit are necessary to synchronize consecutive characters. Parity is a method of error detection. One parity bit configured for odd parity is included in each character.

ASCII letter and number characters are used most often as character data. Punctuation characters are used as delimiters to separate different commands or pieces of data. A special ASCII character, line feed (LF 0AH), is used to indicate the end of a message string. This is called the message terminator. The Model 372 will accept either the line feed character alone, or a carriage return (CR 0DH) followed by a line feed as the message terminator. The instrument query response terminator will include both carriage return and line feed.

6.3.4.2 Message Strings

A message string is a group of characters assembled to perform an interface function. There are three types of message strings: commands, queries, and responses. The computer issues command and query strings through user programs, the instrument issues responses. Two or more command or query strings can be chained together in one communication, but they must be separated by a semi-colon (;). The total communication string must not exceed 255 characters in length.

A command string is issued by the computer and instructs the instrument to perform a function or change a parameter setting. The format is:

```
<command mnemonic><space><parameter data><terminators>.
```

Command mnemonics and parameter data necessary for each one is described in section 6.6. Terminators must be sent with every message string.

A query string is issued by the computer and instructs the instrument to send a response. The query format is:

```
<query mnemonic><?><space><parameter data><terminators>.
```

Query mnemonics are often the same as commands with the addition of a question mark. Parameter data is often unnecessary when sending queries. Query mnemonics and parameter data if necessary is described in section 6.6. Terminators must be sent with every message string. The computer should expect a response very soon after a query is sent.

A response string is the instrument's response or answer to a query string. The response can be a reading value, status report or the present value of a parameter. Response data formats are listed along with the associated queries in section 6.6. The response is sent as soon as possible after the instrument receives the query.

6.3.5 Message Flow Control

It is important to remember that the user program is in charge of the USB communication at all times. The instrument cannot initiate communication, determine which device should be transmitting at a given time, or guarantee timing between messages. All of this is the responsibility of the user program.

When issuing commands the user program alone should:

- Properly format and transmit the command including the terminator as 1 string
- Guarantee that no other communication is started for 50 ms after the last character is transmitted
- Not initiate communication more than 20 times per second

When issuing queries or queries and commands together, the user program should:

- Properly format and transmit the query including the terminator as 1 string
- Prepare to receive a response immediately
- Receive the entire response from the instrument including the terminator
- Guarantee that no other communication is started during the response or for 50 ms after it completes
- Not initiate communication more than 20 times per second

Failure to follow these simple rules will result in inability to establish communication with the instrument or intermittent failures in communication.

6.4 Ethernet Interface

The Ethernet interface provides a means of connecting the Model 372 to an Ethernet based computer network. Ethernet networks provide the ability to communicate across large distances, often using existing equipment (the internet, pre-existing local networks). The Ethernet interface of the Model 372 provides the ability to use TCP socket connections (section 6.4.3) to send commands and queries to the instrument using the common command set detailed in section 6.6. The Model 372 has an embedded web interface that provides status information and additional utilities (section 6.5).

Menu navigation:
Interface→*Enabled*→Ethernet

6.4.1 Ethernet Configuration

There are several parameters for configuring the Model 372 Ethernet interface and three methods for configuring these parameters. This section contains a brief explanation of each of these. A comprehensive discussion of computer networking is beyond the scope of this manual. These settings may depend on your network configuration; contact your network administrator for assistance.

6.4.1.1 Network Address Parameters

Network address parameters include the IP address, the subnet mask, and the gateway address. The network address parameters of the Model 372 can be configured using one of three methods: DHCP, Auto-IP, or Static-IP. See section 6.4.1.2 for details on each of these configuration methods.

- *IP Address:* an IP address is required for a device to communicate using TCP/IP, which is the protocol generally used for Ethernet devices and the Model 372. The IP version used by the Model 372 is IPv4. The IPv6 standard is not supported. All references to the IP protocol from this point forward will be referring to IPv4.

  An IP address is a 32-bit logical address used to differentiate devices on a network. It is most often given in dotted decimal notation, such as nnn.nnn.nnn.nnn where nnn is a decimal number from 0 to 255.

- *Subnet Mask:* a sub network, or subnet, is a group of devices within a network that have a common, designated IP address routing prefix. A subnet mask is a 32-bit "bit mask" that signifies which part of the IP address represents the subnet routing prefix, and which part represents the device's address on the subnet. A subnet mask is most often given in dotted decimal notation, such as nnn.nnn.nnn.nnn where nnn is a decimal number from 0 to 255. When converted to a binary notation, the 32-bit subnet mask should consist of a contiguous group of ones, followed by a contiguous group of zeros. The ones represent which bits in the IP address refer to the subnet, and the zeros represent which bits refer to the device address. For example, the default Static-IP Address of the Model 372 is 192.168.0.12, and the default Static Subnet Mask is 255.255.255.0. Converting this subnet mask to binary shows that the first 24 bits are ones, and the last 8 bits are zeros. This means that the first 24 bits of the Static-IP Address (192.168.0) represent the subnet, and the last 8 bits (12) represent the device.

- *Gateway Address:* a gateway is a network traffic routing device that is used to route communication between networks. If a gateway is not used, then devices on a network can only communicate with other devices on that same network. A Gateway Address is the IP address of the gateway on a network. Contact the network administrator for the gateway address for your network.

6.4.1.2 Network Address Configuration Methods

The network address parameters of the Model 372 can be configured using one of three methods: DHCP, Auto-IP, or Static-IP. DHCP and Auto-IP are automatic configuration methods, and Static-IP requires manual configuration. If supported by the server, DHCP can also be used to automatically configure DNS server addresses, as well as IP address parameters.

An order of precedence is followed when the Model 372 attempts to acquire IP address parameters. If enabled, the DHCP method will be used first. If DHCP is disabled, or if the attempt to acquire parameters from the DHCP server fails, the Model 372 then checks if Auto-IP is enabled. If Auto-IP is enabled, this method will be used. If disabled, or if this attempt fails, the Static-IP method will be used. If the Static-IP method fails, the IP address parameters will not be configured and the Ethernet status will enter an error state. Refer to section 6.4.2.1 if you receive an error message.

Dynamic Host Configuration Protocol (DHCP): DHCP is a method of automatically configuring the IP address, subnet mask, and gateway of Ethernet devices on a network. This method provides simple automatic configuration for users connecting to a network that provides a DHCP server. The network DHCP server will provide an IP address, subnet mask, and gateway address. Depending on the DHCP server configuration, it may also provide primary DNS and secondary DNS addresses as well. DHCP is the simplest method of IP configuration. DHCP does have the disadvantage of not necessarily preserving the IP address through a device reconfiguration, as well as the possibility of being automatically reconfigured when the DHCP "lease" expires. Contact your network administrator to find out the DHCP lease policy on your network.

To use DHCP to automatically configure the IP address, subnet mask, and gateway of the Model 372, simply connect the Model 372 to a network that provides a DHCP server, and set the DHCP parameter to On. By default, the DHCP feature of the Model 372 is On.

Menu navigation:
Interface →*Modify IP Config*→DHCP→(Off or On)

Auto-IP: Auto-IP is a method of automatically configuring the IP address and subnet mask parameters of Ethernet devices on a link-local network. This configuration is performed by the Model 372 and does not require any external device. Auto-IP is defined in RFC 3927 "Dynamic Configuration of IPv4 Link-Local Addresses" and can be found at The Internet Engineering Task Force website at www.ietf.org. The automatically configured address will be in the link-local address group of 169.254.1.0 to 169.254.254.255. This group is reserved for independent, local networks that do not connect to other networks. This method chooses an IP address that is not already active on the network, which eliminates IP address conflicts. A gateway address is not applicable when using Auto-IP, since the purpose of a gateway address is to communicate with outside networks, and by definition Auto-IP only works on link-local networks. A disadvantage of Auto-IP is the limitation of only working with a link-local network, which cannot connect to other networks, including the internet. Another disadvantage lies in the fact that an Auto-IP assigned address will not be preserved through a device reconfiguration, such as a power cycle.

To use Auto-IP to automatically configure a link-local IP address and subnet mask, set the DHCP parameter to Off, then set the Auto-IP parameter to On. By default, the Auto-IP feature of the Model 372 is Off.

Menu navigation:
Interface →*Modify IP Config*→Auto-IP →(Off or On)

Static-IP: Static-IP is a method of manually configuring the IP address, subnet mask, and gateway of Ethernet enabled devices. When using the Static-IP method, the IP address, subnet mask, and gateway must be configured appropriately for the connected network, or for the connected PC, in order to establish connection to the network. A major advantage to the Static-IP method is that the IP address will not change during device reconfiguration (power cycle). Disadvantages of using the Static-IP method include the requirement of knowing how your network is configured in order to choose the correct configuration parameters.

The Static-IP method is always enabled, and therefore will default to this method when both automatic configuration methods (DHCP and Auto-IP) are disabled, or if all enabled automatic configuration methods fail. To use Static-IP to manually configure the IP address, subnet mask, and gateway of the Model 372, set the DHCP and the Auto-IP parameters to Off. Refer to the paragraphs above for details on turning off DHCP and Auto-IP. The Model 372 will now use the Static-IP Address, Static Subnet Mask, Static Gateway, Static Primary DNS, and Static Secondary DNS parameters to attempt to configure the Ethernet interface connection. Refer to section 6.4.1.3 for details on DNS parameters. Contact your network administrator for the appropriate Static-IP parameters for your network.

Menu navigation:
Interface→*Modify IP Config*→Static-IP→(Valid IP Address)
Interface→*Modify IP Config*→ Static Subnet Mask→ (Valid Subnet Mask)
Interface→*Modify IP Config*→Static Gateway→(Valid IP Address)
Interface→*Modify IP Config*→Static Pri DNS→(Valid IP Address)
Interface→*Modify IP Config*→Static Sec DNS→ (Valid IP Address)

6.4.1.3 DNS Parameters

The parameters discussed in this section exist to facilitate the use of the Domain Name System (DNS) to connect to the Model 372 using assignable names rather than cryptic IP addresses. This functionality is provided for convenience only, and is not critical to the connectivity of the Ethernet interface.

DNS Address: A Domain Name System (DNS) is a service that translates names into IP addresses. This service allows for using human readable names for devices on a network. As an example, when a web browser attempts to retrieve the web page at www.lakeshore.com, the browser first performs a forward-lookup on the assigned DNS server to attempt to retrieve the IP address that is represented by the name www.lakeshore.com. If successful, the web browser then uses the retrieved IP address to communicate with the web server that hosts the website at www.lakeshore.com.

The Model 372 can be configured to communicate with a primary and a secondary DNS server using the primary DNS address and the secondary DNS address parameters. Multiple DNS servers are sometimes used for redundancy, but multiple servers are not required, and not all networks provide a DNS server. DNS addresses can be configured automatically using the DHCP method if the network DHCP server is configured to do so.

NOTE

Your DHCP server must be configured appropriately to provide DNS server addresses. Not all DHCP servers provide this functionality on your network.

Hostname: A hostname is a name that is assigned to a device on a network. On a Domain Name System (DNS) enabled network, a hostname can be used alone when connecting from another device on the same domain, or it can be combined with a domain name to connect to devices outside of the local domain. For example, www.lakeshore.com refers to the Lake Shore web server on the Internet, which is a DNS enabled network. The web server hostname is "www", and it resides on the domain "lakeshore.com". To connect to the web server from another device on the lakeshore.com domain, only the hostname "www" must be used. To connect from any other domain on the Internet, the entire fully-qualified name, consisting of the hostname and the domain name (www.lakeshore.com) must be used. Hostnames can only contain alpha-numeric characters and hyphens, but cannot begin or end with a hyphen.

A hostname can be assigned by a network administrator, or if the Model 372 is connected to a network with Dynamic DNS (DDNS) capability, a DNS entry is automatically created for it using the Preferred Hostname and Preferred Domain Name parameters and the assigned IP address.

Menu navigation:
Interface→*Modify IP Config* →Preferred Hostname→(Valid Hostname String)

If DNS reverse-lookup is enabled on the network DNS server, and the DNS address parameters are correctly configured, the Model 372 will perform a reverse-lookup to determine if a hostname is assigned for the Model 372's configured IP address. This will occur regardless of whether the hostname was configured dynamically using DDNS, or manually by the network administrator. The returned hostname will appear in the Actual Hostname parameter, in the View IP Config submenu of the Interface Setup menu.

Menu navigation (Read Only):
Interface →*View IP Config* →Actual Hostname

NOTE

When using naming systems other than DNS, the Model 372 cannot assign the Preferred Hostname or retrieve the Actual Hostname.

Domain Name: A domain is a collection of network devices that are managed according to some common characteristic of its members. Domains can contain subdomains which are subsets within the domain. The hierarchy can contain several dot separated levels which flow from right to left. For example, lakeshore.com contains the top-level-domain "com" and the subdomain "lakeshore". When using the Domain Name System (DNS) to connect to a specific host device on a network, the device's hostname is tacked onto the left of the domain name. For example, the "www" in www.lakeshore.com refers to the Lake Shore web server, located within the internet domain "lakeshore.com."

If the Model 372 is connected to a network with Dynamic DNS (DDNS) capability, a DNS entry is automatically created using the Preferred Hostname and Preferred Domain Name parameters and the assigned IP address. The Preferred Domain Name parameter can only be accessed using the NET interface command (section 6.6.1), or by using the Ethernet configuration page (section 6.4.2) of the embedded website on the Model 372.

If DNS reverse-lookup is enabled on the network DNS server, and the DNS address parameters are correctly configured, the Model 372 will perform a reverse-lookup to determine if a domain name is assigned for the Model 372's configured IP address. This will occur regardless of whether the domain name was configured dynamically using DDNS, or manually by the network administrator. The returned domain name will appear in the Actual Hostname parameter, in the View IP Config submenu of the Interface Setup menu.

NOTE

When using naming systems other than DNS, the Model 372 cannot assign the Preferred Domain Name or retrieve the Actual Domain Name.

Menu navigation:
The preferred domain name can only be entered using a computer interface NET command, and viewed using the NET? query. Refer to section 6.6.1 for details on the NET command and query.

6.4.2 Viewing Ethernet Configuration

When the Ethernet interface is enabled, two submenus become available: Modify IP Config, and View IP Config. All configurable settings are available under the Modify IP Config submenu, and the current state of the Ethernet configuration is detailed in the View IP Config submenu. This is designed to eliminate confusion as to which are the configurable Static-IP settings, and which are the currently configured settings that could have been configured using any of the three configuration methods (DHCP, Auto-IP, or Static-IP). The method used for the currently established connection is shown in the LAN status parameter of the View IP Config submenu (section 6.4.2.1).

6.4.2.1 LAN Status

The LAN status parameter indicates the current status of the Ethernet configuration. This read-only parameter can be accessed using the View IP Config menu.

The possible LAN status states are:

- *Connected–Static:* the IP address parameters have been successfully configured using the Static-IP method
- *Connected–DHCP:* the IP address parameters have been successfully configured using the DHCP method
- *Connected–AutoIP:* the IP address parameters have been successfully configured using the AutoIP method
- *Addr Not Acquired:* the IP address parameters were not successfully configured.
- Duplicate Init IP: when initially attempting to connect to the network, the Static-IP address was found to be in use by another device already configured on the

network. The Model 372 interface will remain unconfigured until an available Static-IP address is entered.

- *Duplicate Ong IP:* an ongoing conflict occurred after being successfully connected to the network, because another device on the network was configured using the same IP address. The Model 372 will automatically unconfigure and remain unconfigured until an available IP address is entered.
- *Cable Unplugged:* the Ethernet cable is either unplugged at one end, or has been damaged
- *Module Error:* the Model 372 has lost contact with the Ethernet module; this may indicate a damaged Ethernet module
- *Acquiring Address:* the Model 372 is attempting to configure the IP address parameters using the enabled methods

6.4.2.2 MAC Address

The Media Access Controller (MAC) Address is a physical hardware address assigned to all Ethernet devices. MAC addresses are 48 bits and are generally written as six groups of two hexidecimal digits separated by colons, for example "01:23:45:67:89:AB". Unlike IP addresses, MAC addresses are tied to the device hardware and cannot be changed.

Menu navigation (read-only):
Interface→*View IP Config*→MAC Address

6.4.2.3 Viewing Network Configuration Parameters and DNS Parameters

The currently configured network parameters are displayed individually in the View IP Config submenu. These parameters could have been configured using either DHCP, Auto-IP, or Static-IP. The LAN Status parameter shows which method was used for the current configuration. When in an error state, or in the intermediate Acquiring Address state, the network configuration parameters will all be displayed as 0.0.0.0. Refer to section 6.4.1.1 through section 6.4.1.3 for details on network configuration parameters and DNS parameters.

Menu navigation (read-only):
Interface→*View IP Config* →IP
Interface→*View IP Config* →Subnet Mask
Interface→*View IP Config*→Gateway IP
Interface→*View IP Config*→Primary DNS IP
Interface→*View IP Config* →Secondary DNS IP
Interface→*View IP Config*→Actual Hostname
Interface→*View IP Config*→TCP Socket Port

6.4.3 TCP Socket Communication

A TCP socket connection interface is provided as the communication medium for the Ethernet interface of the Model 372. A TCP socket connection, or simply "socket connection", is a common connection protocol used by Ethernet devices. The Transmission Control Protocol (TCP) is commonly used for creating a communication channel between one program on one computer and one program on another computer, for example a web browser on a PC and a web server on the Internet. In the case of the Model 372, the protocol is used to create a communication channel between one program on one computer and the command line interface of the Model 372. TCP uses error correction and collision avoidance schemes that make it a very reliable form of Ethernet communication, but has drawbacks of having nondeterministic timing, and can encounter relatively large delays depending on network conditions. These delays can be on the order of seconds. Sockets use port numbers to identify sending and receiving endpoints on network devices. This allows for multiple separate communication links to exist on each device. *The port number used for TCP socket connections on the Model 372 is 7777.*

NOTE **A maximum of two simultaneous socket connections can be made to the Model 372. Any attempts to open a new socket while two socket connections are already open on a Model 372 will fail.**

6.4.4 Embedded Web Interface

The Model 372 provides a web interface via an embedded web server that runs on the instrument. Once the Model 372 is properly connected, and the IP parameters properly configured, the web interface can be opened using a web browser. The web interface should be accessible using any modern web browser, but has only been tested with Microsoft® Internet Explorer® version 11.0.

6.4.4.1 Connecting to the Web Interface

To connect to the web interface, type “http://” followed by the IP address assigned to the Model 372 that you are attempting to connect to. If connecting from a device on the same local network, and a hostname is properly assigned to the Model 372 via a naming service on the network (section 6.4.1.3), then the IP address can be replaced by the hostname. If connecting from a device not on the same local network, but on a network which is connected to the local network of the Model 372, and a hostname and a domain name are properly assigned, the IP address can be replaced by the hostname followed by the domain name, with a dot separator between them. For example if the hostname LSCI-3720001, and the domain name yourdomain.com were assigned via a naming service, then typing “http://LSCI-3720001.yourdomain.com” would open the home web page of the Model 372 embedded website.

6.4.4.2 Web Pages

Each web page contains detailed help information in the form of tool-tips. You can access these tool-tips by hovering the mouse pointer over the various help icons located throughout the embedded website.

Home Page: provides a summary of information specific to the Model 372.

FIGURE 6-4 ***Model 372 home page***

Ethernet Configuration Page: provides a means of reconfiguring the Ethernet configuration parameters of the Model 372.

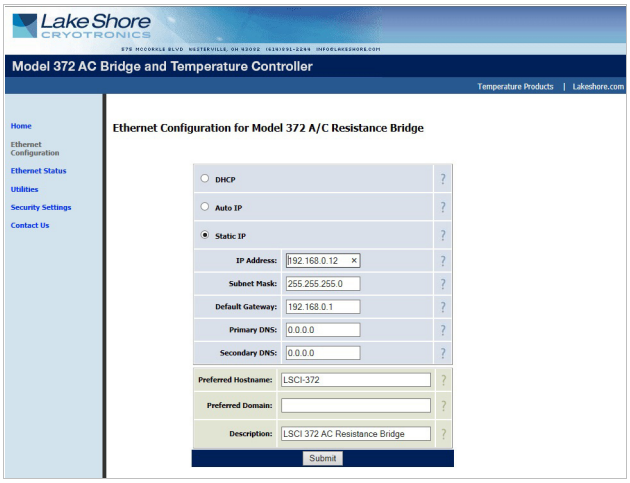


FIGURE 6-5 ***Ethernet configuration page***

Ethernet Status Page: provides status and statistics related to the current Ethernet connection.

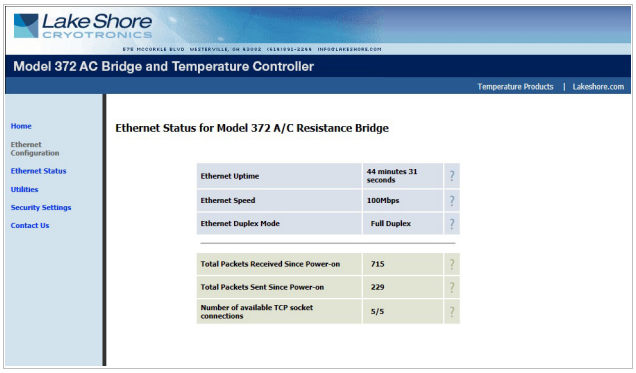


FIGURE 6-6 ***Ethernet status page***

Utilities Page: provides links to launch the embedded curve handler application, the embedded Ethernet firmware updater, and the instrument configurator backup utilities

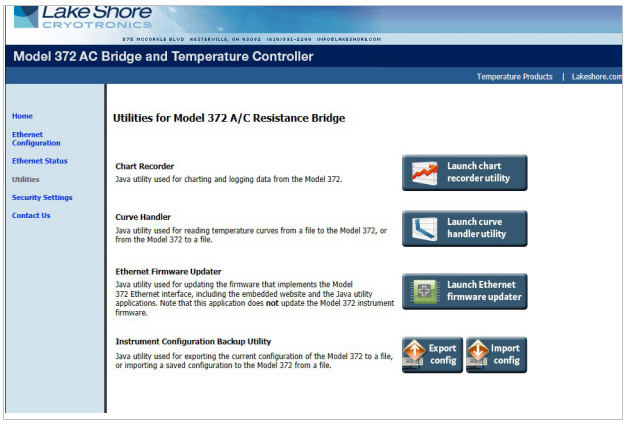


FIGURE 6-7 ***Utilities page***

Security Settings: provides a means of changing the website security settings by allowing the user to enter a new username and password for the website, or to remove password protection from the website. The username and password parameters are available for viewing and editing from the front panel under the Modify IP Config submenu of the Interface menu.

NOTE **Password protection only protects access to the embedded web pages and does not provide any kind of security for TCP Socket access (section 6.4.3).**

NOTE **The website username and password are available from the front panel menu, and therefore can easily be obtained by anyone with access to the Model 372 front panel.**

Contact Us: provides information regarding how to contact representatives of Lake Shore Cryotronics, Inc.

6.5 Utilities

The utilities embedded on the Model 372 are written using the Java™ programming language. This theoretically allows the applications to run properly on many different platforms (Windows®, Mac®, Linux™, etc.), although the applications are only supported on Microsoft Windows® XP or Windows® 7 and Vista®, and have been designed to work with the Java™ Runtime Environment (JRE) version 1.6. To download Java™ JRE, please visit www.java.com.

NOTE **Please note that without the proper JRE installed the utilities will not run properly.**

The applications are launched from the Utilities web page using Java™ Web Start technology. This allows the application to run outside of the web browser in a standalone window. The application can only be launched using the link in the embedded web page, and cannot be permanently installed. When launching the application, multiple security warning messages may appear. These messages are meant to protect from malicious software that can cause harm to, or compromise the security of, your computer or your data. The applications have been thoroughly tested and are considered by Lake Shore to be safe.

NOTE **All software is imperfect and any software may be used by a malicious user for malicious purposes.**

6.5.1 Embedded Curve Handler™

The Embedded Curve Handler™ utility is provided for uploading temperature curve files to the Model 372. The utility is also capable of reading curves from the Model 372 and writing them to a file for storage, or manipulation in a third party program. The Embedded Curve Handler™ supports standard Lake Shore temperature curve files in the ".340" file format, and the Microsoft Excel® ".xls" (Excel® 97 through 2003) file format. Curve files are provided with calibrated sensors purchased from Lake Shore in the ".340" file format. The ".CURVE" file format, which is the format of cubic spline curves, is not supported.

To read a temperature curve from a file: click **Read from File**. Select a properly formatted temperature curve (*.340 or *.xls) file using the Open Browser dialog box. The curve will be loaded into the program and the curve points and graph will be displayed.

To read a temperature curve from the Model 372: click **Read from Instrument**. The Read Curve from Instrument dialog box appears. Select a curve from the drop-down box and click **OK**. The curve will be loaded into the program and the curve points and graph will be displayed.

Once a curve is loaded into the Embedded Curve Handler™ using either the Read from File or Read from Instrument buttons, the loaded curve can be stored either to a user curve location (21 to 59) in the Model 372, or to a file.

To store the curve to a user curve location in the Model 372: click **Write to Instrument.** The Write Curve to Instrument dialog box appears. Select a user curve location to write the loaded temperature curve to, and click **OK**.

To write the currently loaded curve to a file: click **Write to File**. A Save Browser dialog box appears. First use the Files of Type drop-down box to select the file format in which to save the curve. Then choose a directory and a file name, and click **Save** .

The .340 file format is an ASCII text file which can be read and altered using a standard ASCII text editor. Care must be taken when altering the .340 text files to ensure that all of the values are stored in the same position in the file as the original values, using the same number of digits. To alter curve files, it is recommended to use the .xls file format, which can be altered using Microsoft Excel®. If using formulas to alter curves, you must copy the results of the formulas and paste them back into the original cells of the breakpoint values. The Embedded Curve Handler™ cannot interpret formulas in cells. In most versions of Excel®, this can be done by copying the formula results, then pasting them in the appropriate cells using the **Paste Special** command, and selecting **Paste Values**. Refer to the appropriate Microsoft Excel® documentation for details on the Paste Special operation.

NOTE

The Embedded Curve Handler™ cannot read files in the Microsoft Excel® ".xls" (Excel® 2007 or newer) format. When saving files from Excel®, be sure to save them in the ".xls" (Excel® 97 through 2003) format so that the file can be read using the Embedded Curve Handler™ utility.

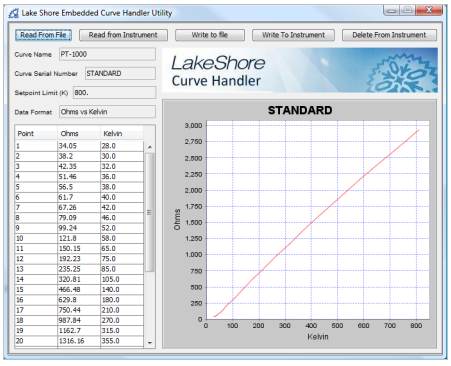


FIGURE 6-8 ***Curve Handler***

6.5.2 Ethernet Firmware Updater

The Ethernet Firmware Updater utility provides a means of updating the firmware that controls the Ethernet functionality of the Model 372. It also updates the embedded website and the Java™ utilities found on the Utilities web page. Please visit www.lakeshore.com for the latest firmware updates.

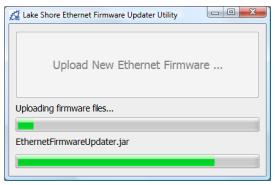


FIGURE 6-9 ***Ethernet Firmware Updater***

NOTE

This utility only updates the Ethernet firmware and not the instrument firmware. Another utility is provided at the Lake Shore website (www.lakeshore .com) for updating the instrument firmware.

To use the Ethernet Firmware Updater utility: first ensure that your Java™ Runtime Environment is at version 1.6.0 or higher and then use this procedure to download the Ethernet firmware Updater utility.

1. Download the latest Model 372 Ethernet Firmware file from www.lakeshore.com.
2. Once the firmware files have been downloaded, connect to the embedded website (section 6.4.4), and navigate to the **Utilities** page.
3. Click **Launch Ethernet Firmware Updater**.
4. Accept any security warning messages that are presented (refer to section 6.5 for an explanation of these security warnings). The Ethernet Firmware Updater application window should now be open.
5. Click **Upload New Ethernet Firmware**, and a file browser window will open.
6. Navigate to the directory where the Model 372 Ethernet firmware is stored. Select the file and click **Open**.

At this point the application should check to see if the firmware you are attempting to update to is newer than what is already installed on the Model 372. If it is, then the firmware should immediately begin uploading, and the progress of the firmware update operation should be displayed using the two progress bars in the application window.

6.5.3 Instrument Configuration Backup Utility

The instrument configuration backup utility provides the means to export the current configuration of the Model 372 to a file, or to import a saved configuration from a file to the Model 372. The utility is useful in situations where the instrument is shared with users who require different configurations, or when the instrument is often moved between systems requiring different configurations. All instrument configuration settings are exported or imported by the utility except for the setpoint and heater range, network settings, and web login settings. These settings are ignored to prevent the outputs from unintentionally turning on and to prevent interrupting communication with the instrument.

To export the current configuration of the Model 372 to a file:

1. On the **Utilities** page in the Model 372 embedded website, click **Export config** (FIGURE 6-7).
2. In the Save File dialog box, select the location and file name to which you want to export the current instrument configuration. Click **Save**.

The utility will export the current configuration from the Model 372 and save it to the specified file.

To import a saved configuration from a file to the Model 372:

1. On the **Utilities** page in the Model 372 embedded website, click **Import config** (FIGURE 6-7).
2. In the Save File dialog box, select the file name from which you want to import the saved instrument configuration settings. Click **Open**.
3. Click **Yes, import settings** in the confirmation box that appears.

The utility will read the configuration from the specified file and import it to the Model 372.

6.5.4 Embedded Chart Recorder

The embedded chart recorder utility is provided to allow users to easily acquire and chart data from the Model 372. The chart recorder utility can simultaneously chart and log any combination of sensor readings, control setpoints, and heater output data from the Model 372. A basic user interface is also provided for changing control parameters on the fly while acquiring data, allowing many basic experiments to be performed without ever having to write any custom software. Log files are stored in the Microsoft Excel® .xls format for easy data manipulation. Free utilities are available online for converting .xls files to comma separated plain text files (.csv) if Microsoft Excel is not available.

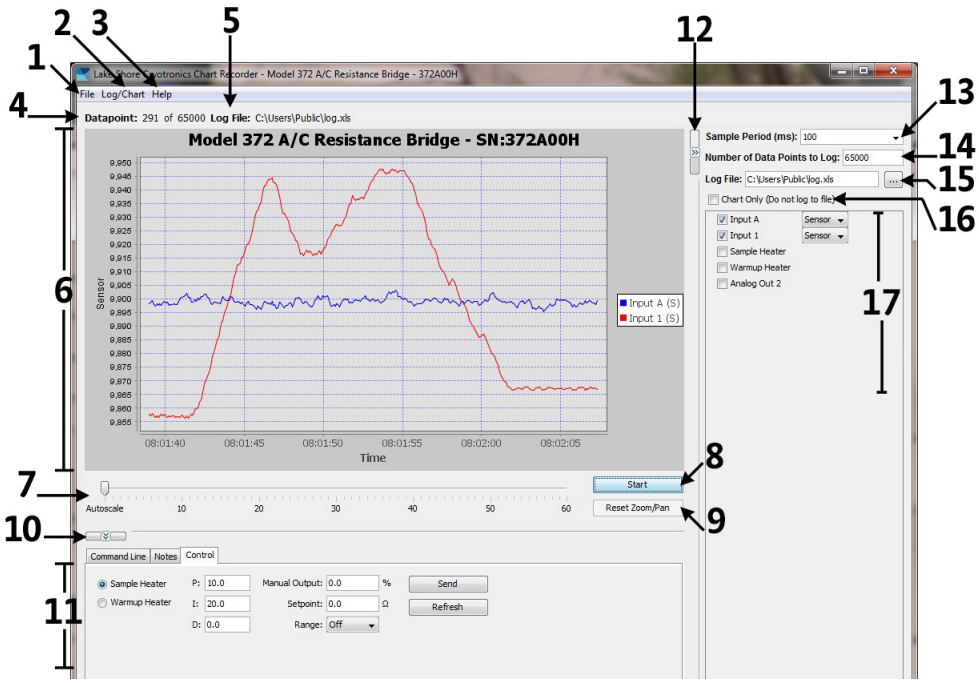


FIGURE 6-10 ***Embedded chart recorder interface***

6.5.4.1 Configuration Panel

The configuration panel is located to the right of the chart and consists of items 12 through 17 in the screenshot above. It is used to configure the charting and logging functionality for the next data acquisition task. When **Start** is pressed, the parameters in the configuration panel are used to determine:

- *Sample period (13)*: the rate at which to acquire readings from the instrument in milli-seconds.
- *Number of data points to log (14)*: the number of data points to log if logging to a file.
- *Log file (15):* the path of the file to use for logging data, if logging to a file.
- *Chart only (16)*: if selected, acquired data is only charted, and is not logged to a file.
- *Readings (17)*: the readings, and units (where applicable) to take during data acquisition.

The configuration panel can be collapsed to increase the size of the chart. To collapse the configuration panel, simply click on **Collapse configuration panel** (12). When collapsed, the same button becomes an **Expand Configuration Panel** button that can be used to restore the configuration panel on the form. When data acquisition is in progress, the configuration panel controls are disabled, but the current settings can still be seen.

6.5.4.2 Starting Data Acquisition

Once the parameters in the configuration panel are set as desired, simply click **Start** to begin data acquisition. If you are logging data to a file, the Number of Data Points to Log parameter is used to determine how many data points to take before terminating data acquisition. However, once data acquisition has begun, the **Start** button becomes a **Stop** button, and data acquisition can be terminated by pressing **Stop** button. If you are not logging to a file, data acquisition will continue until you press **Stop**.

6.5.4.3 Chart Functionality

By default, the chart (6), will autoscale in both the x and y-axis. The time scale slider (7) is provided to adjust the time scale window (x-axis scaling). When less than one hour of data has been logged, the slider will allow a time window between 1 and 60 min, in increments of 1 min. As the total elapsed time increases, the values on the time scale slider will also increase to allow time windows proportional to the elapsed time. A y-axis is added for each unique measurement unit of the selected readings. Each y-axis will be autoscaled, so if more than one reading is being taken in the same unit, the scale for the associated axis will be set such that the largest values of all readings are at the extremes. Data that is charted on the same axis, but that is far apart in magnitude, will result in low resolution for each data series.

Manual zooming of the chart can be achieved either by using the mouse wheel, or by clicking and dragging a box around the area of the chart to zoom to. Manual panning can be achieved by holding the Ctrl key, then clicking and dragging the chart. After manually zooming or panning, autoscaling in both axes is turned off and **Reset Zoom/Pan** becomes active. To return to autoscale mode, click **Reset Zoom/Pan**.

A screenshot of the currently displayed chart can be copied to the clipboard, saved in the PNG image format, or printed directly to a printer using the context menu that appears when right-clicking on the chart. Other chart properties, such as colors and fonts can be customized through this context menu by clicking **Properties**. Note that changes to these chart properties are not saved when the application is closed, so the default values will be restored when reopening the chart recorder utility.

6.5.4.4 Utilities Panel

The utilities panel (11) provides added functionality to assist the user in various common tasks associated with user applications. Three tabs provide a means of selecting between the three utilities.

Command Line: provides command line access for sending commands and queries to the instrument. To send a command or query, type the command or query into the Command text box and click **Send**. Query responses are displayed in the Response box below. Click **Command Summary** to pull up the list of command line commands and queries supported by the instrument.

Notes: provides a means of adding notes to the log file while logging data. The note will be added to the notes column of the log file at the row associated with the most recently acquired data point. To add a note, simply add text to the text box next to the **Save Note** button, then click **Save Note**. Notes will be appended to the note history text box, along with a time stamp. If a note is saved while not currently logging data to a file, the note will only appear in the note history text box, and will only be available while the application is running.

Control: provides easy access to the control functions of the instrument. The P, I, D, Manual Output, Setpoint, and Heater Range settings can be configured here for each control loop on the instrument. The current configuration of the given control loop is displayed when the **Heater** radio button is selected. To update these parameters on the instrument, first select the output control loop to update by choosing a **Heater** radio button. Then update the values in the Control panel and click **Send**. Each control loop must be updated independently, so once the values in the Control panel are updated, click **Send** before clicking another **Heater** radio button.

The utilities panel can be collapsed to increase the size of the chart. To collapse the utilities panel, click **Collapse Utilities Panel** (10). When collapsed, the same button becomes an **Expand Utilities Panel** button that can be used to restore the utilities panel on the form.

6.5.4.5 Menu

The standard dropdown menu includes the following sections:

File (1):
- Interface Configuration—can be used to configure the remote interface connection to the instrument.
- Exit—closes the Chart Recorder application.

Log/Chart (2):
- Configure Log/Chart—simply expands the configuration panel if collapsed.
- Hide Legend—hides the legend in the chart to expand the data plot.

Help (3):
- Getting Started—launches a web page with basic chart recorder instructions.
- About—provides information about the application, including the software revision level.

6.5.4.6 Information

The information panel consists of the following two bits of information:
- Datapoint (4)—the current datapoint number. If logging data, this also shows the total number of data points to be taken in the current data acquisition (i.e. 522 of 1000).
- Log File (5)—the file path of the file that is currently being used to log data.

6.6 Command Summary

This section provides a listing of the interface commands. A summary of all the commands is provided in TABLE 6-6. All the commands are detailed in section 6.6.1, and are presented in alphabetical order.

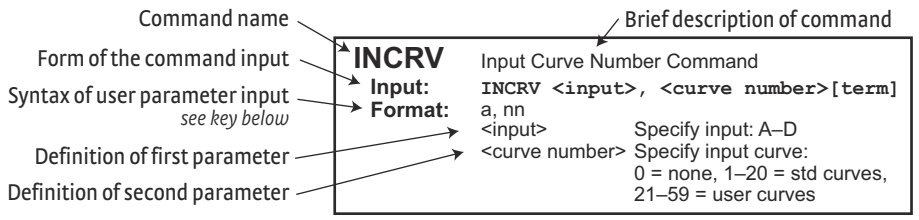


FIGURE 6-11 ***Sample command format***

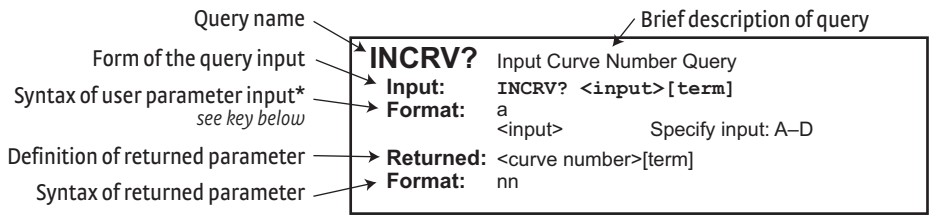


FIGURE 6-12 ***Sample query format***

Command	Function	Page	Command	Function	Page
∗CLS	Clear Interface Cmd	144	INSET	Input Channel Parameter Cmd	157
∗ESE	Event Status Enable Register Cmd	144	INSET?	Input Channel Parameter Query	157
∗ESE?	Event Status Enable Register Query	145	INTSEL	Interface Select Cmd	158
∗ESR?	Standard Event Status Register Query	145	INSTSEL?	Interface Select Query	158
∗IDN?	Identification Query	145	INTYPE	Input Setup Cmd	158
∗OPC	Operation Complete Cmd	145	INTYPE?	Input Setup Query	160
∗OPC?	Operation Complete Query	145	KRDG?	Kelvin Reading Query	160
∗RST	Reset Instrument Cmd	145	LEDS	Front Panel LEDs Cmd	160
∗SRE	Service Request Enable Register Cmd	146	LEDS?	Front Panel LEDs Query	160
∗SRE?	Service Request Enable Register Query	146	LOCK	Keypad Lock Cmd	160
∗STB?	Status Byte Query	146	LOCK?	Keypad Lock Query	160
∗TST?	Self-Test Query	146	MDAT?	Minimum/Maximum Data Query	161
∗WAI	Wait-to-Continue Cmd	146	MNMXRST	Minimum and Maximum Reset Cmd	161
ALARM	Alarm Parameter Cmd	147	MODE	IEEE Interface Mode Cmd	161
ALARM?	Alarm Parameter Query	147	MODE?	IEEE Interface Mode Query	161
ALARMST?	Alarm Status Query	148	MONITOR	Monitor & Reference Output Selection Cmd	161
ALMRST	Alarm Status Cmd	148	MONITOR?	Monitor & Reference Output Selection Query	161
ANALOG	Analog Output Parameter Cmd	148	MOUT	Manual Heater Output Cmd	162
ANALOG?	Analog Output Parameter Query	149	MOUT?	Manual Heater Output Query	162
AOUT?	Analog Output Data Query	149	NET	Network Settings Cmd	162
BAUD	RS-232 Baud Rate Cmd	149	NET?	Network Settings Query	162
BAUD?	RS-232 Baud Rate Query	149	NETID?	Network Configuration Query	163
BEEP	Audible Alarm Beeper Cmd	149	OUTMODE	Output Mode Cmd	163
BEEP?	Audible Alarm Beeper Query	149	OUTMODE?	Output Mode Query	164
BRIGT	Display Brightness Cmf	149	PID	Closed Loop PID Parameter Cmd	164
BRIGT?	Display Brightness Query	150	PID?	Closed Loop PID Parameter Query	164
CMR	Common Mode Reduction Cmd	150	QRDG?	Quadrature Reading Query	164
CMR?	Common Mode Reduction Query	150	RAMP	Setpoint Ramp Parameter Cmd	165
CRVDEL	Curve Delete Cmd	150	RAMP?	Setpoint Ramp Parameter Query	165
CRVHDR	Curve Header Cmd	150	RAMPST?	Setpoint Ramp Status Query	165
CRVHDR?	Curve Header Query	151	RANGE	Heater Range Cmd	165
CRVPT	Curve Data Point Cmd	151	RANGE?	Heater Range Query	165
CRVPT?	Curve Data Point Query	151	RDGK?	Kelvin Reading Query	166
DFLT	Factory Defaults Cmd	151	RDGPWR?	Excitation Power Reading Query	166
DISPFLD	Custom Mode Display Field Cmd	152	RDGR?	Resistance Reading Query	166
DISPFLD?	Custom Mode Display Field Query	152	RDGST?	Input Reading Status Query	166
DISPLAY	Display Setup Cmd	152	RDGSTL?	Reading Settle Status Query	167
DISPLAY?	Display Number Query	153	RELAY	Relay Parameter Cmd	167
DOUT	Digital Output Cmd	153	RELAY?	Relay Parameter Query	167
DOUT?	Digital Output Query	153	RELAYST?	Relay Status Query	167
EMUL	370 Emulation Mode	153	SCAN	Scanner Parameter Cmd	167
EMUL?	370 Emulation Mode Query	153	SCAN?	Scanner Parameter Query	167
FILTER	Filter Parameter Cmd	154	SETP	Temperature Control Setpoint Cmd	168
FILTER?	Filter Parameter Query	154	SETP?	Temperature Control Setpoint Query	168
FREQ	Excitation Frequency Cmd	154	SRDG?	Sensor Reading Query	168
FREQ?	Excitation Frequency Query	154	STILL	Still Output Cmd	168
HTR?	Heater Output Query	155	STILL?	Still Output Query	168
HTRSET	Heater Setup Cmd	155	TLIMIT	Temperature Limit Cmd	168
HTRSET?	Heater Setup Query	155	TLIMIT?	Temperature Limit Query	169
HTRST?	Heater Status Query	155	WARMUP	Warmup Mode Parameter Cmd	169
IEEE	IEEE-488 Interface Parameter Cmd	156	WARMUP?	Warmup Mode Parameter Query	169
IEEE?	IEEE-488 Interface Parameter Query	156	WEBLOG	Website Login Parameters Cmd	169
INCRV	Input Curve Number Cmd	156	WEBLOG?	Website Login Parameter Query	169
INCRV?	Input Curve Number Query	156	ZONE	Control Loop Zone Table Parameter Cmd	170
INNAME	Sensor Input Name Command	157	ZONE?	Control Loop Zone Table Parameter Query	170
INNAME?	Sensor Input Name Query	157			

TABLE 6-6 ***Command summary***

6.6.1 Interface Commands

This section lists the interface commands in alphabetical order.

∗	Begins common interface command
?	Required to identify queries
s[n]	String of alphanumeric characters with length "n." Send these strings using surrounding quotes. Quotes enable characters such as commas and spaces to be used without the instrument interpreting them as delimiters.
nn...	String of number characters that may include a decimal point.
dd	Dotted decimal format, common with IP addresses. Always contains 4 dot separated 3-digit decimal numbers, such as 192.168.000.012.
[term]	Terminator characters
<...>	Indicated a parameter field, many are command specific.
<state>	Parameter field with only on/off or enable/disable states.
<value>	Floating point values have varying resolution depending on the type of command or query issued.

*TABLE 6-7 **Interface commands key***

∗CLS Clear Interface Command

Input `∗CLS[term]`

Remarks Clears the bits in the status byte register and the Standard Event Status Register, and terminates all pending operations. Clears the interface, but not the controller. The related controller command is *RST.

∗ESE Event Status Enable Register Command

Input `∗ESE <bit weighting>[term]`

Format nnn

Remarks Each bit is assigned a bit weighting and represents the enable/disable mask of the corresponding event flag bit in the Standard Event Status Register. To enable an event flag bit, send the command ∗ESE with the sum of the bit weighting for each desired bit. Refer to section 6.2.5 for a list of event flags.

Example To enable event flags 0, 4, and 7, send the command *ESE 145[term]. 145 is the sum of the bit weighting for each bit.

Bit	Bit weighting	Event name
0	1	OPC
2	4	QXE
4	16	EXE
5	32	CME
7	128	PON
Total:	181	

*ESE? Event Status Enable Register Query

Input `*ESE? [term]`
Returned Format <bit weighting>[term]
nnn (refer to section 6.2.5 for a list of event flags)

*ESR? Standard Event Status Register Query

Input `*ESR? [term]`
Returned Format <bit weighting>
nnn
Remarks The integer returned represents the sum of the bit weighting of the event flag bits in the Standard Event Status Register. Refer to section 6.2.5 for a list of event flags.

*IDN? Identification Query

Input `*IDN? [term]`
Returned Format <manufacturer>,<model>,<instrument serial>,<firmware version>[term]
s[4],s[8],s[7],n.n

<manufacturer>	Manufacturer ID
<instrument serial>	Instrument serial number
<firmware version>	Instrument firmware version

Format <model> Instrument model number
Example LSCI,MODEL372,1234567/1234567,1.0

*OPC Operation Complete Command

Input `*OPC [term]`
Remarks Generates an Operation Complete event in the Event Status Register upon completion of all pending selected device operations. Send it as the last command in a command string.

*OPC? Operation Complete Query

`*OPC? [term]`
Returned 1[term]
Remarks Places a 1 in the controller output queue upon completion of all pending selected device operations. Send as the last command in a command string.
Not the same as *OPC.

*RST Reset Instrument Command

Input `*RST [term]`
Remarks Sets controller parameters to power-up settings. Use the DFLT command to set to factory defaults.

*SRE Service Request Enable Register Command

Input `*SRE <bit weighting>[term]`

Format nnn

Remarks Each bit has a bit weighting and represents the enable/disable mask of the corresponding status flag bit in the status byte register. To enable a status flag bit, send the command *SRE with the sum of the bit weighting for each desired bit. Refer to section 6.2.6 for a list of status flags.

Example To enable status flags 4, 5, and 7, send the command *SRE 176[term]. 176 is the sum of the bit weighting for each bit.

Bit	Bit Weighting	Event Name
0	1	RAMPW
1	2	VRC
2	4	VRM
3	8	ALARM
4	16	OVLD
5	32	ESB
7	128	OSB
Total:	191	

*SRE? Service Request Enable Register Query

Input `*SRE?[term]`

Returned <bit weighting>[term]

Format nnn (refer to section 6.2.6 for a list of status flags)

*STB? Status Byte Query

Input `*STB?[term]`

Returned <bit weighting>[term]

Format nnn

Remarks Acts like a serial poll, but does not reset the register to all zeros. The integer returned represents the sum of the bit weighting of the status flag bits that are set in the status byte register. Refer to section 6.2.6 for a list of status flags.

*TST? Self-Test Query

Input `*TST?[term]`

Returned <status>[term]

Format n

<status> 0 = no errors found, 1 = errors found

Remarks The Model 372 reports status based on test done at power up.

*WAI Wait-to-Continue Command

Input `*WAI[term]`

Remarks Causes the IEEE-488 interface to hold off until all pending operations have been completed. This is the same function as the *OPC command, except that it does not set the Operation Complete event bit in the Event Status Register.

ALARM Alarm Parameter Command

Input

```
ALARM <input/channel>, <off/on>, (ignored) <data source/
units>, <high value>, <low value>,<deadband>, <latch>,
(optional) <audible>, (optional) <visible>[term]
```

Format nn,n,n, ±nnn.nnnE±nn, ±nnn.nnnE±nn, ±nnn.nnnE±nn,n,n,n

<input/channel>	Specifies which input or channel to configure: A (control input), 1 to 16 (measurement input), 0 = all channels (measurement input).
<off/on>	Specifies alarm checking on or off: 0 = off, 1 = on.
<data source/units>	Ignored.
<high value>	Sets the value the source is checked against to activate the high alarm.
<low value>	Sets the value the source is checked against to activate low alarm.
<deadband>	Sets the value that the source must change outside of an alarm condition to deactivate an unlatched alarm.
<latch>	Specifies a latched alarm (remains active after alarm condition correction): 0 = non-latching, 1 = latching.
<audible>	Optional. Specifies if the internal speaker will beep when an alarm condition occurs. Valid entries: 0 = off, 1 = on
<visible>	Optional. Specifies if the Alarm LED on the instrument front panel will blink when an alarm condition occurs. Valid entries: 0 = off, 1 = on

Remarks Configures the alarm parameters for a channel. On a Model 370, the alarm had an independent units setting. The 372 uses preferred units, therefore, the data source/units field is ignored, but maintained for backwards compatibility. Therefore, pass a zero into this field when sending the command. The audible and visible parameters are optional as they were not available on the Model 370.

Example ALARM 5,1,0,270.0,0.0,0,1,1,1[term] – turns on alarm checking for measurement input Channel 5, activates the high alarm if the kelvin reading is over 270, and latches the alarm when kelvin reading falls below 270. Alarm condition will cause instrument to beep and the front panel Alarm LED to blink.

ALARM? Alarm Parameter Query

Input

```
ALARM? <input/channel>[term]
```

Format nn

<input/channel>	Specifies which input or channel to query: A (control input), 1 to 16 (measurement input)

Returned <off/on>, <units>, <high value>, <low value>, <deadband>, <latch>, <audible>, <visible>[term]

Format n,n, ±nnn.nnnE±nn, ±nnn.nnnE±nn, ±nnn.nnnE±nn,n,n,n
(refer to command for description)

Remarks The units field will return the preferred units (1 = kelvin, 2 = ohms) for the respective input. The audible and visible fields will not be returned when the instrument is in emulation mode.

ALARMST? Alarm Status Query

Input Format

```
ALARMST? <input/channel>[term]
```

nn

<input/channel> Specifies which input or channel to query: A (control input), 1 to 16 (measurement input)

Returned Format

<high state>,<low state>[term]

n,n

<high state> 0 = off, 1 = on

<low state> 0 = off, 1 = on

ALMRST Alarm Status Command

Input

```
ALMRST[term]
```

Remarks

Clears both the high and low status of all alarms, including latching alarms.

ANALOG Analog Output Parameter Command

Input

```
ANALOG <analog channel>,<polarity>, <mode>, <input/channel>,
<data source>,<high value>, <low value>,
<manual value>[term]
```

Format

n,n,n,nn,n, ±nnn.nnnE±nn, ±nnn.nnnE±nn,±nnnnnn

<analog channel> Specifies analog output channel: 1 to 2.

<polarity> Specifies analog output polarity: 0 = unipolar, 1 = bipolar.

<mode> Specifies data the analog output monitors:

Mode	Output 1	Output 2
0 = Off	✓	✓
1 = Monitor Out		✓
2 = Open Loop (Manual)	✓	✓
3 = Zone	✓	
4 = Still		✓
5 = Closed Loop (PID)	✓	
6 = Warm up	✓	

<input/channel> Specifies which input or channel to monitor: A = control input, 1 to 16 = measurement input channel, 0 = none

<source> Specifies channel data when output is configured for monitor out: 1 = kelvin, 2 = ohms

<high value> If <mode> is monitor out, this parameter represents the data at which the analog output reaches +100% output.

<low value> If <mode> is monitor out, this parameter represents the data at which the analog output reaches –100% output if bipolar, or 0% output if positive only.

<manual value> If <mode> is Open Loop (Manual), Closed Loop (PID), Still, or Warm-up this parameter is the value of the analog output as it applies to the set mode.

Example

ANALOG 2,1,1,4,1,100.0,0.0,0[term]—sets analog/still output (2) to monitor Channel 4 kelvin reading with 100.0 K at +100% output (+10.0 V) and 0.0 K at 0% output (0.0 V). Manual value is ignored.

Remarks

The <polarity>, <mode>, <input/channel> parameters are the same as the parameters in the OUTMODE command. They are included in both commands for backward compatibility and ease of use. When possible, it is recommended to use the OUTMODE command to configure both the warm-up heater and the analog/still output.

When in 370 emulation mode and the mode parameter is set to anything other than off, the output's range will also be set to on. The 370 analog output 1 has been replaced with the warm-up heater. To maintain backward compatibility, the ANALOG command will also configure the warm-up heater.

ANALOG? Analog Output Parameter Query

Input Format `ANALOG? <analog channel>[term]`
n
<analog channel> Specifies analog output channel: 1 or 2.

Returned Format <polarity>,<mode>,<input/channel>,<source>,<high value>,<low value>,<manual value>[term]
n,n,nn,n, ±nnn.nnnE±nn, ±nnn.nnnE±nn,±nnnnnn
(refer to command for definition)

AOUT? Analog Output Data Query

Input Format `AOUT? <output>[term]`
n
<output> Specifies which unpowered analog output to query: 1 or 2.

Returned Format <output percentage>[term]
±nn.nnn

Remarks Returns the output percentage of the unpowered analog output.

BAUD RS-232 Baud Rate Command

Input Format `BAUD <bps>[term]`
n
<bps> Specifies Baud rate: 0 = 300 Baud, 1 = 1,200 Baud, 2 = 9,600 Baud, 3 = 57,600 (default)

BAUD? RS-232 Baud Rate Query

Input `BAUD?[term]`

Returned Format <bps>[term]
n (refer to command for description)

BEEP Audible Alarm Beeper Command

Input Format `BEEP <state>[term]`
n
<state> 0 = off, audible alarm beeper remains off
1 = on, audible alarm beeper is on when any alarm is active

Remarks Enables or disables system beeper sound when an alarm condition is met

BEEP? Audible Alarm Beeper Query

Input `BEEP?[term]`

Returned Format <state>[term]
n (refer to command for description)

BRIGT Display Brightness Command

Input Format `BRIGT <bright>[term]`
n
<bright> Specifies display brightness: 0 = 25%, 1 = 50%, 2 = 75%, 3 = 100%.

Remarks Sets the brightness for the front panel vacuum fluorescent display.

BRIGT? Display Brightness Query

Input `BRIGT? [term]`
Returned Format <bright>[term]
n (refer to command for description)

CMR Common Mode Reduction Command

Input `CMR<state> [term]`
Format n
<state> 0 = off, 1 = on
Remarks Enables or disables common mode reduction. Applies to only the measurement input of all channels.

CMR? Common Mode Reduction Query

Input `CMR? [term]`
Returned Format <state>[term]
n (refer to command for description)

CRVDEL Curve Delete Command

Input `CRVDEL <curve> [term]`
Format nn
<curve> Specifies a user curve to delete. Valid entries: 21 to 59.
Example **CRVDEL 21[term]**—deletes User Curve 21.

CRVHDR Curve Header Command

Input `CRVHDR <curve>,<name>,<SN>,<format>,<limit value>,<coefficient> [term]`
Format nn,s[15],s[10],n,+nnn.nnn,n

<curve>	Specifies which curve to configure. Valid entries: 21 to 59.
<name>	Specifies curve name. Limited to 15 characters.
<SN>	Specifies the curve serial number. Limited to 10 characters.
<format>	Specifies the curve data format. Valid entries: 3 = Ω/K (linear), 4 = log Ω/K (linear), 7 = Ω/K (cubic spline).
<limit value>	Specifies the curve temperature limit in kelvin.
<coefficient>	Specifies the curves temperature coefficient. Valid entries: 1 = negative, 2 = positive.

Example **CRVHDR 21,"RX-102B","00011134",4,1.5,1[term]**—configures user curve 21 with a name of RX-102B, serial no. 00011134, data format of logohms vs. kelvin using linear interpolation, setpoint limit of 1.5 K, and negative coefficient.
Remarks Configures the user curve header. The coefficient parameter will be calculated automatically based on the first 2 curve datapoints. It is included as a parameter for compatability with the CRVHDR? query. When in 370 emulation mode, the user curves are defined as 1 to 20 for backwards compatibility.

Be sure to use quotes when sending strings, otherwise characters such as spaces and other non alpha-numeric characters will be interpreted as a delimiter, and the full string will not be accepted. It is not recommended to use commas or semi-colons in curve names or serial numbers as these characters are used as delimiters for query responses.

CRVHDR? Curve Header Query

Input `CRVHDR? <curve>[term]`

Format nn

<curve>	Valid entries: 1 to 59.

Returned <name>,<SN>,<format>,<limit value>,<coefficient>[term]

Format s[15],s[10],n,+nnn.nnn,n (refer to command for description)

CRVPT Curve Data Point Command

Input `CRVPT <curve>,<index>,<units value>,<temp value>, (optional)<curvature value>[term]`

Format nn,nnn,+nnn.nnnE±nn,+nnn.nnnE±nn,+nnn.nnnE±nn

<curve>	Specifies which curve to configure. Valid entries: 21 to 59.
<index>	Specifies the points index in the curve. Valid entries: 1 to 200.
<units value>	Specifies sensor units for this point to 6 digits.
<temp value>	Specifies the corresponding temperature in kelvin for this point to 6 digits.
<curvature value>	Specifies the curvature value scale factor used to calculate cubic spline coeffecients to 6 digits.

Remarks Configures a user curve data point. When in 370 emulation mode, the user curves are defined as 1 to 20 for backwards compatibility. The <curvature value> field is only required if the curve point being loaded is used for a cubic spline interpolation curve, and can be omitted when sending linear interpolation curves.

Example **CRVPT 21,2,0.10191,470.000,N [term]**—sets User Curve 21 second data point to 0.10191 sensor units and 470.000 K.

CRVPT? Curve Data Point Query

Input `CRVPT? <curve>,<index>[term]`

Format nn,nnn

<curve>	Specifies which curve to query: 1 to 59.
<index>	Specifies the points index in the curve: 1 to 200.

Returned <units value>,<temp value>,(optional)<curvature value>[term]

Format ±nnn.nnnE±nn,+nnn.nnnE±nn,+nnn.nnnE±nn (refer to command for description)

Remarks Returns a standard or user curve data point. The curvature value is only returned when the curve point being queried is part of a cubic spline curve.

DFLT Factory Defaults Command

Input `DFLT 99[term]`

Remarks Sets all configuration values to factory defaults and resets the instrument. The “99” is included to prevent accidentally setting the unit to defaults.

DISPFLD Custom Mode Display Field Command

Input Format `DISPFLD <field>,<input>,<units> [term]`

n,n,n,n

<field>	Specifies field (display location) to configure: 1 to 8.
<input>	Specifies item to display in the field: 0 = None, 1 = Channel 1, 2 = Channel 2, 3 = Channel 3, 4 = Channel 4, 5 = Channel 5, 6 = Channel 6, 7 = Channel 7, 8 = Channel 8, 9 = Channel 9, 10 = Channel 10, 11 = Channel 11, 12 = Channel 12, 13 = Channel 13, 14 = Channel 14, 15 = Channel 15, 16 = Channel 16, 17 = Active Scan Channel, A = control input A
<units>	Valid entries: 1 = kelvin, 2 = ohms, 3= quadrature (measurement input only) 4 = minimum data, 5 = maximum data, 6 = sensor name

Example **DISPFLD 2,1,1[term]**—displays kelvin reading for measurement input channel 1 in display field 2 when display mode is set to Custom.

Remarks This command only applies to the readings displayed in the Custom display mode. All other display modes have predefined readings in predefined locations, and will use the Preferred Units parameter to determine which units to display for each sensor input. Refer to section 4.3 for details on display setup.

DISPFLD? Custom Mode Display Field Query

Input Format `DISPFLD? <field> [term]`

n

<field>	Specifies field (display location) to query: 1 to 8.

Returned Format <input>,<units> [term]

n,n,n (refer to command for description)

DISPLAY Display Setup Command

Input Format `DISPLAY <mode>,<num fields>,<displayed info>[term]`

n,n,n

<mode>	Specifies display mode: 0 = measurement input, 1 = control input, 2 = Custom
<num fields>	When mode is set to Custom, specifies number of fields (display locations) to display: 0 = 2 large, 1 = 4 large, 2 = 8 small.
<displayed info>	Specifies either the active scan channel or, which output, and associated loop information, to display in the bottom left half of the display screen: 0 = None, 1 = sample heater, 2 = warm-up heater, 3 = Active Scan Channel

Example Example: DISPLAY 3,0,0[term]—set display mode to Custom with two large display fields, and the bottom left of the display to show sample heater control loop information.

Remarks The <num fields> and <displayed info> commands are ignored in all display modes except for Custom. In addition, this command is defined differently if the Model 372 is configured for 370 emulation mode. The Model 370 had only one, custom display mode. Because of this, the DISPLAY command only accepted one parameter, the number of locations to display. Therefore, if the Model 372 is in emulation mode and the DISPLAY command is sent, the display mode will be forced to custom mode and the number of locations to display will be interpreted as follows:

Locations specified	Locations shown
1 or 2	2
3 or 4	4
5, 6, 7, or 8	8

DISPLAY? Display Number Query

Input `DISPLAY? [term]`
Returned Format <mode>,<num fields>,< displayed info>[term]
n,n,n (refer to command for description)
Remarks When in emulation mode, command will simply return the number of locations currently displayed.

DOUT Digital Output Command

Input `DOUT<bit weighting> [term]`
Format nn
<bit weighting> Specifies the manual digital output settings: 0 to 31.

Bit	Bit Weighting	Name
0	1	D1
1	2	D2
2	4	D3
3	8	D4
4	16	D5

Remarks This command is only active if no Model 3716 scanner is installed.
Example **DOUT 21 [term]**-manually sets digital output lines D1, D3, and D5 to logic high and D2 and D4 to logic low.

DOUT? Digital Output Query

Input `DOUT? [term]`
Returned Format <bit weighting>[term]
nn (refer to command for description)

EMUL 370 Emulation Mode

Input `EMUL <state> [term]`
Format n
<state> 0 = off, 1 = on
Remarks The 370 emulation mode provide a means of using the Model 372 in place of a Model 370 in a software controlled system without updating the software. The emulation mode setting only affects remote operation; front panel operation of the Model 372 is not changed. Please reference the Model 370 user's manual for information on the interface commands for those models. For more information on using the emulation modes, see section 5.8.

EMUL? 370 Emulation Mode Query

See command for description.

FILTER Filter Parameter Command

Input Format `FILTER <input/channel>,<off/on>,<settle time>,<window>[term]`
nn,n,nnn,nn

<input/channel>	Specifies which input or channel to configure: A (control input), 1 to 16 (measurement input), 0 = all channels (measurement input).
<off/on>	Specifies the filter operating state: 0 = off or 1 = on.
<settle time>	Specifies filter settle time: 1 to 200 s.
<window>	Specifies what percent of full scale reading limits the filtering function. Reading changes greater than this percentage reset the filter: 1 to 80%.

Example **FILTER 5,1,10,2[term]**—filter channel 5 data through a filter with a settling time of 10 s and a 2% of full scale window.

Remarks When the filter is on and the settle time is zero, the instrument continues to calculate the filtered reading, despite the unfiltered readings being displayed. This feature allows the user to quickly toggle between 0 s and the desired settle time to observe the filtering effects on the reading. See section 4.4.7 for more information

FILTER? Filter Parameter Query

Input Format `FILTER? <input/channel>[term]`
nn

<input/channel>	Specifies input or channel to query: A (CONTROL INPUT), 1 to 16 (measurement input).

Returned Format <off/on >,<settle time>,<window>[term]
n,nnn,nn (refer to command for description)

FREQ Excitation Frequency Command

Input Format `FREQ <input>,<frequency>[term]`
n,n

<input>	Specifies which input to configure: 0 (measurement input), A (control input)
<frequency>	Specifies the instruments excitation frequency. 1 = 9.8 Hz, 2 = 13.7 Hz, 3 = 16.2 Hz, 4 = 11.6 Hz, 5 = 18.2 Hz

Remarks Changes the excitation frequency of the respective input. Takes several seconds to complete. If <input> is not specified, 0 (measurement input) is assumed for backwards compatibility.

FREQ? Excitation Frequency Query

Input Format `FREQ? <input>[term]`
n

<input>	Specifies which input to query: 0 (measurement input), A (control input)

Returned Format <frequency>[term]
n (refer to command for description)

Remarks If <input> is not specified, 0 (measurement input) is assumed for backwards compatibility.

HTR? Heater Output Query

Input `HTR? [term]`

Returned Format <heater value>[term]
±nnn.nnnE± nn

<heater value>	Sample heater output in percent (%) of current or in actual power depending on the heater output selection.

Remarks HTR? applies only to the sample heater. Use AOUT? for the warm-up heater and the analog/still output.

HTRSET Heater Setup Command

Input `HTRSET<output>,<heater resistance>,<heater limit/max current>,<max user current>,<current/power>[term]`

Format n,nnn.nnn,n,+nnn.nnn,n

<output>	Specifies which output to configure: 0 = sample heater, 1 = output 1 (warm-up heater)
<heater resistance>	Sample heater: heater load in ohms 1 to 2,000 Output 1 (warm-up heater): Heater resistance setting: 1 = 25 Ω, 2 = 50 Ω
<max current>	Specifies the maximum heater output current for the warm-up heater Warm-up heater: 0 = User specified, 1 = 0.45 A (5 W at 25 Ω, 10 W at 50 Ω), 2 = 2 = 0.63 A (10 W at 25 Ω)
<max user current>	Specifies the maximum heater output current if max current is set to User Specified (warm-up heater only)
<current/power>	Specifies whether the heater output displays in current or in power. Valid entries: 1 = current, 2 = power.

Remarks Power displays in watts for output 0 sample heater and % full scale for output 1 warm-up heater. When configuring the sample heater, a zero should be passed in for the <max current> and <max user current parameters>.

HTRSET? Heater Setup Query

Input `HTRSET?<output>[term]`

Format n

<output>	Specifies which heater output to query: 0 = sample heater, 1 = output 1 (warm-up heater)

Returned Format <htr resistance>,<max current>,<max user current>,<current/power>[term]
+nnn.nnn,n,+nnn.nnn,n (sample heater)
n,n,+nnn.nnn,n (warm-up heater)

HTRST? Heater Status Query

Input `HTRST? <output>[term]`

Format n

<output>	0 = sample heater, 1 = output 1 (warm-up heater).

Returned Format <error code>[term]
n

<error code>	Heater error code: 0 = no error, 1 = heater open error, 2 = heater short error, 3 = voltage compliance.

Remarks HTRST? only applies to sample heater and output 1 (warm-up heater). If <output> is not specified, 0 (sample heater) is assumed for backwards compatibility.

IEEE — IEEE-488 Interface Parameter Command

Input `IEEE <terminator>,<EOI enable>,<address>[term]`

Format n,n,nn

<terminator>	Optional. Ignored.
<EOI enable>	Optional. Ignored.
<address>	Specifies the IEEE address: 1 to 30. (Address 0 and 31 are reserved.)

Example **IEEE 0,0,4[term]**—after receipt of the current terminator, the instrument responds to address 4.

Remarks The terminator and EOI enabled fields are maintained for backwards compatibility with the Model 370. The Model 372 does not allow for configuration of these fields. Command strings must be terminated with a line feed or using the EOI line.

IEEE? — IEEE-488 Interface Parameter Query

Input `IEEE?[term]`

Returned <address>[term]

Format nn (refer to command for description)

Remarks When emulation mode is enabled, IEEE? Returns <terminator>, <EOI enable>, <address>, where <terminator> = 2 = <LF> and <EOI enable> = 0 = enabled.

INCRV — Input Curve Number Command

`INCRV <input>,<curve number>[term]`

Format a,nn

<input>	Specifies which input or channel to configure: A (control input), 1 to 16 (measurement input channel), 0 (all measurement input channels)
<curve number>	Specifies which curve the input uses. If specified curve type does not match the configured input type, the curve number defaults to 0. Valid entries: 0 = none, 1 to 20 = standard curves, 21 to 59 = user curves.

Remarks Specifies the curve an input uses for temperature conversion. When in 370 emulation mode, the user curves are defined as 1 to 20 for backwards compatibility.

Example **INCRV A,23[term]—**Input A uses User Curve 23 for temperature conversion.

INCRV? — Input Curve Number Query

`INCRV <input/channel>[term]`

Format n

<input/channel>	Specifies which input or channel to configure: A (control input), 1 to 16 (measurement input)

Returned <curve number>[term]

Format nn (refer to command for description)

INNAME Sensor Input Name Command

Input Format `INNAME <input/channel>,<name>[term]`

n,s[15]

<input/channel>	Specifies which input or channel to configure: A (control input), 1 to 16 (measurement input)
<name>	Specifies the name to associate with the sensor input.

Example **INNAME 1,"Sample Space"[term]** — The string "Sample Space" will appear on the front panel display, when possible, to identify the sensor information being displayed.

Remarks Be sure to use quotes when sending strings, otherwise characters such as spaces and other non alpha-numeric characters will be interpreted as a delimiter, and the full string will not be accepted. It is not recommended to use commas or semi-colons in sensor input names as these characters are used as delimiters for query responses.

INNAME? Sensor Input Name Query

Input Format `INNAME? <input>[term]`

a

<input>	Specifies input to query: A to D (D1 to D5 for 3062 option).

Returned Format <name>[term]

s[15] (refer to command for description)

INSET Input Channel Parameter Command

Input Format `INSET <input/channel>,<disabled/enabled>,<dwell>,<pause>,<curve number>,<tempco>[term]`

nn,n,nnn,nnn,nn,n

<input/channel>	Specifies which input or channel to configure: A (control input), 1 to 16 (measurement input), 0 = all channels (measurement input).
<disabled/enabled>	Specifies whether the input/channel is disabled or enabled: 0 = disabled, 1 = enabled.
<dwell>	Specifies a value for the autoscanning dwell time: 1 to 200 s. Not applicable for <input/channel> = A (control input).
<pause>	Specifies a value for the change pause time: 3 to 200 s.
<curve number>	Specifies which curve the channel uses: 0 = no curve, 1 to 59 = standard/user curves.
<tempco>	Sets the temperature coefficient that will be used for temperature control if no curve is selected: 1 = negative, 2 = positive.

Example **INSET 5,1,10,3,0,2[term]** — Enables channel 5 with 10 s autoscan dwell, 3 s pause time, and no curve with a positive temperature coefficient.

Remarks At least one measurement input channel must be enabled. If all are configured to disabled, channel 1 will change to enabled.

INSET? Input Channel Parameter Query

Input Format `INSET? <input/channel>[term]`

nn

<input/channel>	Specifies which input or channel to query: A (control input), 1 to 16 (measurement input).

Returned Format <off/on>,<dwell>,<pause>,<curve number>,<tempco>[term]

n,nnn,nnn,nn,n (refer to command for description)

INTSEL Interface Select Command

Input Format `INTSEL <interface>[term]`

n

<interface> Specifies the remote interface to enable: 0 = USB, 1 = Ethernet, 2 = IEEE-488.

Remarks The Ethernet interface will attempt to configure itself based on the current configuration parameters, which can be set using the NET command. Configuring the Ethernet interface parameters prior to enabling the interface is recommended.

INTSEL? Interface Select Query

Input `INTSEL?[term]`

Returned Format <interface>[term]

n (refer to command for description)

INTYPE Input Setup Command

Input `INTYPE <input/channel>,<mode>,<excitation>,<autorange>,<range>,<cs shunt>,<units>[term]`

Format nn,n,nn,nn,n,n,n

<input/channel> Specifies which input or channel to configure: A = control input, 1 to 16 = measurement input channel, 0 = all measurement input channels

<mode> Sensor excitation mode: measurement input: 0 = Voltage Excitation Mode, 1 = Current Excitation Mode. control input: 1 = Current Excitation

<excitation> Measurement input excitation range number:

Voltage range	Current range
1: 2.00 µV	1: 1.00 pA
2:6.32 µV	2: 3.16 pA
3: 20.0 µV	3: 10.0 pA
4: 63.2 **µV**	4: 31.6 pA
5: 200 **µV**	5: 100 pA
6: 632 **µV**	6: 316 pA
7: 2.0 mV	7: 1.00 nA
8: 6.32 mV	8: 3.16 nA
9*: 20.0 mV	9: 10.0 nA
10*: 63.2 mV	10: 31.6 nA
11*: 200 mV	11: 100 nA
12*: 632 mV	12: 316 nA
	13: 1.00 µA
	14: 3.16 µA
	15: 10.0 µA
	16: 31.6 µA
	17: 100 µA
	18: 316 µA
	19: 1.00 mA
	20: 3.16 mA
	21: 10.0 mA
	22: 31.6 mA

**Ranges not available with the 3708 scanner*

Control input current and implied resistance range number:

Range	Current	Resistance
1	316 pA	632 kΩ
2	1 nA	200 kΩ
3	3.16 nA	63.2 kΩ
4	10 nA	20 kΩ
5	31.6 nA	6.32 kΩ
6	100 nA	2 kΩ

<autorange> 0 = Autorange off, 1 = Autorange Current, 2 = ROX 102B Autorange (only available for control input)

<range> Setting ignored for control input. measurement input resistance range:

Range	Resistance
1	2.0 mΩ
2	6.32 mΩ
3	20.0 mΩ
4	63.2 mΩ
5	200 mΩ
6	632 mΩ
7	2.00 Ω
8	6.32 Ω
9	20.0 Ω
10	63.2 Ω
11	200 Ω
12	632 Ω
13	2.00 kΩ
14	6.32 kΩ
15	20.0 kΩ
16	63.2 kΩ
17	200 kΩ
18	632 kΩ
19	2.00 MΩ
20	6.32 MΩ
21	20.0 MΩ
22	63.2 MΩ

<cs shunt> 0 = current source not shunted, excitation on.
1 = current source shunted, excitation off.

<units> Specifies the preferred units parameter for sensor readings and for the control setpoint: 1 = kelvin, 2 = ohms

Remarks When configuring the control input (A), all parameters must be included, but non-applicable parameters will be ignored.

Example **INTYPE 2,1,10,0,15,0,1[term]—**sets measurement input channel 2 to current excitation mode, 20 kΩ resistance range with a 31.6 nA excitation current, autorange off, excitation on with preferred units of kelvin.

INTYPE? Input Setup Query

Input Format `INTYPE? <input>[term]`
nn
<input/channel> Specifies input to query: A = control input; 1 to 16 = measurement input channel

Returned Format <mode>,<excitation>,<autorange>,<range>,<cs shunt>,<units>[term]
n,nn,n,nn,n,n (refer to command for description)

KRDG? Kelvin Reading Query

Input Format KRDG?<input>[term]
n
<input> Specifies which input to query: A = control input; 1 to 16 = measurement input Channel

Returned Format <kelvin value>[term]
±nnn.nnnE±nn

Remarks Also see the RDGST? query.

LEDS Front Panel LEDs Command

Input Format `LEDS <off/on>[term]`
n
<off/on> 0 = LEDs off, 1 = LEDs on

Remarks If set to 0, front panel LEDs will not be functional. Function can be used when display brightness is a problem.

Example **LED 0[term]**—turns all front panel LED functionality off.

LEDS? Front Panel LEDs Query

Input `LEDS?[term]`

Returned Format <off/on> [term]
n (refer to command for description)

LOCK Keypad Lock Command

Input Format `LOCK <state>,<code>[term]`
n,nnn
<state> 0 = Unlocked, 1 = Locked
<code> Specifies lock-out code. Valid entries are 000 to 999.

Remarks Locks out all front panel entries except pressing the **Alarm** key to silence alarms, or selecting to turn the heater off.

Example **LOCK 1,123[term]**—enables keypad lock and sets the code to 123.

LOCK? Keypad Lock Query

Input `LOCK?[term]`

Returned Format <state>,<code>[term]
n,nnn (refer to command for description)

MDAT? Minimum/Maximum Data Query

Input Format `MDAT? <input/channel>[term]`
nn
<input/channel> Specifies which input or channel to query: A (control input), 1 to 16 (measurement input).

Returned Format <min value>,<max value>[term]
±nnn.nnnE±nn, ±nnn.nnnE±nn

Remarks Returns the minimum and maximum input data. Also see the RDGST? command.

MNMXRST Minimum and Maximum Reset Command

Input `MNMXRST[term]`

Remarks Resets the minimum and maximum data for all channels. Active scan channel will reset immediately, while all other channels will reset with the first valid reading they receive.

MODE IEEE Interface Mode Command

Input Format `MODE <mode>[term]`
n
<mode> 0 = local, 1 = remote, 2 = remote with local lockout.

Example **MODE 2[term]**—places the Model 372 into remote mode with local lockout.

MODE? IEEE Interface Mode Query

Input `MODE?[term]`

Returned Format <mode>[term]
n (refer to command for description)

MONITOR Monitor & Reference Output Selection Command

Input Format `MONITOR <source>[term]`
n
<source> 0 = off, 1 = CS NEG, 2 = CS POS, 3 = VCM NEG, 4 = VCM POS, 5 = VDIF, 6 = VAD-MEASUREMENT, 7 = VAD-CONTROL

Remarks Selects the source of the monitor output. The reference output is off when the monitor is off. In addition, the reference output is set to the measurement input when the monitor is configured for sources 1 to 6, and set to the control input when the monitor is configured for source 7.

MONITOR? Monitor & Reference Output Selection Query

Input `MONITOR?[term]`

Returned Format <source>[term]
n (refer to command for description)

MOUT Manual Heater Output Command

Input `MOUT <output>,<value>[term]`

Format ±nn.nnn

<output>	0 = sample heater, 1 = output 1 (warm-up heater), 2 = output 2 (analog/still)
<value>	Specifies value for manual output in percent current or power, depending on the heater output selection.

Example **MOUT 0,22.45[term]**—sample heater manual output is 22.45% of full scale current.
MOUT 0,1.0E-03[term]—sample heater manual output is 1 mW.

Remarks If <output> is not specified, 0 (sample heater) is assumed for backwards compatibility.

MOUT? Manual Heater Output Query

Input `MOUT? <output>[term]`

Format ±nn.nnn

<output>	0 = sample heater, 1 = output 1 (warm-up heater), 2 = output 2 (analog/still).

Returned Format <value>[term]
+nnn.nnnE±nn (refer to command for description)

Remarks If <output> is not specified, 0 (sample heater) is assumed for backwards compatibility.

NET Network Settings Command

Input
```
NET <DHCP>,<AUTO IP>,<IP>,<Sub Mask>,<Gateway>,
<Pri DNS>,<Sec DNS>,<Pref Host>,<Pref Domain>,
<Description>[term]
```

Format n,n,dd,dd,dd,dd,dd,s[15],s[64],s[32],

<DHCP>	0 = DHCP off, 1=DHCP on.
<AUTO IP>	0 = Dynamically configured link-local addressing (Auto IP) off, 1 = on
<IP>	IP address for static configuration.
<Sub Mask>	Subnet mask for static configuration.
<Gateway>	Gateway address for static configuration.
<Pri DNS>	Primary DNS address for static configuration.
<Sec DNS>	Secondary DNS address for static configuration.
<Pref Host>	Preferred Hostname (15 character maximum)
<Pref Domain>	Preferred Domain name (64 character maximum)
<Description>	Instrument description (32 character maximum)

Remarks Be sure to use quotes when sending strings, otherwise characters such as spaces and other non alpha-numeric characters will be interpreted as a delimiter, and the full string will not be accepted. It is not recommended to use commas or semi-colons in host/domain names or the instrument description as these characters are used as delimiters for query responses.

NET? Network Settings Query

Input `NET?[term]`

Returned <DHCP>,<AUTO IP>,<IP>,<Sub Mask>,<Gateway>,<Pri DNS>,<Sec DNS>,<Pref Host>,<Pref Domain>,<Description>[term]

Format n,n,dd,dd,dd,dd,dd,s[15],s[64],s[32] (refer to command for description)

NETID? Network Configuration Query

Input `NETID? [term]`

Returned <lan status>,<IP>,<sub mask>,<gateway>,<pri DNS>,<sec DNS>,<mac addr>,<actual hostname>,<actual domain>[term]

Format n,dd,dd,dd,dd,dd,hh:hh:hh:hh:hh:hh,s[15],s[32]

<lan status>	Current status of Ethernet connection: 0 = Connected Using Static IP, 1 = Connected Using DHCP, 2 = Connected Using Auto IP, 3 = Address Not Acquired Error, 4 = Duplicate Initial IP Address Error, 5 = Duplicate Ongoing IP Address Error, 6 = Cable Unplugged, 7 = Module Error, 8 = Acquiring Address, 9 = Ethernet Disabled. Refer to section 6.4.2.1 for details on lan status.
<IP>	Configured IP address
<sub mask>	Configured subnet mask
<gateway>	Configured gateway address
<pri DNS>	Configured primary DNS address
<sec DNS>	Configured secondary DNS address
<actual hostname>	Assigned hostname
<actual domain>	Assigned domain
<mac addr>	Module MAC address.

Remarks This query returns the configured Ethernet parameters. If the Ethernet interface is not configured then IP, subnet mask, gateway, primary DNS and secondary DNS parameters will be 0.0.0.0.

OUTMODE Output Mode Command

Input `OUTMODE <output>,<mode>,<input/channel>,<powerup enable>,<polarity>,<filter>,<delay>[term]`

Format n,n,nn,n,n,n,nnn

<output>	Specifies which output to configure: 0 = sample heater, 1 = output 1 (warm-up heater), 2 = output 2 (analog/still).
<mode>	Specifies the control mode. Valid entries:

Mode	Sample heater	Output 1	Output 2
0 = Off	✓	✓	✓
1 = Monitor Out			✓
2 = Open Loop (Manual)	✓	✓	✓
3 = Zone	✓	✓	
4 = Still			✓
5 = Closed Loop (PID)	✓	✓	
6 = Warm up		✓	

TABLE 6-8 ***Valid entries for the control mode***

<input>	Specifies which input or channel to control from: 0 = none, A (control input), 1 to 16 (measurement input).
<powerup enable>	Specifies whether the output remains on or shuts off after power cycle. Valid entries: 0 = powerup enable off, 1 = powerup enable on.
<polarity>	Specifies output polarity: 0 = unipolar, 1 = bipolar. (Not applicable to output 1 warm-up heater.
<filter>	Specifies controlling on unfiltered or filtered readings: 0 = unfiltered, 1 = filtered.
<delay>	Delay in seconds for setpoint change during Autoscanning: 1 to 255.

Remarks The <polarity>, <mode>, <input/channel> parameters are the same as the parameters in the ANALOG command. They are included in both commands for backward compatibility and ease of use. <delay> is used only when <input> is assigned to one of the scanned measurement inputs.

Example **OUTMODE 0,5,A,0,0,1[term]**— The sample heater is configured for unipolar, Closed Loop PID mode, using filtered readings from the control input (A). The output will turn off when the power is cycled.

OUTMODE? Output Mode Query

Input Format `OUTMODE? <output>[term]`
n
<output> Specifies which output to query: 0 to 2.

Returned Format <mode>,<input/channel>,<powerup enable>,<polarity>,<filter>,<delay>[term]
n,nn,n,n,n,nnn (refer to command for description)

PID Closed Loop PID Parameter Command

Input Format `PID <output>,<P value>,<I value>,<D value>[term]`
n,+nnnnnn,+nnnnnn,+nnnnnn
<output> 0 = sample heater, 1 = output 1 (warm-up heater).
<P value> The value for control loop Proportional (gain): 0.0 to 1000.
<I value> The value for control loop Integral (reset): 0 to 10000.
<D value> The value for control loop Derivative (rate): 0 to 2500.

Remarks Setting resolution is less than 6 digits indicated. If <output> is not specified, 0 (sample heater) is assumed for backwards compatibility.

Example **PID 10,100,20,0[term]**— P = 10, I = 100 s, and D = 20 s.

PID? Closed Loop PID Parameter Query

Input Format `PID? <output>[term]`
n
<output> 0 = sample heater, 1 = output 1 (warm-up heater).

Returned Format <P value>,<I value>,<D value>[term]
+nnnnnn,+nnnnnn,+nnnnnn (refer to command for description)

Remarks Setting resolution is less than 6 digits indicated. If <output> is not specified, 0 (sample heater) is assumed for backwards compatibility.

QRDG? Quadrature Reading Query

Input Format `QRDG? <channel>[term]`
nn
<channel> Specifies which measurement input channel to query: 1 to 16

Returned Format <Quadrature value>[term]
±nnn.nnnE±nn

Remarks The quadrature reading is only available on the measurement input. The value returned is the reactive (imaginary) reading in ohms for the given channel.

RAMP Setpoint Ramp Parameter Command

Input Format `RAMP <output>,<off/on>,<rate value>[term]`

n,n,+nnnnn

<output>	0 = sample heater, 1 = output 1 (warm-up heater).
<off/on>	Specifies whether ramping is on or off: 0 = off or 1 = on.
<rate value>	Specifies setpoint ramp rate in k/min from 0.001 to 100. The rate is always positive, but will respond to ramps up or down. A rate of 0 generates an instantaneous (step) set-point change, even when setpoint ramping is turned on.

Example **RAMP 0,1,1.5[term]**—when the sample heater setpoint is changed it ramps to the target at 1.5 K/minute.

Remarks If <output> is not specified, 0 (sample heater) is assumed for backwards compatibility.

RAMP? Setpoint Ramp Parameter Query

Input Format `RAMP? <output>[term]`

n

<output>	0 = sample heater, 1 = output 1 (warm-up heater).

Returned Format <off/on>,<rate value>[term]

n,+nnnnn (refer to command for description)

Remarks If <output> is not specified, 0 (sample heater) is assumed for backwards compatibility.

RAMPST? Setpoint Ramp Status Query

Input Format `RAMPST? <output>[term]`

n

<output>	0 = sample heater, 1 = output 1 (warm-up heater).

Returned Format <ramp status>[term]

n

<ramp status>	0 = Not ramping, 1 = Setpoint is ramping.

Remarks If <output> is not specified, 0 (sample heater) is assumed for backwards compatibility.

RANGE Heater Range Command

Input Format `RANGE <output>,<range>[term]`

n,nn

<output>	Specifies which output to configure: 0 = sample heater, 1 = output 1 (warm-up heater), 2 = output 2 (analog/still)
<range>	sample heater: 0 = off, 1 = 31.6 µA, 2 = 100 µA, 3 = 316 µA, 4 = 1.00 mA, 5 = 3.16 mA, 6 = 10.0 mA, 7 = 31.6 mA, 8 = 100 mA output 1 (warm-up heater), output 2 (analog/still): 0 = off, 1 = on

Remarks The range setting has no effect if an output is in the off mode, and does not apply to an output in monitor out mode. An output in monitor out mode is always on.

RANGE? Heater Range Query

Input Format `RANGE <output>[term]`

n

<output>	Specifies which output to query: 0 = sample heater, 1 = output 1 (warm-up heater), 2 = output 2 (analog/still)

Returned Format <range>[term]

n (refer to command for description)

RDGK? Kelvin Reading Query

Input Format `RDGK? <input/channel>[term]`
nn
<input/channel> Specifies which input or channel to query: A (control input), 1 to 16 (measurement input).

Returned Format <kelvin value>[term]
±nnn.nnnE±nn

Remarks Also see RDGST? If no curve is present for the channel, the returned reading will be zero.

RDGPWR? Excitation Power Reading Query

Input Format `RDGPWR? <input/channel>[term]`
nn
<input/channel> Specifies which input or channel to query: A control input), 1 to 16 (measurement input).

Returned Format <excitation power>[term]
±nnn.nnnE±nn

Remarks Also see RDGST? Returns the most recent power calculation for the specified channel.

RDGR? Resistance Reading Query

Input Format `RDGR? <input/channel>[term]`
nn
<input/channel> Specifies which input or channel to query: A (control input), 1 to 16 (measurement input).

Returned Format <ohm value>[term]
±nnn.nnnE±nn

Remarks Also see the RDGST? command.

RDGST? Input Reading Status Query

Input Format `RDGST? <input/channel>[term]`
nn
<input/channel> Specifies which input or channel to query: A (control input), 1 – 16 (measurement input).

Returned Format <status bit weighting>[term]
nnn

Remarks The integer returned represents the sum of the bit weighting of the status flag bits. A “000” response indicates a valid reading is present. If the channel being queried is not the actively scanning channel, the status will represent the last state prior to the channel change.

Bit	Bit Weighting	Status Indicator
0	1	CS OVL
1	2	VCM OVL
2	4	VMIX OVL
3	8	VDIF OVL
4	16	R. OVER
5	32	R. UNDER
6	64	T. OVER
7	128	T. UNDER

RDGSTL? Reading Settle Status Query

Input `RDGSTL? [term]`

Returned Format <Control input status>,<Active Measurement input Channel Status>[term]
n,n

<status>	0 = Valid, 1 = Firmware Filter Settling, 2 = Hardware Settling

RELAY Relay Parameter Command

Input `RELAY <relay number>,<mode>,<channel alarm>,<alarm type>[term]`

Format n,n,nn,n

<relay number>	Specifies which relay to configure: 1 or 2.
<mode>	Specifies relay mode. 0 = off, 1 = on, 2 = Alarms, 3 = Sample heater zone, 4=Warmup heater zone.
<channel alarm>	Specifies which input or channel alarm activates the relay when the relay is in alarm mode: A (control input), 1 to 16 (measurement input), 0 = scan channel.
<alarm type>	Specifies the channel alarm type that activates the relay when the relay is in alarm mode. 0 = Low alarm, 1 = High Alarm, 2 = Both Alarms.

Example **RELAY 1,2,2,0[term]**—relay 1 is setup in Alarms mode and activates when channel 2 low alarm activates.

RELAY? Relay Parameter Query

Input `RELAY? <relay number>[term]`

Format n

<relay number>	Specifies which relay to query: 1 or 2.

Returned Format <mode>,<channel alarm>,<alarm type>[term]
n,nn,n (refer to command for description)

RELAYST? Relay Status Query

Input `RELAYST? <relay number>[term]`

Format n

<relay number>	Specifies which relay to query: 1 or 2.

Returned Format <status>[term]
n 0 = off, 1 = on.

SCAN Scanner Parameter Command

Input `SCAN<input/channel>,<autoscan>[term]`

Format nn,n

<input/channel>	Specifies which input or channel to switch the scanner to: 1 to 16 (measurement input) (or 1 to 8 if a Model 3708 scanner is installed).
<autoscan>	0 = autoscan feature off, 1 = autoscan feature on

Example **SCAN 5,1[term]** — change the scanner to channel 5 and begin autoscanning.

Remarks This command is only active if an optional scanner is installed.

SCAN? Scanner Parameter Query

Input `SCAN? [term]`

Returned Format <input/channel>,<autoscan>[term]
nn,n (refer to command for description).

SETP — Temperature Control Setpoint Command

Input Format `SETP <output><value>[term]`
n,+nnn.nnnE±nn

<output>	0 = sample heater, 1 = output 1 (warm-up heater)
<value>	The value for the setpoint (in the preferred units of the setpoint).

Example **SETP 1.5[term]**—Setpoint is changed to 1.5 K if preferred units are in kelvin.
SETP 2.0E+03[term]—Setpoint is changed to 2.0 kΩ if preferred units are in ohms.

Remarks If <output> is not specified, 0 (sample heater) is assumed for backwards compatibility.

SETP? — Temperature Control Setpoint Query

Input Format `SETP? <output>[term]`
n

<output>	0 = sample heater, 1 = output 1 (warm-up heater)

Returned Format <value>[term]
+nnn.nnnE±nn

Remarks If <output> is not specified, 0 (sample heater) is assumed for backwards compatibility.

SRDG? — Sensor Reading Query

Input Format SRDG? <input>[term]
n

<input/channel>	Specifies which input or channel to query: A (control input), 1 to 16 (measurement input).

Returned Format <sensor units value>[term]
±nnn.nnnE±nn

Remarks Value returned is always in ohms. Also see the RDGST? command.

STILL — Still Output Command

Input Format `STILL<value>[term]`
±nnnnnn

<value>	Specifies value for the Still output in percent.

Example **STILL 22.45[term]** — Still output is 22.45% of full scale.

Remarks Command is only valid if the analog/still output is properly configured for Still mode.

STILL? — Still Output Query

Input `STILL? [term]`

Returned Format <value>[term]
±nnnnnn (refer to command for description).

TLIMIT — Temperature Limit Command

Input Format `TLIMIT <input/channel>,<limit>[term]`
n,+nnnn

<input/channel>	Specifies which input or channel to configure: A (control input, 1 to 16 (measurement input).
<limit>	The temperature limit in kelvin for which to shut down all control outputs when exceeded. A temperature limit of zero turns the temperature limit feature off for the given sensor input.

TLIMIT? Temperature Limit Query

Input Format `TLIMIT? <input>[term]`

n

<input>	Specifies which input to query: A (control input), 1 to 16 (measurement input).

Returned Format < limit>[term]

+nnnn (refer to command for description)

WARMUP Warmup Mode Parameter Command

Input Format `WARMUP <control>,<percentage>[term]`

n,+nnn.nn

<control>	Specifies the type of control used: 0 = Auto Off, 1 = Continuous
<percentage>	Specifies the percentage of full scale current to apply to turn on the external power supply.

Example **WARMUP 1,50[term]**—The warm-up heater will use the continuous control mode with 50% of full-scale current being applied to the load.

Remarks The output mode parameter and the control input parameter must be configured using the OUTMODE command.

WARMUP? Warmup Mode Parameter Query

Input `WARMUP?`

Returned Format <control>,<percentage>[term]

n,+nnn (refer to command for description)

WEBLOG Website Login Parameters Command

Input Format `WEBLOG <username>,<password>[term]`

s[15],s[15]

<username>	15-character string representing the website username.
<password>	15-character string representing the website password.

Example **WEBLOG "user", "pass"**—sets the username to user and the password to pass.

Remarks Strings can be sent with or without quotation marks, but to send a string that contains spaces, commas, or semi-colons quotation marks must be used to differentiate the actual parameter separator.

WEBLOG? Website Login Parameter Query

Input `WEBLOG?[term]`

Returned Format <username>,<password>[term]

s[15],s[15] (refer to command for description)

Remarks Note that all strings returned by the Model 372 will be padded with spaces to maintain a constant number of characters.

ZONE Control Loop Zone Table Parameter Command

Input

```
ZONE <output>, <zone>, <upper bound>, <P value>, <I value>,
<D value>, <mout value>, <range>, <rate>, <relay 1>, <relay
2>[term]
```

Format

n,nn,+nnn.nnnE±nn,+nnnnnn,+nnnnnn,+nnnnnn,+nnnnnn,n,+nnnnnn,n,n

<output>	Specifies which output to configures: 0 to 1.
<zone>	Specifies which zone in the table to configure: 1–10.
<upper bound>	Specifies the upper setpoint boundary of this zone in kelvin.
<P value>	Specifies the P for this zone: 0.0 to 1000.
<I value>	Specifies the I for this zone: 0 to 10000.
<D value>	Specifies the D for this zone: 0 to 2500.
<mout value>	Specifies the manual output for this zone: 0 to 100%.
<range>	Specifies the heater range for this zone. Sample heater: 0–8. Warm-up heater: 0 to 1. (Refer to RANGE for listing.)
<rate>	Specifies the ramp rate for this zone.
<relay 1>	Specifies relay 1's state: 0 = off, 1 = on. Only applicable when relay is configured in zone mode and the relays control output matches this output.
<relay 2>	Specifies the high relay state: 0 = off, 1 = on. Only applicable when relay is configured in Zone mode and the relays control output matches this output.

Remarks

Configures the control loop limit band parameters used in conjunction with the status byte register. Refer to section 6.2.6. When in Emulation mode, the <rate> parameter is omitted and additional <analog 1> and <analog 2> parameters are returned as +0.0000. Configuring Analog 1 and Analog 2 settings are no longer supported. The OUTMODE command must be used to configure either the sample heater or warm-up heater to zone mode.

Example

ZONE 0,1,250.000E-03,10,20,0,0,2,1.2,0,0[term]—The sample heater zone 1 is valid to 250 mK with P = 10, I = 20, D = 0, a manual out of 0%, and a heater range of 2 and a ramp rate of 1.2 K/min. Both relays will be off.

ZONE? Control Loop Zone Table Parameter Query

Input

```
ZONE? <output>,<zone>[term]
```

Format

n,nn

<output>	Specifies which output to query: 0 to 1.
<zone>	Specifies which zone in the table to query. Valid entries: 1 to 10.

Returned

<upper bound>, <P value>, <I value>, <D value>, <mout value>, <range>, <rate>, <relay 1>, <relay 2> [term]

Format

+nnn.nnnE±nn,+nnnnnn,+nnnnnn,+nnnnnn,±nnnnnn,n,±nnnnnn,n,n
(refer to command for description.)

Chapter 7: Options and Accessories

7.1 General

This chapter provides information on the models, options, and accessories available for the Model 372 AC resistance bridge and temperature controller.

7.2 Models and Kits

The list of Model 372 model numbers is provided as follows:

Model	Description of models
372N	AC resistance bridge and temperature controller. Includes a Lake Shore Model 372 AC resistance bridge only with no scanner. Power is configured as shown in TABLE 7-3.
3726	16-channel scanner with standard 3 m (10 ft) connection cable (Model 372 only)
3726-6	16-channel scanner with 6 m (20 ft) connection cable (Model 372 only)
3726-10	16-channel scanner with 10 m (33 ft) connection cable (Model 372 only)
3708	Ultra-low resistance 8-channel scanner with standard 3 m (10 ft) connection cable
3708-6	Ultra-low resistance 8-channel scanner with 6 m (20 ft) connection cable
3708-10	Ultra-low resistance 8-channel scanner with 10 m (33 ft) connection cable

TABLE 7-1 ***Model description***

The list of Model 372 kit number is provided in TABLE 7-2.

Kits	Description of kits
372S	AC Resistance Bridge with Scanner. Includes a Lake Shore Model 372 AC Resistance Bridge with a Lake Shore Model 3726 16 channel scanner and 3 m (10 ft) cable. Power is configured as shown inTABLE 7-3.
372S-6	AC Resistance Bridge with Scanner. Includes a Lake Shore Model 372 AC Resistance Bridge with a Lake Shore Model 3726 16 channel scanner and 6 m (20 ft) cable. Power is configured as shown inTABLE 7-3.
372S-10	AC Resistance Bridge with Scanner. Includes a Lake Shore Model 372 AC Resistance Bridge with a Lake Shore Model 3726 16 channel scanner and 10 m (33 ft) cable. Power is configured as shown in TABLE 7-3.
372U	AC Resistance Bridge with Scanner. Includes a Lake Shore Model 372 AC Resistance Bridge with a Lake Shore Model 3708 8 channel scanner and 3 m (10 ft) cable. Power is configured as shown in TABLE 7-3.
372U-6	AC Resistance Bridge with Scanner. Includes a Lake Shore Model 372 AC Resistance Bridge with a Lake Shore Model 3708 8 channel scanner and 6 m (20 ft) cable. Power is configured as shown in TABLE 7-3
372U-10	AC Resistance Bridge with Scanner. Includes a Lake Shore Model 372 AC Resistance Bridge with a Lake Shore Model 3708 8 channel scanner and 10 m (33 ft) cable. Power is configured as shown in TABLE 7-3.

TABLE 7-2 ***Kit descriptions***

Power configurations—the instrument is configured at the factory for customer-selected power as follows:

1	100 V-US (NEMA 5-15)
2	120 V-US (NEMA 5-15)
3	220 V-EU (CEE 7/7)
4	240 V-EU (CEE 7/7)
5	240 V-UK (BS 1363)
6	240 V-Swiss (SEV 1011)
7	220 V-China (GB 1002)

TABLE 7-3 ***Power configurations***

7.3 Accessories

Accessories are devices that perform a secondary duty as an aid or refinement to the primary unit. Refer to the Lake Shore Temperature Measurement and Control Catalog for details. A list of accessories available for the Model 372 is as follows.

Accessories (part number)	Description of accessories
G-106-233*†	Sensor input mating connector; 6-pin DIN plug; 3 included
G-106-253†‡	DB-25 plug; 4 included
G-106-264†‡	DB-25 hood; 4 included
106-737*†	Terminal block mating connector; 6-pin terminal block for relays
106-765*†	Terminal block mating connector; 7-pin terminal block for sample heater, warm-up heater, and analog/still output.
107-379†‡	Scanner box mounting bracket; used to mount the 3726 and 3708
G-112-374†	Cable assembly; connects the Model 372 to the optional scanner, 3 m (10 ft) long; FIGURE 7-1
G-112-375†	Cable assembly; connects the Model 372 to the optional scanner, 6 m (20 ft) long; FIGURE 7-1
G-112-376†	Cable assembly; connects the Model 372 to the optional scanner, 10 m (33 ft) long; FIGURE 7-1
117-071	Model 372 heater adapter cable—adapts to Model 370-style BNC
119-372*†	Model 372 AC resistance bridge user's manual
117-017†	IEEE-488 cable; 1 m (3 ft) long IEEE-488 computer interface cable
CAL-372-CERT*†	Instrument calibration/recalibration with certificate
CAL-372-DATA*†	Instrument calibration/recalibration with certificate and data
RM-1	Rack mounting kit; mounting brackets, ears and handles to attach 1 Model 372 to a 482 mm (19 in) rack mount cabinet
ES-2-20	Stycast® Epoxy 2850-FT, Catalyst 9 (20 packets, 2 g each). Stycast® is a common, highly versatile, nonconductive epoxy resin system for cryogenic use. The primary use for Stycast® is for vacuum feedthroughs or permanent thermal anchors. Stycast® is an alternative to Apiezon® N Grease when permanent sensor mountings are desired.
ID-10-XX	Indium solder disks (quantity 10). Indium is a semi-precious non-ferrous metal, softer than lead, and extremely malleable and ductile. It stays soft and workable down to cryogenic temperatures. Indium can be used to create solder "bumps" for microelectronic chip attachments and also as gaskets for pressure and vacuum sealing purposes. ID-10-31 indium disks are 7.92 mm diameter × 0.13 mm (0.312 in diameter × 0.005 in) ID-10-56 indium disks are 14.27 mm diameter × 0.127 mm (0.562 diameter × 0.005 in)
IF-5	Indium foil sheets (quantity 5). When used as a washer between DT-470-CU silicon diode or other temperature sensors and refrigerator cold stages, indium foil increases the thermal contact area and prevents the sensor from detaching due to vibration. It also may be used as a sealing gasket for covers, flanges, and windows in cryogenic applications. Each sheet is 0.13 mm × 51 mm × 51 mm (0.005 in × 2 in × 2 in).
GAH-25	Apiezon® H grease, 25 g tube. It is designed for general purposes where operating temperatures necessitate the use of a relatively high melting point grease. Melting point is 523 K (250 °C). Can be removed using Xylene with an isopropyl alcohol rinse.
GAN-25	Apiezon® N grease, 25 g tube. General purpose grease well-suited for cryogenic use because of its low viscosity. It is often used as a means of thermally anchoring cryogenic sensors as well as lubricating joints and o-rings. Contains high molecular weight polymeric hydrocarbon additive that gives it a tenacious, rubbery consistency allowing the grease to form a cushion between mating surfaces. Melting point is 316 K (43 °C). Can be removed using Xylene with an isopropyl alcohol rinse.
VGE-7031	IMI-7031 varnish (formerly GE 7031 varnish) (1 pint can). IMI-7031 insulating varnish and adhesive possesses electrical and bonding properties that, when combined with its chemical resistance and good saturating properties, make it an excellent material for cryogenic temperatures. As an adhesive, IMI-7031 bonds a variety of materials, has fast tack time, and may be air dried or baked. It is also an electrically insulating adhesive at cryogenic temperatures and is often used as a calorimeter cement. When soaked into cigarette paper, it makes a good, high thermal conductivity, low electrical conductivity heat sinking layer. Maximum operating temperature: 423 K (150 °C).
Wire	Lake Shore cryogenic wire. Lake Shore sells the following types of cryogenic wire: DT = Duo-Twist, MN = Single Strand, MW = Manganin, NC = Nichrome Heater, ND = Heavy Duty, QL = Quad-Lead™, and QT = Quad-Twist™. Lake Shore coaxial cable. Lake Shore sells the following types of coaxial cable: CC = Ultra Miniature Coaxial Cable, SR = Semi-Rigid Coaxial Cable, CRYC = CryoCable™.

** Accessories included with a new Model 372*
† RoHS compliant
†‡ Accessories included with a new 3708 or 3726 scanner

TABLE 7-4

FIGURE 7-1 ***Cable assembly to connect Model 372 to optional scanner***

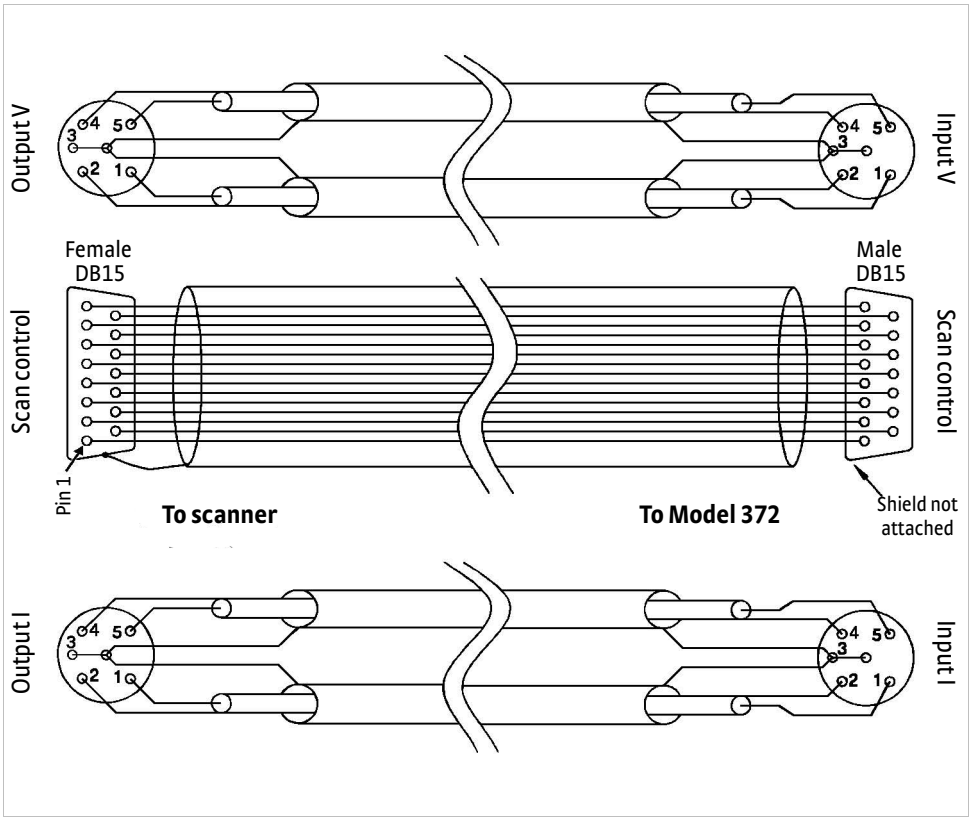


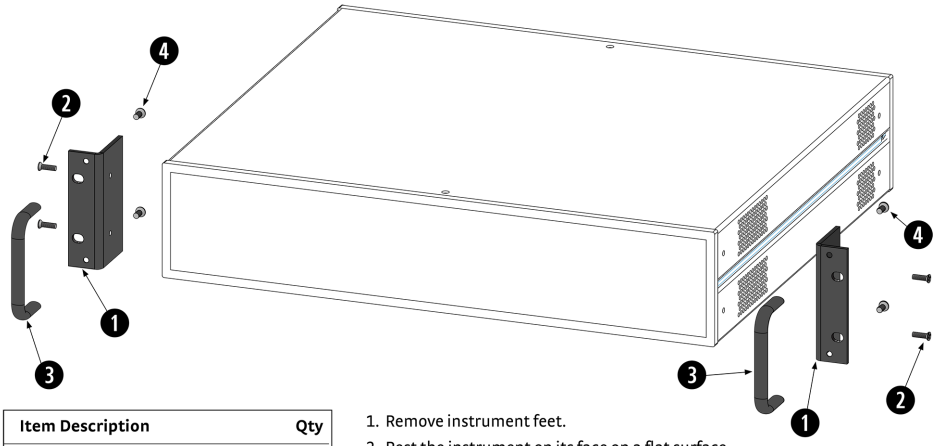
FIGURE 7-2 ***Scan control***

7.4 Rack Mounting

The Model 372 can be installed into a 483 mm (19 in) rack mount cabinet using the optional Lake Shore Model RM-1 rack mount kit. The kit contains the necessary parts that adapt the front of the instrument to fit into a 88.9 mm (3.5 in) tall, full rack space. See https://www.lakeshore.com/rack-kit/ for full details.

NOTE

Ensure that there is a 25 mm (1 in) clearance on both sides of the instrument after rack mounting.



Item	Description	Qty
❶	Rack mount ear	2
❷	Screw, 6-32 × 0.5 in FHM Phillips	4
❸	Rack handles	2
❹	Screw, 8-32 × 0.38 in FHM Phillips	4

1. Remove instrument feet.
2. Rest the instrument on its face on a flat surface.
3. Remove the front screws from the sides of the instrument and retain for future use, if the rack kit is ever removed.
4. Use the supplied 6-32 screws ❷ to attach the rack mount ears to the sides of the instrument.
5. Use the supplied 8-32 screws ❹ to attach the rack handles ❸ to the rack mount ears ❶.

FIGURE 7-3 ***Model RM-1 rack mount kit***

Chapter 8: Service

8.1 General

This chapter provides basic service information for the Model 372 AC resistance bridge and temperature controller. Customer service of the product is limited to the information presented in this chapter. Lake Shore trained service personnel should be consulted if the instrument requires repair.

8.2 USB Troubleshooting

This section provides USB interface troubleshooting for issues that arise with new installations, existing installations, and intermittent lockups.

8.2.1 New Installation

1. Check that the instrument's interface is set to USB.
2. Check that the USB driver is installed properly and that the device is functioning. In Microsoft Windows®, the device status can be checked using Device Manager by right-clicking **Lake Shore Model 372 AC Resistance Bridge and Temperature Controller** under **Ports** (COM & LPT) or **Other Devices** and then clicking **Properties**. Refer to section 6.3.3 for details on installing the USB driver.
3. Check that the correct com port is being used. In Microsoft Windows®, the com port number can be checked using Device Manager under **Ports** (COM & LPT).
4. Check that the correct settings are being used for communication. Refer to section 6.3.3 for details on installing the USB driver.
5. Check cable connections and length.
6. Send the message terminator.
7. Send the entire message string at one time including the terminator. (Many terminal emulation programs do not.)
8. Send only one simple command at a time until communication is established.
9. Be sure to spell commands correctly and use proper syntax.

8.2.2 Existing Installation No Longer Working

1. Power the instrument off, then on again to see if it is a soft failure.
2. Power the computer off, then on again to see if communication port is locked up.
3. Check all cable connections.
4. Check that the com port assignment has not been changed. In Microsoft Windows®, the com port number can be checked using Device Manager under **Ports** (COM & LPT).
5. Check that the USB driver is installed properly and that the device is functioning. In Microsoft Windows®, the device status can be checked using Device Manager by right-clicking **Lake Shore Model 372 AC Resistance Bridge and Temperature Controller** under **Ports** (COM & LPT) or Other Devices and then clicking **Properties**.

8.2.3 Intermittent Lockups

1. Check cable connections and length.
2. Increase the delay between all commands to 100 ms to make sure the instrument is not being overloaded.
3. Ensure that the USB cable is not unplugged and that the Model 372 is not powered down while the com port is open. The USB driver creates a com port when the USB connection is detected, and removes the com port when the USB connection is no longer detected. Removing the com port while in use by software can cause the software to lock up or crash.

8.3 IEEE Interface Troubleshooting

This section provides IEEE interface troubleshooting for issues that arise with new installations, old installations, and intermittent lockups.

8.3.1 New Installation

1. Check the instrument address.
2. Always send a message terminator.
3. Send the entire message string at one time including the terminator.
4. Send only one simple command at a time until communication is established.
5. Be sure to spell commands correctly and use proper syntax.
6. Attempt both Talk and Listen functions. If one works but not the other, the hardware connection is working, so look at syntax, terminator, and command format.

8.3.2 Existing Installation No Longer Working

1. Power the instrument off, then on again to see if it is a soft failure.
2. Power the computer off then on again to see if the IEEE card is locked up.
3. Verify that the address has not been changed on the instrument during a memory reset.
4. Check all cable connections.

8.3.3 Intermittent Lockups

1. Check cable connections and length.
2. Increase the delay between all commands to 50 ms to make sure the instrument is not being overloaded.

8.4 Fuse Drawer

The fuse drawer supplied with the Model 372 holds the instrument line fuses and line voltage selection module. The drawer holds two 5 mm × 20 mm (0.2 in × 0.79 in) time delay fuses. It requires two good fuses of the same rating to operate safely.
Refer to Section 8.6 for details.

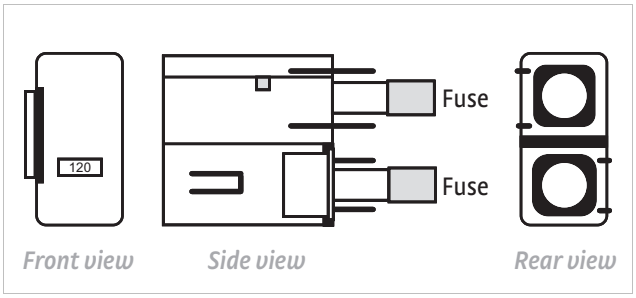


FIGURE 8-1 ***Fuse drawer***

8.5 Line Voltage Selection

Use the following procedure to change the instrument line voltage selector.

WARNING **To avoid potentially lethal shocks, turn off the controller and disconnect it from AC power before performing these procedures.**

1. Identify the line input assembly on the instrument rear panel. See FIGURE 8-2.
2. Turn the line power switch OFF (O).
3. Remove the instrument power cord.
4. With a small screwdriver, release the drawer holding the line voltage selector and fuse.
5. Slide out the removable plastic fuse holder from the drawer.
6. Rotate the fuse holder until the proper voltage indicator shows through the window.
7. Re-assemble the line input assembly in the reverse order.
8. Verify the voltage indicator in the window of the line input assembly.
9. Connect the instrument power cord.
10. Turn the line power switch On (I) Refer to FIGURE 8-2.

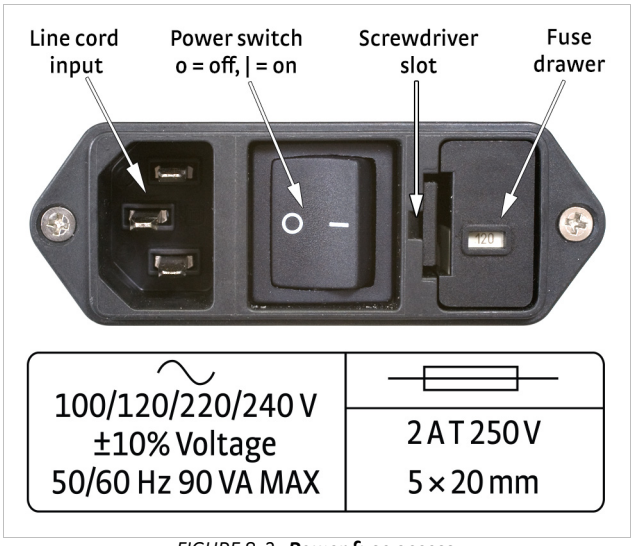


FIGURE 8-2 ***Power fuse access***

8.6 Fuse Replacement

Use this procedure to remove and replace a line fuse.

WARNING **To avoid potentially lethal shocks, turn off controller and disconnect it from AC power before performing these procedures.**

CAUTION **For continued protection against fire hazard, replace only with the same fuse type and rating specified for the line voltage selected.**

NOTE **Test fuse with an ohmmeter. Do not rely on visual inspection of fuse.**

1. Locate the line input assembly on the instrument rear panel. See FIGURE 8-2.
2. Turn the power switch OFF (O).
3. Remove the instrument power cord.
4. With a small screwdriver, release the drawer holding the line voltage selector and fuse.
5. Remove existing fuse(s). Replace with proper slow-blow (time-delay) fuse ratings as follows:

100/120 V/220/240 V	2 A T 250 V	5 × 20 mm

6. Re-assemble the line input assembly in reverse order.
7. Verify voltage indicator in the line input assembly window.
8. Connect the instrument power cord.
9. Turn the power switch ON (I).

8.7 Factory Reset Menu

It is sometimes necessary to reset instrument parameter values or clear the contents of curve memory. Both are stored in nonvolatile memory called NOVRAM, but they can be cleared individually. Instrument calibration is not affected.

8.7.1 Default Values

The factory defaults can be reset, and the user curves cleared, using the Factory Reset menu. To access the Factory Reset menu, press and hold the **Escape** key for 5 s. Once the menu appears, set either Reset to Defaults or Clear Curves, or both, to Yes, then highlight Execute and press **Enter**.

Input setup – general	Default
Input enabled	Enabled
Autorange	Off
Change pause	3 s
Curve	None
Filter	Off
Temperature coefficient	Negative
Temperature Limit	0 K
Preferred units	Sensor
Input setup – input A	**Default**
Range	10 nA (20 kΩ)
Input name	Input A
Input setup – measurement input	**Default**
Excitation mode	Voltage
Excitation	200 µV
Resistance Range	200 kΩ
Scanner dwell time	10 s
Input name	Channel (1 to 16)
Sample heater output setup	**Default**
Output mode	Off
Control input	Input A
Control Filter	Off
Heater resistance	100 Ω
Polarity	Unipolar
Power up enable	Off
Heater output display	Current
Setpoint ramping	Off
Setpoint change pause time	25 s
Warm-up heater output setup	**Default**
Output mode	Off
Control Input	None
Control filter	Off
Heater resistance	25 Ω
Maximum current	0.63 A
Power up enable	Off
Heater output display	Current
Setpoint ramping	Off
Setpoint change pause time	25 s
Display setup	**Default**
Display mode	Measurement input
Brightness	50%
Displayed output	Sample heater
Interface setup – general	**Default**
Enabled	USB
Baud	57,600
Emulation mode	None

Interface setup – IEEE	Default
IEEE address	12
Interface setup – Ethernet	**Default**
DHCP	On
Auto-IP	Off
Static-IP	192.168.0.12
Static subnet mask	255.255.255.0
Static gateway	192.168.0.1
Static primary DNS	0.0.0.0
Static secondary DNS	0.0.0.0
Preferred hostname	LSCI-372
Web username	user
Web password	—
Alarm	**Default**
Alarm	Off
Relay	**Default**
Relay	Off
Keypad locking	**Default**
Mode	Unlocked
Lock code	123
PID/manual heater power (MHO) ouptu	**Default**
Proportional (P)	10.0
Integral (I)	20.0
Derivative (D)	0.0
Manual output	0.000%
Heater	**Default**
Heater range	Off
Setpoint	**Default**
Setpoint value	0.000 K
Remote/local	**Default**
Remote/Local	Local
Zone settings – all zones	**Default**
Upper boundary	0.000 K
Proportional (P)	10.0
Integral (I)	20.0
Derivative (D)	0.0
Manual output	0.000%
Range	Off
Ramp rate	0.0 K/min
Instrument setup	**Default**
Measurement input frequency	13.7 Hz
Control input frequency	16.2 Hz
Common mode reduction	On
Monitor output	Off

TABLE 8-1 ***Default values***

8.7.2 Product Information

Product information for your instrument is also found in the Factory Reset menu. The following information is provided:

- Firmware version
- Firmware date
- Serial number
- Scanner type
- Ethernet version
- Board revision

8.8 Error Messages

The following are error messages that may be displayed by the Model 372 during operation.

Message	Description
CS_OVL	Measurement input current source overload possibly caused by a broken current source lead.
VCM_OVL	Measurement input common mode overload at the first amplifier stage of the voltage input.
VDIF OVL	Overload at the differential amplifier stage of the measurement input voltage input.
VMIX OVL	Overload at the mixer (phase sensitive detector) stage of the measurement input voltage input.
R.OVER	Input is at or over full-scale sensor units.
R.UNDER	Input is at or under negative full-scale sensor units.
T.OVER	Input at or over the high end of the curve.
T.UNDER	Input at or under the low end of the curve.
DISABLED	Input is disabled. Refer to section 4.4.
NOCURV	Input has no curve.Refer to section 4.4.12.
Cannot Communicate with Input DSP	The main microprocessor has lost communication with the sensor input DSP.
A temperature limit has been exceeded	The temperature reading on a sensor input has exceeded the Temperature Limit setting. A detailed message will follow, which includes a reference to which sensor inputs temperature limit has been exceeded.
***** Keypad Locked *****	An attempt has been made to change a parameter while the keypad is locked. Refer to section 4.8.
***** Heater Short Circuit Detected *****	A short circuit condition has been observed on the warm-up heater output. A detailed message will follow. The output will be turned off when this occurs.
***** Heater Open Circuit Detected *****	An open circuit condition has been observed on the warm-up heater output. A detailed message will follow. The output will be turned off when this occurs.
***** Invalid Calibration *****	The calibration memory is either corrupt, or is at the default, uncalibrated state. This message appears when the Model 372 is first powered on. To clear the message, and continue with instrument start-up, press the Escape and Enter keys simultaneously.
***** Firmware Update in Progress *****	The Model 372 is in firmware update mode.
*****Output not configured for still*****	The **Still Output** shortcut key has been pressed and the analog/still output is not configured for still mode.

TABLE 8-2 ***Error messages***

8.9 Calibration Procedure

Instrument calibration can be obtained through Lake Shore Service. Refer to section 8.14 for technical inquiries and contact information.

8.10 Rear Panel Connector Definition

The measurement input, control input, heater terminal block, relay terminal block, USB, Ethernet, IEEE-488 connector, and scan control are defined in FIGURE 8-3 through FIGURE 8-9.

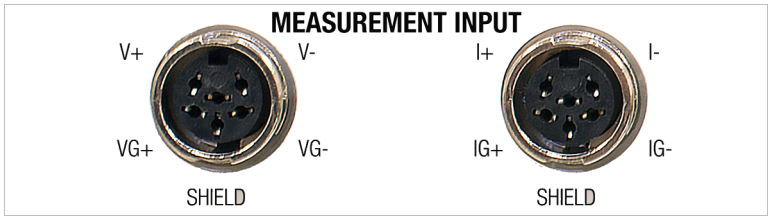


FIGURE 8-3 ***Measurement input***

Pin	Voltage connector		Current connector	
1	V –	Voltage –	I –	Current –
2	VG –	Voltage guard –	IG –	Current guard –
3	SHIELD	Shield	SHIELD	Shield
4	VG +	Voltage guard +	IG +	Current guard +
5	V +	Voltage +	I +	Current +
6	None	Not used	None	Not used

TABLE 8-3 ***Measurement input connector details***

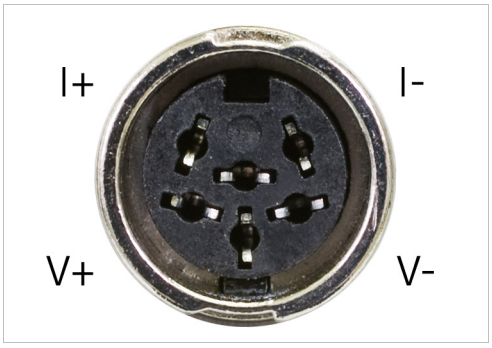


FIGURE 8-4 ***Control input***

Pin	Symbol	Description
1	I–	–Current
2	V–	–Voltage
3	None	Shield
4	V+	+Voltage
5	I+	+Current
6	None	Shield

TABLE 8-4 ***Control input connector details***

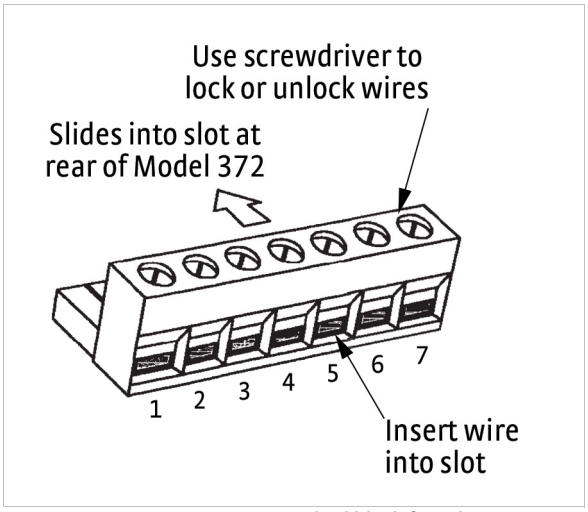


FIGURE 8-5 ***Heater terminal block for relays and Output 3 and 4***

Pin	Description
1	Sample heater +
2	Sample heater –
3	Analog out (still heater) +
4	Analog out (still heater) –
5	Not used (floating)
6	Warm-up heater +
7	Warm-up heater –

TABLE 8-5 ***Heater terminal block pin and connector details***

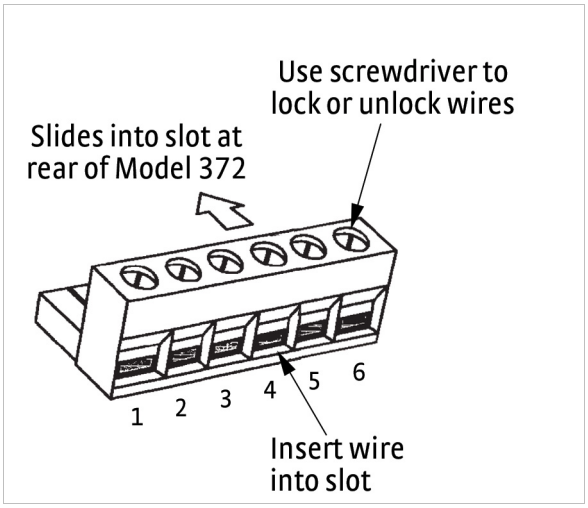


FIGURE 8-6 ***Relay terminal block for relays and Output 3 and 4***

Pin	Description
1	Relay 1 normally open
2	Relay 1 common
3	Relay 1 normally closed
4	Relay 2 normally open
5	Relay 2 normally closed
6	Relay 2 normally closed

TABLE 8-6 ***Relay terminal block pin and connector details***

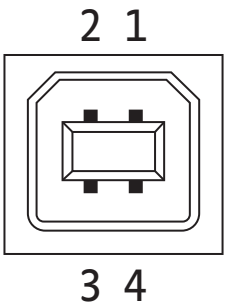


FIGURE 8-7 ***USB pin and connector details***

Pin	Name	Description
1	VCC	+5 VDC
2	D-	Data –
3	D+	Data +
4	GND	Ground

TABLE 8-7 ***USB pin and connector details***

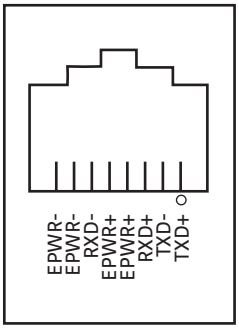


FIGURE 8-8 ***Ethernet pin and connector details***

Pin	Symbol	Description
1	TXD+	Transmit data+
2	TXD-	Transmit data-
3	RXD+	Receive data+
4	EPWR+	Power from switch+ (not used)
5	EPWR+	Power from switch+ (not used)
6	RXD-	Receive data-
7	EPWR-	Power from switch- (not used)
8	EPWR-	Power from switch- (not used)

TABLE 8-8 ***Ethernet pin and connector details***

8.10.1 IEEE-488 Interface Connector

Connect to the IEEE-488 Interface connector on the Model 372 rear panel with cables specified in the IEEE-488 standard. The cable has 24 conductors with an outer shield. The connectors are 24-way Amphenol 57 Series (or equivalent) with piggyback receptacles to allow daisy chaining in multiple device systems. The connectors are secured in the receptacles by 2 captive locking screws with metric threads.

The total length of cable allowed in a system is 2 m (6.6 ft) for each device on the bus, or 20 m maximum. The Model 372 can drive a bus of up to 10 devices. A connector extender is required to use the IEEE-488 interface and relay terminal block at the same time. FIGURE 8-9 shows the IEEE-488 interface connector pin location and signal names as viewed from the Model 372 rear panel.

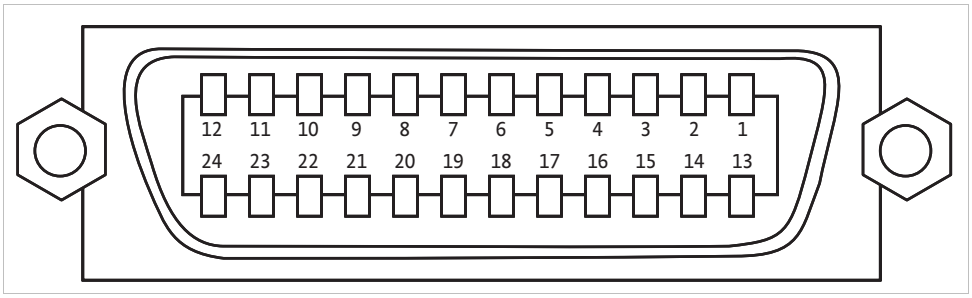


FIGURE 8-9 ***IEEE-488 interface***

Pin	Symbol	Description
1	DIO 1	Data input/output line 1
2	DIO 2	Data input/output line 2
3	DIO 3	Data input/output line 3
4	DIO 4	Data input/output line 4
5	EOI	End or identify
6	DAV	Data valid
7	NRFD	Not ready for data
8	NDAC	No data accepted
9	IFC	Interface clear
10	SRQ	Service request
11	ATN	Attention
12	SHIELD	Cable shield
13	DIO 5	Data input/output line 5
14	DIO 6	Data input/output line 6
15	DIO 7	Data input/output line 7
16	DIO 8	Data input/output line 8
17	REN	Remote enable
18	GND 6	Ground wire—twisted pair with DAV
19	GND 7	Ground wire—twisted pair with NRFD
20	GND 8	Ground wire—twisted pair with NDAC
21	GND 9	Ground wire—twisted pair with IFC
22	GND 10	Ground wire—twisted pair with SRQ
23	GND 11	Ground wire—twisted pair with ATN
24	GND	Logic ground

TABLE 8-9 ***IEEE-488 rear panel connector details***

8.10.2 Scan Control

The scan control is shown in FIGURE 8-10 and defined in TABLE 8-10.

FIGURE 8-10 ***Scan control***

Pin	Name	Description
1	Scan present	Signal to Model 372 that a scanner is installed
2	Digital common	Common or ground for digital control signals
3	Digital common	
4	Unused	—
5	Analog common	Common or ground for analog signals
6		
7		
8	–15 V	–15 V
9	Scan 1	Scan channel select line 1
10	Scan 2	Scan channel select line 2
11	Scan 3	Scan channel select line 3
12	Scan 4	Scan channel select line 4
13	Scan gain	Selects scanner gain of 1 or 100
14	+5 V	+5 V referenced to scanner digital common
15	+15 V	+15 V referenced to scanner analog common
Body	Chassis	Do not use

TABLE 8-10 ***Scan control connector details***

8.11 Firmware Updates

This section provides instructions on updating your firmware. It also provides a table of the updates that have been made thus far.

8.11.1 Updating the Firmware

Periodically, Lake Shore provides updates to instrument firmware and Ethernet firmware. The files for these updates can be downloaded from our website. To access the firmware updates, follow this procedure:

1. Go to http://www.lakeshore.com/products/ac-resistance-bridges/model-372/Pages/Overview.aspx to download the instrument and Ethernet firmware.
2. Enter your name and email address so that we can keep you updated on any new firmware for your instrument.
3. Click the "Go to the download" bar and follow the prompts that are provided.

8.11.2 Record of Updates Made to the Firmware

TABLE 8-11 describes the updates made to the Model 372 firmware, by version.

Instrument firmware version	Features added
1.2	Support for cubic spline interpolation Two new excitation frequencies (11.6 Hz and 18.2 Hz) for both inputs

TABLE 8-11 ***Model 372 firmware releases***

8.12 Analog Signal Troubleshooting

It is likely through the course of installation and usage that the Model 372 will meet conditions that cannot yield a valid resistance reading. These conditions can usually be traced to environmental noise or misapplied measurement parameters. The instrument has been designed with features to simplify diagnosis of problems arising from these sources.

8.12.1 Overload Monitoring

At all times, there are three analog circuit areas of interest monitored by the firmware of the instrument to ensure that the measurement signals stay within useful limits. If any signal exceeds its limit, a descriptive overload message is displayed. An explanation of the error messages and likely causes follows.

8.12.1.1 CSOVL (Current Source Overload — Measurement Input Only)

This message is displayed in the measurement input display field anytime the current source drive signal(s) into the current sample resistor(s) exceeds a 10 V peak limit. The overload can occur at either "CSPOS" or "CSNEG" points in the current source circuit. Refer to FIGURE 8-3 for the location of "CSPOS" and "CSNEG" monitoring points. The signal voltage at either monitoring point can be viewed on an oscilloscope by using the monitor output described in section 4.5.3.

Usual causes of this error include:

- An attempt to measure a resistance that is much greater (3 orders of magnitude) than the selected range.
- An open connection of the current drive leads (I+ and/or I–).

To resolve this condition, first verify that a reasonable resistance range has been selected for the measurement. Next, verify the integrity of current lead connections to the measured resistance.

8.12.1.2 VCM OVL (Common Mode Overload — Measurement Input Only)

Even though differential mode noise may be fully under control by using twisted leads and appropriate shielding, it is still possible to have enough common-mode noise coupled to the measurement leads to exceed the common mode voltage limits of the input instrumentation amplifier. If the combination of signal and common-mode noise components exceeds 10 V peak, the common-mode overload error (VCM

OVL) is displayed. The overload can occur at either “VCMPOS” or “VCNEG” points in the instrumentation amplifier circuit. Refer to FIGURE 8-3 for the location of “VCM-POS” and “VCNEG” monitoring points. The signal voltage at either monitoring point can be viewed on an oscilloscope by using the monitor output described in section 4.5.3.

Usual causes for this error include:

- Improperly shielded measurement leads.
- An improperly grounded Dewar case.

To resolve this condition, first verify that the experimental Dewar case is properly connected to the instrument measurement common and earth ground (section 3.5.5). Next, verify the integrity of the measurement lead shields. Use of the Common Mode Reduction (CMR) feature of the Model 372 reduces this effect electronically. It is particularly effective at excitation currents above 1 μA.

8.12.1.3 VDIF OVL (Differential Overload — Measurement Input Only)

The input stage of the voltage measurement side of the measurement input is a very high input impedance instrumentation amplifier with a high gain of 1000 (10 at voltage excitations of 20 mV and above). If the combination of signal and differential noise components cause the output of this stage to exceed 10 V peak, the differential overload error (VDIF OVL) is displayed. The overload occurs at the “VDIF” point in the instrumentation amplifier circuit. Refer to FIGURE 8-3 for the location of the “VDIF” monitoring point. The signal voltage can be viewed on an oscilloscope by using the monitor output described in section 4.5.3.

Usual causes of this error include:

- An attempt to measure a resistance that is much greater (2 orders of magnitude) than the selected range.
- An open connection of one or both of the voltage measurement leads.
- Significant differential noise on current and/or voltage leads.

To resolve this condition, first verify that a reasonable resistance range has been selected for the measurement. Next, verify the integrity of the voltage lead connections to the measured resistance. If the error persists, verify that the voltage pair of leads is twisted and shielded. Likewise, the current pair of leads should be twisted and shielded. Twisted pair wiring reduces the differential signals potentially created by environmental noise. However, there is no advantage gained by twisting the current pair of leads together with the voltage pair of leads. When twisted leads are not an option (inside a Dewar), the shielding must be verified adequate for the task. The Dewar itself can act as a shield when the case is properly connected. Ensure that the experimental Dewar case is properly connected to the measurement common of the instrument and earth ground. Refer to Installation section 3.5.5.

8.12.1.4 VMIX OVL (Mixer Overload — Measurement Input Only)

Between the instrumentation amplifier section and the ADC sampling and lock-in portion of the DSP phase sensitive detector are several gain stages. If the combination of signal and all differential noise components cause the input to the ADC to exceed 10 V peak, the DSP detects this and informs the main microprocessor to display mixer overload error. Refer to FIGURE 8-3 for the location of the "VMIX" generation point. This is likely to be the most common error message displayed. It is not uncommon to see this error temporarily when changing measurement parameters.

Usual causes for this error are include:

- A temporary transient during current, voltage or range change.
- An attempt to measure a resistance that is greater (1 order of magnitude) than the selected range.
- A differential noise level that is lower than the "VDIF" overload level but high enough after the gain stages to exceed the dynamic range of the phase-sensitive detector.

To resolve this condition, first verify that a reasonable resistance range has been selected for the measurement. Next, verify the integrity of the voltage lead connections to the measured resistance. If the error persists, verify that the voltage pair of leads is twisted and shielded. Likewise, the current pair of leads should be twisted and shielded. Twisted pair wiring reduces the differential signals potentially created by environmental noise. However, there is no advantage gained by twisting the current pair of leads together with the voltage pair of leads. When twisted leads are not an option (inside a Dewar), the shielding must be verified adequate for the task. The Dewar itself acts as a shield when the case is properly connected. Ensure that the experimental Dewar case is properly connected to the measurement common of the instrument and earth ground. Refer to Installation section 3.5.5.

8.12.1.5 R OVER (Range Over)

On both the measurement and control inputs, the analog signals are gained up in a manner that full scale resistance is presented as 2V RMS at the ADC. This message indicates that the selected resistance range is lower than that required for the measured resistance. To resolve the condition, simply increase the resistance range.

8.12.1.6 R UNDER (Range Under)

This message indicates two simultaneous problems:

- Either the current leads or the voltage leads are reversed in the + and – sense.
- The selected range is lower than that required for the measured resistance. To resolve the condition, correct the sensor wiring and increase the resistance range as needed.

NOTE

As a test, just increasing the resistance range will remove the error message but a "negative" resistance will be displayed.

8.12.2 Signal Level Troubleshooting

The Model 372 provides user access to all the error monitoring points in the circuit for troubleshooting convenience. Access to these points is provided through the diagnostic monitor output BNC connector on the back of the instrument. To select the desired monitoring point, refer to section 4.7.4 (Monitor Output Voltages). The reference output provides an excellent way to trigger the oscilloscope when looking at the measurement AC signal in the presence of noise. Note that the reference output signal follows the input signal that is presented on the diagnostic monitor output BNC connector. For example, if the monitor output is configured for the control input ADC, the control input reference frequency will be presented on the reference output. Otherwise, the measurement input reference frequency will be presented on the reference output.

Be aware that the attachment of an earth-grounded oscilloscope to the monitor and/or reference output jacks may induce ground loop related noise into the system that is not normally present. Conversely, it is also possible that the addition of the grounding path through the oscilloscope may actually quiet an improperly grounded system. If in doubt, a differential input to the oscilloscope should be used. A battery-operated oscilloscope is another option.

8.12.2.1 Nominal Signal Levels

For the measurement input, measuring a 100 kΩ "balanced" (or floating) resistor at a voltage excitation of 632 mV and a resistance range of 200 kΩ, with CMR on, the following AC sine-wave signals will be observed at the appropriate signal points:

CSPOS	4.8 VAC Peak
CSNEG	4.8 VAC Peak
VCMPOS	0.228 VAC Peak
VCMNEG	0.228 VAC Peak
VDIF	4.5 VAC Peak
Measurement Input ADC	1 VAC Peak
OFF	No signal

TABLE 8-12 ***Nominal signal levels***

For the control input, when measuring a 10 kΩ "balanced" resistor with a current excitation of 10nA (20 kΩ resistance range), 1 VAC Peak can be observed on the monitor output when it is configured for the control input ADC.

The given levels may vary by 1 or 2%. At the above levels, the observed sine wave should be very clean and noise free. These signal levels are representative of a "balanced" resistance measurement. For the measurement input, if one side of the measured resistance is common to measurement common, large deviations from these voltages will be seen. Also, be reminded that CMR must be turned off in that condition for an accurate measurement.

As excitation is reduced, environmental noise will be seen on the signals. At voltage excitations below 200 µV, the measurement signal levels at CSPOS, CSNEG, VCMPOS and VCMNEG get small enough that a common oscilloscope my not adequately see the measurement signal. However, common mode noise may be quite visible on the CSPOS and CSNEG signals.

8.12.2.2 Noise Signals

In actual installation, the monitor output can be used to determine the character of offending noise. Observed signals will include the measurement or control input signal and any noise signals combined. Front panel selection (refer to section 4.5.3) allows monitoring of different points along the analog circuit path. The following describes noise characteristics backing up through the measurement circuit from the most processed signal to the least processed signal.

The measurement input VAD signal is the output of the input voltage gain stages circuit and is the signal that is directly sampled by the DSP via analog to digital converter for digital processing and display. DSP processing includes phase sensitive detection, rectification, and application of low-pass filter (TC = 0.5 s) so the fundamental excitation frequency (and harmonics) along with any 50/60 Hz. related signals and other noise signals are greatly attenuated. Any DC offset at this point is subtracted in the DSP. This means that a small DC voltage offset (several mV or so) may be present at this monitoring point. An AC sine measurement voltage exceeding +2.50 VRMS triggers an "R. OVER" message. Bear in mind that this signal is capable of going negative, directly indicating a reversal of current or voltage leads to the measured resistor. A "negative" resistance display will occur in this condition. An AC sine measurement voltage exceeding -2.50 VRMS (in the negative direction) triggers an "R. UNDER" message.

The measurement input VDIF monitor point is taken ahead of the gain and passband sections. This point allows broadband monitoring for all differential sources of noise that are impressed across the measured resistor including higher frequencies that the passband filter attenuated. These frequencies might be computer generated, power harmonic related or even radio frequencies (<1 MHz.). Signals observed at this point are differential in nature and impressed across the measured resistor, possibly heating it. A level exceeding 10 V peak at this point triggers a "VDIF OVL" message.

Common-mode voltage can be observed at the CMPOS and CMNEG monitoring points. The normal signal level is very small at these points and may not be easily observed when measuring at low excitations. Although the Model 372 largely ignores common-mode noise, there may be a large enough signal to cause a problem. If a "VCM OVL" message is displayed, the signal character of the offending noise can be observed and verified gone after repair. This is usually due to poor shielding and/or grounding as discussed in section 3.4. A level exceeding 10 V peak at these points triggers a "VCM OVL" message.

The current source drive to the current sampling resistors of the current source section can be observed using CSPOS and CSNEG monitor points. This signal shows predominately the controlling sine wave signal applied to the current sampling resistors, but will also give good insight into common-mode noise voltages that are reflected back through the current source. A level exceeding 10 V peak at these points triggers a "CS OVL" message.

As with the measurement input, the control input VAD signal is the output of the control input voltage gain stages circuit and is the signal that is directly sampled by the DSP via analog to digital converter for digital processing and display. DSP processing includes phase sensitive detection, rectification, and application of low-pass filter (TC = 0.5 s) so the fundamental excitation frequency (and harmonics) along with any 50/60 Hz related signals and other noise signals are greatly attenuated. Any DC offset at this point is subtracted in the DSP. This means that a small DC voltage offset (several mV or so) may be present at this monitoring point. An AC sine measurement volt-

age exceeding +2.50 VRMS triggers an “R. OVER” message. Bear in mind that this signal is capable of going negative, directly indicating a reversal of current or voltage leads to the measured resistor. A “negative” resistance display will occur in this condition. An AC sine measurement voltage exceeding -2.50 VRMS (in the negative direction) triggers an “R. UNDER” message.

8.12.2.3 Phase Relationship

The design of the Model 372 includes a phase sensitive detector algorithm implemented inside the DSP that uses a reference signal directly derived from its oscillator to demodulate the voltage signal from the measured resistor. The reference signal is brought out to the back of the instrument next to the monitor jack. The phase relationship of these two signals is critical to the accuracy of the measurement. Common installations at resistance levels of 100 K or less are not likely to have difficulty with the phase relationship of the two signals. As resistance and/or cable length increases so should concern for this relationship. Cable capacitance is the single biggest cause of this error (refer to section 2.6.6).

To complement the generated quadrature (reactive) reading, the Model 372 has a means to observe the phase shift caused by cable capacitance by observing the VAD monitor point and comparing it against the Reference output. The Reference output can either be used to sync an oscilloscope for observation of the VAD signal or the two signals can be x-y plotted to observe the aperture width of the pattern as an indicator of phase. A simple application of the feature is the observation of phase improvement by the use of driven guards on the measurement leads.

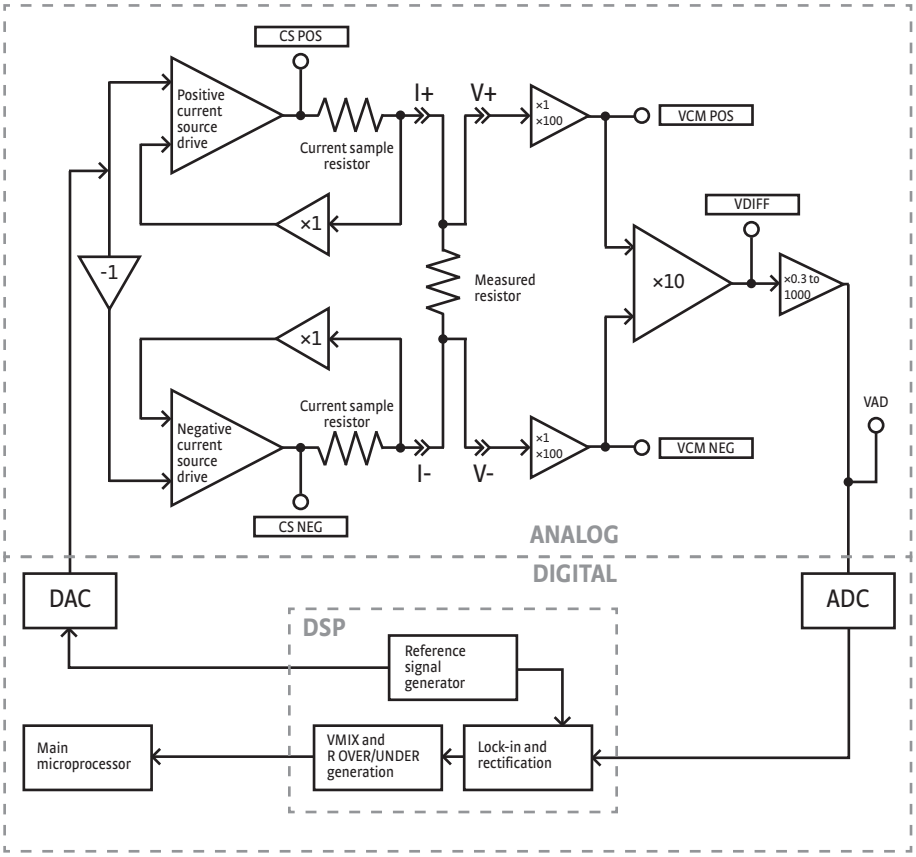


FIGURE 8-11 ***Signal flow***

8.13 Summary of Internal Memory Devices

This section outlines the internal memory devices used inside the Model 372 AC resistance bridge and temperature controller, and provides an explanation of the types of data they contain.

Printed circuit board	Manufacturer	Part number	Description	Location	Function	Volatility	Field modifiable
	Dallas/Maxim	DS89C450	Microprocessor	U17	Main processor code	Non-volatile	Yes
	Texas Instruments	TMS320C5515	DSP	U1	Input processor	Volatile	Yes
	Microchip	24FC512	64 K EEPROM	U91	Input processor code	Non-volatile	Yes
	Cypress	CY14E256LA	32 K NOVRAM	U19	Instrument settings, temporary calibration data	Non-volatile	Yes
	Cypress	CY14E256LA	32 K NOVRAM	U91	Auxiliary NOVRAM for future use, unused at this time	Non-volatile	Yes
	Microchip	24FC1025	128 K EEPROM	U24	Standard curves, calibration data	Non-volatile	Yes
	Microchip	24FC1025	128 K EEPROM	U22	User curves	Non-volatile	Yes
	Digi	DC-ME4-01T-C	4 MB FLASH	U33	Ethernet module firmware, utilities, files	Non-volatile	Yes

TABLE 6-13 ***Summary of internal memory devices***

1. The Dallas/Maxim DS89C450 is a microprocessor with 64k of onboard programmable code memory. The code is loaded using the USB interface.
2. The Texas Instruments TMS320C5515 is a DSP that handles the input readings. It does not have any non-volatile memory in it. This chip is on a daughter card mounted to the main board.
3. The Microchip 24FC512 at location U91 on the daughter card is used to store the code for the DSP processor. The code is loaded using the USB interface to the main processor then to the DSP.
4. The Cypress CY14E256LA at U19 is used to store the instrument settings and temporary curve data. This memory can be reset to default values from the front panel using the Factory Reset menu accessible by pressing and holding the **Escape** key.
5. The Cypress CY14E256LA at U91 was added in case we needed more storage later. We never used this memory for anything.
6. The Microchip 24FC1025 at location U24 is used to store the standard curves, and the instrument calibration data. This data can only be modified by using the computer interface (USB, Ethernet, or IEEE-488).
7. The Microchip 24FC1025 at location U22 is used to store the user curves. This memory can be reset to default values from the front panel using the Factory Reset menu, accessible by pressing and holding the **Escape** key.
8. The Digi DC-ME4-01T-C is a module used to add Ethernet network capability. Included on the module is 4 MB of flash memory used to store the firmware image that runs on the module, as well as the utility applications and supporting files provided on the embedded website. The embedded applications only store data to the host computer. No data from these applications is stored to the embedded flash memory. There is a firmware image log file that is used for debugging purposes stored on the flash memory. There are also small .xml files that contain the most recent hostname and IP address information. All flash memory can be reset to default values by re-loading the Ethernet firmware via the Ethernet interface.

8.14 Technical Inquiries

Refer to the following sections when contacting Lake Shore for application assistance or product service. Questions regarding product applications, price, availability and shipments should be directed to sales. Questions regarding instrument calibration or repair should be directed to instrument service. Do not return a product to Lake Shore without a Return Material Authorization (RMA) number (section 8.14.2).

8.14.1 Contacting Lake Shore

The Lake Shore Technical Support Department is staffed Monday through Friday between the hours of 8:00 AM and 5:00 PM EST, excluding holidays and company shut down days.

The Lake Shore Forum is also a great place to look for solutions, to post issues, and to share successes: http://forums.lakeshore.com/.

Contact Lake Shore Technical Support through any of the means listed below. However, the most direct and efficient means of contacting is to complete the online service request form at https://www.lakeshore.com/support/. Provide a detailed description of the problem and the required contact information. You will receive a response within 24 hours or the next business day in the event of weekends or holidays

Mailing address	Lake Shore Cryotronics Instrument Service Department 575 McCorkle Blvd. Westerville, Ohio USA 43082-8888	
E-mail address	sales@lakeshore.com support@lakeshore.com	Sales Instrument Service
Telephone	614-891-2244 614-891-2243 select the option for Service	Sales Instrument Service
Fax	614-818-1600 614-818-1609	Sales Instrument Service
Web service request	http://www.lakeshore.com/support/	Instrument Service

TABLE 8-14 ***Contact information***

8.14.2 Return of Equipment

The Model 372 AC resistance bridge and temperature controller is packaged to protect it during shipment.

NOTE

The user should retain any shipping carton(s) in which equipment is originally received, in the event that any equipment needs to be returned.

If the original packaging is not available, a minimum of 76 mm (3 in) of shock absorbent packing material should be placed snugly on all sides of the instrument in a sturdy corrugated cardboard box. After receiving your Model 372 AC resistance bridge and temperature controller, please use reasonable care when removing the temperature controller from its protective packaging and inspect it carefully for damage. If it shows any sign of damage, please file a claim with the carrier immediately. Do not destroy the shipping container; it will be required by the carrier as evidence to support claims. Call Lake Shore for return and repair instructions.

All equipment returns must be approved by a member of the Lake Shore Service Department. The service engineer will use the information provided in the service request form and will issue an RMA. This number is necessary for all returned equipment. It must be clearly indicated on both the shipping carton(s) and any correspondence relating to the shipment. Once the RMA has been approved, you will receive appropriate documents and instructions for shipping the equipment to Lake Shore.

8.14.3 RMA Valid Period

RMAs are valid for 60 days from issuance; however, we suggest that equipment needing repair be shipped to Lake Shore within 30 days after the RMA has been issued. You will be contacted if we do not receive the equipment within 30 days after the RMA is issued. The RMA will be canceled if we do not receive the equipment after 60 days.

8.14.4 Shipping Charges

All shipments to Lake Shore are to be made prepaid by the customer. Equipment serviced under warranty will be returned prepaid by Lake Shore. Equipment serviced out-of-warranty will be returned FOB Lake Shore.

8.14.5 Restocking Fee

Lake Shore reserves the right to charge a restocking fee for items returned for exchange or reimbursement.