The model 54 is a next generation four-channel cryogenic impedance bridge capable of measuring resistance, inductance and mutual-inductance from milli-ohms to meg-ohms. Additionally, four control loop outputs support use as a cryogenic temperature controller.

Highlights of the Model 54:

- Four independent input channels, each capable of measuring resistance, mutual-inductance or inductance. Supported sensors include diode, resistance and mutual-inductance devices.
- Operation from <50mK to over 1,000K with an appropriate sensor.
- Expandable to 28 inputs by use of an Ethernet based distributed instrument connection.
- Four Control Loops add high accuracy temperature control.
- Large color display with capacitive touchscreen and full keypad.
- Industrial grade security: Configurable internal firewall, HTTPS encryption and authentication.

Applications:

Ultra-Low Temperature Thermometry
- He3 refrigerators, some Dilution Refrigerators and ADRs.
- Each input supports resistor, diode and mutual-inductance temperature sensors.
- Step-less differential mode sine-wave excitation with constant-voltage settings down to 10\(\mu\)V.
- Easily expandable to 28 independent, non-multiplexed input channels via use of the Ethernet interface.
- High precision heater outputs for excellent control stability.

Material Science
- Resistance, inductance and mutual-inductance measurement.
- Low resistance measurement.

Distributed instrumentation / Computer controller
- Secure Ethernet communications.
- Remote command language is IEEE-488 SCPI compliant, protects your system software from obsolescence.
- LabView™ drivers for all remote interfaces.
- Built-in Embedded EPICS CA server supports large scale distributed instrumentation networks.

General purpose laboratory
- Cryogenic bridge measures resistance, inductance and mutual-inductance.
- Four inputs expandable to 28.
- Four independent control loops.
**Cryogenic Impedance Bridge**

Each of the four input channels of the Model 54 is fabricated using a Cryo-con proprietary signal processing chip that measures impedance by use of an auto-balancing, ratiometric AC bridge. Here, advanced signal processing functions are built into a digital signal processor thereby replacing large amounts of analog circuitry with higher precision and more sophisticated digital algorithms. Impedance measurement in cryogenic systems often requires low level excitation followed by precision signal recovery. To implement this, the Model 54 uses a differential voltage-mode excitation scheme followed by bi-phase lock-in detection.

Differential mode excitation prevents electrical noise pickup currents from flowing through the sensor and the use of passive attenuation reduces the output impedance of the bridge. To further reduce noise, sine-wave excitation is used with user programmable frequencies.

The Model 54 performs signal recovery by first co-sampling excitation voltages and currents. The AC signal vector is then recovered by use of dual bi-phase lock-in detectors.

**Cryogenic Thermometry**

**Negative-Temperature-Coefficient** (NTC) resistors are often used as low temperature thermometers, especially at ultra-low temperature. Examples include Ruthenium-oxide, Carbon-Glass, Cernox™, Carbon-Ceramic, Germanium and several others. The Model 54 provides robust support for these sensors by using constant-voltage AC excitation. Since NTC sensors have high resistance at low temperature, measurement errors can be introduced by the lead capacitance in the sensor connections. The Model 54 eliminates this error by recovering the complete AC signal vector and eliminating the capacitance component.

Another source of error at ultra-low temperature is sensor self-heating due to DC offsets produced by the measurement electronics. The Model 54 measures the DC offset of the excitation current flowing through the sensor then actively tracks and cancels it.

Ultra-low temperature measurements can be negatively affected by coarse steps in sensor excitation current. The Model 54 prevents this by using a step-less, continuously variable excitation source. Since the excitation current is measured to higher accuracy than it can be set, precision is maintained, even with a continuously variable source.

**Positive Temperature Coefficient** (PTC) resistor temperature sensors use the bridge in a passive excitation mode where a selected excitation is set and remains relatively constant over the entire measurement range.

**Silicon diode** sensors are also supported. This is done by switching out AC bridge functions and providing a 10µA DC constant-current excitation mode.

**Conversion to Temperature:** The Model 54 includes built-in sensor calibration curves that support most industrial temperature sensors. Additionally, eight user calibration curves are available for custom or calibrated sensors. For all sensor types, conversion from a sensor reading into temperature is performed by using a Cubic Spline interpolation algorithm. In addition to providing higher accuracy than conventional linear interpolation, the spline function eliminates discontinuities during temperature ramps or sweeps by ensuring that the first and second derivatives are continuous.

**Inductance and Mutual Inductance Measurement**

The Model 54’s bridge circuits are based on bi-phase lock-in detection, therefore, inductance and mutual-inductance measurements can be made to high accuracy. The mutual-inductance based CMN temperature sensors used in MilliKelvin thermometry are directly supported.

Since the Model 54 has four identical and independent inputs, any mix of mutual-inductance, diode or resistance sensors can be used without the need for synchronization of the excitation signals.

**Low Resistance Measurement**

The Model 54 can accurately measure resistance down to less than 0.01Ω. Both R and ΔR measurements are available.

**User Interface**

The Model 54’s user interface is based on a large, high resolution color graphics display with an integrated capacitive touchscreen plus a full 20-key keypad. Optionally, a USB keyboard or mouse may be used.

The Home screen projects four user configurable zones that allow the real-time display of all input channel, control loop and instrument status information. From this screen, accessing any of the instrument’s configuration menus requires only a single key press.

Configuration menus are designed to show real-time status information so the user can instantly view the results of any changes made.
Four Temperature Control Loops
To support flexible cryogenic temperature control applications, the Model 54 has four independent control loops.

The **Loop #1** heater output is a linear, low noise current source. Four full-scale ranges are available from 75W down to 500mW. **Loop #2** is a three-range linear heater that will provide 10, 1.0 or 0.1-Watts full scale. **Loop #3** is linear heater with an output 1.0W. **Loop #4** is a non-powered voltage output.

**Control stability** on each loop is enhanced by the use of an over-sample-plus-dither algorithm that increases output resolution well beyond the limit of the output quantizer.

All control loops are completely independent and any loop may be controlled by any sensor input. Control modes are Manual, PID, Ramp, PID Table and Ramp Table.

![Control Loop Diagram](image)

The field proven **Autotune** function of the Model 54 involves the use of a specific output waveform to first develop a process model, then generate the optimum P, I and D coefficients.

**PID tables** are available that can be used to store optimum control parameters vs. point temperature. Each entry of a PID table contains a setpoint, a control input, PID values and a heater output range setting. When the point is changed, the controller will automatically generate new PID values, a controlling input channel and heater range.

**Cryostat Protection**
Damage to a cryostat or critical sample is a serious problem with any cryogenic system. The Model 54’s Over Temperature Disconnect feature will disable the heater if an over temperature condition exists on any selected input channel. The Maximum Setpoint feature is used to prevent the user from inadvertently entering a higher point than the equipment can tolerate and a Maximum Power Limit will ensure that the controller can never exceed heater power output above the set limit.

Additionally, a fail-safe feature disconnects a control loop when the temperature on it's controlling input is outside a user specified window.

**Alarms and Relays**
Two 10A dry-contact relay outputs can be asserted based on temperature setpoints from user selected input channels.

Visual, remote and audible alarms are supported. Each may be programmed to assert or clear based on temperature setpoints. Alarms may be latched. These are asserted on an alarm condition and will remain asserted until cleared by the user.

**Lowest Noise**
Since the Model 54 was designed for use in the extremely low noise environments it's shielding and grounding scheme effectively reduces or eliminates both radiated and conducted electrical noise. The grounding scheme facilitates the establishment of a single-point-ground that is essential to the elimination power-line and low frequency noise pickup. This ground reference point is usually taken from the instrument's earth ground connection but users may alternatively select an external reference. Radiated RF noise pickup is reduced by a shielding scheme that allows the construction of a complete RFI shield around the instrument and cryostat.

**Remote Control**
Standard Remote Interfaces are Ethernet and a USB serial port emulator. An electrically isolated IEEE-488.2(GPIB) interface is optional.

Two USBA interfaces support memory sticks for data logging. They also support an external keyboard or mouse. The TCP data port server brings fast Ethernet connectivity to data acquisition software including LabView™. Remote interfaces implement an IEEE-488.2 SCPI compliant remote command language that is easy to read. LabView™ drivers are available for all remote interfaces.

**Virtual Inputs**
The Model 54 can be expanded up to 28 input channels by connecting up to three Cryo-con 18i, 14i or 12i temperature monitors to the Ethernet remote interface. Once connected, these virtual inputs appear to the Model 54 as additional inputs. They can be used for temperature control, relays etc.

A Publish-Subscribe interface is used to communicate with remote monitors. Here, the monitors publish input channel data and the Model 54 subscribes.

Virtual input channels are updated in parallel at the full 15Hz rate of the monitors. There is no sequencing or multiplexing.
**Web 2.0 Server**
Using either standard HTTP or encrypted and secure HTTPS, the Model 54’s embedded web server provides complete instrument control and configuration without the need for external platform-dependent support software.

Instrument status can be viewed in real-time and configured from any web browser. Strip-charts of temperature measurements and control loop outputs are displayed in real-time.

Additionally, custom sensor calibration curves in various formats may be uploaded or downloaded. Data-logging files may be downloaded in .csv format.

**EPICS CA Server**
The Experimental Physics and Industrial Control System (EPICS) is a set of open source software tools that are used to create distributed real-time control systems for large scale scientific and industrial applications.

To support these applications, the Model 54 implements an embedded Channel Access server based on EPICS R3.15.

**Firmware updates**
Full instrument firmware updates may be installed by using the Ethernet connection. Cryo-con provides firmware updates, on request, via e-mail. They are free of charge and generally include enhancements and new features as well as problem fixes.

**User Programmable**
The Model 54 can be programmed by the user using the IPython scripting language. All functions of the instrument are available to the programming interface and are executed as standard remote commands.

Python is a common and robust scripting language that includes conditional execution, loops and time delays.

Scripts use an internal data socket to communicate with the Model 54, but external data sockets are also supported. Therefore, scripts can be written to communicate and control any external Ethernet connected device.
Rear Panel Connections

- **Input Connectors**: 6-pin circular snap-in recepticals provide 4-wire measurement connection plus a continuous shield.
- **Loop #1**: 50-Watt heater output. 3 pin detachable terminal block.
- **Loop #2**: 10-Watt heater, part of a 10 pin detachable terminal block.
- **Loop #3**: 1.0-Watt heater, part of a 10 pin detachable terminal block.
- **Loop #4**: 10 / 5.0-Volt output. Detachable terminal block.
- **Relay #1 and #2**: Relay N.O. Contacts.
- **Ethernet / 2x USB A**: RJ-45 with LAN activity indicator LEDs, USBA for external memory, mouse or keyboard.
- **USBB**: Serial Port Emulator.
- **AC Power**: RFI filtered Power Entry Module including fuse drawer and line voltage selector.

Ordering Information

<table>
<thead>
<tr>
<th>Product</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model 54</td>
<td>Four channel cryogenic impedance bridge with four temperature control loops. Includes: User's Manual, four input connectors, heater connector, terminal block plug, detachable power cord and a certificate of calibration. Specify AC Line Voltage or required power cord when ordering (may be changed in the field):</td>
</tr>
<tr>
<td>-100</td>
<td>Configured for 90 - 100VAC with detachable USA power cord.</td>
</tr>
<tr>
<td>-120</td>
<td>Configured for 110 - 120VAC with detachable USA power cord.</td>
</tr>
<tr>
<td>-230</td>
<td>Configured for 220 - 230VAC with detachable universal Euro (Shuko) line cord.</td>
</tr>
<tr>
<td>-240</td>
<td>Configured for 240VAC with detachable universal Euro (Shuko) line cord.</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Accessories</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>4026-016</td>
<td>Additional input connector kit consisting of four 6-pin circular input connectors.</td>
</tr>
<tr>
<td>4026-018</td>
<td>Additional output connector kit consisting of a 3-pin heater connector and a 10-pin terminal block receptacle.</td>
</tr>
<tr>
<td>4122-030</td>
<td>Single instrument 2U rack mount kit.</td>
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</table>

Input Performance

<table>
<thead>
<tr>
<th>Temperature Sensors / Inductance</th>
<th>Diodes</th>
<th>PTC resistors</th>
<th>Inductance</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Input Configuration</strong></td>
<td>Constant-Current DC</td>
<td>Passive AC Bridge</td>
<td>Constant-Voltage AC Bridge</td>
</tr>
<tr>
<td><strong>Input Range</strong></td>
<td>2.25V</td>
<td>1.0mA: 0.1 - 500Ω, 100µA: 1.0K - 5.0KΩ</td>
<td>Min: &lt;10µH, Max: 85mH</td>
</tr>
<tr>
<td><strong>Accuracy</strong>: % Rdg</td>
<td>0.005% ± 80µV</td>
<td>100Ω: 0.01% ± 0.004Ω, 1KΩ: 0.02% ± 0.04Ω</td>
<td>0.05% ± 0.04%</td>
</tr>
<tr>
<td><strong>Resolution</strong>: % Range</td>
<td>10µV</td>
<td>0.0003%</td>
<td>0.003%</td>
</tr>
<tr>
<td><strong>Excitation</strong></td>
<td>10µA DC, 1.0mA, 100µA</td>
<td>100µV</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>C-V Resistance Measurement Resolution</th>
<th>Range</th>
<th>10mV</th>
<th>1.0mV</th>
<th>100µV</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>0.01Ω</strong></td>
<td>10mA 50µΩ</td>
<td>1.0mA 50µΩ</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>0.1Ω</strong></td>
<td>15µΩ</td>
<td>1.0mA 70µΩ</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>1.0Ω</strong></td>
<td>10mA 10µΩ</td>
<td>100µA 70µΩ</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>10.0Ω</strong></td>
<td>100µA 41µΩ</td>
<td>10µA 390µΩ</td>
<td></td>
<td></td>
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<tr>
<td><strong>100.0Ω</strong></td>
<td>1000µA 100µA</td>
<td>1.0µA 28mΩ</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>1000Ω</strong></td>
<td>2mΩ</td>
<td>1.0µA 40mΩ</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>10000Ω</strong></td>
<td>10mΩ 25mΩ</td>
<td>100mA 640mΩ</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>100000Ω</strong></td>
<td>100µA 350mΩ</td>
<td>10nA 150Ω</td>
<td></td>
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</tbody>
</table>
Specifications

User Interface
Display Type: 800x480 color graphics TFT LCD with a capacitive touchscreen.
Keypad: Sealed Silicon Rubber.
Input Channels
There are four input channels, each of which may be independently configured for any of the supported sensor types.
Sensor Connection: 4-wire differential, 6-pin snap-in connector.
Sensor Types: Resistance, mutual-inductance, diode.
Bridge type: Auto balancing ratiometric AC impedance bridge.
Bridge Modes: Constant Voltage or Constant-Current.
Excitation: 12 to 30Hz differential sine-wave.
Voltage Levels: 10mV to 10µV. Maximum excitation current: 10mA, minimum is 1.0mA.
DC Offset: <1nA by active cancellation.
Input Sample Rate: 256Hz per channel.
Signal Processor Functions: Sinewave generation, 4x parallel bi-phase lock-in detection, clipping and noise detection.
Measurement Drift: 15ppm/°C. <10Ω. or >10KΩ: 30ppm/°C.
Isolation: Input channel circuits are electrically isolated from all other internal circuitry but not from each other.
Measurement Filter: 0.5, 1, 2, 4, 8, 16, 32 and 64 Seconds.
Calibration Curves: Built-in curves for industry standard sensors plus eight user curves with up to 200 entries each. Interpolation is performed using a Cubic Spline.

Control Outputs
Number of Independent Control Loops: Four.
Control Input: Any local or remote input.
Loop Update Rate: 1.024kHz per loop with signal dither to extend the dynamic range of the output quantizer.
Isolation: Control loop circuitry is referenced to chassis ground.
Control Type: PID table, Enhanced PID, Ramp or Manual.
PID Tables: Six user PID tables available for storage of setpoint and heater range vs. PID and heater range. 16 entries/table.
Set-point Accuracy: Six+ significant digits.
Fault Monitors: Control loops are disconnected upon detection of a control sensor fault or excessive internal temperature.
Over Temperature Disconnect: Heater may be relay disconnected from user equipment when a specified temperature is exceeded on any selected input.

Loop #1 Control Output
Short circuit protected linear current source.
Ranges: Four output ranges of 75W into 25Ω or 50W, 5.0W and 0.5W into 50Ω.
Resolution: 24 bits.
Readbacks: Heater output current, voltage, heatsink temperature.
Connection: Detachable terminal block.

Loop #2 Control Output
Short circuit protected linear current source.
Ranges: Three output ranges of 10W, 1.0W and 0.1W into 50Ω.
Resolution: 24 bits.
Readbacks: Heater output power, Heatsink temperature.
Connection: Detachable terminal block.

Loop #3 Control Output
Short circuit protected linear current source.
Output: 1.0W into a 100Ω load.
Resolution: 24 bits.
Connection: Detachable terminal block.

Loop #4 Analog Output
Voltage outputs that can be configured as control loops or scaled analog outputs.
Output: zero to 10 / 5.0-Volts. Output impedance: ~2,000Ω.
Resolution: 24 bits.
Connection: Detachable terminal block.

Status Outputs
Audible and Visual Alarms: Independent audible remote and visual alarms.
Relays: Two dry-contact relays. N.O. contacts available. Ratings are 125VAC @ 10A. Maximum switching power: 150W.

Remote Interfaces
Maximum reading rate for all interfaces: 40 rdg/s.
Ethernet: Connects to any Ethernet Local Area Network. Electrically isolated. TCP/IP server provides remote control by using an ASCII command language. HTTP and HTTPS provide built-in web server. SMTP sends e-mail based on alarm conditions. Built-in firewall.
USBB: Serial port emulator. 2x USB: External memory sticks, mouse, keyboard.
IEEE-488.2 (GPIB): External Option, field installable. Electrically isolated.

Firmware
Instrument firmware can be updated in the field via the Ethernet connection. Firmware updates are available via the Internet free of charge.

Architecture
Microprocessor: 32-bit ARM9, 450Mhz.
OS: Embedded Linux, Kernel version 4.5.
Signal Processor: Cryo-con proprietary implementation using a Field Programmable Gate Array.

General
Ambient Temperature: 25°C ± 5°C for specified accuracy.
Mechanical: 8.5"W x 3.5"H x 12"D. One half-width 2U rack. Instrument bail standard, rack mount kits optional.
Weight: 9 Lbs.
AC Power Switch: Front panel.
Power Requirement: 100, 120, 220 or 240VAC +5% -10%. 50 or 60Hz, 150VA.
AC Power Switch: Front panel.
Approval: CE mark, RoHS
Calibration: NIST traceable.

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