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Model 2701 Ethernet-Based DMM / Data Acquisition

User's Manual

2701-900-01 Rev. G / February 2016

2701-900-01G

A Greater Measure of Confidence

KEITHLEY
A Tektronix Company

Model 2701 Ethernet-Based DMM / Data Acquisition System User's Manual

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Cleveland, Ohio, U.S.A.
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KEITHLEY

Safety Precautions

04/09

The following safety precautions should be observed before using this product and any associated instrumentation. Although some instruments and accessories would normally be used with non-hazardous voltages, there are situations where hazardous conditions may be present.

This product is intended for use by qualified personnel who recognize shock hazards and are familiar with the safety precautions required to avoid possible injury. Read and follow all installation, operation, and maintenance information carefully before using the product. Refer to the user documentation for complete product specifications.

If the product is used in a manner not specified, the protection provided by the product warranty may be impaired.

The types of product users are:

Responsible body is the individual or group responsible for the use and maintenance of equipment, for ensuring that the equipment is operated within its specifications and operating limits, and for ensuring that operators are adequately trained.

Operators use the product for its intended function. They must be trained in electrical safety procedures and proper use of the instrument. They must be protected from electric shock and contact with hazardous live circuits.

Maintenance personnel perform routine procedures on the product to keep it operating properly, for example, setting the line voltage or replacing consumable materials. Maintenance procedures are described in the user documentation. The procedures explicitly state if the operator may perform them. Otherwise, they should be performed only by service personnel.

Service personnel are trained to work on live circuits, perform safe installations, and repair products. Only properly trained service personnel may perform installation and service procedures.

Keithley Instruments products are designed for use with electrical signals that are rated Measurement Category I and Measurement Category II, as described in the International Electrotechnical Commission (IEC) Standard IEC 60664. Most measurement, control, and data I/O signals are Measurement Category I and must not be directly connected to mains voltage or to voltage sources with high transient over-voltages. Measurement Category II connections require protection for high transient over-voltages often associated with local AC mains connections. Assume all measurement, control, and data I/O connections are for connection to Category I sources unless otherwise marked or described in the user documentation.

Exercise extreme caution when a shock hazard is present. Lethal voltage may be present on cable connector jacks or test fixtures. The American National Standards Institute (ANSI) states that a shock hazard exists when voltage levels greater than 30V RMS, 42.4V peak, or 60VDC are present. A good safety practice is to expect that hazardous voltage is present in any unknown circuit before measuring.

Operators of this product must be protected from electric shock at all times. The responsible body must ensure that operators are prevented access and/or insulated from every connection point. In some cases, connections must be exposed to potential human contact. Product operators in these circumstances must be trained to protect

themselves from the risk of electric shock. If the circuit is capable of operating at or above 1000V, no conductive part of the circuit may be exposed.

Do not connect switching cards directly to unlimited power circuits. They are intended to be used with impedance-limited sources. NEVER connect switching cards directly to AC mains. When connecting sources to switching cards, install protective devices to limit fault current and voltage to the card.

Before operating an instrument, ensure that the line cord is connected to a properly-grounded power receptacle. Inspect the connecting cables, test leads, and jumpers for possible wear, cracks, or breaks before each use.

When installing equipment where access to the main power cord is restricted, such as rack mounting, a separate main input power disconnect device must be provided in close proximity to the equipment and within easy reach of the operator.

For maximum safety, do not touch the product, test cables, or any other instruments while power is applied to the circuit under test. ALWAYS remove power from the entire test system and discharge any capacitors before: connecting or disconnecting cables or jumpers, installing or removing switching cards, or making internal changes, such as installing or removing jumpers.

Do not touch any object that could provide a current path to the common side of the circuit under test or power line (earth) ground. Always make measurements with dry hands while standing on a dry, insulated surface capable of withstanding the voltage being measured.

The instrument and accessories must be used in accordance with its specifications and operating instructions, or the safety of the equipment may be impaired.

Do not exceed the maximum signal levels of the instruments and accessories, as defined in the specifications and operating information, and as shown on the instrument or test fixture panels, or switching card.

When fuses are used in a product, replace with the same type and rating for continued protection against fire hazard.

Chassis connections must only be used as shield connections for measuring circuits, NOT as safety earth ground connections.

If you are using a test fixture, keep the lid closed while power is applied to the device under test. Safe operation requires the use of a lid interlock.

If a  screw is present, connect it to safety earth ground using the wire recommended in the user documentation.

The  symbol on an instrument means caution, risk of danger. The user should refer to the operating instructions located in the user documentation in all cases where the symbol is marked on the instrument.

The  symbol on an instrument means caution, risk of danger. Use standard safety precautions to avoid personal contact with these voltages.

The  symbol on an instrument shows that the surface may be hot. Avoid personal contact to prevent burns.

The  symbol indicates a connection terminal to the equipment frame.

If this  symbol is on a product, it indicates that mercury is present in the display lamp. Please note that the lamp must be properly disposed of according to federal, state, and local laws.

The **WARNING** heading in the user documentation explains dangers that might result in personal injury or death. Always read the associated information very carefully before performing the indicated procedure.

The **CAUTION** heading in the user documentation explains hazards that could damage the instrument. Such damage may invalidate the warranty.

Instrumentation and accessories shall not be connected to humans.

Before performing any maintenance, disconnect the line cord and all test cables.

To maintain protection from electric shock and fire, replacement components in mains circuits - including the power transformer, test leads, and input jacks - must be purchased from Keithley Instruments. Standard fuses with applicable national safety approvals may be used if the rating and type are the same. Other components that are not safety-related may be purchased from other suppliers as long as they are equivalent to the original component (note that selected parts should be purchased only through Keithley Instruments to maintain accuracy and functionality of the product). If you are unsure about the applicability of a replacement component, call a Keithley Instruments office for information.

To clean an instrument, use a damp cloth or mild, water-based cleaner. Clean the exterior of the instrument only. Do not apply cleaner directly to the instrument or allow liquids to enter or spill on the instrument. Products that consist of a circuit board with no case or chassis (e.g., a data acquisition board for installation into a computer) should never require cleaning if handled according to instructions. If the board becomes contaminated and operation is affected, the board should be returned to the factory for proper cleaning/servicing.

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1
Getting Started

Quick Start — Of the following section topics, three can be used immediately to quickly acquaint yourself with fundamental instrument operations. Use QS1 to familiarize yourself with front panel controls, use QS2 to power-up the instrument, and finally, use QS3 to perform exercises to operate the instrument.

- **General information** — Covers general information that includes contact information, safety symbols and terms, inspection, and available options and accessories.
- **Model 2701 features** — Summarizes the features of Model 2701.
- **Plug-in switching modules** — Summarizes the capabilities of the Keithley Model 77xx series switching modules.

QS1
- **Front and rear panel familiarization** — Summarizes the controls and connectors of the instrument.
- **Rack mounting** — Covers the options available for rack mounting the Model 2701 in a standard 19-inch rack.

QS2
- **Power-up** — Covers line power connection, line voltage setting, fuse replacement, power line frequency, and the power-up sequence.
- **Display** — Provides information about the display of the Model 2701.
- **Defaults and user setups** — Lists the *RST and factory default settings, and covers the three setup configurations available to the user.
- **Remote programming information** — Explains how SCPI commands are presented in this manual.

QS3 • **Quick start exercises** — Provides abbreviated operating information and exercises (front panel and remote programming) to acquaint a user with operation basics.

General information

Contact information

Worldwide phone numbers are listed at the front of this manual. If you have any questions, please contact your local Keithley representative or call a Keithley Application Engineer at 1-800-348-3735 (U.S. and Canada only).

Safety symbols and terms

The following symbols and terms may be found on the instrument or used in this manual:

The  symbol on an instrument indicates that the user should refer to the operating instructions located in the manual.

The  symbol on the instrument shows that high voltage may be present on the terminal(s). Use standard safety precautions to avoid personal contact with these voltages.

The **WARNING** heading used in this manual explains dangers that might result in personal injury or death. Always read the associated information very carefully before performing the indicated procedure.

The **CAUTION** heading used in this manual explains hazards that could damage the instrument. Such damage may invalidate the warranty.

Inspection

Model 2701 was carefully inspected electrically and mechanically before shipment. After unpacking all items from the shipping carton, check for any obvious signs of physical damage that may have occurred during transit. (There may be a protective film over the display lens, which can be removed). Report any damage to the shipping agent immediately. Save the original packing carton for possible future shipment. The following items are included with every Model 2701 order:

- Model 2701 with line cord.
- Safety test leads (Model 1751).
- Accessories as ordered.
- Hardware for rack mounting.
- Certificate of calibration.

- Model 2701 User's Manual - PDF on CD-ROM.
- Model 2701 Instrument networking Instruction Manual - PDF on CD-ROM.
- Model 2700S Quick Start Guide.
- Ethernet cross over cable (3-meters in length).

NOTE *The Model 2701 Service Manual is a separate purchased part. Contact Keithley's Service Department to order this manual.*

Battery

The Model 2701 uses battery-backed memory for the 450,000 reading buffer. A fully charged battery will maintain storage of readings for 30 days (at 23°C). At 50°C, the storage period is degraded to approximately 15 days. See Appendix A for specifications on the rechargeable lithium ion battery.

The battery is warranted for 90 days. However, at 23°C, the battery will typically last three years. See Section 3 of the Model 2701 Service Manual to replace the battery. The Keithley part number for the battery is BA-52.

Options and accessories

Plug-in switching modules

NOTE *Table 1-1 provides a side-by-side comparison of the following Keithley switchinging modules. All multiplexer modules can be configured as two independent multiplexers.*

NOTE *The Model 77xx Series Switching Modules Instruction Manual provides operating and service information for the switching modules. This manual is supplied with each switching module.*

Model 7700 — This differential multiplexer provides 20 channels of 2-pole input or 10 channels of 4-pole input. The internal cold junction allows direct-connection of thermocouples. It also has two 2-pole channels used exclusively for current input.

Model 7701 — This differential multiplexer provides 32 channels of 2-pole input or 16 channels of 4-pole input.

Model 7702 — This differential multiplexer provides 40 channels of 2-pole input or 20 channels of 4-pole input. It also has two 2-pole channels used exclusively for current input.

Model 7703 — This differential multiplexer provides 32 channels of 2-pole input or 16 channels of 4-pole input.

Model 7705 — This control module provides 40 independent 1-pole switching (SPST) channels that are isolated from the internal DMM.

Model 7706 — This all-in-one module provides 20/10 channels of 2/4-pole input, 16 digital outputs, two analog outputs, and one 32-bit counter with gating and totalizer.

Model 7707 — This module provides 10 channels of 2-pole input or 5 channels of 4-pole input. Also provides four independent 8-byte digital I/O channels.

Model 7708 — This differential multiplexer provides 40 channels of 2-pole input or 20 channels of 4-pole input. The internal cold junction allows direct-connection of thermocouples for temperature measurements.

Model 7709 — This module is configured as a 6 × 8 matrix (six rows, eight columns). The matrix consists of 48 crosspoint channels and two backplane isolation channels. For system channel operation, row 1 (8 channels) is connected to DMM Input. For 4-wire measurements, rows 1 and 2 (4 system channels) are connected to the DMM.

Model 7710 — This differential multiplexer provides 20 channels of 2-pole input or 10 channels of 4-pole input. The internal cold junction allows direct-connection of thermocouples for temperature measurements. This module provides high-speed switching and uses long-life relays.

Model 7711 — The Model 7711 is a 50Ω, 2GHz, single-pole dual 1 × 4 RF Multiplexer module (eight channels, no measurement capability). This 1 × 4 multiplexer is a cascading tree design — one of the channels of each is always connected to a common out. It can be used to connect one instrument to multiple devices or multiple instruments to a single device.

Model 7712 — The Model 7712 is a 50Ω, 3.5GHz, single-pole dual 1 × 4 RF Multiplexer module (eight channels, no measurement capability). This 1 × 4 multiplexer is a cascading tree design — one of the channels of each is always connected to a common out. It can be used to connect one instrument to multiple devices or multiple instruments to a single device.

Cables and connector kits for switching modules

Model 7788 DB-50 connector kit — Contains two male DB-50 solder cup connectors with strain relief connector shells. These connectors mate to the female connectors of the Models 7703 and 7705 switching modules.

Model 7789 50/25-pin solder cup connector kit — Contains one male DB-50 and one male DB-25 solder cup connectors. These connectors mate to the female connectors on the Models 7701 and 7709 switching modules.

Model 7790 ribbon cable adapter kit — Contains one female DB-50, one male DB-50, and one male DB-25 IDC ribbon cable connectors. These connectors are used with the Models 7701, 7707, and 7709 switching modules.

Model 7051-X — BNC cable (male to male). 7051-2 is 2 ft long, 7051-5 is 5 ft long, and 7051-10 is 10 ft long. These cable are used with the Model 7711 switching module.

Model 7712-SMA-1 — SMA cable (male to male), 1.0m (3.3 ft) long. This cable is used with the Models 7711 and 7712 switching modules.

Model 7712-SMA-N — Female SMA to male N-type adapter. This adapter is used with the Models 7711 and 7712 switching modules.

S46-SMA-X — SMA cable (male to male). S46-SMA-1 is one foot long and S46-SMA-0.5 is one-half foot long. This cable is used with the Models 7711 and 7712 switching modules.

Cables and adapters (Ethernet, RS-232, and trigger link)

Ethernet cross over cable (3 meters) — Keithley P/N CA-180-3.

Models 8501-1 and 8501-2 trigger link cables — Connect Model 2701 to other instruments with Trigger Link connectors (e.g., Model 7002 Switch System). Model 8501-1 is one meter long; Model 8501-2 is two meters long.

Model 8502 trigger link adapter — Lets you connect any of the two trigger link lines of Model 2701 to instruments that use the standard BNC trigger connectors.

Model 8503 DIN to BNC trigger cable — Lets you connect trigger link lines one (Voltmeter Complete) and one (External Trigger) of Model 2701 to instruments that use BNC trigger connectors. Model 8503 is one meter long.

Model 7009-5 shielded RS-232 cable — Five foot RS-232 cable with a male DB-9 connector on one end and a female DB-9 connector on the other end. Wired as a straight through cable (not null modem).

Software

Control software and software drivers for the Model 2701 are available on the Keithley website: www.tek.com/keithley.

Rack mount kits

Model 4288-1 single fixed rack mount kit — Mounts a single Model 2701 in a standard 19-inch rack.

Model 4288-2 side-by-side rack mount kit — Mounts two instruments (Models 182, 428, 486, 487, 2000, 2001, 2002, 2010, 2400, 2410, 2420, 2430, 2700, 2701, 6430, 6517A, 7001) side-by-side in a standard 19-inch rack.

Model 4288-4 side-by-side rack mount kit — Mounts Model 2701 and a 5.25-inch instrument (Models 220, 224, 230, 263, 595, 614, 617, 775A, 6512) side-by-side in a standard 19-inch rack.

Carrying case

Model 1050 padded carrying case — A carrying case for the Model 2701 includes handles and shoulder strap.

Model 2701 features

Model 2701 is a 6½-digit high-performance multimeter/data acquisition system. It can measure voltage (DC and AC), current (DC and AC), resistance (2- and 4-wire), temperature (thermocouple, thermistor, and 4-wire RTD), frequency and period, and test continuity.

The Model 2701 has two slots that will accommodate Keithley Model 7700 series switching modules (Table 1-1). Each channel of a switching module that is closed or scanned is measured by the Model 2701. For scanning, each channel can have its own unique setup (i.e., function, range, digits, etc.).

More information on the measurement capabilities of the Model 2701 is provided in "DMM measurement capabilities," page 3-2. A connection guide for the Model 7700 is provided in Appendix B. Specifications for the Model 2701 and 7700 switching module are provided in Appendix A.

Additional features of Model 2701 include:

- **Setup storage** — Seven instrument setups (five user, *RST defaults, and factory defaults) can be saved and recalled.
- **Offset-compensated ohms** — A two-measurement process for 4-wire ohms to cancel the effects of thermal EMFs. Available for the 100Ω, 1kΩ, and 10kΩ ranges.
- **Math** — mX+b, percent, and reciprocal (1/X) calculations provide mathematical manipulation of readings.
- **Relative** — Null offsets or establish baseline values.
- **Ratio and channel average** — Ratio and average calculations for two switching module channels.
- **Buffer** — Store up to 450,000 readings in the internal buffer.
- **Limits** — Two sets of high and low reading limits to test devices.
- **Digital I/O port** — Five digital limit test output lines to control external circuitry. The digital trigger link and hardware interlock input can also be accessed at this port.
- **Monitor** — The Model 2701 can monitor a selected channel. A scan can be triggered to start when the Monitor detects a reached reading limit.
- **Remote interface** — Model 2701 can be controlled using the 10BaseT and 100BaseTX autosensing Ethernet or the RS-232 interface.

Plug-in switching modules

Up to two Keithley Model 77xx series switching modules can be installed in the Model 2701. A side-by-side comparison of the switching modules is provided in Table 1-1.

Basic close/open operation for switching module channels is provided in Section 2, while scanning is covered in Section 7. Connection information for the Model 7700 switching module is provided in Appendix B. For all other switching modules, connection information is provided in their respective packing lists.

NOTE *For maximum system performance, it is recommended that all measurement cables be limited to less than 3 meters.*

Pseudocards

Using remote programming, you can assign a pseudocard to an empty switching module slot. With a pseudocard installed, the Model 2701 will operate as if the switching module is installed in the Model 2701. This feature allows you to configure your system without having the actual switching module installed in the unit. There is a pseudocard for every Keithley Model 77xx series switching module. For details, see "Pseudocards," page 2-6.

Identifying installed switching modules

On power-up, the model numbers of installed switching modules are displayed briefly. If a Model 7700, 7701, 7702, 7703, 7705, 7708, 7709, 7710, 7711, or 7712 switching module is removed while the Model 2701 is on, the instrument will operate as if the module is installed. That is, the Model 2701 will operate as if the pseudocard is installed.

NOTE *If a Model 7706 or 7707 is removed while power is on, error +523 "Card hardware error" will occur, and the module will be removed from the system. In general, it is not recommended to install or remove switching modules with the power on.*

The CARD menu and remote query commands can be used to identify modules installed in the mainframe. For details, see "Switching module installation and connections," page 2-4.

Table 1-1
Model 77xx series switching modules

	Model 7700	**Model 7701**	**Model 7702**	**Model 7703**
2-pole Operation	20 channels	32 channels	40 channels	32 channels
4-pole Operation	10 channel pairs	16 channel pairs	20 channel pairs	16 channel pairs
1-pole Operation	N/A	N/A	N/A	N/A
Measure Volts	300V maximum	150V maximum	300V maximum	300V maximum
Measure Amps	Ch 21 & 22, 3A Max	No	Ch 41 & 42, 3A Max	No
Measure Ohms	2/4-wire	2/4-wire	2/4-wire	2/4-wire
Thermocouple Cold Junction	Yes	No	No	No
Relay Type[1]	Latching electro-mechanical	Latching electro-mechanical	Latching electro-mechanical	Non-latching reed
Connector type	Oversized screw terminals	1 female DB-50 1 female DB-25	Oversized screw terminals	2 female DB-50s
Configuration[2]	Multiplexer	Multiplexer	Multiplexer	Multiplexer
Unique features	All DMM functions	All DMM functions except amps	All DMM functions	All DMM functions except amps
	Model 7705	**Model 7706**	**Model 7707**	**Model 7708**
2-pole Operation	N/A	20 channels	10 channels	40 channels
4-pole Operation	N/A	10 channel pairs	5 channel pairs	20 channel pairs
1-pole Operation	40 channels	N/A	N/A	N/A
Measure Volts	300V maximum	300V maximum	300V	300V maximum
Measure Amps	No	No	No	No
Measure Ohms	No	2/4-wire	2/4-wire	2/4-wire
Thermocouple Cold Junction	No	Yes	No	Yes
Relay Type[1]	Latching electro-mechanical	Latching electro-mechanical	Latching electro-mechanical	Latching electro-mechanical
Connector type	2 female DB-50s	Mini screw terminal	1 male DB-50 1female DB-25	Oversized screw terminals
Configuration[2]	Independent SPST channels	Multiplexer	Multiplexer	Multiplexer
Unique features	Multiple channel operation only	16 digital outputs, 2 analog outputs, one counter/totalizer	32 digital inputs/outputs	All DMM functions except amps

Table 1-1 (continued)
Model 77xx series switching modules

	Model 7709	**Model 7710**	**Models 7711 and 7712**	
2-pole Operation	8-channels	20 channels	N/A	
4-pole Operation	4 channel pairs	10 channel pairs	N/A	
1-pole Operation	N/A	N/A	8 channels	
Measure Volts	300V maximum	60V maximum	No[3]	
Measure Amps	No	No	No[3]	
Measure Ohms	2/4-wire	2/4-wire	No[3]	
Thermocouple Cold Junction	No	Yes	No[3]	
Relay Type[1]	Latching electro-mechanical	Solid state opto-coupled FET	High frequency electromechanical	
Connector type	1 female DB-50 1 female DB-25	3.5mm removable screw terminals	10 SMA	
Configuration[2]	6 x 8 matrix	Multiplexer	Multiplexer	
Unique features	Rows 1 & 2 connect to DMM (system channel operation)	High-speed switching and long-life relays	50Ω RF dual 1 x 4 multiplexer Max Frequency: 7711: 2GHz 7712: 3.5GHz	

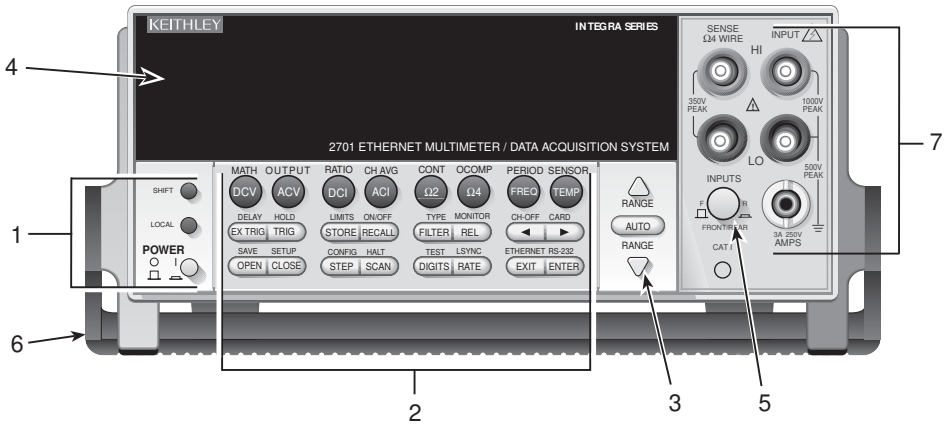
1. Latching relays hold their open/close state after the mainframe is turned off. When turned on, all relays open after a few seconds.
2. All multiplexers can be configured as two independent multiplexers.
3. The Models 7711 and 7712 have no measurement capabilities.

Front and rear panel familiarization (QS1)

Front panel summary

The front panel of Model 2701 is shown in Figure 1-1.

Figure 1-1
Model 2701 front panel



NOTE *Most keys provide a dual function or operation. The nomenclature on a key indicates its unshifted function/operation which is selected by pressing the key. Nomenclature (in blue) above a key indicates its shifted function. A shifted function is selected by pressing the SHIFT key and then the function/operation key.*

1 Special keys and power switch:

SHIFT	Use to select a shifted function or operation.
LOCAL	Cancels remote mode. SHIFT + LOCAL disables keyclick.
POWER	Power switch. In position turns 2701 on (I), out position turns it off (O).

2 Function and operation keys:

Top Row

Unshifted	
DCV	Selects DC voltage measurement function.
ACV	Selects AC voltage measurement function.
DCI	Selects DC current measurement function.
ACI	Selects AC current measurement function.
Ω2	Selects 2-wire resistance measurement function.
Ω4	Selects 4-wire resistance measurement function.
FREQ	Selects frequency measurement function.
TEMP	Selects temperature measurement function.

Shifted	
MATH	Configures and controls mX+b, percent, or reciprocal (1/X) calculation.
OUTPUT	Configures and controls digital and audio (beeper) output for limits.
RATIO	Enables/disables channel ratio.
CH-AVG	Enables/disables channel average.
CONT	Configures and controls continuity test.
OCOMP	Enables/disables offset compensated ohms with Ω4 function selected.
PERIOD	Selects period measurement function.
SENSOR	Configures temperature measurements.
Middle Row	
Unshifted	
EXTRIG	Selects external triggering as the trigger source.
TRIG	Triggers a measurement when in external triggering (EX TRIG).
STORE	Sets the number of readings to store and enables the buffer.
RECALL	Displays stored readings and buffer statistics. Use the ◂, ▸, ▴, and ▾ keys to navigate through buffer.
FILTER	Enables/disables filter for selected function.
REL	Enables/disables relative for selected function.
◂ and ▸	Dual function—Manually scans switching channels. When in a menu, these keys control cursor position for making selections or change values.
Shifted	
DELAY	Sets user delay between trigger and measurement.
HOLD	Holds reading when the selected number of samples is within the selected tolerance.
LIMITS	Sets upper and lower limits for readings.
ON/OFF	Enables/disables limits.
TYPE	Configures and enables filter for selected function.
MONITOR	Selects and enable/disables monitor channel.
CH-OFF	Disables channel for a scan (must be in scan channel setup mode).
CARD	Identifies switching modules installed in mainframe. Set up switching modules that require configuration. View closed channels and channel settings for switching modules that require configuration.
Bottom Row	
Unshifted	
OPEN	Opens closed channel.
CLOSE	Closes specified channel.
STEP	Steps through channels; sends a trigger after each channel.
SCAN	Scans through channels; sends a trigger after last channel.
DIGITS	Sets display resolution for all functions.
RATE	Sets measurement speed (fast, medium, or slow) for all functions.
EXIT	Cancels selection, moves back to measurement display.
ENTER	Accepts selection, moves to next choice or back to measurement display.
Shifted	
SAVE	Saves up to five instrument setups for future recall, and selects power-on setup.
SETUP	Restores a default setup (factory or *RST) or a saved setup. Enables/disables buffer auto clear, auto scan, and auto channel configuration. Sets timestamp, date, and time. Displays serial number of Model 2701.
CONFIG	Selects and configures a simple scan or an advanced scan.
HALT	Disables step/scan.
TEST	Selects the calibration menu, display test or the key-press test.
LSYNC	Enables/disables line cycle synchronization. When enabled, noise induced by the power line is reduced at the expense of speed.
ETHERNET	Enables/disables and configures Ethernet settings.
RS-232	Enables/disables RS-232 interface; selects baud rate, flow control, and terminator.

3 Range keys:

Unshifted

▲ and ▼	Dual function—Selects the next higher/lower measurement range for the selected function. When in a menu, these keys make selections or change values.
AUTO	Enables/disables autorange for the selected function.

4 Display annunciators:

* (asterisk)	Readings being stored in buffer.
↔ (more)	Indicates additional selections are available.
))) (speaker)	Beeper on for continuity or limits testing.
—▷|—	Digital input/output or analog output active (set to non-default value).
4W	4-wire resistance or 4-wire RTD temperature reading displayed.
~AC	AC function selected (ACV, dB, or ACI).
AUTO	Auto range enabled.
BUFFER	Recalling readings stored in buffer.
CHAN	Setup or reading for a switching channel displayed.
DELTA	Channel average enabled.
ERR	Questionable reading or invalid cal step.
FAST	Fast reading rate selected.
FILT	Filter enabled for selected function.
HIGH	Reading has reached or exceeded the enabled high limit.
HOLD	2701 in hold mode.
LOW	Reading has reached or exceeded the enabled low limit.
MATH	mX+b, percent, or reciprocal (1/X) calculation enabled.
MED	Medium reading rate selected.
MON	Monitor channel displayed.
OCOMP	4-wire offset compensated ohms enabled.
RATIO	Channel ratio enabled.
REAR	Front panel input terminals disconnected.
REL	Relative enabled for selected function.
REM	Instrument in Ethernet remote mode.
SCAN	Scanning operation being performed.
SHIFT	Accessing a shifted key.
SLOW	Slow reading rate selected.
SRQ	Service request over Ethernet or RS-232.
STAT	Displaying buffer statistics.
STEP	Stepping operation being performed.
TIMER	Timer controlled triggering in use.
TRIG	External triggering selected.

5 INPUTS switch:

Use to select front panel inputs (out; F) position or switching module inputs (in; R) position.

NOTE *For remote programming, the following command queries the INPUTS switch position:*

```
SYSTem:FRSWitch?          ' Query INPUTS switch; 0 = rear, 1 = front.
```

6 Handle:

Pull out and rotate to desired position.

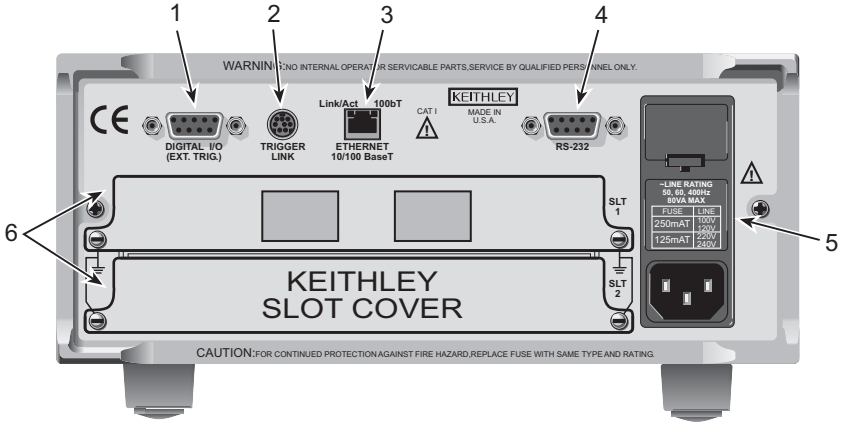
7 Front panel inputs:

INPUT HI and LO	Used for DCV, ACV, Ω2, CONT, FREQ, PERIOD, and thermocouple/thermistor TEMP measurements.
SENSE HI and LO	Use with INPUT HI and LO for Ω4 and RTD TEMP measurements.
AMPS	Use with INPUT LO for DCI and ACI measurements.
Amps fuse holder	Holds current fuse for front panel amps input.

Rear panel summary

The rear panel of Model 2701 is shown in Figure 1-2. As shown, a slot cover is installed on slot 2.

Figure 1-2
Model 2701 rear panel



1 DIGITAL I/O (EXT. TRIG.)

Male DB-9 connector for digital input (trigger link in) and digital outputs.

2 TRIGGER LINK

Eight-pin micro-DIN connector for sending and receiving trigger pulses among connected instruments. Use a trigger link cable or adapter, such as Models 8501-1, 8501-2, 8502, and 8503.

3 ETHERNET

RJ45 female connector for Ethernet operation. Use an RJ45 male/male cable for connection. Two status LEDs are located at the top of the connector. These LEDs indicate the status of the Ethernet (see Section 10, "Ethernet connections").

4 RS-232

Female DB-9 connector for RS-232 operation. Use a straight-through (not null modem) DB-9 shielded cable.

5 Power module

Contains the AC line receptacle, power line fuse, and line voltage setting. The instrument can be configured for line voltages of 100V/120V/220V/240VAC at line frequencies of 50 or 60Hz.

6 Slot 1 and Slot 2

Two slots to accommodate Keithley Model 77xx series switching modules. The Model 2701 is shipped from the factory with slot covers installed. Please note additional slot covers can be requested from Keithley Instruments.

WARNING **Slot covers must be installed on unused slots to prevent personal contact with high voltage circuits.**

Power-up (QS2)

The Model 2701 will operate properly using the following line power voltages and frequencies:

- Line power voltages – 100V, 120V, 220V, and 240V.
- Line power frequencies – 45Hz to 66Hz and 360Hz to 440Hz.

Line power connection

Follow the procedure below to connect the Model 2701 to line power and turn on the instrument.

1. Check to see that the line voltage indicated in the window of the fuse holder assembly (Figure 1-3) is correct for the operating voltage in your area. If not, refer to "Setting line voltage and replacing fuse," page 1-16.

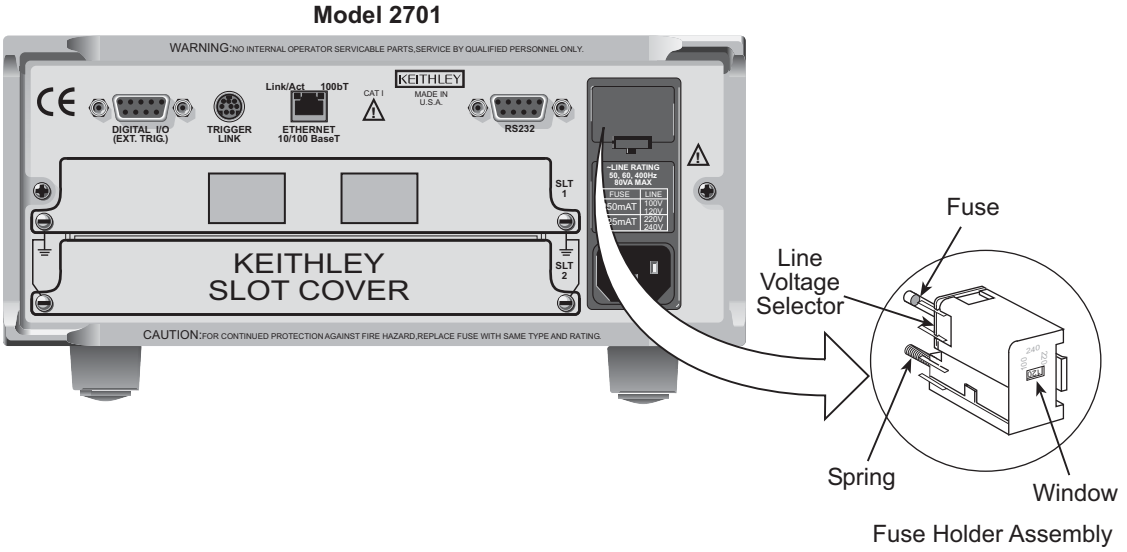
CAUTION **Operating the instrument on an incorrect line voltage may cause damage to the instrument, possibly voiding the warranty.**

2. Before plugging in the power cord, make sure that the front panel power switch is in the off (O) position.
3. Connect the female end of the supplied power cord to the AC receptacle on the rear panel. Connect the other end of the power cord to a grounded AC outlet.

WARNING **The power cord supplied with the Model 2701 contains a separate ground wire for use with grounded outlets. When proper connections are made, instrument chassis is connected to power line ground through the ground wire in the power cord. Failure to use a grounded outlet may result in personal injury or death due to electric shock.**

4. Turn on the instrument by pressing the front panel power switch to the on (|) position.

Figure 1-3
Power module



Line frequency

The Model 2701 will operate at line frequencies from 45Hz to 66Hz and 360Hz to 440Hz. There are no user-settings for line frequency. It is automatically sensed at power-up. The following command can be used to read the line frequency:

```
SYSTem:LFRequency?                    ' Query power line frequency.
```

Setting line voltage and replacing fuse

A rear panel fuse located next to the AC receptacle protects the power line input of the instrument. If the line voltage setting needs to be changed or the line fuse needs to be replaced, perform the following steps.

WARNING **Make sure the instrument is disconnected from the AC line and other equipment before changing the line voltage setting or replacing the line fuse.**

1. Place the tip of a flat-blade screwdriver into the power module by the fuse holder assembly (Figure 1-3). Gently push in and up. Release pressure on the assembly and its internal spring will push it out of the power module.

2. Remove the fuse and replace it with the type listed in Table 1-2.

CAUTION **For continued protection against fire or instrument damage, only replace fuse with the type and rating listed. If the instrument repeatedly blows fuses, locate and correct the cause of the trouble before replacing the fuse.**

3. If configuring the instrument for a different line voltage, remove the line voltage selector from the assembly and rotate it to the proper position. When the selector is installed into the fuse holder assembly, the correct line voltage appears sideways in the window.
4. Install the fuse holder assembly into the power module by pushing it in until it locks in place.

Table 1-2
Fuse ratings

Line voltage	Fuse rating	Keithley P/N
100/120V	0.630A, 250V, 5 × 20 mm, slow-blow	FU-106-.630
220/240V	0.315A, 250V, 5 × 20 mm, slow-blow	FU-106-.315

Power-up sequence

NOTE *If a problem develops while the instrument is under warranty, return it to Keithley Instruments for repair. A short description of any displayed error messages are provided in Appendix C.*

NOTE *The entire power-up cycle takes approximately 30 seconds. Do not attempt to communicate with the Model 2701 during this time period.*

Turn on the Model 2701 by pressing in the front panel POWER button. While booting up, the following messages will be briefly displayed:

LOADING FPGA
LOADING MAIN

If Ethernet is the presently selected interface, the following will be displayed for 10 to 15 seconds:

LOAD ETHRNET

The instrument then briefly displays all display characters and annunciators, and performs self-tests. If all self-tests pass, the firmware revision levels are displayed. An example of this display is:

REV: A01 A01

where: First A01 is the main board ROM revision.
Second A01 is the display board ROM revision.

If Ethernet is the presently selected interface, the IP address will be displayed briefly. Example:

ETHERNET
192.168.000.002

If RS-232 is the presently selected interface, the baud rate will be displayed briefly:

RS-232 MODE
BAUD: 9600

Installed switching modules are then displayed. For example, if there is a Model 7700 switching module installed in both slots, the following messages will be displayed:

1: 7700 2: 7700

If a slot is empty, the message "NONE" will be displayed instead.

If the saved power-on setup is not the factory defaults setup (SYSTem:POSetup PRESet), a message to identify the setup will be briefly displayed ("Defaults and user setups," page 1-21).

After the power-up sequence, the instrument begins its normal display of readings.

NOTE *The serial number of the Model 2701 can be displayed by selecting the SNUM item of the SETUP menu. Press SHIFT and then SETUP to access the menu. For remote operation, the serial number can be read using the *IDN? command (see Section 12 for details).*

NOTE *The serial number and revision levels can be accessed from the internal web page of the Model 2701 using the Internet Explorer. For details, see "Internal web page" in Section 10.*

Keyclick

With keyclick enabled, an audible click will sound when a front panel key is pressed. Perform the following steps to disable or enable keyclick:

1. Press SHIFT and then LOCAL to display the present state of KEYCLICK (ON or OFF).
2. Press ▲ or ▼ to display the desired keyclick state and press ENTER.

Remote programming

The following command controls keyclick:

```
SYSTem:KCLick <b>                    ' Enable or disable keyclick.
```

where: <b> = ON or OFF

NOTE *Keyclick ON is the FACTORY, *RST, and SYSTem:PRESet default.*

Display

Readings are displayed in engineering units (i.e., 100.23mV), while annunciators indicate various states of operation. See "Front panel summary," page 1-10, for a complete listing of display annunciators.

NOTE *The display test allows you to test display digit segments and annunciators. The key test checks the functionality of front panel keys. These tests are accessed by pressing SHIFT and then TEST. Refer to the Model 2701 Service Manual for details.*

Status and error messages

Status and error messages are displayed momentarily. During operation and programming, you will encounter a number of front panel messages. Typical messages are either of status or error variety, as listed in Appendix C.

Remote programming — display

Using remote programming, the Model 2701 can display a custom ASCII message (up to 12 characters). Also, the front panel display and controls can be disabled.

Display commands

The commands are listed in Table 1-3. Details on these commands follow the table.

NOTE *Optional command words and queries are not included in Table 1-3. Table 15-2 provides an unabridged list of all display commands.*

Table 1-3
Display commands

Command	Description	Default*
DISPlay:TEXT:DATA <a>	Define message (<a> = ASCII characters, up to 12).	(none)
DISPlay:TEXT:STATe <b>	Enable or disable message mode (<b> = ON or OFF).	OFF
DISPlay:ENABle <b>	Enable or disable the front panel display (<b> = ON or OFF).	ON

*SYSTem:PRESet and *RST have no effect on DISPlay commands. The listed defaults are power-on defaults.

DISPlay:TEXT:DATA <a> — Define text message

This command defines the text message for display. A message can be as long as 12 characters. A space counts as a character. Excess message characters results in an error. The characters must be enclosed in either single quotes (' ') or double quotes (" ").

DISPlay:TEXT:STATe ON|OFF — Control (on/off) message for display

This command enables and disables the text message mode. When enabled, a defined message is displayed. When disabled, the message is removed from the display.

A user defined text message remains displayed only as long as the instrument is in remote. Taking the instrument out of remote (by pressing the LOCAL key or sending GTL) cancels the message and disables the text message mode.

DISPlay:ENABle ON|OFF — Control display circuitry

This command is used to enable and disable the front panel display circuitry. When disabled, the instrument operates at a higher speed. While disabled, the display is blanked.

All front panel controls (except LOCAL) are disabled. Normal display operation can be resumed by using the ENABle command to enable the display or by putting the Model 2701 into local mode (press LOCAL).

Programming example

The following command sequence displays the text message "TESTING":

```
DISP:TEXT:DATA 'TESTING'            ' Define text message.
DISP:TEXT:STAT ON                   ' Enable text message mode.
```

Defaults and user setups

Model 2701 can be restored to one of two default setup configurations (FACTory or *RST) or five user-saved (SAV0, SAV1, SAV2, SAV3, or SAV4). As shipped from the factory, Model 2701 powers up to the factory (FACT) default settings.

NOTE *Closed channels can be saved in a user setup (SAV0, SAV1, SAV2, SAV3 or SAV4). When the setup is restored, those channels (and only those channels) will be closed. FACT and *RST defaults opens all channels.*

The factory default setup provides continuous triggering, while the *RST default setup places the Model 2701 in the one-shot trigger mode. With one-shot triggering, a measurement is performed whenever the TRIG key is pressed or an initiate command is sent over the remote interface.

The factory and *RST default settings are listed in Table 1-4. Setting differences (Set Diff) between the two default setups are indicated by checkmarks (✔).

For remote programming, the SYSTem:PRESet and *RST commands are used to reset the instrument. The *RST command returns the instrument to the *RST defaults and, for the most part, the SYSTem:PRESet command returns the instrument to the factory default conditions. The exceptions are explained as follows:

- Auto scan and auto channel configuration — FACTory defaults disable auto scan and auto channel configuration, while SYSTem:PRESet has no effect. The *RST defaults (front panel and remote operation) have no effect.
- Memory buffer auto clear — FACTory defaults enable buffer auto clear, while SYSTem:PRESet has no effect. The *RST defaults (front panel and remote operation) have no effect.

The instrument will power up to whichever default setup is saved as the power-on setup.

NOTE *At the factory, the factory default setup is saved as the SAV0, SAV1, SAV2, SAV3, or SAV4 setup.*

Saving and restoring setups

Saving a user setup

1. Configure Model 2701 for the desired measurement application.
2. Press SHIFT and then SAVE to access the save setup menu.
3. Press ▸ to place the cursor on the present setup (SAV0, SAV1, SAV2, SAV3, SAV4).
4. Use the ▲ or ▼ key to display the desired setup and press ENTER. The instrument returns to the normal measurement state.

WARNING **If you make firmware upgrades you will lose all your saved settings.**

Saving a power-on setup

1. Configure Model 2701 for the desired measurement application.
2. Press SHIFT and then SAVE to access the save setup menu.
3. Press the ▲ key to display the present power-on (PWR-ON) setup; FACT, *RST, SAV0, SAV1, SAV2, SAV3, or SAV4.
4. Press ▶ to place the cursor on the present power-on setup.
5. Use the ▲ or ▼ key to display the desired setup and press ENTER. The instrument returns to the normal measurement state.

Restoring a setup

1. Press SHIFT and then SETUP to access the restore setup menu.
2. Press ▶ to place the cursor on the present RESTORE setup (FACT, *RST, SAV0, SAV1, SAV2, SAV3, or SAV4).
3. Use the ▲ or ▼ key to display the desired setup and press ENTER. The instrument returns to the normal measurement state.

NOTE *If the settings for a user setup or power-on setup do not match the switching module types presently installed in the Model 2701, error +520 (Saved setup scancard mismatch) occurs when the setup is recalled. The scan list will reset to the factory defaults and all channels will open. However, the saved setup is still retained in memory and can be restored when the matching switching module is later installed.*

Table 1-4
Default settings

Setting	Factory	*RST	Set Diff
Auto channel configuration	No (off)	No effect	✔
Autozero	On	On	
Buffer	No effect	No effect	
Auto clear	Yes (on)	No effect	✔
Channel Average	Off	Off	
Closed channels	None	None	
Closure count interval	No effect	No effect	
Continuity			
Beeper	On	On	
Digits	4½ digits	4½ digits	
Range	1kΩ	1kΩ	
Rate	Fast (0.01 PLC)	Fast (0.01 PLC)	
Threshold level	10Ω	10Ω	
Current (AC and DC)			
Bandwidth (AC)	30	30	
Digits (AC)	5½ digits	5½ digits	
Digits (DC)	6½ digits	6½ digits	
Filter	On	Off	✔
Window	0.1%	0.1%	
Count	10	10	
Type	Moving	Repeat	✔
Range	Auto	Auto	
Rate (DC)	Slow (5 PLC)	Slow (5 PLC)	
Rel	Off	Off	
Ethernet settings:			
IP address	No effect	No effect	
Subnet	No effect	No effect	
Gateway	No effect	No effect	
MAC	No effect	No effect	
Frequency and Period			
Digits	6½ digits	6½ digits	
Range	10V	10V	
Rate (aperture)	1 second	1 second	
Rel	Off	Off	
Function	DCV		
Keyclick	On	On	

Table 1-4 (continued)
Default settings

Setting	Factory	*RST	Set Diff
Limits	Off	Off	
LO Limit 1	-1	-1	
HI Limit 1	+1	+1	
LO Limit 2	-2	-2	
HI Limit 2	+2	+2	
Line Synchronization	Off	Off	
Math			
mX+B	Off	Off	
Scale Factor	1.0	1.0	
Offset	0.0	0.0	
Units	"X"	"X"	
Percent	Off	Off	
Reference	1.0	1.0	
1/X (Reciprocal)	Off	Off	
Monitor	Off	Off	
Output			
Beeper	Never	Never	
Digital Output	Off	Off	
Logic Sense	High	High	
Pulse	No (off)	No (off)	
Ratio	Off	Off	
Resistance (Ω2 and Ω4)			
Digits	6½ digits	6½ digits	
Filter	On	Off	✔
Window	0.1%	0.1%	
Count	10	10	
Type	Moving	Repeat	✔
Offset compensation (OCOMP)	Off	Off	
Range	Auto	Auto	
Rate	Slow (5 PLC)	Slow (5 PLC)	
Rel	Off	Off	

Table 1-4 (continued)
Default settings

Setting	Factory	*RST	Set Diff
RS-232	No effect	No effect	
Baud rate	No effect	No effect	
Flow control	No effect	No effect	
Terminator	No effect	No effect	
Scanning	Disabled	Disabled	
Auto scan	No (off)	No effect	✔
Type (Simple or Advanced)	No effect	No effect	
Simple scan			
Minimum channel	101, 201, 301, 401, or 501	101, 201, 301, 401, or 501	
Maximum channel	No effect	No effect	
Timer	Off	Off	
Reading count	No effect	No effect	
Advanced scan			
Setup	No effect	No effect	
Immediate trigger	On	On	
Limit triggers	Off	Off	
Timer	Off	Off	
Reading count	No effect	No effect	
Temperature			
Digits	5½ digits	5½ digits	
Filter	On	Off	✔
Window	0.1%	0.1%	
Count	10	10	
Type	Moving	Repeat	✔
Rate	Slow (5 PLC)	Slow (5 PLC)	
Rel	Off	Off	
Sensor	Thermocouple	Thermocouple	
Junction	See Note	See Note	
Open detector	No (off)	No (off)	
Type	K	K	
Units	°C	°C	
Timestamp	No effect	No effect	
Triggering	Continuous	One-shot	✔
Delay	Auto	Auto	
Source	Immediate	Immediate	
Reading hold	Off	Off	
Window	1%	1%	
Count	5	5	

Table 1-4 (continued)
Default settings

Setting	Factory	*RST	Set Diff
Voltage (AC and DC)			
dB	Off	Off	
Reference	1.0	1.0	
Digits (AC)	5½ digits	5½ digits	
Digits (DC)	6½ digits	6½ digits	
Filter	On	Off	✔
Window	0.1%	0.1%	
Count	10	10	
Type	Moving	Repeat	✔
Range	Auto	Auto	
Rate (DC)	Slow (5 PLC)	Slow (5 PLC)	
Rel	Off	Off	

Note: With a Model 7700, 7706, or 7708 installed, the default sensor junction is Internal. Otherwise, the Simulated (23ºC) junction is selected.

Remote programming — default and user setups

Default and user setup commands are listed in Table 1-5.

NOTE *The SYSTem:PRESet and *RST defaults are listed in the SCPI tables in Section 15.*

Table 1-5
Default setup commands

Commands	Description
SYSTem:PRESet *RST	Restore SYSTem:PRESet defaults. Restore *RST defaults.
*SAV <NRf> *RCL <NRf>	Save settings as user setup; <NRf> = 0, 1, 2, 3, or 4. Restore user saved setup; <NRf> = 0, 1, 2, 3, or 4.
SYSTem:POSetup <name>	Specify power-on setup; <name> = RST, PRESet, SAV0, SAV1, SAV2, SAV3, or SAV4.

Programming example

```
*SAV 2                  ' Save present setup in memory location 2.
SYST:POS SAV2           ' Specify SAV2 setup as the power-on setup.
*RST                    ' Return 2701 to RST defaults.
*RCL 2                  ' Return 2701 to setup stored in memory location 2.
```

Remote programming information

Remote programming information is integrated with front panel operation throughout this manual. Programming commands are listed in tables, and additional information that pertains exclusively to remote operation is provided after each table. The tables may reference you to other sections of this manual.

NOTE *Except for Section 11 through Section 15, most programming tables in this manual are abridged. That is, they exclude most optional command words and query commands. Optional command words and query commands are summarized as follows.*

Optional command words — In order to be in conformance with the IEEE-488.2 standard, Model 2701 accepts optional command words. Any command word that is enclosed in brackets ([]) is optional and does not have to be included in the program message.

Query commands — Most command words have a query form. A query command is identified by the question mark (?) that follows the command word. A query command requests (queries) the programmed status of that command.

NOTE *For complete details, see "Programming syntax," page 10-21.*

Quick start exercises (QS3)

This section topic summarizes the following basic instrument operations and provides simple exercises to perform them:

- Basic DMM measurements — front panel inputs.
- Closing and opening channels — system channel operation.
- Simple scanning.
- Trigger and return readings — remote programming.

NOTE *For remote operations, you can use the internal web page of the Model 2701 to send commands, queries, and take readings. See "Internal web page" in Section 10 for details.*

WARNING **For the exercises, it is not necessary to connect an input signal or DUT to the instrument (front panel inputs or switching module inputs). However, if you decide to use an input signal, it is recommended that you keep it at a nonhazardous level (<42V) while learning to use the instrument.**

NOTE *When using the front panel input terminals, the INPUT switch must be in the "F" (out) position. The INPUT switch is located on the right side of the front panel near the input terminals. When using a switching module, the switch must be in the "R" (in) position.*

Basic DMM measurements — front panel inputs

NOTE *See Section 3 for details on basic DMM operation.*

The Model 2701 is shipped from the factory to power-up to factory defaults. The instrument powers up to a setup that continuously measures DC volts. Some of the default settings for the DCV function include auto range enabled, 6½-digit resolution, filter enabled, and slow reading rate. These settings provide a good starting point and in many cases, do not need to be changed.

"Starting-point" default settings are also provided for the other measurement functions. Therefore, to perform basic measurements, simply select the desired function, and "tweak" the setup (range, rate, filter, digits, etc.) as required.

For remote programming, the instrument is typically used in a non-continuous measurement mode. In this mode, the user (via remote command programming) specifies the number of measurements to perform. *RST defaults place the instrument in a non-continuous measurement mode. Most of the other settings for factory and *RST defaults are the same.

For remote programming, the following command is used to select function.

NOTE *Items in brackets ([]) are optional and do not need to be included. Upper case characters are required. Lower case characters are optional and need not be included.*

```
[SENSe[1]]:FUNCtion <func>          'Select measurement function.'
    <func> ='VOLTage[:DC]'          DCV
            'VOLTage:AC'            ACV
            'CURRent[:DC]'          DCI
            'CURRent:AC'            ACI
            'RESistance'            Ω2
            'FRESistance'           Ω4
            'FREQuency'             FREQ
            'PERiod'                PERIOD
            'TEMPerature'           TEMP
```

Each function can have its own unique setup configuration (i.e., range, digits, speed, etc.). For example, the following command words select range and digits:

```
RANGe[:UPPer] <n> ' Specify expected reading.
RANGe:AUTO <b>    ' Enable (ON) or disable (OFF) auto range.
DIGits            ' Set display resolution; 3.5, 4.5, 5.5, or 6.5 (digits).
```

The following examples demonstrate how to include the function name in the command string for configuration commands.

```
VOLT:RANG 10                        '  Select 10V range for DCV.
RES:RANG:AUTO ON                    '  Enable auto range for Ω2.
CURR:DIG 4.5                        '  Set DCI for 4½-digit resolution.
```

NOTE *See Section 4 for details on setting range, digits, rate, bandwidth, and filter.*

Exercise 1 — Basic DMM measurements

The exercise in Table 1-6 measures ACV on the 10V range and stores 15 readings in the buffer.

Table 1-6
Exercise 1—Measure AC volts - store readings in buffer

	Front panel operation	Command sequence
1	For front panel operation, proceed to step 2. For remote programming, clear the buffer[1]:	`TRAC:CLE`
2	Restore defaults[2]: Press SHIFT > press SETUP > select RESTORE: FACT.	`*RST`
3	Select ACV function: Press ACV.	`FUNC 'VOLT:AC'`
4	Select 10V range: Press RANGE ▲ to display "RANGE: 10V".	`VOLT:AC:RANG 10`
6	Store 15 readings in buffer[3]: Press STORE > set for 000015 RDGS > press ENTER.	`SAMP:COUN 15` `READ?`
7	Recall buffer readings[4]: Press RECALL > use edit keys to display readings. Press EXIT to exit recall mode.	`CALC1:DATA?`

1. To avoid problems with remote programming, it is good practice to routinely clear the buffer (`TRAC:CLE`) at the beginning of a program that performs multiple measurements (`SAMP:COUN >1`). Restoring *RST or FACTory defaults does not clear the buffer.
2. FACTory defaults place the instrument in a continuous measurement mode. *RST places the instrument in a non-continuous measurement mode.
3. READ? triggers and returns 15 readings. These 15 readings are automatically stored in the buffer. See Exercise 4 and 5 for more information on the READ? command.
4. Statistics for buffer readings are also stored in the buffer. For remote programming, `CALC1:DATA?` only returns the readings that were stored. It does not return buffer statistics. `CALC2` commands are used to calculate and return buffer statistics (see Section 6 for details).

Closing and opening channels — system channel operation

NOTE *See Section 2 for details on closing and opening switching module channels.*

NOTE *The following discussion assumes a multiplexing switching module (i.e., Model 7700) is installed in slot 1 of the mainframe. Switching module installation is covered in Section 2 (see "Switching module installation and connections," page 2-4).*

An alternative to installing a switching module is to assign slot 1 as a pseudocard using remote programming. The instrument will operate as if a switching module is installed in slot 1. To "install" a 7700 pseudocard in slot 1, send the following command:

```
SYST:PCAR1 C7700
```

System channel operation is used to connect input channels to the DMM of the Model 2701:

- For a 2-wire function (i.e., DCV), closing a system channel connects the input to DMM Input of the Model 2701.

  Figure 1-4 shows system channel 1 closed. For the Ω2 function, the resistance (DUT) would be connected to DMM Input as shown Figure 1-4.

- For a 4-wire function (i.e., Ω4), a channel pair is connected to the DMM when a system channel is closed. The system channel is connected to DMM Input and the paired channel is connected to DMM Sense.

  Figure 1-5 shows system channel 6 closed. For a 4-wire function, the paired channel also closes. For the Model 7700, channels 1 through 10 are paired to channels 11 through 20. When channel 6 is closed, channel 16 also closes. Figure 1-5 shows how the DUT is connected to the DMM for the 4-wire function.

NOTE *Figure 1-4 and Figure 1-5 show simplified schematics of the switching module. They show a single switch closed to connect an input channel to the DMM. In reality, multiple switching is used to make proper connections to the DMM. However, for system channel operation, the user need not be concerned about which switches in the module close.*

Figure 1-4
Connection to DMM for 2-wire function (system channel 101 closed)

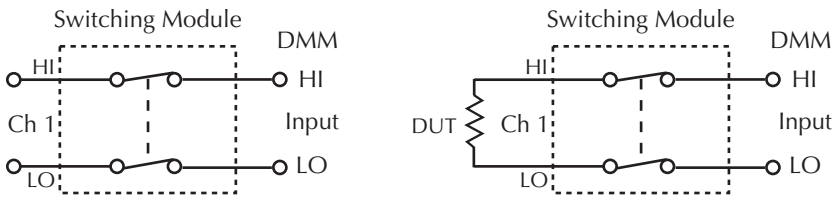
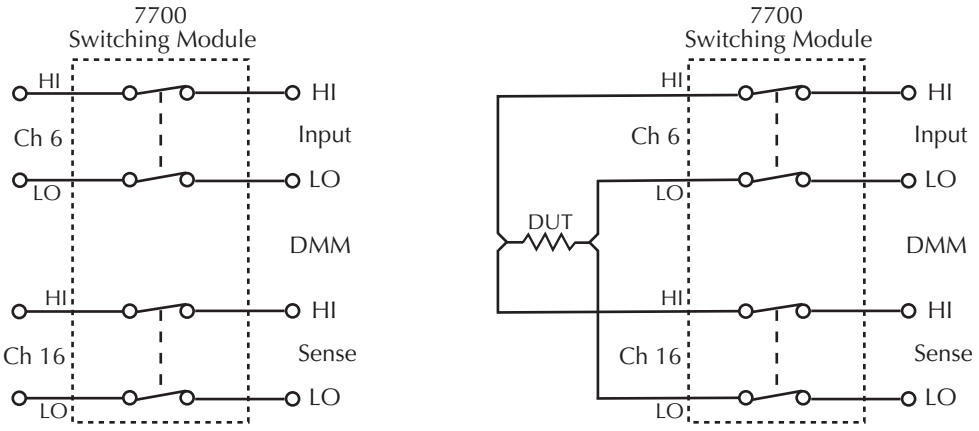


Figure 1-5
Connection to DMM for 4-wire function (system channel 106 closed)



NOTE *Switching module channels can also be controlled using multiple channel operation. This allows individual control of all module channels (switches). Multiple channel operation should only be used by experienced service personnel who recognize the dangers associated with multiple channel closures. See Section 2 for details.*

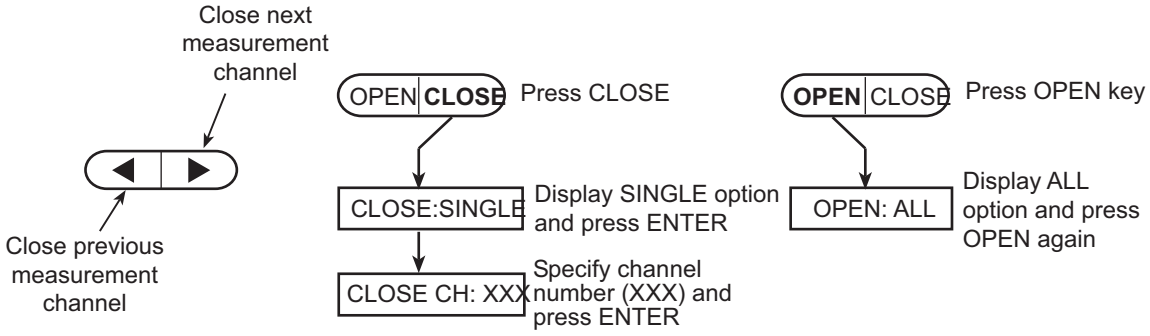
Close/open operation

The following points on operation pertain to system channel operation only:

- Only one input channel (or channel pair) is closed at one time. When you close an input channel, the previously closed input channel(s) will open.
- When a system channel is closed, the channel number will be displayed on the Model 2701. The slot number for the module is also displayed. For example, "103" indicates that system input channel 3 for a module in slot 1 is closed.
- The paired channel for a 4-wire function is not displayed. Only the system channel number is displayed. For example, in Figure 1-5, channel number 106 will be displayed with the Model 7707 installed in slot 1 of the mainframe.
- Switching modules that have current measurement capability have separate channels reserved exclusively for the DCI and ACI functions. For example, the Model 7700 has channels 21 and 22 reserved for amps measurements. With the DCI or ACI function selected, only channels 21 and 22 can be closed. These channels cannot be accessed on any other function.

Figure 1-6 shows the front panel keys used to close and open system channels.

Figure 1-6
Front panel keys to close and open system channels



For remote programming, the following three commands are used for basic system operation to open and close input channels:

```
ROUTe:CLOSe <clist>                 '  Close specified system channel[1].
ROUTe:CLOSe?                        '  Query closed system channel[2].
ROUT:OPEN ALL                       '  Open all channels.
```

1. Only one channel can be specified in the <clist>. For example, to close input channel 3 for a module in slot 1, the following command would be sent:
   `ROUTe:CLOSe (@103)`
2. Only the closed system channel is returned by `ROUTe:CLOSe?`. The paired channel for a 4-wire function is not returned. For example, assume channel 2 in slot 1 is closed. The following response message will be returned:
   `(@102)`

Exercise 2 — Closing and opening channels (system channel operation)

The exercise in Table 1-7 demonstrates a sequence to close and open channels of a Model 7700 installed in slot 1 of the mainframe.

Table 1-7
Exercise 2 — Close and open channels (system channel operation)

	Front panel operation	Command sequence
1	Open all channels*: Press OPEN > display OPEN:ALL > Press OPEN.	`ROUT:OPEN ALL`
2	Select Ω2 function: Press Ω2.	`FUNC 'RES'`
3	Close system channel 101: Press the ▸ key. Channel 1 connects to DMM Input (see Figure 1-4).	`ROUT:CLOS (@101)`
4	Close system channel 102: Press the ▸ key. Channel 2 connects to DMM Input.	`ROUT:CLOS (@102)`
5	Close system channel 106: Press CLOSE > select CLOSE:SINGLE > key in channel 106 > press ENTER. Channel 6 connects to DMM Input.	`ROUT:CLOS (@106)`
6	Select Ω4 function: Press Ω4. 4W annunciator turns on and channels 6 and 16 connect to DMM Input and Sense (see Figure 1-5).	`FUNC 'FRES'`
7	Open all channels*: Press OPEN > display OPEN:ALL > Press OPEN.	`ROUT:OPEN ALL`

*It is a good, safe practice to start and end a switching sequence by opening all channels.

Simple scanning

NOTE *See Section 7 for details on scanning.*

With at least one multiplexer switching module (i.e., Model 7700) installed in the mainframe, the instrument can scan channels that are valid for the selected function.

For front panel operation, Figure 1-7 shows the three basic steps to configure and run a simple scan. The differences between the STEP function and the SCAN function involve the reading count and the timer.

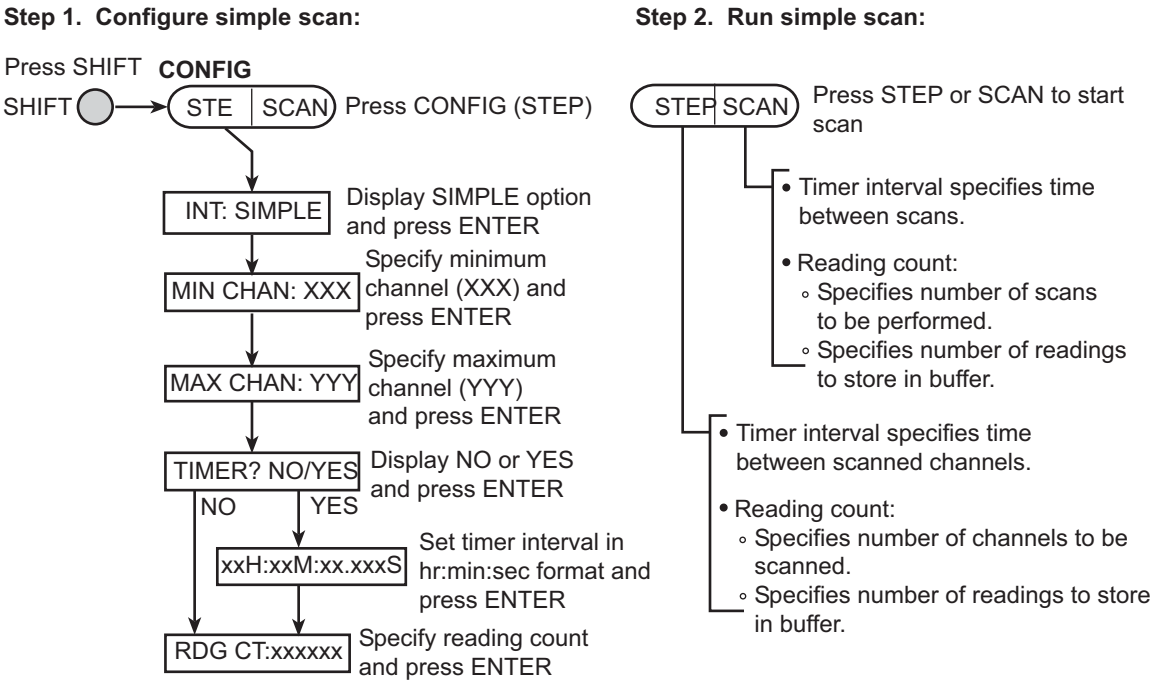
Reading count (RDG CT) — For both STEP and SCAN, the reading count specifies the number of readings to store in the buffer. For STEP, the reading count determines the number of channels to scan.

For SCAN, the reading count also determines the number of scans to perform and is best explained by an example. Assume there are 10 channels in the scan list (i.e., 101 through 110). If you set the reading count to 10 or less, one scan of the 10 channels will be performed. If you set the reading count to any value from 11 to 20, two scans will be performed. A reading count from 21 to 30 gives you three scans, and so on.

Timer interval (TIMER) — For the STEP function, the timer specifies the time delay between scanned channels. For the SCAN function, the interval specifies the time delay between scans. The timer starts when the scan is started. For SCAN, the next scan will not start until the timer interval expires.

NOTE *The Model 2701 can also be configured to run an advanced scan. For an advanced scan, each channel can have its own unique setup (i.e., function, range, etc.). Advanced scanning is covered in Section 7.*

Figure 1-7
Simple scan operation



Step 3. Disable scan mode:



For remote programming, the following commands are used for simple scanning:

```
ROUTe:SCAN <clist>          ' Define scan list*.
TRIGger:COUNt <NRf>         ' Specify number of scans (1 to 450000 or
                              INFinity).
SAMPle:COUNt <NRf>          ' Specify number of channels to scan (1 to
                              450000).
ROUTe:SCAN:LSELect <name>   ' Enable (INT) or disable (NONE) scan.
```

* Any valid switching module channel can be included in the scan list. Make sure to list them from the lowest numbered channel to the highest. For example, to scan channels 1 through 8 of a Model 7700 installed in slot 1, send the following command to define the scan list:

```
ROUTe:SCAN (@101:108)
```

Exercise 3 — Simple scanning

The scanning example in Table 1-8 assumes a Model 7700 installed in slot 1 of the mainframe. The scan will use default settings (DCV) to scan eight channels and store the readings in the buffer.

Table 1-8
Exercise 3 — Simple scanning

	Front panel operation	Command sequence
1	For front panel operation, proceed to step 2. For remote programming, clear the buffer.	`TRAC:CLE`
2	Restore defaults[1]: Press SHIFT > press SETUP > select RESTORE: FACT.	*RST
3	Configure scan: Press SHIFT > press CONFIG > select INT: SIMPLE > set MIN CHAN101 > set MAX CHAN: 108 > select TIMER? NO > set RDG CT:000008.	ROUT:SCAN (@101:108) SAMP:COUN 8
4	Enable and start scan[2]: Press STEP.	ROUT:SCAN:LSEL INT INIT
5	Halt (disable) scanner: Press SHIFT > press HALT.	ROUT:SCAN:LSEL NONE
6	Recall the eight stored readings: Press RECALL > use edit keys to display readings. Press EXIT to exit recall mode.	CALC1:DATA?
7	Open all channels: Press OPEN > display OPEN:ALL > Press OPEN.	`ROUT:OPEN ALL`

1. Factory and `*RST` defaults opens all channels, select the DCV function and sets `TRIG:COUN` to `1`. The trigger count specifies the number of scans to be performed.
2. `ROUT:SCAN:LSEL INT` enables the scan, and `INIT` trigger the start of the scan.

Trigger and return readings — remote programming

There are several commands used to trigger and return readings. The proper commands and sequence to use depend on the trigger state (continuous or non-continuous) and what you are trying to accomplish.

Presented here are three fundamental command sequences that can be used to "trigger and return readings." These three command sequences (exercises) will accommodate most basic measurement scenarios. Simply use the command sequence (exercise) that satisfies your needs:

- Exercise 4 — Trigger and return a single reading
- Exercise 5 — Trigger and return multiple readings
- Exercise 6 — Return a single reading (continuous triggering)

Details on the commands to trigger and return readings are provided in other sections of this manual. For details, refer to the following sections:

Section 3 — See "Trigger and retrieve readings" in Table 3-7.

Section 7 — For scanning, see "Trigger commands" in Table 7-1.

Section 8 — Explains the triggering process.

Section 13 — Covers Signal Oriented Measurement Commands (i.e., FETCh?, READ?).

Section 15 — See Table 15-9 (Trigger command summary).

Appendix D — Shows how trigger and read commands control data flow within the instrument.

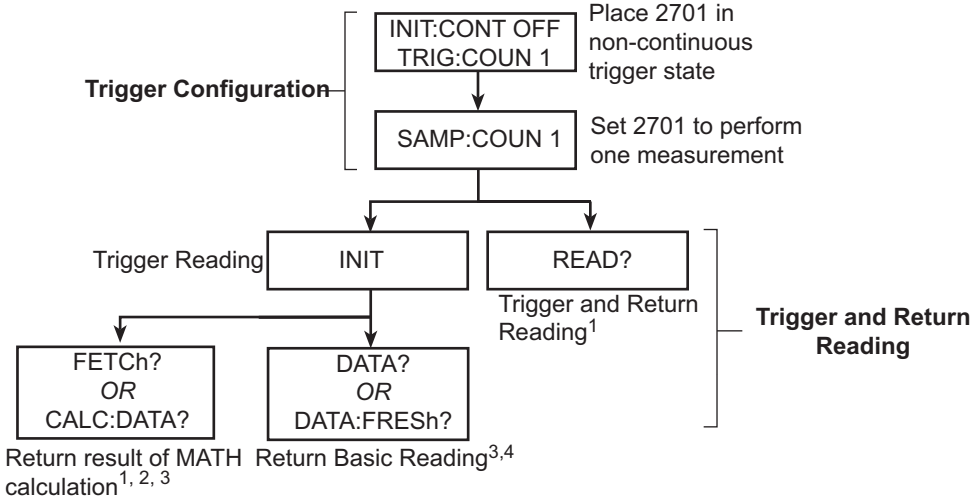
NOTE *Each exercise indicates the commands used to configure triggering ("Trigger configuration"). Once triggering is configured, the commands to trigger and/or return readings can be repeated as often as desired (unless noted otherwise).*

Exercise 4 — Trigger and return a single reading
Exercise 5 — Trigger and return multiple readings

Trigger controlled measurements — The instrument is typically used in a non-continuous trigger mode. In this mode, commands are used to trigger one or more readings. After the specified number of readings are completed, the measurement process stops.

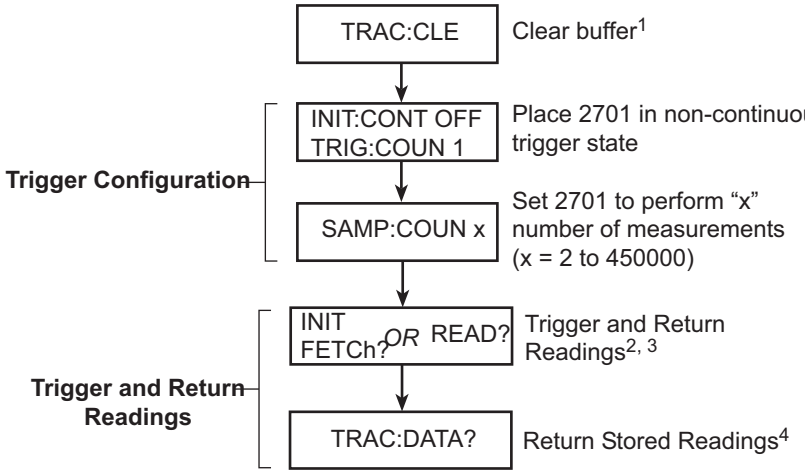
Exercise 4 in Figure 1-8 provides a command sequence to trigger and return one reading. Exercise 5 in Figure 1-9 provides a command sequence to trigger and return multiple readings.

Figure 1-8
Exercise 4 — Trigger and return a single reading



1. If a MATH function (mX+B, percent, or 1/X) is enabled, the result of the calculation will be returned (MATH functions are covered in Section 5).
2. If there is no MATH function enabled, FETCh? and CALC:DATA? will return the basic reading.
3. FETCh?, CALC:DATA?, and DATA? do not trigger readings. They simply return the last reading. If you again send one of these commands before triggering a new reading, the old reading will be returned.
4. DATA:FRESh? can only be used once to return the same reading. Sending it again without first triggering a new reading will cause error -230 (data corrupt or stale).

Figure 1-9
Exercise 5 — Trigger and return multiple readings

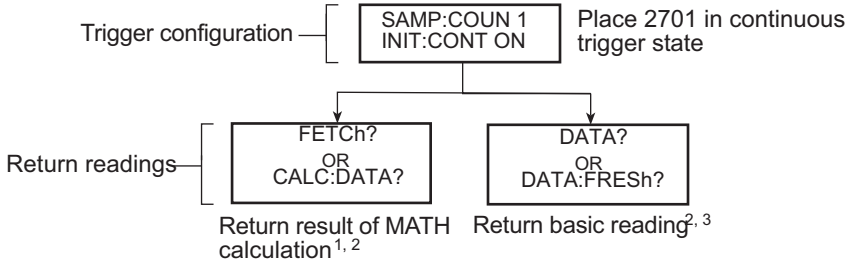


1. In order to trigger and return multiple readings, the buffer must first be cleared of readings that were stored by the TRACe command or front panel operation (see Section 6 for details on buffer operation).
2. INIT triggers the measurements and FETCh? returns the readings. Again sending FETCh? without first sending INIT will return old readings.
3. READ? performs an INIT to trigger the measurements and then FETCh? to return the reading(s).
4. Triggered readings are automatically stored in the buffer. Statistics for buffer readings are also stored in the buffer. CALC2 commands are used to calculate and return buffer statistics (see Section 6 for details).

Exercise 6 — Return a single reading (continuous triggering)

Readings can be returned while the instrument is in the continuous measurement (trigger) mode. Each time a read command is sent, the latest reading is returned. Exercise 6 in Figure 1-10 provides a command sequence to return a single reading while in the continuous trigger state.

Figure 1-10
Exercise 6 — Return a single reading (continuous triggering)



1. If a MATH function (mX+B, percent, or 1/X) is enabled, the result of the calculation will be returned. If there is no MATH function enabled, FETCh? and CALC:DATA? will return the basic reading. MATH functions are covered in Section 5.
2. None of these read commands trigger measurements. They simply return the lastest reading.
   If FETCH?, CALC:DATA?, or DATA? is again sent before a new reading is triggered, the
3. DATA:FRESh? can only be used once to return the same reading. Sending it again before a new reading is triggered will cause error -230 (data corrupt or stale).

2
Closing and Opening Switching Module Channels

- Close/open overview — Summarizes the two operating modes to control switching modules: system channel operation and multiple channel operation.
- Switching module installation and connections — Explains how to install a switching module (or pseudocard) into the Model 2701 mainframe. Also explains where to find connection information which should only be performed by qualified service personnel.
- Channel assignments — Explains the format for specifying the mainframe channel assignment which is made up of the slot number and switching module channel number.
- System channel operation — Provides detailed information for using system channel operation.
- Multiple channel operation — Provides detailed information for using multiple channel operation. Due to safety considerations, this operating mode should only be used by experienced test engineers.
- Identifying installed modules and viewing closed channels — Explains how to use the CARD menu to identify installed switching modules and view closed channels. Explains how to remotely identify installed modules (*OPT?) and summarizes other query commands that can be used to acquire information about the installed modules.
- Model 7700 switching module — Covers operating characteristics that are unique to the Model 7700. Also includes a simplified schematic diagram of the switching module.

Close/open overview

NOTE *For remote operations, you can use the internal web page of the Model 2701 to send commands, queries, and take readings. See "Internal web page" in Section 10 for details.*

NOTE *This section covers basic close/open operations for switching module channels. It also covers the operating characteristics that are unique to the Model 7700 switching module.*

There are two modes of close/open operation:

- System channel operation — This is the mode of operation that should be used exclusively by most (if not all) users. When you close an input channel (or channel-pair), other channels on the switching module close automatically to internally connect it the DMM of the Model 2701.
- Multiple channel operation — This mode of operation provides additional flexibility by providing individual control of each switching module channel. However, careless operation could create a safety hazard and/or damage the switching module and other equipment. Multiple channel operation should only be used by experienced test engineers.

CAUTION To prevent damage to a switching module, do not exceed the maximum signal level input for that module. Most switching modules are rated for 303V. The following command queries maximum module voltage:

SYSTem:CARDx:VMAX? 'Request maximum allowable voltage for 'CARDx (where x is the slot number for 'the module).

For system channel operation, the instrument will display the "OVERFLOW" message when the maximum allowable voltage for the module is being exceeded.

However, for multiple channel operation, the "OVERFLOW" message will not occur until the maximum voltage of the mainframe (not module) is exceeded. Therefore, the "OVERFLOW" message would occur only if 1010V is exceed.

WARNING Careless multiple channel operation could create an electric shock hazard that could result in severe injury or death. Improper operation can also cause damage to the switching modules and external circuitry. Multiple channel operation should be restricted to experienced test engineers who recognize the dangers associated with multiple channel closures.

NOTE The Model 2701 can scan switching module channels. Each channel in the scan can have its own unique setup configuration. Scanning is covered in Section 7.

NOTE When a setup is saved as a user setup (SAV0, SAV1, SAV2, SAV3, or SAV4), closed channels are also saved. When the setup is restored, those channels (and only those channels) will be closed (see "Defaults and user setups," page 1-21).

Switching module installation and connections

In order to exercise close/open operations explained in this section, a switching module (or pseudocard) must be installed in the mainframe. A switching module can be installed by the user, however external connections to the switching module are only to be performed by qualified service personnel.

NOTE *For inexperienced users, it is recommended that DUT and external circuitry not be connected to switching modules. This will allow you to exercise close/open operations without the dangers associated with live test circuits.*

WARNING To prevent electric shock that could result in injury or death, NEVER handle a switching module that has power applied to it:

- Before installing (or removing) a switching module, make sure the Model 2701 is turned off and disconnected from line power.
- If the switching module is already connected to DUT, make sure power is removed from all external circuitry.

Module installation

WARNING Slot covers must be installed on unused slots to prevent personal contact with high voltage circuits.

Perform the following steps to install a switching module into the Model 2701 mainframe:

1. Turn the Model 2701 off and disconnect the power line cord and any other cable connected to the rear panel.
2. Position the Model 2701 so you are facing the rear panel.
3. Remove the slot cover plate from the desired mainframe slot. Retain the plate and screws for future use.
4. With the top cover of the switching module facing up, slide the module into an empty slot. For the last half inch or so, press in firmly to mate the module connector to the mainframe connector.
5. On each side of the module, there is a mounting screw. Tighten these two screws to secure the module to the mainframe. Do not overtighten.
6. Reconnect the power line cable and any other cables to the rear panel.
7. When you turn on the Model 2701, the model number of the switching module will be briefly displayed.

Connections

WARNING Connection information for switching modules is intended for qualified service personnel. Do not attempt to connect DUT or external circuitry to a switching module unless qualified to do so.

WARNING To prevent electric shock that could result in serious injury or death, adhere to the following safety precautions:

- Before making or breaking connections to the switching module, make sure the Model 2701 is turned off and power is removed from all external circuitry.
- Do not connect signals that will exceed the maximum specifications of switching modules. Each module is provided with its own unique specifications.

WARNING If both the front panel terminals and the switching module terminals are connected at the same time, the test lead insulation must be rated to the highest voltage that is connected. For example, if 1000V is connected to the front panel input, the test lead insulation for the switching module must also be rated for 1000V.

WARNING Dangerous arcs of an explosive nature in a high energy circuit can cause severe personal injury or death. If the multimeter is connected to a high energy circuit when set to a current range, low resistance range, or any other low impedance range, the circuit is virtually shorted. Dangerous arcing can result even when the multimeter is set to a voltage range if the minimum voltage spacing is reduced in the external connections. For details to safely make high energy measurements, see Section 3, "High energy circuit safety precautions."

As described in the International Electrotechnical Commission (IEC) Standard IEC 664, the Model 2701 measurement terminals are measurement Category I and must not be connected to mains.

For the Model 7700, detailed connection and wiring information is provided in Appendix B of this manual (Model 7700 Connection Guide). Connection and wiring information for other modules are provided with the individual switch cards.

Pseudocards

Using remote programming, you can assign a pseudocard to an empty switching module slot. With a pseudocard installed, the Model 2701 will operate as if the switching module is installed in the Model 2701. This feature allows you to exercise open/close/scan operations, or configure your system without having the actual switching module installed in the unit. There is a pseudocard for every Keithley Model 77XX series switching module.

A pseudocard cannot be installed from the front panel. However, once it is installed you can take the Model 2701 out of remote and use the front panel. Pressing the LOCAL key takes the Model 2701 out of remote.

When the instrument is turned off, the pseudocard will be lost (uninstalled). Use the following commands to install pseudocards:

```
SYSTem:PCARd1 <name>                ' Install pseudocard in slot 1.
SYSTem:PCARd2 <name>                ' Install pseudocard in slot 2.
<name> =  C7700, C7701, C7702, C7703, C7705, C7706, C7707, C7708, C7709,
          C7710, C7711 or C7712
```

Programming example — The following command sets up the Model 2701 to operate as if a Model 7700 switching module is installed in slot 2, which must be empty. You cannot assign a pseudocard to a slot that already has a switching module installed in it.

```
SYSTem:PCAR2 C7700              ' "Install" pseudocard 7700 for slot 2.
```

Channel assignments

The Model 2701 has two slots for switching modules. To control the appropriate switching module, the slot number must be included with the switching module channel number when you specify a channel. The channel assignment is formatted as follows:

SCH where: S is the slot number
CH is the channel number

Examples:

101 = Slot 1, Channel 1
210 = Slot 2, Channel 10

For remote operation, the 3-digit channel assignment is included in the channel list parameter for the commands. Format examples for the channel list parameter are provided in Table 2-1 and Table 2-2.

System channel operation

The system channel is a closed measurement channel that is internally connected to the internal DMM Input of the Model 2701. The system channel number is displayed on the Model 2701. For a 4-wire function (i.e., Ω4), the paired channel for the system channel is internally connected to DMM Sense. The paired channel is not displayed on the Model 2701. When triggered, the DMM performs a measurement and displays it on the Model 2701.

The system channel is selected by closing a measurement channel using the system channel close keys. These include the ◂ and ▸ keys or the CLOSE key (SINGLE menu option). See "Controlling the system channel," page 2-10, for details.

Other important points about system channel operation include the following:

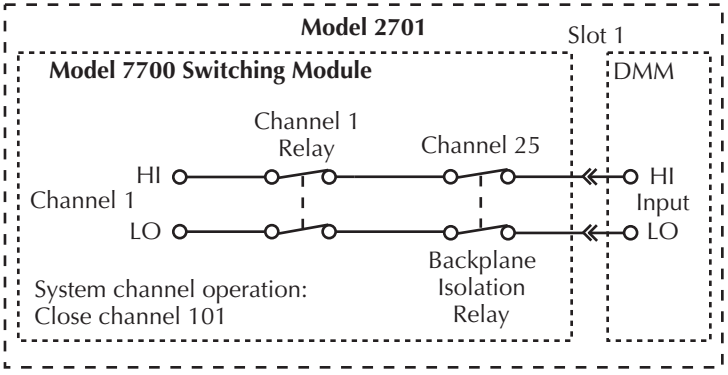
- There can only be one system channel. This is the channel that is presently displayed (and closed) on the Model 2701. When a channel is not displayed, there is no system channel.
- When a measurement channel is closed, the input backplane isolation channel also closes to connect the system channel to DMM input. For a 4-wire function, the paired channel and the sense backplane isolation channel also close to make the sense connections to the DMM.
- When a different measurement channel is closed, the previous system channel opens. The newly closed (and displayed) measurement channel becomes the system channel.
- The system channel close keys can only close measurement channels that will automatically connect to the DMM. Non-measurement channels cannot be closed by the system channel close keys.

NOTE *Use the VIEW option of the CARD menu to display all closed channels in the mainframe (see "CARD menu," page 2-30).*

2-wire functions

Figure 2-1 shows an example of how the system channel is connected to the DMM Input of the Model 2701. Assume a Model 7700 switching module is installed in slot 1 of the mainframe. When channel 101 is closed using the system channel close keys, both the Channel 1 relay and the backplane isolation relay (Channel 25) close to connect the channel to the DMM. The complete simplified schematic of the Model 7700 is provided in Figure 2-12.

Figure 2-1
2-wire system channel connections to Model 2701 DMM



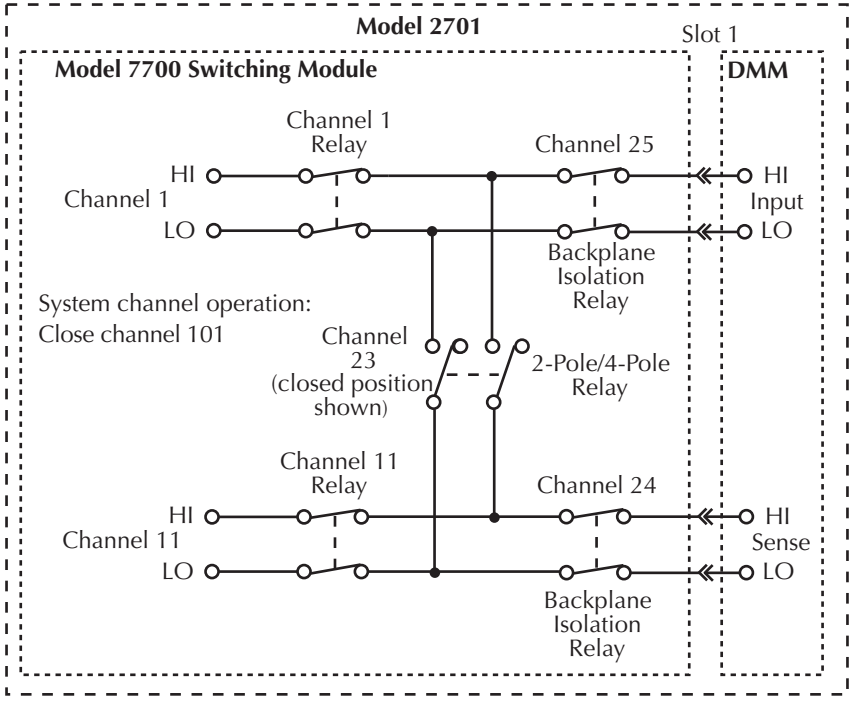
4-wire functions (paired channels)

A 4-wire function, such as Ω4, requires that another measurement channel be paired to the system channel. For example, if the switching module has 20 measurement channels, channels 1 through 10 can be used as the system channel, while channels 11 through 20 are used as the paired channel. For a switching module that has 20 measurement channels, channel 1 is paired to channel 11, channel 2 is paired to channel 12, channel 3 is paired to channel 13, and so on.

Figure 2-2 shows an example of system channel connections for a 4-wire function. Assume a Model 7700 switching module is installed in slot 1 of the mainframe, and a 4-wire function, such as Ω4, is selected. When channel 101 is closed using the system channel close keys, the Channel 1 relay and the input backplane isolation relay (Channel 25) closes to connect the channel to DMM Input. Also, the Channel 11 relay and the sense backplane isolation relay (Channel 24) close to connect the paired channel to DMM Sense. Also, note in Figure 2-2 that the Channel 23 relay closes to isolate channel 1 from channel 11.

The complete simplified schematic of Model 7700 is provided in Figure 2-12.

Figure 2-2
4-wire system channel connections to Model 2701 DMM



Controlling the system channel

When a measurement channel is closed, a previous system channel (and, for a 4-wire function, its paired channel) is first opened. The closed measurement channel becomes the system channel. When a 4-wire function is selected, the paired channel for the system channel also closes.

◂ and ▸ keys

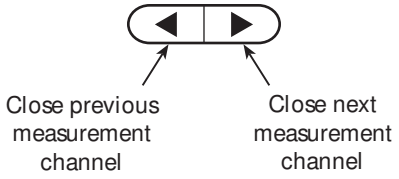
These front panel keys (Figure 2-3) can be used to select the next or previous measurement channel as the system channel. If there are no measurement channels available, one of the following messages will be briefly displayed when one of these keys is pressed:

NO SCAN CARD — This message indicates that there are no switching modules (or pseudocards) installed; both slots are empty.

NO MEAS CARD — This message indicates that none of the installed switching modules (or pseudocards) have measurement channels. For example, the Model 7705 switching module does not have any measurement channels. Those channels cannot be internally connected to the DMM.

NOTE *The ◂ and ▸ keys can also be used to open all channels in the mainframe. Simply increment or decrement the channel number until there is no channel displayed.*

Figure 2-3
System channel operation — closing next or previous measurement channel



CLOSE key (SINGLE menu option)

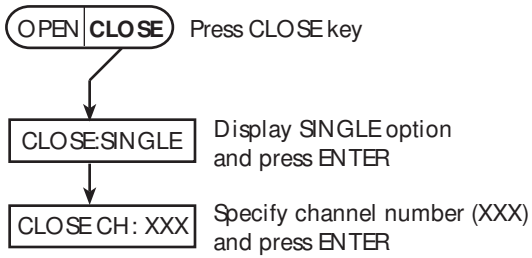
The SINGLE menu option for the CLOSE key can be used to select a measurement channel as the system channel (Figure 2-4). Perform the following steps to select the system channel:

1. Press the CLOSE key. The "CLOSE:SINGLE" message will be displayed.

NOTE *If the "CLOSE:MULTI" message is instead displayed when CLOSE is pressed, it indicates that there are no measurement modules installed in the mainframe. See "Multiple channel operation," page 2-16, to close the channels of a non-measurement module (i.e., Model 7705).*

2. Press ENTER to display the prompt to close a channel (CLOSE CH: XXX).
3. Using ◄, ►, ▲, and ▼, key in the three-digit channel you want to select.
4. Press ENTER. The channel closes and the CHAN annunciator turns on.

Figure 2-4
System channel operation — specifying measurement channel to close



An invalid channel cannot be closed and will cause one of the following error messages to be briefly displayed:

INVALID CHAN — This message indicates that the channel is not a valid measurement channel. The following actions will cause this error:

- Trying to close a non-measurement channel, such as a backplane isolation channel, a channel that sets the pole mode, or a channel that cannot be internally connected to the DMM.
- Trying to close an amps channel while on a non-amps function. The DCI or ACI function must be selected in order to close an amps channel.
- Trying to close a paired-channel while on a 4-wire function. For the Model 7700, channels 1 through 10 are paired to channels 11 through 20 for a 4-wire function. If, for example, you try to close channel 12 while on the Ω4 function, the INVALID CHAN error will occur.
- Trying to close a switching module channel that does not exist.

TOO SMALL or TOO LARGE — These messages also indicate an invalid channel. TOO SMALL indicates that the specified channel and any other lower numbered channel is invalid. TOO LARGE indicates that the specified channel and any other higher numbered channel is invalid.

OPEN key (ALL menu option)

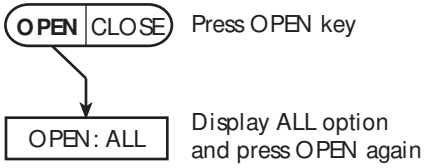
The ALL menu option of the OPEN key opens all channels for all switching modules installed in the Model 2701 (Figure 2-5). For example, if a Model 7700 switching module is installed in slot 1, OPEN: ALL will open all measurement channels (101 to 120, 121, and 122), the backplane isolation channels (124 and 125) and the 2-pole/4-pole channel (123). Figure 2-2 shows the backplane isolation channels and the 2-pole/4-pole channel for the Model 7700.

Perform the following steps to open all channels:

1. Press the OPEN key to display "OPEN: ALL."
2. Press OPEN a second time (or press ENTER) to open all channels.

NOTE *Opening the system channel disables Ratio or Channel Average. Ratio and Channel Average operation are covered in Section 5.*

Figure 2-5
System channel operation — opening all channels in mainframe



Remote programming — system channel control commands

The commands to close and open the system channel are listed in Table 2-1. When a system channel reading is returned, the system channel number will be included in the data string if the CHANnel data element is selected. The FORMat:ELEMents command is used to specify the data elements to be included in the data string (see FORMat commands in Section 14).

Table 2-1
System channel control commands

Commands	Description	Ref
ROUTe:CLOSe <clist>	Specify one measurement channel to close.	a
ROUTe:CLOSe:STATe? <clist>	Query closed channels in specified list (1 = closed).	b
ROUTe:CLOSe?	Returns a <clist> of closed measurement channels.	c
ROUTe:OPEN:ALL	Open all channels, and disable ratio and channel average.	d
Channel list parameter: <clist> = (@SCH) where: S = Mainframe slot number (1 or 2) CH = Switching module channel number (must be 2 digits) Examples: (@101) = Slot 1, Channel 1 (@101, 203) = Slot 1, Channel 1 and Slot 2, Channel 3 (@101:110) = Slot 1, Channels 1 through 10		

Reference:

a. ROUTe:CLOSe <clist>

This command functions the same as the front panel CLOSE key (SINGLE menu option) to select the system channel. Only one measurement channel can be specified in the <clist>.

Trying to close an invalid channel (such as a non-measurement channel) with this command will result in error -222 (Parameter data out of range).

b. ROUTe:CLOSe:STATe? <clist>

This query returns a "0" (open) or "1" (closed) for every measurement channel specified in the <clist>. For example, assume <clist> = (@101, 104, 107, 102). The response message "0, 0, 1, 0" indicates that channel 107 is closed.

The state of non-measurement channels cannot be checked with this command.

c. ROUTe:CLOSe?

This query command returns a <clist> of closed measurement channels, including paired channels for 4-wire functions.

This query command will not return non-measurement channels, such as backplane isolation channels and the pole-mode channel.

d. ROUTe:OPEN:ALL

This command functions the same as the front panel OPEN key (ALL menu option). It simply opens all channels (including non-measurement channels) installed in the mainframe.

Remote programming example (system channel operation)

The following example assumes a Model 7700 installed in slot 1, and the Ω4 function of the Model 2701 is selected. This command sequence connects channel 101 and its paired channel (111) to DMM Input and Sense as shown in Figure 2-2.

```
ROUT:OPEN:ALL                ' Open all channels.
ROUT:CLOS (@101)             ' Close channels 101, 111, 123, 124, and 125.
```

Non-amp and non-measure switching modules

There are Keithley switching modules that do not support current measurements and there are modules that do not support any measurements at all.

Non-amps module — With an amps function selected (DCI or ACI), system channel operation cannot be used to close channels on that module.

Non-measure module — For front panel operation, system channel operation cannot be used to close channels. For remote programming, system channel operation can be used, but only the one specified channel will close. All other channels on the module will open.

Non-amps switching modules

NOTE *Presently, non-amps Keithley modules include the Models 7701, 7703, 7706, 7707, 7708, and 7709. You can check the Keithley website (www.keithley.com) for new modules.*

A non-amp module does not support amps measurements. System channel operation cannot be used to close channels while an amps function (DCI or ICI) is selected.

If an amps function (DCI or ACI) is selected and you attempt to close a system channel, the message "NO AMPS CHAN" will be displayed briefly. For remote programming, error -222 (Parameter data out of range) is generated. Example:

```
SYST:PRES                ' Restores system preset defaults.
SENS:FUNC 'CURR:DC'      ' Selects DCI function.
ROUT:CLOS (@101)         ' Attempts to close system channel 101 - Generates
                         ' error -222.
```

If a system channel is already closed and you attempt to select the DCI or ACI function, the message "INVALID FUNC" will be displayed briefly. For remote programming, error -221 (Settings conflict) is generated. Example:

```
SYST:PRES                    ' Restores system preset defaults.
ROUT:CLOS (@101)             ' Close system channel 101.
SENS:FUNC 'CURR:DC'          ' Attempts to select DCI function - Generates
                             ' error -221.
```

Making amps measurements — In order to perform amps measurements, you must use the front panel inputs of the 2701 mainframe. You can still use the non-amps module for other aspects of the test, but you must use multiple channel operation to close channels. Example:

NOTE *In order to use the front panel inputs, make sure the INPUT switch is in the out (F) position.*

```
SYST:PRES                          ' Restores system preset defaults.
ROUT:MULT:CLOS (@101)              ' Closes channel 101.
SENS:FUNC 'CURR:DC'                ' Selects DCI function - Legal operation.
```

Non-measure switching modules

NOTE *Presently, non-measure Keithley modules include the Models 7705, 7711, and 7712. You can check the Keithley website (www.keithley.com) for new modules.*

Keep the following in mind when using a non-measure module:

- For a non-measure card, no channels are connected to the internal DMM (the channels cannot be connected to the backplane).
- Multiple channel operation should be used to close channels on a non-measure module. For remote operation, the ROUT:MULT commands are used to close channels.
- Front panel system (single) channel operation cannot be used to close channels on a non-measure module. For front panel operation, system channel operation will cause message "NO MEAS CARD" to be displayed.
- A non-measure module may have open/close operations that are specific only to that module. Refer to the appropriate module manual (packing list) for details on operation.
- In order to perform measurements, you must use the front panel inputs of the 2701 mainframe. You can still use the non-measure module to control other operations.

Multiple channel operation

The capability to individually control channels provides you with added flexibility in how you use a switching module. For example, assume you want to route a signal into channel 1 and out channel 20 of a Model 7700 switching module. You would do this by closing channels 1, 20, and 23. If you open channels 24 and 25, you will isolate the input signal from the DMM of Model 2701.

Multiple channel operation allows any channel (or channels) in the test system to be closed or opened. It allows more than one measurement channel to be closed at the same time. It also allows individual control of non-measurement channels, such as backplane isolation channels. Multiple channel operation should only be performed by experienced test system engineers.

WARNING Careless multiple channel operation could create an electric shock hazard that could result in severe injury or death. Improper operation can also cause damage to the switching modules and external circuitry. Multiple channel operation should be restricted to experienced test engineers who recognize the dangers associated with multiple channel closures.

NOTE *Multiple channel operation cannot be used to perform thermocouple temperature measurements using the internal or external reference junction. The simulated reference junction will instead be used and the integrity of the temperature reading will be questionable ("ERR" annunciator turns on). See "Temperature measurements," page 3-33, for details.*

Some other key points for multiple channel operation include the following:

- Closing a channel using multiple channel operation has no affect on other closed channels. Whatever channels were previously closed, remain closed.
- A channel closed using multiple channel operation is not displayed on the Model 2701. Also, the CHAN annunciator does not turn on when a channel is closed.
- Opening a channel using multiple channel operation has no affect on other closed channels. Only the specified channel opens.

NOTE *Use the VIEW option of the CARD menu to display closed channels (see "CARD menu," page 2-30).*

Controlling multiple channels

WARNING When using multiple channel operation, you must be very careful when switching hazardous voltages. If you inadvertently close the wrong channel(s), you could create a shock hazard and/or cause damage to the equipment.

Most switching modules use latching relays. That is, closed channels remain closed when the Model 2701 is turned off. Never handle a switching module that is connected to an external source that is turned on. Turn off all power sources before (1) making or breaking connections to the module, and (2) installing (or removing) the module into (or out of) the Model 2701.

Avoiding corrupt measurements

Aside from the safety issues, improper use of multiple channel operation can result in corrupt measurements. For example, assume two Model 7700s installed in slots 1 and 2, and a 2-wire function selected. If you use multiple channel operation to close channels 201 and 225, you will connect the input at channel 201 to the DMM for measurement.

If you then use system channel operation to close channel 101, channel 125 will also close to connect the input at channel 101 to the DMM. You now have two input channels (101 and 201) connected to DMM Input at the same time, inviting all sorts of problems.

The above problem can be avoided by opening channels 201 and/or 225 before closing channel 101 (and 125) as demonstrated by the following sequence:

1. Multiple channel operation — Close channels 201 and 225 for connection to DMM.
2. Multiple channel operation — Open channels 201 and/or 225 to disconnect from DMM.
3. System channel operation — Close system channel 101 to connect to DMM.

CLOSE key (MULTI menu option)

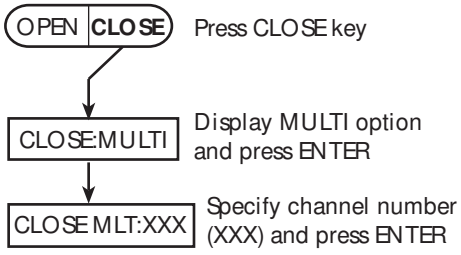
The MULTI menu option for the CLOSE key can be used to close any individual channel in the mainframe (Figure 2-6). Perform the following steps to close a channel:

NOTE *Channels closed by the MULTI option of the CLOSE key are not displayed. Use the VIEW option of the CARD menu to display closed channels (see "CARD menu," page 2-30).*

1. Press the CLOSE key and then use the ▲ or ▼ key to display the "CLOSE:MULTI" message.
2. Press ENTER to display the prompt to close a channel (CLOSE MLT:XXX).
3. Using ◀, ▶, ▲, and ▼, key in the three-digit channel you want to select.
4. Press ENTER to close the channel.

An invalid channel cannot be closed. The error messages associated with system channel operation also apply to multiple channel operation.

Figure 2-6
Multiple channel operation — specifying a channel to close



OPEN key

The OPEN key has two options to open channels: ALL and MULTI. The ALL option simply opens all channels in the mainframe. The MULTI option opens only the specified channel. All other closed channels remain closed. Figure 2-7 summarizes OPEN key operation.

OPEN: ALL — Perform the following steps to open all channels in the mainframe:

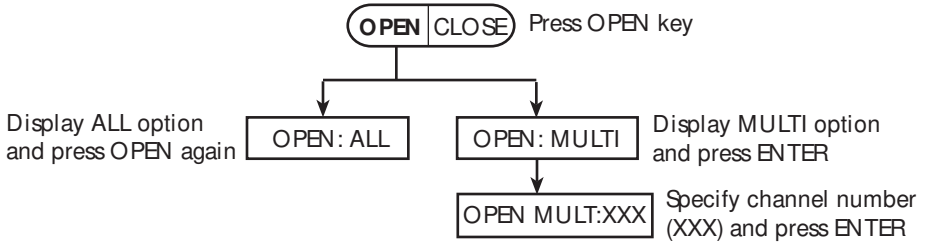
1. Press the OPEN key to display "OPEN: ALL."
2. Press OPEN again (or press ENTER) to open all channels.

OPEN: MULTI — Perform the following steps to open only the specified channel:

1. Press the OPEN key. The "OPEN: ALL" message will be displayed.
2. Press the ▲ or ▼ key to display the "OPEN: MULTI" message.
3. Press ENTER to display the prompt to open a channel (OPEN MLT:XXX).
4. Using ◀, ▶, ▲, and ▼, key in the three-digit channel you want to select.
5. Press ENTER to open the channel.

NOTE *If the channel you open using OPEN: MULTI is the system channel (channel number displayed on the Model 2701), the channel will open, but the system channel number will still be displayed (see "Multiple channel operation anomalies," page 2-22).*

Figure 2-7
Multiple channel operation — opening one or all channels



Remote programming — Multiple channel control commands

The commands to close and open the system channel are listed in Table 2-2.

Table 2-2
Multiple channel control commands

Commands	Description	Ref
ROUTe:MULTiple:CLOSe <clist>	Specify one or more channels to close.	a
ROUTe:MULTiple:OPEN <clist>	Open channels specified in list. Unlisted channels not affected.	b
ROUTe:OPEN:ALL	Open all channels.	c
ROUTe:MULTiple:CLOSe?	Returns a <clist> of all closed channels.	d
ROUTe:MULTiple:CLOSe:STATe? <clist>	Query closed channels in specified list (1 = closed).	e
Channel list parameter: <clist> = (@SCH) where: S = Mainframe slot number (1 or 2) CH = Switching module channel number (must be 2 digits) Examples: (@101) = Slot 1, Channel 1 (@101, 203) = Slot 1, Channel 1 and Slot 2, Channel 3 (@101:110) = Slot 1, Channels 1 through 10		

Reference:

a. ROUTe:MULTiple:CLOSe <clist>

This command functions like the front panel CLOSE key (MULTI menu option) to close channels. When you send this command to close the channels specified in the <clist>, only those listed channels will close. Channels not specified are not affected, and channel pairing is disabled.

NOTE *Channels closed by ROUT:MULT:CLOS are not displayed.*

The ROUT:MULT:CLOS command cannot be used to perform thermocouple temperature measurements using the internal or external reference junction. The simulated reference junction will instead be used and the integrity of the temperature reading will be questionable ("ERR" annunciator on). See "Temperature measurements," page 3-33, for details.

NOTE **OPC or *OPC? should be used with :ROUT:MULT:CLOS if the <clist> is large. Details on *OPC and *OPC? are provided in Section 12.*

b. ROUTe:MULTiple:OPEN <clist>

With this command, you can open one or more switching module channels. When you send this command to open the channels specified in the <clist>, only those listed channels will open. Channels not specified are not affected.

NOTE **OPC or *OPC? should be used with :ROUT:MULT:OPEN if the <clist> is large. Details on *OPC and *OPC? are provided in Section 12.*

c. ROUTe:OPEN:ALL

This command functions the same as the front panel OPEN key (ALL menu option). It simply opens all channels (including non-measurement channels) in the mainframe.

d. ROUTe:MULTiple:CLOSe?

This query command returns a <clist> of all closed channels, including non-measurement channels and paired channels for 4-wire functions.

e. ROUTe:MULTiple:CLOSe:STATe? <clist>

This query returns a "0" (open) or "1" (closed) for every channel specified in the <clist>. It is valid for both measurement and non-measurement channels.

For example, assume channel 125 is closed, and you use this command to query channels 101, 104, and 125 (<clist> = (@101, 104, 125)). The response message returns "0, 0, 1" to indicate that channels 101 and 104 are open, and channel 125 is closed.

Remote programming example (multiple channel operation)

The following example assumes a Model 7700 installed in slot 1. This command sequence connects channel 101 to channel 111 (through channel 123). Note that these two closed channels will be internally isolated from the DMM since the backplane isolation channels (124 and 125) will be open.

NOTE *The following example can be run from the KE2700 Instrument Driver using the example named "CloseChannels" in Table G-1 of Appendix G.*

```
ROUT:OPEN:ALL                          ' Open all channels.
ROUT:MULT:CLOS (@101,111,123)          ' Close channels 101, 111, and 123.
```

When finished with multiple channel operation, it is a good, safe practice to open all channels (`ROUT:OPEN:ALL`).

Multiple channel operation anomalies

- Anomaly #1 — When you use multiple channel operation to open the system channel, the channel will open but the system channel number will still be displayed on the Model 2701. For details, see "Anomaly #1 example — wrong channel displayed."
- Anomaly #2 — For a 4-wire function, you can use multiple channel operation to open the paired channel. If you then use system channel operation to again select the already closed system channel it will not re-close the paired channel. For details, see "Anomaly #2 example — opening the paired channel."

NOTE The following anomaly examples assume a Model 7700 installed in slot 1.

Anomaly #1 example — wrong channel displayed

The following example closes channel 102 and connects it to the DMM Input. However, the Model 2701 will not display the measurement channel that is closed. It will display channel 101 instead of channel 102.

1. Use the ALL option for the OPEN key to open all channels in the mainframe.
   Remote programming: `ROUT:OPEN:ALL`
2. Press the ▸ key to close (and display) channel 101. This closes channel 101 (which is the system channel) and channel 125 to connect it to the DMM Input (Figure 2-1).
   Remote programming: `ROUT:CLOS (@101)`
3. Use the MULTI option for the CLOSE key to close channel 102. The system channel is not affected. Channels 101, 102, and 125 are now closed.
   Remote programming: `ROUT:MULT:CLOS (@102)`
4. Use the MULTI option for the OPEN key, open channel 101. Even though channel 101 is still being displayed on the Model 2701, it is channel 102 that is actually connected to the DMM Input (channels 102 and 125 closed).
   Remote programming: `ROUT:MULT:OPEN (@101)`

To correctly display the channel that is closed (channel 102), repeat step 1 above to open all channels and then use the ▸ key or the `ROUT:CLOS (@102)` command to close (and display) channel 102. This closes channel 102 (which is the system channel) and channel 125 to connect it to the DMM Input.

Anomaly #2 example — opening the paired channel

Assume 4-wire connections to a 1kΩ resistor using channels 1 and 11 of the Model 7700 switching module. Also assume the Ω4 function is selected. The following procedure demonstrates how careless multiple channel operation can cause an overflow reading even though everything else from the front panel "looks right."

1. Use the ALL option for the OPEN key (OPEN: ALL) to open all channels in the mainframe.
   Remote programming: `ROUT:OPEN:ALL`
2. Press the ▸ key to close (and display) channel 101. The following channels close (see Figure 2-2):
   - Channel 101 (system channel).
   - Channel 125 (connects channel 101 to DMM Input).
   - Channel 111 (paired channel for 4-wire measurements).
   - Channel 124 (connects channel 111 to DMM Sense).
   - Channel 123 (isolates channel 101 from channel 111).

   The Model 2701 will display the 1kΩ reading for system channel 101.
   Remote programming: `ROUT:CLOS (@101)`
3. Using the MULTI option for the OPEN key, open channel 111. This opens the connection to DMM Sense and causes an OVRFLW reading. Keep in mind that channel 101 is still closed and displayed as the system channel.
   Remote programming: `ROUT:MULT:OPEN (@111)`
4. In an attempt to clear the overflow reading problem, use the SINGLE option of the CLOSE key to again close channel 101. You might think that this will again close channel 111 to reconnect it to DMM Sense. However, that is not the case. Since channel 101 is still the system channel, selecting it again in this manner is a "no action". Channel 111 does not close.
   Remote programming: `ROUT:CLOS (@101)`

A simple way to resolve the above problem is to repeat step 1 to open all channels, and then repeat step 2 to close channel 101. All the listed channels in step 2 will close to make the 4-wire connection to the 1kΩ resistor.

Dual independent multiplexers

Using multiple channel operation, any multiplexer switching module can be configured as two independent multiplexers. For example, the Model 7700 is normally used as a single 1 × 20 multiplexer, but it can also be configured as two 1 × 10 multiplexers.

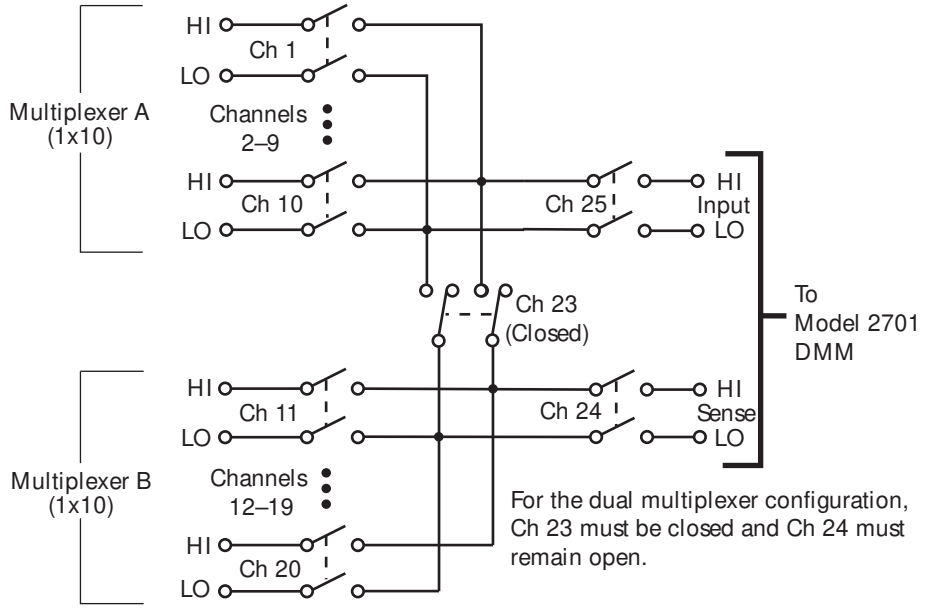
NOTE *Thermocouple temperature measurements using the internal or external reference junction cannot be performed when using multiple channel operation to connect an input channel to the DMM. The simulated reference junction will instead be used resulting in invalid readings ("ERR" annunciator turns on). See "Temperature measurements," page 3-33, for details.*

A multiplexer switching module is configured as two multiplexers by using multiple channel operation to close the 2-pole/4-pole relay. The Model 7700 is configured as two independent multiplexers by closing channel 23. As shown in Figure 2-8, the closed position of channel 23 isolates Multiplexer A (channels 1 through 10) from Multiplexer B (channels 11 through 20).

For the dual multiplexer configuration, only Multiplexer A channels can be internally connected to the DMM of the Model 2701. For the Model 7700, closing channel 25 allows channels 1 through 10 to be measured by the DMM.

When using the dual multiplexer configuration, the sense backplane isolation relay must be kept open to isolate Multiplexer B channels from the sense terminals of the DMM. For the Model 7700, channel 24 must be kept open (Figure 2-8).

Figure 2-8
Dual multiplexer configuration (Model 7700)



Dual multiplexer application

This application demonstrates how to use the Model 7700 as a dual multiplexer to bias and measure 10 DUT. An external source powers DUT, while the DMM of the Model 2701 measures the output of the DUT. To prevent overloading of the external source, each DUT is powered (and measured) separately.

Figure 2-9 shows the connections for this application. The external source is connected to the Sense terminals of the switching module and DUT is connected to channels 1 through 10. Channels 11 through 20 are used to connect external power to each DUT.

For this application, the 2-pole/4-pole relay and backplane isolation relays of the switching module are to be controlled as follows:

- Closing channel 23 connects the External Source to DUT via channels 11 through 20. Closing channel 23 also isolates measure channels (1 through 10) from the source channels (11 through 20). This channel must remain closed while testing DUT.
- Opening channel 24 isolates the external source from the backplane of the Model 2701. This channel must remain open while testing DUT.
- Closing channel 25 connects an input channel (1 through 10) to the DMM.

In Figure 2-9, channels 1 and 11 are closed to test DUT 1. A more detailed view of the test for DUT 1 is shown in Figure 2-10. The test for the other DUTs is similar except that different source and measure channels are closed. Closed channels for each DUT test are listed as follows:

Tested device	Closed channels
DUT 1	1, 11, 23, and 25
DUT 2	2, 12, 23, and 25
DUT 3	3, 13, 23, and 25
DUT 4	4, 14, 23, and 25
DUT 5	5, 15, 23, and 25

Tested device	Closed channels
DUT 6	6, 16, 23, and 25
DUT 7	7, 17, 23, and 25
DUT 8	8, 18, 23, and 25
DUT 9	9, 19, 23, and 25
DUT 10	10, 20, 23, and 25

NOTE Do not use this application to measure the temperature of DUT using a thermocouple with the INTernal or EXTernal reference junction selected. The SIMulated reference junction will instead be used resulting in invalid readings. The "ERR" annunciator will turn on to indicate that the integrity of the temperature reading is questionable.

Figure 2-9
Dual multiplexer application connections

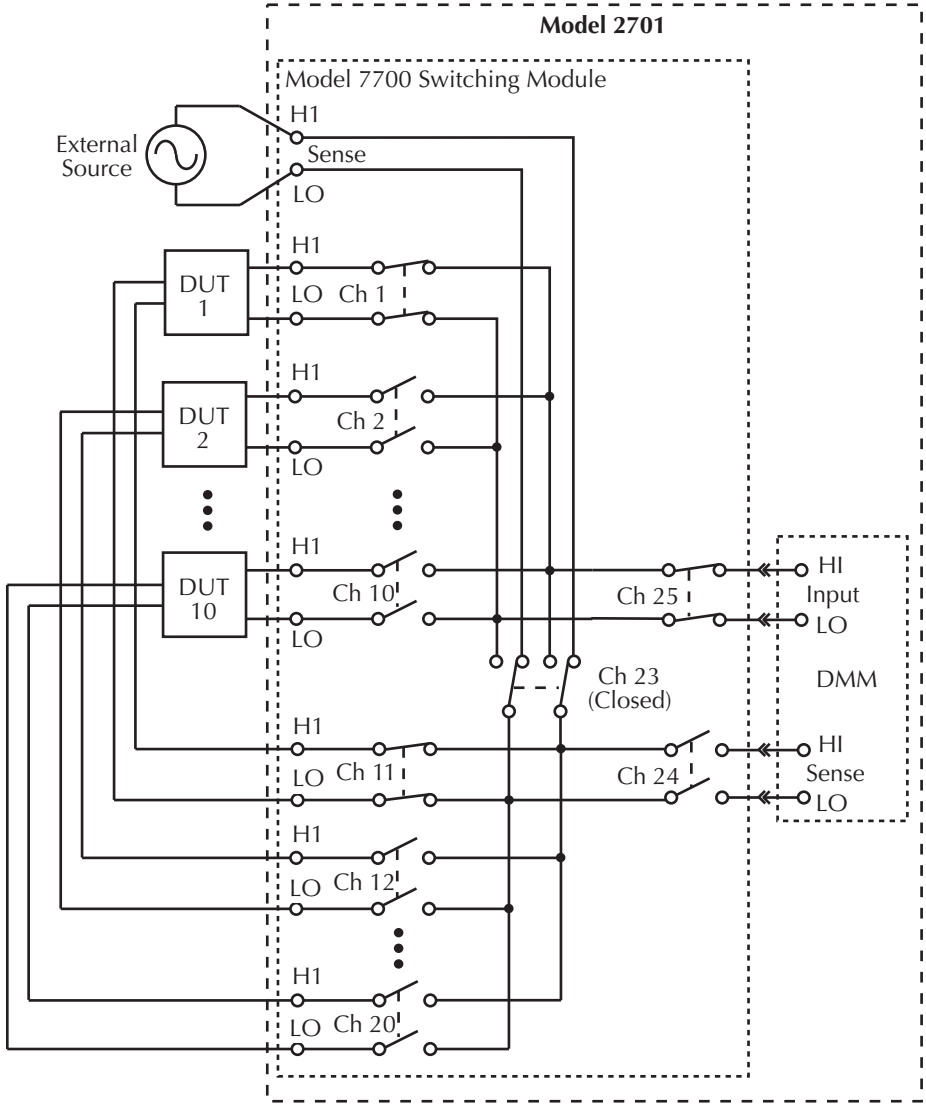
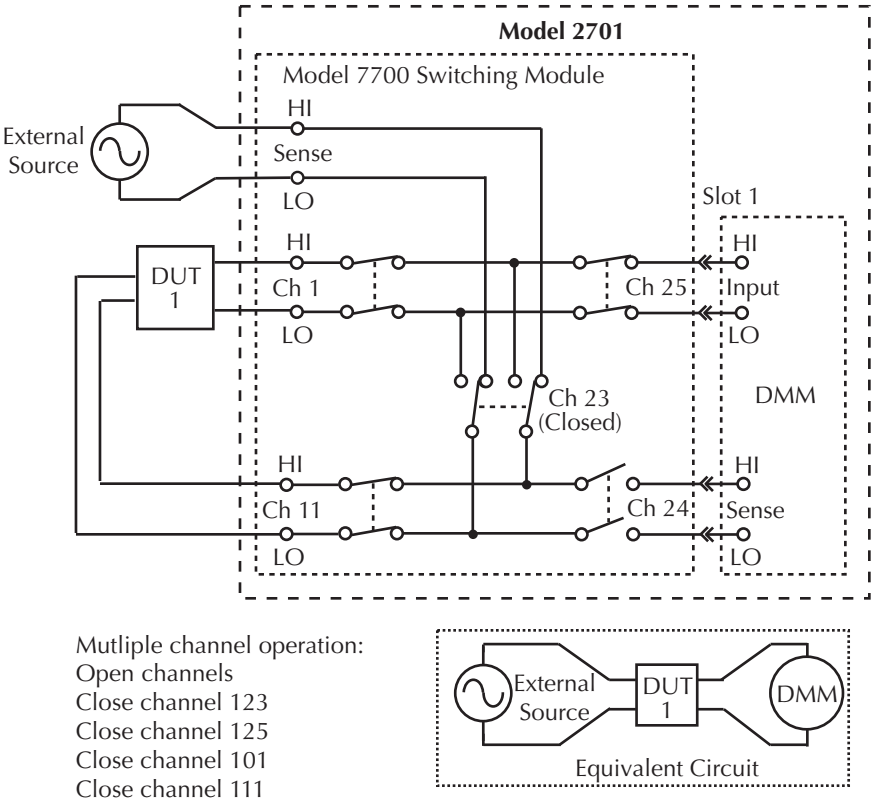


Figure 2-10
Testing DUT 1



Test procedure:

NOTES *The following test procedure assumes a Model 7700 switching module installed in slot 1 of the mainframe.*

The procedure assumes that the instrument is operating in the continuous measurement (triggering) mode (see "Defaults and user setups," page 1-21).

Do not use the following procedure to perform thermocouple temperature measurements with the INTernal or EXTernal reference junction selected. The SIMulated reference junction will instead be used resulting in invalid readings. The "ERR" annunciator will turn on to indicate that the integrity of the temperature reading is questionable.

1. Open all channels. For most switching modules, channels remain closed after the Model 2701 is turned off. Therefore, it is good safe practice to open all channels at the start and end of the test.

   Front panel operation: *Press OPEN > Display ALL > Press OPEN*
   Remote programming: `ROUT:OPEN:ALL`
2. Close channels 23 and 25.

   Front panel operation: *Press CLOSE > Select MULTI > Key in 123 > Press ENTER*
   Press CLOSE > Select MULTI > Key in 125 > Press ENTER
   Remote programming: `ROUT:MULT:CLOS (@123,125)`
3. Close channels 1 and 11 to connect DUT #1 to the DMM and bias supply.

   Front panel operation: *Press CLOSE > Select MULTI > Key in 101 > Press ENTER*
   Press CLOSE > Select MULTI > Key in 111 > Press ENTER
   Remote programming: `ROUT:MULT:CLOS (@101,111)`
4. Measure DUT #1.

   Front panel operation: *Take reading from display*
   Remote programming: *`DATA?`*
5. Open channels 1 and 11.

   Front panel operation: *Press OPEN > Select MULTI > Key in 101 > Press ENTER*
   Press OPEN > Select MULTI > Key in 111 > Press ENTER
   Remote programming: *`ROUT:MULT:OPEN (@101,111)`*
6. Modify steps 3, 4, and 5 to test DUT #2. That is, close channels 2 and 12, measure DUT #2, and then open channels 2 and 12.
7. Test the remaining eight DUT in a similar manner. That is, close the appropriate channels for the DUT, make the measurement, and then open the channels.
8. After the last DUT is tested, repeat step 1 to open all channels.

Identifying installed modules and viewing closed channels

On power-up, the model numbers of installed switching modules are displayed briefly.

If a Model 7700, 7701, 7702, 7703, 7705, 7708, or 7709 switching module is removed while the Model 2701 is on, the instrument will operate as if the module is installed. That is, the Model 2701 will operate as if the pseudocard is installed.

NOTE *If a Model 7706 or 7707 is removed while power is on, error +523 "Card hardware error" will occur and the module will be removed from the system.*

NOTE *In general, it is not recommended to install or remove switching modules with the power on.*

CARD menu

The CARD menu identifies the switching modules installed in the mainframe, and is used for the following operations:

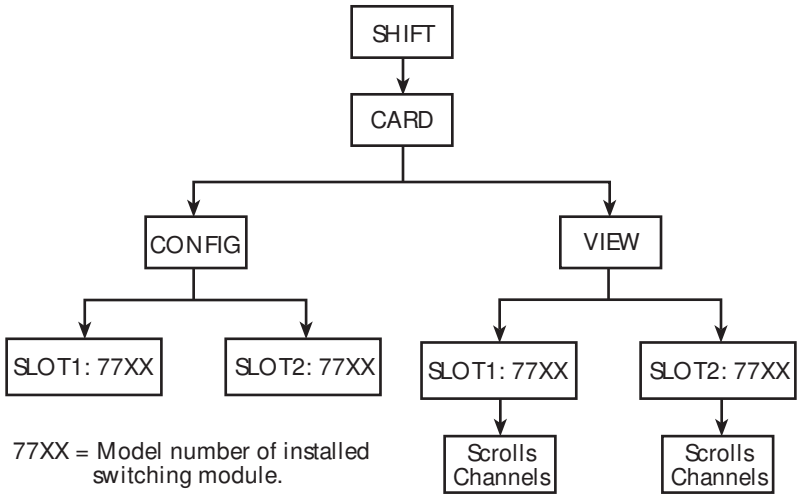
- Configure digital inputs, digital outputs, and analog outputs for switching modules that have one or more of those capabilities (i.e., Models 7706 and 7707).
- View the analog input channels that are presently closed. Also, read digital input ports, digital output ports, and analog output values for switching modules that have one or more of those capabilities.

Menu navigation keys — Once in the menu structure, the manual range keys (▲ and ▼) and the cursor keys (◀ and ▶) are used to display menu items and options, and set parameter values. With the desired item, option, or setting displayed, press the ENTER key to select it. You can cancel a pending selection (and exit the menu structure) by pressing the EXIT key.

Press the SHIFT key and then the CARD key to display the CARD menu. The Card menu tree is shown in Figure 2-11. The items and options of the menu are explained as follows:

NOTE *Identifying installed modules — If you simply want to identify installed modules or pseudocards, select CONFIG or VIEW and use the ▲ and ▼ key to check each slot. When finished, press EXIT.*

Figure 2-11
CARD menu tree



CARD: CONFIG — This menu item is used to configure switching modules. The channels of the Model 7700 switching module and other similar type modules do not need to be configured.

SLOTX: 77XX — Use to configure the switching module in Slot X (where X = 1 or 2). If configuration is not necessary, the instrument will exit from the menu when ENTER is pressed.

NOTE *For switching modules that require configuration, refer to packing list that was shipped with each module.*

CARD: VIEW — This menu item is used to view all analog input channels that are presently closed. These include both measurement and non-measurement channels.

The channels are built into a string that scrolls the display. Four dots identify the end of the string. Model 7700 example (Slot 1) — Assume the Ω4 function is selected and system channel 101 is closed. The following string will scroll across the display:

101, 111, 123, 124, 125 . . . .

Channels 101 and 111 are the paired channels for the 4-wire measurement. Channel 123 is the 4-pole relay setting, and channels 124 and 125 connect input and sense to the DMM of the Model 2701 (Figure 2-2).

NOTE *Some switching modules have analog outputs, digital inputs, and/or digital outputs. The values for these channels are also displayed from the VIEW menu item. For details on a particular switching module, refer to the packing list that was shipped with each module.*

SLOTX: 77XX — Use to scroll the closed channels and channel settings (if applicable) for the switching module in Slot X (where X = 1 or 2).

Scrolling speed — The scrolling speed of the channel string is adjustable or can be paused. The ◂ key slows down scrolling speed and the ▸ key speeds it up. The ENTER key pauses scrolling. Press ENTER a second time to resume scrolling.

Exiting VIEW — To exit from VIEW, press the EXIT key. Pressing an instrument setting key will also exit VIEW, but it will also perform the operation associated with the key. For example, pressing Ω2 will exit VIEW and select the Ω2 function.

NOTE *When a command is received while the display is scrolling, the instrument exits from the CARD menu and the command is executed.*

Switching module queries (remote operation)

For remote operation, there are commands to identify installed switching modules and channels that are closed. There are also commands to acquire general information about the installed modules.

*OPT?

For remote operation, the *OPT? command can be used to determine which switching modules (or pseudocards) are installed in the Model 2701. For example, assume a Model 7700 is installed in slot 1 and the other slot is empty. The following message is the response message for the command:

7700, NONE

ROUTe:CLOSe?
ROUTe:MULTiple:CLOSe?
ROUTe:MULTiple:CLOSe:STATe? <clist>

These query commands are used to determine closed switching module channels.

`ROUT:CLOS?` is used to return a list of closed measurement channels including the paired channel for 4-wire measurements. It will not return non-measurement channels. For details, see Table 2-1 and related reference information.

`ROUT:MULT:CLOS?` is used to return all closed channels (measurement and non-measurement). For details, see Table 2-2 and related reference information.

`ROUT:MULT:CLOS:STAT?` is used to return the state (open or closed) of each specified channel. A "0" is returned for an open channel and a "1" is returned for a closed channel. For details, see Table 2-2 and related reference information.

SYSTem:CARD commands

There is a series of SYSTem:CARD commands that can be used to acquire the following information about a switching module installed in the Model 2701:

- Return the serial number and firmware revision.
- Determine the maximum allowable voltage.
- Determine if the module supports multiplexer or isolated channels.
- Determine if the module has built-in temperature sensors for internal cold junction, thermocouple temperature measurements.
- Determine which channels are used for volts/2-wire measurements and which are used for amps.
- Determine which channels are used for analog or digital output.
- Determine the totalizer channel (Model 7706 only).

The SYSTem:CARD commands are covered in Table 15-7.

Relay closure count

The Model 2701 keeps an internal count of the number of times each module relay has been closed. The total number of relay closures are stored in EEPROM on the card. This count will help you determine if and when any relays require replacement (see module contact life specifications).

Relay closures are counted only when a relay cycles from open to closed state. If you send multiple close commands to the same channel without sending an open command, only the first closure will be counted.

Relay closure count can only be read via remote operation. The commands are summarized in Table 2-3. Details follow the table.

Table 2-3
Relay closure count commands

Commands	Description	Default
ROUTe:CLOSe:COUNt? <clist>	Query close count for specified channels.	
ROUTe:CLOSe:COUNt:INTerval <NRf>	Set count update interval in minutes (10 to 1440).	Note
ROUTe:CLOSe:COUNt:INTerval?	Query relay count update interval.	
Channel list parameter: <clist> = (@SCH) where: S = Mainframe slot number (1, 2, 3, 4, or 5) CH = Switching module channel number (must be 2 digits) Examples: (@101) = Slot 1, Channel 1 (@101, 203) = Slot 1, Channel 1 and Slot 2, Channel 3 (@101:110) = Slot 1, Channels 1 through 10		

Note: Relay count interval set to 15 minutes at the factory. SYSTem:PREset and *RST have no effect on the set interval.

NOTE The relay closure count can be reset to zero. For details, see the Model 2701 Service Manual, "Plug-in module relay closure count."

Reading relay closure count

To determine the closure count of specific channels, send this query via remote:

```
ROUTe:CLOSe:COUNt? <clist>
```

Here, <clist> is the summary of channels. For example, to determine the closure count of channels 1 and 4 of a module in slot 1, the following query would be sent:

```
ROUT:CLOS:COUN? (@101,104)
```

The following query would determine the closure count of slot 1 module channels 1 through 10:

```
ROUT:CLOS:COUN? (@101:110)
```

Setting count update interval

Relay closure counts are updated in temporary RAM every time a channel is closed regardless of how it was closed: by an SCPI command, front panel control, or during a scan. These counts are permanently written to the EEPROM on the card only at a user-set time interval (which is initially set to 15 minutes at the factory) or whenever the counts are queried. Valid intervals (set in integer number of minutes) are between 10 and 1440 minutes (24 hrs).

The lower the interval, the less chance there is of losing relay counts due to power failures. However, writing to the EEPROM more often may reduce scanning throughput. The higher the interval, the less scanning throughput is reduced. However, more relay counts may be lost in the event of a power failure.

NOTE *If the Model 2701 is turned off before the updated count is written to EEPROM, the relay counts will be lost. It is good practice to add the ROUT:CLOS:COUN? <clist> command at the end of a program to manually update the count.*

To set the count update interval, send this command:

```
ROUTe:CLOSe:COUNt:INTerval <NRf>
```

where; <NRf> = 10 to 1440 (minutes)

For example, to set the interval to 30 minutes, send this command:

```
ROUT:CLOS:COUN:INT 30
```

Model 7700 switching module

NOTE *Connection and wiring procedures for the Model 7700 are to be performed by qualified service personnel. This information is provided in Appendix B, "Model 7700 Connection Guide".*

Switching module capabilities

Channels 1 through 20 — The Model 7700 can multiplex one of twenty 2-pole signals or one of ten 4-pole signals into the input of the Model 2701.

Channels 21 and 22 — The Model 7700 can multiplex one of two 2-pole current signals into the input of the Model 2701.

CAUTION To prevent damage to the Model 7700 switching module, do not exceed these maximum signal levels:

Channels 1-20:	300VDC or 300V RMS (425V peak) for AC waveforms, 1A switched, 60W, 125VA
Channels 21, 22:	60VDC or 30V RMS, 3A switched, 60W, 125VA

NOTE *System channel operation — Of the 22 measurement channels, only one channel (or channel pair) can be closed at the same time. When you close a channel (or channel pair), all other measurement channels will open. The user has no control of channels 23, 24, and 25. The open/close state of these channels are determined by the selected function.*

The Model 7700 has six temperature transducers to monitor the cold junction temperature at the screw terminals. For temperature measurements, this internal reference junction allows thermocouples to be connected directly to the screw terminals of the module.

When the Model 2701 is on the DCV, ACV, Ω2, CONT, Ω4, FREQ, PERIOD, or TEMP function, channels 1 through 20 are available. When on a current function (DCI or ACI), channels 21 and 22 are the only available channels.

The Model 7700 can accommodate 4-wire measurements by using channel pairs. Primary channels 1 through 10 become paired to channels 11 through 20. For example, with the Ω4 function selected, channel 1 becomes paired to channel 11. For example, when you close channel 1, channel 11 will also close.

The 2-wire functions include DCV, ACV, DCI, ACI, Ω2, CONT, FREQ, PERIOD, and TEMP (thermocouple and thermistor). The 4-wire functions/operations include Ω4, TEMP (4-wire RTD), RATIO, and CH AVG (ratio and channel average are covered in Section 5).

With a 4-wire function/operation selected, channels are paired as follows:

CH1 and CH11	CH6 and CH16
CH2 and CH12	CH7 and CH17
CH3 and CH13	CH8 and CH18
CH4 and CH14	CH9 and CH19
CH5 and CH15	CH10 and CH20

Schematic diagram

The simplified schematic diagram of the Model 7700 is shown in Figure 2-12. Channels 1 through 20 are used for all measurements except amps. Channels 21 and 22 are used for amps only.

There are two backplane relays (channels 24 and 25) to connect the input channel(s) to the backplane of the Model 2701. With a 2-wire function (except amps) selected, channel 25 will close, and with a 4-wire function selected, both channels 24 and 25 will close.

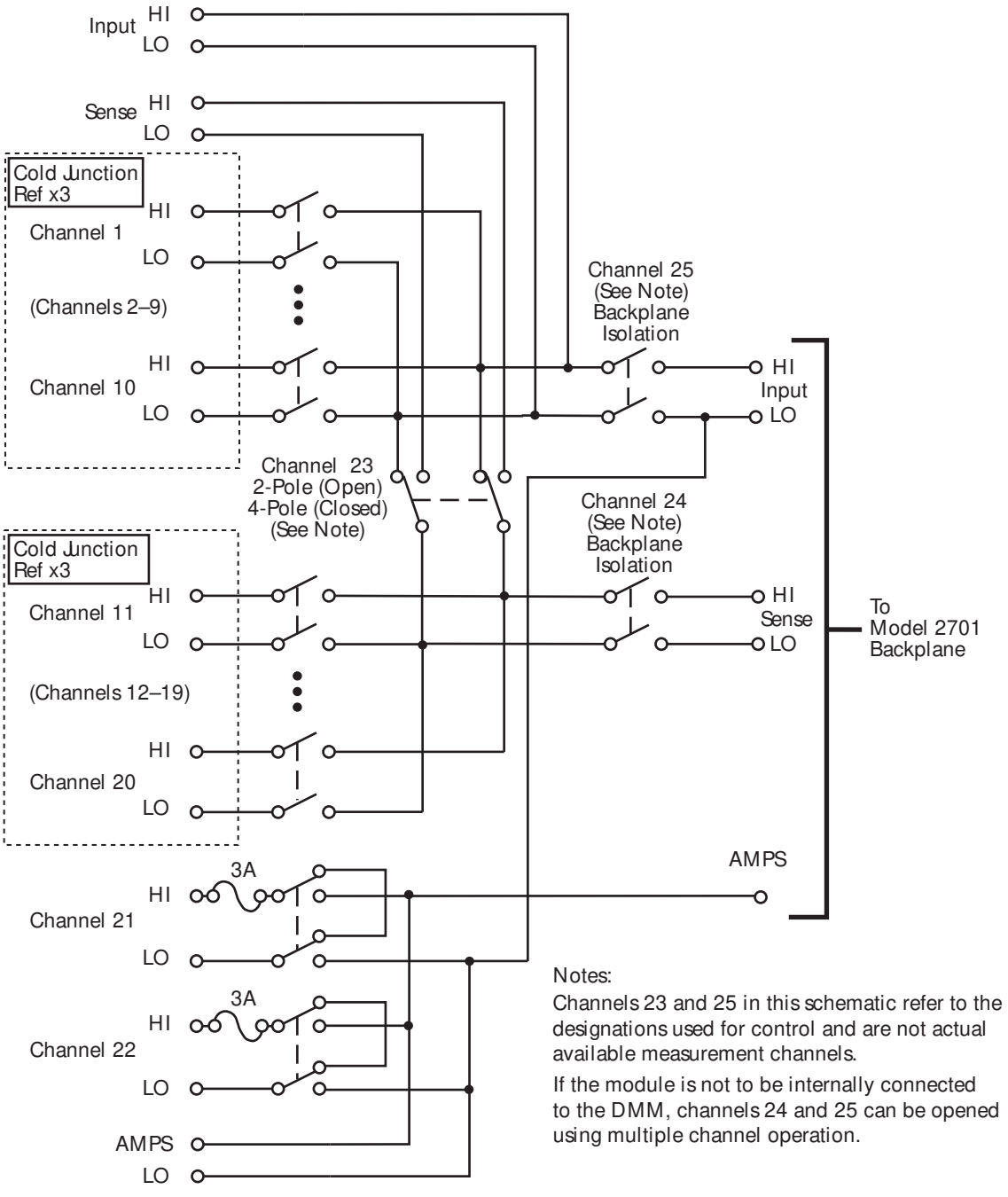
There is a 2-pole/4-pole relay (channel 23) between channels 1 through 10 and channels 11 through 20. When a 2-wire function (i.e., DCV) is selected, channel 23 opens (2-pole position) to allow any of the 20 channels to be connected to the input backplane.

When a 4-wire function is selected, channel 23 closes (4-pole position) to isolate channels 1 through 10 from channels 11 through 20. With a system channel (1 through 10) closed, its paired channel (11 through 20) will also close to connect the sense channel to the sense backplane.

For the two current channels (21 and 22), signal HI and LO are routed directly to the backplane when the channel is closed.

As shown in Figure 2-12, there are also screw terminals labeled "Input," "Sense," and "Amps." The Input and Sense terminals are connected to the inputs of channels 24 and 25 (isolation relays). If channels 1 through 20 are not intended to be connected to the internal DMM, channels 24 and 25 can be controlled independently using multiple channel operation. The Amps terminals are connected directly to the DMM.

Figure 2-12
Model 7700 simplified schematic



Notes:
Channels 23 and 25 in this schematic refer to the designations used for control and are not actual available measurement channels.

If the module is not to be internally connected to the DMM, channels 24 and 25 can be opened using multiple channel operation.

3
Basic DMM Operation

- DMM measurement capabilities — Summarizes the measurement capabilities of the Model 2701 and covers maximum signal levels for switching modules.
- High energy circuit safety precautions — Provides safety information when performing measurements in high energy circuits.
- Performance considerations — Covers some considerations that affect overall performance including warm-up, autozero, and line synchronization.
- Channel list parameter (<clist>) — Summarizes the use of the <clist> parameter which is used throughout this manual to configure scan channels.
- Voltage measurements (DCV and ACV) — Provides detailed information for making basic DC and AC voltage measurements.
- Current measurements (DCI and ACI) — Provides detailed information for making basic DC and AC current measurements.
- Resistance measurements — Provides detailed information for making resistance measurements. Also covered is offset compensated ohms (OCOMP).
- Temperature measurements — Provides detailed information for making thermocouple, thermistor, and 4-wire RTD temperature measurements.
- Frequency and period measurements — Provides detailed information for making frequency and period measurements.
- Continuity testing — Explains how to use the CONT feature to test continuity.
- Remote programming for basic measurements — Covers the commands used to perform basic measurements. Includes some simple programming examples.
- Measurement queries — Summarizes commands typically used to trigger and/or return measured readings.

DMM measurement capabilities

NOTE *Accuracy specifications for all measurement functions and the Model 7700 switching module are provided in Appendix A.*

NOTE *For remote operations, you can use the internal web page of the Model 2701 to send commands, queries, and take readings. See "Internal web page" in Section 10 for details.*

WARNING The Model 2701 measurement inputs are rated measurement Category I.

The equipment cannot be connected to circuits with transients greater than 4kV peak. Do not connect measurement inputs to measurement Category II, III, or IV circuits.

The DMM of the Model 2701 can make the following measurements:

DCV — DC voltage measurements from 0.1µV to 1000V.
ACV — AC voltage measurements from 0.1µV to 750V.
DCI — DC current measurements from 10nA to 3A.
ACI — AC current measurements from 1µA to 3A.
Ω2 — 2-wire resistance measurements from 100µΩ to 120MΩ
Ω4 — 4-wire resistance measurements from 100µΩ to 120MΩ
FREQ — Frequency measurements from 3Hz to 500kHz.
PERIOD — Period measurements from 333ms to 2µs.
TEMP — Temperature measurements from -200°C to 1820°C.
CONT — Continuity testing using the 1kΩ range.

CAUTION When using a switching module, do not exceed the maximum signal levels of the module. To prevent damage to the Model 7700 switching module, do not exceed these maximum signal levels:

Channels 1-20:	300VDC or 300V RMS (425V peak) for AC waveforms, 1A switched, 60W, 125VA
Channels 21, 22:	60VDC or 30V RMS, 3A switched, 60W, 125VA

For the other switching modules, the maximum signal levels are included with their specifications.

NOTE *This section shows DUT connections to the front panel inputs of the Model 2701 and to the Model 7700 switching module. Details on Model 7700 connections are provided in Appendix B.*

High energy circuit safety precautions

To optimize safety when measuring voltage in high energy distribution circuits, read and use the directions in the following warning.

WARNING Dangerous arcs of an explosive nature in a high energy circuit can cause severe personal injury or death. If the multimeter is connected to a high energy circuit when set to a current range or low resistance range, the circuit is virtually shorted. Dangerous arcing can result even when the multimeter is set to a voltage range if the minimum voltage spacing is reduced in the external connections.

As described in the International Electrotechnical Commission (IEC) Standard IEC 664, the Model 2701 measurement inputs are measurement Category I and signal lines must not be directly connected to AC mains.

When making measurements in high energy circuits, use test leads that meet the following requirements:

- Test leads should be fully insulated.
- Only use test leads that can be connected to the circuit (e.g., alligator clips, spade lugs, etc.) for hands-off measurements.
- Do not use test leads that decrease voltage spacing. These diminish arc protection and create a hazardous condition.

WARNING For the front panel inputs, the maximum common-mode voltage (voltage between INPUT LO and the chassis ground) is 500V peak. For a switching module, the maximum common mode voltage is 300VDC or 300V RMS (425V peak) for AC waveforms. Exceeding these values may cause a breakdown in insulation, creating a shock hazard.

Use the following sequence when testing power circuits:

1. De-energize the circuit using the regular installed connect-disconnect device, for example, by removing the device's power cord or by turning off the power switch.
2. Attach the test leads to the circuit under test. Use appropriate safety rated test leads for this application. If over 42V, use double insulated test leads or add an additional insulation barrier for the operator.
3. Set the multimeter to the proper function and range.
4. Energize the circuit using the installed connect-disconnect device and make measurements without disconnecting the multimeter.
5. De-energize the circuit using the installed connect-disconnect device.
6. Disconnect the test leads from the circuit under test.

Performance considerations

NOTE For maximum system performance, it is recommended that all measurement cables be limited to less than 3 meters.

Warm-up

After the Model 2701 is turned on, it must be allowed to warm up for at least two hours to allow the internal temperature to stabilize. If the instrument has been exposed to extreme temperatures, allow extra warm-up time.

Autozero

To help maintain stability and accuracy over time and changes in temperature, the Model 2701 periodically measures internal voltages corresponding to offsets (zero) and amplifier gains. For thermocouple temperature measurements using the internal reference junction (i.e., Model 7700 switching module installed), the internal temperature is also measured. These measurements are used in the algorithm to calculate the reading of the input signal. This process is known as autozeroing.

When autozero is disabled, the offset, gain, and internal temperature measurements are not performed. This increases the measurement speed. However, the zero, gain, and temperature reference points will eventually drift resulting in inaccurate readings of the input signal. It is recommended that autozero only be disabled for short periods of time.

When autozero is enabled after being off for a long period of time, the internal reference points will not be updated immediately. This will initially result in inaccurate measurements, especially if the ambient temperature has changed by several degrees.

NOTE To force a rapid update of the internal reference points, set the integration rate to 0.002 PLC, and then back to the desired rate (i.e., 1.0 PLC). The NPLC commands to set the integration rate are covered in Section 4.

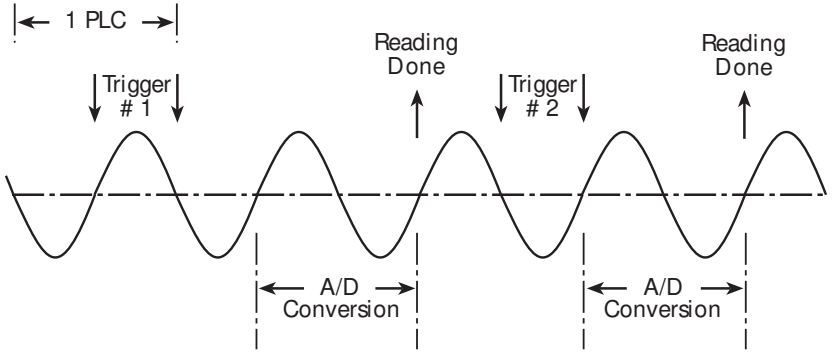
Remote programming can be used to enable or disable autozero (see Table 3-1).

LSYNC (line cycle synchronization)

Synchronizing A/D conversions with the frequency of the power line increases common mode and normal mode noise rejection. When line cycle synchronization is enabled, the measurement is initiated at the first positive-going zero crossing of the power line cycle after the trigger.

Figure 3-1 shows the measurement process that consists of two A/D conversions. If the trigger occurs during the positive cycle of the power line (Trigger #1), the A/D conversion starts with the positive-going zero crossing of the power line cycle. If the next trigger (Trigger #2) occurs during the negative cycle, then the measurement process also starts with the positive-going zero crossing.

Figure 3-1
Line cycle synchronization



Perform the following steps to enable or disable line cycle synchronization:

1. Press SHIFT and then LSYNC to display the present state of line synchronization (OFF or ON).
2. Use the ▲ or ▼ key to display "LINESYNC ON" or "LINESYNC OFF."
3. Press ENTER. The instrument returns to the normal display state.

NOTE *Line synchronization is not available for the AC functions (ACV, ACI, FREQ, or PERIOD) and for integration rates <1 PLC, regardless of the LSYNC setting.*

Remote programming — autozero and LSYNC

Autozero and LSYNC commands

The commands to control autozero and line synchronization are listed in Table 3-1.

Table 3-1
Autozero and LSYNC commands

Commands	Description	Default
*Autozero command**		
SYSTem:AZERo[:STATe] <b>	Enable or disable autozero; <b> = ON or OFF	ON
Line synchronization command		
SYSTem:LSYNc[:STATe] <b>	Enable or disable LSYNC; <b> = ON or OFF	OFF

* After enabling autozero, you can update the internal reference points immediately by setting the integration rate to 0.002 PLC and then back to the desired setting (see NPLC commands in Section 4).

Channel list parameter (<clist>)

Channels of one or more switching modules installed in the Model 2701 can be scanned. Each scan channel can have its own unique setup. For example, a channel could be set to measure DCV on the 10V range, while another channel can be set to measure ACV on the 1V range.

From the front panel, scan channels are configured from the scan configuration menu as explained in Section 7. For remote programming, the <clist> parameter is used to configure scan channels.

Channel list parameter:

<clist> = (@SCH)

where: S = Mainframe slot number (1 or 2)

CH = Switching module channel number (must be 2 digits)

Examples: (@101) = Slot 1, Channel 1
(@101, 203) = Slot 1, Channel 1 and Slot 2, Channel 3
(@101:110) = Slot 1, Channels 1 through 10

Throughout this manual, you will encounter commands that can use the <clist> parameter. The <clist> simply indicates that the associated command can be used to configure a scan channel. For example:

```
SENSe:FUNCtion 'VOLTage:AC'       ' Select ACV function.
SENSe:FUNCtion 'VOLTage:AC',(@101)' Configure scan channel 101 for ACV.
```

While in the normal measurement display state, the first command simply selects the ACV function. The second command configures channel 101 to measure ACV when it is scanned.

See Section 7 for detailed information on scanning.

Voltage measurements (DCV and ACV)

The Model 2701 can make DCV measurements from 0.1µV to 1000V and ACV measurements from 0.1µV to 750V RMS, 1000V peak.

DCV input resistance:	100V and 1000V ranges: 10MΩ 100mV, 1V, and 10V ranges: >10GΩ‖ <400pF or 10MΩ
ACV input impedance:	1MΩ‖ <100pF

DCV input divider

Normally, the input resistance for the 100mVDC, 1VDC, and 10VDC ranges is >10GΩ, while the input resistance of the 100VDC and 1000VDC ranges is 10MΩ However, the input resistance for the three lower DCV ranges can also be set to 10MΩ by enabling the input divider.

With the input resistance lowered, a more stable 0V reading is achieved with an open input. Also, some external devices (such as a high voltage probe) must be terminated to a 10MΩ load.

The input divider cannot be enabled from the front panel. For remote programming, the following command controls the input divider:

```
VOLT:IDIVider <b> ' Enable (ON) or disable (OFF) the DCV input divider.
```

Connections

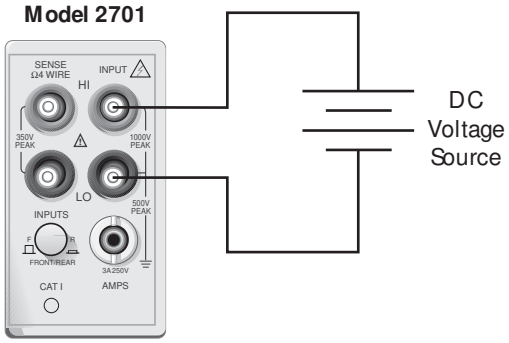
WARNING Even though the Model 2701 can measure up to 1000V peak, the maximum input to a switching module is less. Exceeding the voltage rating of a switching module may cause damage and create a safety hazard. When making connections to an external circuit, always use test leads that are rated for the available voltage and current.

NOTE *When using the front panel inputs, the INPUTS switch must be in the "F" (out) position. For switching modules, it must be in the "R" (in) position.*

Front panel input

When using the front panel input terminals, connect the test leads to the INPUT HI and LO terminals as shown in Figure 3-2.

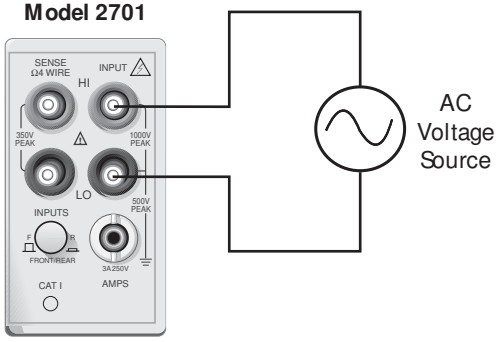
Figure 3-2
DCV and ACV connections using front panel inputs



Input Resistance = 10MΩ on 1000V and 100V ranges;
>10GΩ on 10V, 1V, and 100mV ranges.

Caution: Maximum Input = 1000V peak

A. DCV Connections



Input Impedance = 1MΩ || <100pF

Caution: Maximum Input = 750V RMS, 1000V peak, 8 x 10^7V • Hz

B. ACV Connections

Model 7700 switching module

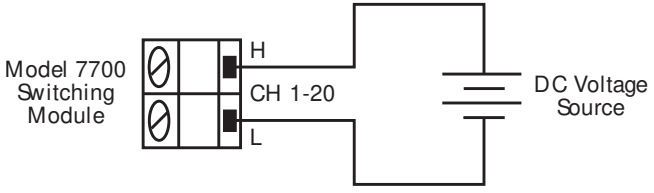
Connections for the Model 7700 switching module are shown in Figure 3-3. For basic DCV and ACV measurements (Figure 3-3A and B), channels 1 through 20 can be used.

Ratio and channel average calculations — Ratio calculates the reading ratio of two channels, while channel average calculates the reading average of two channels. For these calculations, paired switching channels are used. Primary channels 1 through 10 are paired to channels 11 through 20 (channel 1 paired to channel 11, channel 2 paired to channel 12, and so on). As shown in Figure 3-3C, one DC voltage source is connected to a primary channel (i.e., 104) and the other source is connected to its paired channel (i.e., 114).

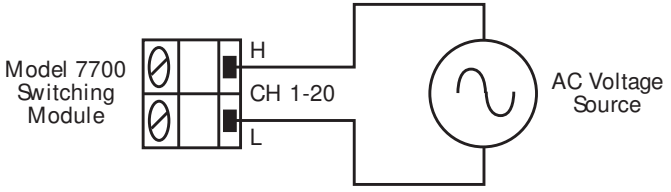
NOTE The ratio and channel average calculations are covered in Section 5.

Figure 3-3
DCV and ACV connections using Model 7700 switching module

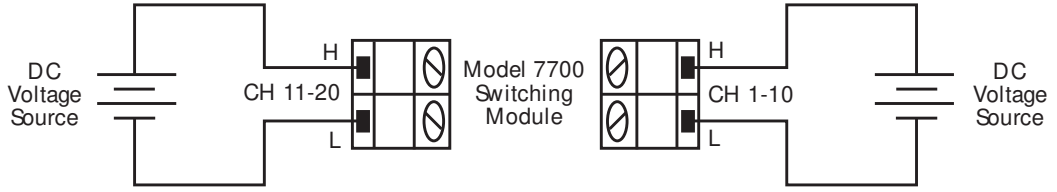
Caution: Maximum input: 300VDC or RMS, 1A switched, 60W, 125VA maximum



A. DCV Connections



B. ACV Connections



C. Ratio and Channel Average Connections (DCV)

Note: The low connections for channels 1 through 10 do not need to be referenced to the low connections for channels 11 through 20.

Volts measurement procedure

NOTE *Make sure the INPUTS switch is in the correct position. To use front panel inputs, it must be in the "F" (out) position. For switching modules, it must be in the "R" (in) position.*

1. If a switching channel is presently closed (displayed), press OPEN to open it.
2. Select the volts measurement function by pressing DCV or ACV.
3. Use the RANGE ▲ and ▼ keys to select a measurement range consistent with the expected voltage or press AUTO to select autoranging (AUTO annunciator turns on). Details on range are provided in Section 4.
4. Apply the voltage(s) to be measured.

CAUTION Do not apply more than maximum input levels indicated in Figure 3-2 and Figure 3-3 or instrument damage may occur. The voltage limit is subject to the 8×10^7VHz product.

Model 7700 switching module — The maximum allowable voltage is 300V DC or 300V RMS (425V peak) for AC waveforms. Exceeding these limits may cause damage to the switching module.

WARNING If both the front panel terminals and the switching module terminals are connected at the same time, the test leads must be rated to the highest voltage that is connected. For example, if 1000V is connected to the front panel input, the test lead insulation for the switching module must also be rated for 1000V.

5. If using a switching module, perform the following steps to close the desired channel:
   a. Press the CLOSE key.
   b. Use ◄, ►, ▲, and ▼ to key in the channel number and press ENTER. The previously closed channel (if there is one) will open and the specified channel will close.

NOTE *While in the normal measurement state, you can use the ◄ and ► keys to close channels. In general, each key press will open the presently closed channel and then close the next higher or lower channel.*

6. Observe the displayed reading. If the "OVERFLOW" message is displayed, select a higher range until a normal reading is displayed (or press AUTO for autoranging). For manual ranging, use the lowest possible range for the best resolution.
7. To measure other switching channels, repeat steps 5 and 6.
8. When finished, press OPEN if there is a channel closed.

AC voltage measurements and crest factor

The root-mean-square (RMS) value of any periodic voltage or current is equal to the value of the DC voltage or current which delivers the same power to a resistance as the periodic waveform does. Crest factor is the ratio of the peak value to the RMS value of a particular waveform.

The crest factor of various waveforms is different, since the peak-to-RMS ratios are variable. For example, the crest factor for a pulse waveform is related to the duty cycle, as the duty cycle decreases, the crest factor increases. The RMS calculations and crest factor (CF) for various waveforms are shown in Figure 3-4 and Figure 3-5.

The Model 2701 is an AC-coupled RMS meter. For an AC waveform with DC content, the DC component is removed before the RMS is calculated. This affects the crest factor in that the peak value of the waveform is different for a DC coupled waveform and an AC coupled waveform. In an AC coupled waveform, the peak is measured from the original DC average value not DC zero. For example, if a voltage pulse is measured on the AC function of the Model 2701 with a peak voltage of V_P and a low voltage of zero volts, the AC coupled peak value will be calculated as follows:

$$AC_{PEAK} = V_P \bullet (1 - \text{duty cycle})$$

Therefore the AC coupled crest factor will differ from the DC coupled waveform. The RMS function will calculate the RMS value based on the pulsed waveform with an average value of zero.

The reason to consider crest factor in accuracy of RMS measurements is because the meter has a limited bandwidth. Theoretically, a sine wave can be measured with a finite bandwidth because all of its energy is contained in a single frequency. Most other common waveforms have a number of spectral components requiring an almost infinite bandwidth above the fundamental frequency to measure the signal exactly. Because the amount of energy contained in the harmonics becomes smaller with increasing frequency, very accurate measurements can be made with a limited bandwidth meter, as long as enough spectral components are captured to produce an acceptable error.

Crest factor is a relative measurement of the harmonic content of a particular waveform and reflects the accuracy of the measurement.

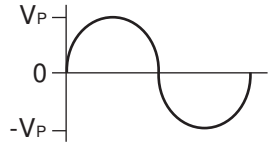
For a rectangular pulse train, the higher the crest factor, the higher the harmonic content of the waveform. This is not always true when making spectral comparisons between different types of waveforms. A sine wave, for example, has a crest factor of 1.414 and a square wave has a crest factor of 1. The sine wave has a single spectral component and the square wave has components at all odd harmonics of the fundamental.

The Model 2701 RMS AC volts and AC amps accuracies are specified for sine waves of different frequency ranges.

Additional error uncertainties are also specified for non-sinusoidal waveforms of specific crest factors and frequencies. The Model 2701 has capabilities of measuring AC waveforms of crest factors up to 5.

Figure 3-4
ACV measurements – sine waves

Sine



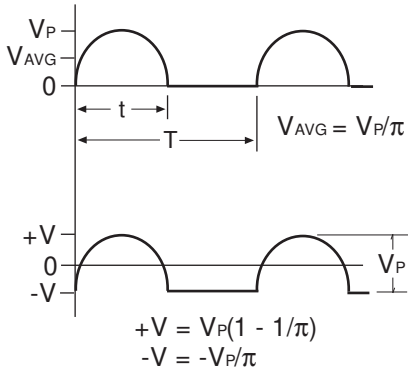
AC coupled RMS:

$$V_{RMS} = \frac{V_P}{\sqrt{2}}$$

Crest Factor:

$$CF = \sqrt{2}$$

Half-Wave Rectified Sine



RMS:

$$V_{RMS} = V_P\sqrt{D/2}$$

where; D (duty cycle) = $\frac{t}{T}$

$$CF = \frac{1}{\sqrt{D/2}}$$

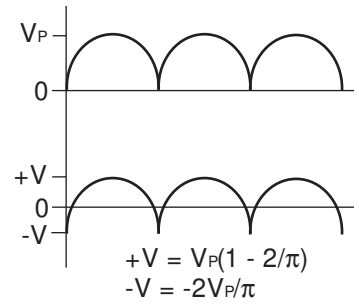
AC coupled RMS:

$$V_{RMS} = \sqrt{(V_P\sqrt{D/2})^2 - (V_P/\pi)^2}$$

$$= V_P\sqrt{(D/2) - (1/\pi^2)}$$

$$CF = \frac{1}{\sqrt{(D/2) - (1/\pi^2)}}$$

Full-Wave Rectified Sine



RMS:

$$V_{RMS} = \frac{V_P}{\sqrt{2}}$$

$$CF = \sqrt{2}$$

AC coupled RMS:

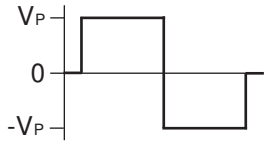
$$V_{RMS} = \sqrt{(V_P/\sqrt{2})^2 - (2V_P/\pi)^2}$$

$$= V_P\sqrt{(1/2) - (4/\pi^2)}$$

$$CF = \frac{1}{\sqrt{(1/2) - (4/\pi^2)}}$$

Figure 3-5
ACV measurements – square, pulse, and sawtooth waves

Square



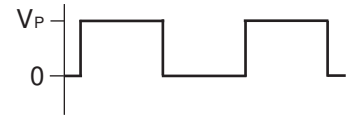
AC coupled RMS:

$V_{RMS} = V_P$

Crest factor:

$CF = 1$

Rectified square

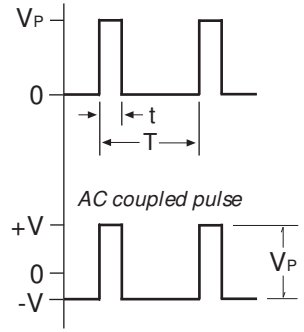


AC coupled RMS:

$V_{RMS} = \frac{V_P}{2}$

$CF = 2$

Pulse



AC coupled RMS:

$V_{RMS} = V_P\sqrt{D(1-D)}$

where; D (duty cycle) = $\frac{t}{T}$

$CF = \frac{1}{\sqrt{D(1-D)}}$

AC coupled peak:

$+V = V_P(1-D)$

$-V = -V_P D$

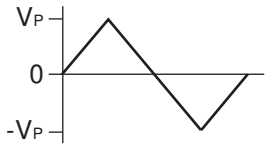
When; $0 < D \leq 0.5$:

$CF = \sqrt{\frac{1}{D} - 1}$

When; $0.5 \leq D < 1$:

$CF = \sqrt{\frac{1}{1-D} - 1}$

Triangular sawtooth



RMS:

$V_{RMS} = 0.557V_P$

$CF = 1.733$

Low level considerations

For sensitive measurements, external considerations beyond the Model 2701 affect the accuracy. Effects not noticeable when working with higher voltages are significant in microvolt signals. The Model 2701 reads only the signal received at its input; therefore, it is important that this signal be properly transmitted from the source. The following paragraphs indicate factors that affect accuracy, including stray signal pick-up and thermal offsets.

Shielding

AC voltages that are extremely large compared with the DC signal to be measured may produce an erroneous output. Therefore, to minimize AC interference, the circuit should be shielded with the shield connected to the Model 2701 input low (particularly for low level sources). Improper shielding can cause the Model 2701 to behave in one or more of the following ways:

- Unexpected offset voltages.
- Inconsistent readings between ranges.
- Sudden shifts in reading.

To minimize pick-up, keep the voltage source and the Model 2701 away from strong AC magnetic sources. The voltage induced due to magnetic flux is proportional to the area of the loop formed by the input leads. Therefore, minimize the loop area of the input leads and connect each signal at only one point.

Thermal EMFs

Thermal EMFs (thermoelectric potentials) are generated by temperature differences between the junctions of dissimilar metals. These can be large compared to the signal that the Model 2701 can measure. Thermal EMFs can cause the following conditions:

- Instability or zero offset is much higher than expected.
- The reading is sensitive to (and responds to) temperature changes. This effect can be demonstrated by touching the circuit, by placing a heat source near the circuit, or by a regular pattern of instability (corresponding to changes in sunlight or the activation of heating and air conditioning systems).

To minimize the drift caused by thermal EMFs, use copper leads to connect the circuit to the Model 2701.

For front panel inputs, a banana plug generates a few microvolts. A clean copper conductor such as #10 bus wire is ideal for this application. For switching modules, use #20 AWG copper wire to make connections. The leads to the Model 2701 may be shielded or unshielded, as necessary. Refer to "Shielding," page E-9.

Widely varying temperatures within the circuit can also create thermal EMFs. Therefore, maintain constant temperatures to minimize these thermal EMFs. A shielded enclosure around the circuit under test also helps by minimizing air currents.

The REL control can be used to null out constant offset voltages.

AC voltage offset

The Model 2701, at 5½ digits resolution, will typically display 100 counts of offset on AC volts with the input shorted. This offset is caused by the offset of the TRMS converter. This offset will not affect reading accuracy and should not be zeroed out using the REL feature. The following equation expresses how this offset (V_{OFFSET}) is added to the signal input (V_{IN}):

$$\text{Displayed reading} = \sqrt{(V_{IN})^2 + (V_{OFFSET})^2}$$

Example: Range = 1VAC
Offset = 100 counts (1.0mV)
Input = 100mV RMS

$$\text{Displayed reading} = \sqrt{(100\text{mV})^2 + (1.0\text{mV})^2}$$
$$= \sqrt{0.01\text{V} + (1 \times 10^{-6}\text{V})}$$
$$= 0.100005\text{V}$$

The offset is seen as the last digit, which is not displayed. Therefore, the offset is negligible. If REL were used to zero the display, the 100 counts of offset would be subtracted from V_{IN}, resulting in an error of 100 counts in the displayed reading.

Current measurements (DCI and ACI)

The Model 2701 can make DCI measurements from 10nA to 3A and ACI measurements from 1µA to 3A RMS.

NOTE *See the previous discussion about crest factor in "Voltage measurements (DCV and ACV)," page 3-8.*

Connections

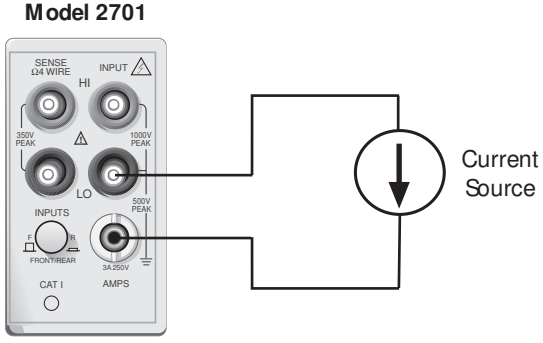
NOTE *When using the front panel inputs, the INPUTS switch must be in the "F" (out) position. For switching modules, it must be in the "R" (in) position.*

WARNING To prevent electric shock, never make or break connections while power is present in the test circuit.

Front panel inputs

When using the front panel input terminals, connect the test leads to the AMPS and INPUT LO terminals as shown in Figure 3-6.

Figure 3-6
DCI and ACI connections using front panel inputs

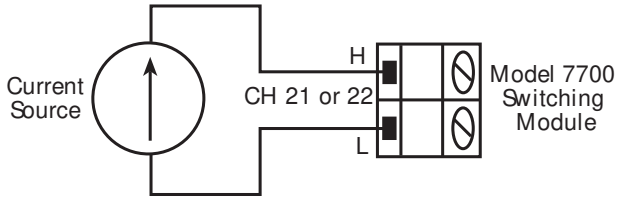


Caution: Maximum Input = 3A DC or RMS

Model 7700 switching module

Connections for the Model 7700 switching module are shown in Figure 3-7. Note that only channels 21 and 22 can be used for current measurements.

Figure 3-7
DCI and ACI connections using Model 7700 switching module



Caution: Maximum input: 60VDC or 30V RMS, 3A switched, 60W, 125VA maximum.

Amps measurement procedure

NOTE *Make sure the INPUTS switch is in the correct position. To use front panel inputs, it has to be in the "F" (out) position. For switching modules, it has to be in the "R" (in) position.*

1. If a switching channel is presently closed (displayed), press OPEN to open it.
2. Select the amps measurement function by pressing DCI or ACI.
3. Use the RANGE ▲ and ▼ keys to select a measurement range consistent with the expected current or press AUTO to select autoranging (AUTO annunciator turns on). Details on range are provided in Section 4.
4. Apply the current(s) to be measured.

CAUTION Do not apply more than 3A to the input or the AMPS fuse will blow.

Model 7700 switching module — When performing current measurements, the maximum allowable voltage is 60VDC or 30V RMS. Exceeding these limits could cause damage to the switching module.

5. If using a switching module, use the ◄ and ► keys to close the desired amps channel (for the Model 7700, 21 or 22). All other channels will be open.

6. Observe the displayed reading. If the "OVERFLOW" message is displayed, select a higher range until a normal reading is displayed (or press AUTO for autoranging). For manual ranging, use the lowest possible range for the best resolution.
7. To measure another amps channel, repeat steps 5 and 6.
8. When finished, press OPEN if there is a channel closed.

NOTE *When you have an amps-only channel closed, you cannot select a non-amps function. For example, if channel 21 of the Model 7700 is closed, you cannot select the DCV function ("INVALID FUNC" displayed).*

AMPS fuse replacement (front panel AMPS input)

WARNING Make sure the instrument is disconnected from the power line and other equipment before replacing the AMPS fuse.

1. Turn off the power and disconnect the power line and test leads.
2. From the front panel, gently push in the AMPS fuse holder with a flat blade screwdriver and rotate the fuse holder one-quarter turn counterclockwise.
3. Remove the fuse and replace it with the same type (3A, 250V, fast-blow, 5 × 20mm). The Keithley part number is FU-99-1.

CAUTION Do not use a fuse with a higher current rating than specified or instrument damage may occur. If the instrument repeatedly blows fuses, locate and correct the cause of the trouble before replacing the fuse.

4. Install the new fuse by reversing the procedure above.

NOTE *For the Model 7700 switching module and other similar modules that support the amps function, there are solder mount amps fuses. See the Model 2701 Service Manual for fuse replacement information.*

Resistance measurements (Ω2 and Ω4)

The Model 2701 has seven ohms ranges to measure resistance from 100µΩ to 120MΩ. Available measurement ranges include 100Ω, 1kΩ, 10kΩ, 100kΩ, 1MΩ, 10MΩ, and 100MΩ.

Information for this topic is structured as follows:

- Connections — 2-wire or 4-wire connections can be made to the front panel input terminals of the mainframe or to a switching module (such as the Model 7700).
- Standard resistance measurements — The Model 2701 can make resistance measurements from 100µΩ to 120MΩ. For resistances >1kΩ, the Ω2 function (2-wire) is typically used for measurements. For resistances ≤1kΩ, the Ω4 function (4-wire) is typically used. The Ω4 function should be used to cancel the effect of test lead (and channel path) resistances.
- Offset-compensated ohms (OCOMP) — The presence of thermal EMFs (voltages) can adversely affect low-resistance measurement accuracy. To overcome these unwanted offset voltages, you can use offset compensated ohms on the 100Ω, 1kΩ, and 10kΩ ranges for the Ω4 function.
- Measurement methods — For the 100Ω to 1MΩ ranges, the Model 2701 uses the constant-current method to measure resistance. The Model 2701 sources a constant current (I) to the resistance and measures the voltage (V). Resistance (R) is then calculated (and displayed) using the known current and measured voltage (R = V/I). For the 10MΩ and 100MΩ ranges, the ratiometric method is used to measure resistance.
- 4-wire common-side (CSID) ohms measurements — Explains the CSID ohms mode which is used with the 7701 module to perform 4-wire common-side ohms measurements.

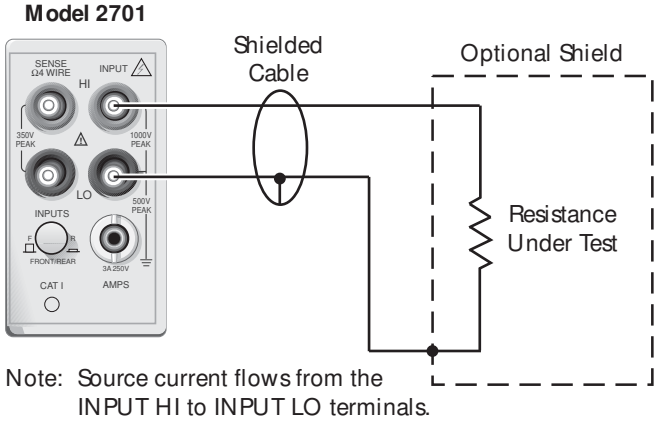
Connections

NOTE *When using the front panel inputs, the INPUTS switch must be in the "F" (out) position. For switching modules, it must be in the "R" (in) position.*

Front panel inputs

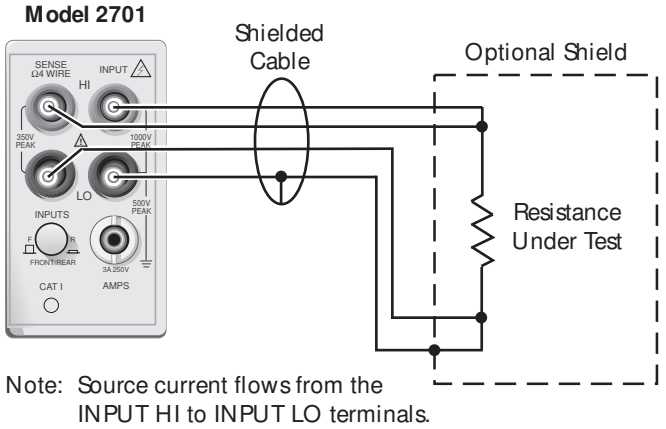
Connections for resistance measurements are shown in Figure 3-8. For 2-wire resistance measurements (Ω2), connect the test leads to INPUT HI and LO as shown in Figure 3-8A. For 4-wire resistance (Ω4), connect the test leads to INPUT HI, INPUT LO, SENSE Ω4 HI, and SENSE Ω4 LO as shown in Figure 3-8B.

Figure 3-8
Ω2 and Ω4 connections for front panel inputs



Note: Source current flows from the INPUT HI to INPUT LO terminals.

A. Ω2 Connections



Note: Source current flows from the INPUT HI to INPUT LO terminals.

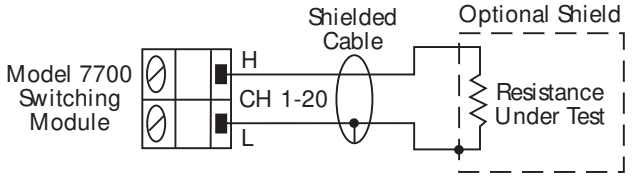
B. Ω4 Connections

Model 7700 switching module

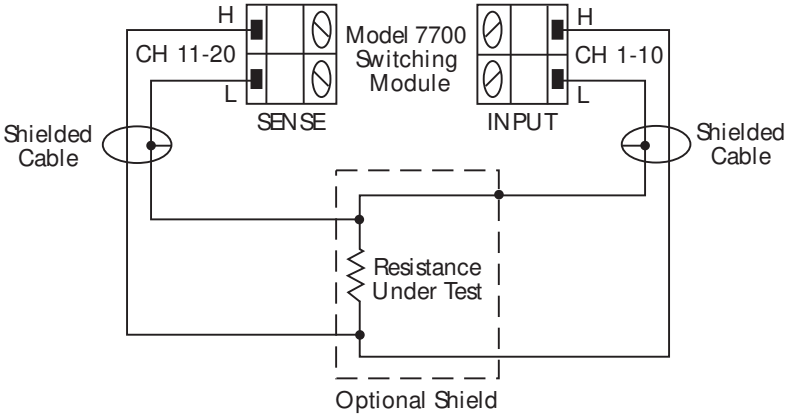
Connections for the switching module are shown in Figure 3-9. As shown in Figure 3-9A, each of the 20 channels can be used to perform Ω2 measurements. For Ω4 measurements, a channel pair is used for each 4-wire measurement as shown in Figure 3-9B.

For Ω4 connections, channels 1 through 10 (which are used as the INPUT terminals) are paired to channels 11 through 20 (which are used as the SENSE terminals). Channel 1 is paired to channel 11, channel 2 is paired to channel 12, and so on.

Figure 3-9
Ω2 and Ω4 connections for Model 7700 switching module



A. Ω2 Connections



Note: Source current flows from input high (H) to input low (L).

B. Ω4 Connections

Shielding

To achieve a stable reading, it helps to shield resistances greater than 100kΩ As shown in Figure 3-8 and Figure 3-9, place the resistance in a shielded enclosure and connect the shield to the input low terminal of the instrument electrically.

Cable leakage

For high resistance measurements in a high humidity environment, use Teflon™ insulated cables to minimize errors due to cable leakage.

Standard resistance measurements

NOTE *Make sure the INPUTS switch is in the correct position. To use front panel inputs, it must be in the "F" (out) position. For switching modules, it must be in the "R" (in) position.*

Perform the following steps to measure resistance:

1. If a switching channel is presently closed (displayed), press OPEN to open it.
2. Select the ohms measurement function by pressing Ω2 or Ω4.
3. Use the RANGE ▲ and ▼ keys to select a measurement range consistent with the expected resistance or press AUTO to select autoranging (AUTO annunciator turns on). Details on range are provided in Section 4.
4. Connect the resistance(s) to be measured.

CAUTION Front panel inputs — Do not apply more than 1000V peak between INPUT HI and LO or instrument damage may occur.

Model 7700 switching module — Do not apply more than 300V DC or 300V RMS (425V peak) for AC waveforms between input high (H) or input low (L) or switching module damage may occur.

5. If using a switching module, perform the following steps to close the desired channel. Keep in mind that for Ω4 measurements, you will close the primary (INPUT) channel (1 through 10). The paired channel will close automatically.
   a. Press the CLOSE key.
   b. Use ◀, ▶, ▲, and ▼, to key in the channel number and press ENTER. The previously closed channel(s) (if any) will open, and the specified channel (or channel pair) will close.

NOTE *While in the normal measurement state, you can use the ◀ and ▶ keys to close channels. In general, each key press will open the presently closed channel and then close the next higher or lower channel.*

6. Observe the displayed reading. If the "OVERFLOW" message is displayed, select a higher range until a normal reading is displayed (or press AUTO for autoranging). For manual ranging, use the lowest possible range for the best resolution.
7. To measure other switching channels, repeat steps 5 and 6.
8. When finished, press OPEN if there is a channel closed.

Offset-compensated ohms

The presence of thermal EMFs (V_{EMF}) can adversely affect low-resistance measurement accuracy. To overcome these unwanted offset voltages, you can use offset-compensated ohms (OCOMP). Offset-compensated ohms measurements can be performed on the 100Ω, 1kΩ, and 10kΩ ranges for the Ω4 function. It cannot be done on the Ω2 function.

NOTE *The various instrument operations, including OCOMP, are performed on the input signal in a sequential manner. See "Signal processing sequence," page D-2 for details. It includes a flowchart showing where in the processing sequence that the OCOMP operation is performed.*

For a normal resistance measurement, the Model 2701 sources a current (I) and measures the voltage (V). The resistance (R) is then calculated (R=V/I) and the reading is displayed.

For offset-compensated ohms, two measurements are performed: one normal resistance measurement and one using the lowest current source setting.

The offset-compensated ohms reading is then calculated as follows:

Offset-compensated ohms reading = $\Delta V/\Delta I$

where: $\Delta V = V2 - V1$
$\Delta I = I2 - I1$

V1 is the voltage measurement with the current source at its normal level.
V2 is the voltage measurement using the lowest current source setting.

The above 2-point measurement process and reading calculation eliminates the resistance contributed by the presence of V_{EMF}.

Enabling/disabling offset-compensated ohms

Offset-compensated ohms is enabled by pressing SHIFT and then OCOMP. When enabled, the OCOMP annunciator is on. Offset-compensated ohms is disabled by again pressing SHIFT and then OCOMP.

Performing offset-compensated ohms measurements

Offset-compensated ohms can only be performed on the Ω4 function using the 100Ω, 1kΩ, or 10kΩ range. Make sure you use 4-wire connections to the DUT (see "Connections," page 3-8).

NOTE *Make sure the INPUTS switch is in the correct position. To use front panel inputs, it must be in the "F" (out) position. For switching modules, it must be in the "R" (in) position.*

1. If a switching channel is presently closed (displayed), press OPEN to open it.
2. Select the 4-wire ohms measurement function by pressing Ω4. Enable offset compensated ohms by pressing SHIFT and then OCOMP (OCOMP annunciator turns on).
3. Use the RANGE ▲ and ▼ keys to select the 100Ω, 1kΩ, or 10kΩ range or press AUTO to enable auto range. If using auto range, offset compensated ohms measurements will not be performed if the instrument goes to the 100kΩ or higher range.
4. Perform steps 4 through 8 of the "Standard resistance measurements," page 3-23, procedure.

NOTE *The OCOMP annunciator will flash when the instrument is on an invalid range (100kΩ through 100MΩ ranges) for offset-compensated ohms. Normal ohms measurements will instead be performed.*

For buffer recall, there is no way to distinguish between a normal ohms reading and an offset-compensated ohms reading. The OCOMP annunciator (off, on, or flashing) has no significance for recalled resistance readings that are displayed. Buffer operation is covered in Section 6.

With offset-compensated ohms enabled, it will be "remembered" by the Ω4 function after you change measurement functions (i.e., DCV). When Ω4 is again selected, offset-compensated ohms will be enabled.

Measurement methods

The Model 2701 uses two methods to measure resistance:

- Constant-current source method (100Ω through 1MΩ ranges) – Sources a constant-current to the DUT. Voltage is measured by the Model 2701 and resistance is then calculated (R = V/I).
- Ratiometric method (10MΩ and 100MΩ ranges) – Test current is generated by a 0.7µA source in parallel with a 10MΩ reference resistor.

Constant-current source method

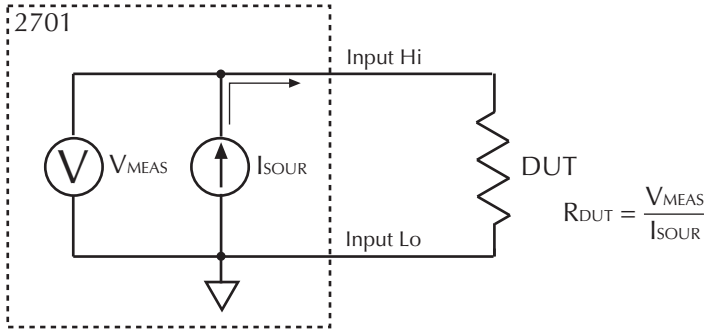
For the 100Ω to 1MΩ ranges, the Model 2701 uses the constant-current method to measure resistance. The Model 2701 sources a constant current (I_{SOUR}) to the DUT and measures the voltage (V_{MEAS}). Resistance (R_{DUT}) is then calculated (and displayed) using the known current and measured voltage ($R_{DUT} = V_{MEAS}/I_{SOUR}$).

The constant-current method is shown in Figure 3-10. The test current sourced to the DUT depends on the selected measurement range. For example, for the 100Ω range, the test current is 1mA. Since the voltmeter of the Model 2701 has very high input impedance (>10GΩ), virtually all the test current (1mA) flows through the DUT.

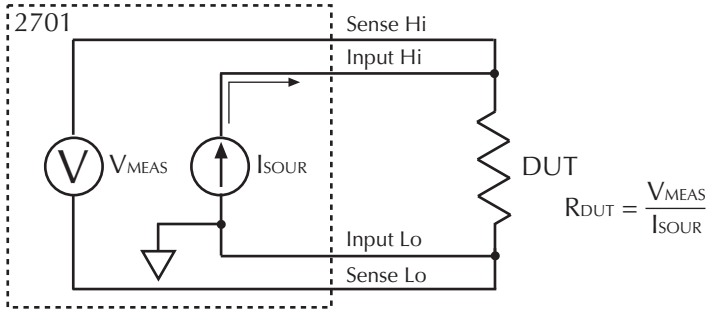
For DUT ≤1kΩ, 4-wire ohms measurements should be used as shown in Figure 3-10B. The voltage is measured at the DUT. This eliminates IR drop in the test leads, which could be significant when measuring low ohm DUT.

Figure 3-10
Constant-current method to measure ohms (100Ω to 1MΩ ranges)

A) 2-wire ohms (Ω2) measurements (100Ω through 1MΩ ranges)



B) 4-wire ohms (Ω4) measurements (100Ω through 1MΩ ranges)



Ratiometric method

For the 10MΩ and 100MΩ ranges, the ratiometric method is used to measure resistance. Test current for this method is generated by a 0.7µA current source (I_{SOUR}) in parallel with a 10MΩ reference resistance (R_{REF}) as shown in Figure 3-11.

Basic circuit theory dictates that the sum of the branch currents (I_{REF} and I_{DUT}) is equal to the source current (I_{SOUR}). Since the voltmeter of the Model 2701 (V_{MEAS}) has very high input impedance (>10GΩ), current through the voltmeter branch is insignificant and can be discounted. Therefore, as shown in Eq. 1, $I_{SOUR} = I_{REF} + I_{DUT}$.

Since I = V/R, Eq. 1 is modified using the V/R equivalents in place of I_{REF} and I_{DUT}. Therefore:

$$I_{SOUR} = (V_{MEAS} / R_{REF}) + (V_{MEAS} / R_{DUT})$$

Eq. 1 is then rearranged to solve for R_{DUT} and is shown in Eq. 2 of Figure 3-11. Keep in mind that V_{MEAS} is measured by the Model 2701. With V_{MEAS}, I_{SOUR}, R_{REF} known, the Model 2701 calculates the resistance of the DUT and displays the result.

NOTE *Eq. 2 in Figure 3-11 assumes that R_{REF} is exactly 10MΩ. In reality, the Model 2701 "measures" the resistance of R_{REF} and uses that value in the equation. The Model 2701 routinely does a "self-calibration". During this process, the precision 0.7µA current is sourced through R_{REF} with an open input. This reference voltage (V_{REF}) is measured and R_{REF} is then calculated:*

$$R_{REF} = V_{REF} / 0.\mu 7$$

As shown in Figure 3-11B, the Ω4 function can also be used to measure ohms for the 10MΩ and 100MΩ ranges. There are actually 3-wire ohm measurements. Sense Hi is not used. Figure 3-11B shows the Sense Hi terminal connected to the DUT but it does not need to be. It can be left open.

The measurement method is similar to the ratiometric method for Ω2, but it performs an extra voltage measurement (V_{LEAD}) to compensate for IR drop in the input test leads. As stated in the specifications (Appendix A) to achieve rated accuracy, the Input Hi and Input Lo test leads must have 10% matching of resistance. To meet that criteria, simply use similar type test leads that are the same length.

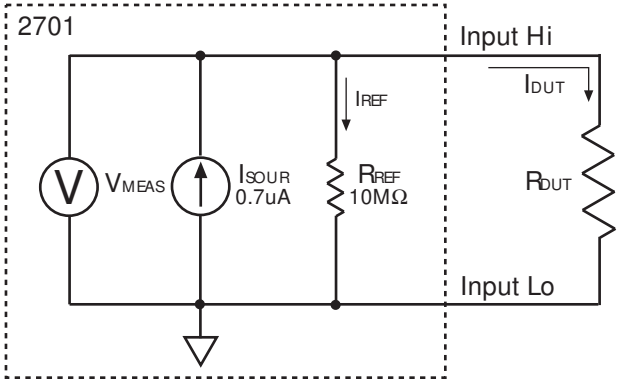
Keep in mind that V_{MEAS} includes the voltage drops of the input test leads (Input Hi and Input Lo). Therefore, the actual voltage drop across the DUT is V_{MEAS} minus the two voltage drops in the test leads.

Since matched input leads are used, the voltage drop for the two test leads are 2 x V_{LEAD}. Therefore; $V_{DUT} = V_{MEAS} - 2(V_{LEAD})$.

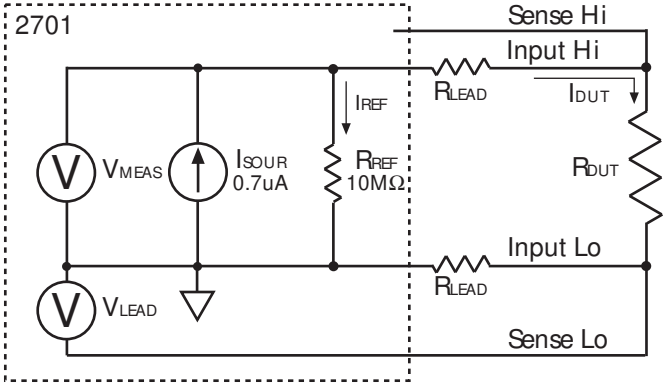
The Model 2701 still uses Eq. 2 to calculate resistance, but it uses V_{DUT} in place of V_{MEAS}. This ratiometric method cancels the effects of input test lead resistance.

Figure 3-11
Ratiometric method to measure ohms (10MΩ and 100MΩ ranges)

A) 2-wire ohms (Ω2) measurements (10MΩ and 100MΩ ranges)



B) 4-wire ohms (Ω4) measurements (10MΩ and 100MΩ ranges)



Ω2 Function

Eq. 1:

$$I_{SOUR} = I_{REF} + I_{DUT}$$

$$= \frac{V_{MEAS}}{R_{REF}} + \frac{V_{MEAS}}{R_{DUT}}$$

Eq. 2:

$$R_{DUT} = \frac{V_{MEAS} \cdot R_{REF}}{(I_{SOUR} \cdot R_{REF}) - V_{MEAS}}$$

$$= \frac{V_{MEAS} \cdot 10M\Omega}{(0.7\mu A \cdot 10M\Omega) - V_{MEAS}}$$

Example:

Asume: $V_{MEAS} = 3.4V$

$$R_{DUT} = \frac{3.4V \cdot 10M\Omega}{(0.7\mu A \cdot 10M\Omega) - 3.4V}$$

$$= 9.444M\Omega$$

Ω4 Function

$V_{DUT} = V_{MEAS} - 2(V_{LEAD})$

For Eq.1, Eq. 2 and the Example, V_{DUT} is used in place of V_{MEAS}.

Effects of open test leads on ohms readings

The Model 2701 will display readings up to 120% of range. Readings above 120% of range will cause the "OVRFLW" message to be displayed. For example, on the 100Ω range readings up to 120Ω will be displayed. Above 120Ω, the "OVRFLW" message is displayed.

The Model 2701 will also display the "OVRFLW" message if a test lead is open during an ohms measurement. A hardware (H/W) detection circuit or software (S/W) detection is used to detect an open input lead. For an Ω4 measurement, a software (S/W) detection routine is used to detect an open sense lead.

Open test lead detection is illustrated in Figure 3-12 for an Ω4 measurement of a 100Ω resistor using the 100Ω range. For an Ω2 measurement, sense circuity is not used. With the test leads properly connected, as shown in Figure 3-12A, 1mA is sourced through the 100Ω DUT. The 100mV drop across the DUT appears on the Input Hi terminal. Resistance is then calculated (100mV / 1mA = 100Ω) and displayed by the Model 2701.

Open input lead detection

100Ω through 1MΩ ranges – For the lower ohms ranges, a hardware detector is used to detect an ope n input lead. The hardware detector uses a comparator circuit to monitor the voltage on the Input Hi terminal. Open circuit voltage on the Input Hi terminal is either 6.6V or 12.8V, depending on the selected measurement range (see resistance specifications in Appendix A). When an input lead (Hi or Lo) is open, as shown in Figure 3-12B, voltage rises to the open-circuit level, which trips the "OVRFLW" message.

10MΩ and 100MΩ ranges – For the two highest ohms ranges, open input lead detection is implemented in software. Open circuit voltage for the 10MΩ and 100MΩ ranges is 7V. For the 10MΩ range, the "OVRFLW" message trips when the open circuit voltage rises to approximately 3.5V. For the 100MΩ range, the "OVRFLW" message trips when the open circuit voltage rises to approximately 6.5V.

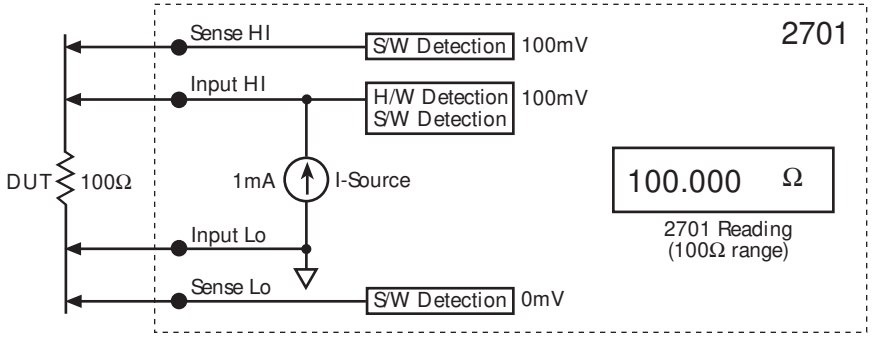
Open sense lead detection

100Ω through 1MΩ ranges – For the Ω4 function, the sense leads must be connected to the DUT. As shown in Figure 3-10B, the sense leads connect the voltmeter of the Model 2701 to the DUT. In general, if a test lead for the voltmeter is open, the reading on the Model 2701 will randomly drift due to the high impedance circuitry of the voltmeter. If this were allowed to happen for the Ω4 function, erroneous ohms readings would be displayed.

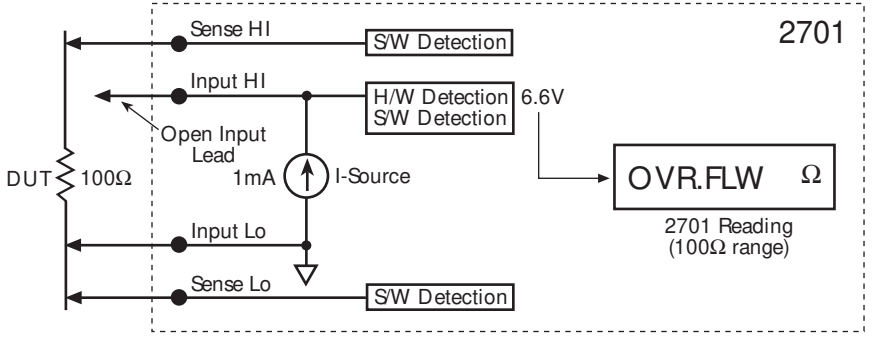
To prevent erroneous ohms readings caused by an open sense lead, the Model 2701 implements software to detect an open sense lead. As shown in Figure 3-12A, with all test leads properly connected, voltage on Sense Hi is at virtually the same potential as Input Hi, and Sense Lo is at virtually 0V. When a sense lead (Hi or Lo) opens, that terminal will drift to -15mV and it will trip the "OVRFLW" message. Figure 3-12C shows detection for an open Sense Hi lead.

Figure 3-12
Open ohms test lead detection

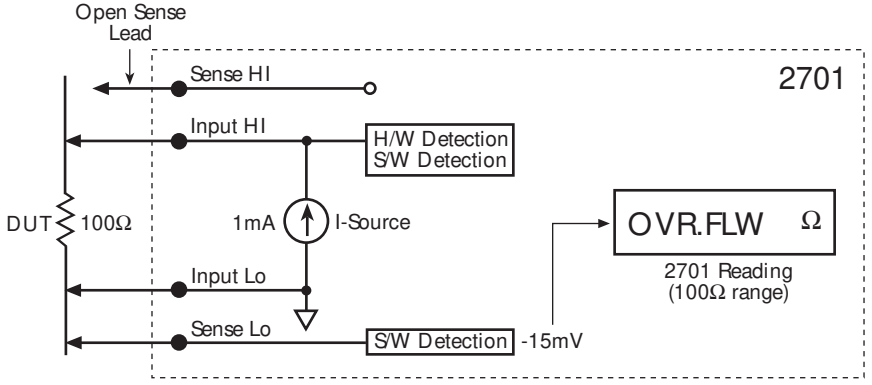
A) Normal 4-wire ohms measurement



B) Open input lead lead detected

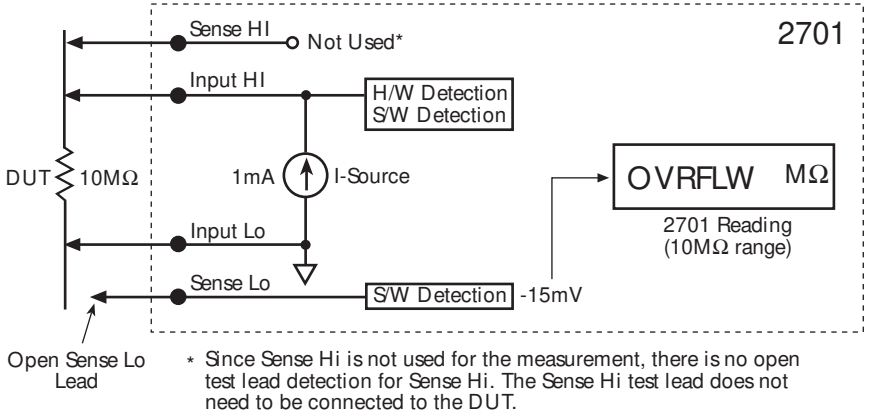


C) Open sense lead lead detected



10MΩ and 100MΩ ranges – Open sense lead detection for the 10MΩ and 100MΩ detection is slightly different and is shown in Figure 3-13. Detection is performed at Sense Lo only. Sense Hi is not used. It does not need to be connected to the DUT. When the Sense Lo lead opens, the Sense Lo terminal will drift to -15mV and trip the "OVRFLOW" message.

Figure 3-13
Open Sense Lo lead detection (10MΩ and 100MΩ ranges)



4-wire common-side (CSID) ohms measurements (7701 module)

For normal 4-wire ohms measurements using a switching module, channels are paired to provide the switch paths for input and sense. Each tested DUT requires two input channels. For example, the 7700 module has 20 channels. With the Ω4 function selected, channel 1 is paired to channel 11, channel 2 is paired to channel 12, and so on. This configuration allows up to 10 DUT to be tested.

The 7701 module has 32 input channels. For normal 4-wire ohms measurements, up to 16 DUT can be tested. However, this module can be configured for common-side (CSID) 4-wire ohms measurements, allowing up to 32 DUT to be tested.

With a 7701 module installed, the 4-wire ohms mode can be selected using the following key-press sequence:

1. Press SHIFT and then press CARD.
2. Select CONFIG.
3. Select slot that has the 7701 (i.e., SLOT1: 7701).
4. Select 4W MODE: NORM (normal) or CSID (common-side).

For remote programming, the following commands are valid with a 7701 module installed:

```
SYSTem:FRESistance:TYPEx, NORMal     ' Select normal 4W mode.
SYSTem:FRESistance:TYPEx, CSIDe      ' Select common-side 4W mode.
SYSTem:FRESistance:TYPEx?            ' Query 4W mode.
```

Where the x in TYPEx is the slot number for the 7701 module.

NOTE *Details on 4-wire common-side ohms measurements using the 7701 module are provided in the manual (packing list) supplied with the module.*

Temperature measurements

The Model 2701 can measure temperature using thermocouples, thermistors, and 4-wire RTDs. When deciding which temperature sensor to use, keep in mind that the thermocouple is the most versatile, the thermistor is the most sensitive, and the 4-wire RTD is the most stable.

Thermocouples

For thermocouples, temperature measurement range depends on which type of thermocouple is being used. Thermocouples that are supported include types J, K, N, T, E, R, S, and B.

Type	Range	Resolution
J	-200°C to 760°C	0.001°C
K	-200°C to 1372°C	0.001°C
N	-200°C to 1300°C	0.001°C
T	-200°C to 400°C	0.001°C
E	-200°C to 1000°C	0.001°C
R	0°C to 1768°C	0.1°C
S	0°C to 1786°C	0.1°C
B	+350°C to 1820°C	0.1°C

When two wires made up of dissimilar metals are joined together, a voltage is generated. The generated voltage is a function of temperature. As temperature changes, the voltage changes. The thermocouple voltage equates to a temperature reading. This is the basic operation principle of the thermocouple.

NOTE *The equation to calculate thermocouple temperature is provided in Appendix F.*

When you connect a thermocouple directly to the input of the Model 2701, at least one of those connections will be a junction made up of two dissimilar metals. Hence, another voltage is introduced and is algebraically added to the thermocouple voltage. The result will be an erroneous temperature measurement.

To cancel the affects of the unwanted thermal voltage, the thermocouple circuit requires a reference junction that is at a known temperature.

Reference junctions

A reference junction is the cold junction in a thermocouple circuit which is held at a stable, known temperature. It is at the cold junction where dissimilar wire connections must be made. As long as the temperature of the cold junction is known, the Model 2701 can factor in the reference temperature to calculate the actual temperature reading at the thermocouple.

The standard reference temperature is the ice point (0°C). The ice point can be precisely controlled and the National Bureau of Standards uses it as the fundamental reference for its voltage-to-temperature conversion tables. However, other known temperatures can be used.

There are two ways for the Model 2701 to acquire the cold junction temperature. It can measure the cold junction using a thermistor or 4-wire RTD or the known temperature value can be entered by the user.

There are three reference junction types supported by the Model 2701: simulated reference junction, internal reference junction, and external reference junction. These reference junctions are explained in the following paragraphs.

NOTE When using multiple channel operation (ROUT:MULT command) to connect a switching module input channel to the DMM, the SIMulated reference junction will be used if the INTernal or EXTernal reference junction is selected.

Simulated reference junction

An example of a simulated reference junction is an ice bath (Figure 3-14A and B). The copper wire to thermocouple wire connections are immersed (but electrically isolated) in the ice bath, and the user enters the 0°C simulated reference temperature into the Model 2701. The simulated reference temperature for the Model 2701 can be set from 0 to 65°C.

The Model 2701 measures the input voltage and factors in the simulated reference temperature to calculate the temperature reading at the thermocouple.

NOTE The most accurate temperature measurements are achieved by using a simulated reference junction using an ice point reference.

Internal reference junction

"Internal" implies that a temperature transducer(s) is used to measure the cold junction (CJC). For the Model 7700 switching module, the cold junction is the screw terminals with voltage temperature sensors strategically placed to measure the temperature of the cold junction.

The Model 2701 measures the temperature of the cold junction (screw terminals), measures the input voltage, and then calculates the temperature reading at the thermocouple.

External reference junction

For switching modules that do not have built-in sensors to measure temperature, each module can use a thermistor or 4-wire RTD to acquire the reference temperature. Connect a thermistor to channel 1 or connect a 4-wire RTD to channel 1 and its paired channel.

Position the temperature transducer near the terminals for the channel(s) being used to measure temperature. Be sure to electrically insulate the transducer leads to keep them from making contact with other conductors.

When you close channel 1 to measure the cold junction temperature, that temperature reading will be used to calculate the temperature when you close a thermocouple channel.

Open thermocouple detection

Long lengths of thermocouple wire can have a large amount of capacitance that is seen at the input of the DMM. If an intermittent open occurs in the thermocouple circuit, the capacitance could cause an erroneous on-scale reading.

The Model 2701 has an open thermocouple detection circuit. When enabled, a 10µA pulse of current is applied to the thermocouple before the start of each temperature measurement. If >12kΩ is detected (open thermocouple), the OVRFLW message will be displayed. If <12kΩ is detected, the current is turned off and a normal thermocouple temperature measurement is performed.

NOTE *Channel average cannot be used with thermocouple temperature measurements if open thermocouple detection is enabled.*

Thermistors

For thermistors, the temperature measurement range is -80°C to 150°C (0.01°C resolution). Thermistor types that are supported include the 2.2kΩ, 5kΩ, and 10kΩ types.

The thermistor is a temperature sensitive resistor. Its resistance changes non-linearly with changes in temperature. Most thermistors have a negative temperature coefficient. As temperature increases, the resistance decreases. The Model 2701 measures the resistance of the thermistor and calculates the temperature reading.

Of all the temperature transducers, the thermistor is the most sensitive. It can quickly detect minute changes in temperature. It is a good choice when measuring very small changes in temperature. The downside for this increased sensitivity is the loss of linearity. Since they are especially non-linear at high temperatures, it is best to use them for measurements below 100°C.

NOTE *Curve fitting constants are used in the equation to calculate thermistor temperature. The thermistor manufacturer's specified curve fitting constants may not be exactly the same as the ones used by the Model 2701. "Thermistor equation," page F-6, provides the equation and the constants used by the Model 2701. It also explains how to select a thermistor when the manufacturer's constants and the ones used by the Model 2701 do not match.*

4-wire RTDs

For 4-wire RTDs, the temperature measurement range is -200°C to 630°C (0.01°C resolution). RTD types that are supported include D100, F100, PT385, and PT3916. A USER type is available to modify RTD parameters, such as the resistance at 0°C. The USER type can be enabled from the front panel, but the settings can only be changed using remote programming.

The RTD has a metal construction (typically platinum). The resistance of the RTD changes with changes in temperature. The Model 2701 measures the resistance and calculates the temperature reading. When using default RTD parameters, the resistance of the RTD will be 100Ω at 0°C.

Of all the temperature transducers, the RTD exhibits the most stability and linearity. The Model 2701 performs the 4-wire measurement using offset compensated ohms. This provides the most accurate way to measure the low resistance of the RTD.

NOTE *The equations used by the Model 2701 to calculate the temperature vs. resistance readings listed in the RTD reference tables are provided in Appendix F.*

NOTE *Only one USER RTD per scan list.*

Connections

NOTE When using the front panel inputs, the INPUTS switch must be in the "F" (out) position. For switching modules, it must be in the "R" (in) position.

Thermocouple connections

Connections for thermocouples are shown in Figure 3-14. Thermocouples are color coded to identify the positive (+) and negative (-) leads (Table 3-2). Note that the negative (-) lead for U.S. type T/Cs is red.

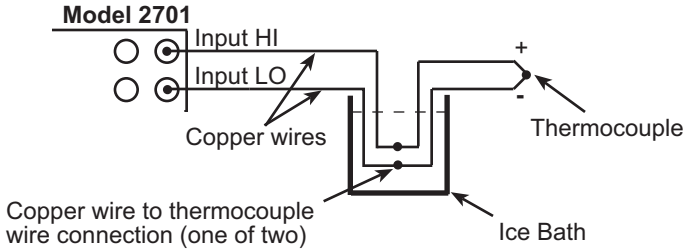
For front panel inputs, you need to use a simulated reference junction for thermocouple temperature measurements. An ice bath, as shown in Figure 3-14A, serves as an excellent cold junction since it is relatively easy to hold the temperature to 0°C. Notice that copper wires are used to connect the thermocouple to the Model 2701 input.

NOTE The positive lead of the type T thermocouple is made of copper. Therefore, that lead can be connected directly to the input of the Model 7700. It does not have to be maintained at the simulated reference temperature (i.e., immersed in ice bath).

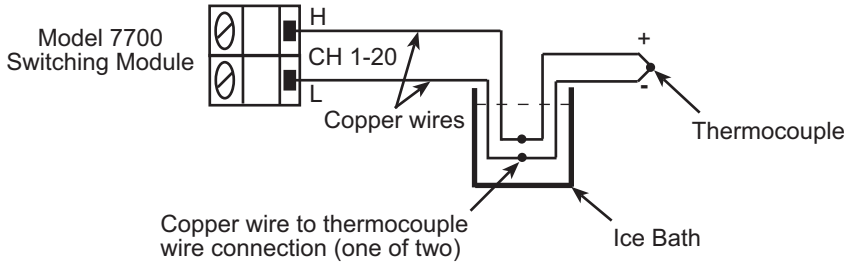
For the Model 7700 switching module, you can also use a simulated reference junction as shown in Figure 3-14B or you can connect the thermocouple wires directly to the screw terminals (internal reference junction) as shown in Figure 3-14C. Using a simulated reference junction may be inconvenient but it will provide more accurate temperature measurements (assuming the user enters a precise reference temperature).

With open thermocouple detection disabled, the Model 2701 can calculate the average temperature of two thermocouple channels using Channel Average (see Section 5 for details). As shown in Figure 3-14D, one thermocouple is connected to a primary channel (1 through 10), and the other thermocouple is connected to its paired channel (11 through 20). Channel 1 is paired to channel 11, channel 2 is paired to channel 12, and so on. Keep in mind that a simulated reference junction (i.e. ice bath) can instead be used for these thermocouple temperature measurements.

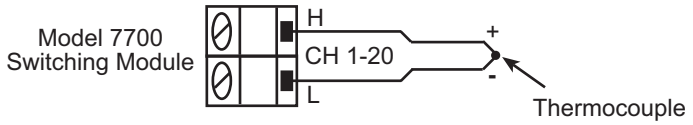
Figure 3-14
Thermocouple connections



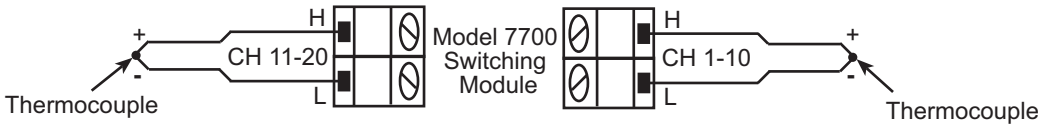
A. Simulated reference junction (front panel inputs)



B. Simulated reference junction (Model 7700)



C. Internal reference junction (Model 7700)



D. Channel average calculation, internal reference junction (Model 7700)

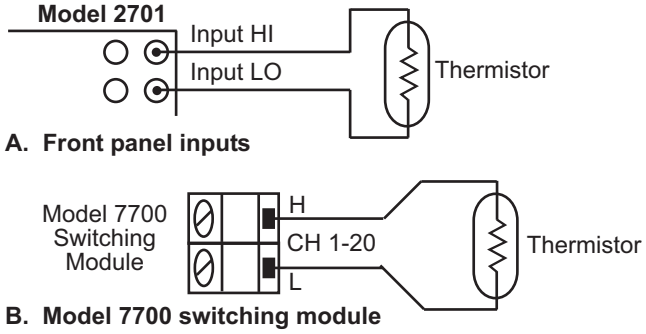
Table 3-2
Color codes — thermocouple wires

T/C type		Positive (+)	Negative (-)	T/C type		Positive (+)	Negative (-)
J	U.S.	White	Red	E	U.S.	Purple	Red
	British	Yellow	Blue		British	Brown	Blue
	DIN	Red	Blue		DIN	Red	Black
	Japanese	Red	White		Japanese	Red	White
	French	Yellow	Black		French	Yellow	Blue
K	U.S.	Yellow	Red	R	U.S.	Black	Red
	British	Brown	Blue		British	White	Blue
	DIN	Red	Green		DIN	Red	White
	Japanese	Red	White		Japanese	Red	White
	French	Yellow	Purple		French	Yellow	Green
N	U.S.	Orange	Red	S	U.S.	Black	Red
	British	—	—		British	White	Blue
	DIN	—	—		DIN	Red	White
	Japanese	—	—		Japanese	Red	White
	French	—	—		French	Yellow	Green
T	U.S.	Blue	Red	B	U.S.	Gray	Red
	British	White	Blue		British	—	—
	DIN	Red	Brown		DIN	Red	Gray
	Japanese	Red	White		Japanese	Red	Gray
	French	Yellow	Blue		French	—	—

Thermistor connections

A thermistor can be connected directly to the front panel inputs or to any of the 20 input channels of the Model 7700 switching module as shown in Figure 3-15.

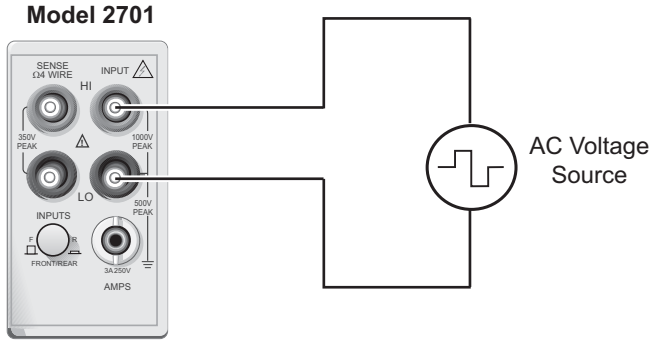
Figure 3-15
Thermistor connections



4-wire RTD connections

Shown in Figure 3-16 are 4-wire RTD connections to the Model 2701. For the Model 7700 switching module, paired channels are used to perform the 4-wire measurement. The two input leads of the RTD are connected to a primary channel (1 through 10), while the two sense leads are connected to its paired channel (11 through 20). Channel 1 is paired to channel 11, channel 2 is paired to channel 12, and so on.

Figure 3-16
4-wire RTD connections



Input Impedance = 1MΩ in parallel with <100pF

Caution: Maximum Input = 1000V peak, 8 x 10^7V·Hz

Temperature measurement configuration

The Model 2701 is configured to measure temperature from the temperature measurement configuration menu. Use the following general rules to navigate through the menu structure:

- Press SHIFT and then SENSOR to enter the menu structure.
- Cursor position is indicated by a flashing menu item or parameter. Cursor position is controlled by the ◄ and ► keys.
- With the cursor on a menu item or parameter, use the ▲ and ▼ keys to scroll through the available options.
- A displayed menu item and parameter is selected by pressing ENTER.
- You can exit from the menu structure by pressing EXIT. However, any ENTERed selections will apply.

Thermocouple temperature measurement configuration

The steps to configure thermocouple measurements are provided in Table 3-3. After pressing SHIFT and then SENSOR, the menu starts at step 1 to select measurement units.

Each time you press ENTER to make a selection, the menu will automatically go to the next selection. After pressing ENTER for the last step, the instrument will return to the normal measurement state.

NOTE *An INT card is a switching module that has an internal reference junction (i.e., Model 7700). The INT reference junction setting cannot be selected if there is not at least one INT card installed in the unit. With no INT cards installed, selecting INT will cause the "NO INT CARDS" message to be displayed briefly.*

With at least one INT card installed, the INT reference junction can be selected. However, if you select it for the front panel inputs or for a switching module that does not have an internal reference junction (i.e., Model 7702), the simulated (SIM) reference junction will instead be used and the "ERR" annunciator will turn on.

Table 3-3
Thermocouple temperature measurement configuration

Step	Menu structure	Description
1	UNITS: C, F, or K	Select temperature measurement units (°C, °F, or K).
2	SENS: TCOUPLE	Select the thermocouple transducer.
3	TYPE: J, K, T, E, R, S, B, or N	Select thermocouple type.
4	JUNC: SIM, INT, or EXT	Select the SIMulated, INTernal, or EXTernal reference junction.*
	SIM: 000°C to 065°C, 273K to 338K, or 032°F to 149°F	For the SIMulated reference junction, set the reference junction temperature. The displayed units depend on the present UNITS setting.
5	OPEN DET: Y or N	Enable (Y) or disable (N) the open thermocouple detector.

*When using multiple channel operation (ROUT:MULT command) to connect a switching module input channel to the DMM, the SIMulated reference junction will be used if the INTernal or EXTernal reference junction is selected.

Thermistor temperature measurement configuration

The steps to configure thermistor measurements are provided in Table 3-4. After pressing SHIFT and then SENSOR, the menu starts at step 1 to select measurement units.

Each time you press ENTER to make a selection, the menu will automatically go to the next selection. After pressing ENTER for the last step, the instrument will return to the normal measurement state.

Table 3-4
Thermistor temperature measurement configuration

Step	Menu structure	Description
1	UNITS: C, F, or K	Select temperature measurement units (°C, °F, or K).
2	SENS: THRMSTR	Select the thermistor transducer.
3	TYPE: 2200Ω, 5000Ω, or 10kΩ	Select thermistor resistance.

4-wire RTD temperature measurement configuration

The Alpha, Beta, Delta, and Ω at 0°C parameters for the five basic RTD types are provided in Table 3-5. Note that these parameters can be modified using remote programming.

Table 3-5
RTD parameters

Type	Standard	Alpha	Beta	Delta	Ω at 0°C
PT100	ITS-90	0.00385055	0.10863	1.49990	100Ω
D100	ITS-90	0.003920	0.10630	1.49710	100Ω
F100	ITS-90	0.003900	0.11000	1.49589	100Ω
PT385	IPTS-68	0.003850	0.11100	1.50700	100Ω
PT3916	IPTS-68	0.003916	0.11600	1.50594	100Ω

The steps to configure 4-wire RTD measurements are provided in Table 3-6. After pressing SHIFT and then SENSOR, the menu starts at step 1 to select measurement units.

Each time you press ENTER to make a selection, the menu will automatically go to the next selection. After pressing ENTER for the last step, the instrument will return to the normal measurement state.

NOTE *As shown in Table 3-6, you can select the USER sensor type, but you cannot change the USER parameters from the front panel. The parameters for the USER type can only be set using remote programming (see TEMPerature:FRTD commands in Table 3-7).*

Table 3-6
4-wire RTD temperature measurement configuration

Step	Menu Structure	Description
1	UNITS: C, F, or K	Select temperature measurement units (°C, °F, or K).
2	SENS: 4W-RTD	Select the 4-wire RTD transducer.
3	TYPE: PT100, D100, F100, PT385, PT3916, or USER	Select 4-wire RTD type.

Temperature measurement procedure

NOTE Make sure the INPUTS switch is in the correct position. To use front panel inputs, it must be in the "F" (out) position. For switching modules, it must be in the "R" (in) position.

1. If a switching channel is presently closed (displayed), press OPEN to open it.
2. Select the temperature measurement function by pressing TEMP.
3. Configure the temperature measurement as previously explained in "Temperature measurement configuration," page 3-42."
4. Connect the temperature transducer(s) to be measured.
5. If using a switching module, perform the following steps to close the desired channel. Keep in mind that for 4-wire RTD measurements, you will close the primary (INPUT) channel (1 through 10). The channel that it is paired to will close automatically.
   a. Press the CLOSE key.
   b. Use ◄, ►, ▲, and ▼ to key in the channel number and press ENTER. The previously closed channel(s) (if any) will open and the specified channel (or channel pair) will close.

NOTE While in the normal measurement state, you can use the ◄ and ► keys to close channels. In general, each key press will open the presently closed channel and then close the next higher or lower channel.

6. Observe the displayed reading.
7. To measure other switching channels, repeat steps 5 and 6.
8. When finished, press OPEN if there is a channel closed.

Frequency and period measurements

The Model 2701 can make frequency measurements from 3Hz to 500kHz on voltage ranges of 100mV, 1V, 10V, 100V, and 750V. Period (1 / frequency) measurements can be taken from 2µs to 333ms on the same voltage ranges as the frequency.

Input impedance:1MΩ‖ <100pF, AC coupled.

The instrument uses the volts input to measure frequency. The AC voltage range can be changed with the RANGE ▲ and ▼ keys. The signal voltage must be greater than 10% of the full-scale range.

CAUTION The voltage limit is subject to the 8×10^7VHz product.

Trigger level

Frequency and period use a zero-crossing trigger, meaning that a count is taken when the frequency crosses the zero level. The Model 2701 uses a reciprocal counting technique to measure frequency and period. This method generates constant measurement resolution for any input frequency. The multimeter's AC voltage measurement section performs input signal conditioning.

Gate time

The gate time is the amount of time the Model 2701 uses to sample frequency or period readings. Use the RATE key to set the gate time; SLOW sets the gate time to 1.0 sec, MED sets it to 0.1 sec, and FAST sets it to 0.01 sec. For remote programming, the gate time can be set from 0.01 to 1.0 sec using the FREQuency:APERture and PERiod:APERture commands (Table 3-7). Note however, that if you set a gate time other than 1.0, 0.1, or 0.01 sec, the SLOW, MED, and FAST annunciators will be off.

The Model 2701 completes a reading when it receives its first zero-crossing after the gate time expires. In other words, the reading is completed 1/2 cycle after the gate time has expired. For example, to sample a 3Hz frequency, you may wait up to three seconds before the Model 2701 returns a reading.

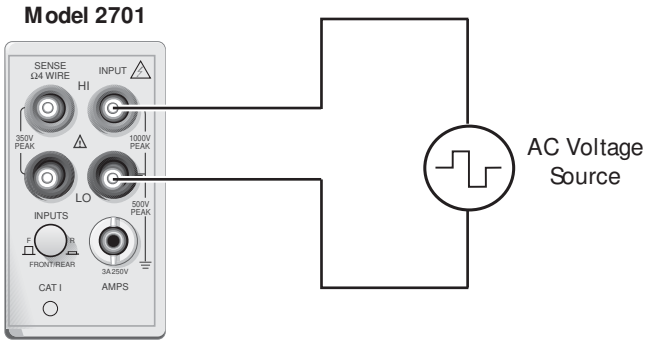
Connections

NOTE *When using the front panel inputs, the INPUTS switch must be in the "F" (out) position. For switching modules, it must be in the "R" (in) position.*

Front panel input

When using the front panel input terminals, connect the test leads to the INPUT HI and LO terminals as shown in Figure 3-17.

Figure 3-17
FREQ and PERIOD connections for front panel inputs



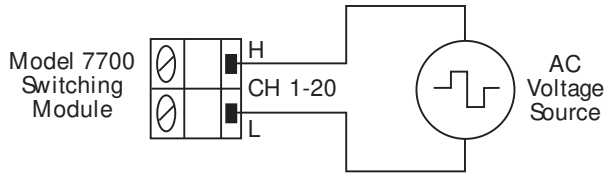
Input Impedance = 1MΩ in parallel with <100pF

Caution: Maximum Input = 1000V peak, 8 x 10^7 V•Hz

Model 7700 switching module

Connections for the Model 7700 switching module are shown in Figure 3-18. For this 2-wire measurement, channels 1 through 20 can be used.

Figure 3-18
FREQ and PERIOD connections using Model 7700 switching module



Caution: Maximum = 300V peak or RMS, 8 x 10^7 V•Hz

Frequency and period measurement procedure

NOTE *Make sure the INPUTS switch is in the correct position. To use front panel inputs, it must be in the "F" (out) position. For switching modules, it must be in the "R" (in) position.*

1. If a switching channel is presently closed (displayed), press OPEN to open it.
2. Perform one of the following steps to select the function:
   - Press FREQ to perform frequency measurements.
   - Press SHIFT and then FREQ to perform period measurements.
3. Use the RANGE ▲ and ▼ keys to select a measurement range consistent with the expected AC voltage. Details on range are provided in Section 4.
4. Apply the AC voltage(s) to be measured.

CAUTION Do not apply more than the maximum input levels indicated in Figure 3-17 and Figure 3-18 or instrument damage may occur.

5. If using a switching module, perform the following steps to close the desired channel:
   a. Press the CLOSE key.
   b. Use ◀, ▶, ▲, and ▼ to key in the channel number and press ENTER. The previously closed channel (if there is one) will open and the specified channel will close.

NOTE *While in the normal measurement state, you can use the ◀ and ▶ keys to close channels. In general, each key press will open the presently closed channel and then close the next higher or lower channel.*

6. Observe the displayed reading. If the "OVERFLOW" message is displayed, select a higher range until a normal reading is displayed. Use the lowest possible range for the best resolution.
7. To measure other switching channels, repeat steps 5 and 6.
8. When finished, press OPEN if there is a channel closed.

Continuity testing

The instrument can test continuity using the 2-wire 1kΩ range. After selecting continuity, you will be prompted to enter the threshold resistance level (1 to 1000Ω). When the measured circuit is below the set threshold level, the instrument will beep and display the resistance readings. When the measured circuit is above the threshold level, the instrument

will not beep and either display the resistance reading or the message "OPEN". If the reading is below 1100Ω, it will be displayed. If the reading is 1100Ω or above, "OPEN" will instead be displayed.

NOTE *The reading rate for continuity is fixed at 0.01 PLC.*

Limits and digital outputs cannot be used when testing continuity with the continuity (CONT) function. If you need to use these operations, use the Ω2 function to test continuity.

Connections

NOTE *When using the front panel inputs, the INPUTS switch must be in the "F" (out) position. For switching modules, it must be in the "R" (in) position.*

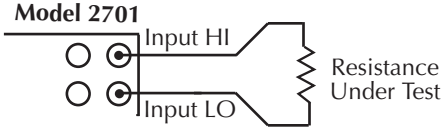
Front panel input

When using the front panel input terminals, connect the test leads to the INPUT HI and LO terminals as shown in Figure 3-19A.

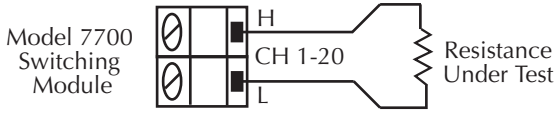
Model 7700 switching module

Connections for the Model 7700 switching module are shown in Figure 3-19B. Since this is a 2-wire ohms measurement, channels 1 through 20 can be used.

Figure 3-19
Continuity connections



A. Front panel connections



Note: Source current flows from input high to input low.

B. Model 7700 connections

Continuity testing procedure

NOTE Make sure the INPUTS switch is in the correct position. To use front panel inputs, it must be in the "F" (out) position. For switching modules, it must be in the "R" (in) position.

1. Apply the resistance to be tested and, if using a switching module, close the appropriate channel.
2. Press SHIFT and then CONT to display the present threshold LEVEL.
3. Use ◄, ►, ▲, and ▼ to key in the desired level (1 to 1000Ω) and press ENTER.

   If the measured circuit is below the set threshold level, the instrument will beep and display the resistance readings.

   If the measured circuit is above the threshold level, the instrument will not beep and either display the resistance reading or the message "OPEN".

   If the reading is below 1100Ω, it will be displayed. If the reading is 1100Ω or above, "OPEN" will instead be displayed.
4. To disable continuity testing, select a different function (i.e., press DCV).

NOTE The beeper can be disabled using the SYSTem:BEEPer:STATe OFF command. However, the beeper will automatically enable the next time the continuity testing function is selected.

Limits and digital outputs cannot be used when testing continuity with the continuity (CONT) function. If you need to use these operations, use the Ω2 function to test continuity.

Remote programming for basic measurements

Basic measurement commands

NOTE *When measurements are performed, the readings are fed to other enabled processing operations. Appendix D explains "Data flow (remote operation)" and the commands used to return the various processed readings.*

Commands to perform basic measurements are listed in Table 3-7.

Table 3-7
Basic measurement commands

Commands[1]	Description	Default	Ref
Select measurement function			
[SENSe[1]]	Optional root command.		
:FUNCtion <name> [, <clist>]	Select measurement function: <name> = 'VOLTage[:DC]', 'VOLTage:AC', 'CURRent[:DC]', 'CURRent:AC', 'RESistance', 'FRESistance', 'CONTinuity', 'FREQuency', or 'PERiod'. *Note: [:DC] is optional.*	VOLT	a
DCV function			
[SENSe[1]]	Optional root command.		
:VOLTage[:DC]:IDIVider <b>	Enable/disable DCV input divider; <b> = ON or OFF.	OFF	
Ω4 function			
[SENSe[1]]	Optional root command.		
:FRESistance:OCOMpensated <b> [, <clist>]	Enable/disable offset-compensated ohms.	OFF	b
SYSTem	Root command for SYSTem subsystem.		
:FRESistance:TYPEx, <name>	Select 4-wire ohms mode; <name> = NORMal or CSIDe. x = Slot number (1 or 2).	NORM	

Table 3-7 (continued)
Basic measurement commands

Commands[1]	Description	Default	Ref
TEMP function			
[SENSe[1]]	Optional root command.		
:TEMPerature:TRANsducer <name> [, <clist>]	Select temperature transducer; <name> = TCouple, FRTD, or THERmistor.	TC	
:TEMPerature:TCouple[:TYPE] <type> [, <clist>]	Select T/C type; <type> = J, K, T, E, R, S, B, or N.	K	
:TEMPerature:TCouple:ODETect <b>	Enable/disable open thermocouple detector; <b> = ON or OFF.	OFF	
:TEMPerature:TCouple:RJUNction: RSELect <name> [, <clist>]	Select reference junction[2]; <name> = SIMulated, INTernal, or EXTernal.	Note 3	c
:TEMPerature:TCouple:RJUNction: SIMulated <n> [, <clist>]	Set the simulated reference temperature; <n> = 0 to 65 (°C), 32 to 149 (°F), or 273 to 338 (K).	23°C	d
:TEMPerature:THERmistor <NRf> [, <clist>]	Set thermistor type in ohms; <NRf> = 1950 to 10050.	5000	
:TEMPerature:FRTD:TYPE <name> [, <clist>]	Select FRTD type; <name> = PT100, D100, F100, PT3916, PT385, or USER.	PT100	e
:TEMPerature:FRTD:RZERo <NRf> [, <clist>]	Specify constant for USER type; <NRf> =0 to 10000.	100	
:TEMPerature:FRTD:ALPHa <NRf> [, <clist>]	Specify constant for USER type; <NRf> = 0 to 0.01.	0.00385	
:TEMPerature:FRTD:BETA <NRf> [, <clist>]	Specify constant for USER type; <NRf> = 0 to 1.00.	0.111	
:TEMPerature:FRTD:DELTa <NRf> [, <clist>]	Specify constant for USER type; <NRf> = 0 to 5.00.	1.507	
FREQ function			
[SENSe[1]]	Optional root command.		
:FREQuency:THReshold:VOLTage: RANGe <n> [, <clist>]	Select threshold voltage range; <n> = 0 to 1010.	10	f
:FREQuency:APERture <n> [, <clist>]	Set gate time for FREQ measurements in secs; <n> = 0.01 to 1.0.	1.0	g

Table 3-7 (continued)
Basic measurement commands

Commands[1]	Description	Default	Ref
PERIOD function			
:PERiod:THReshold:VOLTage:RANGe <n> [, <clist>]	Select threshold voltage range; <n> = 0 to 1010.	10	f
:PERiod:APERture <n> [, <clist>]	Set gate time for PERIOD measurements in secs; <n> = 0.01 to 1.0.	1.0	g
CONT function			
[SENSe[1]]	Optional root command.		
:CONTinuity:THReshold <NRf>	Set continuity threshold in ohms; <NRf> = 1 to 1000.	10	
SYSTem:BEEPer <b>	Enable/disable beeper; <b> = ON or OFF.	ON	
Set temperature measurement units			
UNIT:TEMPerature <name>	Set temperature units; <name> = C, CEL, F, FAR, or K.		h
Trigger and retrieve readings			i
INITiate:CONTinuous <b>	Enable/disable continuous initiation; <b> = ON or OFF.	Note 4	
INITiate	Trigger one or more measurements.		
[SENSe[1]]	Optional root command.		
:DATA[:LATest]?	Returns the last reading string.		
:DATA:FRESh?	Returns the last "fresh" reading string.		
FETCh?	Return reading(s).		
READ?	Trigger and return reading(s).		

Channel list parameter:
<clist> = (@SCH)
where: S = Mainframe slot number (1 or 2)
CH = Switching module channel number (must be 2 digits)
Examples: (@101) = Slot 1, Channel 1
(@101, 203) = Slot 1, Channel 1 and Slot 2, Channel 3
(@101:110) = Slot 1, Channels 1 through 10

1. The <clist> parameter is used to configure one or more channels for a scan.
2. When using multiple channel operation (ROUT:MULT command) to connect a switching module channel to the DMM for thermocouple temperature measurements, the SIMulated reference junction will be used if the INTernal or EXTernal reference junction is selected. The "ERR" annunciator will turn on to indicate that the integrity of the temperature reading is questionable.
3. With a Model 7700, 7706, or 7708 installed, the default sensor junction is Internal. Otherwise, the Simulated (23°C) junction is selected.
4. The *RST default is OFF and the SYSTem:PRESet default is ON.

Reference

a. FUNCtion <name> [, <clist>]

Note that the <name> parameters in the table are enclosed in single quotes (' '). However, double quotes (" ") can instead be used. For example:

FUNC 'VOLT:AC' = FUNC "VOLT:AC"

Scan configuration — When using the <clist> command to configure a scan channel, the scan channel must first be set to the appropriate function before sending other commands to configure it. For example, to set scan channel 101 to use offset-compensated ohms, the following command sequence would be sent:

```
FUNC 'FRES',  (@101)       ' Set scan channel 101 to
                             ¾4 function.
FRES:OCOM  ON, (@101)      ' Enable offset-compensated
                             ohms for scan channel 101.
```

If scan channel 101 was not first set for the Ω4 function, the following errors will occur for the following operations:

- Error -221 (Settings conflict) will occur when trying to enable offset-compensated ohms for that channel.
- Error +700 (Invalid function in scanlist) will occur when trying to query the state of offset-compensated ohms for that channel:

  `FRES:OCOM ON? (@101)`

Details on scanning are provided in Section 7.

b. FRESistance:OCOMpensated <b> [, <clist>]

The instrument does not have to be on the Ω4 function to enable offset-compensated ohms. When Ω4 is selected, offset-compensated ohms will be enabled.

When using the <clist> parameter to configure a scan channel for offset-compensated ohms, that channel must already be set for Ω4. If set for another function, a settings conflict (-221) will occur.

TEMPerature:TCouple:RJUNction:RSELect <name> [, <clist>]

c. To use the EXTERnal reference junction, the scan channel (101, 201, 301, 401, or 501) to be used for the measurement must already be configured to use a thermistor or 4-wire RTD transducer. Otherwise, a settings conflict error (-221) will occur. The TEMPerature:TRANsducer command is used to select the transducer.

NOTE *The following command can instead be used to select the reference junction:*

TEMPerature:RJUNction:RSELect <name> [, <clist>]

d. TEMPerature:TCouple:RJUNction:SIMulated <n> [, <clist>]
The units for the simulated reference temperature depend on the present temperature measurement units as set by UNIT:TEMPerature (see Ref h).

NOTE *The following command can instead be used to set the simulated reference temperature:*

TEMPerature:RJUNction:SIMulated <n> [, <clist>]

e. TEMPerature:FRTD:RZERo <NRf> [, <clist>]
TEMPerature:FRTD:ALPHa <NRf> [, <clist>]
TEMPerature:FRTD:BETA <NRf> [, <clist>]
TEMPerature:FRTD:DELTa <NRf> [, <clist>]

These commands are used to set the parameters for the USER RTD type. Note that the RZERo command sets the "Ω at 0°C" parameter. When any of these commands are sent, the USER RTD type is automatically selected.

f. FREQuency:THReshold:VOLTage:RANGe <n> [, <clist>]
PERiod:THReshold:VOLTage:RANGe <n> [, <clist>]

These commands are used to specify the expected input level. The instrument will then automatically select the most sensitive current or voltage threshold range.

g. FREQuency:APERture <n> [, <clist>]
PERiod:APERture <n> [, <clist>]

The rate annunciators indicate the following aperture settings:

SLOW = 1 sec
MED = 0.1 sec
FAST = 0.01 sec

For all other aperture times, the rate annunciators are turned off.

h. UNIT:TEMPerature <name>

To set temperature measurement units to °C, use the C or CEL parameter. For °F, use the F or FAR parameter. For Kelvin, use the K parameter.

i. Trigger and retrieve readings:

NOTE *Detailed information on the processes to trigger and retrieve readings is provided in Section 8, Section 13, and Appendix D.*

INITiate:CONTinuous <b>
INITiate

With continuous initiation disabled (INITiate:CONTinuous OFF), you can use the INITiate command to trigger one or more measurements.

NOTE *Note that sending INITiate while the instrument is performing measurements will cause error -213 (init ignored).*

DATA[:LATest]?
DATA:FRESh?

These commands do not trigger a reading. They simply return the last reading string. The reading reflects what is applied to the input.

While the instrument is performing measurements, you can use these commands to return the last reading. If the instrument is not performing measurements, DATA[:LATest]? will keep returning the same reading string.

DATA:FRESh? can only be used once to return the same reading string. That is, the reading must be "fresh." Sending this command again to retrieve the same reading string will generate error -230 (data corrupt or stale) or cause a time-out. In order to again use DATA:FRESh? a new (fresh) reading must be triggered.

FETCh?
READ?

FETCh? is similar to DATA[:LATest]]? in that it can be used to return the last reading. However, it can also be used to return more than one reading. When returning more than one reading, the readings are automatically stored in the buffer.

In order to return multiple reading strings, continuous initiation must be disabled (INIT:CONT OFF) so that the sample count (SAMPle:COUNt), which specifies the number of measurements to be performed, can be set >1. After INITiate is sent to trigger the measurements, FETCh? will return the reading strings.

In general, READ? performs an INIT to trigger measurements and then a FETCh? to retrieve the reading strings. With continuous initiation disabled (INITiate:CONTinuous OFF), you can use the READ? command to trigger and return readings. The sample count determines the number of reading strings to be returned. With the sample count >1, the returned readings are automatically stored in the buffer.

NOTE *When readings are stored in the buffer by the TRACe command (or by front panel data store operation), INIT and multi-sample READ? queries are locked out. With readings in the buffer that were stored in that manner, you cannot use the INIT or READ? command if sample count is >1 (error -225, out of memory). Buffer operation is covered in Section 6.*

Basic measurement programming examples

Example #1 — continuous triggering

The following command sequence places the Model 2701 in a continuous trigger mode to measure ACV. Whenever DATA? is sent the last measured reading will be sent to the computer.

NOTE *The following example can be run from the KE2700 Instrument Driver using the example named "CTMMV" in Table G-1 of Appendix G.*

```
SYST:PRES          ' Continuous measurement mode (INIT:CONT ON).
FUNC 'VOLT:AC'     ' Select ACV function.
DATA?              ' Request last measured reading.
```

Example #2 — one-shot triggering

The following command sequence places the Model 2701 in a one-shot trigger mode to measure offset-compensated ohms. Whenever READ? is sent, a measurement will be triggered and the measured reading will be sent to the computer.

NOTE *The following example can be run from the KE2700 Instrument Driver using the example named "Ohmm" in Table G-1 of Appendix G.*

```
*RST               ' One-shot measurement mode (INIT:CONT OFF).
FUNC 'FRES'        ' Select Ω4 function.
FRES:RANG 1e3      ' Select 1kΩ range.
FRES:OCOM ON       ' Enable offset-compensated ohms.
READ?              ' Trigger and return one reading.
```

Example #3 — temperature measurement using Model 7700

The following command sequence places the Model 2701 in a one-shot trigger mode to perform a thermocouple temperature measurement at channel 101 (Model 7700 switching module installed in slot 1). With channel 101 closed, the INIT command triggers one measurement and the DATA? command sends the measured reading to the computer.

```
*RST                 ' One-shot measurement mode (INIT:CONT OFF).
FUNC 'TEMP'          ' Select TEMP function.
UNIT:TEMP F          ' Select °F TEMP units.
TEMP:TRAN TC         ' Select thermocouple transducer.
TEMP:TC:TYPE J       ' Select type J thermocouple.
TEMP:RJUN:RSEL SIM   ' Select simulated reference junction.
TEMP:RJUN:SIM 32     ' Set reference temperature to 32°F (ice
point).
ROUT:CLOS (@101)     ' Close channel 101.
INIT                 ' Trigger one measurement.
DATA?                ' Return measured reading.
```

Example #4 — Scan configuration (Model 7700)

The following commands configure scan channels 101, 102, and 121 of a Model 7700 installed in slot 1. When channel 101 is scanned, DCV will be selected. When channel 102 is scanned, Ω2 will be selected. When channel 121 is scanned, DCI will be selected.

NOTE The following example can be run from the KE2700 Instrument Driver using the example named "ConfigChan" in Table G-1 of Appendix G.

```
FUNC 'VOLT',(@101)  ' Configure scan channel 101 for DCV.
FUNC 'RES',(@102)   ' Configure scan channel 102 for Ω2.
FUNC 'CURR',(@121)  ' Configure scan channel 121 for DCI.
```

NOTE Detailed information on scanning is provided in Section 7.

Measurement queries

NOTE For more information on read commands, see Section 8 (Triggering), Section 13 (SCPI Signal Oriented Measurement Commands), and Appendix D (Signal Processing Sequence and Data Flow).

:FETCh?

What it does

This command will simply return the latest available reading from an instrument.

Limitations

If the instrument does not have a reading available (indicated by dashes in the display), sending this command will cause a –230, "Data corrupt or stale" error. This query will not cause the box to trigger a reading nor will it "wait" for a result if a reading is in progress. It is possible to get the same reading over and over using this query. It will continue to give the same result until one of two things has happened:

- A new reading has been triggered.
- The old reading has been invalidated by changing ranges or by changing function.

Where appropriate

Since this query does not trigger a reading and can give duplicate results, there are not many cases where this command should be used. The ":DATA:FRESh?" query (see page 3-47) is often a better choice. If this query is used, the following conditions should be met:

- A reading has been triggered either by free running (:INIT:CONT ON and :TRIG:SOUR IMM), by some event such as a remote trigger (*TRG), or by an external trigger (:TRIG:SOUR EXT).
- It is confirmed that the reading is completed, either by the setting of the RAV bit in the status model or by allowing sufficient time to pass for the reading to complete.

:READ?

What it does

This command performs three actions. It will reset the trigger model to the idle layer (equivalent to the :ABORt command), take the trigger model out of idle (equivalent to the :INIT command), and return a reading (equivalent to a :FETCh? query). This command will always return a new reading, since aborting the trigger model will invalidate any old readings and trigger a new one. This query will "wait" for a new reading to become available before the instrument sends a result back.

Limitations

This command will not work if the trigger source is set for BUS or EXTERNAL. This will cause a –214, "Trigger deadlock" error. Under this condition, use a :FETCh? query or a :DATA:FRESh? query (see page 3-60). If the trigger model is continuously initiating (:INIT:CONT ON), sending this query may cause a –213, "Init ignored" error, but it will still give a new reading.

When appropriate

If the instrument receives a *RST command, then it defaults to :INIT:CONT OFF, :TRIG:SOUR IMM, and :TRIG:COUNT 1. Sending a :READ? query under these conditions will trigger a new reading.

:MEASure[:<function>]?

What it does

This query will reconfigure the instrument to the function specified in the query, set the trigger source for immediate, set the trigger count to 1, and configure the measurement parameters to *RST defaults. It will then trigger a single reading, and return the result.

Limitations

This query is much slower than a :READ? or :FETCh? query because it has to reconfigure the instrument each time it is sent. It will reset the NPLC, autoranging, and averaging to default settings.

When appropriate

This is an ideal command for taking one-shot measurements if the default settings for a measurement are appropriate and speed is not a requirement.

[:SENSe[1]]:DATA:FRESh?

What it does

This query is similar to :FETCh? in that it returns the latest reading from the instrument, but it has the advantage of making sure that it does not return the same reading twice.

Limitations

Like the :FETCh? query, this command does not trigger a reading.

When appropriate

This is a much better choice than the :FETCh? query because it cannot return the same reading twice. This would be a good query to use when triggering by BUS or EXTERNAL, because it will wait for a reading to complete if a reading is in progress.

The :CALC:DATA:FRESh? query is similar to the :DATA:FRESh? query, but applies to readings that have math applied to them (e.g.:MX+B scaling).

[:SENSe[1]]:DATA[:LATest]?

What it does

This query will return the last reading the instrument had, regardless of what may have invalidated that reading, such as changing ranges or functions.

Limitations

This query is fully capable of returning meaningless, old data.

When appropriate

If, for some reason, the user wanted the last completed reading, even after changing ranges or other measurement settings, which would invalidate the old reading.

The :CALC:DATA:LATest? query is similar to the :DATA:LAT? query, but applies to readings that have math applied to them (e.g.,:MX+B scaling).

Examples

One-shot reading, DC volts, no trigger, fastest rate

```
*RST
:SENSe:FUNCtion 'VOLTage:DC'
:SENSe:VOLTage:DC:RANGe 10          // Use fixed range for fastest readings.
:SENSe:VOLTage:DC:NPLC 0.002        // Use lowest NPLC setting for fastest readings.
:DISPlay:ENABle OFF                 // Turn off display to increase speed.
:SYSTem:AZERo:STATe OFF             // Disable autozero to increase speed,
                                    // but may cause drift over time.
:SENSe:VOLTage:DC:AVERage:STATe OFF  // Turn off filter for speed.
:READ?
(Enter reading)
```

One-shot reading, DC volts, bus trigger, auto ranging

```
*RST
:TRIGger:SOURce BUS
:SENSe:FUNCtion 'VOLTage:DC'
:SENSe:VOLTage:DC:RANGe:AUTO ON
:INITiate
*TRG                                // Triggers reading
:SENSe:DATA:FRESh?
(Enter reading)
```

One-shot reading, external trigger, auto delay enabled

```
*RST
:TRIGger:SOURce EXTernal
:TRIGger:DELay:AUTO ON          // Note: Auto trigger delay only takes effect with
                                // trigger source set for BUS or EXTernal.
:SENSe:FUNCtion 'VOLTage:DC'
:SENSe:VOLTage:DC:RANGe:AUTO ON
:INITiate
(external trigger)
:SENSe:DATA:FRESh?
(enter reading)                 // This step will time out if the trigger has not occurred.
```

4
Range, Digits, Rate, Bandwidth, and Filter

- Range — Provides details on measurement range selection. Includes the commands for remote programming.
- Digits — Provides details on selecting display resolution. Includes the commands for remote programming.
- Rate and bandwidth — Provides details on integration rate and bandwidth (for AC measurements). Includes the commands for remote programming.
- Filter — Provides details on filtering. Includes the commands for remote programming.

Range

The range setting is "remembered" by each measurement function. When you select a function, the instrument will return to the last range setting for that function.

Measurement ranges and maximum readings

The selected range affects both accuracy of the measurement as well as the maximum level that can be measured. The measurement ranges and maximum readings for all functions, except FREQ, PERIOD, and TEMP, are listed in Table 4-1.

Input values that exceed the maximum readings cause the message "OVERFLOW" to be displayed.

Table 4-1
Measurement ranges and maximum readings

Function	Ranges	Maximum reading
DCV	100mV, 1V, 10V, 100V, 1000V	±1010V
ACV	100mV, 1V, 10V, 100V, 750V	757.5V
DCI	20mA, 100mA, 1A, 3A	±3.1A
ACI	1A, 3A	3.1A
Ω2	100Ω, 1kΩ, 10kΩ, 100kΩ, 1MΩ, 10MΩ, 100MΩ	120MΩ
Ω4*	100Ω, 1kΩ, 10kΩ, 100kΩ, 1MΩ, 10MΩ, 100MΩ	120MΩ

*Offset compensated ohms (OCOMP) can be performed on the 100Ω, 1kΩ, and 10kΩ ranges.

FREQ and PERIOD — Frequency measurements from 3Hz to 500kHz and period measurements from 2µs to 333µs can be made on the ACV ranges.

TEMP — There is no range selection for temperature measurements. Temperature measurements are performed on a single, fixed range. Depending on which type of sensor is being used, the maximum temperature readings range from –200°C to 1820°C. Appendix A (Specifications), lists the reading range for each sensor type.

Manual ranging

To change range, press the RANGE ▲ or ▼ key. The instrument changes one range per key press. The selected range is displayed for one second. Note that the manual range keys have no effect on temperature (TEMP).

If the instrument displays the "OVERFLOW" message on a particular range, select a higher range until an on-range reading is displayed. Use the lowest range possible without causing an overflow to assure best accuracy and resolution.

Auto ranging

To enable auto range, press the AUTO key. The AUTO annunciator turns on when auto ranging is selected. While auto ranging is enabled, the instrument automatically selects the best range to measure the applied signal. Auto ranging should not be used when optimum speed is required. Note that the AUTO key has no effect on temperature (TEMP).

Up-ranging occurs at 120% of range. The Model 2701 will down-range when the reading is $\leq$10% of nominal range.

To disable auto ranging, press AUTO. This will leave the instrument on the present range. You can also disable auto ranging by pressing the ▲ or ▼ key, however a range change may occur.

Scanning

When a simple scan is configured, the present function and range setting will apply to all channels in the scan. When an advanced scan is configured, each channel can have its own unique range setting. Details to configure and run a scan are provided in Section 7.

For remote programming, the <clist> parameter is used to configure channels for a scan.

Remote programming — range

Range commands

The commands to set range are listed in Table 4-2. Additional information on these commands follow the table.

NOTE Query commands and some optional command words are not included in Table 4-2. All commands for the SENSe subsystem are provided in Table 15-5.

Table 4-2
Range commands

Commands[1, 2]	Description	Default
[SENSe[1]]	Optional root command.	
:VOLTage[:DC]:RANGe <n> [, <clist>]	Select DCV range; <n> = 0 to 1010 (V).	1000
:VOLTage[:DC]:RANGe:AUTO <b> [, <clist>]	Control DCV auto range; <b> = ON or OFF.	ON
:VOLTage:AC:RANGe <n> [, <clist>]	Select ACV range; <n> = 0 to 757.5 (V).	750
:VOLTage:AC:RANGe:AUTO <b> [, <clist>]	Control ACV auto range; <b> = ON or OFF.	ON
:CURRent[:DC]:RANGe <n> [, <clist>]	Select DCI range; <n> = 0 to 3 (A).	3
:CURRent[:DC]:RANGe:AUTO <b> [, <clist>]	Control DCI auto range; <b> = ON or OFF.	ON
:CURRent:AC:RANGe <n> [, <clist>]	Select ACI range; <n> = 0 to 3 (A).	3
:CURRent:AC:RANGe:AUTO <b> [, <clist>]	Control ACI auto range; <b> = ON or OFF.	ON
:RESistance:RANGe <n> [, <clist>]	Select Ω2 range; <n> = 0 to 120e6 (Ω).	120e6
:RESistance:RANGe:AUTO <b> [, <clist>]	Control Ω2 auto range; <b> = ON or OFF.	ON
:FRESistance:RANGe <n> [, <clist>]	Select Ω4 range; <n> = 0 to 120e6 (Ω).	120e6
:FRESistance:RANGe:AUTO <b> [, <clist>]	Control Ω4 auto range; <b> = ON or OFF.	ON
Channel list parameter: <clist> = (@SCH) where: S = Mainframe slot number (1 or 2) CH = Switching module channel number (must be 2 digits) Examples: (@101) = Slot 1, Channel 1 (@101, 203) = Slot 1, Channel 1 and Slot 2, Channel 3 (@101:110) = Slot 1, Channels 1 through 10		

1. The <clist> parameter is used to configure one or more channels for a scan. Each channel in the <clist> must be set to the function specified by the range command. If not, a conflict error (-221) will occur. For example, VOLTage:AC:RANGe 1, (@101) is only valid if scan channel 101 is set for the ACV function.
2. [:DC] is optional for the commands to set DCV and DCI range.

Manual ranging

The range is selected by specifying the expected reading as an absolute value using the <n> parameter for the appropriate :RANGe command. The Model 2701 will then go to the most sensitive range for that expected reading. For example, if you expect a reading of approximately 3V, let the parameter (<n>) equal 3 to select the 10V range.

Auto ranging

The :RANGe:AUTO command is coupled to the command to select range manually (:RANGe <n>). When auto range is enabled, the parameter value for :RANGe <n> changes to the automatically selected range value. When auto range is disabled, the instrument remains at the selected range. When a valid :RANGe <n> command is sent, auto ranging disables.

Range programming examples

NOTE *The following examples can be run from the KE2700 Instrument Driver using the example named "MultiRange" in Table G-1 of Appendix G.*

Example #1 — The following commands select range for DCV, Ω2, and DCI:

```
VOLT:RANG 0.5                          ' Select 1V range for DCV.
RES:RANG 2e3                           ' Select 10kΩ range for Ω2.
CURR:RANG 0.1                          ' Select 100mA range for DCI.
```

Example #2 — The following command sequence configures channel 101 of the Model 7700 to select the 10VDC range when it is scanned.

```
FUNC 'VOLT',(@101)                     ' Set 101 for DCV function.
VOLT:RANG 1.5,(@101)                   ' Set 101 for 10V range.
```

Digits

The DIGITS key sets display resolution for the Model 2701 from 3½ to 6½ digits. From the front panel, setting digits for one function affects all the other functions. For example if you set DCV for 3½ digits, the other functions will also set to 3½ digits. For remote programming, each mainframe input function can have its own unique digits setting.

Digits has no effect on the remote reading format. The number of displayed digits does not affect accuracy or speed. Speed is set by the RATE key.

Setting display resolution — To set display resolution, press the DIGITS key until the desired number of digits is displayed.

Scanning

When a simple scan is configured, the present digits setting will apply to all channels in the scan. When an advanced scan is configured, each channel can have its own unique digits setting. Details to configure and run a scan are provided in Section 7.

For remote programming, the <clist> parameter is used to configure channels for a scan.

Remote programming — digits

Digits commands

The commands to control display resolution (digits) are listed in Table 4-3. Additional information on these commands follow the table.

NOTE Query commands are not included in Table 4-3. All commands for the SENSe subsystem are provided in Table 15-5.

Table 4-3
Digits commands

Commands*	Description	Default
[SENSe[1]]	Optional root command.	
:VOLTage[:DC]:DIGits <n> [, <clist>]	Set # of digits for DCV; <n> = 4 to 7.	7
:VOLTage:AC:DIGits <n> [, <clist>]	Set # of digits for ACV; <n> = 4 to 7.	6
:CURRent[:DC]:DIGits <n> [, <clist>]	Set # of digits for DC1; <n> = 4 to 7.	7
:CURRent:AC:DIGits <n> [, <clist>]	Set # of digits for ACI; <n> = 4 to 7.	6
:RESistance:DIGits <n> [, <clist>]	Set # of digits for Ω2; <n> = 4 to 7.	7
:FRESistance:DIGits <n> [, <clist>]	Set # of digits for Ω4; <n> = 4 to 7.	7
:TEMPerature:DIGits <n> [, <clist>]	Set # of digits for TEMP; <n> = 4 to 7.	6
:FREQuency:DIGits <n> [, <clist>]	Set # of digits for FREQ; <n> = 4 to 7.	7
:PERiod:DIGits <n> [, <clist>]	Set # of digits for PERIOD; <n> = 4 to 7.	7
Channel list parameter: <clist> = (@SCH) where: S = Mainframe slot number (1 or 2) CH = Switching module channel number (must be 2 digits) Examples: (@101) = Slot 1, Channel 1 (@101, 203) = Slot 1, Channel 1 and Slot 2, Channel 3 (@101:110) = Slot 1, Channels 1 through 10		

*The <clist> parameter is used to configure one or more channels for a scan. Each channel in the <clist> must be set to the function specified by the digits command. If not, a conflict error (-221) will occur. For example, VOLTage:AC:DIGits 4.5, (@101) is only valid if scan channel 101 is set for the ACV function.

Setting digits

Even though the parameters for the DIGits command are expressed as integers (4 to 7), you can specify resolution using a real number. For example, to select 3½ digit resolution, let <n> = 3.5. Internally the instrument rounds the entered parameter value to the nearest integer.

As implied by the commands in Table 4-3, each mainframe input function can have its own unique digits setting.

Digits programming examples

NOTE *The following examples can be run from the KE2700 Instrument Driver using the example named "Digits" in Table G-1 of Appendix G.*

Example #1 — The following commands set digits for DCV and ACI:

```
VOLT:DIG 5.5                        ' Set DCV to 5½ digits.
CURR:AC:DIG 4                       ' Set ACI to 3½ digits.
```

Example #2 — The following command sequence configures channels 101 through 110 of the Model 7700 to select 4½ digits when they are scanned.

```
FUNC 'RES', (@101:110)              ' Select Ω2 function.
RES:DIG 4.5,(@101:110)              ' Set scan channels to 4½ digits.
```

Rate and bandwidth

Rate

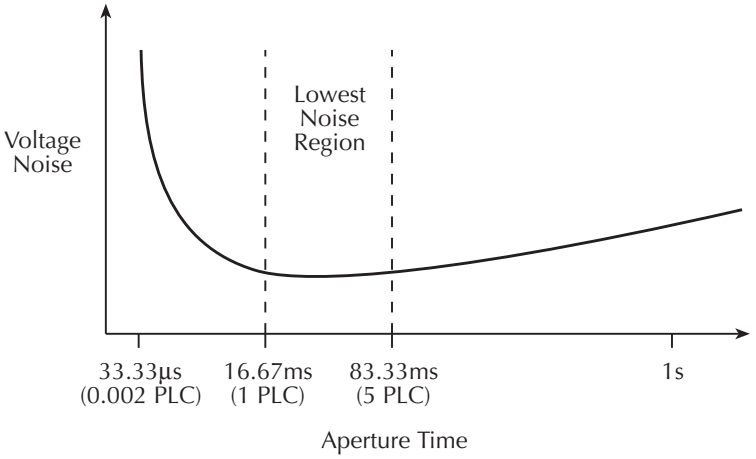
Setting the rate sets the integration time (measurement speed) of the A/D converter, the period of time the input signal is measured (also known as aperture). The integration time affects the amount of reading noise, as well as the ultimate reading rate of the instrument.

The integration time is specified in parameters based on the number of power line cycles (NPLC), where 1 PLC for 60Hz is 16.67msec (1/60) and 1 PLC for 50Hz and 400Hz is 20msec (1/50).

In general, the fastest integration time (0.1 PLC from the front panel, 0.002 PLC from the bus) results in increased reading noise and fewer usable digits, while the slowest integration time (5 PLC from the front panel, 50 PLC from the bus) provides the best common-mode and normal-mode rejection. In-between settings are a compromise between speed and noise.

The Model 2701 has a parabola-like shape for its speed vs. noise characteristics and is shown in Figure 4-1. The Model 2701 is optimized for the 1 PLC to 5 PLC reading rate. At these rates (lowest noise region in graph), the Model 2701 will make corrections for its own internal drift and still be fast enough to settle a step response <100ms.

Figure 4-1
Speed vs. noise characteristics



The front panel RATE key settings for all but the AC functions are explained as follow:

- FAST sets integration time to 0.1 PLC. Use FAST if speed is of primary importance (at the expense of increased reading noise and fewer usable digits).
- MEDium sets integration time to 1 PLC. Use MEDium when a compromise between noise performance and speed is acceptable.
- SLOW sets integration time to 5 PLC. SLOW provides better noise performance at the expense of speed.

For the AC functions (ACV, ACV dB, and ACI), the RATE key sets integration time and bandwidth. As listed in Table 4-4, FAST sets NPLC to 1, while the MEDium and SLOW NPLC settings are ignored (see "Bandwidth," page 4-10, for details).

Table 4-4
Rate and bandwidth settings

Function	Rate and bandwidth		
	Fast	Medium	Slow
DCV, DCI	NPLC=0.1	NPLC=1	NPLC=5
ACV, ACI	NPLC=1, BW=300	NPLC=X, BW=30	NPLC=X, BW=3
Ω2, Ω4	NPLC=0.1	NPLC=1	NPLC=5
FREQ, PERIOD	APER=0.01s	APER=0.1s	APER=1s
Continuity	NPLC=0.01	N/A	N/A

Notes: NPLC = number of power line cycles.
BW = lower limit of bandwidth (in Hz).
APER = aperture in seconds.
N/A = not available.
X = setting ignored.

From the front panel, setting the rate for one function affects all the other functions. For example, if you set DCV for medium speed, the other functions will also set to medium speed. For remote programming, each function can have its own unique rate setting (0.002 to 50 or 60 PLC).

NOTE Rate cannot be set for continuity. It is fixed at 0.01 PLC.

Setting rate

FAST, MED, or SLOW — The RATE key is used to set rate (measurement speed from the front panel). Simply press RATE until the desired speed annunciator (FAST, MED, or SLOW) turns on.

NOTE The Model 2701 uses internal references to calculate an accurate and stable reading. When the NPLC setting is changed, each reference must be updated to the new NPLC setting before a reading is generated. Therefore, frequent NPLC setting changes can result in slower measurement speed.

Bandwidth

Bandwidth specifies the lowest frequency of interest for AC measurements. The RATE setting determines the bandwidth setting:

- SLOW — 3Hz to 300kHz
- MEDium — 30Hz to 300kHz
- FAST — 300Hz to 300kHz

When the Slow bandwidth (3Hz to 300kHz) is chosen, the signal goes through an analog RMS converter. The output of the RMS converter goes to a fast (1kHz) sampling A/D and the RMS value is calculated from 1200 digitized samples (1.2s).

When the Medium bandwidth (30Hz to 300kHz) is chosen, the same circuit is used. However, only 120 samples (120ms) are needed for an accurate calculation because the analog RMS converter has turned most of the signal to DC.

In the Fast bandwidth (300Hz to 300kHz), the output of the analog RMS converter (nearly pure DC at these frequencies) is simply measured at 1 PLC (16.6ms). For remote programming, the integration rate can be set from 0.002 PLC to 50 or 60 PLC.

Table 4-4 lists the front panel bandwidth settings for the AC measurement functions. For remote programming, the FAST, MED, and SLOW annunciators are only lit when conditions in the table are met. In other cases, the annunciators are turned off.

Scanning

When a simple scan is configured, the present rate or bandwidth setting will apply to all channels in the scan. When an advanced scan is configured, each channel can have its own rate or bandwidth setting. Details to configure and run a scan are provided in Section 7.

For remote programming, the <clist> parameter is used to configure channels for a scan.

Remote programming — rate and bandwidth

Rate and bandwidth commands

The commands to set the integration rate and bandwidth are listed in Table 4-5. Additional information on these commands follows the table.

NOTE *Query commands are not included in Table 4-5. All commands for the SENSe subsystem are provided in Table 15-5.*

Table 4-5
Rate and bandwidth commands

Commands [1, 6]	Description	Default
Integration rate commands		
[SENSe[1]]		
:VOLTage[:DC]:NPLCycles <n> [, <clist>]	Set rate for DCV in PLCs; <n> = 0.002 to x.[2]	5.0
:VOLTage[:DC]:APERture <n> [, <clist>]	Set rate for DCV in secs; <NRf> = 3.333e-5 to 1.	(Note 3)
:VOLTage:AC:NPLCycles <n> [, <clist>]	Set rate for ACV in PLCs; <n> = 0.002 to x.[2,4]	5.0
:VOLTage:AC:APERture <n> [, <clist>]	Set rate for ACV in secs; <n> = 3.333e-5 to 1.[4]	(Note 3)
:CURRent[:DC]:NPLCycles <n> [, <clist>]	Set rate for DCI in PLCs; <n> = 0.002 to x.[2]	5.0
:CURRent[:DC]:APERture <n> [, <clist>]	Set rate for DCI in secs; <n> = 3.333e-5 to 1.	(Note 3)
:CURRent:AC:NPLCycles <n> [, <clist>]	Set rate for ACI in PLCs; <n> = 0.002 to x.[2,4]	5.0
:CURRent:AC:APERture <n> [, <clist>]	Set rate for ACI in secs; <n> = 3.333e-5 to 1.[4]	(Note 3)
:RESistance:NPLCycles <n> [, <clist>]	Set rate for Ω2 in PLCs; <n> = 0.002 to x.[2]	5.0
:RESistance:APERture <n> [, <clist>]	Set rate for Ω2 in secs; <n> = 3.333e-5 to 1.	(Note 3)
:FRESistance:NPLCycles <n> [, <clist>]	Set rate for Ω4 in PLCs; <n> = 0.002 to x.[2]	5.0
:FRESistance:APERture <n> [, <clist>]	Set rate for Ω4 in secs; <n> = 3.333e-5 to 1.	(Note 3)
:TEMPerature:NPLCycles <n> [, <clist>]	Set rate for TEMP in PLCs; <n> = 0.002 to x.[2]	5.0
:TEMPerature:APERture <n> [, <clist>]	Set rate for TEMP in secs; <n> = 3.333e-5 to 1.	(Note 3)

Table 4-5 (continued)
Rate and bandwidth commands

Commands [1, 6]	Description	Default
Bandwidth commands		
[SENSe[1]]		
:VOLTage:AC:DETector:BANDwidth <NRf> [, <clist>]	Set AC bandwidth for ACV in Hertz; <NRf> = 3 to 3e5.[5]	30
:CURRent:AC:DETector:BANDwidth <NRf> [, <clist>]	Set AC bandwidth for ACI in Hertz; <NRf> = 3 to 3e5.[5]	30
Channel list parameter: <clist> = (@SCH) where: S = Mainframe slot number (1 or 2) CH = Switching module channel number (must be 2 digits) Examples: (@101) = Slot 1, Channel 1 (@101, 203) = Slot 1, Channel 1 and Slot 2, Channel 3 (@101:110) = Slot 1, Channels 1 through 10		

Notes:
1. The <clist> parameter is used to configure one or more channels for a scan. Each channel in the <clist> must be set to the function specified by the command. If not, a conflict error (-221) will occur. For example, RESistance:NPLCycles 1, (@101) is only valid if scan channel 101 is set for the Ω2 function.
2. For 60Hz line power, x = 60. For 50Hz line power, x = 50.
3. For 60Hz line power, the default is 16.67msec. For 50Hz line power, the default is 20msec.
4. Commands to set rate for ACV and ACI are only valid if bandwidth is set to 300 (300Hz to 300kHz). See "Rate and bandwidth conflict error," page 4-13, for details.
5. The instrument will actually accept a parameter value up to 10e6, but it will default to 3e5.
6. [:DC] is optional for the commands to set DCV and DCI integration rate.

Aperture

Aperture is a different way to specify the integration rate. As previously explained, 1 PLC sets the integration rate to 16.67msec (assuming 60Hz line power). You can instead use an APERture command as follows to set the same integration rate:

```
:APERture  16.67e-3
```

Bandwidth

There are three bandwidth settings for ACV and ACI measurements: 3 (3Hz to 300kHz), 30 (30Hz to 300kHz), and 300 (300Hz to 300kHz). To achieve the best accuracy for ACV and ACI measurements, use the bandwidth setting that best reflects the frequency of the input signal. For example, if the input signal is 40Hz, then a bandwidth setting of 30 should be used.

To set bandwidth, simply specify (approximately) the frequency of the input signal. The instrument will automatically set the bandwidth as follows:

<NRf>	= 3 to 29	3Hz to 300kHz
	= 30 to 299	30Hz to 300kHz
	= 300 to 300e3	300Hz to 300kHz

NOTE *A rate command (:NPLCycles or :APERture) for ACV and ACI is only valid if the bandwidth for that AC function is set to 300 (300Hz to 300kHz). See "Rate and bandwidth conflict error," page 4-13, for details.*

Rate and bandwidth conflict error

For bandwidth settings of 3 and 30, the normal A/D conversion method is not used for ACV and ACI measurements. Therefore, integration rate commands (:NPLCycles and :APERture) for these bandwidth settings will cause a settings conflict error (-221) and not be executed.

For a bandwidth setting of 300, the normal A/D conversion method is used, therefore the integration rate commands can be used.

The default bandwidth setting is 30 for both ACV and ACI. If you want to set an integration rate for an AC function, you will have to first set the bandwidth to 300.

Rate and bandwidth programming examples

NOTE *The following examples can be run from the KE2700 Instrument Driver using the example named "RateBandwidth" in Table G-1 of Appendix G.*

Example #1 — The following command sequence sets ACV rate to 5 PLC. In order to set rate for an AC function, bandwidth must first be set to 300:

```
VOLT:AC:DET:BAND 300                ' Set ACV bandwidth to 300.
VOLT:AC:NPLC 5                      ' Set ACV rate to 5 PLC.
```

NOTE *VOLT:AC:DET:BAND must be set to 300 before the VOLT:AC:NPLC command can be sent.*

Example #2 — The following command sequence configures channels 101 and 103 of the Model 7700 to set integration rate to 6 PLC when they are scanned.

```
FUNC 'VOLT', (@101, 103)            ' Select DCV function.
VOLT:NPLC 6, (@101, 103)            ' Set rate to 6 PLC.
```

Filter

The digital filter is used to stabilize noisy measurements. The displayed, stored, or transmitted reading is a windowed-average of a number of reading conversions (from 1 to 100).

The filter setup is "remembered" and can be unique for each measurement function (DCV, ACV, DCI, ACI, Ω2, Ω4, and TEMP). When you select a function, the instrument will return to the last filter setup for that function.

NOTE The various instrument operations, including Filter, are performed on the input signal in a sequential manner. See "Signal processing sequence," page D-2, for details. It includes flowcharts showing where in the processing sequence that filtering is performed.

Filter characteristics

In general, the digital filter places a specified number of A/D conversions ("Filter count") into a memory stack. These A/D conversions must occur consecutively within a selected reading window (Filter Window). The readings in the stack are then averaged to yield a single filtered reading. The stack can be filled in two ways (Filter Type): moving or repeating. Details on digital filter characteristics are provided as follows:

Filter type

There are two digital filter types: moving and repeating. The moving average filter uses a first-in first-out stack, where the newest reading conversion replaces the oldest. An average of the stacked reading conversions yield a filtered reading. After the specified number of reading conversions ("Filter count") fill the stack, the moving filter gives a new reading for every new conversion. This process is depicted in Figure 4-2A.

The repeating filter takes a specified number of conversions, averages them, and yields a filtered reading. It then flushes its stack and starts over. This character is useful when scanning (readings for other channels are not averaged with the present channel). The stack is then cleared and the process starts over (see Figure 4-2B).

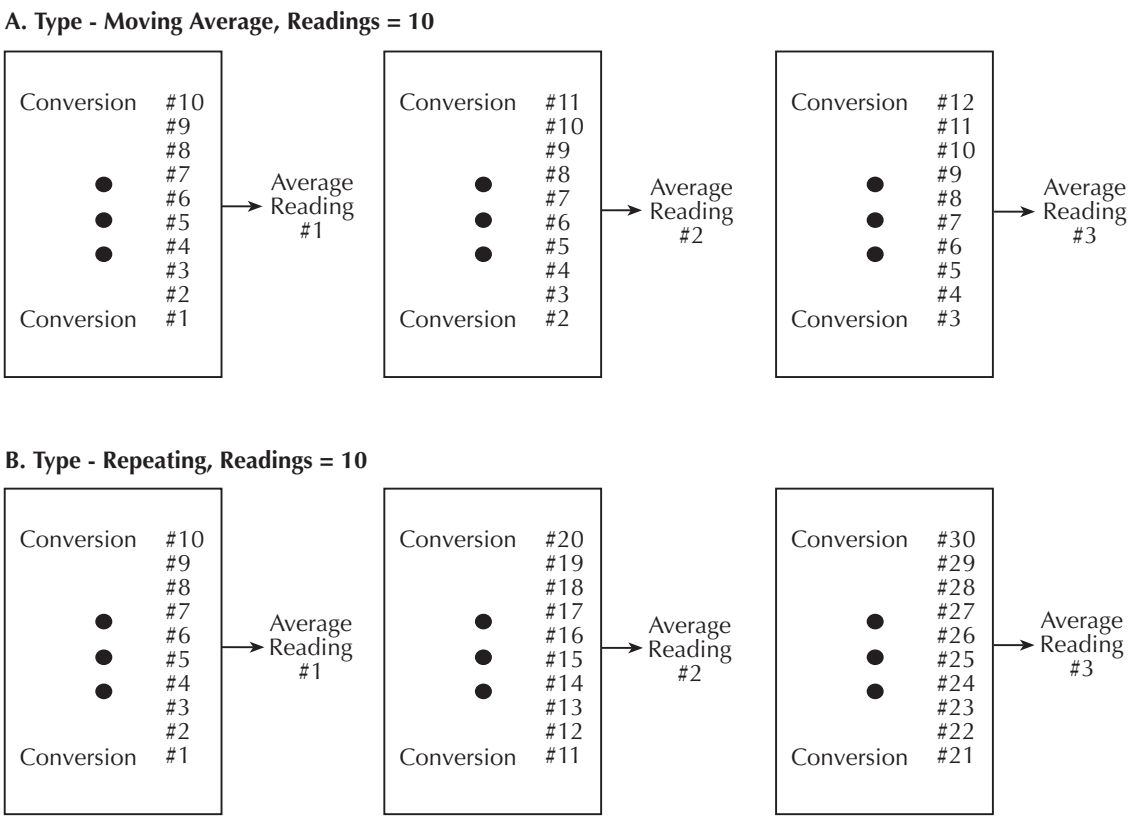
NOTE The moving filter cannot be used when scanning. If a scan channel is set up to use the moving filter, the filter will not turn on. Scanning is covered in Section 7.

Filter count

The filter count specifies how many consecutive A/D conversions (within the filter window) to place in the memory stack. When the stack is full, the A/D conversions are averaged to calculate the final filtered reading. The filter count can be set from 1 to 100. Note that with a filter count of 1, no averaging is done. However, only readings within the "Filter window" will be displayed, stored, or transmitted.

NOTE *While the filter processes readings, the FILT annunciator blinks. Readings that are being displayed while the FILT annunciator blinks are not final filtered readings. When the FILT annunciator stops blinking, the filter has settled.*

Figure 4-2
Moving and repeating filters



Filter window

The digital filter uses a "noise" window to control filter threshold. As long as the input signal remains within the selected window, A/D conversions continue to be placed in the stack. If the signal changes to a value outside the window, the filter resets and the filter starts processing again starting with a new initial conversion value from the A/D converter.

The noise window, which is expressed as a percentage of range (or maximum temperature reading), allows a faster response time to large signal step changes (e.g., scanned

readings). A reading conversion outside the plus or minus noise window fills the filter stack immediately.

If the noise does not exceed the selected window, the reading is based on the average of the reading conversions. If the noise does exceed the selected window, the reading is a single reading conversion and new averaging starts from this point. The noise window for the two filter types are compared in Figure 4-3.

The five window selections from the front panel are 0.01%, 0.1%, 1%, 10%, and NONE (no window). For remote programming, the window can be set to any value from 0.01% to 10% or NONE.

For voltage, current, and resistance, the filter window is expressed as a percent of range. For example, on the 10V range, a 10% window means that the filter window is ±1V.

For temperature, the filter window is expressed as a percent of the maximum temperature reading. The maximum temperature depends on which thermocouple is being used. For example, for a Type J thermocouple, the maximum reading is 760°C; a 10% window means that the filter window is ±76°C. For temperatures below 0°C, the overflow point is -200ºC, so a 10% filter window is ±20ºC. If using ºF units, a 20% filter window is calculated as follows: 9/5 x 20 = 36. The filter window for the 20% window is ±36ºC.

Filter example

Filter Type - Moving

Filter Window = 0.01% of range

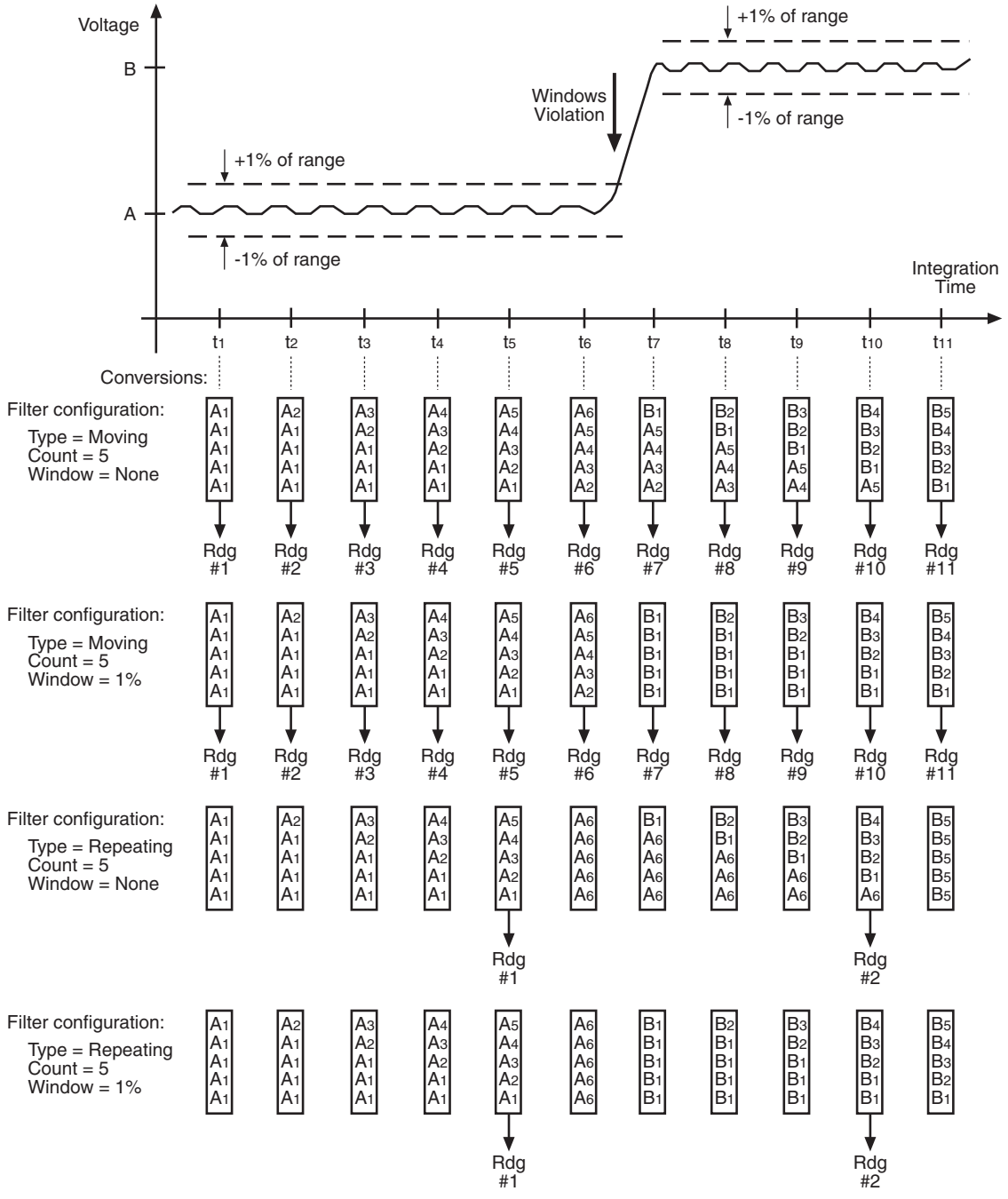
Filter Count = 10

Filter State = On

Ten readings fill the stack to yield a filtered reading. Now assume the next reading (which is the 11^{th}) is outside the window. A reading will be processed (displayed); however, the stack will be loaded with that same reading. Each subsequent valid reading will then displace one of the loaded readings in the stack. The FILT annunciator will flash until 10 new readings fill the stack.

NOTE *Bit 8 of the Operation Event Status Register sets when the filter window has properly settled (or the filter is disabled). See Section 11, "Status Structure," for details.*

Figure 4-3
Filter window



Filter control and configuration

The FILTER key toggles the state of the Filter. When the Filter is enabled, the FILT annunciator is on. The FILT annunciator will flash when the filter is not settled. When disabled, the FILT annunciator is off. The filter can be configured while it is enabled or disabled.

The filter is configured from the filter configuration menu (Figure 4-4). Perform the following steps to configure the filter:

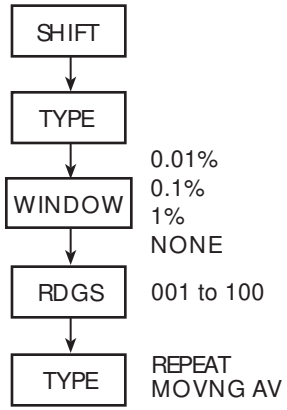
1. Select the desired function.
2. Press SHIFT and then TYPE. The present WINDOW setting will be displayed.
3. Use the RANGE ▲ or ▼ key to display the desired window setting (0.01%, 0.1%, 1%, 10%, or NONE) and press ENTER.
4. Use the ◀, ▶, ▲, and ▼ keys to display the number of readings to filter (1 to 100) and press ENTER.
5. Use the ▲ or ▼ key to display the desired filter type (moving or repeating) and press ENTER. The filter turns on and the instrument returns to the normal measurement state.

NOTE *While the filter is enabled (FILT annunciator on), changes to the configuration take effect as soon as they are made. With filter disabled (FILT annunciator off), changes to the configuration take place when the filter is enabled.*

While the filtering operation is in progress, the FILT annunciator blinks. Readings will continue to be processed (i.e., displayed, stored, sent over the bus), but they could be questionable. When the FILT annunciator stops blinking, the filter has settled.

Changing function or range causes the filter to reset. The filter then assumes the state (enabled or disabled) and configuration for that function or range.

Figure 4-4
Filter configuration flow chart



Scanning

The moving filter cannot be used when scanning. A scan channel cannot be configured to use the moving filter. Also, the filter window is not used when scanning.

When a simple scan is configured, the present filter count and state will apply to all channels in the scan. The window setting is ignored (effectively set to NONE) and if the moving filter is selected, the filter will not enable when the scan is run.

For the advanced scan, filter state (on or off) and count can be set for each channel. You cannot set unique filter count, type, and window settings from the advanced scan setup menu.

For remote programming, the <clist> parameter is used to set filter count and state for each channel in the scan. You cannot set unique filter type and window settings.

NOTE Details on configuring a scan using filtering in a scan are provided in Section 7.

Remote programming — filter

Filter commands

The filter commands are listed in Table 4-6. Additional information on these commands follow the table.

NOTE Query commands are not included in Table 4-6. All commands for the SENSe subsystem are provided in Table 15-5.

Table 4-6
Filter commands

Commands[1, 4]	Description[5]	Default
DCV filter commands		
[SENSe[1]]	Optional root command.	
:VOLTage[:DC]:AVERage:TCONtrol <name>	Select filter type; <name> = MOVing or REPeat.	(Note 2)
:VOLTage[:DC]:AVERage:WINDow <NRf>	Set filter window in %; <NRf> = 0 to 10.	0.1
:VOLTage[:DC]:AVERage:COUNt <n> [, clist]	Specify filter count; <n> = 1 to 100.	10
:VOLTage[:DC]:AVERage:STATe <b> [, clist]	Enable or disable the filter.	(Note 3)
ACV filter commands		
[SENSe[1]]	Optional root command.	
:VOLTage:AC:AVERage:TCONtrol <name>	Select filter type; <name> = MOVing or REPeat.	(Note 2)
:VOLTage:AC:AVERage:WINDow <NRf>	Set filter window in %; <NRf> = 0 to 10.	0.1
:VOLTage:AC:AVERage:COUNt <n> [, clist]	Specify filter count; <n> = 1 to 100.	10
:VOLTage:AC:AVERage:STATe <b> [, clist]	Enable or disable the filter.	(Note 3)
DCI filter commands		
[SENSe[1]]	Optional root command.	
:CURRent[:DC]:AVERage:TCONtrol <name>	Select filter type; <name> = MOVing or REPeat.	(Note 2)
:CURRent[:DC]:AVERage:WINDow <NRf>	Set filter window in %; <NRf> = 0 to 10.	0.1
:CURRent[:DC]:AVERage:COUNt <n> [, clist]	Specify filter count; <n> = 1 to 100.	10
:CURRent[:DC]:AVERage:STATe <b> [, clist]	Enable or disable the filter.	(Note 3)
ACI filter commands		
[SENSe[1]]	Optional root command.	
:CURRent:AC:AVERage:TCONtrol <name>	Select filter type; <name> = MOVing or REPeat.	(Note 2)
:CURRent:AC:AVERage:WINDow <NRf>	Set filter window in %; <NRf> = 0 to 10.	0.1
:CURRent:AC:AVERage:COUNt <n> [, clist]	Specify filter count; <n> = 1 to 100.	10
:CURRent:AC:AVERage:STATe <b> [, clist]	Enable or disable the filter.	(Note 3)

Table 4-6 (continued)
Filter commands

Commands[1, 4]	Description[5]	Default
Ω2 filter commands		
[SENSe[1]]	Optional root command.	
:RESistance:AVERage:TCONtrol <name>	Select filter type; <name> = MOVing or REPeat.	(Note 2)
:RESistance:AVERage:WINDow <NRf>	Set filter window in %; <NRf> = 0 to 10.	0.1
:RESistance:AVERage:COUNt <n> [, clist]	Specify filter count; <n> = 1 to 100.	10
:RESistance:AVERage:STATe <b> [, clist]	Enable or disable the filter.	(Note 3)
Ω4 filter commands		
[SENSe[1]]	Optional root command.	
:FRESistance:AVERage:TCONtrol <name>	Select filter type; <name> = MOVing or REPeat.	(Note 2)
:FRESistance:AVERage:WINDow <NRf>	Set filter window in %; <NRf> = 0 to 10.	0.1
:FRESistance:AVERage:COUNt <n> [, clist]	Specify filter count; <n> = 1 to 100.	10
:FRESistance:AVERage:STATe <b> [, clist]	Enable or disable the filter.	(Note 3)
TEMP filter commands		
[SENSe[1]]	Optional root command.	
:TEMPerature:AVERage:TCONtrol <name>	Select filter type; <name> = MOVing or REPeat.	(Note 2)
:TEMPerature:AVERage:WINDow <NRf>	Set filter window in %; <NRf> = 0 to 10.	0.1
:TEMPerature:AVERage:COUNt <n> [, clist]	Specify filter count; <n> = 1 to 100.	10
:TEMPerature:AVERage:STATe <b> [, clist]	Enable or disable the filter.	(Note 3)

Channel list parameter:
<clist> = (@SCH)
where: S = Mainframe slot number (1 or 2)
CH = Switching module channel number (must be 2 digits)
Examples: (@101) = Slot 1, Channel 1
(@101, 203) = Slot 1, Channel 1 and Slot 2, Channel 3
(@101:110) = Slot 1, Channels 1 through 10

Notes:
1. The <clist> parameter is used to configure one or more channels for a scan. Each channel in the <clist> must be set to the function specified by the filter command. If not, a conflict error (-221) will occur. For example, VOLTage:AVERage:STATe ON, (@101) is only valid if scan channel 101 is set for the DCV function.
2. REPeat is the *RST default and MOVing is the SYSTem:PRESet default. From the front panel, the factory default is MOVing.
3. OFF is the *RST default and ON is the SYSTem:PRESet default.
4. [:DC] is optional for the commands to set DCV and DCI filter.
5. Filter window — Parameter value 0 for the WINDow commands sets the filter window to NONE.

Filter programming examples

Example #1 — The following command sequence configures filtering for the DCI function:

NOTE The following example can be run from the KE2700 Instrument Driver using the example named "MAFilter" in Table G-1 of Appendix G.

```
CURR:AVER:TCON MOV                  ' Select the moving filter.
CURR:AVER:WIND 0.01                 ' Set filter window to 0.01%.
CURR:AVER:COUN 10                   ' Set to filter 10 readings.
CURR:AVER ON                        ' Enable filter.
```

Example #2 — The following command sequence configures channels 101 through 115 of the Model 7700 to use the repeat filter when they are scanned.

NOTE The following example can be run from the KE2700 Instrument Driver using the example named "RAFilter" in Table G-1 of Appendix G.

```
FUNC 'VOLT'                         ' Select DCV function.
VOLT:AVER:TCON REP                  ' Select the repeating filter.
VOLT:AVER:COUN 20,(@101:115)        ' Set to filter 20 readings.
VOLT:AVER ON,(@101:115)             ' Enable filter.
```

5
Relative, Math, Ratio, Channel Average, and dB

- Relative — Explains how to null an offset or establish a baseline value. Includes the commands for remote programming.
- Math — Covers the three basic math operations: mX+b, percent, and reciprocal (1/X). Includes the commands for remote programming.
- Ratio and channel average — Explains how to use these calculations to display the ratio or average of two switching channels.
- dB — Explains how to use remote programming to configure the instrument to perform DCV dB and ACV dB measurements.

WARNING When using these functions, the display may indicate a non-hazardous voltage, but hazardous voltage may be present on the input connectors.

Relative

The rel (relative) function can be used to null offsets or subtract a baseline reading from present and future readings. When rel is enabled, the instrument uses the present reading as a relative value. Subsequent readings will be the difference between the actual input value and the rel value.

You can define a rel value for each function. Once a rel value is established for a measurement function, the value is the same for all ranges. For example, if 50V is set as a rel value on the 100V range, the rel is also 50V on the 1000V, 10V, 1V, and 100mV ranges.

Therefore, when you perform a zero correction by enabling REL, the displayed offset becomes the reference value. Subtracting the offset from the actual input zeroes the display, as follows:

Actual Input – Reference = Displayed Reading

A rel value can be as large as the highest range.

Selecting a range that cannot accommodate the rel value does not cause an overflow condition, but it also does not increase the maximum allowable input for that range. For example, on the 10V range, the Model 2701 still overflows for a 12V input.

NOTE The various instrument operations, including Relative, are performed on the input signal in a sequential manner. See "Signal processing sequence," page D-2, for details. It includes flowcharts showing where in the processing sequence that the Rel operation is performed.

Basic operation

NOTE If using switching module inputs, make sure the front panel INPUTS switch is set to the REAR position (in). If using the front panel inputs, the switch must be in the FRONT position (out).

1. Select the desired measurement function and an appropriate range setting.
2. Apply the signal to be relayed to a switching channel input or to the front panel inputs.

NOTE For the Model 7700 switching module, channels 21 and 22 are available for DCI and ACI. Channels 1 through 20 are available for all other functions.

3. If using a switching module, use the ◂ or ▸ key to select (close) the input channel. If using the front panel inputs (FRONT inputs selected), it does not matter if a switching channel is closed.
4. Press the REL key to set the rel value. The display will zero and the REL annunciator will turn on.
5. Apply the signal to be measured.

Pressing REL a second time disables rel.

You can input a rel value manually using the mX+b function. Set M for 1 and B for any value you want. The mX+b function is covered in this section (see "Math," page 5-7).

Scanning

When a simple scan is configured, the present rel setting will apply to all channels in the scan. When an advanced scan is configured, each channel can have its own unique rel setting. Details to configure and run a scan are provided in Section 7.

For an advanced scan, the following general procedure shows how to configure a scan channel to use rel:

1. While in the normal measurement state, select the appropriate function and close the appropriate channel. For example, if scan channel 101 is going to be configured for DCV and use rel, select DCV and close channel 101.
2. Apply the DCV signal to be rel'ed to the closed channel. This could be an offset or a baseline level.
3. Press the REL key to enable rel (REL annunciator on). The input signal level is used as the rel value.
4. When configuring the advanced scan (as explained in Section 7), select the desired channel, press DCV and then press REL (REL annunciator on).

When the channel is scanned, rel will enable using the rel value established in step 3.

For remote programming, the <clist> parameter is used to configure channels for a scan.

Remote programming — rel

Rel commands

The rel commands to set range are listed in Table 5-1. Additional information on these commands follow the table.

NOTE Query commands are not included in Table 5-1. All commands for the SENSe subsystem are provided in Table 15-5.

Table 5-1
Rel commands

Commands[1]	Description	Default
Rel commands for DCV		
[SENSe[1]]	Optional root command.	
:VOLTage[:DC]:REFerence <n> [, <clist>]	Specify rel value; <n> = -1010 to 1010 (V).	0
:VOLTage[:DC]:REFerence:STATe <b> [, <clist>]	Enable/disable rel; <b> = ON or OFF.	OFF
:VOLTage[:DC]:REFerence:ACQuire [, <clist>]	Use input signal as rel value.	
Rel commands for ACV		
[SENSe[1]]	Optional root command.	
:VOLTage:AC:REFerence <n> [, <clist>]	Specify rel value; <n> = -757.5 to 757.5 (V).	0
:VOLTage:AC:REFerence:STATe <b> [, <clist>]	Enable/disable rel; <b> = ON or OFF.	OFF
:VOLTage:AC:REFerence:ACQuire [, <clist>]	Use input signal as rel value.	
Rel commands for DCI		
[SENSe[1]]	Optional root command.	
:CURRent[:DC]:REFerence <n> [, <clist>]	Specify rel value; <n> = -3.1 to 3.1 (A).	0
:CURRent[:DC]:REFerence:STATe <b> [, <clist>]	Enable/disable rel; <b> = ON or OFF.	OFF
:CURRent[:DC]:REFerence:ACQuire [, <clist>]	Use input signal as rel value.	
Rel commands for ACI		
[SENSe[1]]	Optional root command.	
:CURRent:AC:REFerence <n> [, <clist>]	Specify rel value; <n> = -3.1 to 3.1 (A).	0
:CURRent:AC:REFerence:STATe <b> [, <clist>]	Enable/disable rel; <b> = ON or OFF.	OFF
:CURRent:AC:REFerence:ACQuire [, <clist>]	Use input signal as rel value.	

Table 5-1 (continued)
Rel commands

Commands[1]	Description	Default
Rel commands for Ω2		
[SENSe[1]]	Optional root command.	
:RESistance:REFerence <n> [, <clist>]	Specify rel value; <n> = 0 to 120e6 (Ω).	0
:RESistance:REFerence:STATe <b> [, <clist>]	Enable/disable rel; <b> = ON or OFF.	OFF
:RESistance:REFerence:ACQuire [, <clist>]	Use input signal as rel value.	
Rel commands for Ω4		
[SENSe[1]]	Optional root command.	
:FRESistance:REFerence <n> [, <clist>]	Specify rel value; <n> = 0 to 120e6 (Ω).	0
:FRESistance:REFerence:STATe <b> [, <clist>]	Enable/disable rel; <b> = ON or OFF.	OFF
:FRESistance:REFerence:ACQuire [, <clist>]	Use input signal as rel value.	
Rel commands for TEMP[2]		
[SENSe[1]]	Optional root command.	
:TEMPerature:REFerence <n> [, <clist>]	Specify rel value; <n> = -328 to 3310 (°C).	0
:TEMPerature:REFerence:STATe <b> [, <clist>]	Enable/disable rel; <b> = ON or OFF.	OFF
:TEMPerature:REFerence:ACQuire [, <clist>]	Use input signal as rel value.	
Rel commands for FREQ		
[SENSe[1]]	Optional root command.	
:FREQuency:REFerence <n> [, <clist>]	Specify rel value; <n> = 0 to 1.5e7 (Hz).	0
:FREQuency:REFerence:STATe <b> [, <clist>]	Enable/disable rel; <b> = ON or OFF.	OFF
:FREQuency:REFerence:ACQuire [, <clist>]	Use input signal as rel value.	
Rel commands for PERIOD		
[SENSe[1]]	Optional root command.	
:PERiod:REFerence <n> [, <clist>]	Specify rel value; <n> = 0 to 1 (sec).	0
:PERiod:REFerence:STATe <b> [, <clist>]	Enable/disable rel; <b> = ON or OFF.	OFF
:PERiod:REFerence:ACQuire [, <clist>]	Use input signal as rel value.	

Channel list parameter:
<clist> = (@SCH)
where: S = Mainframe slot number (1 or 2)
CH = Switching module channel number (must be 2 digits)
Examples: (@101) = Slot 1, Channel 1
(@101, 203) = Slot 1, Channel 1 and Slot 2, Channel 3
(@101:110) = Slot 1, Channels 1 through 10

1. The <clist> parameter is used to configure one or more channels for a scan. Each channel in the <clist> must be set to the function specified by the rel (reference) command. If not, a conflict error (-221) will occur. For example, VOLTage:AC:REFerence 1, (@101) is only valid if scan channel 101 is set for the ACV function.
2. [:DC] is optional for the commands to set DCV and DCI rel.

"Pressing REL" using rel commands

When the front panel REL key is pressed, the displayed reading is used as the rel value. Subsequent readings are then the result of the actual input value and the rel value.

The :REFerence:ACQuire and :REFerence:STATe ON commands (in that order) can be used to "press" the REL key. For example, the following command sequence is the equivalent of pressing the REL key while on the DCV function:

```
VOLT:REF:ACQ                          ' Acquire reading as rel value.
VOLT:REF:STAT ON                      ' Enable rel.
```

Setting rel values

The :REFerence <n> command specifies the rel value for the specified function, while the :ACQuire command uses the input signal as the rel value. The :ACQuire command is typically used to zero the display. For example, if the instrument is displaying a 1µV offset, sending :ACQuire and enabling rel (STATe ON) zeroes the display.

The ACQuire command is only functional if the instrument is on the specified function. For example. If the instrument is on the DCV function, the only valid acquire command is VOLT:DC:REF:ACQ. Also, if the instrument is overflowed ("OVERFLOW") or a reading has not been triggered ("------"), an execution error (-200) occurs when :ACQuire is sent.

The :REFerence <n> command is coupled to the ACQuire command. When a rel value is set using :REFerence <n>, the :REFerence? query command returns the programmed value. When rel is set using :ACQuire, the :REFerence? query command returns the acquired rel value.

Rel programming examples

Example #1 — The following command sequence zeroes the display for DCV.

NOTE The following example can be run from the KE2700 Instrument Driver using the example named "Relative1" in Table G-1 of Appendix G.

```
FUNC 'VOLT'                           ' Select DCV.
VOLT:REF:ACQ                          ' Use input level as rel value for DCV.
VOLT:REF:STAT ON                      ' Enable rel.
```

Example #2 — The following command sequence configures channel 101 of the Model 7700 to enable rel and use a 1V rel value when it is scanned.

NOTE The following example can be run from the KE2700 Instrument Driver using the example named "Relative2" in Table G-1 of Appendix G.

```
FUNC 'VOLT',(@101)                    ' Select DCV for channel 101.
VOLT:REF 1,(@101)                     ' Set 1V rel value.
VOLT:REF:STAT ON,(@101)               ' Enable rel.
```

Example #3 — The following command sequence configures channel 101 of the Model 7700 to zero, correct the DCV input when it is scanned.

NOTE *The following example can be run from the KE2700 Instrument Driver using the example named "Relative3" in Table G-1 of Appendix G.*

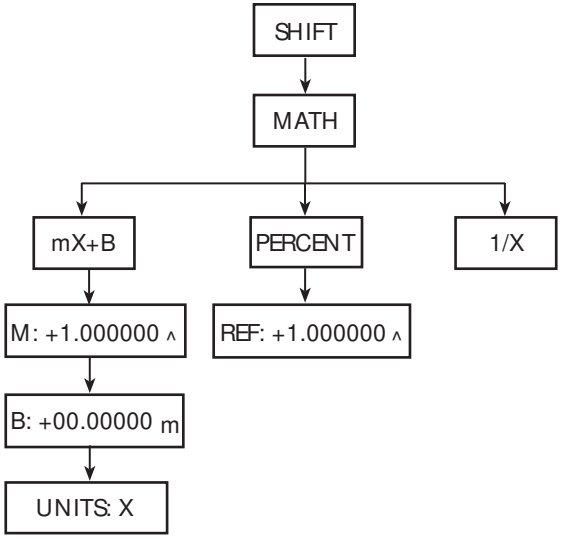
```
FUNC 'VOLT',(@101)                ' Select DCV for channel 101.
ROUT:CLOS (@101)                  ' Close channel 101.
VOLT:REF:ACQ (@101)               ' Use input to channel 101 as rel value.
VOLT:REF:STAT ON,(@101)           ' Enable rel.
```

Math

The Model 2701 has three built-in math calculations that are accessed from the MATH menu: mX+b, percent, and reciprocal (1/X). Figure 5-1 shows the MATH menu tree. Note that the settings shown in the menu tree are the factory defaults.

NOTE *The various instrument operations, including Math, are performed on the input signal in a sequential manner. See "Signal processing sequence," page D-2, for details. It includes flowcharts showing where in the processing sequence that the Math operation is performed.*

Figure 5-1
MATH menu tree



NOTE *A Math operation can be used with the ratio and channel average calculation. The ratio or channel average reading will be used in the calculation for the selected math function.*

mX+b

This math operation lets you manipulate normal display readings (X) mathematically according to the following calculation.

$Y = mX + b$

where: X is the normal display reading.
m and b are the user-entered constants for scale factor and offset.
Y is the displayed result.

NOTE When using Rel, the rel'ed reading of the input signal is used by the mX+b calculation.

mX+b configuration

1. Press SHIFT and then MATH to display the math menu.
2. Press the RANGE ▲ and ▼ key to display "mX+b" and press ENTER to display the present scale factor:

   M: +1.000000 ▲ (factory default)

3. Key in the scale factor value. The ◀ and ▶ keys control cursor position and the ▲ and ▼ keys increment/decrement the digit value. To change range, place the cursor on the multiplier and use the ▲ and ▼ keys (m = ×0.001, ▲ = ×1, K = ×1000, and M = ×1,000,000). With the cursor on the polarity sign, the ▲ and ▼ keys toggle polarity.
4. Press ENTER to enter the m value and display the offset (b) value:

   b: +00.00000 m (factory default)

5. Key in the offset value.
6. Press ENTER to enter the b value and display the one-character units designator:

   UNITS: X (factory default)

7. Use the cursor keys and the ▲ and ▼ key if you wish to change the units designator. The character can be any letter in the alphabet (A through Z), the degree symbol (°), or the ohms symbol (Ω).
8. Press ENTER. The MATH annunciator will turn on and the result of the calculation will be displayed. Note that the calculation will be applied to all measurement functions.
9. To disable mX+b, again press SHIFT and then MATH. The MATH annunciator will turn off.

mX+b rel

The mX+b function can be used to manually establish a rel value. To do this, set the scale factor (m) to 1 and set the offset (b) to the rel value. Each subsequent reading will be the difference between the actual input and the rel value (offset).

Percent

This math function determines percent deviation from a specified reference value. The percent calculation is performed as follows:

$$\text{Percent} = \frac{\text{Input} - \text{Reference}}{\text{Reference}} \times 100\%$$

where: Input is the normal display reading.
Reference is the user entered constant.
Percent is the displayed result.

NOTE *When using Rel, the rel'ed reading of the input signal is used by the percent calculation.*

Percent configuration

1. Press SHIFT and then MATH to display the math menu.
2. Press the RANGE ▲ and ▼ key to display "PERCENT" and press ENTER to display the present reference value:

   REF +1.000000 ▲ (factory default)

3. Key in the reference value. The ◀ and ▶ keys control cursor position and the ▲ and ▼ keys increment/decrement the digit value. To change range, place the cursor on the multiplier and use the ▲ and ▼ keys (m = ×0.001, ▲ = ×1, K = ×1000, and M = ×1,000,000). With the cursor on the polarity sign, the ▲ and ▼ keys toggle polarity.
4. Press ENTER. The MATH annunciator will turn on and the result of the calculation will be displayed. Note that the calculation will be applied to all measurement functions.
5. To disable mX+b, again press SHIFT and then MATH. The MATH annunciator will turn off.

NOTE *The result of the percent calculation is positive when the input exceeds the reference and negative when the input is less than the reference.*

The result of the percent calculation may be displayed in exponential notation. For example, a displayed reading of +2.500E+03% is equivalent to 2500% (2.5K%).

Reciprocal (1/X)

The reciprocal of a reading is displayed when the reciprocal (1/X) math function is enabled:

Reciprocal = 1/X

where: X is the normal input reading

The displayed units designator for reciprocal readings is "R." This units designator cannot be changed.

Example — Assume the normal displayed reading is 2.5Ω The reciprocal of resistance is conductance. When the reciprocal math function is enabled, the following conductance reading will be displayed:

0.4 R

Reciprocal (1/X) configuration

1. Press SHIFT and then MATH to display the math menu.
2. Press the RANGE ▲ or ▼ key to display "1/X" and press ENTER. The MATH annunciator will turn on and the result of the calculation will be displayed. Note that the calculation will be applied to all measurement functions.
3. To disable 1/X, again press SHIFT and then MATH. The MATH annunciator will turn off.

NOTE *The result of the 1/X calculation may be displayed in exponential notation. For example, a displayed reading of +2.500E+03 R is equivalent to 2500 R (2.5K R).*

When using Rel, the rel'ed reading of the input signal is used by the 1/X calculation.

Basic operation

NOTE *If using switching module inputs, make sure the front panel INPUTS switch is set to the REAR position (in). If using the front panel inputs, the switch must be in the FRONT position (out).*

1. Configure and enable the mX+b, percent, or reciprocal (1/X) math function as previously explained.
2. Select the desired measurement function.
3. Apply the signal to be measured to a switching channel input or to the front panel inputs.

NOTE *For the Model 7700 switching module, channels 21 and 22 are available for DCI and ACI. Channels 1 through 20 are available for all other functions.*

4. If using a switching module (REAR inputs selected), use the ◂ or ▸ key to select (close) the input channel. If using the front panel inputs (FRONT inputs selected), it does not matter if a switching channel is closed. The result of the math calculation will be displayed.

Scanning

When a simple scan is configured, the present math calculation will apply to all channels in the scan. When an advanced scan is configured, each channel can have its own unique math setup. Details to configure and run a scan are provided in Section 7.

For remote programming, the <clist> parameter is used to configure channels for a scan.

Remote programming — math

Math commands

NOTE When measurements are performed, the readings are fed to other enabled processing operations, including Math. Appendix D explains "Data flow (remote operation)," page D-7 and the commands used to return Math results.

The commands to perform math calculations are listed in Table 5-2. Details on these commands follow the table.

NOTE Queries are not included in Table 5-2. All the math commands are provided in Table 15-5.

Table 5-2
Math commands

Commands[1]	Description	Def
CALCulate[1]:FORMat <name> [, <clist>]	Select calculation; <name> = NONE, MXB, PERCent, or RECiprocal.	PERC
CALCulate[1]:KMATh:MMFactor <NRf> [, <clist>]	Set mX+b "m" factor; <NRf> = -4294967295 to +4294967295.	1
CALCulate[1]:KMATh:MBFactor <NRf> [, <clist>]	Set mX+b "b" factor; <NRf> = -4294967295 to +4294967295.	0
CALCulate[1]:KMATh:MUNits <char> [, <clist>]	Set mX+b units; see "Setting mX+b units."	'X'
CALCulate[1]:KMATh:PERCent <NRf> [, <clist>]	Set reference value for percent; <NRf> = -4294967295 to +4294967295.	1
CALCulate[1]:KMATh:PERCent:ACQuire	Use input signal as reference value.	
CALCulate[1]:STATe <b> [, <clist>]	Enable or disable calculation; <b> = ON or OFF.	(Note 2)
CALCulate[1]:DATA[:LATest]?	Return last result of calculation.	
CALCulate[1]:DATA:FRESh?	Return last "fresh" result of calculation.	
Channel list parameter: <clist> = (@SCH) where: S = Mainframe slot number (1 or 2) CH = Switching module channel number (must be 2 digits) Examples: (@101) = Slot 1, Channel 1 (@101, 203) = Slot 1, Channel 1 and Slot 2, Channel 3 (@101:110) = Slot 1, Channels 1 through 10		

1. The <clist> parameter is used to configure one or more channels for a scan.
2. *RST default is ON, SYSTem:PRESet is OFF.

Setting mX+b units

The <char> parameter for CALCulate:KMATh:MUNits must be one character enclosed in single or double quotes. It can be any letter of the alphabet, the degrees symbol (°), or the ohms symbol (Ω).

The ohms symbol (Ω) and the degrees symbol (°) are not ASCII characters and therefore, must be substituted with the '[' and '\' characters as follows:

CALCulate:KMAth:MUNits '['	Use ohms symbol (Ω) as units designator.
CALCulate:KMAth:MUNits '\'	Use degrees symbol (°) as units designator.

Percent reference

The :PERCent <NRf> command specifies the reference value for the percent calculation, while the :PERCent:ACQuire command uses the input signal as the reference value.

The :ACQuire command is only functional if a reading is available. If the instrument is overflowed ("OVERFLOW") or a reading has not been triggered ("------"), an execution error (-200) occurs when :ACQuire is sent.

The :PERCent <NRf> command is coupled to the :PERCent:ACQuire command. When a reference value is set using :PERCent <NRf>, the :PERCent? query command returns the programmed value. When reference is set using :ACQuire, the :PERCent? query command returns the acquired reference value.

Reading math result

CALCulate[1]:DATA[:LATest]? or CALCulate:DATA:FRESh? can be used to retrieve the result of the selected math calculation. These commands do not trigger a reading. They simply return the last reading string. The reading reflects the result of the calculation.

While the instrument is performing measurements, you can use these commands to return the last reading. If the instrument is not performing measurements, CALC:DATA? will keep returning the same reading string.

CALC:DATA:FRESh? can only be used once to return the same reading string. That is, the reading must be "fresh." Sending this command again to retrieve the same reading string will generate error -230 (data corrupt or stale) or cause the system to time-out. In order to again use DATA:FRESh?, a new (fresh) reading must be triggered.

If math is disabled (CALCulate:FORMat NONE or CALCulate:STATe OFF), the "raw" reading will be retrieved by CALC:DATA? and CALC:DATA:FRESh?.

Math programming examples

Example #1 — The following command sequence performs the mX+b calculation for channels 101 and 102 of the Model 7700.

NOTE The following example can be run from the KE2700 Instrument Driver using the example named "Linear" in Table G-1 of Appendix G.

```
CALC:FORM MXB                          ' Select mX+b calculation.
CALC:KMAT:MMF 2                        ' Set 'm' factor to 2.
CALC:KMAT:MBF 100                      ' Set 'b' factor to 100.
CALC:STAT ON                           ' Enable math calculation.
ROUT:CLOS (@101)                       ' Close channel 101.
CALC:DATA?                             ' Read mX+b result for channel 101.
ROUT:CLOS (@102)                       ' Close channel 102.
CALC:DATA?                             ' Read mX+b result for channel 102.
```

Example #2 — The following command sequence configures channels 101 through 110 of the Model 7700 to perform the percent calculation when they are scanned.

NOTE The following example can be run from the KE2700 Instrument Driver using the example named "Percent" in Table G-1 of Appendix G.

```
CALC:FORM PERC,(@101:110)              ' Select percent calculation.
CALC:KMAT:PERC 100,(@101:110)          ' Set reference to 100.
CALC:STAT ON,(@101:110)                ' Enable math calculation.
```

Ratio and channel average

With a switching module installed in the Model 2701, the ratio or average of two channels can be calculated and displayed. The ratio calculation can be done on the DCV function and the channel average calculation can be done on the DCV and TEMP (thermocouples only) functions.

Ratio and channel average are calculated as follows:

$$\text{Ratio} = \frac{\text{Chan A}}{\text{Chan B}}$$

$$\text{Channel Average} = \frac{\text{Chan A} + \text{Chan B}}{2}$$

where: Chan A is the selected (closed) channel.
Chan B is the paired channel for the installed switching module.
Ratio and Channel Average is the displayed result of the respective calculation.

Paired channels are used for ratio and channel average. For example, the Model 7700 switching module has 20 channels that can use ratio and channel average. The primary channels (1 through 10) are linked to the paired channels (11 through 20). Channel 1 is paired to channel 11, channel 2 is paired to channel 12, and so on.

When ratio or channel average is enabled, the Model 2701 measures the closed primary channel. It then opens the primary channel and closes and measures the paired channel. Ratio or channel average is then calculated from the two readings and displayed. If the Model 2701 is configured for continuous measurements, the two-channel scan will continue to repeat and refresh the display with each new calculated reading.

The ratio or channel average calculation can only be enabled if a valid switching channel is closed. If no channel is closed when you attempt to enable one of these calculations, the message "CLOSE A CHAN" message will be displayed to remind you to first close a valid channel.

A primary channel must be closed before you can enable ratio or channel average. If a paired channel is instead closed, message "INVALID CHAN" will be displayed to indicate the settings conflict.

NOTE *The various instrument operations, including Ratio or Channel Average, are performed on the input signal in a sequential manner. See "Signal processing sequence," page D-2, for details. It includes a flowchart showing where in the processing sequence that Ratio or Ch Avg operation is performed.*

Basic operation

NOTE Make sure the INPUTS switch is set to the REAR position (in).

1. Select and configure (range, filter, rel, etc.) a valid measurement function. For ratio, the only valid function is DCV. For channel average, the only valid functions are DCV and TEMP (TCs only).
2. Use the ◂ or ▸ key to select (close) a primary channel (101 through 110 for the Model 7700). The CLOSE key can also be used.
3. Apply one signal to the selected primary channel and apply the other signal to the paired channel. For the Model 7700, if the closed primary channel is 101, the paired channel is 111.
4. Enable Ratio or Channel Average:
   - Ratio — Press SHIFT and then RATIO. The RATIO annunciator will turn on to indicate that the displayed readings are the result of the ratio calculation.
   - Channel Average — Press SHIFT and then CHA-AVG. The DELTA annunciator will turn on to indicate that the displayed readings are the result of the channel average calculation. To disable channel average, again press SHIFT and then CH-AVG.
5. When finished, there are two ways to disable the calculation:
   - Press the OPEN key. The calculation will disable and the channel will open.
   - Press SHIFT and then RATIO to disable ratio or press SHIFT and then CHA-AVG to disable channel average. The calculation will disable, but the channel will remain closed.

NOTE The paired channel number is not displayed when it is measured. Only the primary channel is displayed during the 2-channel scan for the calculation.

Enabling ratio disables channel average and conversely, enabling channel average disables ratio.

If either of the channel readings over range ("OVRFLW"), the result of the calculation will also be "OVRFLW."

When using limits with ratio or channel average, the limit values will be compared to the result of the calculation and not to the individual channels.

With ratio or channel average enabled, pressing a function key will display the "EXIT RATIO" or "EXIT CHA-AVG" message to indicate that the calculation must first be disabled as explained in step 5 of the above procedure.

Scanning

Ratio and channel average can be used in an advanced scan. The 2-channel scan for the calculation is performed for every primary channel that is scanned. For example, assume the Model 7700 is installed in slot 1 and is configured to perform the ratio calculation for 10 channels. When channel 101 is scanned, measurements are performed on channels 101 and on its paired channel (111). The calculation is performed and the result is displayed. When the next channel (102) is scanned, measurements are performed on that channel (102) and on its paired channel (112). The calculation is performed and the result is displayed. This process continues for each scanned channel.

When an advanced scan is configured, each channel can have its own unique setup. That is, one or more channels can use ratio and other channel(s) can use channel average. Details to configure and run a scan are provided in Section 7.

Advanced scan configuration notes:

1. When a calculation (ratio or channel average) is enabled for a primary scan channel, the following setup actions occur:
   - The calculation enables for the paired channel.
   - The primary channel setup (function, range, rel, etc.) will be copied to the paired channel.
2. The filter setup for both scan channels are controlled by the primary channel.
3. After the calculation is enabled, the range setting can be independently set for both the primary and paired channel.
4. Before the calculation is enabled, rel can be independently set for both the primary and paired channel. In general, set up rel from the normal measurement state, then go into the advanced menu and enable rel for the primary and/or paired channel. See "Relative," page 5-2, for details on setting rel for scan channels.
5. Settings such as NPLC, aperture, bandwidth, OCOMP, etc., are ignored on the paired channel. These settings are controlled by the primary channel.
6. For remote programming, the <clist> parameter is used to configure channels for a scan (Table 5-3).

Remote programming — ratio and channel average

Ratio and channel average commands

The ratio and channel average are listed in Table 5-3. Details on these commands follow the table.

NOTE Queries are not included in Table 5-3. All the math commands are provided in Table 15-5.

Table 5-3
Ratio and channel average commands

Commands*	Description	Def
[SENSe[1]]	Optional root command.	
:RATio[:STATe] <b> [, <clist>]	Enable/disable ratio; <b> = ON or OFF.	OFF
:RATio:DELay <NRf> [, <clist>]	Set delay (in secs); <NRf> = 0 to 99999.999.	0.5
:CAVerage[:STATe] <b> [, <clist>]	Enable/disable channel average; <b> = ON or OFF.	OFF
:CAVerage:DELay <NRf> [, <clist>]	Set delay (in secs); <NRf> = 0 to 99999.999.	0.5
Channel list parameter: <clist> = (@SCH) where: S = Mainframe slot number (1 or 2) CH = Switching module channel number (must be 2 digits) Examples: (@101) = Slot 1, Channel 1 (@101, 203) = Slot 1, Channel 1 and Slot 2, Channel 3 (@101:110) = Slot 1, Channels 1 through 10		

*The <clist> parameter is used to configure one or more channels for a scan.

Enabling/disabling ratio or channel average

As with front panel operation, enabling ratio disables channel average and conversely, enabling channel average disables ratio.

Ratio and channel average delay

:RATio:DELay or :CAVerage:DELay sets the delay between the two channel measurements for the enabled calculation. This delay is applied after the trigger delay in the trigger model (see Section 8 for details). This delay cannot be set from the front panel. The 0.5s default delay keeps the relays from cycling too fast. Setting a shorter delay may shorten the life of the relays.

It does not matter which of the two commands you use to set the delay. The set delay affects both ratio and channel average.

Ratio and channel average programming examples

Example #1 — The following command sequence performs the ratio calculation using primary channel 102 of the Model 7700.

NOTE *The following example can be run from the KE2700 Instrument Driver using the example named "Ratio1" in Table G-1 of Appendix G.*

```
*RST                                    ' One-shot measure mode.
FUNC 'VOLT'                             ' Select DCV function.
ROUT:CLOS (@102)                        ' Close channel 102.
RAT ON                                  ' Enable the ratio calculation.
READ?                                   ' Read the result of the calculation.
```

Example #2 — The following command sequence configures channels 103 and 105 for the ratio and channel average calculations. When channel 103 is scanned, the ratio calculation is based on DCV measurements of channels 103 and 113. When channel 105 is scanned, the channel average calculation is based on TEMP measurements of channels 105 and 115.

NOTE *The following example can be run from the KE2700 Instrument Driver using the example named "Ratio2" in Table G-1 of Appendix G.*

```
FUNC 'VOLT',(@103)                      ' Set 103 for DCV.
RAT ON,(@103)                           ' Set 103 for ratio on.
FUNC 'TEMP',(@105)                      ' Set 105 for TEMP.
CAV ON,(@105)                           ' Set 105 for channel average on.
```

dB

Expressing DC or AC voltage in dB makes it possible to compress a large range of measurements into a much smaller scope. The relationship between dB and voltage is defined by the following equation:

$$dB = 20\log \frac{V_{IN}}{V_{REF}}$$

where: V_{IN} is the DC or AC input signal.
V_{REF} is the specified voltage reference level.

The instrument will read 0dB when the reference voltage level is applied to the input.

If a relative value is in effect when dB is selected, the value is converted to dB then REL is applied to dB. If REL is applied after dB has been selected, dB has REL applied to it.

NOTE *The dB calculation takes the absolute value of the ratio V_{IN} / V_{REF}.*

The largest negative value of dB is -160dB. This will accommodate a ratio of $V_{IN} = 1\mu V$ and $V_{REF} = 1000V$.

dB configuration

Remote programming must be used to configure the Model 2701 for dB measurements. It cannot be configured from the front panel.

Scanning

Typically a scan using dB is configured and run using remote programming. However, once dB is selected using remote programming, a simple dB scan can be configured and run from the front panel. When the simple scan is configured, it will use the dB measurement setup for each channel in the scan. Details on configuring and running a scan are provided in Section 7.

NOTE *See* Section 7 *to configure and run a scan.*

Remote programming — dB

dB commands

The dB commands are listed in Table 5-4. Details on these commands follow the table.

NOTE *Queries are not included in Table 5-4. All the dB commands are provided in Table 15-10.*

Table 5-4
dB commands

Commands*	Description	Def
DCV dB commands		
UNITs:VOLTage[:DC] <name>	Select DCV measurements; <name> = V or DB.	V
UNITs:VOLTage[:DC]:DB:REFerence <n>	Set reference in volts; <n> = 1e-7 to 1000.	1
ACV dB commands		
UNITs:VOLTage:AC <name>	Select ACV measurements; <name> = V or DB.	V
UNITs:VOLTage:AC:DB:REFerence <n>	Set reference in volts; <n> = 1e-7 to 1000.	1
Channel list parameter: <clist> = (@SCH) where: S = Mainframe slot number (1 or 2) CH = Switching module channel number (must be 2 digits) Examples: (@101) = Slot 1, Channel 1 (@101, 203) = Slot 1, Channel 1 and Slot 2, Channel 3 (@101:110) = Slot 1, Channels 1 through 10		

*The <clist> parameter is used to configure one or more channels for a scan. Each channel in the <clist> must be set to the function specified by the rel (reference) command. If not, a conflict error (-221) will occur. For example, UNITs:VOLTage:AC dB, (@101) is only valid if scan channel 101 is set for the ACV function.

Programming examples — dB

Example #1 — The following command sequence configures the Model 2701 to perform DCV dB measurements. A 1V input will be measured as 0dB.

```
FUNC 'VOLT'                          ' Select DCV function.
UNIT:VOLT DB                         ' Select DCV dB.
UNIT:VOLT:DB:REF 1                   ' Set dB reference to 1V.
```

Example #2 — The following command sequence configures channels 101 and 105 of the Model 7700 to perform ACV dB measurements when they are scanned. A 10V input will be measured as 0dB.

```
FUNC 'VOLT:AC',(@101,105)            ' Set 101 and 105 for ACV.
UNIT:VOLT:AC DB,(@101,105)           ' Set 101 and 105 for dB.
UNIT:VOLT:AC:DB:REF 10               ' Set 101 and 105 for 10VAC dB
                                       reference.
```

6
Buffer

- Buffer overview — Summarizes basic buffer (data store) capabilities.
- Front panel buffer — Explains how to store and recall readings. Discusses the various statistics available on buffer data including minimum and maximum values, average (mean), standard deviation, and peak-to-peak values.
- Remote programming buffer — Summarizes the commands to control the data store and provides a programming example.

Buffer overview

The Model 2701 has a data store (buffer) to store from 2 to 450,000 readings. The instrument stores the readings that are displayed during the storage process. Each timestamped reading includes the buffer location number and a timestamp.

The data store also provides statistical data on the measured readings stored in the buffer. These include minimum, maximum, average, peak-to-peak, and standard deviation.

NOTE When scanning, the readings are automatically stored in the buffer.

NOTE The various instrument operations, including buffer operation, are performed on the input signal in a sequential manner. See "Signal processing sequence," page D-2, for details. It includes flowcharts showing where in the processing sequence that buffer operations occur.

Front panel buffer

Auto clear

With buffer auto clear enabled, the buffer is cleared (readings lost) before a new storage operation starts. The buffer can be manually cleared by setting the number of readings to store (buffer size) to 000000.

NOTE When editing the reading count over the front panel, press AUTO to reset the count to 000000. You can then press <ENTER> to clear the buffer.

When buffer auto clear is disabled, the buffer is not cleared and the buffer size is set to 450000. Each subsequent storage operation appends the readings to the buffer. When the buffer fills with 450,000 readings, the storage process stops. The 450,000 readings are cleared before the next storage operation starts.

With buffer auto clear disabled, the only two valid buffer size values are 450000 and 000000. Buffer size 000000 clears the buffer. Entering any other buffer size value resets the buffer size to 450000.

NOTE *If the buffer is empty when the Model 2701 is turned off, buffer auto clear will enable when it is turned back on.*

If the buffer is not empty, the instrument will power up to the last auto clear setting. Keep in mind that if the instrument powers up with buffer auto clear off, buffer size is fixed at 450000. You will have to enable auto clear to change the buffer size.

*The auto clear setting (on or off) is not affected by SYSTem:PRESet or *RST (front panel or remote operation). However, front panel FACTory defaults enables buffer auto clear.*

Enabling/disabling buffer auto clear

1. Press SHIFT and then SETUP.
2. Use the ▲ and ▼ keys to display the present state of buffer auto clear (BUF AUTOCLR); Y (yes) or N (no). To retain the present state of buffer auto clear, press ENTER or EXIT.

NOTE *If you change the state of buffer auto clear, the buffer will clear.*

3. To change the state of buffer auto clear, press ▶ to place the cursor on the present setting (Y or N).
4. Use the ▲ or ▼ key to display the desired setting (Y=enabled, N=disabled) and press ENTER.

NOTE *For remote programming, the TRACe:CLEar and TRACe:CLEar:AUTO commands are used to clear the buffer (Table 6-1).*

Timestamps

Each stored reading is referenced to either a real-time clock timestamp or to a relative timestamp.

Relative timestamp — With relative selected, there are two timestamp types for each reading: absolute and delta. The absolute timestamp (S) references each stored reading to zero seconds. Therefore, the first reading in the buffer has an absolute timestamp of zero seconds. The delta timestamp (dS) indicates the time (in seconds) between the displayed reading and the reading before it. The resolution for each timestamp is 1µsec.

NOTE *With auto clear disabled and the relative timestamp selected, every stored reading is referenced to the first reading (#0), even if the buffer is stopped and started again. For example, assume you stored 10 readings in the buffer and one hour later, you store 10 more readings. The timestamps for all 20 readings are referenced to the first reading. Therefore, the timestamp for the 11th reading (#10) is one hour (3600 seconds).*

When the Model 2701 is turned off, the relative timestamp resets to 0 sec when the instrument is turned back on. If you have readings stored in the buffer and auto clear is disabled when the unit is turned off, subsequent stored readings will be appended to the old group of readings. However, the relative timestamps for the new readings will be referenced to 0 sec.

When recalling stored readings from the front panel, both absolute and delta timestamps are provided. For remote operation, the absolute or delta timestamp is returned with each buffer reading. The TRACe:TSTamp:FORMat command selects the relative timestamp type (Table 6-1).

Real-time clock timestamp — With the real-time clock selected, each stored reading is timestamped with the time and date. For the time, the seconds reading has 0.01 sec resolution.

Configuring timestamp

Setting time and date

For the real-time clock, the time and date is set at the factory. However, you can check and correct the time and date as follows:

Perform the following steps to set the time:

1. Press SHIFT and then SETUP.
2. Use the ▲ and ▼ keys to display SET TIME and press ENTER. The displayed clock will be running in the hour/minute/second AM/PM format.
3. Use the edit keys (◀ , ▶ , ▲ , and ▼) to set the hour, minute, and AM/PM (seconds cannot be set), and press ENTER.

Perform the following steps to set the date:

1. Press SHIFT and then SETUP.
2. Use the ▲ and ▼ keys to display SET DATE and press ENTER to display the date in the month/day/year format.
3. Use the edit keys (◀ , ▶ , ▲ , and ▼) to set the date (month/day/year) and press ENTER.

Selecting timestamp

Perform the following steps to select either the real-time clock timestamp or the relative timestamp:

NOTE *Changing the timestamp will clear the buffer if a storage is in process. The message "BUF CLEARED" will be displayed to indicate the buffer readings were lost. If no storage is in process, changing the timestamp will not clear the buffer.*

1. Press SHIFT and then SETUP.
2. Use the ▲ and ▼ keys to display "TSTAMP."
3. Press the ▶ key to place the cursor on the presently selected timestamp (REL or RTCL).
4. Use the ▲ or ▼ key to display the relative (REL) or real-time clock (RTCL) and press ENTER.

Storing readings

Perform the following steps to store readings:

1. Set up the Model 2701 for the desired configuration.
2. Press the STORE key.
3. Use the ◀ , ▶ , ▲ , and ▼ keys to specify the number of readings to store in the buffer (2 to 450000). Pressing the AUTO key sets the readings count to 000000.

NOTE *With buffer auto clear disabled, the only valid buffer size values are 450000 and 000000 (which clears the buffer). Any other buffer size value is ignored.*

4. Press ENTER. The asterisk (*) annunciator turns on to indicate the buffer is enabled. It will turn off when the storage is finished.
5. The buffer can be stopped at any time by pressing EXIT.

NOTE *Stored readings are not lost when the instrument is turned off. To clear the buffer, set the reading value to "000000" and press ENTER.*

For remote programming, the continuous storage mode can be selected. After the buffer fills, operation wraps around to the beginning of the buffer (location #0) and starts to overwrite old reading data (see TRACe:FEED:CONTrol command in Table 6-1).

Recalling readings

Readings stored in the buffer are displayed by pressing the RECALL key. The readings are positioned at the left side of the display, while the buffer location number (reading number) and timestamps are positioned at the right side.

Perform the following steps to view stored readings and buffer statistics:

1. Press RECALL. The "BUFFER" annunciator indicates that stored readings are being displayed. The double-arrow annunciator indicates that more data can be viewed with the ◀, ▶, ▲, and ▼ keys.
2. As shown in Figure 6-1 and Figure 6-2, use the ◀, ▶, ▲, and ▼ keys to navigate through the reading numbers, reading values, statistics, and timestamps. For any of the buffer statistics (standard deviation, average, peak-to-peak, minimum, and maximum), the "STAT" annunciator is on.

NOTE *The longer you hold in the ▲ or ▼ key, the faster you will scroll through the buffer. After a while, scrolling speed will increase by incrementing (or decrementing) the buffer reading number by 100 and then finally by 1,000. When you get close to the desired reading number, release the ▲ or ▼ key. Again, press and hold in the ▲ or ▼ key to scroll one reading at a time.*

Figure 6-1
Recalling buffer data — relative timestamp

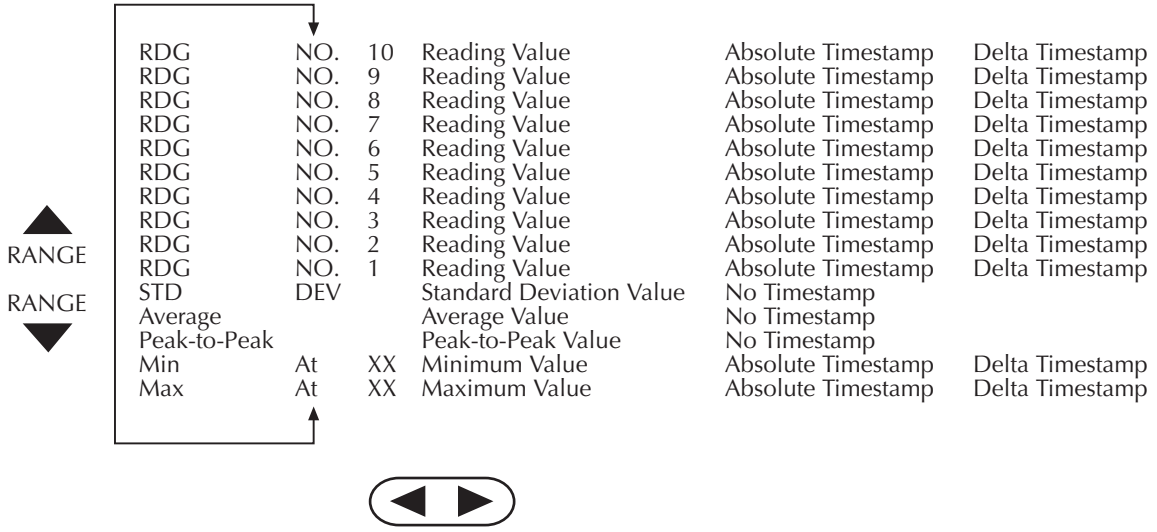
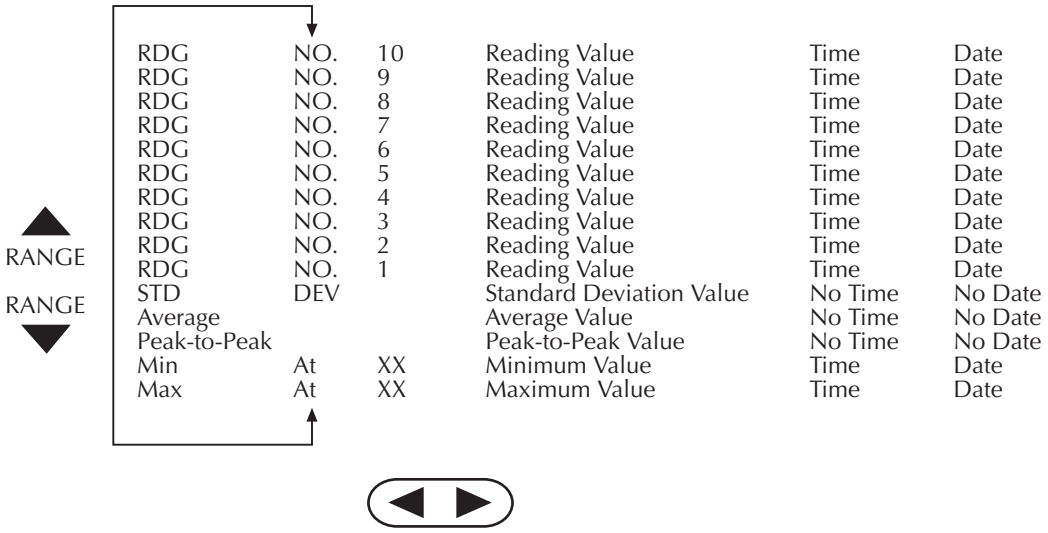


Figure 6-2
Recalling buffer data — real-time clock timestamp



Buffer statistics

Minimum and maximum

This mode displays the minimum and maximum readings stored in the buffer. The buffer location number and timestamp are also provided for these readings.

Peak-to-peak

This mode displays the peak-to-peak reading (peak-to-peak = Maximum - Minimum).

Average

The average mode displays the mean (average) of all measured readings stored in the buffer. The following equation is used to calculate mean:

$$y = \frac{\sum_{i=1}^{n} X_i}{n}$$

where: y is the average.
X_i is a stored reading.
n is the number of stored readings.

Standard deviation

This mode displays the standard deviation of buffered readings. The following equation is used to calculate standard deviation:

$$y = \sqrt{\frac{\sum_{i=n-1}^{n} X_i^2 - \left(\frac{1}{n}\left(\sum_{i=1}^{n} X_i\right)^2\right)}{n-1}}$$

where: y is the standard deviation.
X_i is a stored reading.
n is the number of stored readings.

NOTE *If the standard deviation calculation is being performed on a buffer that has more than 1000 readings, the "CALCULATING" message will flash to indicate that the Model 2701 is busy. While busy with the calculation, front panel keys will not operate. It will take approximately five seconds to calculate standard deviation on 450,000 readings.*

Remote programming — buffer

NOTE *When readings are stored in the buffer by the TRACe command (or by front panel data store operation), INIT and multi-sample READ? queries are locked out. With readings in the buffer that were stored in that manner, you cannot use the INIT or READ? command if sample count is >1 (error -225, out of memory).*

NOTE *The measurement event register can be read to check when the buffer becomes ¼, ½, ¾, or full. Status registers are covered in Section 11. "Example 3 – Read BHF bit of measurement event register" shows how to read the BHF (buffer half full) bit of the measurement event register.*

Buffer commands

NOTE *When measurements are performed, the readings are fed to other enabled operations, including the Buffer. Appendix D explains "Data flow (remote operation)," page D-7, and the commands used to read the buffer and buffer statistics.*

The commands to perform buffer operations are listed in Table 6-1. Details on these commands follow the table.

NOTE *Optional command words and most queries are not included in Table 6-1. The unabridged tables for all SCPI commands are provided in Section 15.*

Table 6-1
Buffer commands

Command	Description	Default[1]	Ref
SYSTem:TIME <hr, min, sec>	Set clock time in 24-hour format.		a
SYSTem:DATE <yr, mo, day>	Set clock date; yr specified as 20xx.		b
SYSTem:TSTamp:TYPE <name>	Select timestamp; <name> = RELative or RTCLock.	REL	c
SYSTem:TSTamp:TYPE?	Query timestamp type that will be used for the next buffer storage.		c
TRACe:TSTamp:TYPE?	Query timestamp type for readings presently in buffer.		c
TRACe:CLEar	Clear the buffer immediately.		d
TRACe:CLEar:AUTO <b>	Enable/disable buffer auto-clear; <b> = ON or OFF.	ON	d
TRACe:FREE?	Query bytes available and bytes in use.		e
TRACe:POINts <NRf>	Specify size of buffer; <NRf> = 2 to 450000.	100	f
TRACe:POINts?	Query size of buffer.		f
TRACe:POINts:ACTual?	Query number of readings stored in buffer.		f
TRACe:TSTamp:FORMat <name>	Select timestamp format; <name> = ABSolute or DELTa.	ABS	g
TRACe:FEED <name>	Select source of readings; <name> = SENSe[1], CALCulate[1], or NONE.	CALC	h
TRACe:FEED:CONTrol <name>	Set buffer control; <name> = NEVer, NEXT, or ALWays.	NEV	h
TRACe:DATA?	Read all readings in the buffer.		i
TRACe:DATA:SELected? <start>, <count>	Specify readings to be returned; <start> = starting point, <count> = number of readings.		j
TRACe:NEXT?	Query buffer location for next stored reading.		j
TRACe:NOTify <NRf>	Specify number of stored readings that will set Trace Notify bit (B6) of measurement event register; <NRf> = 1 to 449999 (must be less than TRACe:POINts value).		k
FORMat:ELEMents <item list>	Specify elements for TRACe:DATA? response message; <item list> = READing, CHANnel, UNITs, RNUMber, and TSTamp.	(Note 2)	l
CALCulate2:FORMat <name>	Select buffer statistic; <name> = MINimum, MAXimum, MEAN, SDEViation, PKPK, or NONE.	NONE	m
CALCulate2:STATe <b>	Enable/disable statistic calculation; <b> = ON or OFF.	OFF	m
CALCulate2:IMMediate	Calculate data in buffer.		m
CALCulate2:IMMediate?	Calculate data and read result.		m
CALCulate2:DATA?	Read the selected buffer statistic.		m

Notes:
1. SYSTem:PRESet and *RST have no effect on TRACe commands. The listed defaults for TRACe commands are set at the factory.
2. The SYSTem:PRESet and *RST default is READ, UNIT, RNUM, and TST.

a. **SYSTem:TIME** <hr, min, sec> **Set clock time**

Use to set the clock time in the 24-hour format (hr/min/sec). Seconds can be set to 0.01 sec resolution. Examples:

```
SYST:TIME 13, 23, 36            'Set time to 1:23:36 PM.
SYST:TIME 3, 25, 28.5           'Set time to 3:25:28.5 AM.
```

The SYSTem:TIME? command can be used to read the time. Note that it returns the actual clock time and not the time parameter specified by the TIME command.

b. **SYSTem:DATE** <yr, mo, day> **Set clock date**

Use to set the clock date in the year/month/day format. When setting the year, a 4-digit value must be used. Example:

```
SYSTem:DATE 1999, 11, 10        'Set clock date to November 10, 1999.
```

c. **SYSTem:TSTamp:TYPE** RELative | RTClock **Select timestamp**
SYSTem:TSTamp:TYPE? **Query timestamp type; next storage**
TRACe:TSTamp:TYPE? **Query timestamp type; readings in buffer**

SYSTem:TSTamp:TYPE <name> — Use to select the relative timestamp or the real-time timestamp. Note that changing the timestamp will clear the buffer if a storage is in process. If no storage is in process, changing the timestamp will not clear the buffer.

SYSTem:TSTamp:TYPE? and TRACe:TSTamp:TYPE? — Both of these commands query the timestamp type. However, SYSTem:TSTamp:TYPE? queries the timestamp that will be used for the next storage operation, while TRACe:TSTamp:TYPE? queries the timestamp for readings that are presently stored in the buffer.

d. **TRACe:CLEar** **Clear the buffer**
TRACe:CLEar:AUTO ON | OFF **Control (on/off) buffer auto-clear**

TRACe:CLEar — Used to clear the buffer. Buffer readings are not lost (cleared) when the Model 2701 is turned off.

When TRAC:CLE is sent while displaying stored readings, the message "BUF CLEARED" is briefly displayed and the instrument returns to the normal measurement state.

TRACe:CLEar:AUTO — With auto-clear enabled, the buffer will automatically clear when the storage process starts. When disabled, readings will append to old readings in the buffer until the buffer becomes full (450,000 readings) or the storage process is stopped. Disabling auto-clear automatically sets the buffer size to 450,000.

e. **TRACe:FREE?** **Query status of storage memory**

Returns two values separated by commas. The first value indicates, in bytes, memory available for storage, while the second value indicates the number of bytes being used for stored readings.

f. **TRACe:POINts <NRf>** **Set buffer size (2 to 450000)**
TRACe:POINts? **Query buffer size**
TRACe:POINts:ACTual? **Query # of readings stored in buffer**

TRACe:POINts <NRf> – With buffer auto-clear enabled, you can set the buffer to store from 2 to 450,000 readings. A buffer size of zero or one is not valid (error -222).

With buffer auto-clear disabled, you cannot use this command to set buffer size (error -221) because it is fixed at 450,000.

NOTE *The ¼ full and ¾ buffer full measurement events are not intended to be used with buffer size smaller than four readings.*

TRACe:POINts? and TRACe:POINTs:ACTual? – The :POINts? command queries the set size of the buffer, while :POINTs:ACTual? queries the number of readings presently stored in the buffer.

g. **TRACe:TSTamp:FORMat** ABSolute | DELta **Select timestamp format**

For front panel operation, both timestamp formats (absolute and delta) can be recalled. For remote programming, you can only use one timestamp at a time.

NOTE *Changing the timestamp format clears the buffer.*

The timestamp will only be included with a returned buffer reading if it is specified as a data element (see FORMat:ELEMents).

h. **TRACe:FEED** SENSe | CALCulate | NONE **Select source of readings**
TRACe:FEED:CONTrol NEXT| ALWays | NEVer **Select buffer control**

TRACe:FEED — The SENSe parameter selects readings before any enabled mX+b, Percent, or Reciprocal math calculation. For the CALCulate parameter, the result of the calculation is stored in the buffer. The NONE parameter disables storage into the buffer. Math functions are covered in Section 5.

NOTE *In order to store readings in the buffer, TRACe:FEED cannot be set to NONE.*

TRACe:FEED:CONTrol — Selecting NEXT enables the buffer. After the specified number of readings (buffer size) are stored, buffer operation disables. The ALWays parameter places the buffer into a continuous filling mode. After the specified number of readings are stored, operation wraps back to the first buffer location and overwrites the previous readings. The NEVer parameter disables buffer operation.

i. **TRACe:DATA? Read buffer**

Use TRACE:DATA? to retrieve all readings that are stored in the buffer. You can send this command even if the instrument is still storing readings. When TRACe:DATA? is sent, it will return the readings stored up to that point in time. Subsequent TRACe:DATA? commands will not retrieve readings already returned. However, once the buffer has filled and you have retrieved all buffer readings, you can again send TRACe:DATA? to retrieve all the stored readings.

The data elements returned with each stored reading depends on which ones are selected with FORMat:ELEMents command (see Section 14 for details).

j. **TRACe:DATA:SELected? <start>, <count> Specify readings to return**
TRACe:NEXT? Query location of last buffer reading

Use the TRACe:DATA:SELected? command to specify which stored readings to return. The <start> parameter specifies the first stored reading to return. Note that the first stored reading in the buffer is #0. The <count> parameter specifies the number of readings to return.

When the storage process is aborted, you can use TRACe:NEXT? to determine the buffer location for the next stored reading. For example, if the last reading is stored at memory location #36, TRACe:NEXT? will return the value 37. This query is useful when using the buffer in the continuous storage mode (TRACe:FEED:CONTrol ALWays) as demonstrated by the following example.

Example — Assume the buffer is configured for continuous (wrap-around) storage and the buffer size is 100. At some point you stop the storage process and want to return all the readings that were stored since the last time the buffer filled. The following command will return the buffer location for the next stored reading:

```
TRACe:NEXT?                    ' Query buffer location for next stored
                                 reading.
```

Assume that the above query returned value 37. Now you can use that value as the <count> parameter for the following command to return the 37 readings (0 through 36):

```
TRACe:SELected:DATA? 0, 36     ' Return buffer readings 0 through 36.
```

NOTE When using the RS-232 interface, the TRAC:DATA:SEL? command should always be used when recalling more than 100 points of buffer data. For large buffers, the PC may lose synchronization and data can be lost. To avoid this, use this query command to recall buffer data in 100 point chunks.

k. **TRACe:NOTify** <NRf> **Specify number of readings that will set Trace Notify bit**

<NRf> = 1 to 449999

Use this command to specify the number of stored readings that will set bit B6 (Trace Notify) of the measurement event register. See Section 11 for details on status structure.

The maximum valid parameter value for this command is one less than the present buffer size (which is set by the TRACe:POINTs command). For example, TRACe:POINts 450000 sets the buffer size to 450,000 readings. For this buffer size, the maximum valid parameter value for TRACe:NOTify is 449999 (450000-1).

When an invalid parameter value is specified, the command is ignored and causes error -222 (parameter data out of range).

l. **FORMat:ELEMents** <item list> **Select elements for TRACe:DATA?**

<item list> = READing, CHANnel, UNITs, RNUMber, TSTamp

The data returned by TRACe:DATA? can include from one to all five data elements shown in the above item list. For example, if you want the units and reading number included with the reading, you would send this command:

```
FORMat:ELEMents  READing, UNITs, RNUMber.
```

Only the elements defined by the list are used. Elements not included in the list are not used. You can specify the elements in the list in any order, but they must be separated by commas.

The data elements that can accompany the reading are summarized as follows. More details on data elements are provided in Section 14, "FORMat commands."

- CHANnel — References the reading to a switching module channel. If the reading is not for a switching module, channel 000 will be returned.
- UNITs — Identifies the measurement function (i.e., VDC).
- RNUMber — References the reading to the buffer reading number.
- TSTamp — Timestamps the reading (ABSolute or DELTa timestamp as set by the TRACe:TSTamp:FORMat command).
- FORMat:ELEMents — READing, CHANnel, UNITs, RNUMber, TSTamp, LIMits.

Choose the elements to be outputted with each DATA? or each buffer reading in a TRAC:DATA? RNUMber is reading number; TSTamp is Timestamp as set by the SYST:TSTamp:TYPE command. The other elements should be self-explanatory. The query acts the same as 2000, except there are six possible elements instead of 3. Therefore, if only READ is selected, then FORM:ELEMents? returns the string "READ,,,,,". The LIMits are returned in ASCII format as a four-bit number abcd, where (a) corresponds to High Limit 2, (b) is Low Limit 2, (c) is High Limit 1, and (d) is Low Limit 1. A zero in the bit position indicates a passing limit, while a 1 indicates failure. In the binary formats, the limit information must be decoded from the value 0-15 returned, where the MSB is High Limit 2 and the LSB is Low Limit 1. For example, a value of 10 returned in the limits field would indicate that High Limit 2 and High Limit 1 both failed.

Real-time timestamps are not available for output data formats other than ASCII. The element TSTamp can still be selected and will show up when FORM:ELEM? is queried, but no timestamp will be included in the output data.

m.

CALCulate2:FORMat <name>	**Select buffer statistic**
CALCulate2:STATe ON | OFF	**Control (on/off) buffer statistic**
CALCulate2:IMMediate	**Calculate data in buffer**
CALCulate2:IMMediate?	**Calculate and read result**
CALCulate2:DATA?	**Read result of statistic calculation**

<name> = MINimum | MAXimum | MEAN | SDEViation | PKPK | NONE

After the selected buffer statistic is enabled, IMMediate or IMMediate? must be sent to calculate the statistic from the data in the buffer. The CALCulate2:DATA? command does not initiate a calculate operation. It simply returns the result of the last calculation. If new data is stored in the buffer, you must again send IMMediate or IMMediate? to recalculate the statistic from that new data.

NOTE *If the standard deviation calculation is being performed on a buffer that has more than 1000 readings, the "CALCULATING" message will flash to indicate that the Model 2701 is busy. While busy with the calculation, remote programming commands will not execute.*

NOTE *Use *OPC or *OPC? with CALC2:IMM and CALC2:IMM? when performing the standard deviation calculation on a large buffer. See Section 12 for details on *OPC and *OPC?*

NOTE *The Model 2701 should take 5 to 6 seconds to perform standard deviation on 450,000 readings.*

Programming example

The following command sequence stores 20 readings in the buffer and then calculates the mean for those readings:

NOTE *The following example can be run from the KE2700 Instrument Driver using the example named "BufStats" in Table G-1 of Appendix G.*

```
' Store readings:
TRAC:CLE:AUTO ON                ' Enable buffer auto-clear.
TRAC:POIN 20                    ' Set buffer size to 20.
TRAC:FEED SENS                  ' Select raw readings for storage.
TRAC:FEED:CONT NEXT             ' Start storage process.
TRAC:DATA?                      ' Request all stored readings.

' Calculate mean:
CALC2:FORM MEAN                 ' Select mean calculation.
CALC2:STAT ON                   ' Enable mean calculation.
CALC2:IMM?                      ' Perform calculation and request result.
```

7
Scanning

- Scanning fundamentals — Explains channel assignments (slot/channel programming format), the difference between sequential and non-sequential scans, and the basic scan process. Block diagrams (known as trigger models) are provided to help explain the STEP and SCAN operations.
- Scan configuration — Provides the step-by-step procedures to configure a simple scan or an advanced scan. Covers other scan options, including delay, monitor, auto configuration, saving setups, and auto scan.
- Scan operation — Provides the step-by step procedures to perform a basic scan, a manual/external trigger scan, and a monitor scan.
- Remote programming — scanning — Provides the commands used for scan operation and includes a simple scanning programming example. Also summarizes various aspects of remote scan operation.
- Scanning examples — Provides a couple of typical scan operation examples (front panel and remote programming).

Scanning fundamentals

The Model 2701 can scan the channels of up to two installed Keithley switching modules. Each scan channel can have its own unique setup. Aspects of operation that can be uniquely set for each channel include function, range, rate, AC bandwidth, rel, filter, digits, math, Ω offset compensation, TEMP transducers, limits, channel average, channel ratio, and volts dB.

NOTE *Readings for scanned channels are automatically stored in the buffer. With buffer auto clear enabled (which is the default), the buffer clears when the scan is started. When disabled, scan readings are appended to the buffer. The TRACe:CLEar:AUTO <b> command is used to enable/disable buffer auto clear (Section 6).*

A pseudocard can be installed in an empty slot. With the 7700 pseudocard installed, the instrument will operate as if a Model 7700 switching module is installed in the slot. This allows the user to configure a scan and exercise its operation before the switching module is installed in the Model 2701. Use the following commands to install 7700 pseudocards in empty slots:

SYSTem:PCARd1 C7700	*'Install' 7700 pseudocard in slot 1.*
SYSTem:PCARd2 C7700	*'Install' 7700 pseudocard in slot 2.*

Pseudocards for other switching modules can instead be installed. Details on installing other pseudocards are provided in Section 2.

There are SCPI commands to query the capabilities of the installed switching modules. For example, the following queries are provided to determine which channels of a Model 7700 in slot 1 are available for volts/2-wire ohms and which channels are available for amps. Note that the returned values for the Model 7700 switching module are shown in parenthesis.

```
SYSTem:CARD1:VCHannel[:STARt]?  ' Query first volt/Ω2 channel(7700; "1").
SYSTem:CARD1:VCHannel:END?      ' Query last volt/Ω2 channel (7700; "20").
SYSTem:CARD1:ACHannel[:STARt]?  ' Query first amps channel (7700; "21").
SYSTem:CARD1:ACHannel:END?      ' Query last amps channel (7700; "22").
```

All the commands to query switching module capabilities are covered in Table 15-7.

Channel assignments

A switching module has a certain number of channels. For example, the Model 7700 switching module has 22 channels (1 through 22). When you encounter a 1 or 2-digit channel number in this manual, the switching module channel is the point of discussion.

A switching module can be installed in one of two slots of the mainframe. Therefore, to close/open or scan a channel, it is necessary to specify the slot location and channel number of the switching module. This is accomplished by using a 3-digit channel number for the mainframe. The first digit (1 or 2) indicates the slot number and the next two digits indicate the channel number of the switching module. Examples:

Channel 101	Slot 1, channel 1
Channel 112	Slot 1, channel 12
Channel 220	Slot 2, channel 20

Sequential and non-sequential scans

Only a sequential scan can be configured from the front panel. For a sequential scan, the scan proceeds from the lowest numbered channel to the highest. For example, assume channels 101, 102, 105, 108, and 109 are selected for a scan. The scan will run in this order: 101 > 102 > 105 > 108 > 109.

For remote programming, a non-sequential scan can be configured. Channels are scanned in the order that they are listed in the scan list. This allows backward scanning. For example, assume the following scan list:

(@101, 102, 104, 105, 103, 109)

The above scan will run in this order: 101 > 102 > 104 > 105 > 103 >109. Notice that after channel 105 is scanned, the unit backs up to scan channel 103. It then proceeds forward to scan channel 109. Any scan that performs backward scanning is considered a non-sequential scan. For more information on non-sequential scanning, see the reference information for the ROUT:SCAN command that follows Table 7-1.

NOTE *Non-sequential scanning is only intended to be performed using remote programming. Unexpected results may occur if a non-sequential scan is run from the front panel.*

Scan process

Basic scan — For functions that use 2-wire measurements, the basic scan process is to (1) open any closed channel, (2) close a channel, and then (3) perform the measurement. This 3-step process is repeated for each channel in the scan. The last scanned channel opens.

Channel pair scan — For the functions that use 4-wire measurements (Ω4 and 4-wire RTD TEMP), the scan process uses paired channels. The scan process is to (1) open any closed channels, (2) close the paired channels, and then (3) perform the 4-wire measurement. The last scanned channel pair opens.

NOTE For the Model 7700 switching module, primary channels 1 through 10 are paired to channels 11 through 20. Channel 1 is paired to channel 11, channel 2 is paired to channel 12, channel 3 is paired to channel 13, and so on.

Calculations using channel pairs — Ratio and channel average performs measurements on two channels and then calculates (and displays) the result. Therefore, these 2-channel calculations also use paired channels. The scan process is to (1) open any closed channels, (2) close the primary (displayed) channel and perform a measurement, (3) open the primary channel, (4) close the paired channel and perform a measurement, (5) calculate and display the result, and finally (6) open the paired channel.

NOTE When scanning, the displayed channel number (i.e., 101) is not necessarily the channel that is presently closed.

If both a reading AND a scan channel are displayed, the reading and annunciators pertain to that channel, but that channel is no longer closed. The next channel in the scan list is the one that is now closed. Therefore, the reading (and annunciators) pertains to the channel and does not necessarily indicate the present state of the Model 2701.

If the display is blanked (-------), the displayed channel is closed and has not been measured.

Trigger models

NOTE The following information on trigger model operations apply specifically to front panel operation.

Block diagrams, known as trigger models, are used to show the two fundamental scan functions: STEP or SCAN. These two scan functions are enabled by the STEP and SCAN keys respectively. The trigger models for scanning are shown in Figure 7-1 and Figure 7-2.

NOTE *The trigger model in Figure 7-2 also applies for bus operation. See "Remote programming — scanning," page 7-26, for differences between front panel and remote scanning.*

For the following discussion, refer to Figure 7-1 for STEP operation and Figure 7-2 for SCAN operation.

Figure 7-1
Trigger model with STEP function

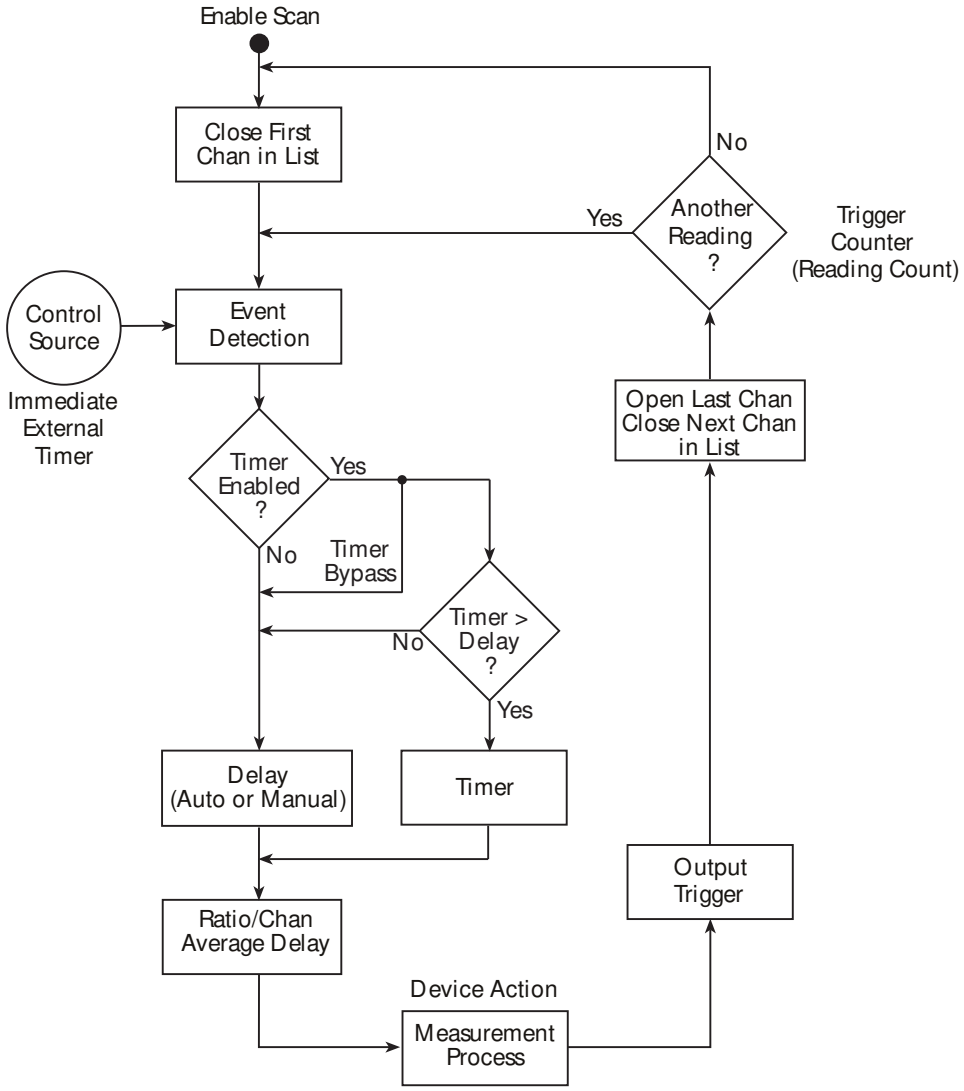
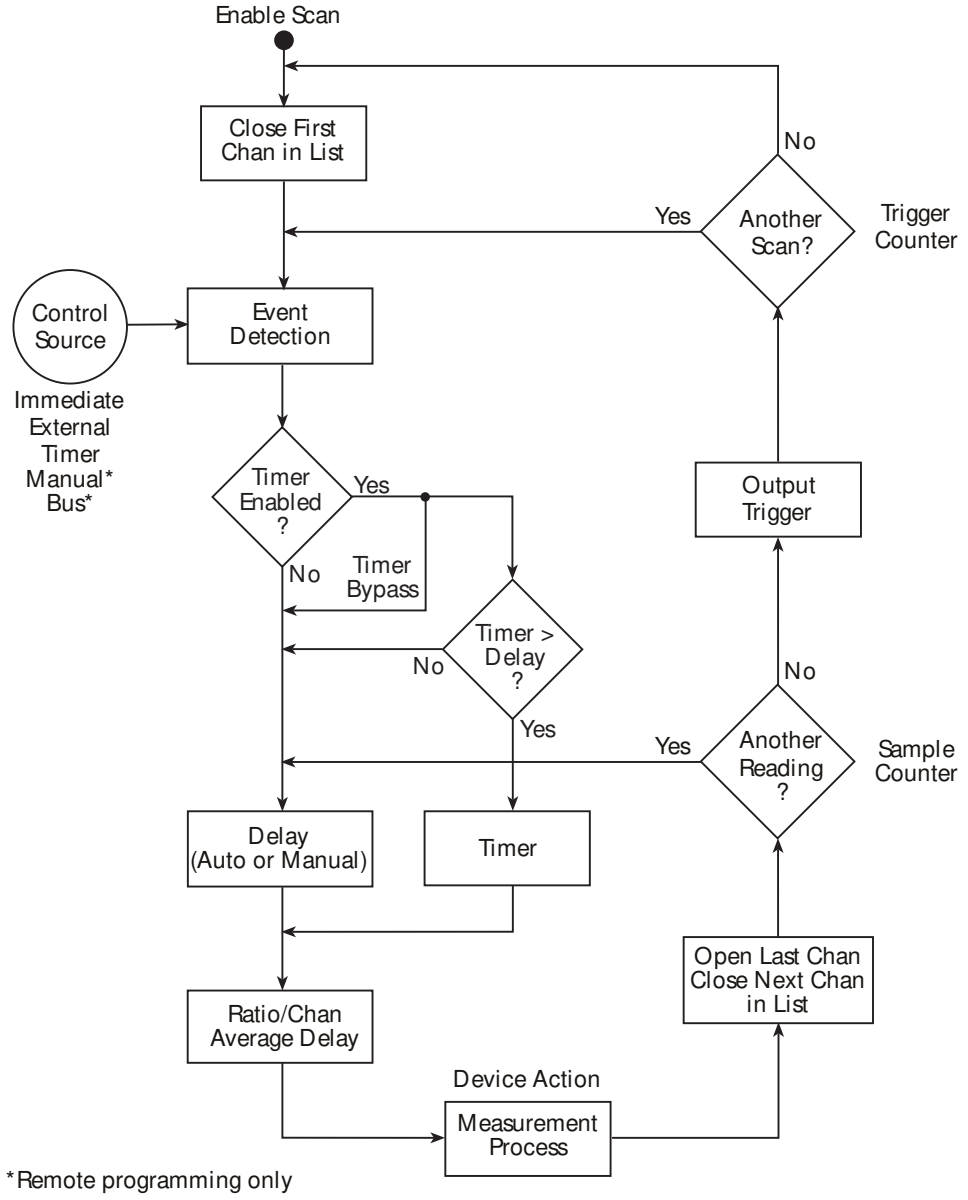


Figure 7-2
Trigger model with SCAN function



STEP operation overview — When the STEP key is pressed, the Model 2701 leaves the idle state, closes the first channel, and waits for the programmed trigger event. After the trigger is detected, the instrument may be subjected to one or more delays before performing the measurement.

After a reading is taken and stored in the buffer, the Model 2701 outputs a trigger pulse, opens the closed channel, and then closes the next channel in the scan list. The instrument then waits for another trigger event to measure the channel. After the last channel is scanned, the instrument returns to the idle state with the first channel in the scan list closed.

SCAN operation overview — When the SCAN key is pressed, the Model 2701 leaves the idle state, closes the first channel, and waits for the programmed trigger event. After the trigger is detected, the instrument may be subjected to one or more delays before performing the measurement.

After a reading is taken and stored in the buffer, the Model 2701 opens the closed channel and then closes the next channel in the scan list. Operation keeps looping around to measure all channels in the scan list. After the last channel in the scan list is measured, the Model 2701 outputs a trigger pulse.

If programmed to again scan the channels in the scan list, the Model 2701 will wait at the control source for another trigger event. After all the scan list channels are again measured, the Model 2701 will output another trigger pulse. After all programmed scans are completed, the instrument returns to the idle state with the first channel in the scan list closed.

The individual components of the trigger models are explained as follows:

Idle

When a scan is enabled (STEP or SCAN annunciator on), operation goes into the idle state and immediately drops down to the control source. Note that after the last channel in the scan is measured, operation returns to the idle state, where measurements are halted and the first channel in the list is closed.

Control sources

For front panel operation, there are three control sources to manage the scan: Immediate, Timer, and External Trigger. Operation is held up at the selected control source until the appropriate trigger event is detected.

STEP operation — When the trigger event is detected, a channel is measured. The scan pointer then loops back to the control source and waits for the next trigger event to occur.

SCAN operation — When the trigger event is detected, all the channels in the scan list are scanned. The scan pointer then returns to the control source and waits for the next trigger event to be detected.

Immediate control source

With immediate triggering, event detection is immediate allowing channels to be scanned.

Timer control source

With the timer source enabled (selected), event detection is immediately satisfied. On the initial pass through the loop, the Timer Bypass is enabled allowing operation to bypass the Timer and continue to the Delay block.

On each subsequent pass through the loop, the Timer Bypass is disabled. Operation is then delayed by the Timer or the Delay. If the user-set Timer interval is greater than the user-set Delay, the Timer will control the length of the delay. Otherwise, the length of the delay is controlled by the user-set Delay period.

The Timer interval can be set from 0 to 999999.999 seconds. The timer resets to its initial state when the scan is completed.

STEP operation — As shown in Figure 7-1, the timer control source affects the timing between scanned channels.

SCAN operation — As shown in Figure 7-2, the timer control source affects the timing between scans. It has no effect on the timing between scanned channels.

External trigger control source

Pressing the EX TRIG key places the instrument in the external trigger mode (TRIG annunciator on). When the STEP or SCAN key is then pressed, that scan is enabled. However, the scan does not start until an external trigger is received or the TRIG key is pressed. The external trigger or TRIG keypress satisfies event detection.

STEP operation — Each time an external trigger is received (or TRIG key is pressed), one channel is scanned.

SCAN operation — Each time an external trigger is received (or TRIG key is pressed), one complete scan is performed.

Delays

As shown in the trigger models, operation may be subjected to one or more delays before a channel is measured.

NOTE *As previously explained, if the timer control source is selected and its user-set interval is greater than the user-set Delay, the Timer interval will supersede the Delay period after the first pass through the loop.*

Delay (Auto or Manual) — The user can select either auto delay or manual delay. With auto delay selected, the instrument automatically selects a delay period that will provide sufficient settling for function changes, autorange changes, and multi-phase measurements.

The auto delay period cannot be adjusted by the user. It is a fixed delay for the selected function and range (Table 8-1).

NOTE *When scanning, the auto delay times in Table 8-1 are valid for all control sources (Immediate, External, Timer, Manual, or Bus).*

With manual delay selected, the user can set the delay period from 0 seconds to 99 hours, 99 minutes, 99.999 seconds. However, if you set a delay shorter than the corresponding auto delay period, measurement uncertainty increases (noisy and/or unsettled readings may result).

NOTE *Keep in mind that if the timer control source is selected, the Delay period is only in effect for the first pass through the loop.*

Ratio/Chan Average Delay — With ratio or channel average enabled, a delay is typically used to keep the channel relays from cycling too fast. The default delay period is 0.5 seconds but can be set from 0 to 999999.999 seconds using remote programming (see Section 5 for details). Ratio and channel average are covered in Section 5.

NOTE *The Ratio/Chan Average Delay is in addition to the Timer or Delay (Auto or Manual). That is, it occurs after the Timer interval or Delay period elapses.*

Device action

The channel measurement process is performed at this block. If repeat filter is enabled, the filter process is also performed.

Reading count

NOTE For both STEP and SCAN, the reading count specifies the number of readings to store in the buffer.

STEP operation — The reading count specifies the number of channels to scan. This can be equal to, less than, or greater than the number of channels in the scan list. The last scanned channel remains closed. If you start the scan again, it will start at the next channel.

If the reading count is set to infinity (INF), the scan will continuously repeat until you stop it.

NOTE One counter is used for STEP operation. As shown in Figure 7-1, reading count sets the Trigger Counter.

SCAN operation — When a scan is started, one or more complete scans will be performed. The number of channels in the scan list determines the number of channels for each scan. The reading count determines the number of scans to perform and is best explained by an example. Assume there are 10 channels in the scan list. If you set the reading count to 10 or less, one scan of the 10 channels will be performed. If you set the reading count to any value from 11 to 20, two scans will be performed. A reading count from 21 to 30 gives you three scans, and so on.

If the reading count is set to infinity (INF), the scan will continuously repeat until you stop it.

NOTE As shown in Figure 7-2, two counters are used for SCAN operation. The Trigger counter controls the number of scans and the Sample Counter controls the number of channels for each scan. The number of channels in the scan list and the programmed reading count automatically sets the Trigger Counter and the Sample Counter.

The Sample Count is equal to the scan list length. For example, if channels 101, 102, and 103 are programmed to be scanned, the Sample Count is 3.

Output trigger

STEP operation — After each channel is scanned, an output trigger is applied to the rear panel Trigger Link connector.

SCAN operation — After all channels in the scan list are scanned, an output trigger is applied to the rear panel Trigger Link connector.

Scan configuration

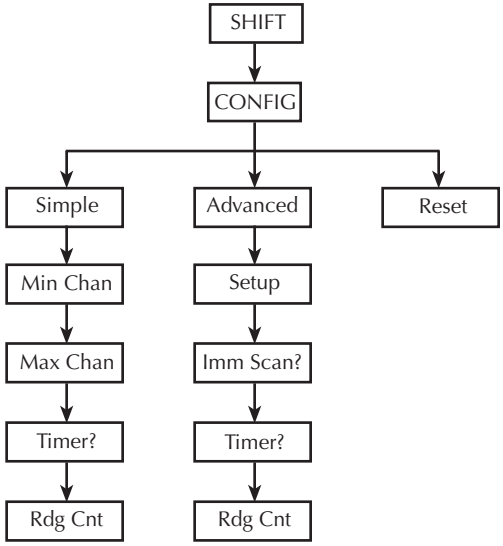
A scan is configured from the scan configuration menu which is accessed by pressing SHIFT and then CONFIG. Figure 7-3 shows the basic flowchart to configure a scan. After entering the menu structure you can configure a simple scan, an advanced scan, or reset the configuration to the default setup for a simple scan. Refer to the flowchart in Figure 7-3 for the following discussions on "Scan reset," "Simple scan," and "Advanced scan."

NOTE *Only a sequential scan can be configured from the front panel. For a sequential scan, the scan proceeds from the lowest numbered channel to the highest.*

Non-sequential (backward) scanning is only intended to be performed using remote programming. Unexpected results may occur if a non-sequential scan is run from the front panel.

For more information, see "Scanning fundamentals — Sequential and non-sequential scans," page 7-3.

Figure 7-3
Scan configuration flowchart



NOTE *The instrument is always configured to run a scan. On power-up, each available channel uses the power-on default setup. For example, for factory power-on default settings and two Model 7700s installed, the instrument will scan channels 101 through 220 when the scan is run. See Section 1 for details on power-on default settings.*

There are two scan configurations: simple and advanced. When you configure the simple scan, the instrument uses the present instrument setup for each channel in the scan. For the advanced scan, each channel can have its own unique setup. As explained in "Trigger models," page 7-4, there is a user-set delay (auto or manual) that is in effect for both the simple and advanced scan.

Channel setup considerations

Rel — In order to use an acquired rel value for an advanced scan channel, the rel value has to be acquired with the instrument in the normal measurement state. Details to set rel for scan channels are provided in "Relative," page 5-2. Scanning examples (front panel and remote programming) at the end of this section demonstrate how to set rel values for scan channels.

Filter — The moving filter cannot be used in a scan; only the repeat filter can be used. If you configure a channel (or channels) to use the moving filter, the filter will be off when the scan is run. See Section 4 for details on filter.

Hold — Reading hold cannot be used with scanning. Do not set up a scan channel to use hold and do not run a scan with hold enabled.

NOTE When in the scan setup menu, use the edit keys (◄ , ► , ▲ , and ▼) to make selections and set values. Displayed selections and settings are entered by pressing the ENTER key.

Saving the configured scan

The configured scan can be saved in a user-saved setup (SAV0, SAV1, SAV2, SAV3, or SAV4). For a front panel configured scan, the reading count and timer values are also saved (B04 and later software). However, if the settings for a user setup or power-on setup do not match the switching module type presently installed, error +520 (Saved setup scancard mismatch) occurs when the setup is recalled. The scan resets to the factory default settings and all channels will open. The saved setup is still retained in memory and can be restored when the matching switching module is later installed.

The displayed front panel CONFIG menu operates differently from other menus when a saved front panel scan is recalled. The reading count value in the menu may not reflect the actual reading count of the scan. For example:

Assume a Model 7700 module configured for a10-channel scan and a reading count of 30. For this configuration, the instrument will scan through the scan list three times. Now assume the scan setup is saved in SAV1, and SAV1 is the power-on default. After cycling power, press SCAN or STEP to run the scan. The scan will run properly. That is, the 10 channels will be scanned three times. However, if you check the reading count in the front panel CONFIG menu, the reading count will be 10 (instead of 30). This is because the scan list length "suggests" the reading count value during the setup process.

NOTE Saving and recalling user-setups is covered in Section 1 (see "Defaults and user setups" on page 1-21).

Scan reset

From the scan configuration menu, you can reset the scan configuration to the default setup for a simple scan.

For the Model 7700 switching module, channels 21 and 22 are turned off (not used) and channels 1 through 20 are configured as follows:

Function - DCV
Range - Auto
Rate - Slow

All other multimeter features and functions are disabled.

When the scan is run by pressing STEP or SCAN, channels 1 through 20 will be scanned and the 20 DCV readings will be stored in the buffer.

Perform the following steps to reset the scan configuration:

1. Press SHIFT and then CONFIG to enter the scan configuration menu.
2. Press the ▲ or ▼ key to display INT: RESET and press ENTER.

After briefly displaying "LIST RESET," the instrument returns to the normal measurement state.

Simple scan

For a simple scan, you specify a starting channel (MIN CHAN) and an ending channel (MAX CHAN) for the scan. These settings determine the number of channels in the scan. For example, if you set MIN CHAN to 101 and MAX CHAN to 110, there will be 10 channels in the scan list.

The starting channel number must be lower than the ending channel number. If you enter an invalid value, the message "TOO SMALL" or "TOO LARGE" will be displayed briefly. The displayed channel number will default to the lowest available channel (i.e., 101) or the highest available channel (i.e., 220).

Perform the following steps to configure a simple scan:

1. While in the normal measurement mode, set up the instrument for your test. This setup will be used for all selected channels in the scan.
2. Press SHIFT and then CONFIG to access the scan setup menu.
3. Press the ▲ or ▼ key to display "INT: SIMPLE" and press ENTER.
4. Set the minimum channel (MIN CHAN) for the scan and press ENTER.
5. Set the maximum channel (MAX CHAN) for the scan and press ENTER.
6. Enable (YES) or disable (NO) the timer and press ENTER. See "STEP and SCAN keys" for details on timer operation.

7. If you enabled the timer, set the timer interval using the hour/minute/second format. The timer can be set from 0.001 sec (00H:00M:00.001S) to 99 hrs, 99 min, 99.999 sec (99H:99M:99.999S). Note that pressing the AUTO key sets the timer to 0.001 sec. With the desired interval displayed, press ENTER.
8. The displayed reading count (RDG CNT) sets the number of channels to scan (STEP) or the number of scans to run (SCAN). You can change the reading count to any finite value from 2 to 450000 or you can select infinite (continuous scanning). To select infinite, set the reading count to 000000 to display INF. See "Trigger models," page 7-4, for details on reading count. With the desired reading count setting displayed, press ENTER to return to the normal measurement display state.

Advanced scan

For an advanced scan, each enabled channel can have its own unique setup. Channels that are disabled are excluded from the scan list.

When you enter the channel setup menu, the displayed information indicates the present setup for the selected channel. The position of the decimal point in the "SETUP" message indicates present range. Examples:

S.ETUP	V:101	1V range for channel 101. If the AC annunciator is off, the function is DCV. If it is on, ACV is selected.
SE.TUP	KΩ:102	10kΩ range for channel 102. If the 4-wire annunciator is off, the function is Ω2. If it is on, Ω4 is selected.
SET.UP	mA:121	100mA range for channel 121. If the AC annunciator is off, the function is DCI. If it is on, ACI is selected.
SETUP	°C:103	TEMP function selected for channel 103.
SETUP	HZ:104	FREQ function selected for channel 104.
SETUP	S:105	PERIOD function selected for channel 105.
SETUP	PR:111	For the Model 7700, channel 111 is paired to channel 101 and cannot be changed. Channel pairing occurs when Ratio or Channel Average is enabled, or when a 4-wire function (Ω4 or 4-wire RTD TEMP) is selected.

The annunciators indicate which of the other instrument settings are enabled for the selected channel. When you edit settings for the selected channel (auto range, rel, rate, etc.), the related annunciators will turn on/off.

Advanced scan setup notes

1. The CHAN annunciator is on while in the scan setup menu.
2. For some channel-specific setups, you have to configure them from a menu. For example, to set up and enable mX+B, you have to use MATH menu. While in that menu, the CHAN annunciator will flash to indicate that you are editing the mX+b math setup for that channel in the scan list. When you exit from the mX+b setup menu, the CHAN annunciator stops flashing.
3. Paired channels — A paired channel function or operation can only be selected for a primary channel. For the Model 7700, channels 1 through 10 are the primary channels. Trying to select a paired channel function or operation for channels 11 through 22 will result in "INVALID CHAN."
4. Function changes — When you press a function key, the selected channel assumes the mainframe setup for that function. Also, available channels (for the specified slot) that follow will assume that setup. Model 7700 example: If you press DCV for channel 101, channels 101 through 120 will assume the DCV setup. Note that channels for slot 2 are not affected.

   When you press the Ω4 function key for a primary channel, the subsequently paired channels will be displayed briefly. Model 7700 example: If you press Ω4 for channel 108, channels 109 and 110 will also assume the Ω4 function and the message "118-120 PRD" will be displayed to indicate the paired channels.

   A channel that is paired to a primary channel is not affected by function changes. Model 7700 example: Assume channel 102 is paired to channel 112. Now select channel 103 and press DCV. All following channels, except channel 112, will assume the DCV setup. Channel 112 remains paired to channel 102. However, if you select channel 101 and press DCV, channel 102 will change to DCV and not be paired to channel 112 anymore. Therefore all 20 channels will assume the DCV setup.
5. Setting changes — When you press a key to change a setting (i.e., range, rel, digits, etc.), only the selected scan channel is affected. Model 7700 example: If you make a range change for channel 103, the range settings for other channels are not affected.

NOTE Only one USER RTD per scan list.

Advanced scan setup procedure

Step 1: Select the advanced scan configuration menu

1. Press SHIFT and then CONFIG to access the scan setup menu.
2. Press the ▲ or ▼ key to display INT: ADVANCED and press ENTER.

Step 2: Edit scan channels

1. Use the ◀ or ▶ key to select channel 101:

   SETUP V:101 (factory default)

NOTE The CLOSE key can instead be used to select a scan channel to be edited. Press CLOSE, use the ▲ or ▼ keys to display the channel and then press ENTER.

2. You can disable the channel or use it in the scan. Perform step a or step b:
   a. If you do not want to use the channel, press SHIFT and then CH-OFF to disable the channel. Available channels that follow will also disable. Note, however, that channels for slot 2 are not affected.
   b. If you want the channel in the scan, you can either use the presently selected function or select a valid measurement function. When you press a function key (i.e., DCV), the channel assumes the setup of the selected function. Available channels that follow will assume the same setup. Note, however, that channels for slot 2 are not affected.

NOTE For the Model 7700, DCI and ACI cannot be selected for channels 101 through 120 and channels 201 through 220. DCI and ACI are the only functions that can be set for channels 121, 122, 221, and 222.

3. If you did not disable the channel, make your setup changes (if any) for the selected function. These changes do not affect the following channels.
4. Using the ◀ or ▶ keys or the CLOSE key to select the channel, repeat Step 2:2 and Step 2:3 to set other channels.
5. When finished setting up channels, press ENTER to proceed to set up triggering.

NOTE If there are not at least two channels in the scan list (two or more channels enabled), the "INVALID LIST" message will appear briefly. You will not be able to exit from the scan configure menu or finish the scan setup until you enable at least two channels.

NOTE The remaining steps are used to check or change the setups for triggering, timer, and reading count. If you are not going to make changes to any of those setups, you can exit from the scan setup menu by pressing EXIT twice. The instrument returns to the normal measurement mode.

Step 3: Enable immediate scan

The present state of immediate scan (IMM SCAN) is displayed, Y (yes, which is the factory and *RST default) or N (no). With immediate scan enabled, the scan will start when you press the STEP or SCAN key. Use the ▲ or ▼ key to display IMM SCAN: Y and press ENTER.

NOTE *Disable immediate scan (IMM SCAN: N) when you wish to use a monitored reading limit to trigger the start of the scan. This technique to start a scan is covered later in this section. See "Scan operation," page 7-21.*

Step 4: Timer controlled scan

The present state of the TIMER will be displayed, NO or YES. If you do not wish to use the timer, use the ▲ or ▼ key to display TIMER? NO (which is the factory and *RST default) and press ENTER.

To use the timer, use the ▲ or ▼ key to display TIMER? YES and press ENTER. The timer interval is displayed in the hour/minute/second format. The timer can be set from 0.001 sec (00H:00M:00.001S) to 99 hr, 99 min, 99.999 sec (99H:99M:99.999S). Note that pressing the AUTO key sets the timer to 0.001 sec. With the desired interval displayed, press ENTER.

Step 5: Set the reading count

The displayed reading count (RDG CNT) sets the number channels to scan (STEP) or the number of scans to run (SCAN). You can change the reading count to any finite value from 2 to 450000 or you can select infinite (continuous scanning). To select infinite, set the reading count to 00000 to display INF. With the desired reading count setting displayed, press ENTER. The instrument returns to the normal measurement mode.

See "Trigger models," page 7-4, for details on reading count.

Setting delay

As shown in Figure 7-1 and Figure 7-2, a delay (auto or manual) can be set by the user. With auto delay selected, the delay period depends on function and range (Table 8-1). With manual delay selected, the delay period can be set from 0 secs to 99 hrs, 99 mins, 99.999 secs.

Perform the following steps to set auto or manual delay:

1. With the instrument in the normal measurement display state, press SHIFT and then DELAY.
2. Press ▲ or ▼ to display AUTO (auto delay) or MAN (manual delay) and press ENTER.
3. If you selected MAN, yo77xxu will be prompted to set the delay in the hour/ minute/
   second time format. Use the ◀ , ▶ , ▲ , and ▼ keys to set the delay.

NOTE Pressing the AUTO key sets the manual delay to 0.001 sec.

4. With the desired manual delay displayed, press ENTER.

For remote programming, the TRIGer:DELay <NRf> and TRIGger:DELay:AUTO <b> commands are used to set the delay. See Table 7-1 for details.

NOTE The delay for ratio and channel average can only be set using remote programming (Table 5-3).

Monitor channel

While in the normal measurement state, a scan list channel can be used to monitor readings. When a channel is selected to be the monitor, it will assume the setup of the scan list channel.

NOTE If you change the setup while a monitor channel is closed, that setup will be copied to that channel in the scan list.

When a scan is started, the first channel in the scan list will be briefly displayed. While the scan is in progress, the display will only show the reading(s) for the monitor channel. After the last channel is scanned, the scan will disable with the monitor channel closed.

Monitor can be used with limit testing to trigger the start of a scan. When the monitor detects that a set reading limit has been reached, the scan is triggered to start. The detailed procedure to perform a monitor scan is provided in "Scan operation — Monitor scan," page 7-35.

NOTE *An overflow reading ("OVRFLW" message displayed) is interpreted by the Model 2701 as a positive reading, even if the input signal is negative. This could inadvertently trigger a monitor scan (see "Scan operation — Monitor scan," page 7-35).*

The monitor channel must be a channel that is in the scan list. If the monitor channel is removed from the scan list, the lowest channel in the scan list will become the monitor channel.

To set monitor, the instrument can be in the normal measurement state or enabled while in the advanced scan menu. There are two methods to select a monitor channel: Method 1 selects it while a channel is closed and Method 2 selects it with no channels closed.

NOTE *The monitor channel must be a channel that is in the scan list.*

Method 1:

1. Use the CLOSE key or the ◄ and ► keys to close the channel that you want to be the monitor.
2. Press SHIFT and then MONITOR (MON annunciator turns on).

Method 2:

1. If a channel is closed, press OPEN to open it.
2. Press SHIFT and then MONITOR.
3. Use the ◄ , ► , ▲ , and ▼ keys to display the monitor channel (i.e., MONITOR 101) and press ENTER. The monitor channel closes and the MON annunciator turns on.

To disable monitor, again press SHIFT and then MONITOR (MON annunciator turns off).

Once enabled, you can change the monitor channel using the CLOSE key or the ◄ and ► keys. If you open the monitor channel, the monitor does not disable but it does become inactive (MON annunciator turns off). When a channel is closed, monitor becomes active (MON annunciator turns on).

While in the normal measurement state, the present monitor channel dictates which channel in the scan list is the monitor. Therefore, if you change the monitor channel, the scan list monitor channel also changes.

When you change the monitor channel while in the normal measurement state, the instrument setup does not change. If you want the monitor channel to assume the setup of the scan list channel, you must disable the monitor and then re-enable it.

Auto channel configuration

Auto channel configuration allows you to recall scan list setups. With auto channel configuration enabled, a closed channel assumes the scan list setup. With this feature, you can inspect the channel setups of the scan or manually scan channels. When a scan channel is disabled (not in scan list), it cannot be closed with auto channel configuration enabled.

As with normal operation, when you use the ◄, ►, or CLOSE to close a channel (or channel pair), any other closed channels are first opened.

Perform the following steps to enable or disable auto channel configuration.

1. Press SHIFT and then SETUP.
2. Use the ▲ or ▼ key to display the auto configuration (CH AUTOCFG) setting: N (no) or Y (yes).
3. Press the ► key to place the cursor on the present setting (N or Y) and press the ▲ or ▼ key to change the setting.
4. Press ENTER to return to the normal measurement state.

NOTES *Auto channel configuration cannot be enabled if there is a non-scan channel presently closed. For example, assume the scan list consists of channels 105 through 110, and channel 101 (a non-scan channel) is presently closed. When you attempt to enable auto channel configuration from the front panel, the message "NOT IN SCAN" is briefly displayed. For remote operation, error -221 (settings conflict) occurs.*

With auto channel configuration enabled, the ◄ and ► keys will not properly step through a non-sequential scan list. Therefore, auto channel configuration should not be used for a non-sequential scan list. For information on non-sequential scans, see "Scanning fundamentals — Sequential and non-sequential scans," page 7-3.

For remote operation, the ROUT:CLOS:ACON command is used to enable or disable auto channel configuration (Table 7-1).

Saving setup

Up to five instrument setups can be saved in memory using the SHIFT > SAVE menu (SAV0, SAV1, SAV2, SAV3, or SAV4). A user-saved setup can also be used as the power-on setup. A user-saved setup can be restored from the SHIFT > SETUP menu. Details on user-setups are covered in Section 1.

Auto scan

When auto scan is enabled, the scan operation is saved in memory. If power to the Model 2701 is interrupted, the scan will resume when power is restored. With auto scan enabled, the last scan setup becomes the power-on setup. It takes precedence over the factory, *RST, or user-saved power-on setup.

Perform the following steps to set auto scan.

1. While in the normal measurement state, press SHIFT and then SETUP.
2. Use the ▲ and ▼ keys to display the auto scan (AUTOSCAN) setting: N (no) or Y (yes).
3. To change the setting, press ▶ to place the cursor on the setting (N or Y) and press ▲ or ▼ to change the setting.
4. Press ENTER to exit from the menu structure.

NOTE *With auto scan enabled, DO NOT save the present setup as the power-on default setup. If you do so, an interrupted scan will not resume.*

If during the power-up sequence the Model 2701 detects a card ID change for any slot, auto scan configuration will disable and an interrupted scan will not be resumed. Error +517 occurs (cannot resume scan) to indicate that the scan has been disabled. The instrument assumes the normal power-on setup.

The Model 7706 does not support auto scan. Trying to enable auto scan with a Model 7706 card installed will cause error -221 (settings conflict).

Scan operation

A basic scan is controlled solely by the STEP and SCAN keys. When one of these keys is pressed, the STEP or SCAN operation will be performed. For the manual/external trigger scan, the TRIG key or triggers received from another instrument starts the STEP or SCAN operation. For the monitor scan, a channel monitors readings. When a set reading limit is reached, STEP or SCAN will start.

Basic scan

Perform the following steps to run the presently configured scan:

1. To start the scan, press STEP or SCAN.
2. The STEP or SCAN annunciator turns on and channels are scanned from the lowest to highest number channel. Channels that are turned off will not be scanned.
3. Keep in mind that the Timer Delay for STEP occurs between channels, while the Timer Delay for SCAN occurs between scans. If the timer is off, both scans will run at virtually the same speed.
4. With reading count set to a finite value, the last channel scanned will open and the first channel in the scan list will close. Keep in mind that the scan is still enabled (STEP or SCAN annunciator on). When you press STEP or SCAN, the scan will continue starting with the next channel.
5. With reading count set to infinite, the scan will keep repeating.

NOTE *While the scan is enabled (STEP or SCAN annunciator on), most front panel keys are inoperative and will cause the message "HALT SCANNER" to be displayed.*

6. To disable the scan, press SHIFT and then HALT.

Buffer

To recall scanned readings stored in the buffer, press RECALL and use the ◄, ►, ▲, and ▼ keys to navigate through the buffer. Note that the buffer can be read while the instrument is storing readings. See Section 6 for details on recalling buffer readings. When finished, make sure to exit from buffer recall by pressing the EXIT key.

NOTE *Channels for an advanced scan can be configured using different mX+ B units (i.e., ° and Ω), temperature sensors (i.e., 4-wire RTD and thermistor) and measurement type (i.e., OCOMP ohms and DCV).*

However, when readings are recalled from the buffer, the display may not indicate the correct mX+ B units symbol or annunciator for each channel. For example, assume one channel used OCOMP ohms, while a second used Ω2. When the readings are recalled, the OCOMP annunciator may remain on for both channels.

This display anomaly is due to memory limitations. Preserving the mX+ B units and annunciators for each channel would reduce the number of readings that could be stored in the buffer.

Manual/external trigger scan

The only difference between a manual/external trigger scan and the basic scan is control. The basic scan runs as soon as the STEP or SCAN key is pressed. The manual/external trigger scan is controlled by the front panel TRIG key or by triggers received from another instrument.

NOTE *For the following procedure, the Model 2701 can be triggered by pressing the TRIG key or by receiving a trigger pulse from another instrument. Section 8 provides details on triggering.*

1. If the scanner is presently enabled (STEP or SCAN annunciator on), press SHIFT and then HALT to disable it.
2. Press the EX TRIG to place the instrument in the external triggering mode. The TRIG annunciator turns on and the reading is blanked (-------).
3. Press STEP or SCAN to enable the scan (STEP or SCAN annunciator turns on).
4. The TRIG key or input triggers control the scan as follows:

   STEP operation — In general, each time the Model 2701 is triggered, one channel is scanned. When the STEP key is pressed to enable the scan, the first channel in the scan list closes. When the first trigger occurs, a measurement is taken, the channel opens, and the next channel closes. This process continues for each channel in the scan. After the last channel in the scan list is scanned, the first channel in the scan list closes.

   The reading count determines how many channel measurements will be performed during the scan sequence. If the reading count is greater than the scan list length, operation loops back to the beginning of the scan list and continues.

   After a scan sequence (as determined by the reading count) is completed, the scan remains enabled (STEP annunciator on), but the Model 2701 goes into the idle state. If you wish to repeat the scan sequence, you will have to first take the Model 2701 out of idle. This can be done by pressing the STEP (or TRIG) key.

   SCAN operation — In general, when the Model 2701 is triggered, a complete scan of all the channels in the scan list is performed. When the SCAN key is pressed to enable the scan, the first channel in the scan list closes. When a trigger occurs, one scan of the scan list channels is performed. After the last channel is scanned, the first channel in the scan list will close.

   Reading count determines how many scans will be performed (see "Trigger models," page 7-4). If programmed for another scan, it will start when another trigger occurs.

   After the last scan is completed, the scan remains enabled (SCAN annunciator on), but the Model 2701 goes into the idle state. If you wish to repeat the scans, you will have to first take the Model 2701 out of idle. This can be done by pressing the SCAN (or TRIG) key.
5. When finished, press SHIFT and then HALT to disable the scan, and press EX TRIG to take the Model 2701 out of the external triggering mode.

Monitor scan (analog trigger)

A channel can be assigned as a monitor channel. When the monitor channel detects that a reading limit has been reached, the scan will be triggered to start.

There are four reading limits that can be used to trigger the start of the scan: low limit 1 (LLIM1), high limit 1 (HLIM1), low limit 2 (LLIM2), and high limit 2 (HLIM2). The scan will start when any enabled reading limit event is detected by the monitor channel. Details on Limits are provided in Section 9.

NOTE *An overflow reading ("OVRFLW" message displayed) is interpreted by the Model 2701 as a positive reading, even if the input signal is negative. This could inadvertently trigger a monitor scan. For example, assume the monitor channel is monitoring a negative input signal and the instrument is configured to trigger a monitor scan if a positive input signal is detected. If for some reason, the negative input signal exceeds the measurement range, the overflow reading will be interpreted as positive and trigger the start of the scan.*

Perform the following steps to run a monitor scan:

NOTE *The last enabled scan function (STEP or SCAN) will be used for the monitor scan.*

1. Perform Step 1 and Step 2 of the "Advanced scan setup procedure," page 7-16, to set up scan channels. With the channel to be used as the monitor selected, set and enable limits as follows. Note that you only need to set values for limits that are going to be used.
   a. Press SHIFT and then LIMITS to access the limits menu. Note that the CHAN annunciator flashes to indicate that the menu is being used to set up a scan channel.
   b. Use the ◄, ►, ▲, and ▼ keys to set high limit 1 (HLIM1) and press ENTER.
   c. Set low limit 1 (LLIM1) and press ENTER.
   d. Set high limit 2 (HLIM2) and press ENTER.
   e. Set low limit 2 (LLIM2) and press ENTER. The instrument returns to the scan setup menu.
   f. Press SHIFT and then ON/OFF to display the present state of LIMITS (ON or OFF). Again, the CHAN annunciator flashes to indicate that the menu is for a scan channel.
   g. Press the ▲or ▼ key to display "LIMITS:ON" and press ENTER. The instrument returns to the scan setup menu. Note that the HIGH and LOW annunciators are on to indicate that limits are enabled.

   After all scan channels are set up, press ENTER. The present state of IMM SCAN is Y (yes) or N (no).

2. Press the ▲or ▼ key to display IMM SCAN: N and press ENTER.
   a. Press the ▲or ▼ key to enable or disable low limit 1 (LLIM1 SCAN:N/Y) and press ENTER.
   b. Press the ▲or ▼ key to enable or disable high limit 1 (HLIM1 SCAN:N/Y) and press ENTER.
   c. Press the ▲or ▼ key to enable or disable low limit 2 (LLIM2 SCAN:N/Y) and press ENTER.
   d. Press the ▲or ▼ key to enable or disable high limit 2 (HLIM2 SCAN:N/Y) and press ENTER.
3. Finish configuring the scan by performing Step 4 and Step 5 of the "Advanced scan setup procedure," page 7-16.

NOTE *For a remote programmed monitor scan, use the ROUTe:MONitor:POINts command to specify the number of channels to scan (Table 7-1).*

4. While in the normal measurement state, select and enable the monitor channel as explained in "Scan configuration — Monitor channel," page 7-18.

   When the reading limit for the monitor channel is reached, the scan will be triggered to start. When the monitor channel is scanned, the display will show the reading that triggered the scan.

   If the reading limit event is still present on the monitor channel when the scan finishes, the scan will be triggered to run again. Note that the scan can also be run by pressing STEP or SCAN.
5. To disable the monitor scan, perform the following steps:
   a. To disable monitor, press SHIFT and then MONITOR (MON annunciator turns off).
   b. To disable limits, press SHIFT and then ON/OFF. Press ▲or ▼ to display "LIMITS: OFF" and press ENTER.

Remote programming — scanning

NOTE Scanning examples (remote programming and front panel operation) are provided at the end of this section.

Trigger model

The trigger model for bus operation is shown in Figure 7-2. Bus operation is similar to front panel SCAN operation, with the following significant differences:

Idle — The instrument goes into the idle state (measurements halted) after the last scan channel is measured. For front panel operation, the instrument stays in idle until the next scan is started. For bus operation, the instrument will not stay in idle unless continuous initiation is disabled. There are two commands to disable continuous initiation:

```
INITitate:CONTinuous OFF              ' Disable continuous initiation.
*RST                                  ' Restore *RST defaults.
```

The instrument will remain in idle until it receives an initiate command. Typical commands to initiate one scan cycle include:

```
INITiate' Initiate one scan cycle.
READ? ' Initiate one scan cycle and request "sample" readings.
```

More information on using these commands is provided by Reference c that follows Table 7-1.

Control sources — For bus operation, there are two additional control sources: Bus and Manual. For the Bus control source, scan operation is controlled by bus triggers (i.e., *TRG) or by using the TRIG key. For the Manual control source, event detection is controlled solely by the TRIG key. Note that the instrument has to be in local order to use the TRIG key. The LOCAL key takes the instrument out of remote.

Trigger and sample counters — For front panel SCAN operation, the number of channels in the scan list and the programmed reading count automatically sets the trigger and sample counters. For remote operation, these two counters are set by the TRIGGer:COUNt and SAMPle:COUNt commands.

NOTE To set sample count >1, continuous initiation must be disabled (see "Idle," page 7-7). Note that only sample count readings are stored in the buffer. See Section 8 for detailed information on the trigger model.

Channel setup

The <clist> parameter is used to set up scan channels. For example, the following examples show how to set up scan channel 101:

```
FUNC 'VOLT', (@101)                  ' Set 101 for DCV.
VOLT:RANG 10, (@101)                 ' Set 101 for 10V range.
VOLT:DIG 4.5, (@101)                 ' Set 101 for 4½ digit resolution.
VOLT:NPLC 3, (@101)                  ' Set 101 rate for 3 PLC.
```

NOTE *In the above command sequence, channel 101 is first set for DCV before sending the other commands to set range, digits, and rate. If channel 101 was instead set to a different function (i.e., RESistance), the VOLT commands to set range, digits, and rate would generate error +700 (Invalid function in scanlist).*

Buffer

For front panel scanning, the reading count specifies the number of readings to store in the buffer. For remote scanning, the sample count specifies the number of readings to store in the buffer.

Readings stored in the buffer by the TRAC command (or by front panel data store operation) must be cleared before sending INITiate or READ? to take the instrument out of idle. The following command clears the buffer:

```
TRACe:CLEar                          ' Clear buffer.
```

Scanning commands

Scanning commands are listed in Table 7-1. Additional information on these commands follow the table.

NOTE *Query commands and optional command words are not included in Table 7-1. The unabridged SCPI tables are provided in Section 15.*

Table 7-1
Scanning commands

Commands	Description	Default	Ref
Scan commands			
ROUTe:SCAN <clist>	Specify list of channels to be scanned.		a
ROUTe:SCAN?	Returns list of channels to be scanned.		
ROUTe:SCAN:TSOurce <list>	Select trigger(s) to start scan; <list> = IMMediate or HLIMit1, LLIMit1, HLIMit2, LLIMit2.	IMM	b
ROUTe:SCAN:NVOLatile <b>	Enable or disable auto scan; <b> = ON or OFF.	(Note 1)	
ROUTe:SCAN:LSELect <name>	Enable/disable scan; <name> = INTernal (on) or NONE (off).	NONE	
ROUTe:MONitor <clist>	Specify one channel to be monitored.		c
ROUTe:MONitor:POINts <NRf>	Specify number of channels to scan; <NRf> = 2 to 450000.	(Note 3)	d
ROUTe:MONitor:STATe <b>	Enable/disable monitor; <b> = ON or OFF.	OFF	
ROUTe:MONitor:DATA?	Returns the most recent monitor reading.		
ROUTe:CLOSe:ACONfigure <b>	Enable or disable auto channel configuration.		
Limits commands			
CALCulate3:LIMit1:UPPer <n>	Set high limit 1 for monitor; <n> = -4294967295 to +4294967295.	1.0	
CALCulate3:LIMit1:LOWer <n>	Set low limit 1 for monitor; <n> = -4294967295 to +4294967295.	-1.0	
CALCulate3:LIMit2:UPPer <n>	Set high limit 2 for monitor; <n> = -4294967295 to +4294967295.	2.0	
CALCulate3:LIMit2:LOWer <n>	Set low limit 2 for monitor; <n> = -4294967295 to +4294967295.	-2.0	
CALCulate3:LIMit1:STATe <b>	Enable/disable limit 1 test; <b> = ON or OFF.	OFF	
CALCulate3:LIMit2:STATe <b>	Enable/disable limit 2 test; <b> = ON or OFF.	OFF	
Trigger commands			
TRIGger:SOURce <name>	Select control source; <name> = IMMediate, TIMer, MANual, BUS, or EXTernal.	IMM	
TRIGger:TIMer <n>	Set timer interval in sec; <n> = 0.001 to 999999.999.	0.1	
TRIGger:COUNt <NRf>	Set trigger count; <NRf> = 1 to 450000 or INFinity.	(Note 2)	e
TRIGger:DELay <n>	Set delay in sec; <n> = 0 to 999999.999.	0	
TRIGger:DELay:AUTO <b>	Enable/disable auto delay; <b> = ON or OFF.	ON	
SAMPle:COUNt <NRf>	Set sample count; <NRf> = 1 to 450000.	1	e
SAMPle:COUNt?	Query sample count.		
INITiate:CONTinuous <b>	Enable/disable continuous initiation; <b> = ON or OFF.		f
INITiate	Initiate one scan cycle.		f
READ?	Initiate one scan cycle and request sample readings.		f

Table 7-1 (continued)
Scanning commands

Commands	Description	Default	Ref
Buffer commands			
TRACe:DATA?	Read buffer readings.		
TRACe:CLEar	Clear buffer.		
Channel list parameter: <clist> = (@SCH) where: S = Mainframe slot number (1 or 2) CH = Switching module channel number (must be 2 digits) Examples: (@101) = Slot 1, Channel 1 (@101, 203) = Slot 1, Channel 1 and Slot 2, Channel 3 (@101:110) = Slot 1, Channels 1 through 10			

Notes:
1. Not affected by *RST and SYSTem:PRESet. Front panel factory default is OFF.
2. *RST sets count to 1, and SYSTem:PRESet sets count to INFinity.
3. The default value depends on which switching module is installed.

Reference

a. ROUTe:SCAN <clist> — Channels will be scanned in the order that they are listed. The following example shows the proper format for specifying channels in a scan list for a sequential scan:

```
ROUT:SCAN (@101:110,201,204,206)
```

For the above scan list, the scan will run starting with the lowest numbered channel (101) and then sequence up (forward) to the highest numbered channel (206).

Remote programming can also be used to run non-sequential scans. Any scan list configured to scan backward is considered a non-sequential scan. The following examples configure non-sequential scan lists:

```
Example 1) ROUT:SCAN (@101:105,103,106:110)
Example 2) ROUT:SCAN (@110:101)
```

Example 1 — The scan starts with channel 101 and proceeds to channel 105. After channel 105 is scanned, the unit backs up to scan channel 103, then proceeds forward to scan channels 106 through 110.

Example 2 — The scan starts with channel 110 then proceeds backward to channel 101.

NOTE *Non-sequential scanning is only intended to be performed using remote programming. Unexpected results may occur if a non-sequential scan is run from the front panel.*

There must be at least two channels in the scan list. Creating a scan list that has only one channel will generate error -221 (settings conflict).

Effects of function changes on the scan list

NOTE *To avoid unexpected problems with scans (as explained after this note), it is recommended that the scan list (ROUT:SCAN) be created AFTER scan channel functions are selected (SENS:FUNC).*

Changing from a 2-wire function to a 4-wire function will change the scan list. This is demonstrated as follows:

The following commands show the proper sequence to configure a simple 20-channel DCV scan using a Model 7700 installed in slot 1:

```
SENS:FUNC 'VOLT',(@101:120)         ' Set channels for DCV.
ROUT:SCAN (@101:120)                ' Specify scan list.
```

When the scan is changed to a 4-wire function, the scan list will change. For example, assume the above scan is changed to the Ω4 function as follows:

```
SENS:FUNC 'FRES',(@101:110)
```

For the 4-wire resistance function, channels 101 through 110 will be paired to channels 111 through 120. ROUT:SCAN? returns the following scan list:

```
(@101:110)
```

Now assume the scan is returned to DCV function as follows:

```
SENS:FUNC 'VOLT',(@101:120)
```

The above command sets channels 101 through 120 for DCV. However, it will NOT affect the scan list. ROUT:SCAN? still returns a 10 channel scan list:

```
(@101:110)
```

The following command will set the scan list for 20 channels:

```
ROUT:SCAN (@101:120)
```

b. ROUTe:SCAN:TSOurce <list>

<list> = IMMediate
= HLIMit1, HLIMit2, LLIMit1, LLIMit2

As with front panel operation, the scan can start immediately when it is enabled and triggered, OR it can be started by a reached reading limit detected by the monitor channel. For immediate, the IMMediate command must be the only parameter in the list. To use reading limits, each limit must be separated by a comma (,).

Examples:

```
ROUT:SCAN:TSO IMM           ' Start scan when it is enabled and
                              triggered.
ROUT:SCAN:TSO HLIM1,LLIM1   ' Enable high limits 1 and low limits 1.
```

Note that any reached limit will start the scan.

c. ROUTe:MONitor <clist> — The channel that you specify as the monitor must be a channel that is in the scan list. If it is not, the first channel in the scan list will automatically become the monitor channel.

   If the <clist> has more than one channel, error -223 (too much data) occurs and the command is not executed.

d. ROUTe:MONitor:POINts — Use this command to specify the number of channels to scan each time the monitor scan is triggered to start. For example, assume the monitor scan list has 10 channels. To scan that list once, send ROUT:MON:POIN 10. To scan that list twice, use parameter value 20. For three scans, send parameter value 30 and so on.

e. SAMPle:COUNt and TRIGger:COUNt — Sample count specifies the number of readings to scan and store in the buffer, while the trigger count specifies the number of scans to perform.

   If the sample count is greater than the number of channels in the scan list (scan list length), operation wraps around to the beginning of the scan list and continues. For example, assume the scan list is made up of channels 101, 102, and 103, and the sample count is set to 4. After channels 101, 102, and 103 are scanned, operation loops around to scan channel 101 again. The first and last readings in the buffer will be channel 101.

   When performing multiple scans (trigger count >1), sample readings overwrite the readings stored for the previous scan.

   Continuous initiation must be disabled in order to set the sample counter >1 (see Reference c).

f. INITiate:CONTinuous, INITiate and READ? — In order to initiate a single scan cycle using INITiate or READ?, continuous initiation must be disabled. If you send INIT or READ? with continuous initiation enabled, error -213 (Init ignored) will occur.

   You cannot use READ? or INITiate if sample count >1 AND there are readings stored in the buffer by the TRAC command or by front panel data store operation (error -225, out of memory). Either set the sample count to one or clear the buffer (TRACe:CLEar).

Scanning programming example

The following program will scan 10 channels (101 through 110):

NOTE The following example can be run from the KE2700 Instrument Driver using the example named "ScanChan" in Table G-1 of Appendix G.

```
TRAC:CLE                        ' Clear buffer.
INIT:CONT OFF                   ' Disable continuous initiation.
TRIG:SOUR IMM                   ' Select the immediate control source.
TRIG:COUN 1                     ' Set to perform one scan.
SAMP:COUN 10                    ' Set to scan 10 channels.
ROUT:SCAN (@101:110)            ' Set scan list channels; 101 through 110.
ROUT:SCAN:TSO IMM               ' Start scan when enabled and triggered.
ROUT:SCAN:LSEL INT              ' Enable scan.
READ?                           ' Trigger scan and request the readings.
```

Scanning examples

The following scanning examples assume that the Model 7700 switching module is installed in slot 1 of the mainframe.

Tables are used for the procedure steps to configure and run scan examples. The left side of the table provides the front panel procedure, while the right side shows the equivalent remote programming commands. Where appropriate, menu sequences are provided to summarize a front panel operation or selection. For example:

SHIFT SETUP > RESTORE: FACT

For the above menu sequence, press SHIFT and then SETUP to access the menu. Use the edit keys (◄ , ► , ▲ , and ▼) to display RESTORE: FACT and then press ENTER to select it.

External trigger scan

For this example, an external instrument is used to trigger the start of the 2-channel scan. Trigger pulse requirements and trigger cable connections are covered in Section 8.

NOTE For this example, the front panel TRIG key can be used in place of an external input trigger. Each time the TRIG key is pressed, the 2-channel scan will run.

One channel (101) measures temperature and the other channel (102) measures resistance. The two readings are stored in the buffer. Each time the scan is run, the two readings will be appended (added) to the buffer.

A type K thermocouple is used to measure temperature. Since the internal cold (reference) junction of the Model 7700 is being used, the thermocouple can be connected directly to the screw terminals of the switching module.

Operation

A simplified model of external trigger scan operation is shown in Figure 7-4, while the procedure steps and programming commands are listed in Table 7-2.

As shown in the operation model, when the scan is enabled, channel 101 closes and the Model 2701 waits for an external trigger. When the trigger is received, channels 101 and 102 are measured. Operation then returns to the control source where it waits for another trigger.

NOTE *After the scan is enabled (Table 7-2, step 5), the TRIG key can be used to trigger the scan.*

Figure 7-4
External trigger scan example

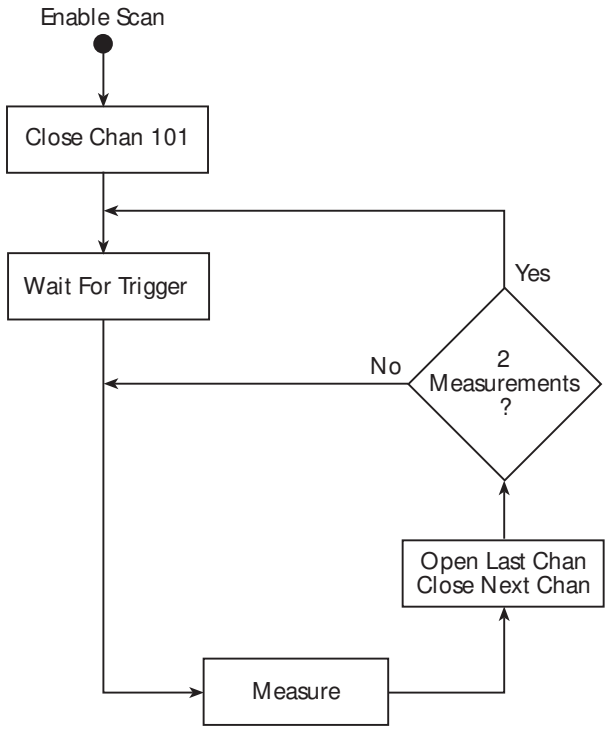


Table 7-2
External trigger scan example

	Front panel operation	Remote programming
1	Restore defaults:	
	Restore defaults (SHIFT SETUP > RESTORE: FACT).	`*RST`
2	For front panel operation, proceed to step 3.	
	For remote programming, clear buffer and disable	`TRAC:CLE`
	buffer auto clear:	`TRAC:CLE:AUTO OFF`
3	Configure advanced scan:	
	(SHIFT CONFIG > ADVANCED):	
a	Channel 101:	
	Select TEMP function.	`FUNC 'TEMP',(@101)`
	Configure temperature (SHIFT SENSOR):	
	Select thermocouple sensor (SENS: TCOUPLE).	`TEMP:TRAN TC,(@101)`
	Select type K thermocouple (TYPE: K).	`TEMP:TC:TYPE K,(@101)`
	Select internal reference junction (JUNC: INT).	`TEMP:RJUN:RSEL INT,(@101)`
b	Channel 102:	
	Select Ω2 function.	`FUNC 'RES',(@102)`
	Select 1MΩ range.	`RES:RANG 1e6,(@102)`
c	Disable (off) channels 103 through 122 (SHIFT CH-OFF).	`ROUT:SCAN (@101,102)`
d	Enable immediate scan (IMM SCAN: Y).	`ROUT:SCAN:TSO IMM`
e	Disable timer (TIMER? NO).	
f	Set reading count to infinity (RDG CNT: INF).	`TRIG:COUN INF`
		`SAMP:COUN 2`
4	Select external trigger control source:	
	Press EX TRIG.	`TRIG:SOUR EXT`
5	Enable scan:	
	Press SCAN.	`ROUT:SCAN:LSEL INT`
		`INIT`

Monitor scan

For this example, channel 101 of the Model 7700 is used to monitor temperature. When the temperature reading reaches 30°C, it will start the scan. For this 4-channel scan, channel 101 measures temperature, while channels 102, 103, and 104 measure DCV.

This example uses the channel average feature to measure temperature. With channel average enabled, two temperature measurements will be taken; one at channel 101 and another at its paired channel (111). The two measured readings are then averaged to yield a single reading. It is this averaged temperature reading that will start the scan when it reaches 30°C. Refer to Section 5 for details on channel average.

Two type K thermocouples are used to measure temperature. Since the internal cold (reference) junction of the Model 7700 is being used, the thermocouples can be connected directly to the screw terminals of the switching module.

Operation

A simplified model of monitor scan operation is shown in Figure 7-5, while the procedure steps and programming commands are listed in Table 7-3.

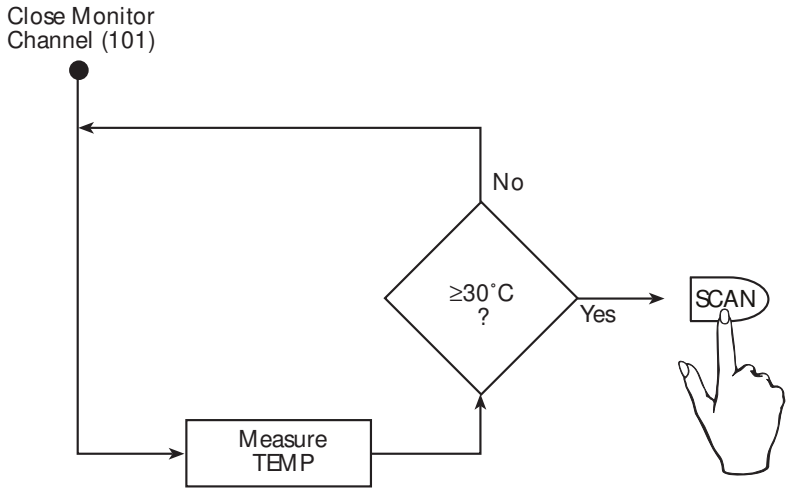
In Figure 7-5, notice that there are two modes of operation. While in the monitor mode, the Model 2701 continuously performs temperature measurements. Keep in mind that channel average is being used. Therefore each temperature reading is the average of two temperature measurements (one on channel 101 and one on channel 111). As long as the average temperature reading remains below 30°C, the instrument will remain in the monitor mode.

When the temperature reading reaches 30°C, the Model 2701 switches over to the scan mode. Figuratively speaking, it is as if a "finger" presses the SCAN key when the monitor detects that the average temperature is at or above 30°C.

The instrument is configured to scan four channels. The monitor TEMP channel reading and three DCV channel readings are stored in the buffer. After the fourth channel is measured, operation returns to the monitor mode to again measure temperature. Note that if the average temperature is still at or above 30°C, the "finger" will again press SCAN to start the scan.

Figure 7-5
Monitor scan example

Monitor Mode:



Scan Mode:

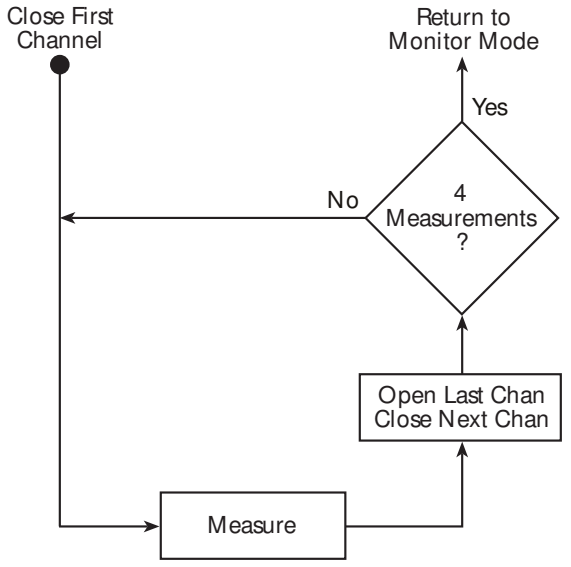


Table 7-3
Monitor scan example

	Front panel operation	Remote programming
1	Restore defaults (SHIFT SETUP > RESTORE: FACT).	`SYST:PRES`
2	For front panel operation, proceed to step 3. For remote programming, clear the buffer:	 `TRAC:CLE`
3	Configure advanced scan: SHIFT CONFIG > ADVANCED:	
a	Channel 101:	
	Select TEMP function.	`FUNC 'TEMP',(@101)`
	Configure temperature (SHIFT SENSOR):	
	Select Thermocouple sensor (SENS: TCOUPLE).	`TEMP:TRAN TC,(@101)`
	Select type K thermocouple (TYPE: K).	`TEMP:TC:TYPE K,(@101)`
	Select internal reference junction (JUNC: INT).	`TEMP:RJUN:RSEL INT,(@101)`
b	Set and enable high limit 1:	
	Set limit to 30 (SHIFT LIMITS > HI1:+30.00000).	`CALC3:LIM1:UPP 30,(@101)`
	Enable (on) limit (SHIFT OFF/ON > LIMITS: ON).	`CALC3:LIM1:STAT ON,(@101)`
	Close channel 101.	`ROUT:CLOS (@101)`
	Enable Channel Average (SHIFT CH AVG).	`CAV ON,(@101)`
c	Channel 102, 103, and 104:	
	Select DCV function.	`FUNC 'VOLT',(@102:104)`
	Select 10V range.	`VOLT:RANG 10,(@102:104)`
	Set filter count to 20 (SHIFT TYPE > 020 RDGS).	`VOLT:AVER:COUN 20,(@102:104)`
	Enable filter (FILTER).	`VOLT:AVER:STAT ON,(@102:104)`
d	Disable (off) channels 105 through 222 (SHIFT CH OFF).	`ROUT:SCAN (@101:104)`
e	Disable immediate scan (IMM SCAN: N) and enable high limit 1 (HLIM1 SCAN:Y).	`ROUT:SCAN:TSO HLIM1`
f	Disable timer (TIMER? NO).	
g	Set reading count to 4.	`ROUT:MON:POIN 4`
4	Select and enable monitor channel (SHIFT MONITOR >101).	`ROUT:MON (@101)` `ROUT:MON:STAT ON`

8
Triggering

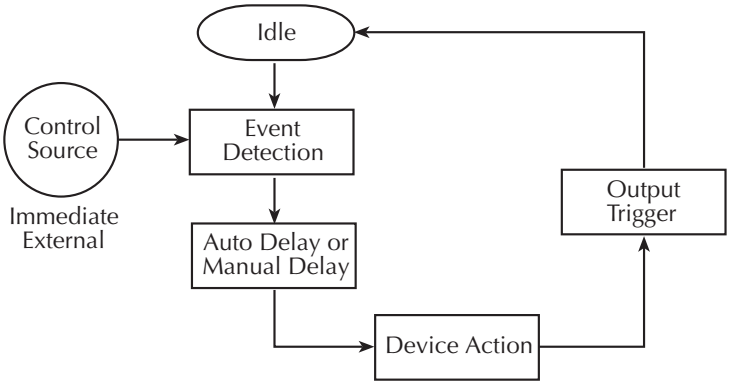
- **Trigger model** — Explains the various components of the front panel trigger model, which controls the triggering operations of the instrument.
- **Reading hold** — Explains the Reading Hold feature which is used to screen out readings that are not within a specified reading window.
- **External triggering** — Explains external triggering which allows the Model 2701 to trigger and be triggered by other instruments.
- **Remote programming – triggering** — Covers remote operation for triggering including the trigger model and the commands.

Trigger model

The flow chart in Figure 8-1 summarizes triggering as viewed from the front panel. It is called a trigger model because it is modeled after the SCPI commands used to control triggering.

NOTE *For scanning, the trigger model has additional control blocks, such as a Timer. These are described in Section 7 (Figure 7-1 and Figure 7-2). The complete trigger model, which is based on bus operation, is shown and discussed in "Remote programming – triggering," page 8-16.*

Figure 8-1
Front panel trigger model (without scanning)



Idle

When not scanning and in the continuous trigger mode (factory default setup), the instrument will not stay in idle. Operation will continuously fall through the idle state and proceed to the Event Detection block of the trigger model. When in the one-shot trigger mode (*RST default setup), the TRIG key must be pressed to take the instrument out of idle. After each measurement, the instrument returns to idle and requires the TRIG key to be pressed to continue. The FACT (factory) default setup or *RST default setup is selected from the SHIFT > SETUP menu (see "Defaults and user setups," page 1-21).

When scanning, the unit is considered idle at the end of a scan operation when the reading for the last channel remains displayed. To restore triggers, press SHIFT and then HALT. See Section 7 for details on scanning.

Control source and event detection

The control source holds up operation until the programmed event occurs and is detected. The control sources are described as follows:

- **Immediate** — With this control source, event detection is immediately satisfied allowing operation to continue.
- **External** — Event detection is satisfied for any of the following three conditions:
  - An input trigger via the Trigger Link line EXT TRIG is received.
  - The front panel TRIG key is pressed. (The Model 2701 must be taken out of remote before it will respond to the TRIG key. Use the LOCAL key or send SYSTem:LOCal over the Ethernet or RS-232.)
  - Trigger command (*TRG) is received over the Ethernet or RS-232.

Delay (auto or manual)

A programmable delay is available after event detection. It can be set manually or an auto delay can be used. With auto delay selected, the instrument automatically selects a delay period that will provide sufficient settling for function changes, autorange changes, and multi-phase measurements.

Normal measurement state — With auto delay selected and the External or Bus control source selected, the Model 2701 selects a delay based on the selected voltage range. The auto delay period cannot be adjusted by the user. The auto delays are listed in Table 8-1. With one of the other control sources selected, the auto delay is 0.000s for all functions and ranges.

Scanning — When scanning, the nominal delay will be long enough to allow each switching module channel relay to settle before making the measurement. When scanning, the auto delay times in Table 8-1 are valid for all control sources.

Table 8-1
Auto delay settings

Function	Range and delay						
DCV	100mV 1ms	1V 1ms	10V 1ms	100V 5ms	1000V 5ms		
ACV	100mV 25ms	1V 25ms	10V 25ms	100V 25ms	750V 25ms		
FREQ and PERIOD	100mV 1ms	1V 1ms	10V 1ms	100V 1ms	750V 1ms		
DCI	20mA 2ms	100mA 2ms	1A 2ms	3A 2ms			
ACI			1A 400ms	3A 400ms			
Ω2, Ω4	100Ω 3ms	1kΩ 3ms	10kΩ 13ms	100kΩ 25ms	1MΩ 100ms	10MΩ 150ms	100MΩ 250ms
Continuity		1kΩ 3ms					
TEMP	The auto delay for thermocouples is 1ms. For thermistors and 4-wire RTDs, the auto delay period is the same as the delay for the resistance range that is used for the measurement.						

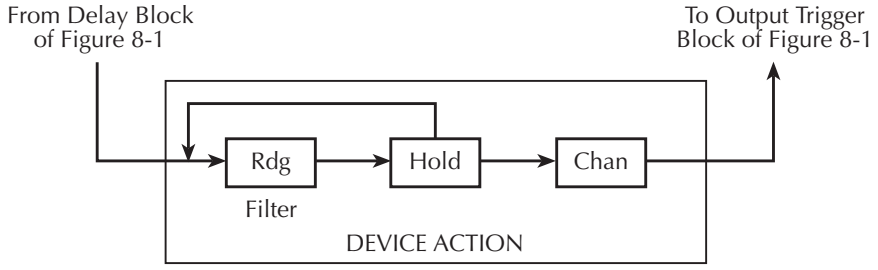
The delay function is accessed by pressing SHIFT and then DELAY. The present delay setting (AUTO or MANual) is displayed. Press the ▲ or ▼ key to display the desired setting and press ENTER.

If MANual is chosen, also enter the duration of the delay in the hour/minute/second format using the ◀, ▶, ▲, and ▼ keys. The maximum is 99H:99M:99.999S:. Note that pressing the AUTO key sets the delay to 0.001 sec. Press ENTER to accept the delay or EXIT for no change.

Device action

The primary device action is a measurement. However, the device action block could include the following additional actions (Figure 8-2):

Figure 8-2
Device action



- **Filtering** — If the repeating filter is enabled, the instrument samples the specified number of reading conversions to yield single, filtered reading. Only one reading conversion is performed if the filter is disabled or after the specified number of reading conversions for a moving average filter is reached. After a reading (Rdg) is procured, operation proceeds to Hold.
- **Hold** — The Hold feature is used to screen out reading anomalies. When enabled, the user selects a window and count for Hold. In general, when a reading is outside the window it is rejected, operation loops back to the beginning of the Device Action as shown in Figure 8-2. The hold count specifies how many readings have to be within the window before it is accepted. See "Reading hold (autosettle)," page 8-6, for operation details. After a Hold Reading is acquired, operation proceeds to Channel Closure.
- **Channel Closure** — When scanning, the last device action is channel control. Using the hold feature provides an auto settling time for switching relays. Each open/close transition will restart the hold process and a reading for each channel will not occur until the relay settles.

Output trigger

After the device action, an output trigger occurs and is available at the rear panel Trigger Link connector. This trigger can be used to trigger another instrument to perform an operation (e.g., select the next channel for an external scan).

Reading hold (autosettle)

With hold enabled (HOLD annunciator on), the first processed reading becomes the "seed" reading and operation loops back within the device action block. After the next reading is processed, it is checked to see if it is within the selected hold window (0.01%, 0.1%, 1%, or 10%) of the "seed" reading. If the reading is within the window, operation again loops back within the device action block. This looping continues until the specified number (2 to 100) of consecutive readings are within the window. If one of the readings is not within the window, the instrument acquires a new "seed" reading and the hold process continues.

When a hold reading is acquired, an audible beep is sounded (if enabled) and the reading is considered a "true measurement." The reading is held on the display until an "out of window" reading occurs to restart the hold process.

For remote operation, the hold process seeks a new "seed" once it has been satisfied and the reading has been released. For basic front panel operation, the hold process does not seek a new "seed" until the held condition is removed.

NOTE *Hold cannot be used when scanning.*

Hold example

1. Press SHIFT and then HOLD to display the present window (0.01%, 0.1%, 1%, or 10%).
2. To change the window, press the ▲ or ▼ key to display the desired window.
3. Press ENTER. The present hold count is displayed (2 to 100).
4. To change the hold count, use the ◀, ▶, ▲, and ▼ keys to display the desired count.
5. Press DCV to measure DC voltage.
6. Apply the test signal to the input of the Model 2701. Once the signal becomes stable enough to satisfy the hold condition, the reading is released and the beeper sounds (if enabled).
7. Remove the hold condition by disconnecting the signal from the input. Hold will then seek a new "seed."
8. To disable HOLD, press SHIFT and then HOLD.

Beeper control

The beeper for Hold can be enabled or disabled from the OUTPUT menu as follows:

1. Press SHIFT and then OUTPUT.
2. Use the ▲ or ▼ key to display the present beeper (BEEP) state: NEVER, OUTSIDE, or INSIDE.
3. Perform step a or b:
   a. To enable the beeper, use the ▲ or ▼ key to display OUTSIDE or INSIDE.
   b. To disable the beeper, use the ▲ or ▼ key to display NEVER.
4. Press ENTER. The instrument returns to the normal display state. The instrument returns to the normal measurement state.

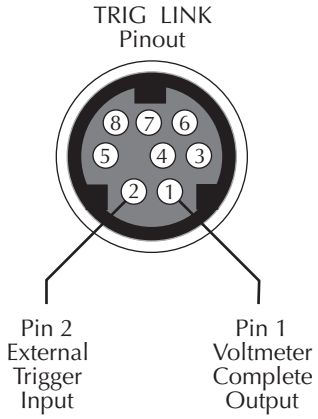
External triggering

The EX TRIG key selects triggering from three external sources: trigger link, digital I/O, and the TRIG key. When EX TRIG is pressed, the TRIG annunciator lights and dashes are displayed to indicate the instrument is waiting for an external trigger. From the front panel, press the TRIG key to trigger a single reading. Pressing the EX TRIG key again toggles back to continuous triggers.

The Model 2701 uses two lines of the TRIG LINK rear panel connector as External Trigger (EXT TRIG) input and Voltmeter Complete (VMC) output. The EXT TRIG line allows the Model 2701 to be triggered by other instruments. The VMC line allows the Model 2701 to trigger other instruments.

Line 1 is configured as VMC and line 2 as EXT TRIG. The connector pinout is shown in Figure 8-3.

Figure 8-3
TRIG LINK pinout



Pin Number	Description
1	Voltmeter Complete Output
2	External Trigger Input
3	No Connection
4	No Connection
5	No Connection
6	No Connection
7	Signal Ground
8	Signal Ground

Digital I/O

Pin 6 (Ext Trig) of the Digital I/O can also be used as the external trigger input for the Model 2701. Line 2 of the TRIG LINK is physically connected to pin 6 of the Digital I/O connector.

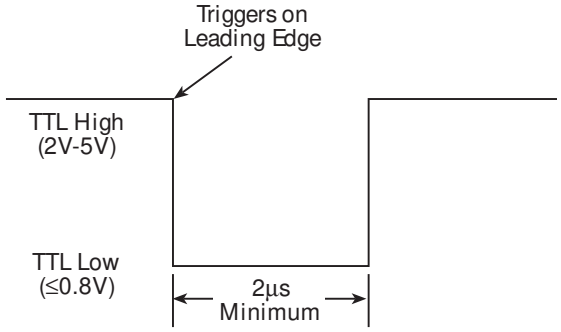
The Digital I/O has a hardware interlock line (pin 8) that allows the use of an external circuit to control input triggers. When that line is left open or pulled high (+5V), input triggers are enabled. When pulled low to 0V, input triggers are disabled. When disabled, the Model 2701 will not respond to an input trigger.

Details on the Digital I/O are provided in Section 9.

External trigger

The EXT TRIG input requires a falling-edge, TTL-compatible pulse with the specifications shown in Figure 8-4. In general, external triggers can be used to control measure operations. For the Model 2701 to respond to external triggers, the trigger model must be configured for it.

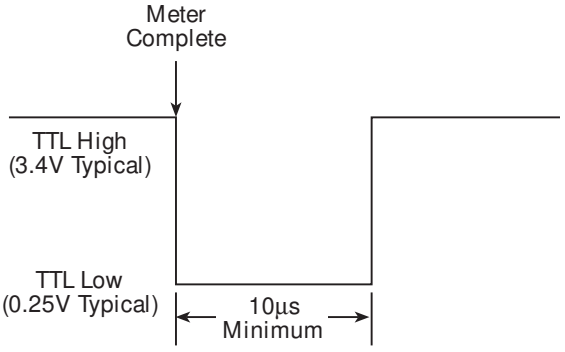
Figure 8-4
Trigger link input pulse specifications (EXT TRIG)



Voltmeter complete

The VMC output provides a TTL-compatible output pulse that can be used to trigger other instruments. The specifications for this trigger pulse are shown in Figure 8-5. Typically, you would want the Model 2701 to output a trigger after the settling time of each measurement.

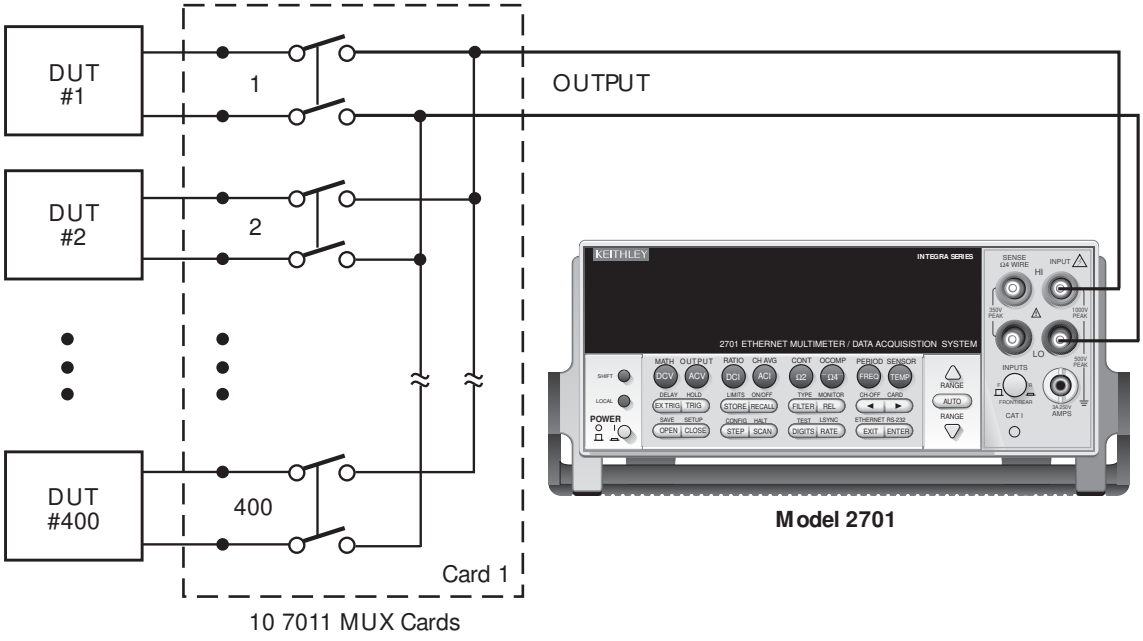
Figure 8-5
Trigger link output pulse specifications (VMC)



External triggering example

For a test system that requires a large number of switching channels, the Model 2701 can be used with external scanners such as the Keithley Models 7001 and 7002. For example, 10 Model 7011s installed in the Model 7002 can provide up to 400 2-pole channels, as shown in Figure 8-6.

Figure 8-6
DUT test system



The Trigger Link connections for this test system are shown in Figure 8-7. Trigger Link of the Model 2701 is connected to Trigger Link (either IN or OUT) of the Model 7002. Note that with the default trigger settings on the Model 7002, line #1 is an input and line #2 is an output. This complements the trigger lines on the Model 2701.

For this example, the Models 2701 and 7002 are configured as follows:

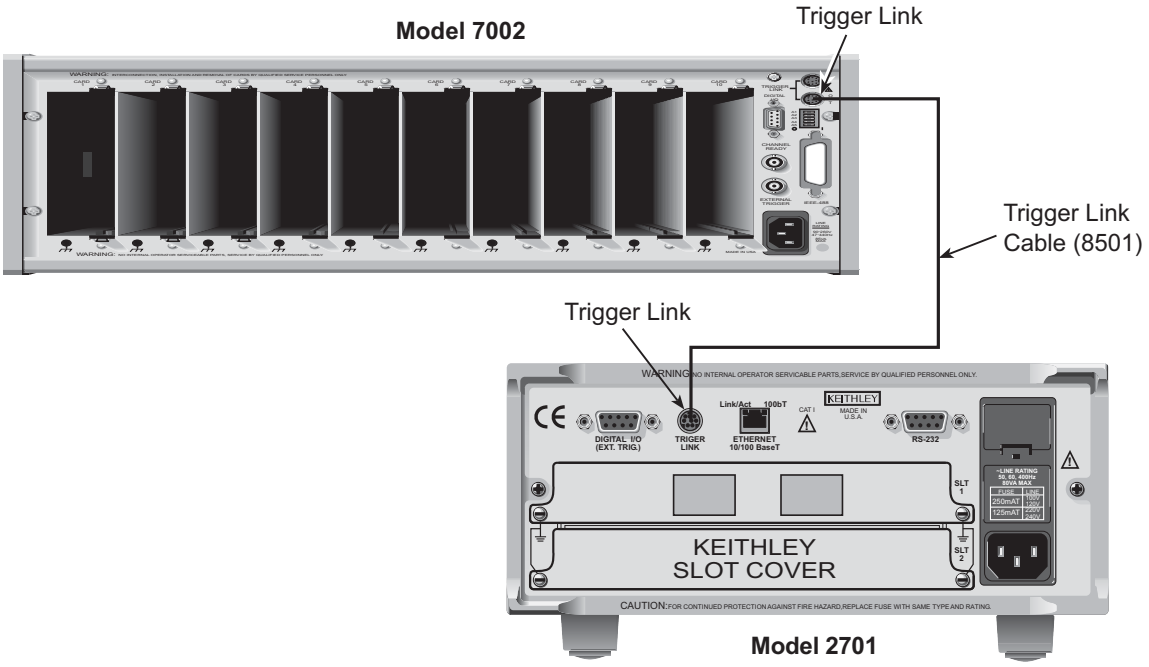
Model 2701

Factory defaults restored (accessed from SHIFT-SETUP)
External triggers (accessed from EX TRIG)
Buffer enabled and set to store 400 readings

Model 7002

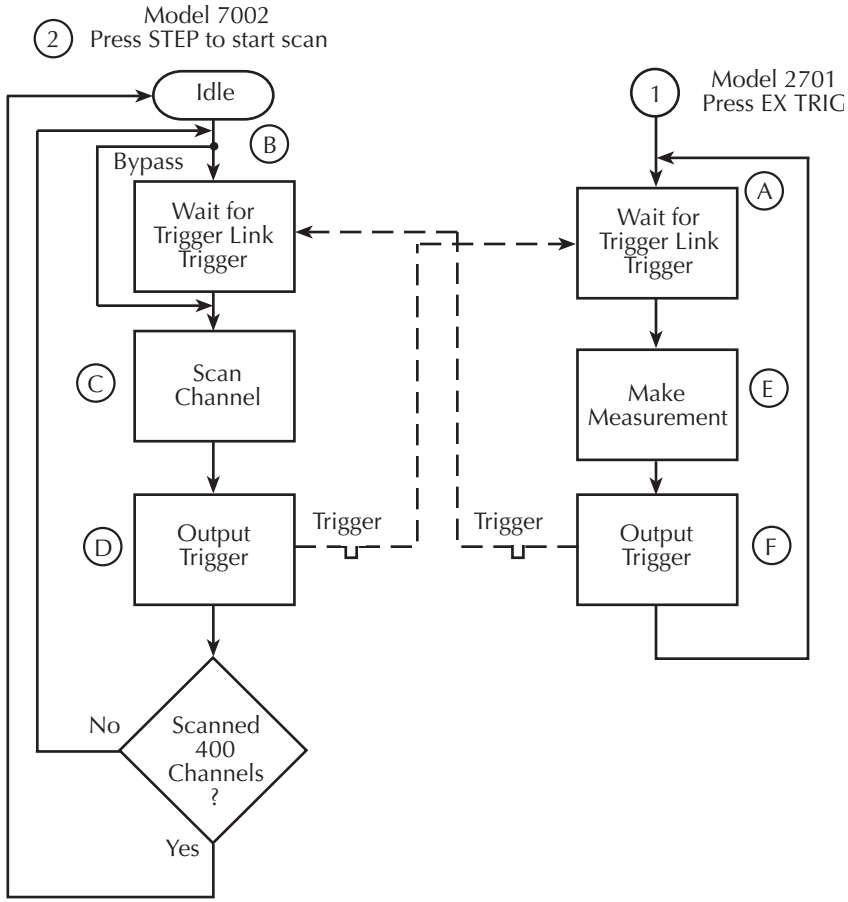
Factory defaults restored
Scan list = 1!1-1!400
Number of scans = 1
Channel spacing = TrigLink

Figure 8-7
Trigger link connections



1. Press EX TRIG to place the Model 2701 in the external trigger mode.
2. Press STEP on the Model 7002 to take it out of idle and start the scan. The scanner's output pulse triggers the Model 2701 to take a reading, store it, and send a trigger pulse. The following explanation on operation is referenced to the operation model shown in Figure 8-8.

Figure 8-8
Operation model for triggering example



A. Pressing EX TRIG on the Model 2701 places it at point A in the flowchart, where it is waiting for an external trigger.

B. Pressing STEP on the Model 7002 takes it out of the idle state and places operation at point B in the flow chart.

C. For the first pass through the model, the scanner does not wait at point B for a trigger. Instead, it closes the first channel.

D. After the relay settles, the Model 7002 outputs a Channel Ready pulse. Since the instrument is programmed to scan 400 channels, operation loops back up to point B, where it waits for an input trigger.

E & F. Model 2701 operation is at point A waiting for a trigger. The output Channel Ready pulse from the Model 7002 triggers the Model 2701 to measure DUT #1 (point E). After the measurement is complete, the Model 2701 outputs a completion pulse (point F) and then loops back to point A where it waits for another input trigger.

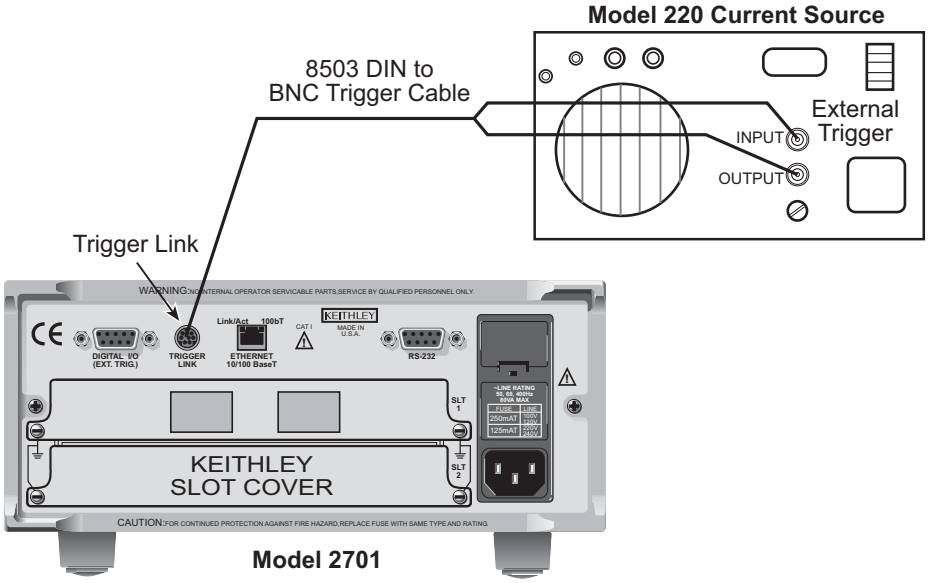
The trigger applied to the Model 7002 from the Model 2701 closes the next channel in the scan. This triggers the Model 2701 to measure the next DUT. The process continues until all 400 channels are scanned, measured, and stored in the buffer.

External triggering with BNC connections

An adapter cable is available to connect the micro-DIN Trigger Link of the Model 2701 to instruments with BNC trigger connections. The Model 8503 DIN to BNC Trigger Cable has a micro-DIN connector at one end and two BNC connectors at the other end. The BNC cables are labeled VMC (trigger line 1) and EXT TRIG (trigger line 2).

Figure 8-9 shows how a Keithley Model 220 Current Source can be connected to the Trigger Link of the Model 2701 using the adapter cable. When used with the STEP mode of the Model 220, you can perform synchronized source-measure operations without the use of a computer. Whenever the Model 220 receives a trigger from the Model 2701, it will step to the next current source value.

Figure 8-9
DIN to BNC trigger cable



Remote programming – triggering

Trigger model (remote operation)

The following paragraphs describe how the Model 2701 operates for remote operation. The flow chart in Figure 8-10 summarizes operation over the bus. The flow chart is called the trigger model because operation is controlled by SCPI commands from the Trigger subsystem. Key SCPI commands are included in the trigger model.

Idle and initiate

The instrument is considered to be in the idle state whenever operation is at the top of the trigger model. As shown in Figure 8-10, initiation needs to be satisfied to take the instrument out of idle. While in the idle state, the instrument cannot perform any measure or step/scan operations.

The following commands will return operation to the top of the trigger model (idle) at the START point of the trigger model:

- ABORt
- *RCL 0, 1, 2, or 3
- SYSTem:PREset
- *RST

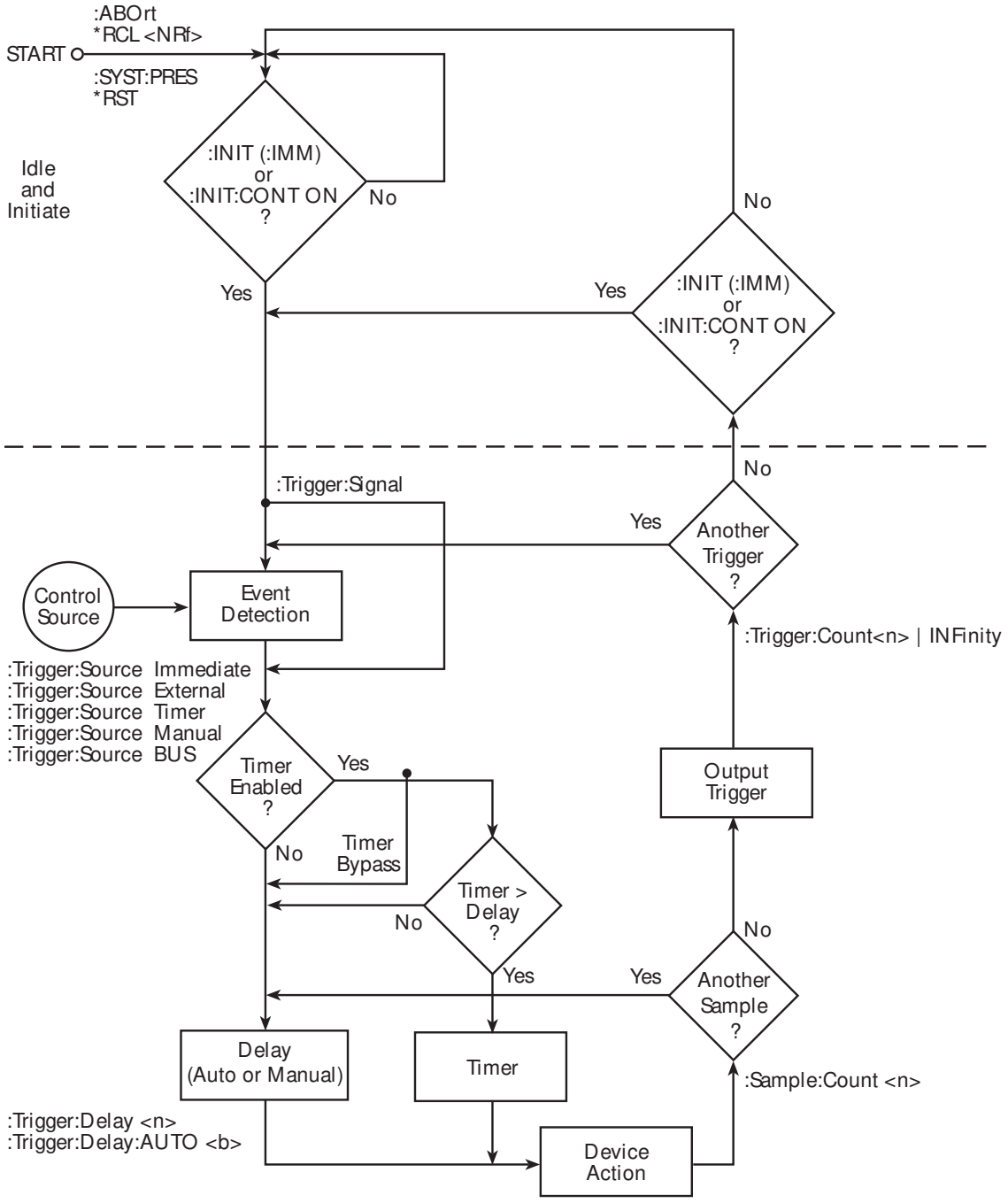
What happens next depends on the state of initiation. If continuous initiation is already enabled, the instrument will leave the idle state. SYSTem:PRESet enables continuous initiation. Therefore, operation will immediately leave the idle state when it is sent. The *RCL command will do the same if INITiation:CONTinuous ON is a user-saved default. *RST disables continuous initiation. Therefore, the instrument will remain in the idle state.

Either of the following two initiate commands will take the instrument out of the idle state:

- INITiate
- INITiate:CONTinuous ON

NOTE *While in remote, pressing the LOCAL key restores continuous front panel operation.*

Figure 8-10
Trigger model (remote operation)



Trigger model operation

Once the instrument is taken out of idle, operation proceeds through the trigger model down to the device action. In general, the device action includes a measurement and, when scanning, closes the next channel.

Control Source — As shown in Figure 8-10, a control source is used to hold up operation until the programmed event occurs. The control source options are as follows:

- **IMMediate** — Event detection is immediately satisfied allowing operation to continue.
- **MANual** — Event detection is satisfied by pressing the TRIG key. The Model 2701 must be in LOCAL mode for it to respond to the TRIG key. Press the LOCAL key or send SYSTem:LOCal via the Ethernet or RS-232 to remove the instrument from the remote mode.
- **TIMer** — With the timer source enabled (selected), event detection is immediately satisfied. On the initial pass through the loop, the Timer Bypass is enabled allowing operation to bypass the Timer and continue on to the Delay block.

On each subsequent pass through the loop, the Timer Bypass is disabled. Operation is then delayed by the Timer or the Delay. If the user-set Timer interval is larger than the user-set Delay, the Timer will control the length of the delay. Otherwise, the length of the delay is controlled by the user-set Delay period.

The Timer interval can be set from 0 to 999999.999 seconds. The timer source is only available during scan operation. The timer resets to its initial state when the instrument goes into the normal mode of operation or into the idle state.

- **EXTernal** — Event detection is satisfied when an input trigger via the TRIG LINK connector is received by the Model 2701.
- **BUS** — Event detection is satisfied when a bus trigger (*TRG) is received by the Model 2701.

Delay and Device Action — These blocks of the trigger model operate the same for both front panel and remote operation. See the front panel "Trigger model," page 8-2, for operating information on these trigger model blocks. Also see "Reading hold (autosettle)," page 8-6, for details on Hold.

Counters — Programmable counters are used to repeat operations within the trigger model. For example, if performing a 10-channel scan, the sample counter would be set to 10. Operation will continue until all 10 channels are scanned and measured. If you wanted to repeat the scan three times, you would set the trigger counter to three.

For a sample count value >1, the sample readings will automatically be stored in the buffer. For example, with sample count set to 5, the five measured readings will be stored in the buffer. If the trigger model is configured to repeat the sample readings (i.e. trigger count = 2), those five new readings will overwrite the original five readings in the buffer.

Output Trigger — The Model 2701 will send one or more output triggers. The output trigger is applied to the Trigger Link connector on the rear panel. It can be used to trigger an external instrument to perform an operation.

The trigger model can be configured to output a trigger after the completion of a series of measurements or after every measurement. For example, with the sample counter set to 10 and the trigger counter set to one, a trigger will be sent after the 10 measurements are performed. If instead, the trigger counter is set to 10 and the sample counter is set to 1, a trigger will be sent after each measurement.

Triggering commands

Commands for triggering are summarized in Table 8-2.

Table 8-2
SCPI commands — triggering

Commands	Description	Default	Ref
ABORt	Reset trigger system.		a
INITiate[:IMMediate]	Initiate one trigger cycle.		b
INITiate:CONTinuous <b>	Enable/disable continuous initiation; ON or OFF.	Note 1	c
FETCh?	Request the last reading(s).		d
READ?	Perform an ABORt, INITiate, and a FETCh?		d
TRIGger:SOURce <name>	Select control source; IMMediate, TIMer, MANual, BUS, or EXTernal.	IMM	e
TRIGger:TIMer <n>	Set timer interval; 0 to 999999.999 (sec).	0.1	
TRIGger:COUNt <NRf>	Set trigger count; 1 to 450000 or INFinity.	Note 2	
TRIGger:DELay <n>	Set delay; 0 to 999999.999 (sec).	0	
TRIGger:DELay:AUTO <b>	Enable or disable auto delay.		f
TRIGger:SIGNal	Loop around control source.		g
SAMPle:COUNt <NRf>	Set sample count; 1 to 450000.	1	h
[:SENSe[1]	Optional root command for HOLD commands.		i
:HOLD:WINDow <NRf>	Set Hold window in %; <NRf> = 0.01 to 20.	1	
:HOLD:COUNt <NRf>	Set Hold count; <NRf> = 2 to 100.	5	
:HOLD:STATe <b>	Enable or disable Hold.	OFF	
:SYSTem:BEEPer:STATe <b>	Enable or disable the beeper.	ON	
*RST	Restore *RST defaults (see "Default" column of this table). Places 2701 in the idle state.		

Notes:
1. SYSTem:PRESet enables continuous initiation.*RST disables continuous initiation.
2. SYSTem:PRESet sets the trigger count to INF (infinity). *RST sets the count to 1.

Reference

a. **ABORt** — With continuous initiation disabled, the 2701 goes into the idle state. With continuous initiation enabled, operation continues at the top of the trigger model.

b. **INITiate** — Whenever the instrument is operating within the trigger model, sending this command causes an error and will be ignored.

c. **INITiate:CONTinuous <b>** — With continuous initiation enabled, you cannot use the READ? command or set sample count (SAMPle:COUNt) greater than one.

d. **FETCh?**
READ? — See Section 3, Section 13, and Appendix D for details on using these commands to trigger and retrieve readings.

NOTE *[SENSe[1]]:DATA[:LATest]? and [SENSe[1]]:DATA:FRESh? can be used to retrieve the last reading. These commands are also explained in Section 3, Section 13, and Appendix D.*

e. **TRIGger:SOURce <name>** — With the timer control source selected, use the TRIGger:TIMer command to set the interval.

f. **DELay:AUTO <b>** — The auto delay times are listed in Table 8-1. Disabling auto delay sets the delay time to 0.

g. **TRIGger:SIGNal** — Send this action command to bypass the control source when you do not wish to wait for the programmed event to occur. The instrument must be waiting at the control source for the event when this command is sent. Otherwise, an error occurs and the command is ignored.

h. **SAMPle:COUNt** — A sample count >1 specifies how many readings will automatically be stored in the buffer. However, with continuous initiation enabled, you cannot set the sample count greater than one.

i. **[SENSe[1]]:HOLD** commands — Hold cannot be set when the scanner is enabled (ROUTe:SCAN:LSEL INT). Sending a hold command will result in a settings conflict error (-221).

Programming example

The following program fragment triggers (and stores in the buffer) 10 readings:

```
*RST                              ' Restore *RST defaults.
TRAC:CLE                          ' Clear buffer.
TRIG:DEL 0.5                      ' Set delay for 0.5sec.
SAMP:COUN 10                      ' Set sample count to 10.
READ?                             ' Trigger, store, and request readings.
```

9
Limits and Digital I/O

- **Limits** — Explains how to perform limit tests on measured readings.
- **Digital I/O** — Covers the digital I/O port. Explains how the five digital outputs respond to the results of limit tests.
- **Remote programming — limits and digital output** — Summarizes the commands to perform limit tests and control the digital I/O port.
- **Application — sorting resistors** — Provides an application to test the tolerances of 100Ω resistors. Provides the digital output response to the various pass/fail combinations of the limit tests.

Limits

NOTE *Limits cannot be used with the CONT function.*

When using limits, you can set and control the values that determine the HIGH/IN/LOW status of subsequent measurements. The limit test is performed on the result of an enabled Rel, Math, Ratio, or Channel Average operation.

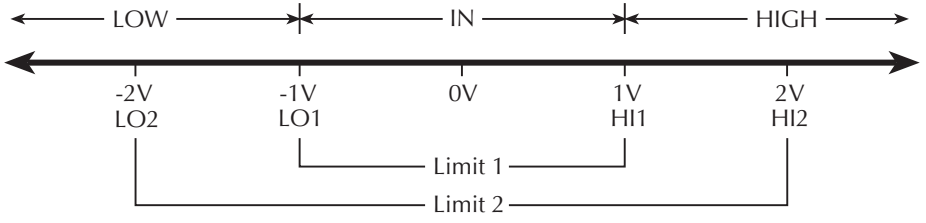
NOTE *The various instrument operations, including Limits, are performed on the input signal in a sequential manner. See "Signal processing sequence," page D-2, for details. It includes flow charts showing where in the processing sequence that Limits are tested.*

There are two sets of limits. Limit 1 uses high and low limits (HI1 and LO1), as does Limit 2 (HI2 and LO2). The HIGH/IN/LOW status indication applies to the first limit (limit 1 or limit 2) that fails. Figure 9-1 illustrates the following limits which are the factory defaults:

Limit 1: HI1 = +1V and LO1 = -1V
Limit 2: HI2 = +2V and LO2 = -2V

Keep in mind that a limit value for Limit 2 does not have to exceed the Limit 1 value. For example, Limit 2 can be set to ±1V and Limit 1 can be set to ±2V. In this case, Limit 2 will fail before Limit 1.

Figure 9-1
Default limits



When a reading is within both limits, the message "IN" will be displayed. When the reading is high or low, the HIGH or LOW annunciator turns on and the number "1" or "2" will replace the "IN" message. A "1" indicates that Limit 1 has failed, while "2" indicates that Limit 2 has failed. However, if the reading is outside both limits, the number "1" will be displayed.

For the limits shown in Figure 9-1, a reading of +1.5V is outside Limit 1, but inside Limit 2. The HIGH annunciator will turn on and display the number "1." For a reading of +2.5V, which is outside both Limit 1 and Limit 2, the same status indication (HIGH, "1") will be displayed since Limit 1 takes precedence.

Overflow readings — A reading that exceeds the present measurement range causes the "OVRFLW" message to be displayed. The "IN," "1," and "2" messages are not displayed while in the overflow condition. The HIGH annunciator will turn on to indicate an out of limits reading.

The LOW annunciator is not used for an overflow reading. An overflow reading is interpreted by the Model 2701 as a positive reading, even if the input signal is negative. That is the reason why the LOW annunciator does not turn on.

NOTE *When a switching module channel is closed, the message "I" replaces the message "IN" to indicate that the reading is inside both Limit 1 and Limit 2.*

For limit test readings that get stored in the buffer, the limits status indicators are displayed for each recalled reading.

When a limit test reading is returned using remote programming, limit test status can be included with the reading. See Section 14, "FORMat commands" for details.

When using Limits with Ratio or Ch Avg the limit values will be compared to the result of the calculation and not to the individual channels.

Beeper — A beeper is also available for limit testing. There are three beeper options: NEVER, OUTSIDE, and INSIDE. These options are explained as follows:

NEVER — With this option, the beeper is disabled.

OUTSIDE — With this option, the beeper sounds when the reading is outside (HIGH or LOW) of Limit 1 or Limit 2. Again referring to Figure 9-1, a +1.5V reading is outside (HIGH) Limit 1 and the beeper will sound.

INSIDE — With this option, the beeper will sound when the reading is inside Limit 1 and/or Limit 2. If the reading is inside Limit 1, the beeper will sound raspy. If the reading is outside Limit 1, but inside Limit 2, the beeper will sound at a lower pitch. The beeper will not sound for readings outside both limits. For the limits shown in Figure 9-1, a 0.5V reading will sound the beeper at its normal pitch, a 1.5V reading will sound the beeper at a lower pitch, and for a 2.5V reading, the beeper will not sound.

Tips to use Limit 2 test

Limits 1 < Limits 2 — When the set limits for Limit 1 are less than the limits for Limit 2 (i.e., Figure 9-1), use the INSIDE beeper. As previously explained, when the reading is between Limit 1 and Limit 2, the beeper will sound raspy.

Limits 1 > Limits 2 — When the set limits for Limit 1 are greater than the limits for Limit 2, use the OUTSIDE beeper. When the reading is between Limit 1 and Limit 2, the beeper will sound raspy.

Scanning

When a simple scan is configured, the present limit values and state will apply to all channels in the scan. When an advanced scan is configured, each channel can have its own unique limits configuration. Details to configure and run a scan are provided in Section 7.

For remote programming, the <clist> parameter is used to configure channels for a scan.

Basic limits operation

The limits configuration is the same for all functions. For example, if a reading limit is set to 1, that will equate to 1V for a voltage function, 1A for a current function, and 1Ω for an ohms function.

Setting limits

1. Press SHIFT and then LIMITS to display the high limit for Limit 1 (HI1).
2. Use ◄, ►, ▲, and ▼ to key in the HI1 limit and press ENTER.
   When editing a reading, use the range designator (m, ^, K, M, or G) as a multiplier. With the cursor on the range designator, each press of ▲ or ▼ will increase or decrease the reading by a factor of 10.
3. Key in the low limit for Limit 1 (LO1) and press ENTER.
4. Key in the high limit for Limit 2 (HI2) and press ENTER.
5. Key in the low limit for Limit 2 (LO2) and press ENTER. The instrument will return the normal measurement state.

Beeper settings

The beeper is configured from the OUTPUT menu (shown in Table 9-1) as follows:

1. Press SHIFT and then OUTPUT.
2. Use the ▲ or ▼ key to display the present beeper (BEEP) setting: NEVER, INSIDE, or OUTSIDE.
3. Press ► to position the cursor on the present beeper setting, use the ▲ or ▼ key to display the desired setting and press ENTER. The instrument will return to the normal measurement state.

NOTE *Remote programming cannot be used to set the beeper. It can only be set from the front panel.*

Enabling/disabling limits

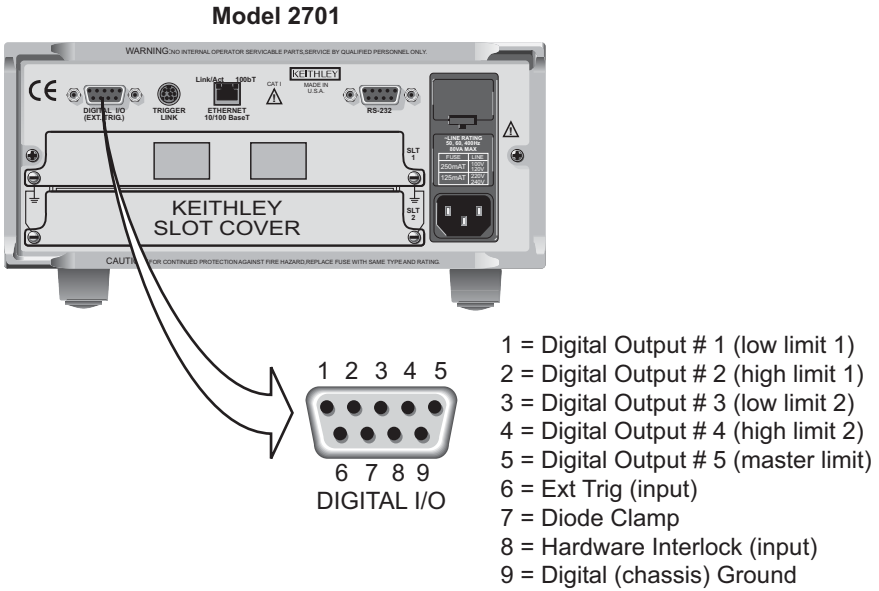
Press SHIFT and then ON/OFF to display the present state (off or on) of limits. To enable limits, use the ▲ or ▼ key to display "LIMITS: ON" and press ENTER.

To disable limits, again press SHIFT and then ON/OFF, select "LIMITS: OFF" and press ENTER.

Digital I/O

Model 2701's Digital I/O port is accessed at a male DB-9 connector located on the rear panel. The connector location and pin designations are shown in Figure 9-2.

Figure 9-2
Digital I/O port



Digital input (trigger link input)

When enabled, the Trigger In (pin 6) and Digital Ground (pin 9) can be used as the trigger link input for external triggering. Pin 6 is physically connected to the input line (pin 2) of the TRIG LINK connector.

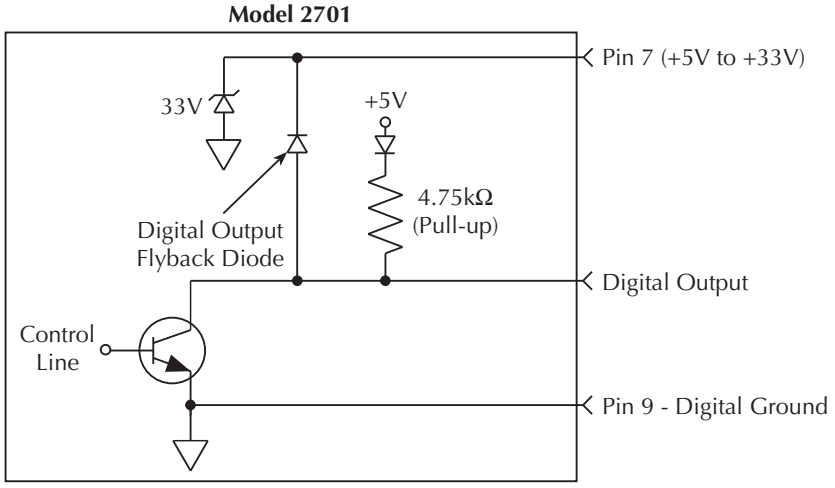
Pin 8 of the digital I/O is used to enable or disable Trigger In. Trigger In is enabled by leaving pin 8 open or pulling it high (+5V). Trigger In is disabled by setting pin 8 low (0V).

NOTE *External triggering is covered in Section 8.*

Digital outputs

The digital I/O port has five digital outputs. Each digital output can be used as a sink to control devices (e.g., relays) or as a source to provide input to external logic (TTL or CMOS) circuitry. The simplified schematic for the digital outputs are shown in Figure 9-3. Note that this illustration shows the schematic for one digital output. All five digital output circuits are identical.

Figure 9-3
Digital I/O port simplified schematic



The five digital output lines (pins 1 through 5) are controlled by limit operations. Each of these five outputs correspond to the following limit operations:

Digital Output 1 - Low Limit 1 (LO1)
Digital Output 2 - High Limit 1 (HI1)
Digital Output 3 - Low Limit 2 (LO2)
Digital Output 4 - High Limit 2 (HI2)
Digital Output 5 - Master Limit (logical OR of the four above limits)

When a limit (LO1, HI2, LO2, HL2) is reached, the digital output line for that limit will be pulled high or low. When a reading is within the limit, the output line is released. Digital output 5 is the logical OR of the four limits. Therefore, if any of the four limits are reached or exceeded, output 5 will be pulled high or low.

NOTE *When the reading is taken and a limit has been reached, there is a short delay before the digital output line is active. As measured from the output trigger (TLINK), the delay is about 10msec when closing a channel and about 2msec without a channel closure. Because of additional time needed for data conversion, the delay can be up to 10 times longer for temperature readings. Allow for this delay when designing test systems.*

Logic sense

The selected logic sense (active high or active low) determines if an output is pulled high or low when the limit is reached. If logic sense is set high, the output line will be pulled high when the reading reaches or exceeds the limit. If logic sense is set low, the output line will be pulled low to 0V when the reading reaches or exceeds the limit.

Pulse option

Pulse option is available for the digital outputs. When enabled, an output line will pulse high or low (depending on the logic sense setting) for each reading that reaches or exceeds the limit. The factory default time duration for the pulse is 2ms (maximum), but can be set from 0.001 to 99999.999 seconds using remote programming. Pulse time cannot be set from the front panel.

NOTE *The commands to set pulse time and enable/disable pulse output are listed in Table 9-2. See "Digital output commands" in the table.*

The pulse time does not affect measurement speed. If a subsequent in-limit reading occurs while the output line is being pulsed, the line will be released immediately (pulse terminated).

Master limit latch

The master limit line is pulled high or low when one or more of the other four limits are reached or exceeded. The master limit line can be programmed to release when a reading is inside all four limits or the master limit can be latched when a failure occurs. When latched, the master limit line will not release until operation within the trigger model returns to and passes the control source (see Section 7 for details on triggering).

When scanning, the latched master limit line will not release until the scan is finished and another scan is started. For example, if after testing a resistor network the master limit line did set, then the network has passed all tests.

Sink mode — controlling external devices

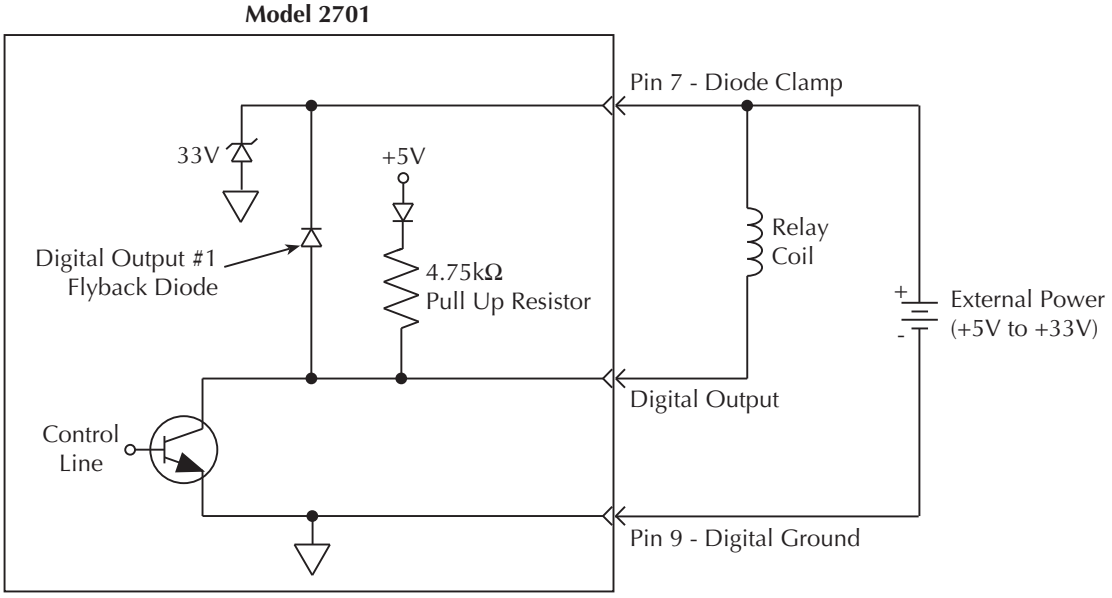
Each output can be operated from an external supply (voltage range from +5V to +33V applied through the external device being driven). The high current sink capacity of the output driver allows direct control of relays, solenoids, and lamps (no additional circuitry needed).

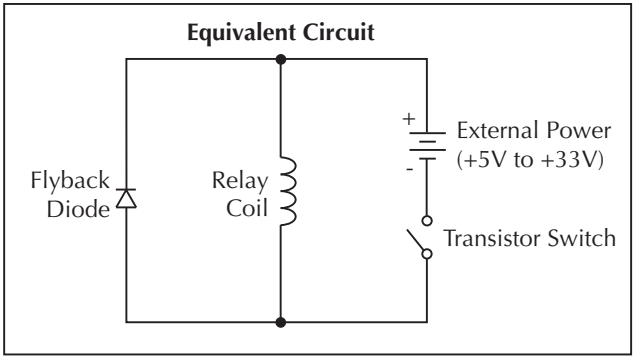
As shown in Figure 9-3, each of the digital, open-collector outputs includes a built-in pull up resistor connected to +5V. The output transistor is capable of sinking 250mA from voltages up to +33V. Each output channel contains a fly-back diode for protection when switching inductive loads (such as a low power solenoid or relay coils). To use these fly-back diodes, connect the external supply voltage to pin 7 of the digital I/O port. Make sure the external supply voltage is between +5V and +33V and the current required by the device does not exceed 250mA.

CAUTION **On pin 7, do not exceed +33V. For the output lines, do not exceed the maximum sink current. The maximum sink current for an output line is 250mA. Exceeding these limits may cause damage to the instrument that is not covered by the warranty.**

An externally powered relay connected to the digital output port is shown in Figure 9-4. Other externally powered devices can be similarly connected by replacing the relay with the device. When the output line is pulled low (0V), the output transistor sinks current through the external device. In the high state, the output transistor is off (transistor switch open). This interrupts current flow through the external device.

Figure 9-4
Controlling externally powered relays





Source mode — logic control

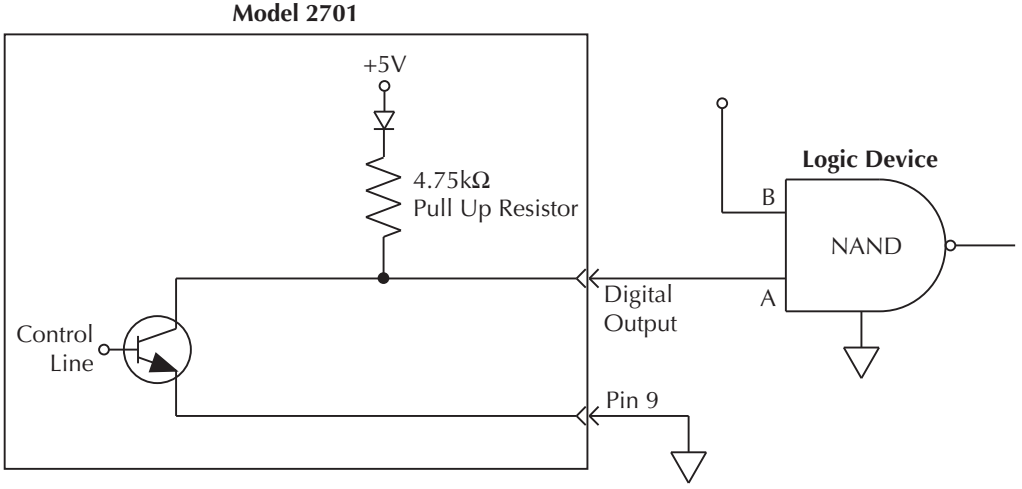
The digital outputs can be used as logic inputs to active TTL, low-power TTL, or CMOS inputs. For this mode of operation, the output lines can source up to 200µA.

CAUTION **Each output line can source up to 200µA. Exceeding 200µA may cause damage to Model 2701 that is not covered by the warranty.**

Figure 9-5 shows how to connect a logic device to one of the output lines. When the output line is pulled high, the transistor will turn off (transistor switch open) to provide a reliable logic high output (>3.75V). When the output line goes low, the transistor turns on (transistor switch closed) to route current to digital ground. As a result, a low logic output (0V) is provided at the output.

If the second input (B) of the NAND gate is connected to another output line of the port, the output of the NAND gate will go to logic 0 when both digital outputs are set high.

Figure 9-5
NAND gate control



Setting digital output

The OUTPUT menu (shown in Table 9-1) is used to control and configure digital outputs. Menu items for the digital output include:

- **DOUTPUT** — Use to enable (ON) or disable (OFF) the digital outputs.
- **PULSE** — Use to enable (YES) or disable (NO) the pulse option for the digital outputs.

NOTE *The factory default pulse time is 2ms maximum. Using remote programming, pulse time can be set from 0.001 to 99999.999 sec. It cannot be set from the front panel.*

- **LSENSE** — Use to select the logic sense: active HIGH or active LOW. With active high selected, an output will be at approximately +5V when a reading is at or exceeds the limit. Conversely, with active low selected, an output will be at 0V when a reading reaches or exceeds the limit.
- **MASTR LATCH** — Use to enable (Y) or disable (N) the master limit latch. When enabled, the master limit remains latched when a reading limit is reached or exceeded. When disabled, the master limit line releases immediately when the reading is inside all four limits.

Table 9-1
OUTPUT menu

Menu item	Setting	Description
DOUTPUT	ON or OFF	Enable/disable digital outputs.
PULSE	YES or NO	Enable/disable digital pulse output.
LSENSE	HIGH or LOW	Select logic sense.
BEEP	NEVER, INSIDE, or OUTSIDE	Set beeper for limits (see "Limits" for details).
MASTR LATCH	Y or N	Enable/disable master limit latch.

Perform the following steps to enable and configure digital outputs:

1. Press SHIFT and then OUTPUT.
2. If the digital output is already on (DOUTPUT: ON), proceed to step 3. Otherwise, press ▸ to move the cursor to the right, press ▴ or ▾ key to display "ON," and press ENTER.
3. Use the ▾ key to display the master limit latch (MASTR LATCH) setting: N (no) or Y (yes).
4. If you want to retain the present master limit setting, proceed to step 5. Otherwise, press ▸ to move the cursor to the right, press ▴ or ▾ key to display "Y" or "N," and press ENTER.
5. Use the ▾ key to display the present logic sense (LSENSE) setting: HIGH or LOW.
6. If you want to retain the present logic sense setting, proceed to step 7. Otherwise, press ▸ to move the cursor to the right, press ▴ or ▾ key to display "HIGH" or "LOW," and press ENTER.
7. Use the ▾ key to display the present PULSE mode setting: NO or YES.
8. To retain the present pulse mode setting, press ENTER. Otherwise, press ▸ to move the cursor to the right, press ▴ or ▾ key to display "NO" or "YES," and press ENTER.

Scanning

While limits can be configured on a per scan channel basis, the digital output configuration cannot. Therefore, for all scan channels that are set to use limits, the digital output will function according to how the Model 2701 is set up when the scan is run.

Remote programing — limits and digital output

Limits and digital output commands

The limits and digital output commands are provided in Table 9-2.

Table 9-2
Limits and digital I/O commands

Commands*	Description	Def	Ref
Limit 1 commands			
CALCulate3:LIMit1:UPPer <NRf> [, <clist>]	Set HI1 limit; <NRf> = -4294967295 to +4294967295.	1	
CALCulate3:LIMit1:LOWer <NRf> [, <clist>]	Set LO1 limit; <NRf> = -4294967295 to +4294967295.	-1	
CALCulate3:LIMit1:STATe <b> [, <clist>]	Enable/disable Limit 1 test; <b> = ON or OFF.		a
CALCulate3:LIMit1:FAIL?	Query test result; 0 = pass (in), 1 = fail (high or low).		b
CALCulate3:LIMit1:CLEar	Clear fail indication.		c
CALCulate3:LIMit1:CLEar:AUTO <b>	Enable/disable auto clear; <b> = ON or OFF.	ON	c
Limit 2 commands			
CALCulate3:LIMit2:UPPer <NRf> [, <clist>]	Set HI2 limit; <NRf> = -4294967295 to +4294967295.	2	
CALCulate3:LIMit2:LOWer <NRf> [, <clist>]	Set LO2 limit; <NRf> = -4294967295 to +4294967295.	-2	
CALCulate3:LIMit2:STATe <b> [, <clist>]	Enable/disable Limit 1 test; <b> = ON or OFF.		a
CALCulate3:LIMit2:FAIL?	Query test result; 0 = pass (in), 1 = fail (high or low).		b
CALCulate3:LIMit2:CLEar	Clear fail indication.		c
CALCulate3:LIMit2:CLEar:AUTO <b>	Enable/disable auto clear; <b> = ON or OFF.	ON	c
Digital output commands			
CALCulate3:OUTPut:LSENse <name>	Set logic sense; <name> = AHIGh or ALOW.	AHIGh	
CALCulate3:OUTPut:[STATe] <b>	Enable/disable digital outputs; <b> = ON or OFF.	OFF	
CALCulate3:OUTPut:PULSe:TIMe <NRf>	Set output pulse time in secs; <NRf> = 0.001 to 99999.999.	0.002	
CALCulate3:OUTPut:PULSe[:STATe] <b>	Enable/disable pulse output; <b> = ON or OFF.	OFF	
CALCulate3:MLIMit:LATChed <b>	Enable/disable master limit latch.	OFF	

Channel list parameter:
<clist> = (@SCH)
where: S = Mainframe slot number (1 or 2)
CH = Switching module channel number (must be 2 digits)
Examples: (@101) = Slot 1, Channel 1
(@101, 203) = Slot 1, Channel 1 and Slot 2, Channel 3
(@101:110) = Slot 1, Channels 1 through 10

*The <clist> parameter is used to configure one or more channels for a scan.

NOTE *When measurements are performed, the readings are fed to other enabled operations, including Limits. Appendix D explains "Data flow (remote operation)" and the commands used to read the result of limit tests.*

Reference

a. CALCulate3:LIMit1:STATe <b> [, <clist>]
CALCulate3:LIMit2:STATe <b> [, <clist>]

Unlike front panel operation, Limit 1 and Limit 2 can be controlled (on/off) separately for remote programming. The front panel limit indicators are affected as follows:

Limit 1 enabled — The front panel HIGH/IN/LOW indicators work the same as they do for front panel operation.

Limit 1 disabled and Limit 2 enabled — The status indicators pertain to Limit 2. When the reading is within Limit 2, the message "I2" is displayed. When the reading reaches or exceeds the high or low limit, the HIGH or LOW annunciator will turn on and the number "2" will be displayed.

NOTE *When limits are disabled from the front panel, both Limit 1 and Limit 2 disable for remote operation.*

b. CALCulate3:LIMit1:FAIL?
CALCulate3:LIMit2:FAIL?

These commands are used to query the results of Limit 1 and Limit 2:

0 = Passing (reading within the high and low limits)
1 = Failing (reading has reached or exceeded the high or low limit)

The "1" response message does not tell you which limit (high or low) has been reached. To determine which limit has failed, you will have to read the measurement event register (Section 12).

c. CALCulate3:LIMit1:CLEar
CALCulate3:LIMit1:CLEar:AUTO <b>
CALCulate3:LIMit2:CLEar
CALCulate3:LIMit2:CLEar:AUTO <b>

These commands are used to clear the fail ("1") indications for Limit 1 and Limit 2. If auto clear is enabled for a limit, the fail indication clears when instrument operation enters the idle state. With auto clear disabled, the fail indication will remain until it is cleared by the :CLEar command.

Limits and digital outputs programming example

The following command sequence configures the Model 2701 to perform Limit 1 test on a DCV reading. If the 100mV limit is reached, digital output # 2 will be pulled low. If the -100mV limit is reached, digital output #1 will be pulled low.

NOTE *The following example can be run from the KE2700 Instrument Driver using the example named "Limits" in Table G-1 of Appendix G.*

```
*RST                                  ' One-shot measurement mode (DCV).
CALC3:LIM1:UPP 0.1                    ' Set HI1 limit to 100mV.
CALC3:LIM1:LOW -0.1                   ' Set LO1 limit to -100mV.
CALC3:LIM1:STAT ON                    ' Enable Limit 1.
CALC3:OUTP:LSEN ALOW                  ' Set logic sense to active low.
CALC3:OUTP ON                         ' Enable digital outputs.
READ?                                 ' Trigger and request reading.
CALC3:LIM1:FAIL?                      ' Request result of limit 1 test.
```

Application — sorting resistors

For this application, the idea is to sort a batch of 100Ω resistors into three bins. Bin 1 is for resistors that are within 1% of the nominal value. Bin 2 is for resistors that exceed 1% tolerance, but are within 5%. Bin 3 is for resistors that exceed 5% tolerance.

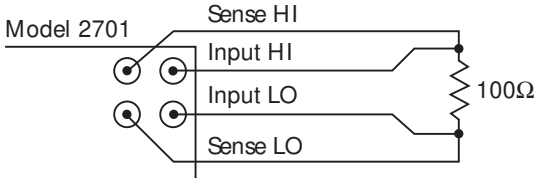
The digital outputs of the Model 2701 can be used to further automate the test system by controlling a compatible component handler to perform the binning operations.

Limits

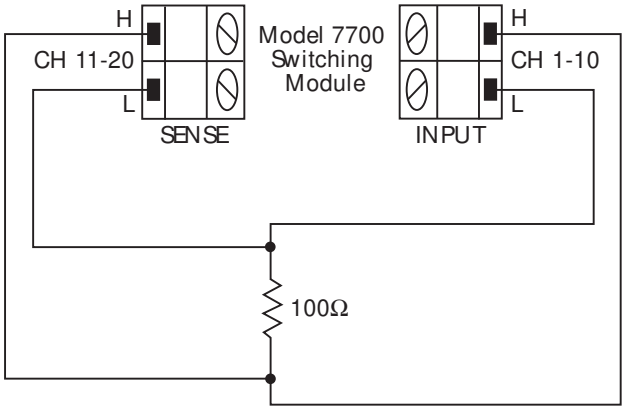
Limit testing is used to test resistor tolerances. Figure 9-6 shows a basic setup using 4-wire offset-compensated ohms to test 100Ω resistors.

Figure 9-6
Setup to test 100Ωresistors

A) Front panel inputs



B) Model 7700



Limit 1 will be used to test for the 1% tolerance and Limit 2 will be used to test for the 5% tolerance.

The resistance values for the 1% and 5% tolerances are calculated as follows:

$$R_{1\%} = 100\Omega \times 1\% = 100\Omega \times 0.01 = 1\Omega$$

$$R_{5\%} = 100\Omega \times 5\% = 100\Omega \times 0.05 = 5\Omega$$

The high and low limits are then calculated as follows:

$$\text{HI Limit 1} = 100\Omega + R_{1\%} = 100\Omega + 1\Omega = 101\Omega$$

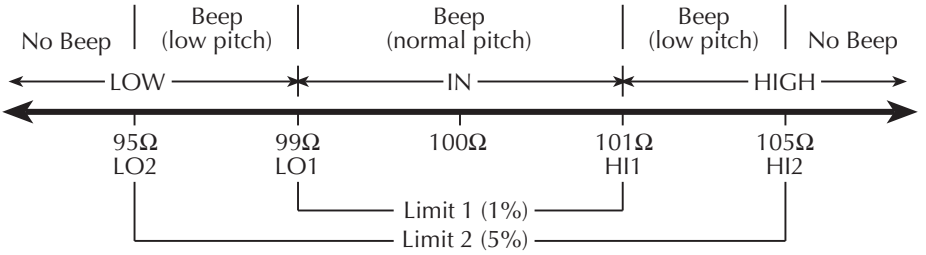
$$\text{LO Limit 1} = 100\Omega - R_{1\%} = 100\Omega - 1\Omega = 99\Omega$$

$$\text{HI Limit 2} = 100\Omega + R_{5\%} = 100\Omega + 5\Omega = 105\Omega$$

$$\text{LO Limit 2} = 100\Omega - R_{5\%} = 100\Omega - 5\Omega = 95\Omega$$

The limits are illustrated in Figure 9-7.

Figure 9-7
Limits to sort 100Ωresistors (1%, 5%, and >5%)



Front Panel Operation — For front panel operation, the INSIDE beeper mode must be used. A normal pitch beep and the message IN indicates that the resistor is within the 1% tolerance limit (Figure 9-7). This 1% resistor belongs in Bin 1. A raspy beep and the "1" message indicates that the resistor is >1% tolerance but <5% tolerance. This 5% resistor belongs in Bin 2. For resistors >5%, no beep will sound. Place these resistors in Bin 3.

Remote Operation — For remote operation, make sure both Limit 1 and Limit 2 are enabled. The following table evaluates the three possible pass/fail combinations for this example.

Limit 1 result	Limit 2 result	Resistor tolerance	Bin assignment
Pass	Pass	1%	1
Fail	Pass	5%	2
Fail	Fail	>5%	3

Keep in mind that a fail condition must be reset before testing the next resistor. Fail can be reset manually or automatically (see Table 9-2, CLEar command).

Digital outputs

With the digital outputs of the Model 2701 enabled, the digital outputs will respond as follows for each resistor reading:

LO limit 2	LO limit 1	HI limit 1	HI limit 2	Resistor tolerance	bin	Affected outputs*
Pass	Pass	Pass	Pass	1%	1	None
Pass	Fail	Pass	Pass	5%	2	#1 and #5
Pass	Pass	Fail	Pass	5%	2	#2 and #5
Fail	Fail	Pass	Pass	>5%	3	#1, #3, and #5
Pass	Pass	Fail	Fail	>5%	3	#2, #4, and #5

*Affected outputs are pulled (or pulsed) high or low when a limit test fails.

10
Remote Operations

- **Operation enhancements** — Summarizes some of the more important operations that can only be performed using remote operation.
- **System commands** — Summarizes the commands used to select and configure an interface for remote programming. Also covers other system commands that pertain to remote operation.
- **Ethernet setup** — Shows some typical Ehternet systems, covers connections, and explains how to select and configure the Ethernet.
- **Front panel aspects of Ethernet operation** — Summarizes error messages, status indicators, and using the LOCAL key.
- **Programming syntax** — Describes the basic programming syntax for both common and SCPI commands.
- **RS-232 interface operation** — Outlines use of the RS-232 interface to control the Model 2701.

Operation enhancements

There are some operations you can do over the Ethernet and RS-232 interface that you cannot do from the front panel. The more important ones are summarized below.

Pseudocards

Using remote operation, you can assign a pseudocard to an empty switching module slot. With a pseudocard installed, the Model 2701 will operate as if the switching module is installed in the Model 2701. This feature allows you to configure your system without having the actual switching module installed in the unit. There is a pseudocard for every Keithley Model 7700 series switching module.

A single SCPI command (SYSTem:PCARdX, where X=1 or 2) is used to install a pseudocard in an empty switching module slot. Details are provided in Section 2.

A pseudocard cannot be installed from the front panel. However, once it is installed, you can take the Model 2701 out of remote and use the front panel. When the instrument is turned off, the pseudocard will be lost (uninstalled).

Autozero

Autozero is part of the normal measurement process to assure stable, accurate measurements. Autozero can be disabled to increase measurement speed. However, the readings will eventually become inaccurate over time and temperature changes.

Autozero can only be disabled using remote programming. It cannot be disabled from the front panel. Autozero is covered in Section 3.

dB calculation

Using remote programming, you can select the dB calculation for DC or AC voltage. The dB calculation makes it possible to compress a large range of measurements into a much smaller scope. See Section 5 to select and configure the dB calculation.

You cannot select dB from the front panel. However, once it is selected you can take the Model 2701 out of remote and use the front panel. When the instrument is reset to default conditions (or turned off), dB will be lost.

Separate function setups

A few settings from the front panel are global. That is, the setting on one function also applies to the other functions. For example, if you set DCV for 3½ digits, all the other functions will also be set to 3½ digits. Using remote programming, each function can have its own unique setup. For example, DCV can be set to 3½ digits, ACI can be set to 4½ digits, and DCI can be set to 5½ digits.

Global settings from the front panel that can be set separately using remote programming include digits, rate, and filter configuration (except on/off, which can be set separately).

NOTE *Do not confuse function setups with scan channel setups. For scan channels, separate settings for digits, rate, and filter configuration can be set from either the front panel or remote programming. See Section 7 for details on scan channel setup.*

DCV input divider

Using remote programming, you can enable the DCV input divider for the 100mV, 1V, and 10V ranges. When enabled, the input resistance for these DCV ranges are reduced to 10MΩ See Section 3 for details on the DCV input divider.

Multiple channel operation

For normal system channel operation, when one measurement channel is closed, the previous measurement channel opens. With the use of the ROUTe:MULTiple commands, you gain independent control of all switching module channels, including the relays that connect the input signal to the DMM. See Section 2 for details.

System commands

Interface

SYStem subsystem commands are used to select and configure the interface for remote programming. System commands for the Ethernet are provided in Table 10-2, while system commands for the RS-232 interface are provided in Table 10-3.

NOTE *The Model 2701 has an internal web page. From this web page, you can send commands to the 2701 and take readings. See "Internal web page" for details.*

Password

A user-defined password can be used to disable protected commands. Most Model 2701 commands are protected. When the use of password is enabled, there are commands to either disable or enable the protected commands.

At the factory, the Model 2701 is assigned the following password name:

"DEFAULT"

The password is case sensitive and must be enclosed in quotes, as shown above.

NOTE *From the front panel, the password can be cleared. When cleared, the use of password is disabled and the password name resets to "DEFAULT". The password can be cleared using the SETUP menu as follows:*

- *Press SHIFT*
- *Press SETUP*
- *Use the edit keys to display CLR PASSWORD: N or Y*

  where: N = no (do not clear) and Y = yes (clear)
- *Press ENTER*

The password commands are listed in Table 10-1. The password commands are used to perform the following operations:

- Disable or enable the use of a password. Disabling the use of a password enables all protected commands:

  ```
  SYSTem:PASSword:ENABle OFF      ' Disable password.
  SYSTem:PASSword:ENABle ON       ' Enable password.
  ```

  NOTE *The password can also be enabled or disabled from the Model 2701's internal web page (see "Internal web page," page 10-16).*

- Disable protected commands. This places the Model 2701 in the password-protected mode. In this mode, the only commands that can be sent are the ones listed in Note 2 at the bottom of Table 10-1. Example using "DEFAULT" as the password:

  ```
  SYSTem:PASSword:CDISable "DEFAULT"
  ```

  NOTE *If the password is disabled, sending the :CDISable command automatically enables the password and then places the Model 2701 in the password-protected mode.*

- Enable protected commands. This takes the Model 2701 out of the password-protected mode. Example using "DEFAULT" as the password:
  SYSTem:PASSword:CENable "DEFAULT"
- Query the password protection state (enabled or disabled). Example:
  SYSTem:PASSword:CENable:STATe?
- Change the password. The password is case sensitive and can include non-ASCII characters from 1 to 255. Make sure to enclose the password in quotes. Example to change password to "INTEGRA":
  SYSTem:PASSword:NEW "INTEGRA".

NOTE *The password can be changed from the Model 2701's internal web page (see "Internal web page," page 10-16).*

NOTES:

1. Sending a password-protected command causes error -203 (command protected).
2. Using an incorrect password in a password command causes error -221 (settings conflict).
3. The present password and command protection state are not affected by *RST or SYSTem:PRESet.

Battery

System settings, such as remote programming interface settings, are saved in non-volatile memory. The rechargeable lithium ion battery is used for the 450,00 reading buffer. The system commands to acquire status information about the battery are listed in Table 10-1.

Error codes associated with the battery:

+555 Cannot charge battery – Will occur approximately one hour after power-up if the battery cannot charge and needs to be replaced.

+556 Battery removed – Will occur one time on power-up. Subsequent power-ups will not repeat this error.

NOTE *Details on the rechargeable lithium ion battery are provided in Section 1 (see "Battery," page 1-3).*

Miscellaneous system commands

Also included in Table 10-1 are system commands to control remote/local operation, re-boot the 2701, and acquire the serial number and revision of the main PC board. System commands not covered in this section are provided in Section 14. All SYSTem commands are listed in Table 15-7.

Table 10-1
SYSTem commands

Command	Description
SYSTem	
:LOCal	Take 2701 out of remote and restore operation of front panel controls.
:REMote	Place 2701 in remote.
:RWLock	Lockout front panel controls.
:RESet	Immediately re-boots the 2701.
:BOARd	PC board:
:SNUMber?	Acquire serial number of PC board.
:REVision?	Acquire revision level of PC board.
:BATTery	Battery:
:PRESent?	Is a battery installed?; 0 = no, 1 = yes.
:STATus?	Returns "OK", "MEMORY LOST," or "CHARGING FAILURE". Memory is lost when the battery is not installed and upon a reset after a firmware upgrade. A charging failure occurs when it is time for a new battery.
:PASSword	Password:
:ENABle <b>	Enable or disable the use of a password.
:ENABle?	Query the state of password usage.
:CDISable <password>	Disables protected commands.[1, 2]
[:CENable] <password>	Enables protected commands.[1]
:STATe <b>	Returns "0" if password protected commands are disabled. Returns "1" if they are enabled.
:NEW <password>	Set new password.[1]

1. There is no query form for this command.
2. The following commands and queries are NOT disabled by :PASSword:CDISable. Commands and queries not listed are not affected by :PASS:CDIS.

*ESE?	*OPT?	SYST:BOAR:SNUM?	SYST:PASS:CDIS
*ESR?	*SRE	SYST:BOAR:REV?	SYST:PASS:CEN
*IDN?	*SRE?	SYST:ERR?	SYST:PASS:CEN:STAT?
*OPC	*STB?	SYST:LFR?	SYST:REM
*OPC?	STAT:QUE:NEXT?	SYST:LOC	SYST:VER

Ethernet setup

Ethernet standards

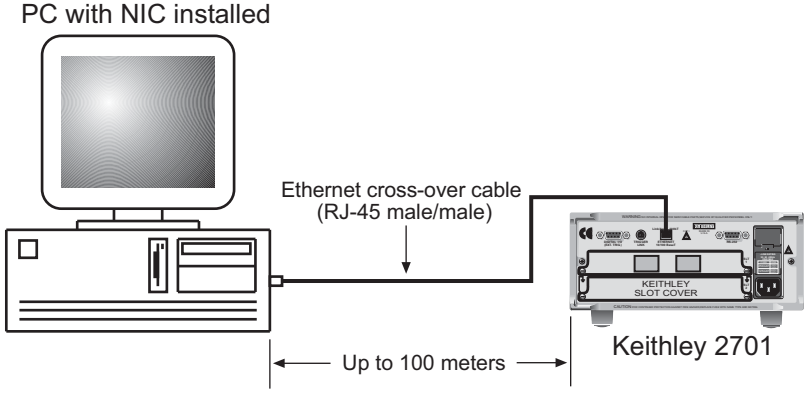
The Model 2701 conforms to these standards:

- TCP/IP
- HTTP
- IEEE-802.3
- SCPI 1996.0 (Standard Commands for Programmable Instruments)

Typical Ethernet systems

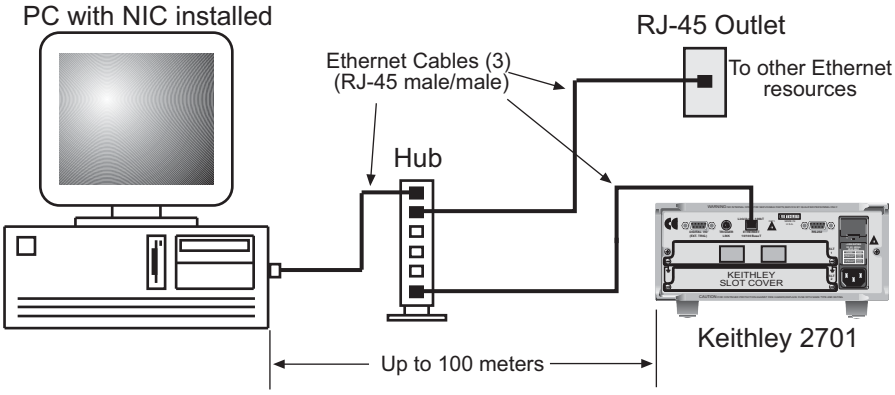
The four typical Ethernet systems using a Model 2701 are shown in Figures 10-1 through 10-4. The simplest system connects a Model 2701 directly to a PC equipped with a NIC (Network Interface Card) as shown in Figure 10-1. The Ethernet cable can be up to 100 meters in length.

Figure 10-1
Direct 2701 connection to PC



Adding a hub as shown in Figure 10-2, expands the system into a small LAN (Local Area Network). The hub allows additional Ethernet instruments to be connected to the PC.

Figure 10-2
Small LAN system using a hub



Adding a second NIC in the PC, as shown in Figure 10-3, expands the network system and provides improved performance because there is no corporate LAN data traffic on the instrument LAN. It also provides additional security between two groups of users. Finally, Figure 10-4 shows a simplified diagram of a network system using a router or servers.

Figure 10-3
Isolated LAN system using two NICs (Network Interface Cards)

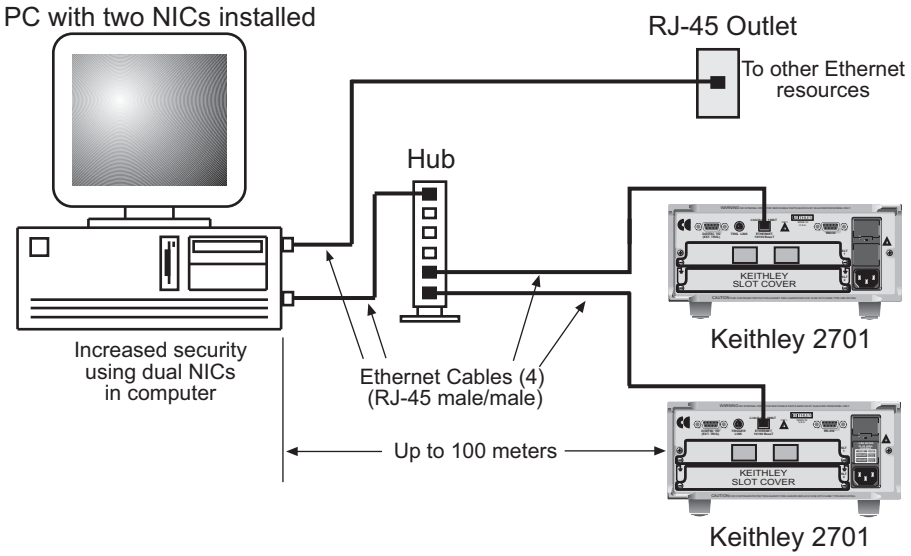
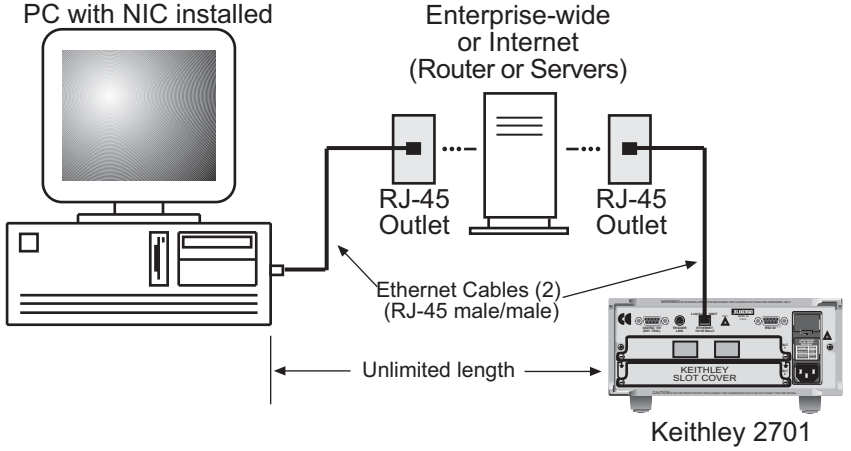


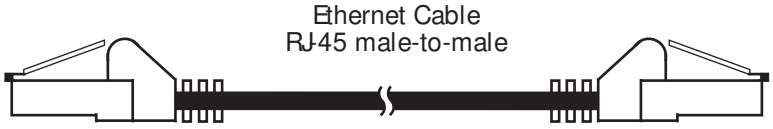
Figure 10-4
Enterprise-wide or internet network system



Ethernet connections

The Model 2701 is connected to the Ethernet using a male-to-male RJ-45 Ethernet cable (see Figure 10-5). The Ethernet connector for the Model 2701 is shown in Figure 10-6. With power off, connect one end of the cable to the Model 2701 and connect the other end to the Ethernet connector of the PC, hub, or receptacle.

Figure 10-5
RJ-45 Ethernet cable (male/male)

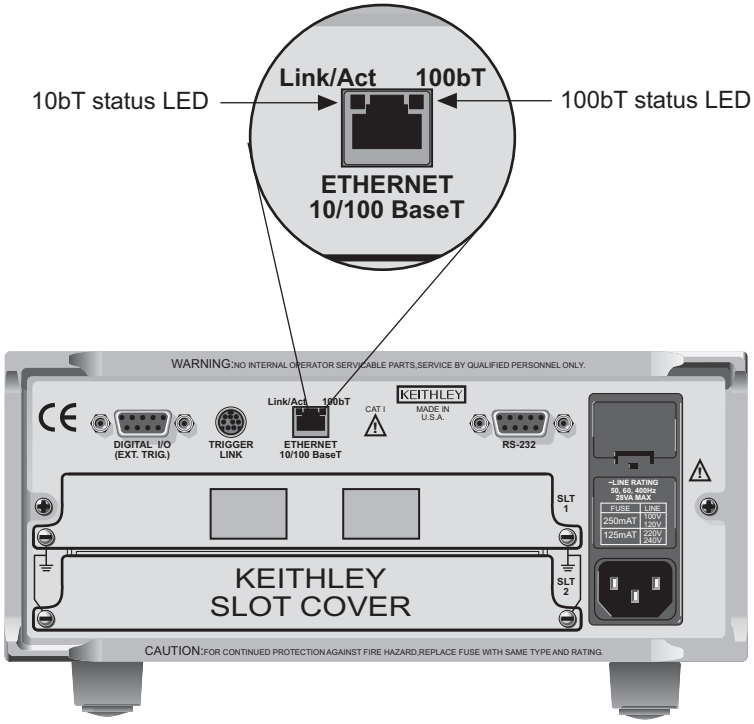


RJ-45 connector status LEDs

The female RJ-45 connector (shown in Figure 10-6) has two status LEDs located at the top of the connector. These LEDs provide the following status:

LED	State	Ethernet status
Link/Act	Off	Network NOT connected
Link/Act	On	Network connected
Link/Act	Blinking	Traffic is traversing the port
100bT	Off	10 mb/s network speed
100bT	On	100 mb/s network speed

Figure 10-6
Model 2701 Ethernet connector



Ethernet settings

NOTE *Ethernet fundamentals and details on the valid Ethernet settings are provided in the Model 2701 Instrument Networking Manual. The following information explains how to use the front panel Ethernet menu and SCPI commands to check and/or change Ethernet settings.*

Ethernet settings include the following:

- Dynamic Host Control Protocol (DHCP) – Enable or disable.
- IP address
- Subnet mask
- Ethernet gateway
- MAC address of the 2701 – This fixed address for the 2701 cannot be changed.

Ethernet settings can be made from either the front panel or remote programming.

NOTE *Error code +550 Unitialized Ethernet module will occur on power-up if the Ethernet settings are corrupt or the MAC address is FF:FF:FF:FF:FF:FF.*

Contact Keithley immediately if this error occurs. Make sure to have the serial number of you Model 2701 handy when you call. The serial number is displayed from the SETUP menu. Press SHIFT and then SETUP to access the menu, then use the up RANGE key to display the serial number (SNUM).

When you call, Keithley will give you the MAC address of your unit. After you have the address, press SHIFT and then ETHERNET to bring up the MAC address edit mode. You can then enter the new address in decimal.

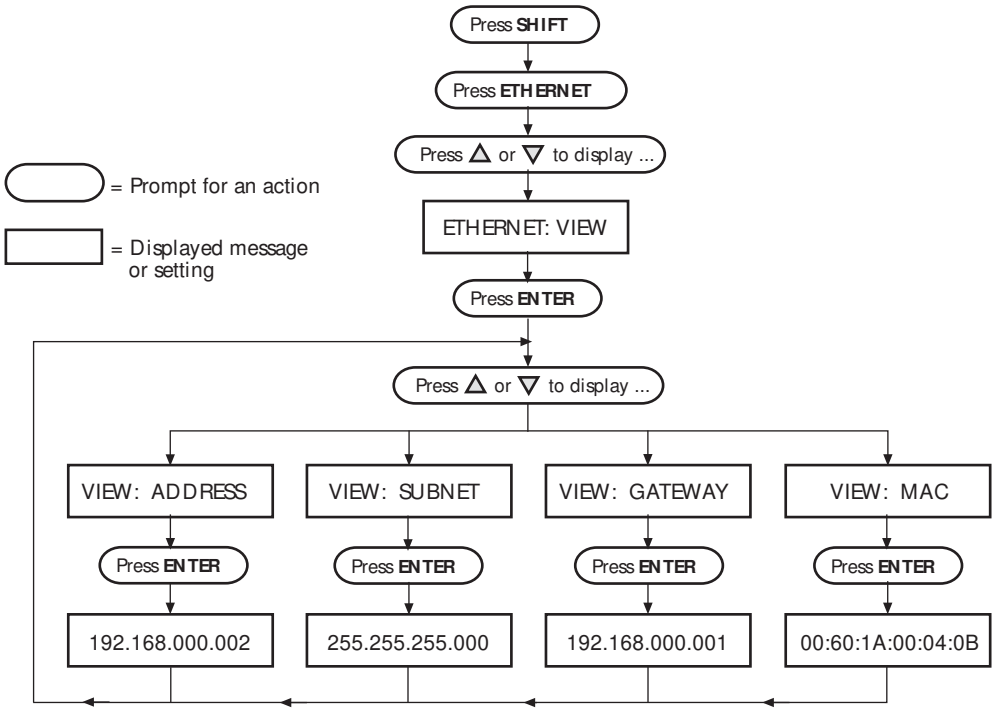
Front panel Ethernet setup

The front panel Ethernet menu provides two options: VIEW and SET. The VIEW is used to check the present Ethernet settings. Settings cannot be changed from this menu stucture. The SET option is used to change the Ethernet settings.

VIEW Ethernet settings – Use the flowchart in Figure 10-7 to check the Ethernet settings. Figure 10-7 shows the settings set at the factory. All but the MAC address can be changed by the user using the SET menu.

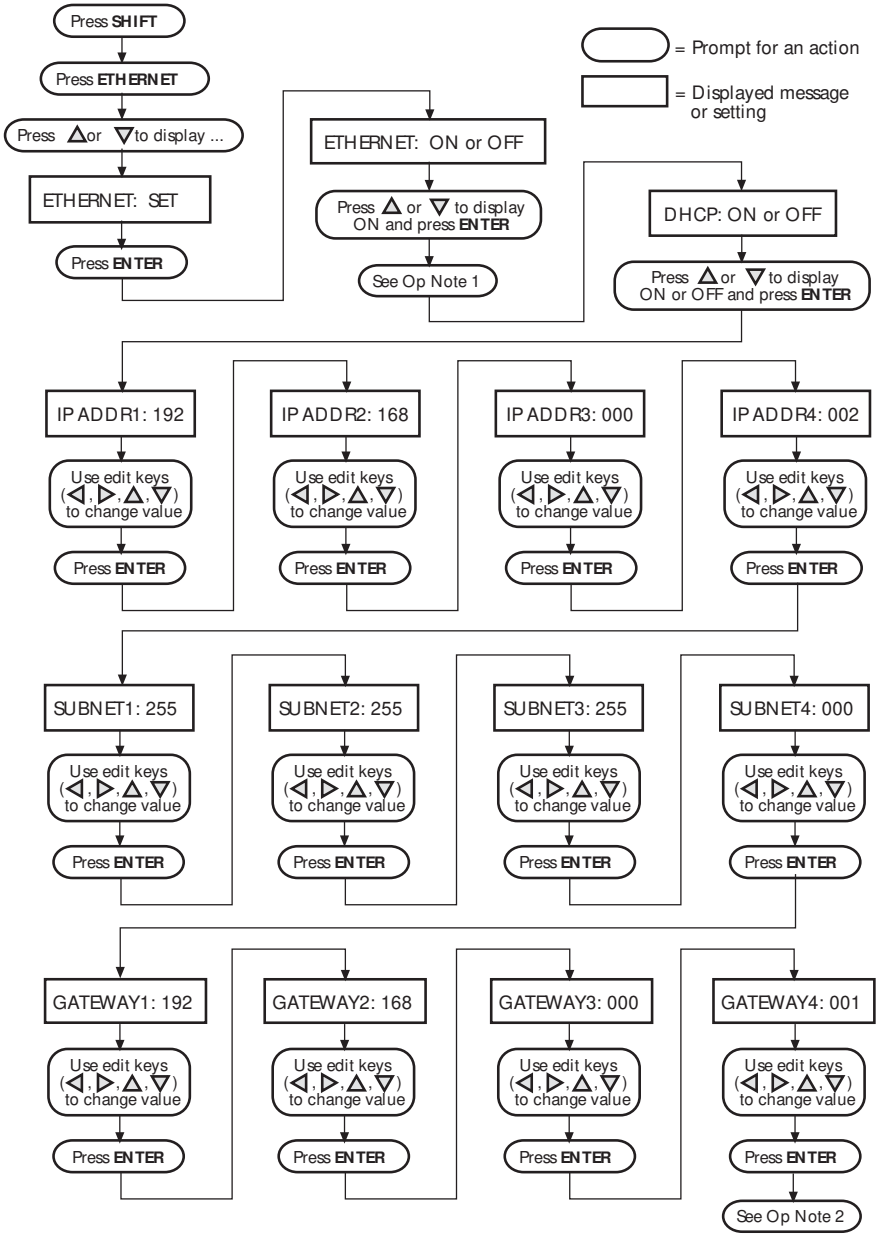
SET Ethernet – Ethernet settings can be changed using the flowchart in Figure 10-8. For the IP Address, Subnet, and Gateway, the setting is divided into four parts (1 through 4). The settings shown in Figure 10-8 are the values set at the factory.

Figure 10-7
Flowchart to VIEW Ethernet settings



NOTE: *Press **EXIT** to exit the menu structure.*

Figure 10-8
Flowchart to SET Ethernet



Op Notes:
1. If Ethernet was off, turning it on will cause the 2701 to re-boot. To change Ethernet settings, return to the beginning of this flowchart and start over.
2. After pressing ENTER for the Gateway4 settting, the 2701 will re-boot.
3. Changing Ethernet settings or remote interfaces automatically reboots the Model 2701. Reboot process takes 28 seconds.

Remote programming

System commands to select and configure Ethernet are listed in Table 10-2.

NOTE *Ethernet and RS-232 settings are not affected by *RST or SYSTem:PRESet. The Ethernet settings set at the factory are shown in Figure 10-7 and Figure 10-8.*

Table 10-2
SYSTem commands for Ethernet

Command	Description
SYSTem	
:COMMunicate	Ethernet and RS-232 commands:
:SELect <name>	Select communications mode; ETHernet or SERial.
:ETHernet	Ethernet:
:ADDRess <value>	Set IP address of 2701; "n.n.n.n".
:ADDRess?	Query IP address of 2701.
:MASK <value>	Sets the subnet mask; "n.n.n.n".
:MASK?	Query subnet mask.
:GATeway <value>	Set the Ethernet gateway; "n.n.n.n".
:GATeway?	Query the Ethernet gateway.
:DHCP <b>	Enable or disable Dynamic Host Control Protocol (DHCP).
:DHCP?	Query state of DHCP.
:MAC?	Returns MAC address of 2701; 6 hexadecimal values separated by colons (00:60:1A:00:04:0B).

Internal web page

The Model 2701 has an internal web page (see Figure 10-9 and Figure 10-10). The web page is organized as follows:

- Configuration summary:
  - **Network Settings** – You can view and/or change the network settings of the Model 2701.
  - **Instrument Information** – Provides read-only information about the Model 2701 (revision levels, serial numbers, and calibration status).
  - **Installed Cards** — Provides read-only information about switching modules installed in the mainframe (revision level, serial number, and calibration status).
  - **Instrument Settings** — Establish the date, time, and enable (yes) or disable (no) the use of password.
- **Interactive control panel** — From the control panel, the user can send commands and queries to Model 2701. Also, with the click of button, the instrument will continuously take readings. Readings, responses to queries, and any error messages are displayed in the control panel:
  - **Take Measurements** — Click Initiate to start continuous readings.
  - **SCPI Programming** — Type in the edit field a command or query and click Send.

Opening the web page

System requirements

Internet Explorer (IE 5.0 or greater) is needed to open the 2701 web page. Make sure the PC and Model 2701 is properly set for Ethernet operation. Details on using the Ethernet is provided in the Model 2701 Instrument Networking Instruction Manual. The following example demonstrates correct settings for the Model 2701 and the PC:

Example – Assume the 2701 is using the default IP Address and Subnet mask:

Model 2701 settings:
IP Address = 192.168.000.002
192.168.000 is the Network ID
002 is the Node Designation
Subnet mask = 255.255.255.000

PC settings:
IP Address = 192.168.000.004
192.168.000 is the Network ID
004 is the Node Designator
Subnet mask = 255.255.255.000

As shown above for the IP Address, the Network ID of the 2701 and PC must be the same. The Node Designators must be different. However the Subnet mask must be the same for the 2701 and the PC.

Local intranet address

Using Internet Explorer, a local intranet address is used to open the web page. The web page address is the same as the IP Address of the Model 2701. Assuming the default IP Address is being used, the following intranet address will open the web page:

http://192.168.0.2

If the use of password is enabled, you will be prompted to enter the password. If you forgot the password, you can either contact your network administrator for the password or you can clear the password from the front panel of the Model 2701. To clear the password and open the web page, perform the following:

- Model 2701:
  - Press LOCAL > press SHIFT > press SETUP > display CLR PASSWORD:Y > press ENTER

    Clearing the password disables its use and resets it to "DEFAULT".

    With the web page open, the use of password can be enabled and changed (if desired).

Configuration summary

The configuration summary, shown in Figure 10-9, provides the various details about the Model 2701. You will see Instrument Information, Installed Cards, Network Settings (where you can input the IP Adress, Subnet Mask, Gateway, and IP Mode), and the Instrument Settings. The Instrument Settings is where you enter the Date, Time, and Enable a password by choosing Yes or No (no will disable the password option). Once you have established your settings, click Update Settings in order to save the informaiton (see Figure 10-9).

NOTE *If you change the Ethernet settings and they conflict with the PC, you will lose the connection to the Model 2701. Ethernet settings for the Model 2701 can be fixed from the front panel.*

Interactive control panel

The control panel allows the user to control the Model 2701. You can send commands and queries. Readings, responses to queries, and error messages are displayed in the control panel. Details on using the control panel are provided in Figure 10-10.

Figure 10-9
Model 2701 Configuration internal web page

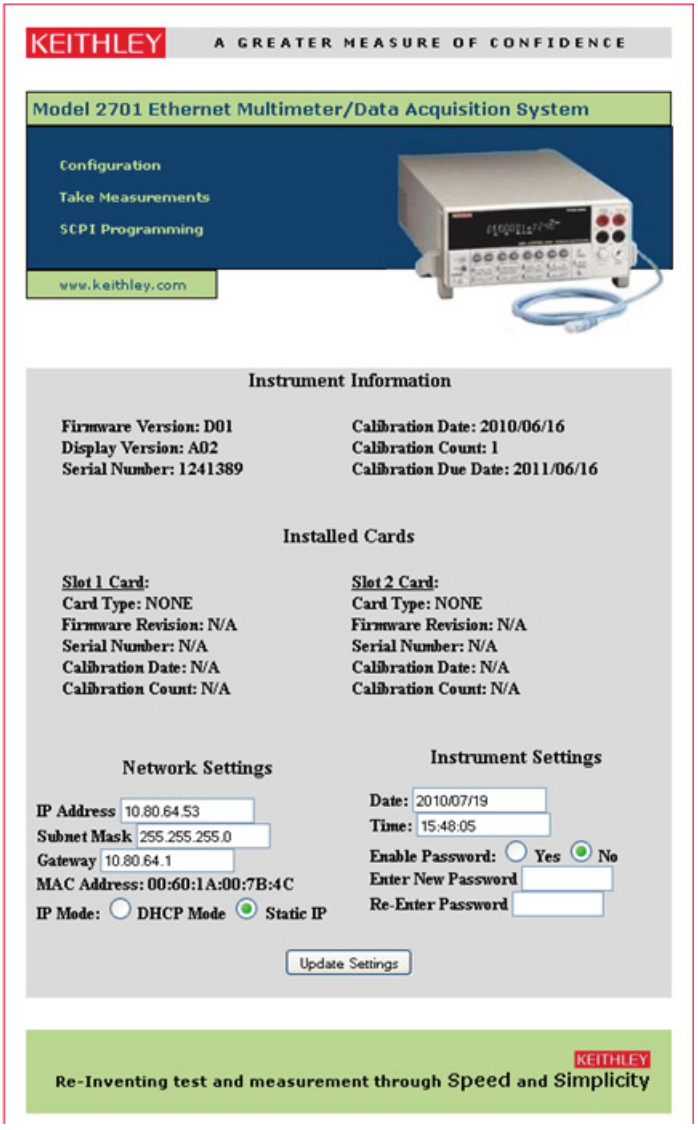
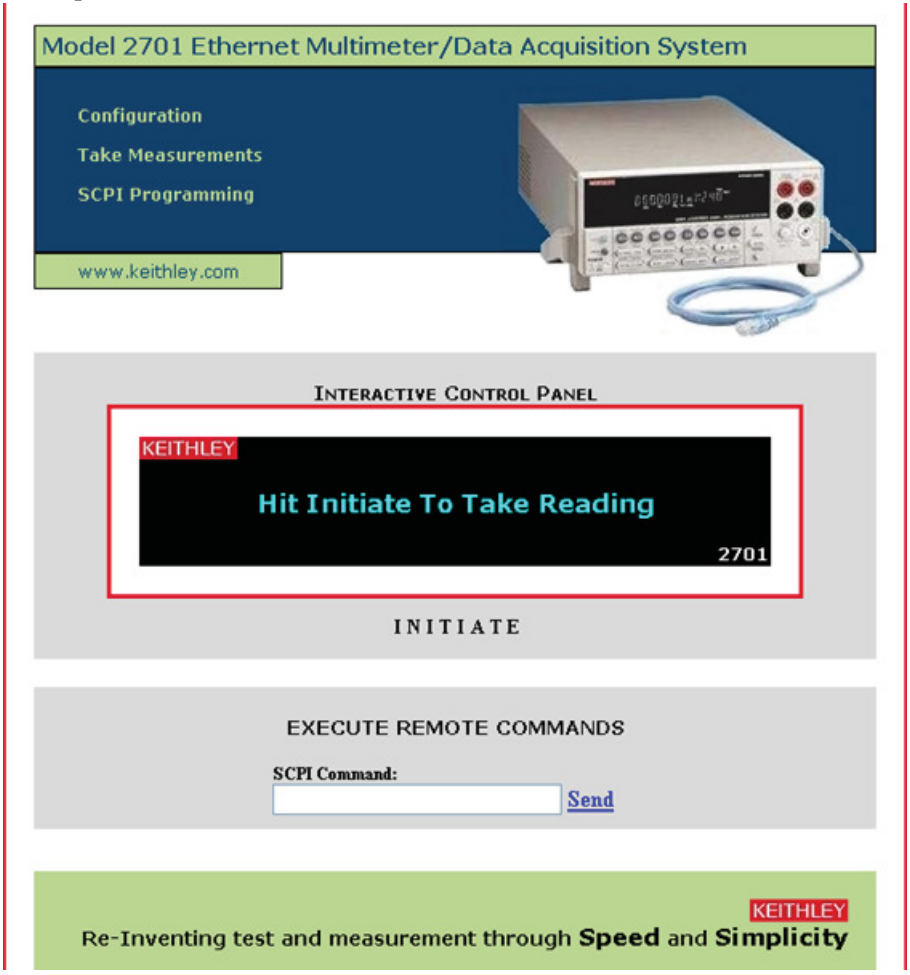


Figure 10-10
Web page control panel



NOTE *After you send a command it is recommended that you add the system error query (for instance, TRIG:COUN 20;:SYST:ERR?) to make sure errors did not occur from the sent command. For example, append :SYST:ERR? to the end of any command to check the status. However, do not add this command to queries because they will return their own data.*

Front panel aspects of Ethernet operation

This section describes aspects of the front panel that are part of Ethernet operation, including messages, status indicators, and the LOCAL key.

Error and status messages

See Appendix C for a list of error and status messages associated with programming. The instrument can be programmed to generate an SRQ and command queries can be performed to check for specific error conditions.

Status indicators

The REM (remote) and SRQ (service request) annunciators show remote operation status. Each of these indicators is described below.

REM

This indicator shows when the instrument is in the remote state. When the instrument is in remote, all front panel keys, except for the LOCAL key, are locked out. When REM is turned off, the instrument is in the local state and front panel operation is restored.

NOTE *If SYSTem:RWLock is in effect, LOCAL will be locked out. If TRIGger:SOURce is set to manual, the TRIG key will be active in remote.*

SRQ

You can program the instrument to generate a service request (SRQ) when one or more errors or conditions occur. When this indicator is on, a service request has been generated. This indicator stays on until the serial poll byte is read or all the conditions that caused SRQ have been cleared. See Section 11, "Status Structure," for more information.

LOCAL key

The LOCAL key cancels the remote state and restores local operation of the instrument.

Pressing the LOCAL key also turns off the REM indicator and returns the display to normal if a user-defined message was displayed.

If the SYSTem:RWLock command is in effect, the LOCAL key is also inoperative.

Programming syntax

The information in this section covers syntax for both common commands and SCPI commands. For information not covered here, see the IEEE-488.2 and SCPI standards. See Sections 12 through 15 for more details on common and SCPI commands.

Command words

Program messages are made up of one or more command words.

Commands and command parameters

Common commands and SCPI commands may or may not use a parameter. The following are some examples:

*SAV <NRf>	Parameter <NRf> required
*RST	No parameter used
SYSTem:BEEPer <b>	Parameter <b> required
SYSTem:PRESet	No parameter used

NOTE *At least one space between the command word and the parameter is required.*

Brackets [ ] — Some command words are enclosed in brackets ([ ]). These brackets are used to denote an optional command word that does not need to be included in the program message. For example:

INITiate[:IMMediate]

These brackets indicate that IMMediate is implied (optional) and does not have to be used. Thus, the above command can be sent in one of two ways:

INITiate
or
INITiate:IMMediate

Notice that the optional command is used without the brackets. When using optional command words in your program, do not include the brackets.

Parameter types — The following are some of the more common parameter types:

<b> Boolean — Used to enable or disable an instrument operation. 0 or OFF disables the operation and 1 or ON enables the operation. Example:

SYSTem:LSYNc ON	Enable line synchronization

<name> Name parameter — Select a parameter name from a listed group. Example:

<name> = NEVer
= NEXt
= ALWays

TRACe:FEED:CONTrol NEXt

<NRf> Numeric representation format — This parameter is a number that can be expressed as an integer (e.g., 8), a real number (e.g., 23.6), or an exponent (2.3E6). Example:

SYSTem:KEY 11 Press EXIT key from over the bus

<n> Numeric value — A numeric value parameter can consist of an NRf number or one of the following name parameters: DEFault, MINimum, MAXimum. When the DEFault parameter is used, the instrument is programmed to the *RST default value. When the MINimum parameter is used, the instrument is programmed to the lowest allowable value. When the MAXimum parameter is used, the instrument is programmed to the largest allowable value. Examples:

ARM:TIMer 0.1	Sets timer to 100 msec.
ARM:TIMer DEFault	Sets timer to 0.1 sec.
ARM:TIMer MINimum	Sets timer to 1 msec.
ARM:TIMer MAXimum	Sets timer to 99999.99 sec.

<clist> Channel list — Specify one or more channels. Example:

ROUTe:SCAN (@101:110) Scan list; slot 1, channels 1-10

<list> List — Specify one or more numbers for a list. Example:

STATus:QUEue:ENABle (-110:-222) Enable errors -110 through -222

Angle brackets < > Angle brackets (< >) are used to denote a parameter type. Do not include the brackets in the program message. For example:

RATio <b>

The <b> indicates a Boolean-type parameter is required. Therefore, to enable channel ratio, you must send the command with the ON or 1 parameter as follows:

RATio ON
RATIO 1

Query commands

This type of command requests (queries) the presently programmed status. It is identified by the question mark (?) at the end of the fundamental form of the command. Most commands have a query form:

TRIGger:TIMer? Queries the timer interval.

Most commands that require a numeric parameter (<n>) can also use the DEFault, MINimum, and MAXimum parameters for the query form. These query forms are used to determine the *RST default value and the upper and lower limits for the fundamental command. Examples are:

TRIGger:TIMer? DEFault	Queries the *RST default value.
TRIGger:TIMer? MINimum	Queries the lowest allowable value.
TRIGger:TIMer? MAXimum	Queries the largest allowable value.

Case sensitivity

Common commands and SCPI commands are not case sensitive. You can use upper or lower case and any case combination. Examples:

*RST	=	*rst
DATA?	=	data?
SYSTem:PRESet	=	system:preset

Long-form and short-form versions

A SCPI command word can be sent in its long-form or short-form version. The command subsystem tables in Section 15 provide the long-form version. However, the short-form version is indicated by upper case characters. Examples:

SYSTem:PRESet	long-form
SYST:PRES	short-form
SYSTem:PRES	long-form and short-form combination

Note that each command word must be in long-form or short-form and not something in between. For example, SYSTe:PRESe is illegal and will generate an error. The command will not be executed.

Short-form rules

Use the following rules to determine the short-form version of any SCPI command:

- If the length of the command word is four letters or less, no short form version exists. Example:

  :auto = :auto

These rules apply to command words that exceed four letters:

- If the fourth letter of the command word is a vowel (including "y"), delete it and all the letters after it. Example

  immediate = imm

- If the fourth letter of the command word is a consonant, retain it but drop all the letters after it. Example:

  format = form

- If the command contains a question mark (?; query) or a non-optional number included in the command word, you must include it in the short-form version. Example:

  :delay? = :del?

- Command words or characters that are enclosed in brackets ([ ]) are optional and need not be included in the program message.

NOTE *For fastest response to commands, always use short forms.*

Program messages

A program message is made up of one or more command words sent by the computer to the instrument. Each common command is a three letter acronym preceded by an asterisk (*). SCPI commands are categorized in the STATus subsystem and are used to explain how command words are structured to formulate program messages.

STATus	Path (Root)
:OPERation	Path
:ENABle <NRf>	Command and parameter
:ENABle?	Query command
:PRESet	Command

Single command messages

The above command structure has three levels. The first level is made up of the root command (STATus) and serves as a path. The second level is made up of another path (:OPERation) and a command (:PRESet). The third path is made up of one command for the :OPERation path. The three commands in this structure can be executed by sending three separate program messages as follows:

stat:oper:enab <NRf>
stat:oper:enab?
stat:pres

In each of the above program messages, the path pointer starts at the root command (stat) and moves down the command levels until the command is executed.

Multiple command messages

You can send multiple command messages in the same program message as long as they are separated by semicolons (;). The following is an example showing two commands in one program message:

stat:oper; stat:oper:enab <NRf>

When the above is sent, the first command word is recognized as the root command (stat). When the next colon is detected, the path pointer moves down to the next command level and executes the command. When the path pointer sees the colon after the semicolon (;), it resets back to the root level and starts over.

Commands that are on the same command level can be executed without having to retype the entire command path. Example:

stat:oper:enab <NRf>; enab?

After the first command (:enab) is executed, the path pointer is at the third command level in the structure. Since :enab? is also on the third level, it can be typed in without repeating the entire path name. Notice that the leading colon for :enab? is not included in the program message. If a colon were included, the path pointer would reset to the root level and expect a root command. Since :enab? is not a root command, an error would occur.

Command path rules

- Each new program message must begin with the root command, unless it is optional (e.g., [SENSe]). If the root is optional, simply treat a command word on the next level as the root. For fastest operation, do not send optional data.
- A colon (:) can be used at the beginning of a program message. However, using the colon slows down execution time. Example:

  stat:pres = :stat:pres
- When the path pointer detects a colon (:) it moves down to the next command level. An exception is when the path pointer detects a semicolon (;), which is used to separate commands within the program message (see next rule).
- When the path pointer detects a colon (:) that immediately follows a semicolon (;), it resets back to the root level.
- The path pointer can only move down. It cannot move up a level. Executing a command at a higher level requires that you start over at the root command.

Using common and SCPI commands in the same message

Both common commands and SCPI commands can be used in the same message as long as they are separated by semicolons (;). A common command can be executed at any command level and will not affect the path pointer. Example:

stat:oper:enab <NRf>; *ESE <NRf>

Program message terminator (PMT)

Each program message must be terminated with an LF (line feed), CR (carriage return), CR-LF or LF-CR. The command processor will hang if your computer does not provide this termination. The following example shows how a multiple command program message must be terminated:

trig:coun 1 <PMT>

Command execution rules

- Commands execute in the order that they are presented in the program message.
- An invalid command generates an error and, of course, is not executed.
- Valid commands that precede an invalid command in a multiple command program message are executed.
- Valid commands that follow an invalid command in a multiple command program message are ignored.

Response messages

A response message is the message sent by the instrument to the computer in response to a query command program message.

Sending a response message

After sending a query command, the response message is placed in the Output Queue.

Multiple response messages

If you send more than one query command in the same program message (see "Multiple command messages," page 10-25), the multiple response messages for all the queries are sent to the computer. The responses are sent in the order the query commands were sent and are separated by semicolons (;). Items within the same query are separated by commas (,). The following example shows the response message for a program message that contains four single item query commands:

0; 1; 1; 0

Response message terminator (RMT)

Each response is terminated with an LF (line feed). The following example shows how a multiple response message is terminated:

0; 1; 1; 0 <RMT>

Message exchange protocol

Two rules summarize the message exchange protocol:

Rule 1. You must always tell the Model 2701 what to send to the computer.

The following two steps must always be performed to send information from the instrument to the computer:

1. Send the appropriate query command(s) in a program message.
2. Retrieve the data from the 2701.

Rule 2. The complete response message must be received by the computer before another program message can be sent to the Model 2701.

RS-232 interface operation

Sending and receiving data

The RS-232 interface transfers data using eight data bits, one stop bit, and no parity. Make sure the controller you connect to the multimeter also uses these settings.

You can break data transmissions by sending a ^C (decimal 3) or ^X (decimal 18) character string to the instrument. This clears any pending operation and discards any pending output.

You can break an RS-232 transmission of buffer readings by pressing LOCAL and then EXIT. The next command to send buffer data (i.e., TRACe:DATA?) will start at the beginning, rather than where the transmission was halted.

Baud rate

The baud rate is the rate at which the Model 2701 multimeter and the programming terminal communicate. Choose one these available rates:

- 115.2k
- 57.6k
- 38.4k
- 19.2k
- 9600
- 4800
- 2400
- 1200
- 600
- 300

The factory selected baud rate is 9600.

When you choose a baud rate, make sure that the programming terminal that you are connecting to the Model 2701 can support the baud rate you selected. Both the multimeter and the other device must be configured for the same baud rate.

Signal handshaking (flow control)

Signal handshaking between the controller and the instrument allows the two devices to communicate to each other regarding being ready or not ready to receive data.

Software flow control

Software flow control is in the form of X__ON and X__OFF characters and is enabled when XonXoFF is selected from the RS232 FLOW menu. When the input queue of the Model 2701 becomes more than I full, the instrument issues an X_OFF command. The control program should respond to this and stop sending characters until the Model 2701 issues the X_ON, which it will do once its input buffer has dropped below half-full. The Model 2701 recognizes X_ON and X_OFF sent from the controller. An X_OFF will cause the Model 2701 to stop outputting characters until it sees an X_ON. Incoming commands are processed after the <CR> character is received from the controller.

NOTE *For RS-232 operation, *OPC or *OPC? should be used with slow responding commands. A list of the slowest responding commands and details on *OPC and *OPC? are provided in Section 12.*

XonXoFF is the FACT and *RST default flow control setting.

If NONE is the selected flow control, then there will be no signal handshaking between the controller and the Model 2701. Data will be lost if transmitted before the receiving device is ready.

NOTE *Even with XonXoFF selected, the computer may lose data from the Model 2701 if the return string is very large (approximately 30,000 or more characters) and one of the higher baud rates is selected. With no flow control (NONE selected), the error occurs with a much smaller return string. Your program could provide some type of error checking for these situations.*

NOTE *Another solution to the problem is to use the TRACe:DATA:SELected? <start>, <count> command to return small portions (100 points) of a very large buffer. With this command, you specify a buffer location (<start>) and the number of readings to return (<count>). See Section 6 for details.*

Hardware flow control

Hardware handshaking can instead be used for flow control. The RS-232 interface provides two control lines (RTS and CTS) for this purpose (see Figure 10-11 and Table 10-4.) When the 2701 is ready to send (RTS) data, it will transmit when it receives the clear to send (CTS) signal from the computer.

Terminator

The Model 2701 can be configured to terminate each program message that it transmits to the controller with any of the following combinations of <CR> and <LF>.

<CR>	Carriage return
<CR+LF>	Carriage return and line feed
<LF>	Line feed
<LF+CR>	Line feed and carriage return

Selecting and configuring RS-232 interface

After selecting (enabling) the RS-232 interface, you will then set the baud rate, flow control, and terminator.

1. Press the SHIFT key and then the RS-232 key. The RS 232 ON or RS 232 OFF message will be displayed.
2. If the RS-232 is already ON, press ENTER and proceed to step 3. Otherwise, press the ▸ key to place the cursor on OFF, press the ▴ or ▾ key to display the ON state, and then press ENTER.

NOTE *Enabling (ON) the RS-232 interface disables (OFF) the Ethernet. Disabling the RS-232 interface enables the Ethernet. Changing the state reboots the Model 2701.*

3. To retain the presently displayed BAUD rate, press ENTER and proceed to step 4. Otherwise, press the ▸ key to place the cursor on the baud rate value, use the ▴ or ▾ key to display the desired baud rate, and then press ENTER.
4. To retain the presently displayed FLOW control, press ENTER and proceed to step 5. Otherwise, press the ▸ key to place the cursor on the flow control setting, use the ▴ or ▾ key to display the alternate flow control setting, and then press ENTER.
5. To retain the presently displayed terminator (Tx TERM), press ENTER. Otherwise, press the ▸ key to place the cursor on the terminator setting, use the ▴ or ▾ key to display the desired terminator, and then press ENTER.

The commands to select and configure the RS-232 interface are listed in Table 10-3.

Table 10-3
SYSTem commands to configure RS-232

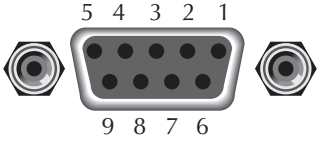
Command	Description
:COMMunicate	Ethernet and RS-232 (serial) commands:
:SELect <name>	Select communications mode; SERial or ETHernet
:SERial	RS-232:
:BAUD <n>	Set baud rate; 300, 600, 1200, 2400, 4800, 9600, 19200, 38400, 57600, or 115200.
:BAUD?	Query baud rate.
:PACE <name>	Control Xon/Xoff flow control; XON (on) or NONE (off).
:PACE?	Query state of flow control.
:TERMinator <name>	Select output terminator; CR, LF, CRLF, or LFCR.
:TERMinator?	Query output terminator.
:CONTrol	Control RTS/CTS hardware handshaking:
:RTS <name>	Enable (IBFull or RFR) or disable (OFF) hardware handshaking.
:RTS?	Query state of hardware handshaking.
:SEND <data>	Send data (serial port) to another instrument.
:ENTer?	Read data from serial port.

RS-232 connections

The RS-232 serial port is connected to the serial port of a computer using a straight-through RS-232 cable terminated with DB-9 connectors. Do not use a null modem cable**.** The serial port uses the transmit (TXD), receive (RXD), ready to send (RTS), clear to send (CTS), and signal ground (GND) lines of the RS-232 standard. Figure 10-11 shows the rear panel connector for the RS-232 interface and Table 10-4 shows the pinout for the connector.

If your computer uses a DB-25 connector for the RS-232 interface, you will need a cable or adapter with a DB-25 connector on one end and a DB-9 connector on the other, wired straight through (not null modem).

Figure 10-11
RS-232 interface connector



Rear Panel Connector

Table 10-4
RS-232 connector pinout

Pin #	Description
1	No connection
2	TXD, transmit data
3	RXD, receive data
4	No connection
5	GND, signal ground
6	Not used
7	RTS, ready to send
8	CTS, clear to send
9	No connection

Table 10-5 provides pinout identification for the 9-pin (DB-9) or 25-pin (DB-25) serial port connector on the computer (PC).

Table 10-5
PC serial port pinout

Signal	DB-9 pin #	DB-25 pin #
DCD, data carrier detect	1	8
RXD, receive data	2	3
TXD, transmit data	3	2
DTR, data terminal ready	4	20
GND, signal ground	5	7
DSR, data set ready	6	6
RTS, request to send	7	4
CTS, clear to send	8	5
RI, ring indicator	9	22

Error messages

See Appendix C for RS-232 error messages (+800 through +808).

11
Status Structure

- Overview — Provides an operational overview of the status structure for the Model 2701.
- Clearing registers and queues — Covers the actions that clear (reset) registers and queues.
- Programming and reading registers — Explains how to program enable registers and read any register in the status structure.
- Status byte and service request (SRQ) — Explains how to program the Status Byte to generate service requests (SRQs). Shows how to use the serial poll sequence to detect SRQs.
- Status register sets — Provides bit identification and command information for the four status register sets: Standard Event Status, Operation Event Status, Measurement Event Status, and Questionable Event Status.
- Queues — Provides details and command information on the Output Queue and Error Queue.

Overview

The Model 2701 provides a series of status registers and queues allowing the operator to monitor and manipulate the various instrument events. The status structure is shown in Figure 11-1. The heart of the status structure is the Status Byte Register. This register can be read by the user's test program to determine if a service request (SRQ) has occurred and what event caused it.

Status byte and SRQ

The Status Byte Register receives the summary bits of four status register sets and two queues. The register sets and queues monitor the various instrument events. When an enabled event occurs, it sets a summary bit in the Status Byte Register. When a summary bit of the Status Byte is set and its corresponding enable bit is set (as programmed by the user), the RQS/MSS bit will set to indicate that an SRQ has occurred.

Status register sets

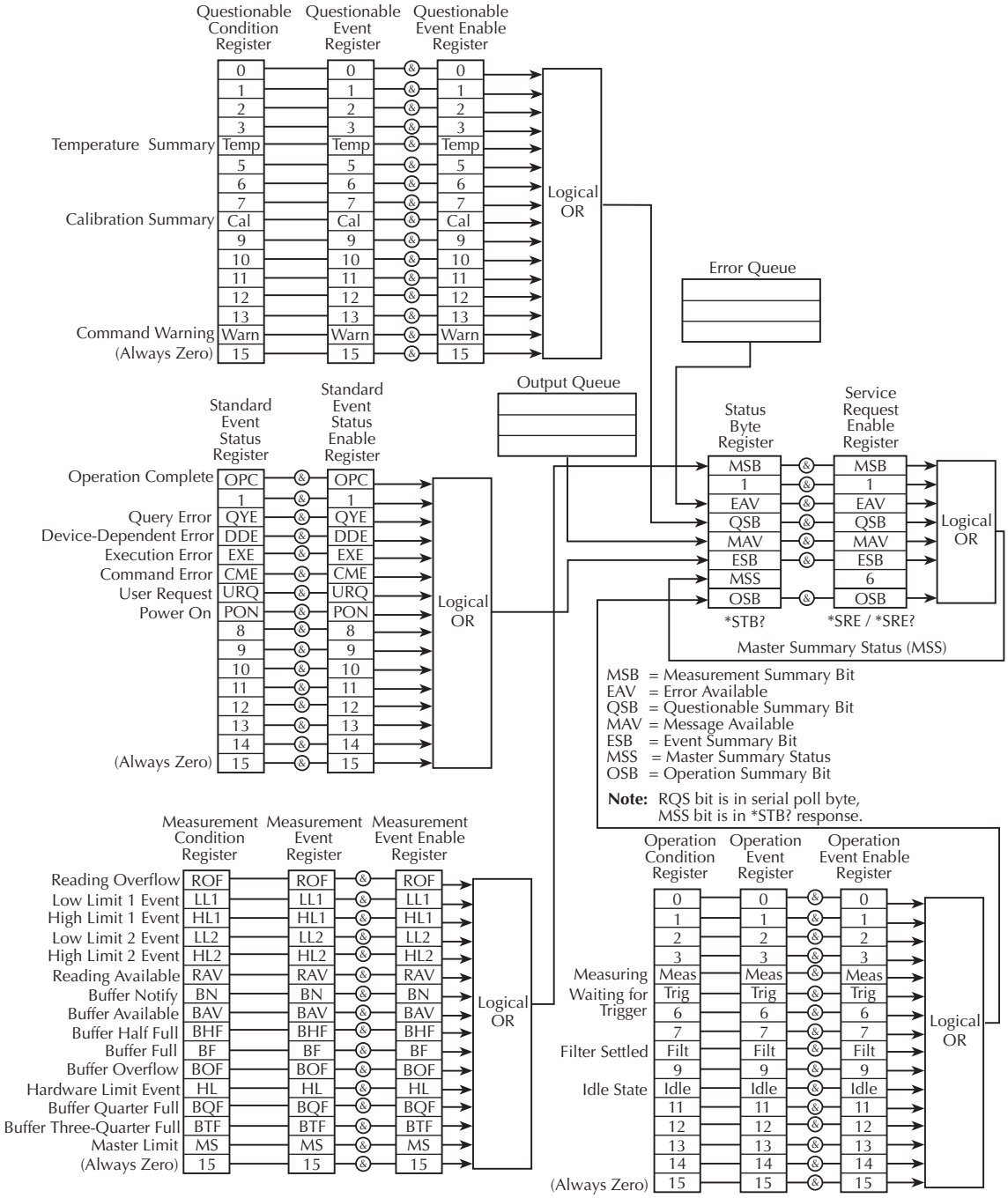
A typical status register set is made up of a condition register, an event register, and an event enable register. A condition register is a read-only register that constantly updates to reflect the present operating conditions of the instrument.

When an event occurs, the appropriate event register bit sets to 1. The bit remains latched to 1 until the register is reset. When an event register bit is set and its corresponding enable bit is set (as programmed by the user), the output (summary) of the register will set to 1, which in turn sets the summary bit of the Status Byte Register.

Queues

The Model 2701 uses an Output Queue and an Error Queue. The response messages to query commands are placed in the Output Queue. As various programming errors and status messages occur, they are placed in the Error Queue. When a queue contains data, it sets the appropriate summary bit of the Status Byte Register.

Figure 11-1
Model 2701 status register structure



Clearing registers and queues

When the Model 2701 is turned on, the bits of all registers in the status structure are cleared (reset to 0) and the two queues are empty. Commands to reset the event, event enable registers, and the Error Queue are listed in Table 11-1. In addition to these commands, any enable register can be reset by sending the 0 parameter value with the individual command to program the register.

*NOTE SYSTem:PRESet and *RST have no effect on status structure registers and queues.*

Table 11-1
Common and SCPI commands to reset registers and clear queues

Commands	Description	Notes
Reset registers		
*CLS	Reset all bits of the following event registers to 0: Standard Event Register Operation Event Register Measurement Event Register Questionable Event Register	1
STATus:PRESet	Reset all bits of the following enable registers to 0: Operation Event Enable Register Measurement Event Enable Register Questionable Event Enable Register	1
Clear error queue		
*CLS	Clear all messages from Error Queue	2
STATus:QUEue:CLEar	Clear messages from Error Queue	3
SYSTem:CLEar	Clear messages from Error Queue	3

Notes:
1. The Standard Event Enable Register is not reset by STATus:PRESet or *CLS. Send the 0 parameter value with *ESE to reset all bits of that enable register to 0 (see "Status byte and service request commands," page 11-10).
2. STATus:PRESet has no effect on the Error Queue.
3. Use either of the two clear commands to clear the Error Queue.

Programming and reading registers

Programming enable registers

The only registers that can be programmed by the user are the enable registers. All other registers in the status structure are read-only registers. The following explains how to ascertain the parameter values for the various commands used to program enable registers. The actual commands are covered later in this section.

A command to program an event enable register is sent with a parameter value that determines the desired state (0 or 1) of each bit in the appropriate register. An enable register can be programmed using any of the following data formats for the parameter value: binary, decimal, hexadecimal, or octal.

The bit positions of the register (Figure 11-2) indicate the binary parameter value. For example, if you wish to sets bits B4, B3, and B1, the binary value would be 11010 (where B4=1, B3=1, B1=1, and all other bits are 0). When you use one of the other formats, convert the binary number to its decimal, hexadecimal, or octal equivalent:

Binary 11010 = Decimal 26 = Hexadecimal 1A = Octal 32

Note that Figure 11-2 includes the decimal weight for each register bit. To set bits B4, B3, and B1, the decimal parameter value would be the sum of the decimal weights for those bits (16+8+2 = 26).

Figure 11-2
16-bit status register

A) Bits 0 through 7

Bit Position	B7	B6	B5	B4	B3	B2	B1	B0
Binary Value	0/1	0/1	0/1	0/1	0/1	0/1	0/1	0/1
Decimal Weights	128 (2^7)	64 (2^6)	32 (2^5)	16 (2^4)	8 (2^3)	4 (2^2)	2 (2^1)	1 (2^0)

B) Bits 8 through 15

Bit Position	B15*	B14	B13	B12	B11	B10	B9	B8
Binary Value	0	0/1	0/1	0/1	0/1	0/1	0/1	0/1
Decimal Weights	___	16384 (2^{14})	8192 (2^{13})	4096 (2^{12})	2048 (2^{11})	1024 (2^{10})	512 (2^9)	256 (2^8)

* By SCPI standard definition, B15 is not used. The bit is always 0.

The <NDN> (non-decimal numeric) parameter type is used to send non-decimal values. These values require a header (#B, #H, or #Q) to identify the data format being sent. The letter in the header can be upper or lower case. The <NRf> (numeric representation format) parameter type is used to send decimal values and does not use a header. The following examples show the proper parameter syntax for setting Bits B5, B3, and B2:

#b101100	Binary format (<NDN> parameter type)
#h2C	Hexadecimal format (<NDN> parameter type)
#q54	Octal format (<NDN> parameter type)
44	Decimal format (<NRf> parameter type)

Valid characters for the non-decimal parameter values are shown as follows:

<NDN> format	Valid characters
Binary	1s and 0s
Hexadecimal	0 through 9 and A through F
Octal	0 through 7

Reading registers

Any register in the status structure can be read by using the appropriate query (?) command. The following explains how to interpret the returned value (response message). The actual query commands are covered later in this section.

The response message will be a value that indicates which bits in the register are set. That value (if not already binary) will have to be converted to its binary equivalent. For example, for a binary value of 100101, bits B5, B2, and B0 are set.

The returned value can be in the binary, decimal, hexadecimal, or octal format. The FORMat:SREGister command is used to select the data format for the returned value (see Table 11-2).

For non-decimal formats, one of the following headers will accompany the returned value to indicate which format is selected:

#B = Header for binary values
#H = Header for hexadecimal values
#Q = Header for octal values

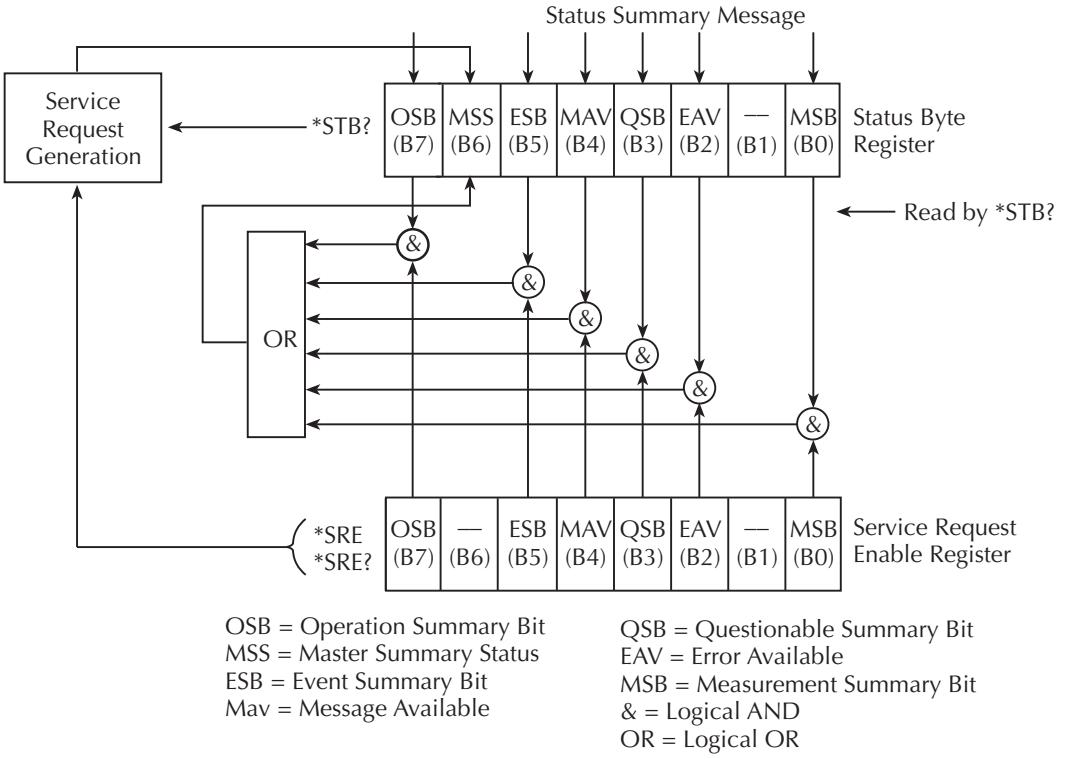
Table 11-2
Data format command for reading status registers

Command	Description	Default
:FORMat:SREGister <name>	Select data format for reading status registers: <name> = ASCii Decimal format HEXadecimal Hexadecimal format OCTal Octal format BINary Binary format	ASCii

Status byte and service request (SRQ)

Service request is controlled by two 8-bit registers: the Status Byte Register and the Service Request Enable Register. Figure 11-3 shows the structure of these registers.

Figure 11-3
Status byte and service request (SRQ)



Status byte register

The summary messages from the status registers and queues are used to set or clear the appropriate bits (B0, B2, B3, B4, B5, and B7) of the Status Byte Register. These summary bits do not latch and their states (0 or 1) are solely dependent on the summary messages (0 or 1). For example, if the Standard Event Register is read, its register will clear. As a result, its summary message will reset to 0, which in turn will reset the ESB bit in the Status Byte Register.

The bits of the Status Byte Register are described as follows:

- Bit B0, Measurement Summary Bit (MSB) — Set summary bit indicates that an enabled measurement event has occurred.
- Bit B1 — Not used.
- Bit B2, Error Available (EAV) — Set summary bit indicates that an error or status message is present in the Error Queue.
- Bit B3, Questionable Summary Bit (QSB) — Set summary bit indicates that an enabled questionable event has occurred.
- Bit B4, Message Available (MAV) — Set summary bit indicates that a response message is present in the Output Queue.
- Bit B5, Event Summary Bit (ESB) — Set summary bit indicates that an enabled standard event has occurred.
- Bit B6, Master Summary Status (MSS) — Set bit indicates that an enabled summary bit of the Status Byte Register is set.
- Bit B7, Operation Summary (OSB) — Set summary bit indicates that an enabled operation event has occurred.

Service request enable register

The generation of a service request is controlled by the Service Request Enable Register. This register is programmed by you and is used to enable or disable the setting of bit B6 (MSS) by the Status Summary Message bits (B0, B2, B3, B4, B5, and B7) of the Status Byte Register. As shown in Figure 11-3, the summary bits are logically ANDed (&) with the corresponding enable bits of the Service Request Enable Register. When a set (1) summary bit is ANDed with an enabled (1) bit of the enable register, the logic "1" output is applied to the input of the OR gate and, therefore, sets the MSS bit in the Status Byte Register.

The individual bits of the Service Request Enable Register can be set or cleared by using the *SRE common command. To read the Service Request Enable Register, use the *SRE? query command. The Service Request Enable Register clears when power is cycled or a parameter value of 0 is sent with the *SRE command (*SRE 0). The commands to program and read the SRQ Enable Register are listed in Table 11-3.

Status byte and service request commands

The commands to program and read the Status Byte Register and Service Request Enable Register are listed in Table 11-3. For details on programming and reading registers, see "Programming enable registers" and "Reading registers".

*NOTE To reset the bits of the Service Request Enable Register to 0, use 0 as the parameter value for the *SRE command (*SRE 0).*

Table 11-3
Status Byte and Service Request Enable Register commands

Command	Description	Default
*STB?	Read Status Byte Register.	
*SRE <NDN> or <NRf>	Program the Service Request Enable Register:	(Note)
	<NDN> = #Bxx…x Binary format (each x = 1 or 0)	
	= #Hx Hexadecimal format (x = 0 to FF)	
	= #Qx Octal format (x = 0 to 377)	
	<NRf> = 0 to 255 Decimal format	
*SRE?	Read the Service Request Enable Register	

Note: *CLS and STATus:PRESet have no effect on the Service Request Enable Register.

Programming example — set MSS (B6) when error occurs

The second command in the following sequence enables EAV (error available). When an invalid command is sent (line 4), bits B2 (EAV) and B6 (MSS) of the Status Byte Register set to 1. The last command reads the Status Byte Register. To determine the exact nature of the error, you will have to read the Error Queue (see "Queues" on page 11-22).

NOTE The following example can be run from the KE2700 Instrument Driver using the example named "PollSRQ" in Table G-1 of Appendix G.

```
*CLS                                ' Clear Error Queue.
*SRE 4                              ' Enable EAV.
FORM:SREG BIN                       ' Select binary format.
*XYZ                                ' Generate error.
*STB?                               ' Read Status Byte Register.
```

Status register sets

As shown in Figure 11-1, there are four status register sets in the status structure of the Model 2701: Standard Event Status, Operation Event Status, Measurement Event Status, and Questionable Event Status.

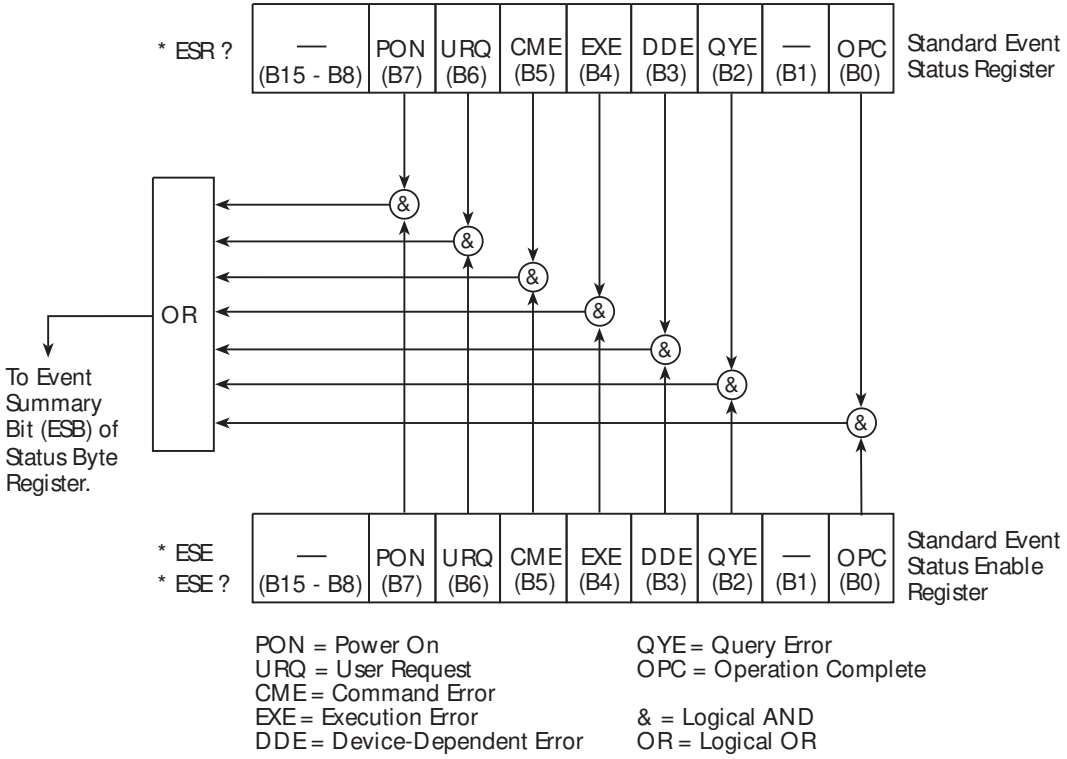
Register bit descriptions

Standard event register

The used bits of the Standard Event Register (Figure 11-4) are described as follows:

- Bit B0, Operation Complete (OPC) — Set bit indicates that all pending selected device operations are completed and the Model 2701 is ready to accept new commands. This bit only sets in response to the *OPC? query command. See Section 12 for details on *OPC and *OPC?.

Figure 11-4
Standard event status



- Bit B1 — Not used.
- Bit B2, Query Error (QYE) — Set bit indicates that you attempted to read data from an empty Output Queue.

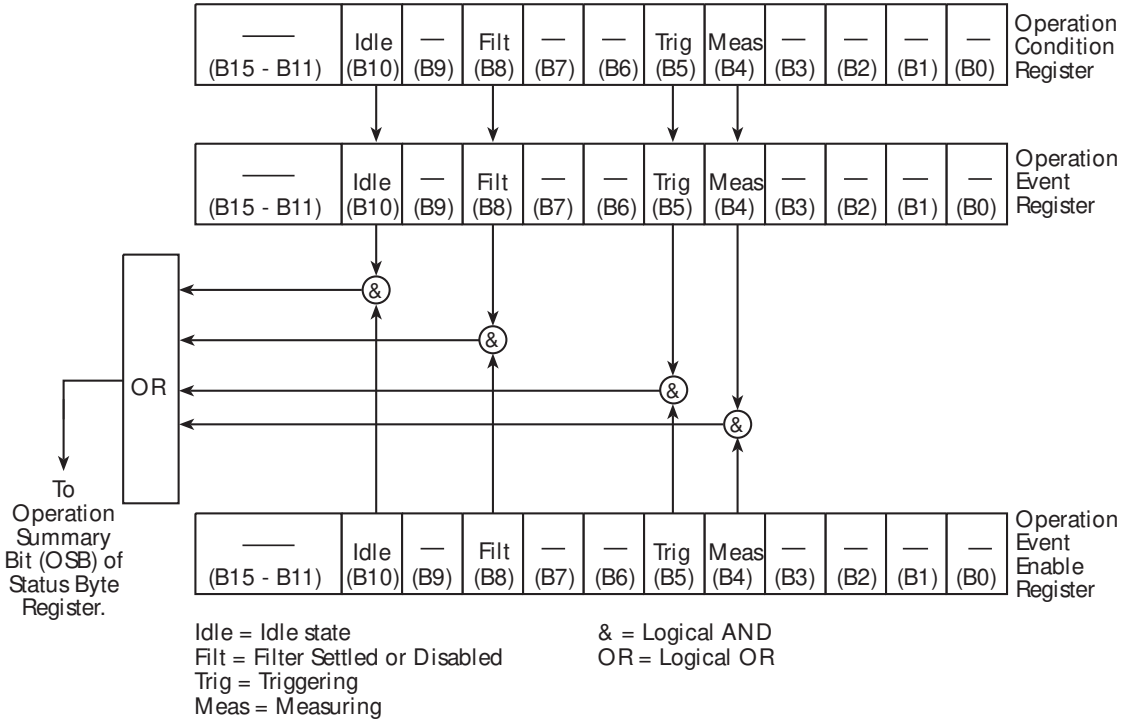
- Bit B3, Device-Dependent Error (DDE) — Set bit indicates that an instrument operation did not execute properly. Some of the errors specific to the Model 2701 that will set this bit include the following:
  - Error +516: Battery backed RAM error — Data stored in RAM has been lost. Replace the battery if frequent failures occur.
  - Error +517: Cannot resume scan — Due to a card ID change, auto scan has disabled. The scan will not resume after a power interruption. For details, see "Scan configuration — Auto scan," page 7-21."
  - Error +520: Saved setup scancard mismatch — Settings for a user setup or power-on setup do not match the switching module types presently installed. For details, see "Defaults and user setups," page 1-21.
  - Error +523: Card hardware error — Communication with the microprocessor on a switching module card has been lost.
  - Error +524: Unsupported card detected — The Model 2701 has detected an installed Model 77XX switching module that is not supported by the current version of firmware.
- Bit B4, Execution Error (EXE) — Set bit indicates that the Model 2701 detected an error while trying to execute a command.
- Bit B5, Command Error (CME) — Set bit indicates that a command error has occurred:
  - IEEE-488.2 syntax error – Instrument received a message that does not follow the defined syntax of the IEEE-488.2 standard.
  - Semantic error – Instrument received a command that was misspelled or received an optional IEEE-488.2 command that was not implemented.
  - The instrument received a Group Execute Trigger (GET) inside a program message.
- Bit B6, User Request (URQ) — Set bit indicates that the LOCAL key on the Model 2701 front panel was pressed.
- Bit B7, Power On (PON) — Set bit indicates that the Model 2701 has been turned off and turned back on since the last time this register has been read.

Operation event register

The bits of the Operation Event Register (Figure 11-5) are described as follows:

- Bits B0 through B3 — Not used.
- Bit B4, Measuring (Meas) — Set bit indicates that the instrument is performing a measurement.
- Bit B5, Waiting for Trigger (Trig) — Set bit indicates that the Model 2701 is in the trigger layer waiting for a trigger event to occur.
- Bits B6 and B7 — Not used.
- Bits B8, Filter Settled (Filt) — Set bit indicates that the filter has settled or the filter is disabled.
- Bit B9 — Not used.
- Bit B10, Idle State (Idle) — Set bit indicates the Model 2701 is in the idle state.
- Bits B11 through B15 — Not used.

Figure 11-5
Operation event status



Measurement event register

The used bits of the Measurement Event Register (Figure 11-6) are described as follows:

- Bit B0, Reading Overflow (ROF) — Set bit indicates that the reading exceeds the measurement range of the instrument.
- Bit B1, Low Limit 1 Event (LL1) — Set bit indicates that a reading has reached or exceeded Low Limit 1.
- Bit B2, High Limit 1 Event (HL1) — Set bit indicates that a reading has reached or exceeded High Limit 1.
- Bit B3, Low Limit 2 Event (LL2) — Set bit indicates that a reading has reached or exceeded Low Limit 2.
- Bit B4, High Limit 2 Event (HL2) — Set bit indicates that a reading has reached or exceeded High Limit 2.
- Bit B5, Reading Available (RAV) — Set bit indicates that a reading was taken and processed.

NOTE A programming example to read the RAV bit is provided in "Example 2 – Read RAV bit of measurement event register" on page 11-20.

- Bit B6, Buffer Notify (BN) — Set bit is a notification that the user-specified number of readings have been stored in the buffer. The TRACe:NOTify command specifies the number of stored readings that will set this bit (see Section 6 for details).
- Bit B7, Buffer Available (BAV) — Set bit indicates that there are at least two readings in the buffer.
- Bit B8, Buffer Half Full (BHF) — Set bit indicates that the trace buffer is half full.

NOTE A programming example to read the BHF bit is provided in "Example 3 – Read BHF bit of measurement event register" on page 11-20.

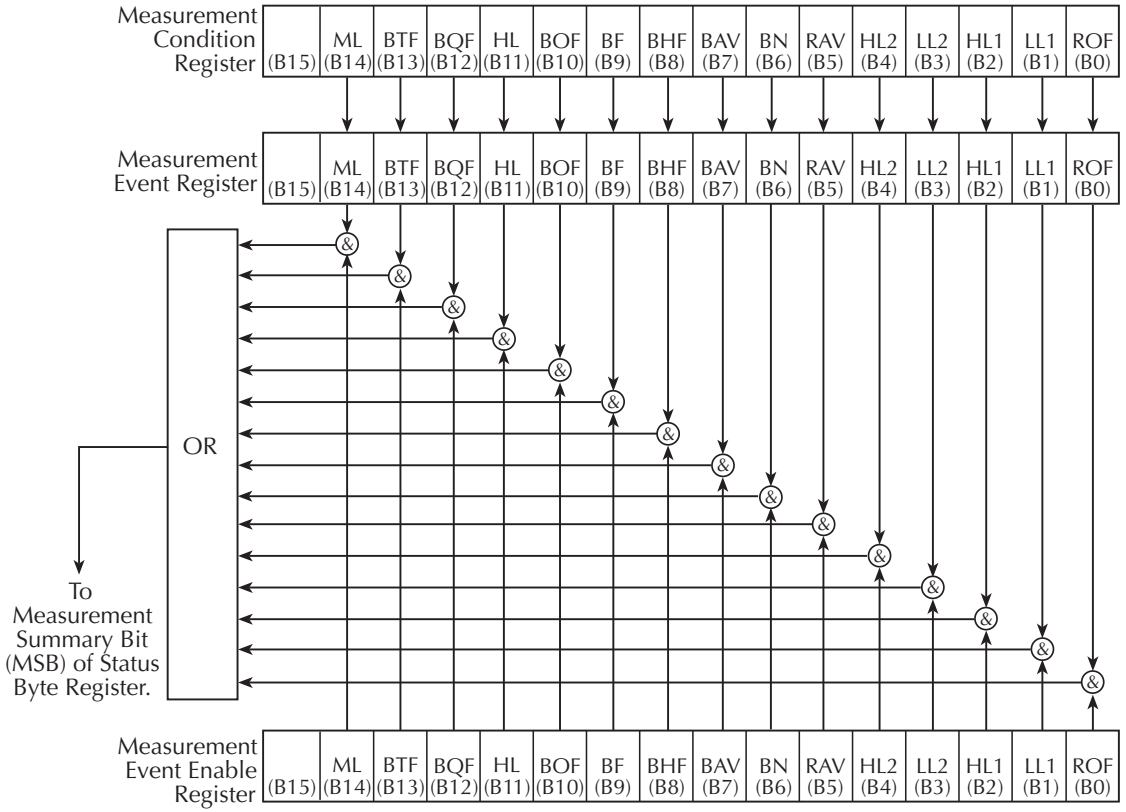
- Bit B9, Buffer Full (BF) — Set bit indicates that the trace buffer is full.
- Bit B10, Buffer Overflow (BOF) — Set bit indicates that the filled buffer has wrapped and written over previously stored readings.
- Bit B11, Hardware Limit Event (HL) — Set bit indicates that a reading has exceeded the hardware limit.
- Bit B12, Buffer Quarter Full (BQF) — Set bit indicates that the trace buffer is one-quarter full.

NOTE Bits B12 (¼ full) and B13 (¾ full) are not intended to be used with buffer sizes smaller than four readings.

- Bit B13, Buffer Three-Quarter Full (BTF) — Set bit indicates that the trace buffer is three-quarters full.

- Bit B14, Master Limit (ML) — Set bit indicates that one or more of the other limits have been reached or exceeded.
- Bit B15 — Not used.

Figure 11-6
Measurement event status



ML = Master Limit
BTF = Buffer Three-quarter Full
BQF = Buffer Quarter Full
HL = Hardware Limit Event
BOF = Buffer Overflow
BF = Buffer Full
BHF = Buffer Half Full
BAV = Buffer Available
BN = Buffer Notify
RAV = Reading Available
HL2 = High Limit 2 Event
LL2 = Low Limt 2 Event
HL1 = High Limit 1 Event
LL1 = Low Limit 1 Event
ROF = Reading Overflow

& = Logical AND
OR = Logical OR

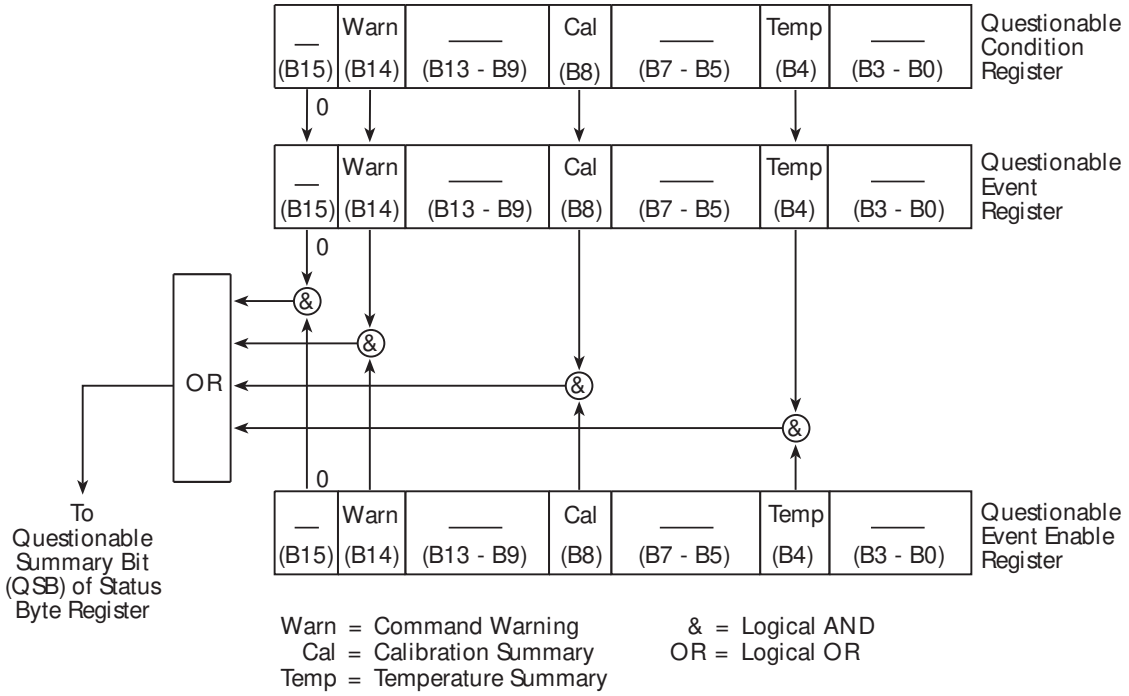
Questionable event register

The used bits of the Questionable Event Register (Figure 11-7) are described as follows:

- Bits B0 through B3 — Not used.
- Bit B4, Temperature Summary (Temp) — Set bit indicates that an invalid reference junction measurement has occurred for thermocouple temperature measurements.
- Bits B5, B6, and B7 — Not used.
- Bit B8, Calibration Summary (Cal) — Set bit indicates that an invalid calibration constant was detected during the power-up sequence. The instrument will instead use a default calibration constant. This error will clear after successful calibration of the instrument.
- Bits B9 through B13 — Not used.
- Bit B14, Command Warning (Warn) — Set bit indicates that a Signal Oriented Measurement Command parameter has been ignored.
- Bit B15 — Not used.

NOTE Whenever a questionable event occurs, the ERR annunciator will turn on. The annunciator will turn off when the questionable event clears.

Figure 11-7
Questionable event status



Condition registers

As Figure 11-1 shows, each status register set (except the Standard Event Register set) has a condition register. A condition register is a real-time, read-only register that constantly updates to reflect the present operating conditions of the instrument. For example, while the Model 2701 is in the idle state, bit B10 (Idle) of the Operation Condition Register will be set. When the instrument is taken out of idle, bit B10 clears.

The commands to read the condition registers are listed in Table 11-4. For details on reading registers, see "Reading registers," page 11-7.

Table 11-4
Condition register commands

Command	Description
STATus:OPERation:CONDition?	Read Operation Condition Register.
STATus:MEASurement:CONDition?	Read Measurement Condition Register.
STATus:QUEStionable:CONDition?	Read Questionable Condition Register.

Note: The format of the response messages for the above queries is set by the FORMatt:SREGister command.

Event registers

As Figure 11-1 shows, each status register set has an event register. When an event occurs, the appropriate event register bit sets to 1. The bit remains latched to 1 until the register is reset. Reading an event register clears the bits of that register. *CLS resets all four event registers.

The commands to read the event registers are listed in Table 11-5. For details on reading registers, see "Reading registers," page 11-7.

Table 11-5
Event register commands

Command	Description
*ESR?	Read Standard Event Status Register.
STATus:OPERation:[:EVENt]?	Read Operation Event Register.
STATus:MEASurement:[:EVENt]?	Read Measurement Event Register.
STATus:QUEStionable:[:EVENt]?	Read Questionable Event Register.

Notes:
1. The format of the response messages for the above queries is set by the FORMatt:SREGister command.
2. Power-up and *CLS resets all bits of all event registers to 0. STATus:PRESet has no effect.

Event enable registers

As Figure 11-1 shows, each status register set has an enable register. Each event register bit is logically ANDed (&) to a corresponding enable bit of an enable register. Therefore, when an event bit is set and the corresponding enable bit is set (as programmed by the user), the output (summary) of the register will set to 1, which in turn sets the summary bit of the Status Byte Register.

The commands to program and read the event enable registers are listed in Table 11-6. For details on programming and reading registers, see "Programming enable registers," page 11-5, and "Reading registers," page 11-7.

NOTE *The bits of any enable register can be reset to 0 by sending the 0 parameter value with the appropriate enable command (i.e. STATus:OPERation:ENABle 0).*

Table 11-6
Event enable registers commands

Command	Description
*ESE <NDN> or <NRf> *ESE?	Program Standard Event Enable Register. Read Standard Event Enable Register.
STATus:OPERation:ENABle <NDN> or <NRf> STATus:OPERation:ENABle?	Program Operation Event Enable Register. Read enable register.
STATus:MEASurement:ENABle <NDN> or <NRf> STATus:MEASurement:ENABle?	Program Measurement Event Enable Register. Read enable register.
STATus:QUEStionable:ENABle <NDN> or <NRf> STATus:QUEStionable:ENABle?	Program Questionable Event Enable Register. Read enable register.

Parameters:

<NDN>	= #Bxx…x	Binary format (each x = 1 or 0)
	= #Hx	Hexadecimal format (x = 0 to 7FFF)
	= #Qx	Octal format (x = 0 to 77777)
<NRf>	= 0 to 32767	Decimal format

Notes:
1. The format of the response messages for the above queries is set by the FORMatt:SREGister command.
2. Power-up and STATus:PRESet resets all bits of all enable registers to 0. *CLS has no effect.

Programming examples

Example 1 – Program and read a register set

NOTE The following example can be run from the KE2700 Instrument Driver using the example named "Prmr" in Table G-1 of Appendix G.

The following command sequence programs and reads the measurement register set:

```
STAT:MEAS:ENAB 512                ' Enable BFL (buffer full).
STAT:MEAS:COND?                   ' Read Measurement Condition Register.
STAT:MEAS?                        ' Read Measurement Event Register.
```

*NOTE Examples 2 and 3 demonstrate the proper method to read an individual bit of an event register. In general, the state of an event register bit is determined by enabling the event bit, then reading the status byte (*STB?).*

Example 2 – Read RAV bit of measurement event register

The following command sequence demonstrates the proper method to read the RAV bit of the measurement event register:

```
*RST                 ' Put 2701 in "one-shot" mode.
*CLS                 ' Clear measurement event register.
STAT:PRES            ' Clear measurement event enable register.
STAT:MEAS:ENAB 32    ' Enable RAV bit (B5)of the measurement event register.
INIT                 ' Trigger one measurement.
*STB?                ' Read status byte register.
```

*CLS and STAT:PRES resets the measurement register bits to zero. The :ENAB command enables the reading available bit B5 (RAV) of the measurement event register. When a reading is triggered and becomes available, bit B0 (MSB) of the status byte will set. INIT triggers a reading and *STB? reads the status byte.

Since you are only interested in bit B0 of the status byte, it is recommended that your program routine mask out the other bits, which may also be set. For example, *STB? may return decimal "17". The binary bit pattern for decimal 17 is as follows:

B7	B6	B5	B4	B3	B2	B1	B0	
0	0	0	1	0	0	0	1	*STB? returns decimal "17" (B4 and B0 set)

If, in your program, you logically AND the above returned binary value with 00000001, you will mask out bits B1 through B7:

B7	B6	B5	B4	B3	B2	B1	B0	
0	0	0	1	0	0	0	1	*STB? returns decimal 17 (B0 and B4 set)
0	0	0	0	0	0	0	1	Mask to read B0 (decimal 1)
0	0	0	0	0	0	0	1	Result of logic AND operation (decimal 1)

As shown in the above result for the AND operation, when B0 is set, your program routine will generate a "1" to indicate that RAV is set. If B0 is not set (0), the AND operation will result in "0" to indicate that RAV is not set.

Example 3 – Read BHF bit of measurement event register

The buffer half full bit (BHF) is read in the same manner that the RAV bit was read in Example 2. The difference being that the BHF bit is enabled (not the RAV bit). The following example performs 500 measurements and stores them in the buffer.

NOTE Details on using the buffer is provided in Section 6.

While measuring and storing readings, the status byte is continuously read to detect when the BHF bit sets. This example also shows how to use *OPC (operation complete) to determine when the measure-measure process is finished.

```
*RST                ' Put 2701 in "one-shot" mode.
*CLS                ' Clears measurement event register.
STAT:PRES           ' Clears measurement event enable register.
STAT:MEAS:ENAB 256  ' Enables BHF bit B8 of the measurement event register.
*ESE 1              ' Enables OPC bit B0 of the standard event register.
TRAC:POIN 500       ' Sets buffer size to 500 readings.
TRAC:FEED SENS      ' Sets to store raw readings.
TRIG:COUN 500       ' Sets 2701 to perform 500 measurements.
TRAC:FEED:CONT NEXT ' Enables buffer.
INIT                ' Starts measurement and storage process.
*OPC                ' Sets OPC bit B0 of standard event register after the
                    ' measure-store process is finished.
```

While readings are being triggered and stored in the buffer, the following command (*STB?) can be put into a program loop to continuously read the status byte.

```
*STB?               ' Read status register.
```

By masking the status byte with binary 00000001 (decimal 1), only B0 will be read by *STB?. The AND'ed result of the mask and the *STB? response will be either "0" (BHF clear) or "1" (BHF set).

In the above command sequence, *ESE 1 enables the OPC bit. After *OPC is sent, the OPC bit will set when the measure-store process is finished. After the BHF bit sets, you can then continuously read the status byte to determine when the OPC bit sets. When OPC sets, bit B5 (ESB) in the status byte sets. Since this time you only want to read bit B5, a different mask will be needed:

B7	B6	B5	B4	B3	B2	B1	B0	
0	0	1	0	0	0	0	0	Mask to read B5 (decimal 32)

When a returned value for *STB? is AND'ed with the above mask, it will read "0" (OPC clear) or "32" (OPC set).

NOTE *More information on *OPC is provided in Section 12.*

Queues

The Model 2701 uses two queues, which are first-in, first-out (FIFO) registers:

- Output Queue — Used to hold reading and response messages.
- Error Queue — Used to hold error and status messages.

The Model 2701 status model (Figure 11-1) shows how the two queues are structured with the other registers.

Output queue

The Output Queue holds data that pertains to the normal operation of the instrument. For example, when a query command is sent, the response message is placed in the Output Queue.

When data is placed in the Output Queue, the Message Available (MAV) bit in the Status Byte Register sets. A data message is cleared from the Output Queue when it is read. The Output Queue is considered cleared when it is empty. An empty Output Queue clears the MAV bit in the Status Byte Register.

An appropriate query command is used to read a message from the Output Queue.

Error queue

The Error Queue holds error and status messages. When an error or status event occurs, a message that defines the error/status is placed in the Error Queue.

When a message is placed in the Error Queue, the Error Available (EAV) bit in the Status Byte Register is set. An error/status message is cleared from the Error Queue when it is read. The Error Queue is considered cleared when it is empty. An empty Error Queue clears the EAV bit in the Status Byte Register.

The Error Queue holds up to 10 error/status messages. The commands to read the Error Queue are listed in Table 11-7. When you read a message in the Error Queue, the "oldest" message is read and then removed from the queue. If the queue becomes full, the message "350, 'Queue Overflow'" will occupy the last memory location. On power-up, the Error Queue is empty. When empty, the message "0, No Error" is placed in the queue.

Messages in the Error Queue are preceded by a code number. Negative (-) numbers are used for SCPI-defined messages and positive (+) numbers are used for Keithley-defined messages. The messages are listed in the appendices at the end of this manual.

On power-up, all error messages are enabled and will go into the Error Queue as they occur. Status messages are not enabled and will not go into the queue. As listed in Table 11-7, there are commands to enable and/or disable messages. For these commands, the <list> parameter is used to specify which messages to enable or disable. The messages are specified by their codes. The following examples show various forms for using the <list> parameter.

<list>	= (-110)	Single message
	= (-110:-222)	Range of messages (-110 through -222)
	= (-110:-222, -220)	Range entry and single entry (separated by a comma)

When you enable messages, messages not specified in the list are disabled. When you disable messages, each listed message is removed from the enabled list.

NOTE *To prevent all messages from entering the Error Queue, send the enable command along with the null list parameter as follows:*

STATus:QUEue:ENABle ().

Table 11-7
Error queue commands

Command	Description	Notes
STATus:QUEue:[:NEXT]?	Read and clear oldest error/status (code and message).	1
STATus:QUEue:ENABle <list>	Specify error and status messages for Error Queue.	2
STATus:QUEue:ENABle?	Read the enabled messages.	
STATus:QUEue:DISable <list>	Specify messages not to be placed in queue.	2
STATus:QUEue:DISable?	Read the disabled messages.	
STATus:QUEue:CLEar	Clear messages from Error Queue.	
SYSTem:ERRor?	Read Error Queue.	1
SYSTem:CLEar	Clear messages from Error Queue.	

Notes:
1. Power-up and *CLS empties the Error Queue. STATus:PRESet has no effect.
2. Power-up enables error messages and disables status messages. *CLS and STATus:PRESet have no effect.

Programming example — read error queue

The following example can be run from the KE2700 Instrument Driver using the example named "ReadErrorQueue" in Table G-1 of Appendix G.

The following command reads the error queue:

```
STAT:QUE?
```

12
Common Commands

Common commands (summarized in Table 12-1) are device commands that are common to all devices on the bus. These commands are designated and defined by the IEEE-488.2 standard.

Table 12-1
Common commands and queries

Mnemonic	Name	Description	Ref
*CLS	Clear status	Clears all event registers and error queue.	Sec 11
*ESE <NDN) or <NRf>	Event enable command	Program the standard event enable register.	Sec 11
*ESE?	Event enable query	Read the standard event enable register.	Sec 11
*ESR?	Event status register query	Read the standard event enable register and clear it.	Sec 11
*IDN?	Identification query	Returns the manufacturer, model number, serial number, and firmware revision levels of the unit.	A
*OPC	Operation complete command	Set the operation complete bit in the standard event register after all pending commands have been executed.	B
*OPC?	Operation complete query	Places an ASCII "1" into the output queue when all pending selected device operations have been completed.	C
*OPT?	Option query	Returns the model numbers of the switching modules installed in the Model 2701. Returns "NONE" if a slot is empty.	D
*RCL <NRf>	Recall command	Returns Model 2701 to the user-saved setup (0, 1, 2, 3, or 4).	E
*RST	Reset command	Returns Model 2701 to the *RST default conditions.	F
*SAV <NRf>	Save command	Saves the present setup as the user-saved setup (0, 1, 2, 3, or 4).	E
*SRE <NDN> or <NRf>	Service request enable command	Programs the service request enable register.	Sec 11
*SRE?	Service request enable query	Reads the service request enable register.	Sec 11
*STB?	Status byte query	Reads the status byte register.	Sec 11
*TRG	Trigger command	Sends a bus trigger to Model 2701.	G
*TST?	Self-test query	Performs a checksum test on ROM and returns the result.	H
*WAI	Wait-to-continue command	Wait until all previous commands are executed.	I

A *IDN? — identification query

Reads identification code

The identification code includes the manufacturer, model number, serial number, and firmware revision levels and is sent in the following format:

KEITHLEY INSTRUMENTS Model 2701, xxxxxxx, yyyyy/zzz

Where: xxxxxxx is the serial number.

yyyyy/zzzzz is the firmware revision levels of the digital board ROM and display board ROM.

B *OPC — Operation Complete

Set the OPC bit in the standard event register after all pending commands are complete.

Description

After the *OPC command is sent, the Operation Complete bit (bit B0) of the Standard Event Status Register will set immediately after the last pending command is completed. If the corresponding bit (Bit B0) in the Standard Event Enable Register and Bit 5 (Event Summary Bit) of the Service Request Enable Register is set, the MSS (Master Summary Status) bit in the Status Byte Register will set.

When used with the immediate initiation command (:INITiate), the OPC bit in the Standard Event Status Register will not set until the Model 2701 goes back into the idle state. The :INIT command operation is not considered finished until the Model 2701 goes back into the idle state. See the description for *WAI for more information on command execution.

Programing example – The first group of commands program sends the *OPC command after the :INITiate command and verifies that the OPC bit in the Standard Event Status Register does not set while the instrument continues to make measurements (not in idle). The second group of commands return the Model 2701 to the idle state and verifies that the OPC bit did set.

```
SYST:PRES                    ' Returns 2701 to default setup.
INIT:CONT OFF                ' Disables continuous initiation.
ABORt                        ' Aborts operation. Places 2701 in idle.
INIT:IMM                     ' Initiate one trigger cycle.
*OPC                         ' Sends the OPC command.
*ESR?                        ' Reads the Standard Event Status Register.
```

The returned value of 0 denotes that the bit (bit 0) is not set indicating that the :INITiate operation is not complete.

```
ABORt                          ' Aborts operation. Places 2701 in idle.
*ESR?                          ' Reads the Standard Event Status Register.
```

The returned value of 1 denotes that the bit (bit 1) is set indicating that the :INITiate operation is now complete.

```
SYST:PRES                      ' Returns 2701 to default setup.
```

*NOTE The following commands take a long time to process and may benefit from using *OPC or *OPC?:*

- **RST and SYST:PRES*
- **RCL and *SAV*
- *ROUT:MULT:CLOS and ROUT:MULT:OPEN – Only if the <clist> is long.*
- *CALC2:IMM and CALC2:IMM?– Only when performing the standard deviation calculation on a large buffer. A 450,000 point buffer takes around 5 to 6 seconds.*

*NOTE A programming example in Section 11 (Example 3 located after Table 11-6) shows how to use *OPC to determine when a measure-store process is finished.*

C *OPC?—Operation Complete Query

Place a '1' in the output queue after all pending operations are completed

Description

When this common command is sent, an ASCII "1" will be placed in the Output Queue after the last pending operation is completed. The "1" in the Output Queue will be sent to the computer.

The "1" in the Output Queue will set the MAV (Message Available) bit (B4) of the Status Byte Register. If the corresponding bit (B4) in the Service Request Enable Register is set, the RQS/MSS (Request for Service/Master Summary Status) bit in the Status Byte Register will set.

When used with the Initiate Immediately command (:INITiate), a "1" will not be placed into the Output Queue until the Model 2701 goes back into the idle state. The :INIT command operation is not considered finished until the Model 2701 goes back into the idle state. See the description for *WAI for more information on command execution.

The execution of OPC? is not completed until it has placed the "1" in the Output Queue.

Programming example – The following command sequence demonstrates how to use *OPC? to signal the end of a measurement process:

```
SYST:PRES                    ' Returns 2701 to default setup.
INIT:CONT OFF                ' Disables continuous initiation.
ABORt                        ' Aborts operation. Places 2701 in idle.
TRIG:COUN 1                  ' These two commands configure the 2701
SAMP:COUN 5                  ' to perform five measurements.
INIT                         ' Starts measurement process.
*OPC?                        ' Sends OPC? command.
```

After all five measurements are performed and the instrument returns to the idle state, an ASCII '1' will be placed in the Output Queue. The '1' from the Output Queue is sent to the computer.

```
SYST:PRES                    ' Returns 2701 to default setup.
```

NOTE *The following commands take a long time to process and may benefit from using *OPC or *OPC?:*

- **RST and SYST:PRES*
- **RCL and *SAV*
- *ROUT:MULT:CLOS and ROUT:MULT:OPEN – Only if the <clist> is long.*
- *CALC2:IMM and CALC2:IMM?– Only when performing the standard deviation calculation on a large buffer. A 450,000 point buffer takes around 5 to 6 seconds.*

D *OPT? — option query

Query installed switching modules

Use this query command to determine which switching modules are installed in the Model 2701. For example, if a Model 7703 is installed in slot 1 and the other slot is empty, the response message will look like this:

7703, NONE

Note that the model number of an installed pseudocard is returned in the same manner. See Section 2 for details on pseudocards.

E *SAV <NRf> — save / *RCL <NRf> — recall

*SAV <NRf> — save: Save present setup in memory

*RCL <NRf> — recall: Return to setup stored in memory

Parameters
0 = Memory location 0
1 = Memory location 1
2 = Memory location 2
3 = Memory location 3
4 = Memory location 4

Use the *SAV command to save the present instrument setup configuration in memory for later recall. Any control affected by *RST can be saved by the *SAV command. The *RCL command is used to restore the instrument to the saved setup configuration. Five setup configurations can be saved and recalled. A saved setup is approximately 4k bytes in size.

Model 2701 ships from the factory with SYSTem:PRESet defaults loaded into the available setup memory. If a recall error occurs, the setup memory defaults to the SYSTem:PRESet values.

NOTE **OPC or *OPC? should be used with *SAV and *RCL, which are slow responding commands. Details on *OPC and *OPC? are provided in this section.*

Programming example:

```
*SAV 2           ' Save present setup in memory location 2.
*RST             ' Return 2701 to RST defaults.
*RCL 2           ' Return (recall) 2701 to setup stored in memo location 2.
```

F *RST — reset

Return Model 2701 to RST defaults

When the *RST command is sent, Model 2701 performs the following operations:

1. Returns Model 2701 to the RST default conditions (see "Default" column of SCPI tables).
2. Cancels all pending commands.
3. Cancels response to any previously received *OPC and *OPC? commands.

NOTE **OPC or *OPC? should be used with *RST, which is a slow responding command. Details on *OPC and *OPC? are provided in this section.*

G *TRG — trigger

Send bus trigger to Model 2701

Use the *TRG command to issue a trigger to Model 2701. Use the *TRG command as an event to control operation. Model 2701 reacts to this trigger if BUS is the programmed arm control source. The control source is programmed from the TRIGger subsystem.

NOTE *Details on triggering are provided in Section 8.*

Programming example — The following command sequence configures Model 2701 to be controlled by bus triggers. The last line, which sends a bus trigger, triggers one measurement. Each subsequent bus trigger will also trigger a single measurement.

NOTE *The following example can be run from the KE2700 Instrument Driver using the example named "BusTrg" in Table G-1 of Appendix G.*

```
*RST                                    ' Restore RST defaults.
TRIG:SOUR BUS                           ' Select BUS control source.
TRIG:COUN INF                           ' Set trigger layer count to infinity.
INIT                                    ' Take 2701 out of idle.
*TRG                                    ' Trigger one measurement.
```

H *TST? — self-test query

Run self test and read result

Use this query command to perform a checksum test on ROM. The command places the coded result (0 or 1) in the output queue. The coded result is sent from the output queue to the computer.

A returned value of zero (0) indicates that the test passed and a value of one (1) indicates that the test failed.

I *WAI — Wait-to-Continue

Prevent execution of commands until previous commands are completed

Description

Two types of device commands exist:

- Sequential commands – A command whose operations are allowed to finish before the next command is executed.
- Overlapped commands – A command that allows the execution of subsequent commands while device operations of the Overlapped command are still in progress.

Use the *WAI command to suspend the execution of subsequent commands until the device operations of all previous Overlapped commands are finished. The *WAI command is not needed for Sequential commands.

The Model 2701 has three overlapped commands:

- :INITiate
- :INITiate:CONTinuous ON
- *TRG

*NOTE See *OPC, *OPC?, and *TRG for more information.*

The INITiate commands remove the Model 2701 from the idle state. The device operations of :INITiate are not considered complete until the Model 2701 returns to idle. By sending the *WAI command after the INITiate command, all subsequent commands will not execute until the Model 2701 goes back into idle.

The *TRG command issues a bus trigger that could be used to provide the arm, scan, and measure events for the Trigger Model. By sending the *WAI command after the *TRG command, subsequent commands will not executed until the pointer for the Trigger Model has finished moving in response to *TRG and has settled at its next state.

Programming example – The following command sequence shows how to use the *WAI command to allow the 2701 to wait for the programmed measurements to be completed before requesting a reading.

```
SYST:PRES          ' Returns 2701 to default setup.
INIT:CONT OFF      ' Disables continuous initiation.
ABORt              ' Aborts operation. Places 2701 in idle.
TRIG:COUN 1        ' These two commands configure the 2701
SAMP:COUN 30       ' to perform 30 measurements.
INIT               ' Starts measurement process.
*WAI               ' Sends the WAI command. Program waits for
                   ' 2701 to go into idle before executing next command.
DATA?              ' Requests one reading.
```

13
SCPI Signal Oriented Measurement Commands

The signal oriented measurement commands are used to acquire readings. You can use these high level instructions to control the measurement process. These commands are summarized in Table 13-1.

NOTE When measurements are performed, the readings are fed to other enabled operations. Appendix D explains "Data flow (remote operation)" and provides additional information on using FETCh?, READ?, and MEASure? to acquire readings.

Table 13-1
Signal oriented measurement command summary

Command	Description
CONFigure:<function> [<rang>], [<res>], [<clist>]	Places the Model 2701 in a "one-shot" measurement mode for the specified function.
FETCh?	Requests the latest reading.
READ?	Performs an ABORt, INITiate, and FETCh?.
MEASure[:<function>]? [<rang>], [<res>], [<clist>]	Performs an ABORt, CONFigure:<function>, and READ?. (See Note).
Channel list parameter: <clist> = (@SCH) where: S = Mainframe slot number (1 or 2) CH = Switching module channel number (must be 2 digits) Examples: (@101) = Slot 1, Channel 1 (@101, 203) = Slot 1, Channel 1 and Slot 2, Channel 3 (@101:110) = Slot 1, Channels 1 through 10	

Note: Only one channel can be specified in the <clist> for the MEASure? command.

NOTE *The CONFigure:<function> and MEASure:<function>? commands can be sent without any of the optional parameters (<rang>, <res>, <clist>). For details, see the "Description" for the CONFigure and MEASure commands.*

When using the <clist> parameter, it is interpreted as the last parameter. Any parameter after <clist> will generate error -102 (syntax error).

If only one parameter is used and it is not a <clist>, it is interpreted as the range parameter (<rang>).

If two parameters are used and the second one is not a <clist>, the first parameter is the range parameter (<rang>) and the second is the resolution parameter (<res>).

The CONFiguration and MEASure? commands for the TEMPerature and CONTinuity functions do not use the <rang> and <res> parameters. The command is ignored and causes error -108 (parameter not allowed).

The CONFigure and MEASure? commands cannot be used while scanning. The command is ignored and causes error -221 (settings conflict).

CONFigure:<function> [<rang>], [<res>], [<clist>]

CONFigure:VOLTage[:DC] [<rang>], [<res>], [<clist>]	Configure DCV
CONFigure:VOLTage:AC [<rang>], [<res>], [<clist>]	Configure ACV
CONFigure:CURRent[:DC] [<rang>], [<res>], [<clist>]	Configure DCI
CONFigure:CURRent:AC [<rang>], [<res>], [<clist>]	Configure ACI
CONFigure:RESistance [<rang>], [<res>], [<clist>]	Configure Ω2
CONFigure:FRESistance [<rang>], [<res>], [<clist>]	Configure Ω4
CONFigure:FREQuency [<rang>], [<res>], [<clist>]	Configure FREQ
CONFigure:PERiod [<rang>], [<res>], [<clist>]	Configure PERIOD
CONFigure:TEMPerature [<clist>]	Configure TEMP
CONFigure:CONTinuity [<clist>]	Configure CONT

Parameters

<rang> = Range parameter for the specified function. For example, for DCV, range parameter value 10 selects the 10V range. See the "NOTES" that follow Table 13-1 for additional information.

<res> =

0.1	i.e., 100.0 V (3½ digits)
0.01	i.e., 10.00 V (3½ digits)
0.001	i.e., 1.000 V (3½ digits)
0.0001	i.e., 1.0000 V (4½ digits)
0.00001	i.e., 1.00000 V (5½ digits)
0.000001	i.e., 1.000000 V (6½ digits)

The resolution of the <res> parameter value and the selected range sets the number of display digits. As shown above, with the 100V range selected and <res> = 0.1, a 100V reading will be displayed as 100.0 V (3½ digits).

The display will default to 3½ digits when using parameter values that attempt to set the display below 3½ digits. For example, a 10V reading using <res> = 0.1 for the 10V range is displayed as 10.00 V, not 10.0 V.

A command using parameter values that attempt to set the display above 7½ digits is ignored and generates error -221 (settings conflict error).

The <res> parameter is ignored when a <clist> is included in the command string. Resolution for the scanlist channel(s) is determined by the present setting for the specified function and by the present resolution setting for the specified function.

See the "NOTES" that follow Table 13-1 for additional information.

<clist> = Channel(s) in the scanlist to be configured. When the channel list parameter (<clist>) is included, the present instrument settings are not affected. Instead, the channel(s) in the <clist> for the specified function is configured. See the "NOTES" that follow Table 13-1 for additional information.

Query CONFigure? Query the selected function.

Description <clist> included — When the <clist> parameter is included with CONFigure command, the specified channel(s) for the scanlist assumes the *RST default settings for the specified function. Range can also be set for the channel(s) by including the <rang> parameter. If the resolution parameter (<res>) is included, it will be ignored.

The present measurement function and the trigger model settings are not affected when the CONFigure command is sent with the <clist> parameter.

<clist> not included — When the <clist> parameter is not included, the CONFigure command configures the instrument for subsequent measurements on the specified function. Range and resolution can also be set for the specified function.

This command places the instrument in a "one-shot" measurement mode. You can then use the READ? command to trigger a measurement and acquire a reading (see READ?).

When this command is sent without the <clist> parameter, the Model 2701 will be configured as follows:

- The function specified by this command is selected. If specified, range and/or resolution are also set.
- All controls related to the selected function are defaulted to the *RST values.
- Continuous initiation is disabled (INITiate:CONTinuous OFF).
- The control source of the Trigger Model is set to Immediate.
- The count values of the Trigger Model are set to one.
- The delay of the Trigger Model is set to zero.
- The Model 2701 is placed in the idle state.
- All math calculations are disabled.
- Buffer operation is disabled. A storage operation presently in process will be aborted.
- Autozero is enabled.

Programming examples

Programming example #1 — The following command configures scan-list channels 101 through 105 for 4-wire resistance measurements on the 1MΩ range.

```
CONF:FRES 1e6, (@101:105)
```

Programming example #2 — The following command selects the DCV function, 10V range, 3½ digit resolution, and performs the "no <clist>" CONFigure operations:

```
CONF:VOLT 10, 3.5
```

FETCh?

Description

This command requests the latest post-processed reading. After sending this command and addressing the Model 2701 to talk, the reading is sent to the computer. This command does not affect the instrument setup.

This command does not trigger a measurement. The command simply requests the last available reading.

FETCh? can also be used to return more than one reading. When returning more than one reading, the readings are automatically stored in the buffer.

In order to return multiple reading strings, continuous initiation must be disabled (INIT:CONT OFF) so that the sample count (SAMPle:COUNt), which specifies the number of measurements to be performed, can be set >1. After INITiate is sent to trigger the measurements, FETCh? will return the reading strings.

FETCh? is automatically asserted when the READ? or MEASure? command is sent.

NOTE *FETCh? can repeatedly return the same reading. Until there is a new reading, this command continues to return the old reading.*

When an instrument setting that is relevant to the readings in the sample buffer is changed, the FETCh? command will cause error -230 (data corrupt or stale) or a bus time-out to occur. To get FETCh? working again, a new reading must be triggered.

READ?

Description

This command is typically used with the instrument in the "one-shot" measurement mode to trigger and acquire a specified number of readings. The SAMPle:COUNt command is used to specify the number of readings (see Trigger Subsystem). Note that with sample count >1, the readings are stored in the buffer.

When this command is sent, the following commands execute in the order they are presented:

ABORt
INITiate
FETCh?

When ABORt is executed, the instrument goes into the idle state if continuous initiation is disabled. If continuous initiation is enabled, the operation re-starts at the beginning of the Trigger Model.

If the instrument is in the idle state, INITiate takes the instrument out of the idle state. If continuous initiation is enabled (INITiate:CONTinuous ON), then the INITiate command generates error -213 (init ignored).

NOTE *If continuous initiation is enabled, the READ? command will generate error -213 (init ignored). It can be disabled by sending INITiate:CONTinuous OFF. The *RST command can also be used to disable continuous initiation. It also places the Model 2701 in the "one-shot" measurement mode:*

```
*RST     ' Disable continuous initiation and place 2701 in "one-shot" mode.
READ?  ' Trigger and return one reading.
```

NOTE *When readings are stored in the buffer by the TRACe command (or by front panel data store operation), INIT and multi-sample READ? queries are locked out. With readings in the buffer that were stored in that manner, you cannot use the INIT or READ? command if sample count is >1 (error -225, out of memory). Buffer operation is covered in Section 6.*

*The buffer of the Model 2701 is nonvolatile. Therefore, readings stored in the buffer are not lost when the instrument is turned off or when *RST or SYSTem:PRESet is sent. When writing test programs that perform multi-sample measurements (SAMPle:COUNTt >1), you may want to add the TRACe:CLEar command at the beginning to clear the buffer. However, be careful not to inadvertently clear stored readings that are needed.*

MEASure:<function>? [<rang>], [<res>], [<clist>]

MEASure:VOLTage[:DC]? [<rang>], [<res>], [<clist>]	Measure DCV
MEASure:VOLTage:AC? [<rang>], [<res>], [<clist>]	Measure ACV
MEASure:CURRent[:DC]? [<rang>], [<res>], [<clist>]	Measure DCI
MEASure:CURRent:AC? [<rang>], [<res>], [<clist>]	Measure ACI
MEASure:RESistance? [<rang>], [<res>], [<clist>]	Measure Ω2
MEASure:FRESistance? [<rang>], [<res>], [<clist>]	Measure Ω4
MEASure:FREQuency? [<rang>], [<res>], [<clist>]	Measure FREQ
MEASure:PERiod? [<rang>], [<res>], [<clist>]	Measure PERIOD
MEASure:TEMPerature? [<clist>]	Measure TEMP
MEASure:CONTinuity? [<clist>]	Measure CONT

Parameters

<rang> = Range parameter for the specified function. For example for DCV, range parameter value 10 selects the 10V range. See the "NOTES" that follow Table 13-1 for additional information.

<res> =

0.1	i.e., 100.0 V (3½ digits)
0.01	i.e., 10.00 V (3½ digits)
0.001	i.e., 1.000 V (3½ digits)
0.0001	i.e., 1.0000 V (4½ digits)
0.00001	i.e., 1.00000 V (5½ digits)
0.000001	i.e., 1.000000 V (6½ digits)

The resolution of the <res> parameter value and the selected range sets the number of display digits. As shown above, with the 100V range selected and <res> = 0.1, a 100V reading will be displayed as 100.0 V (3½ digits).

The display will default to 3H digits when using parameter values that attempt to set the display below 3½ digits. For example, a 10V reading using <res> = 0.1 for the 10V range is displayed as 10.00 V, not 10.0 V.

A command using parameter values that attempt to set the display above 7½ digits is ignored and generates error -221 (settings conflict error).

See the "NOTES" that follow Table 13-1 for additional information.

<clist> = Single channel only. When included, this is the channel to be closed and measured.

Description

The MEASure? command combines all of the other signal oriented measurement commands to perform a "one-shot" measurement and acquire the reading. If the <clist> parameter is included, the specified channel will close before performing the measurement.

When a MEASure? command is sent, the specified function is selected. If specified, range and resolution will also set.

Depending on the specified resolution, the measurement rate is set as follows:

6½-digits	NPLC = 1.0 Medium
5½-digits	NPLC = 0.1Fast
3½ or 4½-digits	NPLC = 0.01>Fast

If resolution is not specified, 6½-digit resolution and medium speed will be selected when MEAS? is sent.

All other instrument settings related to the selected function are reset to the *RST defaults.

NOTE *If a function is not specified, the command executes as if the present function is specified. For example, assume the Ω2 function is presently selected. When MEAS? is sent, the instrument resets to the *RST defaults for the Ω2 function and then performs a measurement.*

When this command is sent, the following commands execute in the order that they are presented:

ABORt
CONFigure:<function>
READ?

When ABORt is executed, the instrument goes into the idle state if continuous initiation is disabled. If continuous initiation is enabled, the operation re-starts at the beginning of the Trigger Model.

When CONfigure is executed, the MEASure? parameters (<rang>, <res>, and <clist>) are executed and the instrument goes into the "one-shot" measurement mode. It is similar to sending the CONFigure command with no <clist> parameter. See CONFigure for more details.

When READ? is executed, its operations will then be performed. In general, another ABORt is performed, then an INITiate, and finally a FETCh? to acquire the reading. See READ? for more details.

Programming examples

Programming example #1 — The following command measures DCV on channel 101 using the 10V range with 3½ digit display resolution:

```
MEAS:VOLT? 10, 0.01, (@101)
```

Programming example #2 — The following command measures DCV on the 100V range:

```
MEAS:VOLT? 100
```

14
FORMat and Miscellaneous SYSTem Commands

- FORMat commands — Covers the SCPI commands to configure the format that readings are transmitted.
- Miscellaneous SYSTem commands — Covers miscellaneous SYSTem commands.

FORMat commands

The commands in this subsystem (Table 14-1) are used to select the elements for acquired readings and to select the data format for reading status event registers.

NOTE Details on the FORMat:SREGister command are provided in Section 11 (see "Programming and reading registers").

Table 14-1
SCPI commands — data format

Command	Description	Default
FORMat:ELEMents <item list>	Specify data elements; READing, UNITs, TSTamp, RNUMber, CHANnel, LIMits.	All
FORMat:SREGister <name>	Select data format for reading status event registers; ASCii, HEXadecimal, OCTal, or BINary.	ASCii

FORMat:ELEMents <item list>

Parameters
- READing = DMM reading
- UNITs = Units
- TSTamp = Timestamp
- RNUMber = Reading number
- CHANnel = Channel number
- LIMits = Limits reading

The specified elements are included in the data string in response to FETCh?, READ?, MEASure?, and TRACe:DATA?. Note that each element in the item list must be separated by a comma (i.e. send "FORMat:ELEMents READing, UNITs, TSTamp, RNUMber, CHANnel, LIMits" to include all elements in the data string). The elements for the ASCii format are shown in Figure 14-1.

An overflow reading is returned as +9.9E37. When a specified data element has invalid data associated with it, NAN (Not A Number) will be the response. NAN is returned as +9.9E37.

Timestamp — Timestamp references the returned data string to a point in time. There are two timestamps: relative and real-time clock. The following command selects the timestamp:

```
SYSTem:TSTamp:TYPE <name>        ' Select timestamp type; RELative or RTCL.
```

The relative timestamp operates as a timer that starts at zero seconds when the instrument is turned on or when the relative timestamp is reset (SYSTem:TSTamp:RELative:RESet). After 99,999.99 seconds, the timer resets back to zero and starts over.

For buffer readings recalled from the front panel, the relative timestamp is referenced to the first reading stored in the buffer (absolute format) which is timestamped at 0 seconds and to the time between each stored reading (delta format). For remote programming, you can only return the absolute or delta timestamp. The following command is used to select relative timestamp format for the buffer:

```
TRACe:TSTamp:FORMat            ' Select timestamp format; ABSolute or DELTa.
```

Reading number — The reading counter starts at zero when the Model 2701 is turned on. When returning buffer readings using TRACe:DATA?, each reading will be referenced to the first reading, which is #0. The following command will reset the counter:

```
SYSTem:RNUMber:RESet.
```

Channel number — The channel number indicates the switching module channel for the reading. Channel number 000 indicates that no channel was closed.

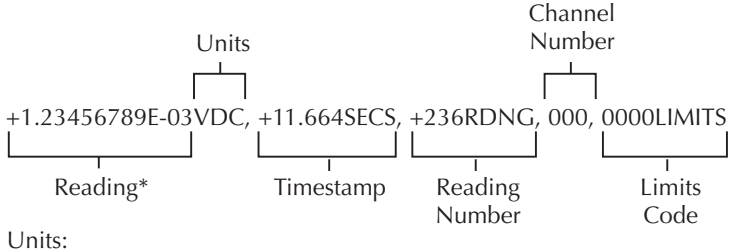
Limits — For the ASCII data format, limit test results are returned as a 4-bit binary number "abcd" where:

a = High limit 2
b = Low limit 2
c = High limit 1
d = Low limit 1

A "0" indicates that the limit has passed, while a "1" indicates that the limit has failed.

For the binary data formats, the limits information must be decoded from the returned value (0 to 15). Convert the value to its binary equivalent for "abcd" where "d" is the LSD and "a" is the MSD. For example, the value 10 converted to its binary equivalent is1010. That means High Limit 2 and High Limit 1 have failed.

Figure 14-1
ASCII data format



Units:

VDC	=	DC Volts	HZ	=	Frequency
VAC	=	AC Volts	SECS	=	Period
ADC	=	DC Current	C	=	Temperature in C
AAC	=	AC Current	F	=	Temperature in F
OHM	=	2-Wire Resistance or Continuity	K	=	Temperature in K

OHM4W = 4-Wire Resistance

*An overflow reading is displayed as +9.9E37 with no limits.

Miscellaneous SYSTem commands

SYSTem commands not covered in other sections of the manual are documented here. Table 15-7 lists all SYSTem commands and provides references on where to find more information.

SYSTem:PRESet

Returns the instrument to states optimized for front panel operation. SYSTem:PRESet defaults are listed in the SCPI tables in Section 15.

NOTE **OPC or *OPC? should be used with SYST:PRES, which is slow responding command. Details on *OPC and *OPC? are provided in Section 12.*

SYSTem:VERSion

Read the version of the SCPI standard being used by Model 2701. Example response message: 1996.0.

SYSTem:KEY <NRf>

Parameters

1 = SHIFT key
2 = DCV key
3 = ACV key
4 = DCI key
5 = ACI key
6 = Ω2 key
7 = Ω4 key
8 = FREQ key
9 = -------
10 = -------
11 = RANGE up arrow key
12 = AUTO key
13 = RANGE down arrow key
14 = ENTER key
15 = Cursor right arrow key
16 = TEMP key
17 = LOCAL key
18 = EX TRIG key
19 = TRIG key
20 = STORE key
21 = RECALL key
22 = FILTER key
23 = REL key
24 = Cursor left arrow key
25 = -------
26 = OPEN key
27 = CLOSE key
28 = STEP key
29 = SCAN key
30 = DIGITS key
31 = RATE key
32 = EXIT key

This command is used to simulate front panel key presses. For example, to select the volts measurement function, send the following command to simulate pressing the "DCV" key: SYSTem:KEY 2. The key-press codes are also shown in Figure 14-2.

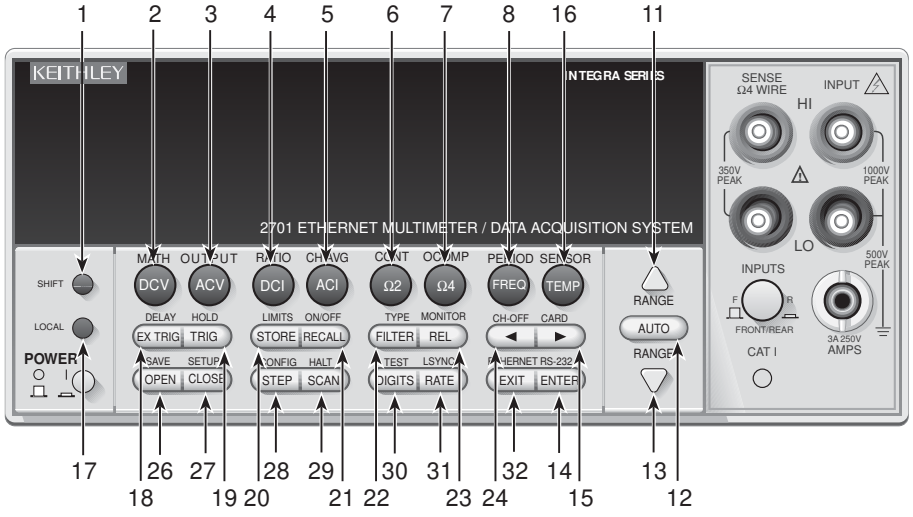
The queue for the :KEY? query command can only hold one key-press. The :KEY? command is used to acquire the key-press code number for the last key "pressed". This query command will only return the key "pressed" by the :KEY command. It will not return a key physically pressed by the operator.

SYSTem:BEEPer[:STATe] <b>

You can disable the beeper for limits and continuity tests. However, when limits or CONT is again selected, the beeper will automatically enable.

Parameters <b> = 0 Disable beeper
= 1 Enable beeper

Figure 14-2
Key-press codes



15
SCPI Reference Tables

Reference tables

Table 15-1 through Table 15-10 summarize the commands to operate the Model 2701 and Model 7700 switching module.

NOTE *The commands listed in the following tables pertain to operation of the Model 2701 and the Model 7700 switching module. For commands that are unique to operation of other switching modules, refer to the packing list provided with each switch module.*

Table 15-1 — CALCulate command summary
Table 15-2 — DISPlay command summary
Table 15-3 — FORMat command summary
Table 15-4 — ROUTe command summary
Table 15-5 — SENSe command summary
Table 15-6 — STATus command summary
Table 15-7 — SYSTem command summary
Table 15-8 — TRACe command summary
Table 15-9 — Trigger command summary
Table 15-10 — UNIT command summary

General notes:

- Brackets ([ ]) are used to denote optional character sets. These optional characters do not have to be included in the program message. Do not use brackets in the program message.
- Angle brackets (< >) are used to indicate parameter type. Do not use angle brackets in the program message.
- The Boolean parameter (<b>) is used to enable or disable an instrument operation. 1 or ON enables the operation and 0 or OFF disables the operation.
- Upper case characters indicate the short-form version for each command word.
- Default Parameter — Listed parameters are both the *RST and SYSTem:PRESet defaults, unless noted otherwise. Parameter notes are located at the end of each table.
- Ref — The reference column indicates where to find detailed information on the command(s).
- SCPI — A checkmark (✔) indicates that the command and its parameters are SCPI confirmed. An unmarked command indicates that it is an SCPI command, but does not conform to the SCPI standard set of commands. It is not a recognized command by the SCPI consortium. SCPI confirmed commands that use one or more non-SCPI parameters are explained by notes.

Table 15-1
CALCulate command summary

Command	Description	Default parameter	Ref	SCPI
CALCulate[1]	Subsystem to control CALC 1:		Sec 5	✔
:FORMat <name> [<, clist>]	Select math format (NONE, MXB, PERCent, or RECiprocal).	PERCent		✔
:FORMat? [<clist>]	Query math format.			✔
:KMATh	Path to configure math calculations:			
:MMFactor <NRf> [, <clist>]	Set "m" factor for mx+b (-4294967295 to +4294967295).[1]	1		
:MA1Factor <NRf> [, <clist>]	Set "m" factor for mx+b (-4294967295 to +4294967295).[1]	1		
:MMFactor? [<clist>]	Query "m" factor.[1]			
:MA1Factor? [<clist>]	Query "m" factor.[1]			
:MBFactor <NRf> [, <clist>]	Set "b" factor for mx+b (-4294967295 to +4294967295).[2]	0		
:MA0Factor <NRf> [, <clist>]	Set "b" factor for mx+b (-4294967295 to +4294967295).[2]	0		
:MBFactor? [<clist>]	Query "b" factor.[2]			
:MA0Factor? [<clist>]	Query "b" factor.[2]			
:MUNits <char>	Specify units for mx+b reading.[3]	'X'		
:MUNits?	Query "mx+b" units.			
:PERCent <NRf> [, <clist>]	Set target value for PERCent calculation (-4294967295 to +4294967295).	1		
:ACQuire	Use input signal as target value.			
:PERCent? [<clist>]	Query percent.			
:STATe <b> [, <clist>]	Enable or disable kmath calculation.	(Note 4)		✔
:STATe? [< clist>]	Query state of kmath function.			✔
:DATA?	Read result of kmath calculation.			✔
CALCulate2	Subsystem to control CALC 2:		Sec 6	✔
:FORMat <name>	Select math format: (MEAN, SDEViation, MAXimum, MINimum, PKPK, or NONE).	NONE		✔
:FORMat?	Query math format.			✔
:STATe <b>	Enable or disable calculation.	(Note 4)		✔
:STATe?	Query state of math function.			✔
:IMMediate	Recalculate raw input data in buffer.			✔
:IMMediate?	Perform calculation and read result.			✔
:DATA?	Read math result of CALC 2.			✔

Table 15-1 (continued)
CALCulate command summary

Command	Description	Default parameter	Ref	SCPI
CALCulate3	Subsystem to control CALC 3 (limit test):		Sec 9	✔
:MLIMit	Path for master limit command:			
:LATChed <b>	Enable or disable master limit latch.	OFF		
:OUTPut	Path for limit output commands:			
[:STATe] <b>	Enable or disable limit outputs.	OFF		
[:STATe]?	Query state of limit outputs.			
:PULSe	Path to control limit output pulsing:			
[:STATe] <b>	Enable or disable limit output pulsing.	OFF		
[:STATe]?	Query state of limit output pulsing.			
:TIME <NRf>	Set output pulse time in sec (0.001 to 99999.999).	0.002		
:TIME?	Query output pulse time.			
:LSENse <name>	Set logic sense of all limit lines (AHIGh or ALOW).	AHIGh		
:LSENse?	Query logic sense of limit lines.			
:LIMit1	Path to control LIMIT 1 test:			✔
:UPPer	Path to configure upper limit:			✔
[:DATA] <n> [, <clist>]	Set upper limit (-4294967295 to +4294967295).	1		✔
[:DATA]? [<clist>]	Query upper limit.			✔
:LOWer	Path to configure lower limit:			✔
[:DATA] <n> [, <clist>]	Set lower limit (-4294967295 to +4294967295).	-1		✔
[:DATA]? [<clist>]	Query lower limit.			✔
:STATe <b> [, <clist>]	Enable or disable limit test.	OFF		✔
:STATe? [<clist>]	Query state of limit test.			✔
:FAIL?	Query test result (1 = failing).			✔
:CLEAR	Path to clear events:			✔
[:IMMediate]	Clear high and low events.			✔
:AUTO <b>	Enable or disable auto-clear.	ON		✔
:AUTO?	Query auto-clear.			✔

Table 15-1 (continued)
CALCulate command summary

Command	Description	Default parameter	Ref	SCPI
CALCulate3				
:LIMit2	Path to control LIMIT 2 test:			✔
:UPPer	Path to configure upper limit:			✔
[:DATA] <n> [, <clist>]	Set upper limit (-4294967295 to +4294967295).	2		✔
[:DATA]? [<clist>]	Query upper limit.			✔
:LOWer	Path to configure lower limit:			✔
[:DATA] <n> [, <clist>]	Set lower limit (-4294967295 to +4294967295).	-2		✔
[:DATA]? [<clist>]	Query lower limit.			✔
:STATe <b> [, <clist>]	Enable or disable limit test.	OFF		✔
:STATe? [<clist>]	Query state of limit test.			✔
:FAIL?	Query test result (1 = failing).			✔
:CLEAR	Path to clear events:			✔
[:IMMediate]	Clear high and low events.			✔
:AUTO <b>	Enable or disable auto-clear.	ON		✔
:AUTO?	Query auto-clear.			✔

Notes:
1. The :MMFactor and :MA1Factor commands perform the same operations.
2. The :MBFactor and :MA0Factor commands perform the same operations.
3. For mX+b units, <char> = one character; 'A' through 'Z', degrees symbol ('°'), or ohms symbol ('Ω').
4. ON is the *RST default parameter and OFF is the SYSTem:PRESet default.

Table 15-2
DISPlay command summary

Command	Description	Default parameter	Ref	SCPI
DISPlay		(see Note)	Sec 1	
[:WINDow[1]]				✔
:TEXT	Path to control user text messages.			✔
:DATA <a>	ASCII message "a" (up to 12 characters).	(none)		✔
:DATA?	Query text message.			✔
:STATe <b>	Enable or disable message mode.	OFF		✔
:STATe?	Query text message state.			✔
:ENABle <b>	Enable or disable the front panel display.	ON		✔
:ENABle?	Query state of the display.			✔

Note: *RST and SYSTem:PRESet have no effect on commands in this subsystem. The listed defaults are power-on defaults.

Table 15-3
FORMat command summary

Command	Description	Default parameter	Ref	SCPI
FORMat				
:ELEMents <item list>	Specify data elements (READing, CHANnel, UNITs, RNUMber, TSTamp, and LIMits).	(see Note)	Sec 14	✔
:ELEMents?	Query data elements.			✔
:SREGister <name>	Select data format for reading status registers: <name> = ASCii Decimal format HEXadecimal Hexadecimal format OCTal Octal format BINary Binary format	ASCii	Sec 11	✔
:SREGister?	Query data format for reading status registers.			✔

Note: The SYSTem:PRESet and *RST default is READ, UNIT, RNUM, and TST.

Table 15-4
ROUTe command summary

Command	Description	Default parameter	Ref	SCPI
ROUTe				
:MONitor <clist>	Specify one channel to be monitored.		Sec 7	
:STATe <b>	Enable or disable channel monitoring.	OFF		
:STATe?	Query state of channel monitoring.			
:DATA?	Returns the most recent monitor reading.			
:POINts <NRf>	For a monitor scan, specify number of channels to scan (2 to 450000).	(Note 1)		
:POINts?	For a monitor scan, query number of channels to scan.			
:MONitor?	Query the channel to be monitored.			
:CLOSe <clist>	Close the one specified channel (all others will open).		Sec 2	
:STATe? <clist>	Query closed channels in specified list; 1 = closed.			
:ACONfigure <b>	Enable or disable auto-configure.	(Note 2)		
:ACONfigure?	Query state of auto-configure.			
:COUNt? <clist>	Query closure count for specified channels.		Sec 2	
:INTerval <NRf>	Set count update interval in minutes (10 to 1440).	(Note 3)		
:INTerval?	Query relay count update interval.			
:CLOSe?	Returns a <clist> of closed channels.			
:OPEN:ALL	Open all channels.		Sec 2	

Table 15-4 (continued)
ROUTe command summary

Command	Description	Default parameter	Ref	SCPI
ROUTe				
:MULTiple	Path to control multiple channels:		Sec 2	
:OPEN <clist>	Open channel(s) specified in list. Unlisted channels not affected.			
:CLOSe <clist>	Close channel(s) specified in list[4]. Unlisted channels not affected.			
:STATe? <clist>	Query closed channels in specified list; 1 = closed.			
:CLOSe?	Return list of all closed channels.			
:SCAN	Path to configure scan:		Sec 7	✔
[:INTernal] <clist>	Specify list of channels to be scanned.			✔
[:INTernal]?	Query scan list.			✔
:TSOurce <list>	Select trigger source to start the scan (IMMediate, or HLIMit1, HLIMit2, LLIMit1, and LLIMit2).	IMM		
:TSOurce?	Query trigger source for scan.			
:NVOLatile <b>	Enable or disable nonvolatile memory for scanning (autoscan).	(Note 2)		
:NVOLatile?	Query nonvolatile memory setting.			
:LSELect <name>	Enable (INTernal) or disable (NONE) scan.	NONE		
:LSELect?	Query state of scan.			

Notes:
1. Default value depends on which switching module is installed.
2. Not affected by *RST and SYSTem:PRESet. Front panel factory default is OFF.
3. Not affected by *RST and SYSTem:PRESet. Interval set to 15 minutes at the factory.
4. The ROUT:MULT:CLOS command cannot be used to measure thermocouple temperature using the internal or external reference junction. The simulated reference junction will instead be used. See "Temperature measurements," page 3-33, for details.

Table 15-5
SENSe command summary

Command	Description	Default parameter	Ref	SCPI
[SENSe[1]]				
:FUNCtion <name> [, <clist>]	Select function: 'VOLTage[:DC]', 'VOLTage :AC', 'CURRent[:DC]', 'CURRent:AC', 'RESistance', 'FRESistance', 'TEMPerature', 'FREQuency', 'PERiod', 'CONTinuity'.	VOLT:DC	Sec 3	✔
:FUNCtion? [<clist>]	Query function.			✔
:DATA[:LATest]?	Return the last reading.		Sec 3	✔
:DATA:FRESh?	Return the last "fresh" reading.		Sec 3	
:HOLD	Path to control Hold feature:		Sec 8	
:WINDow <NRf>	Set Hold window in % (0.01 to 20).	1		
:WINDow?	Query Hold window.			
:COUNt <NRf>	Set Hold count; 2 to 100.	5		
:COUNt?	Query Hold count.			
:STATe <NRf>	Enable or disable Hold.	OFF		
:STATe?	Query state of Hold.			
:CAVerage	Channel average calculation:		Sec 5	
:DELay <NRf> [, <clist>]	Set delay between the two measurements in seconds (0 to 99999.999).[1]	0.5		
:DELay? [<clist>]	Query delay.			
[:STATe] <b> [, <clist>]	Enable or disable channel average.	OFF		
[:STATe]? [, <clist>]	Query state of channel average.			
:RATio	Channel ratio calculation:	OFF	Sec 5	
:DELay <NRf> [, <clist>]	Set delay between the two measurements in seconds (0 to 99999.999).[1]	0.5		
:DELay? [<clist>]	Query delay.			
[:STATe] <b> [, <clist>]	Enable or disable channel ratio.	OFF		
[:STATe]? [, <clist>]	Query state of channel ratio.			

Table 15-5 (continued)
SENSe command summary

Command	Description	Default parameter	Ref	SCPI
[SENSe[1]]				
:VOLTage[:DC]	Path to configure DC voltage.		Sec 3	✔
:APERture <n> [, <clist>]	Set integration rate in seconds (3.333333e-5 to 1).	(Note 2)	Sec 4	
:APERture? [<clist>]	Query aperture integration rate.			
:NPLCycles <n> [, <clist>]	Set integration rate in line cycles (60Hz; 0.002 to 60, 50Hz; 0.002 to 50).	5.0	Sec 4	✔
:NPLCycles? [<clist>]	Query line cycle integration rate.			✔
:RANGe	Path to set measurement range:		Sec 4	✔
[:UPPer] <n> [, <clist>]	Select range (0 to 1010).	1000		✔
[:UPPer]? [<clist>]	Query range.			✔
:AUTO <b> [, <clist>]	Enable or disable auto range.	ON		✔
:AUTO? [<clist>]	Query state of auto range.			✔
:DIGits <n> [, <clist>]	Specify measurement resolution (4 to 7).	7	Sec 4	
:DIGits? [<clist>]	Query resolution.			
:REFerence <n> [, <clist>]	Specify reference (-1010 to 1010).	0	Sec 5	✔
:STATe <b> [, <clist>]	Enable or disable reference.	OFF		✔
:STATe? [<clist>]	Query state of reference.			✔
:ACQuire [, <clist>]	Use input signal as reference.			
:REFerence? [<clist>]	Query reference value.			✔
:AVERage	Path to configure and control filter:		Sec 4	
:TCONtrol <name>	Select filter type: (MOVing or REPeat).	(Note 3)		
:TCONtrol?	Query filter type.			
:WINDow <NRf>	Set filter window in % of range (0 to 10).	0.1		
:WINDow?	Query filter window.			
:COUNt <n> [, <clist>]	Specify filter count (1 to 100).	10		
:COUNt? [<clist>]	Query filter count.			
[:STATe] <b> [, <clist>]	Enable or disable filter.	(Note 4)		
[:STATe]? [<clist>]	Query state of digital filter.			
:IDIVider <b>	Enable or disable 10MΩ input divider.	OFF	Sec 3	
:IDIVider?	Query state of input divider.			

Table 15-5 (continued)
SENSe command summary

Command	Description	Default parameter	Ref	SCPI
[SENSe[1]]				
:VOLTage:AC	Path to configure AC voltage.		Sec 3	✔
:APERture <n> [, <clist>]	Set integration rate in seconds (3.333333e-5 to 1).	(Note 2)	Sec 4	
:APERture? [<clist>]	Query aperture integration rate.			
:NPLCycles <n> [, <clist>]	Set integration rate in line cycles (60Hz; 0.002 to 60, 50Hz; 0.002 to 50).	5.0	Sec 4	✔
:NPLCycles? [<clist>]	Query line cycle integration rate.			✔
:RANGe	Path to set measurement range:		Sec 4	✔
[:UPPer] <n> [, <clist>]	Select range (0 to 757.5).	750		✔
[:UPPer]? [<clist>]	Query range.			✔
:AUTO <b> [, <clist>]	Enable or disable auto range.	ON		✔
:AUTO? [<clist>]	Query state of auto range.			✔
:DIGits <n> [, <clist>]	Specify measurement resolution (4 to 7).	6	Sec 4	
:DIGits? [<clist>]	Query resolution.			
:REFerence <n> [, <clist>]	Specify reference (-757.5 to 757.5).	0	Sec 5	✔
:STATe <b> [, <clist>]	Enable or disable reference.	OFF		✔
:STATe? [<clist>]	Query state of reference.			✔
:ACQuire [, <clist>]	Use input signal as reference.			
:REFerence? [<clist>]	Query reference value.			✔
:AVERage	Path to configure and control filter:		Sec 4	
:TCONtrol <name>	Select filter type: (MOVing or REPeat).	(Note 3)		
:TCONtrol?	Query filter type.			
:WINDow <NRf>	Set filter window in % of range (0 to 10).	0.1		
:WINDow?	Query filter window.			
:COUNt <n> [, <clist>]	Specify filter count (1 to 100).	10		
:COUNt? [<clist>]	Query filter count.			
[:STATe] <b> [, <clist>]	Enable or disable filter.	(Note 4)		
[:STATe]? [<clist>]	Query state of digital filter.			
:DETector	Path to set bandwidth:		Sec 4	
:BANDwidth <NRf> [, <clist>]	Set AC detector bandwidth in Hertz (3 to 3e5).	30		
:BANDwidth? [<clist>]	Query bandwidth.			

Table 15-5 (continued)
SENSe command summary

Command	Description	Default parameter	Ref	SCPI
[SENSe[1]]				
:CURRent[:DC]	Path to configure DC current.		Sec 3	✔
:APERture <n> [, <clist>]	Set integration rate in seconds (3.333333e-5 to 1).	(Note 2)	Sec 4	
:APERture? [<clist>]	Query aperture integration rate.			
:NPLCycles <n> [, <clist>]	Set integration rate in line cycles (60Hz; 0.002 to 60, 50Hz; 0.002 to 50).	5.0	Sec 4	✔
:NPLCycles? [<clist>]	Query line cycle integration rate.			✔
:RANGe	Path to set measurement range:		Sec 4	✔
[:UPPer] <n> [, <clist>]	Select range (0 to 3.1).	3		✔
[:UPPer]? [<clist>]	Query range.			✔
:AUTO <b> [, <clist>]	Enable or disable auto range.	ON		✔
:AUTO? [<clist>]	Query state of auto range.			✔
:DIGits <n> [, <clist>]	Specify measurement resolution (4 to 7).	7	Sec 4	
:DIGits? [<clist>]	Query resolution.			
:REFerence <n> [, <clist>]	Specify reference (-3.1 to 3.1).	0	Sec 5	✔
:STATe <b> [, <clist>]	Enable or disable reference.	OFF		✔
:STATe? [<clist>]	Query state of reference.			✔
:ACQuire [, <clist>]	Use input signal as reference.			
:REFerence? [<clist>]	Query reference value.			✔
:AVERage	Path to configure and control filter:		Sec 4	
:TCONtrol <name>	Select filter type: (MOVing or REPeat).	(Note 3)		
:TCONtrol?	Query filter type.			
:WINDow <NRf>	Set filter window in % of range (0 to 10).	0.1		
:WINDow?	Query filter window.			
:COUNt <n> [, <clist>]	Specify filter count (1 to 100).	10		
:COUNt? [<clist>]	Query filter count.			
[:STATe] <b> [, <clist>]	Enable or disable filter.	(Note 4)		
[:STATe]? [<clist>]	Query state of digital filter.			

Table 15-5 (continued)
SENSe command summary

Command	Description	Default parameter	Ref	SCPI
[SENSe[1]]				
:CURRent:AC	Path to configure AC current.		Sec 3	✔
:APERture <n> [, <clist>]	Set integration rate in seconds (3.333333e-5 to 1).	(Note 2)	Sec 4	
:APERture? [<clist>]	Query aperture integration rate.			
:NPLCycles <n> [, <clist>]	Set integration rate in line cycles (60Hz; 0.002 to 60, 50Hz; 0.002 to 50).	5.0	Sec 4	✔
:NPLCycles? [<clist>]	Query line cycle integration rate.			✔
:RANGe	Path to set measurement range:		Sec 4	✔
[:UPPer] <n> [, <clist>]	Select range (0 to 3.1).	3		✔
[:UPPer]? [<clist>]	Query range.			✔
:AUTO <b> [, <clist>]	Enable or disable auto range.	ON		✔
:AUTO? [<clist>]	Query state of auto range.			✔
:DIGits <n> [, <clist>]	Specify measurement resolution (4 to 7).	6	Sec 4	
:DIGits? [<clist>]	Query resolution.			
:REFerence <n> [, <clist>]	Specify reference (-3.1 to 3.1).	0	Sec 5	✔
:STATe <b> [, <clist>]	Enable or disable reference.	OFF		✔
:STATe? [<clist>]	Query state of reference.			✔
:ACQuire [, <clist>]	Use input signal as reference.			
:REFerence? [<clist>]	Query reference value.			✔
:AVERage	Path to configure and control filter:		Sec 4	
:TCONtrol <name>	Select filter type: (MOVing or REPeat).	(Note 3)		
:TCONtrol?	Query filter type.			
:WINDow <NRf>	Set filter window in % of range (0 to 10).	0.1		
:WINDow?	Query filter window.			
:COUNt <n> [, <clist>]	Specify filter count (1 to 100).	10		
:COUNt? [<clist>]	Query filter count.			
[:STATe] <b> [, <clist>]	Enable or disable filter.	(Note 4)		
[:STATe]? [<clist>]	Query state of digital filter.			
:DETector	Path to set bandwidth:		Sec 4	
:BANDwidth <NRf> [, <clist>]	Set AC detector bandwidth in Hertz (3 to 3e5).	30		
:BANDwidth? [<clist>]	Query bandwidth.			

Table 15-5 (continued)
SENSe command summary

Command	Description	Default parameter	Ref	SCPI
[SENSe[1]]				
:RESistance	Path to configure resistance.		Sec 3	✔
:APERture <n> [, <clist>]	Set integration rate in seconds (3.333333e-5 to 1).	(Note 2)	Sec 4	
:APERture? [<clist>]	Query aperture integration rate.			
:NPLCycles <n> [, <clist>]	Set integration rate in line cycles (60Hz; 0.002 to 60, 50Hz; 0.002 to 50).	5.0	Sec 4	✔
:NPLCycles? [<clist>]	Query line cycle integration rate.			✔
:RANGe	Path to set measurement range:		Sec 4	✔
[:UPPer] <n> [, <clist>]	Select range (0 to 120e6).	120e6		✔
[:UPPer]? [<clist>]	Query range.			✔
:AUTO <b> [, <clist>]	Enable or disable auto range.	ON		✔
:AUTO? [<clist>]	Query state of auto range.			✔
:DIGits <n> [, <clist>]	Specify measurement resolution (4 to 7).	7	Sec 4	
:DIGits? [<clist>]	Query resolution.			
:REFerence <n> [, <clist>]	Specify reference (0 to 120e6).	0	Sec 5	✔
:STATe <b> [, <clist>]	Enable or disable reference.	OFF		✔
:STATe? [<clist>]	Query state of reference.			✔
:ACQuire [, <clist>]	Use input signal as reference.			
:REFerence? [<clist>]	Query reference value.			✔
:AVERage	Path to configure and control filter:		Sec 4	
:TCONtrol <name>	Select filter type: (MOVing or REPeat).	(Note 3)		
:TCONtrol?	Query filter type.			
:WINDow <NRf>	Set filter window in % of range (0 to 10).	0.1		
:WINDow?	Query filter window.			
:COUNt <n> [, <clist>]	Specify filter count (1 to 100).	10		
:COUNt? [<clist>]	Query filter count.			
[:STATe] <b> [, <clist>]	Enable or disable filter.	(Note 4)		
[:STATe]? [<clist>]	Query state of digital filter.			

Table 15-5 (continued)
SENSe command summary

Command	Description	Default parameter	Ref	SCPI
[SENSe[1]]				
:FRESistance	Path to configure four-wire resistance.		Sec 3	✔
:APERture <n> [, <clist>]	Set integration rate in seconds (3.333333e-5 to 1).	(Note 2)	Sec 4	
:APERture? [<clist>]	Query aperture integration rate.			
:NPLCycles <n> [, <clist>]	Set integration rate in line cycles (60Hz; 0.002 to 60, 50Hz; 0.002 to 50).	5.0	Sec 4	✔
:NPLCycles? [<clist>]	Query line cycle integration rate.			✔
:RANGe	Path to set measurement range:		Sec 4	✔
[:UPPer] <n> [, <clist>]	Select range (0 to 120e6).	120e6		✔
[:UPPer]? [<clist>]	Query range.			✔
:AUTO <b> [, <clist>]	Enable or disable auto range.	ON		✔
:AUTO? [<clist>]	Query state of auto range.			✔
:DIGits <n> [, <clist>]	Specify measurement resolution (4 to 7).	7	Sec 4	
:DIGits? [<clist>]	Query resolution.			
:REFerence <n> [, <clist>]	Specify reference (0 to 120e6).	0	Sec 5	✔
:STATe <b> [, <clist>]	Enable or disable reference.	OFF		✔
:STATe? [<clist>]	Query state of reference.			✔
:ACQuire [, <clist>]	Use input signal as reference.			
:REFerence? [<clist>]	Query reference value.			✔
:AVERage	Path to configure and control filter:		Sec 4	
:TCONtrol <name>	Select filter type: (MOVing or REPeat).	(Note 3)		
:TCONtrol?	Query filter type.			
:WINDow <NRf>	Set filter window in % of range (0 to 10).	0.1		
:WINDow?	Query filter window.			
:COUNt <n> [, <clist>]	Specify filter count (1 to 100).	10		
:COUNt? [<clist>]	Query filter count.			
[:STATe] <b> [, <clist>]	Enable or disable filter.	(Note 4)		
[:STATe]? [<clist>]	Query state of digital filter.			
:OCOMpensated <b> [, <clist>]	Enable or disable offset compensation.	OFF	Sec 3	
:OCOMpensated? [<clist>]	Query state of offset compensation.			

Table 15-5 (continued)
SENSe command summary

Command	Description	Default parameter	Ref	SCPI
[SENSe[1]]				
:TEMPerature	Path to configure temperature:		Sec 3	✔
:APERture <n> [, <clist>]	Set integration rate in seconds (3.333333e-5 to 1).	(Note 2)	Sec 4	
:APERture? [<clist>]	Query aperture integration rate.			
:NPLCycles <n> [, <clist>]	Set integration rate in line cycles (60Hz; 0.002 to 60, 50Hz; 0.002 to 50).	5.0	Sec 4	✔
:NPLCycles?	Query line cycle integration rate.			✔
:DIGits <n> [, <clist>]	Specify measurement resolution (4 to 7).	6	Sec 4	
:DIGits? [<clist>]	Query resolution.			
:REFerence <n> [, <clist>]	Specify reference in °C (-328 to 3310).	0	Sec 5	✔
:STATe <b> [, <clist>]	Enable or disable reference.	OFF		✔
:STATe? [<clist>]	Query state of reference.			✔
:ACQuire [, <clist>]	Use input signal as reference.			
:REFerence? [<clist>]	Query reference value.			✔
:AVERage	Path to configure and control filter:		Sec 4	
:TCONtrol <name>	Select filter type: (MOVing or REPeat).	(Note 3)		
:TCONtrol?	Query filter type.			
:WINDow <NRf>	Set filter window in % of range (0 to 10).	0.1		
:WINDow?	Query filter window.			
:COUNt <n> [, <clist>]	Specify filter count (1 to 100).	10		
:COUNt? [<clist>]	Query filter count.			
[:STATe] <b> [, <clist>]	Enable or disable filter.	(Note 4)		
[:STATe]? [<clist>]	Query state of digital filter.			
:TRANsducer <name> [, <clist>]	Select temperature transducer (TCouple, FRTD, or THERmistor).	TCouple	Sec 3	
:TRANsducer? [<clist>]	Query transducer type.			

Table 15-5 (continued)
SENSe command summary

Command	Description	Default parameter	Ref	SCPI
[SENSe[1]]				
:TEMPerature				
:TCouple	Path to configure thermocouple:[5]		Sec 3	
[:TYPE] <type> [, <clist>]	Select T/C type (J, K, T, E, R, S, B, N).	K		
[:TYPE]? [<clist>]	Query T/C type.			
:ODETect <b>	Enable or disable T/C open detector.	OFF		
:ODETect?	Query state of T/C open detector.			
:RJUNction	Path to configure reference junction:[5, 6]			
:RSELect <name> [, <clist>]	Select reference junction (SIMulated, INTernal, or EXTernal).	(Note 7)		
:RSELect? [<clist>]	Query reference junction.			
:SIMulated <n> [, <clist>]	Set simulated reference temperature; 0 to 65 (°C), 32 to 149 (°F), or 273 to 338 (K).	23		
:SIMulated? [<clist>]	Query simulated reference temperature.			
:THERmistor	Path to configure thermistor:		Sec 3	
[:TYPE] <NRf> [, <clist>]	Set thermistor type in ohms (1950 to 10050).	5000		
[:TYPE]? [<clist>]	Query thermistor type.			
:FRTD	Path to configure 4-wire RTD:		Sec 3	
:TYPE <name> [, <clist>]	Select FRTD type (PT100, D100, F100, PT3916, PT385, or USER).	PT100		
:TYPE? [<clist>]	Query FRTD type.			
:RZERo <NRf> [, <clist>]	Specify constant for USER type (0 to 10000).	100		
:RZERo? [<clist>]	Query rzero.			
:ALPHa <NRf> [, <clist>]	Specify constant for USER type (0 to 0.01).	0.00385		
:ALPHa? [<clist>]	Query alpha.			
:BETA <NRf> [, <clist>]	Specify constant for USER type (0 to 1.00).	0.111		
:BETA? [<clist>]	Query beta.			
:DELTa <NRf> [, <clist>]	Specify constant for USER type (0 to 5.00).	1.507		
:DELTa? [<clist>]	Query delta.			

Table 15-5 (continued)
SENSe command summary

Command	Description	Default parameter	Ref	SCPI
[SENSe[1]]				
:FREQuency	Path to configure frequency.		Sec 3	
:APERture <n> [, <clist>]	Sets gate time for frequency measurements in seconds (0.01 to 1.0).	1.0	Sec 4	
:APERture? [<clist>]	Query frequency gate time.			
:DIGits <n> [, <clist>]	Specify measurement resolution (4 to 7).	7	Sec 4	
:DIGits? [<clist>]	Query resolution.			
:REFerence <n> [, <clist>]	Specify reference (0 to 1.5e7).	0	Sec 5	
:STATe <b> [, <clist>]	Enable or disable reference.	OFF		
:STATe? [<clist>]	Query state of reference.			
:ACQuire [, <clist>]	Use input signal as reference.			
:REFerence? [<clist>]	Query reference value.			
:THReshold	Path to select the threshold voltage range:		Sec 3	✔
:VOLTage				✔
:RANGe <n> [, <clist>]	Select threshold range (0 to 1010).	10		
:RANGe? [<clist>]	Query threshold range.			
:PERiod	Path to configure period:		Sec 3	
:APERture <n> [, <clist>]	Sets gate time for period measurements in seconds (0.01 to 1.0).	1.0	Sec 4	
:APERture? [<clist>]	Query period gate time.			
:DIGits <n> [, <clist>]	Specify measurement resolution (4 to 7).	7	Sec 4	
:DIGits? [<clist>]	Query resolution.			
:REFerence <n> [, <clist>]	Specify reference (0 to 1).	0	Sec 5	
:STATe <b> [, <clist>]	Enable or disable reference.	OFF		
:STATe? [<clist>]	Query state of reference.			
:ACQuire [, <clist>]	Use input signal as reference.			
:REFerence? [<clist>]	Query reference value.			
:THReshold	Path to select the threshold voltage range:		Sec 3	
:VOLTage				
:RANGe <n> [, <clist>]	Select threshold range (0 to 1010).	10		
:RANGe? [<clist>]	Query threshold range.			

Table 15-5 (continued)
SENSe command summary

Command	Description	Default parameter	Ref	SCPI
[SENSe[1]]				
:CONTinuity	Path to configure continuity test:		Sec 3	
:THReshold <NRf>	Set threshold resistance in ohms (1 to 1000).	10		
:THReshold?	Query threshold resistance.			

Notes:

1. CAVerage:DELay and RATio:DELay are coupled. Changing the delay for channel average also changes the delay for channel ratio and vice versa.
2. For 60Hz line power, the default for aperture is 83.33msec. For 50Hz, the default is 100msec.
3. REPeat is the *RST default and MOVing is the SYSTem:PRESet default. From the front panel, the factory default is MOVing.
4. OFF is the *RST default and ON is the SYTem:PRESet default.
5. The following commands can instead be used to select the reference junction and set the simulated reference temperature:

TEMPerature:RJUNction:RSELect <name> [, <clist>]	Select reference junction; SIMulated, INTernal, or EXTernal.
TEMPerature:RJUNction:RSELect? [<clist>]	Query reference junction.
TEMPerature:RJUNction:SIMulated <n> [, <clist>]	Set simulated reference temperature; 0 to 50 (°C), 32 to 122 (°F), or 273 to 323 (K).
TEMPerature:RJUNction:SIMulated? [<clist>]	Query simulated reference temperature.

6. When using multiple channel operation (ROUT:MULT command) to connect a switching module channel to the DMM for thermocouple temperature measurements, the SIMulated reference junction will be used if the INTernal or EXTernal reference junction is selected.
7. With a Model 7700, 7706, or 7708 installed, the default sensor junction is Internal. Otherwise, the Simulated (23°C) junction is selected.
8. Only one USER RTD per scan list.

Table 15-6
STATus command summary

Command	Description	Default parameter	Ref	SCPI
STATus		(Note 1)	Sec 11	✔
:MEASurement	Measurement event registers:			
[:EVENt]?	Read the event register.[6]	(Note 2)		
:ENABle <NDN> or <NRf>	Program the enable register.	(Note 3)		
:ENABle?	Read the enable register.[6]			
:CONDition?	Read the condition register.[6]			
:OPERation	Operation status registers:			✔
[:EVENt]?	Read the event register.[6]	(Note 2)		✔
:ENABle <NDN> or <NRf>	Program the enable register.	(Note 3)		✔
:ENABle?	Read the enable register.[6]			✔
:CONDition?	Read the condition register.[6]			✔
:QUEStionable	Questionable status registers:			✔
[:EVENt]?	Read the event register.[6]	(Note 2)		✔
:ENABle <NDN> or <NRf>	Program the enable register.	(Note 3)		✔
:ENABle?	Read the enable register.[6]			✔
:CONDition?	Read the condition register.[6]			✔
:PRESet	Return status registers to default states.			✔
:QUEue	Path to access error queue:			✔
[:NEXT]?	Read the most recent error message.	(Note 4)		✔
:ENABle <list>	Specify error and status messages for queue.	(Note 5)		✔
:ENABle?	Read the enabled messages.			✔
:DISable <list>	Specify messages not to be placed in queue.	(Note 5)		
:DISable?	Read the disabled messages.			
:CLEar	Clears all messages from Error Queue.			

Notes:

1. Commands in this subsystem are not affected by *RST and SYSTem:PRESet. The effects of cycling power, *CLS, and STATus:PRESet are explained by the following notes.
2. Event Registers: Power-up and *CLS – Clears all bits of the registers.
   STATus:PRESet – No effect.
3. Enable Registers: Power-up and STATus:PRESet – Clears all bits of the registers.
   *CLS – No effect.
4. Error Queue: Power-up and *CLS – Clears the Error Queue.
   STATus:PRESet – No effect.
5. Enable/Disable Error Queue Messages: Power-up – Clears list of messages.
   *CLS and STATus:PRESet – No effect.
6. The format for the response message (decimal, hexadecimal, octal, or binary) is set by the FORMat:SREGister command.

Table 15-7
SYSTem command summary

Command	Description	Default parameter	Ref	SCPI
SYSTem				
:PRESet	Return to :SYST:PRES defaults.		Sec 14	✔
:POSetup <name>	Select power-on setup: (RST, PRESet, SAV0, SAV1, SAV2, SAV3, or SAV4).		Sec 1	
:POSetup?	Query power-on setup.			
:FRSWitch?	Query INPUTS switch (0 = rear, 1 = front).		Sec 1	
:BEEPer	Path to control beeper.		Sec 14	
[:STATe] <b>	Enable or disable beeper.	ON		✔
[:STATe]?	Query state of beeper.			✔
:KCLick <b>	Turn the keyclick on/off.	ON	Sec 1	
:KCLick?	Query the keyclick status.			
:KEY <NRf>	Simulate key-press (1 to 31; see Figure 14-2).		Sec 14	✔
:KEY?	Query the last "pressed" key.			✔
:AZERo	Path to set up autozero.		Sec 3	
[:STATe] <b>	Enable or disable autozero.	ON		
[:STATe]?	Query autozero.			
:LSYNc	Path to control line synchronization:		Sec 3	
[:STATe] <b>	Enable or disable line-sync.	OFF		
[:STATe]?	Query state of line-sync.			
:LFRequency?	Query power line frequency.		Sec 1	
:FRESistance	Path to select 4-wire ohms mode:		Sec 3	
:TYPEx <name>	Select 4-wire ohms mode (NORMal or CSIDe) for 7701 installed in slot x (x = 1 or 2).			
:TYPEx?	Query selected 4-wire ohms mode.			
:PCARdX <name>	Set up an empty slot (X = 1 or 2) as a pseudocard (C7700, C7701, C7702, C7703, C7705, C7706, C7707, C7708, C7709, C7710, C7711, C7712).		Sec 2	
:CARDX	Path to query switching module in specified slot[1] (X = slot number for module).			
:SNUMber?	Request serial number[2].			
:SWRevision?	Request firmware revision[2].			
:VMAX?	Request maximum allowable voltage.			
:MUX?	Support multiplexer channels?; 1 = yes, 0 = no.			
:ISOLated?	Support isolated channels?; 1 = yes, 0 = no.			

Table 15-7 (continued)
SYSTem command summary

Command	Description	Default parameter	Ref	SCPI
SYSTem				
:CARDX				
:TCOMpensated?	Built-in temperature sensors for T/C cold junction?; 1 = yes, 0 = no.			
:VCHannel	Path to query volts/2-wire channels:			
[:STARt]?	Request lowest numbered volts/2-wire channel (usually 1); 0 = voltage measurements not supported.			
:END?	Request highest numbered volts/2-wire channel; 0 = voltage measurements not supported.			
:ACHannel	Path to query amps channels:			
[:STARt]?	Request lowest numbered amps channel; 0 = amps measurements not supported.			
:END?	Request highest numbered amps channel; 0 = amps measurements not supported.			
:ICHannel	Path to query isolated channels. An isolated channel includes 2/4-pole and backplane relays.			
[:STARt]?	Request the first isolated channel. 0 = no isolated channels.			
:END?	Request the last isolated channel. 0 = no isolated channels.			
:AOUTput	Path to query analog output channels:			
[:STARt]?	Request highest numbered analog output channel; 0 = analog output not supported.			
:END?	Request lowest numbered analog output channel; 0 = analog output not supported.			
:DOUTput	Path to query digital output channels:			
[:STARt]?	Request lowest numbered digital output channel; 0 = digital output not supported.			
:END?	Request highest numbered digital output channel; 0 = digital output not supported.			
:TCHannel?	Query the totalizer channel.			
:DINPut	Path to query digital input channels:			
[:STARt]?	Request lowest numbered digital input port; 0 = digital input not supported.			
:END?	Request highest numbered digital output channel; 0 = digital input not supported.			

Table 15-7 (continued)
SYSTem command summary

Command	Description	Default parameter	Ref	SCPI
SYSTem				
:CARDX				
:SNOpen?	Query whether card is "single no-open" type (i.e., 7711): 1 = yes, 0 = no.			
:BANKs?	For "single no-open" card, query number of banks. If not "single no-open" type, error -221 (settings conflict) results.			
:SWOpen?	Query whether card is "single with-open" type (i.e., 7711): 1 = yes, 0 = no.			
:BANKs?	For "single with-open" card, query number of banks.			
:CSOhms?	Query whether card supports common-side 4-wire ohms (i.e., 7701).			
:TIME <hr, min,sec>	Set system time using 24-hour format.		Sec 6	
:TIME?	Query system time.			
:DATE <yr, mo, day>	Set system date (yr = 20xx).		Sec 6	
:DATE?	Query system date.			
:TSTamp	Path to set timestamp:		Sec 6	
:TYPE <name>	Select timestamp type (RELative or RTCLock).	REL		
:TYPE?	Query timestamp type that will be used for the next buffer storage.			
:RELative	Path to reset relative timestamp:			
:RESet	Reset relative timestamp to 0.			
:RNUMber	Path to reset reading number:		Sec 14	
:RESet	Reset reading number. Next reading will be #1.			
:ERRor?	Query Error Queue.	(Note 3)	Sec 11	✔
:CLEar	Clears messages from the Error Queue.		Sec 11	
:VERSion?	Query rev level of SCPI standard.		Sec 14	✔
:LOCal	Take 2701 out of remote and restore operation of front panel controls.			
:REMote	Place 2701 in remote.			
:RWLock	Lockout front panel controls.			
:RESet	Immediately reboots the 2701.			

Table 15-7 (continued)
SYSTem command summary

Command	Description	Default parameter	Ref	SCPI
SYSTem				
:BOARd	PC board:			
:SNUMber?	Acquire serial number of PC board.			
:REVision?	Acquire revision level of PC board.			
:BATTery	Battery:			
:PRESent?	Is a battery installed?; 0 = no, 1 = yes.			
:STATus?	Returns "OK", "MEMORY LOST", or "CHARGING FAILURE". Memory is lost when the battery is not installed and upon a reset after a firmware upgrade. A charging failure occurs when it is time for a new battery.			
:PASSword	Password:			
:ENABle <b>	Enables or disables the use of password.			
:ENABle?	Query password use.			
:CDISable <password>	Disables protected commands.			
[:CENable] <password>	Enables protected commands.			
:STATe <b>	Returns "0" if password protected commands are disabled. Returns "1" if enabled.			
:NEW <password>	Set new password.			
:COMMunicate	Ethernet and RS-232 commands:			
:SELect <name>	Select communications mode; ETHernet or SERial.			
:ETHernet	Ethernet:			
:ADDRess <value>	Set IP address of 2701; "n.n.n.n".			
:ADDRess?	Query IP address of 2701.			
:MASK <value>	Sets the subnet mask; "n.n.n.n".			
:MASK?	Query subnet mask.			
:GATeway <value>	Set the Ethernet gateway; "n.n.n.n".			
:GATeway?	Query the Ethernet gateway.			
:DHCP <b>	Enable or disable Dynamic Host Control Protocol (DHCP).			

Table 15-7 (continued)
SYSTem command summary

Command	Description	Default parameter	Ref	SCPI
SYSTem				
:COMMunicate				
:ETHernet				
:DHCP?	Query state of DHCP.			
:MAC?	Returns MAC address of 2701; 6 hexadecimal values separated by colons (00:60:1A:00:04:0B).			
:SERial	RS-232:			
:BAUD <n>	Set baud rate; 300, 600, 1200, 2400, 4800, 9600, 19200, 38400, 57600, or 115200.			✔
:BAUD?	Query baud rate.			✔
:PACE <name>	Control Xon/Xoff flow control; XON (on) or NONE (off).			✔
:PACE?	Query state of flow control.			✔
:TERMinator <name>	Select output terminator; CR, LF, CRLF, or LFCR.			✔
:TERMinator?	Query output terminator			✔
:CONTrol	Control RTS/CTS hardware handshaking:			✔
:RTS <name>	Enable (IBFull or RFR) or disable (OFF) hardware handshaking.			✔
:RTS?	Query state of hardware handshaking.			✔
:SEND <data>	Send data (from serial port) to another instrument.[4]			
:ENTer?	Read data from serial port.[4]			

Note:
1. If there is no card in the specified slot, error -241 Hardware Missing will occur.
2. If a pseudocard is installed in the slot, the message "????????" will be returned when querying the serial number or firmware revision.
3. Power-up and *CLS clears the error queue. *RST, SYSTem:PRESet and STATus:PRESet has no effect on the error queue.
4. Valid only when Ethernet is the selected interface.

Table 15-8
TRACe command summary

Command	Description	Default parameter*	Ref	SCPI
TRACe|:DATA	Use TRACe or DATA as root command.		Sec 6	
:CLEar	Path to clear the buffer.			
[:IMMediate]	Clear the buffer.			
:AUTO <b>	Enable or disable buffer auto-clear.	ON		
:AUTO?	Query state of buffer auto-clear.			
:FREE?	Query bytes available and bytes in use.			✔
:POINts <NRf>	Specify size of buffer (2 to 450000).	100		✔
:POINts?	Query buffer size.			✔
:ACTual?	Query number of readings stored in buffer.			✔
:NOTify <NRf>	Specify number of stored readings that will set Trace Notify bit (B6) of measurement event register (1 to 449999). Must be less than TRACe:POINts value.	50		
:NOTify?	Query trace notify value.			
:NEXT?	Query buffer location for next stored reading.			
:TSTamp	Path to set timestamp format:			
:FORMat <name>	Select timestamp format (ABSolute or DELTa).	ABS		
:FORMat?	Query timestamp format.			
:TYPE?	Query timestamp type for readings presently in buffer.			
:FEED <name>	Select source of readings (SENSe[1], CALCulate[1], or NONE).	CALC		✔
:CONTrol <name>	Select buffer control mode (NEVer, NEXT, or ALWays).	NEV		✔
:CONTrol?	Query buffer control mode.			✔
:FEED?	Query source of readings for buffer.			✔
:DATA?	Read all readings in the buffer.			✔
:DATA:SELected? <start>, <count>	Specify readings to be returned; specify starting point (first reading is #0) and number of readings (count).			

*SYSTem:PRESet and *RST have no effect on commands in this subsystem. The listed defaults are defaults set at the factory.

Table 15-9
Trigger command summary

Command	Description	Default parameter	Ref	SCPI
INITiate	Subsystem command path:		Sec 8	✔
[:IMMediate]	Initiate one trigger cycle.			✔
:CONTinuous <b>	Enable or disable continuous initiation.	(Note 1)		✔
:CONTinuous?	Query continuous initiation.			✔
ABORt	Reset trigger system.			✔
TRIGger[:SEQuence[1]]	Path to program Trigger Layer:			✔
:COUNt <n>	Set measure count (1 to 450000 or INFinity).	(Note 2)		✔
:COUNt?	Query measure count.			✔
:DELay <n>	Set delay (0 to 999999.999 sec).	0		✔
:AUTO <b>	Enable or disable auto delay.	ON		
:AUTO?	Query state of delay.			
:DELay?	Query delay.			✔
:SOURce <name>	Select control source (IMMediate, TIMer, MANual, BUS, or EXTernal).	IMM		✔
:SOURce?	Query control source.			✔
:TIMer <n>	Set timer interval (0.001 to 999999.999 sec).	0.1		✔
:TIMer?	Request the programmed timer interval.			✔
:SIGNal	Loop around control source.			✔
SAMPle				
:COUNt <NRf>	Specify sample count (1 to 450000).	1		
:COUNt?	Query sample count.			

Notes:
1. Defaults for continuous initiation:
   SYSTem:PRESet enables continuous initiation.
   *RST disables continuous initiation.
2. Defaults for count:
   SYSTem:PRESet sets the count to INF (infinity).
   *RST sets the count to 1.

Table 15-10
UNIT command summary

Command	Description	Default parameter	Ref	SCPI
UNIT				
:TEMPerature <name>	Select temperature units (C, CEL, F, FAR, or K).	C	Sec 3	✔
:TEMPerature?	Query temperature units.			✔
:VOLTage	Path to configure voltage units.		Sec 5	
[:DC] <name> [, <clist>]	Select DCV measurement units (V or DB).	V		
:DB	Path to set DB reference voltage:			
:REFerence <n>	Specify reference in volts (1e-7 to 1000).	1		
:REFerence?	Query reference.			
[:DC]? [<clist>]	Query DCV units.			
:AC <name> [, <clist>]	Select ACV measurement units (V or DB).	V		
:DB	Path to set DB reference voltage.			
:REFerence <n>	Specify reference in volts (le-7 to 1000).	1		
:REFerence?	Query DB reference.			
:AC? [<clist>]	Query ACV units.			

A
Specifications

Model 2701 Ethernet / Data Acquisition System

Put 2701 specs here

Accuracy calculations

The information below discusses how to calculate accuracy for both DC and AC characteristics.

Calculating DC characteristics accuracy

DC characteristics accuracy is calculated as follows:

Accuracy = ±(ppm of reading + ppm of range)
(ppm = parts per million and 10ppm = 0.001%)

As an example of how to calculate the actual reading limits, assume that you are measuring 5V on the 10V range. You can compute the reading limit range from one-year DCV accuracy specifications as follows:

Accuracy = ±(30ppm of reading + 5ppm of range)
±[(30ppm × 5V) + (5ppm × 10V)]
±(150µV + 50µV)
±200µV

Thus, the actual reading range is: 5V± 200µV or from 4.9998V to 5.0002V.

DC current and resistance calculations are performed in exactly the same manner using the pertinent specifications, ranges, and input signal values.

Calculating AC characteristics accuracy

AC characteristics accuracy is calculated similarly, except that AC specifications are given as follows:

Accuracy = (% of reading + % of range)

As an example of how to calculate the actual reading limits, assume that you are measuring 120V, 60Hz on the 750V range. You can compute the reading limit range from ACV one-year accuracy specifications as follows:

Accuracy = ±(0.06% of reading + 0.03% of range)
±[(0.0006 × 120V) + (0.0003 × 750V)]
±(0.072V + 0.225V)
±0.297V

In this case, the actual reading range is: 120V± 0.297V or from 119.703V to 120.297V.

AC current calculations are performed in exactly the same manner using the pertinent specifications, ranges, and input signal values.

Calculating dBm characteristics accuracy

As an example of how to calculate the actual reading limits for a 13dBm measurement with a reference impedance of 50Ω, assume an applied signal of 0.998815V. The relationship between voltage and dBm is as follows:

$$dBm = 10 \log \frac{V_{IN}^2 / R_{REF}}{1mW}$$

From the previous example on calculating DC characteristics accuracy, it can be shown that a measurement of 0.998815V on the 1V range has an uncertainty of ±36.9644mV or 0.998778V to 0.998852V, using one-year specifications.

Expressing 0.998778V as dBm:

$$dBm = 10 \log \frac{(0.998778V)^2 / 50\Omega}{1mW} = 12.99968dBm$$

and expressing 0.998852V as dBm:

$$dBm = \frac{(0.998852V)^2 / 50\Omega}{1mW} = 13.00032dBm$$

Thus, the actual reading range is 13dBm ±0.00032dBm.

dBm and dB for other voltage inputs can be calculated in exactly the same manner using pertinent specifications, ranges, and reference impedances.

Calculating dB characteristics accuracy

The relationship between voltage and dB is as follows:

$$dB = 20 \log \frac{V_{IN}}{V_{REF}}$$

As an example of how to calculate the actual readings limits for dB, with a user-defined VREF of 10V, you must calculate the voltage accuracy and apply it to the above equation.

To calculate a -60dB measurement, assume 10mV RMS for a VREF of 10V. Using the 100mV range, one-year, 10Hz - 20kHz frequency band, and SLOW rate, the voltage limits are as follows:

Accuracy = ±[(0.06% of reading) + (0.03% of range)]
±[(0.0006 × 10mV) + (0.0003 × 100mV)]
±(6µV + 30µV)
±36µV

Thus, the actual reading accuracy is 10mV ±36mV or 10.036mV to 9.964mV. Applying the voltage reading accuracy into the dB equation yields:

$$dBm = 20 \log \frac{10.036mV}{10V} = -59.96879dB$$

$$dBm = 20 \log \frac{9.964mV}{10V} = -60.03133dB$$

Thus, the actual reading accuracy is -60dB + 0.031213dB to -60dB - 0.031326dB.

dBm and dB for other voltage inputs can be calculated in exactly the same manner using pertinent specifications, ranges, and other reference voltages.

Additional derating factors

In some cases, additional derating factors must be applied to calculate certain accuracy values. For example, an additional derating factor of 0.02ppm/V must be added to DCV specifications for voltages over 500V. Before calculating accuracy, study the associated specifications very carefully to see if any derating factors apply.

Optimizing measurement accuracy

The configurations listed below assume that the multimeter has had factory setups restored.

NOTE *For maximum system performance, it is recommended that all measurement cables be limited to less than 3 meters.*

DC voltage, DC current, and resistance:

- Select 6½ digits, 10 PLC, filter ON (up to 100 readings), fixed range.
- Use REL on DC voltage and 2-wire resistance measurements.
- Use 4-wire resistance measurements for best accuracy.

AC voltage and AC current:

- Select 6½ digits, 10 PLC, filter ON (up to 100 readings), fixed range.

Temperature:

- Select 6½ digits, 10 PLC, filter ON (up to 100 readings).

Optimizing measurement speed

The configurations listed below assume that the multimeter has had factory setups restored.

DC voltage, DC current, and resistance:

- Select 3½ digits, 0.002 PLC, filter OFF, fixed range.

AC voltage and AC current:

- Select 3½ digits, 0.002 PLC, filter OFF, fixed range.

Temperature:

- Select 3½ digits, 0.002 PLC, filter OFF.

For all functions, turn off the display, autozero, and set the trigger delay to zero. Use the :SAMPle:COUNt and READ? bus commands.

B
Model 7700 Connection Guide

Card configuration — schematic

Figure B-1 shows a simplified schematic diagram of the Model 7700 module. As shown, the Model 7700 has channels that are grouped into two banks of ten channels (twenty channels total). Backplane isolation is provided for each bank. Each bank also includes separate cold junction reference points. The first bank contains channels 1 through 10 while the second bank contains channels 11 through 20. Each channel of the 20-channel multiplexer card is wired with separate inputs for HI/LO providing fully isolated inputs. The Model 7700 also provides two channels of current input, Channels 21 and 22.

Although the Model 7700 relays are the latching type (relays hold their state even after power has been removed), all relay states are set to open a few seconds after either a power cycle or a *RST command is issued.

Connections to DMM functions for system channel operation are provided through the card backplane connector.

- Current provided through two protected channels (Channels 21 and 22).
- INPUT connections.
- SENSE (Ω4-wire) connections.

AMP and LO common connections to the DMM are also provided.

Channel 23 (2W/4W Configuration), Channel 24 (Sense Isolation), and Channel 25 (Input Isolation) are normally automatically configured by the 2701 for system channel operation. However, by using multiple channel operation (refer to Section 2), channels can be individually controlled.

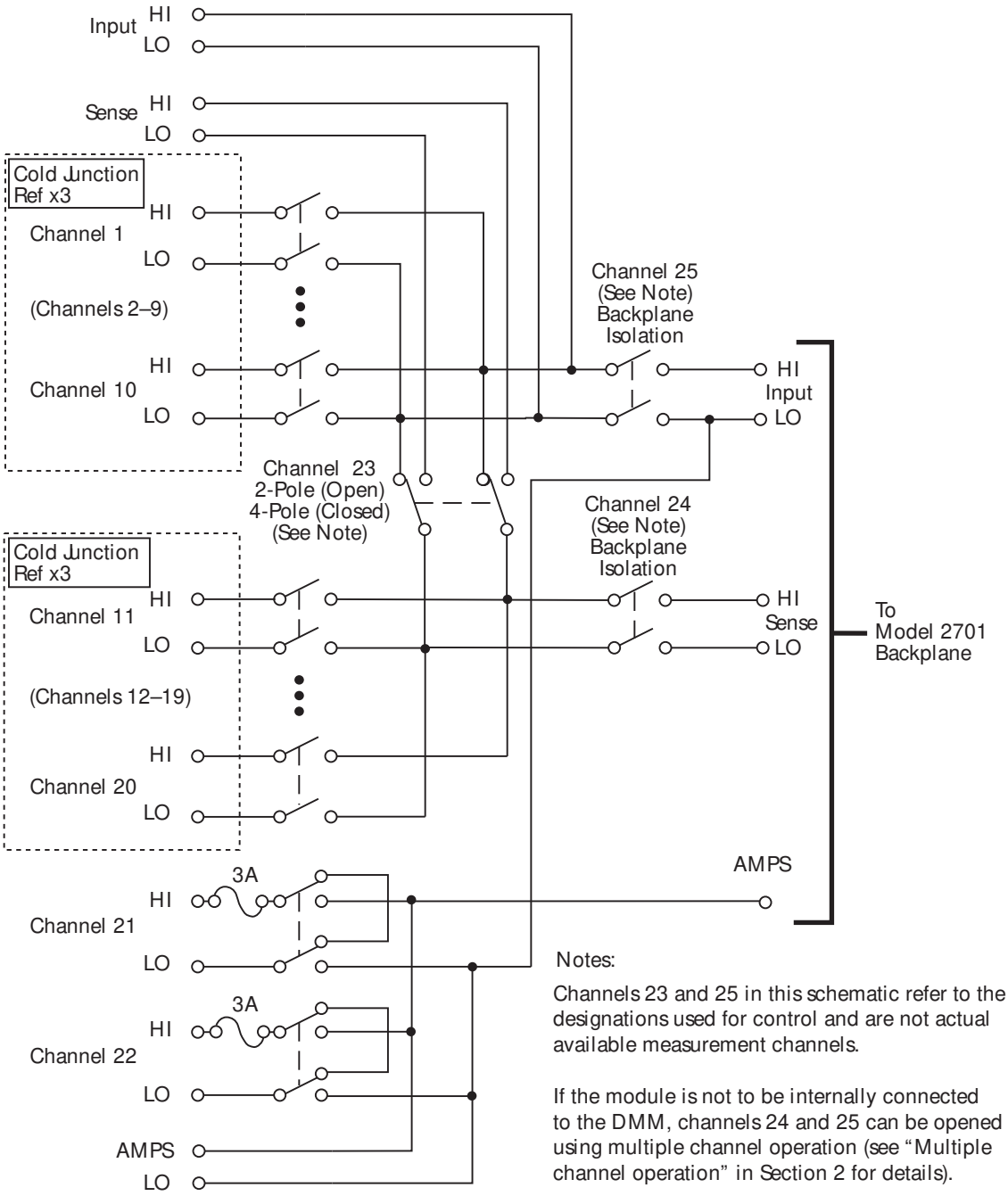
NOTE *Connect 4-wire sense leads using channels 11–20.*

To disconnect channels 11–20 from channels 1–10, send:
`ROUT:MULT:CLOS (@123)` *(note opposite logic).*

When automatically configured for 4-wire measurements (including 4-wire Ω, RTD temperature, Ratio, and Channel Average) the channels are paired as follows:

CH1 and CH11	CH6 and CH16
CH2 and CH12	CH7 and CH17
CH3 and CH13	CH8 and CH18
CH4 and CH14	CH9 and CH19
CH5 and CH15	CH10 and CH20

Figure B-1
Simplified schematic for Model 7700



Notes:

Channels 23 and 25 in this schematic refer to the designations used for control and are not actual available measurement channels.

If the module is not to be internally connected to the DMM, channels 24 and 25 can be opened using multiple channel operation (see "Multiple channel operation" in Section 2 for details).

Connections and wiring

WARNING The following information is intended for qualified service personnel. Do not make or break switching module connections unless qualified to do so.

WARNING To prevent electric shock that could result in serious injury or death, adhere to the following safety precautions:

- Before removing or installing the switching module in the mainframe, make sure the Model 2701 is turned off and disconnected from line power.
- Before making or breaking connections to the switching module, make sure power is removed from all external circuitry.
- Do not connect signals that will exceed the maximum specifications of the Model 7700. Specifications are provided in Appendix A.

WARNING If both the front panel terminals and the switching module terminals are connected at the same time, the test lead insulation must be rated to the highest voltage that is connected. For example, if 1000V is connected to the front panel input, the test lead insulation for the switching module must also be rated for 1000V.

WARNING Dangerous arcs of an explosive nature in a high energy circuit can cause severe personal injury or death. If the multimeter is connected to a high energy circuit when set to a current range, low resistance range, or any other low impedance range, the circuit is virtually shorted. Dangerous arcing can result even when the multimeter is set to a voltage range if the minimum voltage spacing is reduced in the external connections. For details to safely make high energy measurements, see "High energy circuit safety precautions" in Section 3.

As described in the International Electrotechnical Commission (IEC) Standard IEC 664, the Model 2701 is Installation Category I and must not be connected to mains.

Screw terminals

Figure B-2 shows how to access the screw terminals on the Model 7700. Channel designations for the screw terminals are contained in Figure B-3.

Figure B-2
Screw terminal access

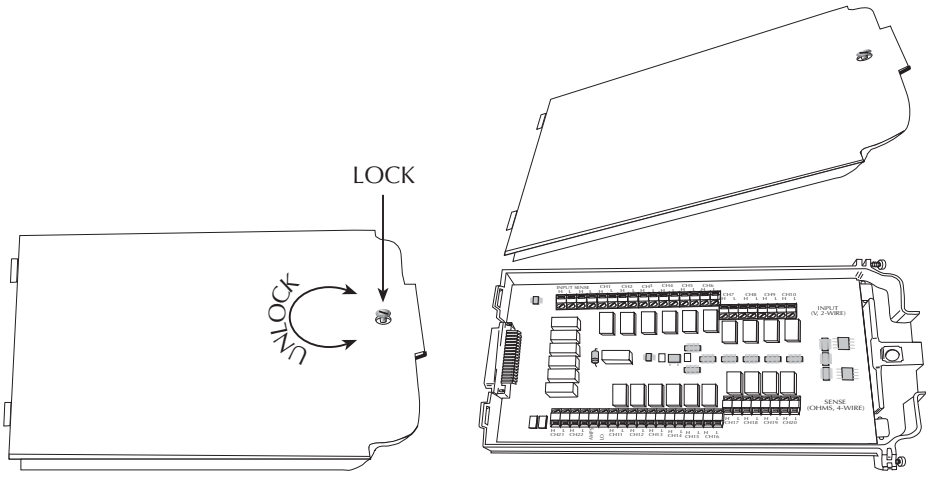
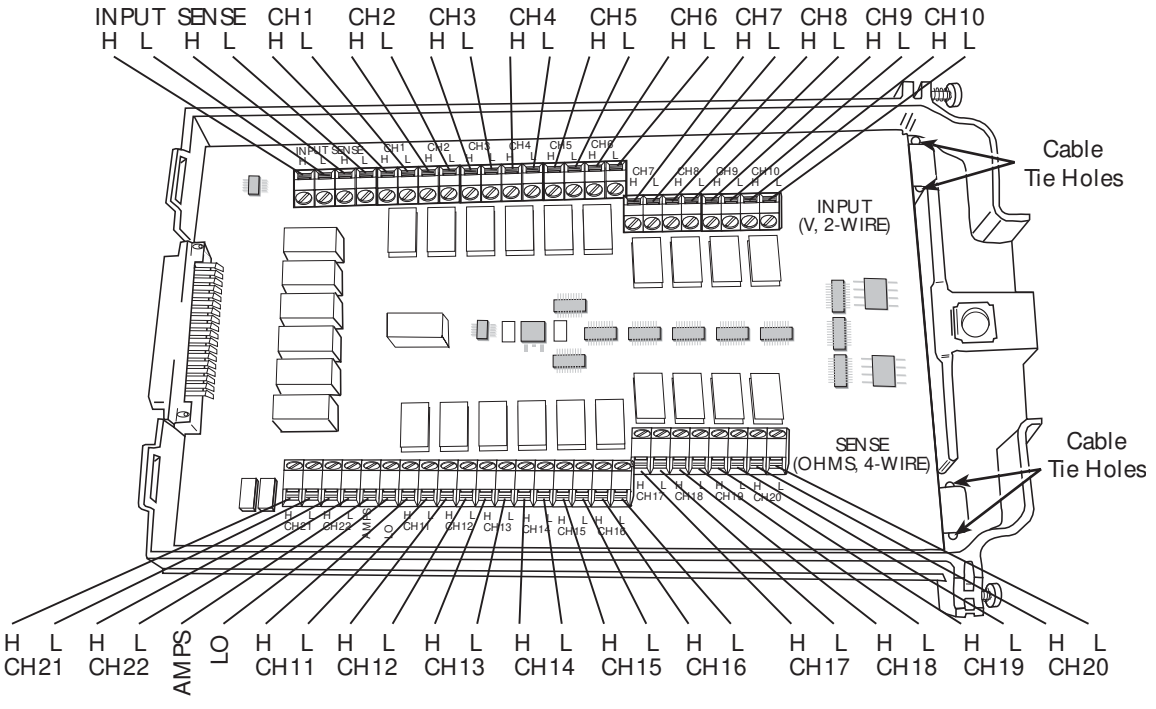


Figure B-3
Model 7700 screw terminal channel designations



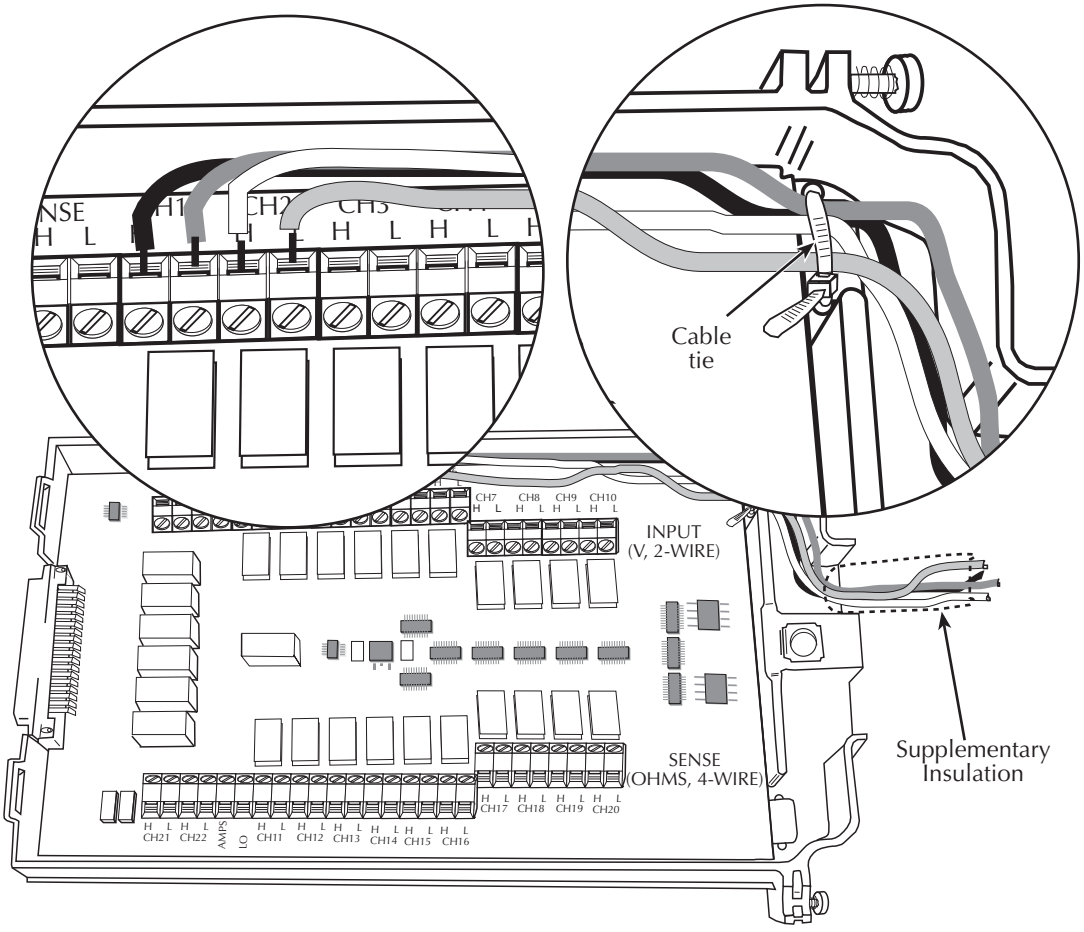
Wiring procedure

Use the following procedure to wire the Model 7700 module. Make all connections using correct wire size (up to 20 AWG). Also, make sure to add supplementary insulation around the harness for voltages above 42V peak (Figure B-4).

WARNING All wiring and supplementary insulation must be rated for the maximum voltage in the system. For example, if 1000V is applied to the front terminals of the DMM, the plug-in module wiring must be rated for 1000V.

1. Make sure all power is discharged from the Model 7700 module.
2. Access the screw terminals (Figure B-2).
3. Using a small flat-blade screwdriver, loosen terminal screws and install wires as desired. (Figure B-4 shows connections to channels 1 and 2.)
4. Route wire along wire-path and secure with cable tie as shown.
5. Fill in a copy of the connection log (Table B-1) and affix it to the module cover.
6. Close and lock cover.

Figure B-4
Wire dressing



Typical connections

The following examples show typical wiring connections for the following types of measurements:

- Thermocouple connections, Figure B-5
- Ω2-Wire and thermistor connections, Figure B-6
- Ω4-Wire and RTD connections, Figure B-7
- Current connections (AC or DC), Figure B-8
- Voltage connections (AC or DC), Figure B-9

Figure B-5
Thermocouple connections

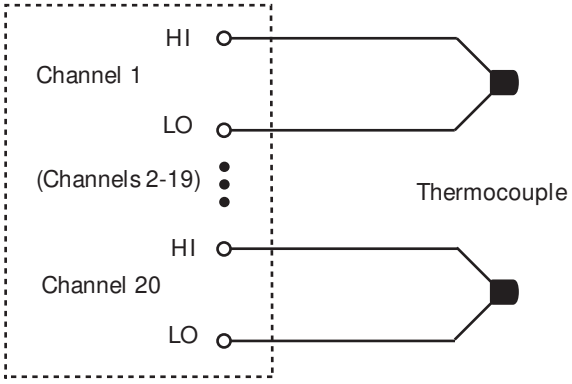


Figure B-6
Ω2-Wire and thermistor connections

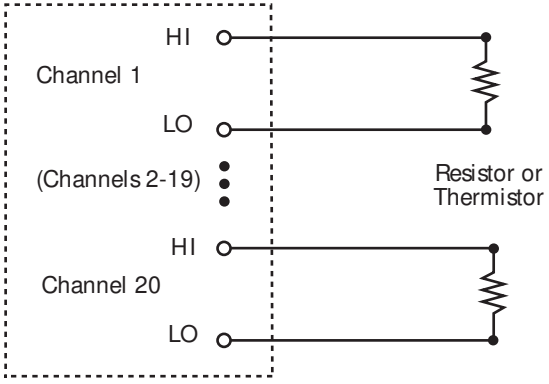


Figure B-7
Ω4-Wire and RTD connections

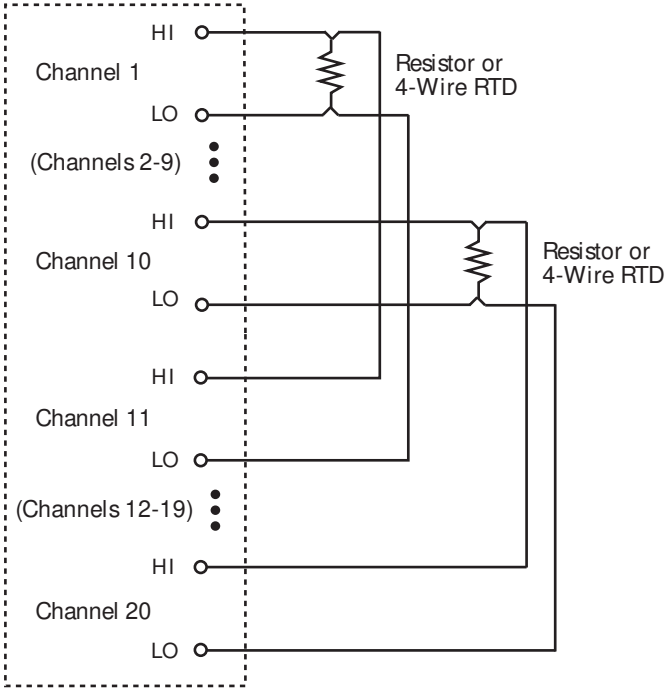


Figure B-8
Current connections (AC or DC)

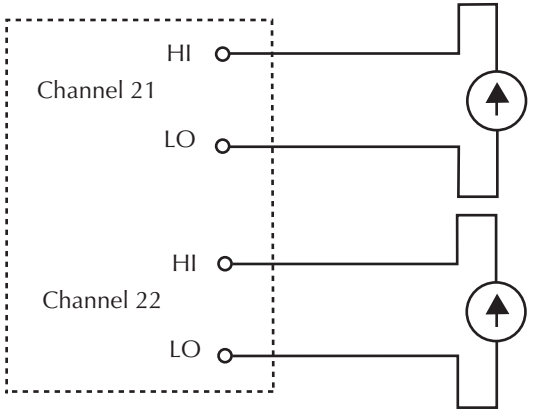
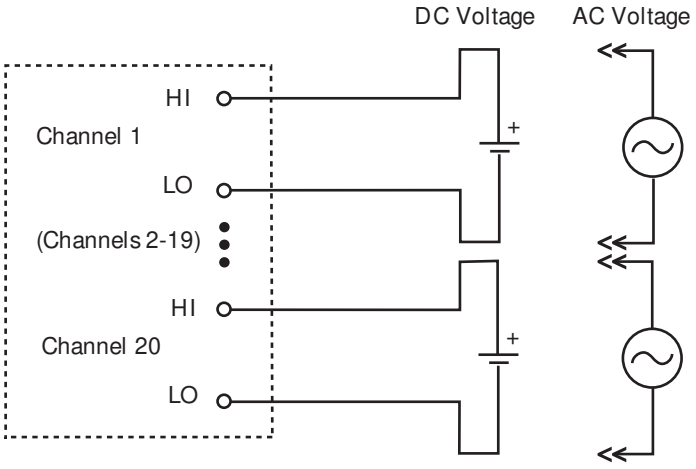


Figure B-9
Voltage connections (DC or AC)



Connection log

Make a copy of Table B-1 and affix it to the cover of the Model 7700. Use this to record connection information and channel descriptions as needed.

Table B-1
Connection log Model 7700

Channel		Color	Description
AMPS COM	H		
	L		
INPUT	H		
	L		
SENSE	H		
	L		
CH1	H		
	L		
CH2	H		
	L		
CH3	H		
	L		
CH4	H		
	L		
CH5	H		
	L		
CH6	H		
	L		
CH7	H		
	L		
CH8	H		
	L		
CH9	H		
	L		
CH10	H		
	L		
CH11	H		
	L		
CH12	H		
	L		
CH13	H		
	L		
CH14	H		
	L		
CH15	H		
	L		
CH16	H		
	L		
CH17	H		
	L		
CH18	H		
	L		
CH19	H		
	L		
CH20	H		
	L		
AMPS 21	H		
	L		
AMPS 22	H		
	L		

C
Status and Error Messages

Table C-1
Status and error messages

Number	Description	Event
-440	Query unterminated after indefinite response	EE
-430	Query deadlocked	EE
-420	Query unterminated	EE
-410	Query interrupted	EE
-363	Input buffer overrun	SYS
-350	Queue overflow	SYS
-330	Self-test failed	EE
-314	Save/recall memory lost	EE
-315	Configuration memory lost	EE
-285	Program syntax error	EE
-284	Program currently running	EE
-282	Illegal program name	EE
-281	Cannot create program	EE
-260	Expression error	EE
-241	Hardware missing	EE
-230	Data corrupt or stale	EE
-225	Out of memory	EE
-224	Illegal parameter value	EE
-223	Too much data	EE
-222	Parameter data out of range	EE
-221	Settings conflict	EE
-220	Parameter error	EE
-215	Arm deadlock	EE
-214	Trigger deadlock	EE
-213	Init ignored	EE
-212	Arm ignored	EE
-211	Trigger ignored	EE
-210	Trigger error	EE
-203	Command protected	EE
-202	Settings lost due to rtl	EE
-201	Invalid while in local	EE
-200	Execution error	EE
-178	Expression data not allowed	EE
-171	Invalid expression	EE
-170	Expression error	EE
-168	Block data not allowed	EE
-161	Invalid block data	EE
-160	Block data error	EE

Table C-1 (continued)
Status and error messages

Number	Description	Event
-158	String data not allowed	EE
-154	String too long	EE
-151	Invalid string data	EE
-150	String data error	EE
-148	Character data not allowed	EE
-144	Character data too long	EE
-141	Invalid character data	EE
-140	Character data error	EE
-128	Numeric data not allowed	EE
-124	Too many digits	EE
-123	Exponent too large	EE
-121	Invalid character in number	EE
-120	Numeric data error	EE
-114	Header suffix out of range	EE
-113	Undefined header	EE
-112	Program mnemonic too long	EE
-111	Header separator error	EE
-110	Command header error	EE
-109	Missing parameter	EE
-108	Parameter not allowed	EE
-105	GET not allowed	EE
-104	Data type error	EE
-103	Invalid separator	EE
-102	Syntax error	EE
-101	Invalid character	EE
-100	Command error	EE
+000	No error	SE

Table C-1 (continued)
Status and error messages

Number	Description	Event
+101	Operation complete	SE
+121	Device calibrating	SE
+122	Device settling	SE
+123	Device ranging	SE
+124	Device sweeping	SE
+125	Device measuring	SE
+126	Device calculating	SE
+161	Program running	SE
+171	Waiting in trigger layer	SE
+174	Re-entering the idle layer	SE
+180	Filter settled	SE
+301	Reading overflow	SE
+302	Low limit 1 event	SE
+303	High limit 1 event	SE
+304	Low limit 2 event	SE
+305	High limit 2 event	SE
+306	Reading available	SE
+307	Buffer user-selectable event	SE
+308	Buffer available	SE
+309	Buffer half full	SE
+310	Buffer full	SE
+311	Buffer overflow	SE
+312	Buffer one quarter full	SE
+313	Buffer three quarters full	SE
+314	Master limit event	SE

Table C-1 (continued)
Status and error messages

Number	Description	Event
	Calibration messages:	
+400	10vdc zero error	EE
+401	100vdc zero error	EE
+402	10vdc full scale error	EE
+403	-10vdc full scale error	EE
+404	100vdc full scale error	EE
+405	-100vdc full scale error	EE
+406	1k 2-w zero error	EE
+407	10k 2-w zero error	EE
+408	100k 2-w zero error	EE
+409	10M 2-w zero error	EE
+410	10M 2-w full scale error	EE
+411	10M 2-w open error	EE
+412	1k 4-w zero error	EE
+413	10k 4-w zero error	EE
+414	100k 4-w zero error	EE
+415	10M 4-w sense lo zero error	EE
+416	1k 4-w full scale error	EE
+417	10k 4-w full scale error	EE
+418	100k 4-w full scale error	EE
+419	1M 4-w full scale error	EE
+420	10M 4-w full scale error	EE
+421	10m adc zero error	EE
+422	100m adc zero error	EE
+423	10m adc full scale error	EE
+424	100m adc full scale error	EE
+425	1 adc full scale error	EE
+426	10 4-w zero error	EE
+427	1k 4-w zero error	EE
+428	10 2-w zero error	EE
+429	10k 4-w zero error	EE
+430	10k 4-w ocomp Ion full scale	EE
+438	Date of calibration not set	EE
+439	Next date of calibration not set	EE
+450	100m vac dac error	EE
+451	1 vac dac error	EE
+452	10 vac dac error	EE
+453	100 vac dac error	EE
+454	100m vac zero error	EE
+455	100m vac full scale error	EE

Table C-1 (continued)
Status and error messages

Number	Description	Event
+456	1 vac zero error	EE
+457	1 vac full scale error	EE
+458	1 vac noise error	EE
+459	10 vac zero error	EE
+460	10 vac full scale error	EE
+461	10 vac noise error	EE
+462	100 vac zero error	EE
+463	100 vac full scale error	EE
+464	750 vac zero error	EE
+465	750 vac full scale error	EE
+466	750 vac noise error	EE
+467	Post filter offset error	EE
+468	1 aac zero error	EE
+469	1 aac full scale error	EE
+470	3 aac zero error	EE
+471	3 aac full scale error	EE
+472	1V 10Hz amplitude error	EE
+473	Frequency gain error	EE
+474	1K Ohm loff Ocomp FS error	EE
+475	10K Ohm loff Ocomp FS error	EE
+476	Temperature Cold Cal error	EE
+477	Analog output zero error	EE
+478	Analog output pos. gain error	EE
+479	Analog output neg. gain error	EE
+480	1k 4-w dckt Ioff zero error	EE
+481	1k 4-w dckt Ion zero error	EE
+482	1k 4-w dckt Ioff full scale error	EE
+483	1k 4-w dckt Ion full scale error	EE
+484	100 4-w dckt Ioff zero error	EE
+485	100 4-w dckt Ion zero error	EE
+486	100 4-w ocomp Ion zero error	EE
+487	100 4-w ocomp Ion full scale error	EE
+488	100 4-w dckt Ioff full scale error	EE
+489	100 4-w dckt Ion full scale error	EE
+490	10 4-w dckt Ioff zero error	EE
+491	10 4-w dckt Ion zero error	EE
+492	10 4-w dckt full scale error	EE
+493	10 4-w full scale error	EE
+494	10 4-w ocomp Ion zero error	EE
+495	10 4-w ocomp Ion full scale error	EE

Table C-1 (continued)
Status and error messages

Number	Description	Event
+496	1 4-w dckt Ioff zero error	EE
+497	1 4-w dckt Ion zero error	EE
+498	1 4-w dckt Ion full scale error	EE
+499	1V 10Hz frequency error	EE
+500	Calibration data invalid	EE
+510	Reading buffer data lost	EE
+512	Power-on state lost	EE
+513	AC calibration data lost	EE
+514	DC calibration data lost	EE
+515	Calibration dates lost	EE
+516	Battery backed RAM error	EE
+517	Cannot resume scan	EE
+518	Card calibration data lost	EE
+519	Card calibration dates lost	EE
+520	Saved setup scancard mismatch	EE
+521	Card relay counts lost	EE
+523	Card hardware error	EE
+524	Unsupported card detected	EE
+525	Scancard memory pattern mismatch	EE
+550	Unitialized ethernet module	EE
+555	Cannot charge battery	EE
+556	Battery removed	EE
+558	A/D Timeout	EE
+610	Questionable calibration	SE
+611	Questionable temperature	SE
+700	Invalid function in scanlist	EE
+800	RS-232 Framing error detected	EE
+802	RS-232 Overrun detected	EE
+803	RS-232 Break detected	EE
+805	Invalid system communication	EE
+808	ASCII only with RS-232	EE
+900	Internal system error	EE

EE = error event
SE = status event
SYS = system error event

NOTE *SCPI-confirmed messages are described in Volume 2: Command Reference of the Standard Commands for Programmable Instruments. Refer to the SYSTem:ERRor? command.*

D
Signal Processing Sequence and Data Flow

Signal processing sequence

Basic signal processing

The signal is applied to the multimeter input via front panel input terminals or a switching module. When a channel is closed or scanned, the signal connected to that channel (or channel-pair for 4-wire measurements) is connected to the input.

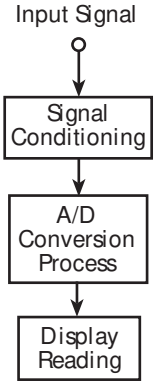
Figure D-1 is a flowchart that shows the basic processing sequence of an input signal. With all the various features (filter, rel, math, ratio, channel average, buffer, etc.) of the Model 2701 disabled, the input signal is conditioned and measured (A/D conversion process). The reading is then displayed on the Model 2701.

Based on the selected measurement function and range, signal conditioning transforms the input signal into a DC voltage that is applied to the A/D converter.

The A/D Conversion Process measures the DC signal voltage and internal voltages that correspond to offsets (zero) and amplifier gains. For TC temperature measurements using a switching module that has an internal reference junction (i.e., Model 7700), the internal temperature is also measured. These measurements are used in an algorithm to accurately calculate the reading of the input signal. The voltage, current, resistance, frequency (or period), or temperature reading is then displayed by the Model 2701.

NOTE *The multiple measurement process used by the A/D converter is known as autozeroing. It can be disabled to increase speed (only the signal is measured). However, stability and accuracy will be affected over time and changes in temperature.*

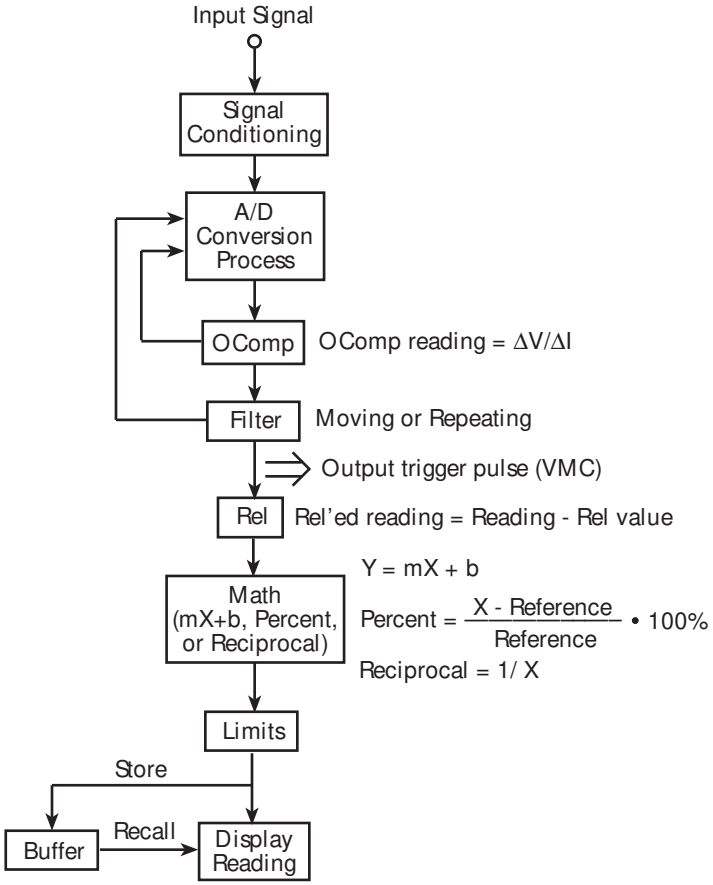
Figure D-1
Basic signal processing



Signal processing using instrument features

Figure D-2 shows the processing sequence for an input signal with various instrument features enabled. If a feature is not enabled, the reading simply falls through to the next enabled feature or to the display.

Figure D-2
Signal processing using instrument features



OComp (offset-compensated ohms)

The Model 2701 performs a normal ohms measurement by sourcing a known current (I), measuring the voltage (V), and then calculating the resistance (R = V/I). Offset-compensated ohms cancels the effects of thermal EMFs which can adversely affect low-resistance measurements.

With OCOMP enabled, the Model 2701 performs one normal resistance measurement and then loops back to perform a second resistance measurement with the internal current source set to its lowest level. The offset-compensated ohms reading is then calculated as shown in Figure D-2.

NOTE For details on OCOMP measurements, see"Offset-compensated ohms," page 3-24.

Filter

The filter is used to stabilize noisy readings. With the filter enabled, the specified number of readings are averaged to yield a single filtered reading. There are two types of filters: moving and repeating.

A filter stack is used to temporarily store the specified number of readings to be averaged. In general, for the moving filter, each measurement process adds a reading to the stack (oldest reading discarded) and then averages the stack to yield a filtered reading. For the repeating filter, each measurement process fills the stack with new readings (all previous readings discarded) and then averages the stack to yield a filtered reading.

NOTE For details on filter operation, see "Filter," page 4-14.

Output trigger pulse (VMC)

An output trigger pulse from the Model 2701 can be used to trigger an external instrument to perform an operation. In general, a trigger pulse is the output at this point in the flowchart for each processed reading.

An exception is the SCAN function for scanning. For the SCAN function, an output trigger is not output until after the specified number of channels (as set by the sample counter) are scanned.

NOTE For details on scan operation, see "Trigger models," page 7-4.

Rel

Next in the signal processing sequence is the Rel operation. Rel is used to null offsets or subtract a baseline rel value from the reading. With Rel enabled, the Rel'ed reading is calculated as shown in Figure D-2.

NOTE For details on Rel operation, see "Relative," page 5-2.

Math

Next in the signal processing sequence is a Math operation (mX+b, Percent, or Reciprocal). These math operations allow you to mathematically manipulate the reading (X) that is applied to this block in the flowchart. With one of the Math functions enabled, the math result is calculated as shown in Figure D-2.

NOTE For details on Math operations, see "Math," page 5-7.

Limits

The reading that is applied to the Limits block in the flow chart is not modified and is the reading that is displayed on the Model 2701. With Limits enabled, the reading is tested against two sets of high and low limits. Along with the displayed reading, annunciators and messages are used to indicate the result of the limits testing.

NOTE For details on Limits testing, see "Limits," page 9-2.

Buffer

With the buffer (data store) enabled, each displayed reading is stored and timestamped. The buffer also provides statistics on the stored statistics. Buffer statistics include minimum and maximum, peak-to-peak, average, and standard deviation.

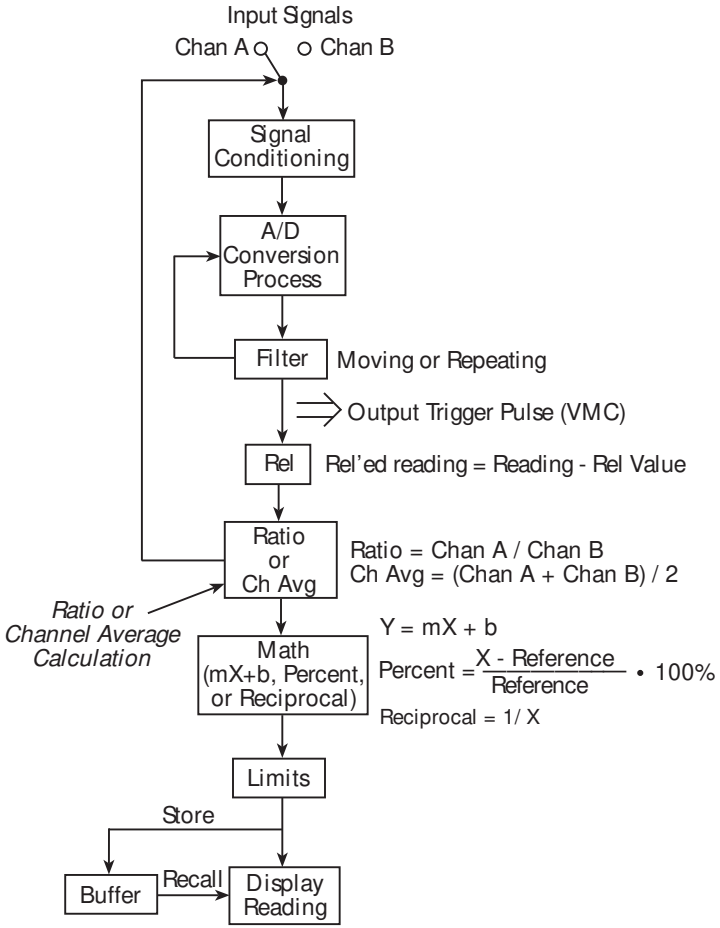
When buffer recall is enabled, stored readings and the buffer statistics are displayed on the Model 2701.

NOTE For details on the Buffer, see Section 6.

Signal processing using Ratio or Ch Avg

With a switching module installed, the ratio or average of two channels can be calculated. Figure D-3 shows where Ratio or Ch Avg is calculated in the signal processing sequence.

Figure D-3
Signal processing using Ratio or Channel Average



With a channel closed and Ratio or Ch Avg enabled, the reading that is applied to the "Ratio or Ch Avg" block in the flowchart is used as the Chan A value for the calculation. The paired-channel then closes and that reading is used as the Chan B value for the calculation. Ratio or Ch Avg is then calculated as shown in Figure D-3.

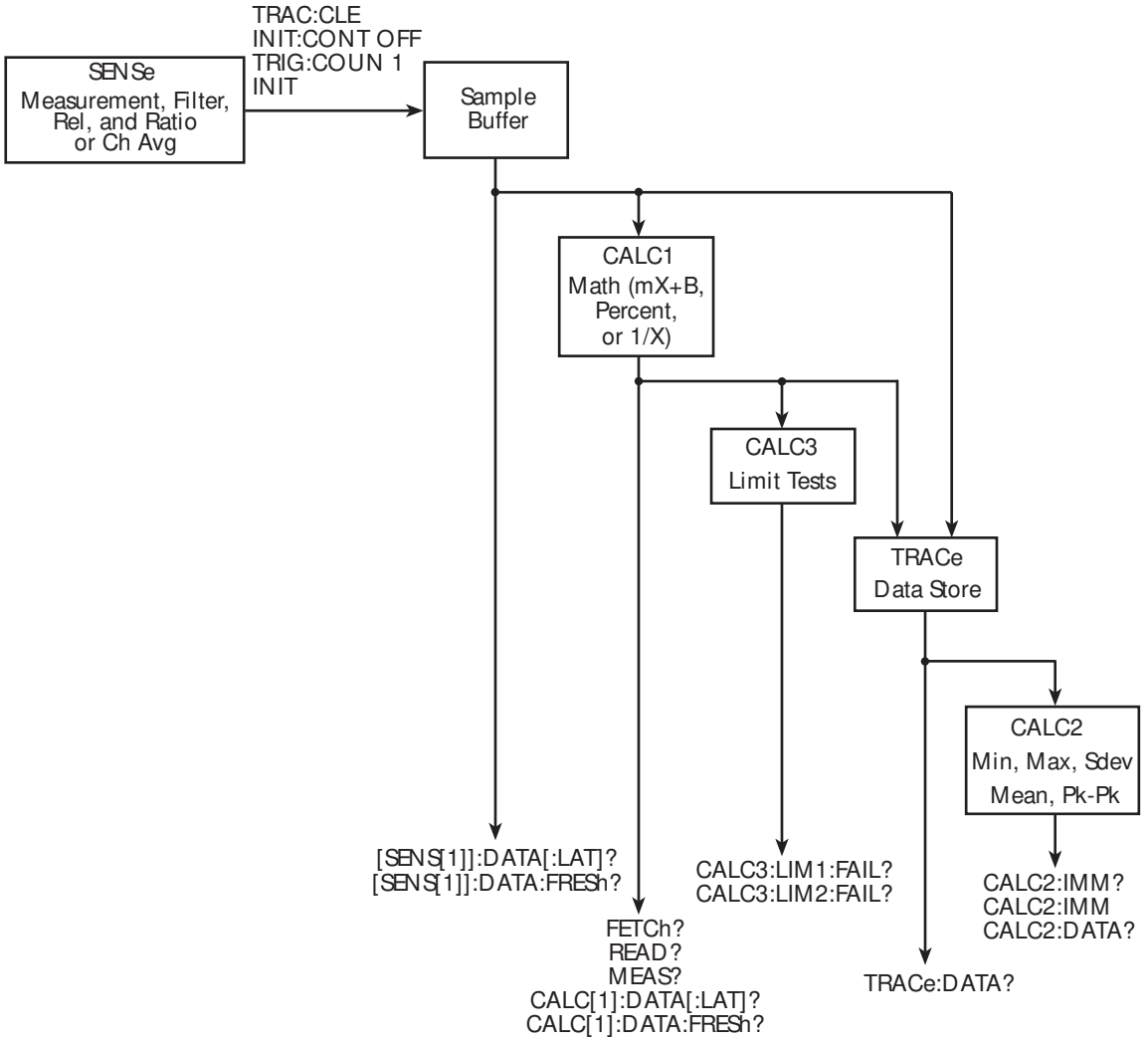
As shown, the result of Ratio or Ch Avg can then be used by an enabled Math operation.

NOTE For details on these calculations, see "Ratio and channel average," page 5-15.

Data flow (remote operation)

Remote operation can be used with triggering configured to perform a specified number of measurements and then stop. The various read commands (SENS:DATA?, FETCh?, READ?, MEAS?, CALC2:DATA?, TRACe:DATA?, and CALC1:DATA?) return the data array(s) acquired during the measurement cycle. Data flow for this triggering configuration is summarized by the block diagram shown in Figure D-4. Refer to this block diagram for the following discussion.

Figure D-4
Data flow for remote operation



NOTE For the following discussion, a "data array" is defined as the group of data elements that are included with each measured reading. Each data array includes the reading, as well as the channel, reading number, units, timestamp, and limits result (see "FORMat:ELEMents <item list>," page 14-2, for details).

For example, assume the selected data elements to be returned by a read command include the reading, units designator, and reading number. Now assume a 1VDC input and the READ? command is sent to trigger two readings and return the two data arrays. The two returned data arrays would look like this:

+1.00000000E+00VDC, +00000RDNG#, +1.00000000E+00VDC, +00001RDNG#
(Data Array #1) (Data Array #2)

SENSe and sample buffer

The TRACe:CLEar command clears the data store, INITiate:CONTinuous OFF command disables continuous initiation, and TRIGger:COUNt 1 configures the instrument to perform one measurement cycle. The INIT command can then be used to initiate the measurement cycle. When the INIT command is sent, the programmed number of measurements (set by the SAMPle:COUNt command) are performed and the respective data is temporarily stored in the sample buffer.

For example, if 20 measurements were performed (SAMP:COUN 20), then 20 data arrays will be stored in the sample buffer. Data from this buffer is then routed to other enabled data flow blocks. The data in the sample buffer remains there until data from another measurement cycle overwrites the buffer.

NOTE The trigger count (TRIG:COUN) determines how many measurement cycles are performed. However, only the data arrays for the last measurement cycle end up in the sample buffer. For example, assume TRIG:COUN 2 and SAMP:COUN 20. The first measurement cycle stores 20 data arrays in the sample buffer. The second measurement cycle then overwrites the 20 data arrays in the sample buffer.

[SENS[1]]:DATA[LATest]?
[SENS[1]]:DATA:FRESh?

These commands are used to return (read) the last processed data array stored in the sample buffer.

[SENS[1]]:DATA[:LATest]?

This command returns (reads) one data array. It returns the last processed data array stored in the sample buffer. If, for example, 10 data arrays are stored in the sample buffer, only the last (10^{th}) data array is returned.

DATA? does not affect data in the sample buffer. Therefore, subsequent executions of DATA? acquires the same data array. In order to return a new reading, you must first trigger a new reading(s) and then use DATA?.

When using DATA? to retrieve data, it is good practice to include reading numbers in the data arrays. Reading numbers that do not change will indicate that the same data array is being returned.

NOTE *The FORMat:ELEMents command (see Section 14) is used to include the reading number (RNUM) element in each data array.*

[SENS[1]]:DATA:FRESh?

This command is similar to DATA[:LATest]? in that is also returns the last processed data array stored in the buffer. However, it can only be used once to retrieve the same data array. That is, the data array reading must be "fresh." Sending this command again to read the same (stale) data array will not work. It will generate an error (-230; data corrupt or stale) or cause the Model 2701 to time-out. In order for DATA:FRESh? to respond, you must first trigger a new (fresh) reading.

Using this command to retrieve data ensures that only new (fresh) readings are returned (no readings are repeated). However, as previously noted, problems may occur if a new reading is not ready (available) when this command is executed.

FETCh?
READ?
MEASure?
CALC[1]:DATA[LATest]?
CALC[1]:DATA:FRESh?

As shown in Figure D-4, these commands are used to read data arrays output from the CALC1 Math block. However, if there is no math function enabled, these commands read the data arrays in the sample buffer.

NOTE For more information on FETCh?, READ?, and MEASure?, see Section 13, "SCPI Signal Oriented Measurement Commands."

FETCh?

With no math function enabled, this command reads the data arrays stored in the sample buffer. If, for example, there are 20 data arrays stored in the sample buffer, then all 20 data arrays will be sent to the computer when FETCh? is executed.

With a math function (mX+B, Percent, or 1/X) enabled, the reading in each data array returned by FETCh? is the result of the math calculation.

Note that FETCh? does not affect data in the sample buffer. Therefore, subsequent executions of FETCh? acquire the same data.

NOTE When an instrument setting that is relevant to the readings in the sample buffer is changed, the FETCh? command will cause error -230 (data corrupt or stale) or a bus time-out to occur. To get FETCh? working again, a new reading must be triggered.

READ?

The READ? command performs an INITiate and then a FETCh?. The INITiate triggers a measurement cycle which puts new data in the sample buffer. With no math function enabled, FETCh? reads the data arrays from the sample buffer. With a math function enabled, the readings are the result of the math calculation.

The following conditions must be met in order to use READ?:

- Continuous initiation must be disabled. It can be disabled by sending *RST or INIT:CONT OFF.
- If there are readings stored in the data store, the sample count (SAMP:COUN) must be set to 1.
- To use a sample count >1, the data store must be cleared (empty). It can be cleared by sending TRAC:CLE.

MEASure?

The MEASure? command places the instrument in a "one-shot" measurement mode (which places one data array in the sample buffer) and then performs a READ?. With no math function enabled, the one data array in the sample buffer is read. With a math function enabled, the reading is the result of the math calculation.

CALC[1]:DATA[:LATest]?
CALC[1]:DATA:FRESh?

These two commands are similar to the LATest? and FRESh? commands for the SENSe1 subsystem, except that returned data arrays are the result of the math calculation. See [SENS[1]]:DATA[:LATest]? and [SENS[1]]:DATA:FRESh? for details on the differences between LATest? and FRESh?.

With a math function enabled, both CALC[1]:DATA? and CALC[1]:DATA:FRESh? return a single data array whose reading is the result of the math calculation. Note that the calculation is performed on the last data array stored in the sample buffer. These commands do not affect data in the sample buffer. Therefore, subsequent executions of these commands return the same data.

With no math function enabled, these commands return the last data array stored in the sample buffer.

CALC3:LIM1:FAIL?
CALC3:LIM2:FAIL?

Each reading applied to the CALC3 Limit Tests block is tested when Limits operations are enabled. When comparing the reading to the programmed high and low limits of Limit 1, CALC3:LIM1:FAIL? returns a "0" (inside limits) or a "1" (outside limits). Similarly, CALC3:LIM2:FAIL? compares the reading to the high and low limits of Limit 2.

NOTE *Each data array returned by the read commands (SENS:DATA?, FETCh?, READ?, MEAS?, CALC2:DATA?, TRACe:DATA?, and CALC1:DATA?) will include the result code for limit tests if the limits data element is selected. See "FORMat:ELEMents <item list>," page 14-2, to select the limits element and interpret the code.*

TRACe:DATA?

When the data store is enabled, sample buffer data or CALC1 results are stored in the buffer. The TRACe:DATA? command reads the entire contents of the data store. The selected feed (TRAC:FEED SENSe or TRAC:FEED CALC1), determines which group of readings are stored.

CALC2:IMM?
CALC2:IMM
CALC2:DATA?

Statistical information (minimum, maximum, mean, standard deviation, and peak-to-peak) is available for the readings stored in the buffer (data store). When the desired calculation is selected (using the CALC2:FORMat command) and CALC2 is enabled (CALC2:STATe ON), use the CALC2:IMM? or CALC2:IMM command to perform the calculation:

- When CALC2:IMM? is used, the statistic is calculated and result is returned.
- When CALC2:IMM is used to calculate the statistic, the CALC2:DATA? command is then used to return the result.

The CALC2:DATA? command does not initiate a calculate operation. It simply returns the result of the last calculation.

If you calculate a statistic for an empty buffer, the number 9.910000E+37 will be returned when it is read.

If you perform a calculation with no statistic selected (CALC2:FORM NONE) or CALC2 disabled (CALC2:STAT OFF), the result of the last statistic calculation will be returned when a read operation (CALC2:IMM? or CALC2:DATA?) is performed. However, if there was no calculation previously performed, the number 9.910000E+37 will instead be returned.

Continuous measurement mode

With continuous initiation enabled (INIT:CONT ON), the instrument continuously performs (and displays) measurements. Data flow is the same except that only one data array is stored in the sample buffer at a time. The single data array is then fed to the other enabled data flow blocks. When the next measurement occurs, that data array overwrites the previous data array in the sample buffer. The new data is then fed to the other data flow blocks. When SENS:DATA?, FETCh?, READ?, or CALC1:DATA? is sent, the latest data array will be returned.

NOTE The READ? command tries to perform an INIT operation. This will cause error -213 (Init ignored) to occur since the instrument is already initiating measurements.

NOTE When the instrument is not in the continuous measurement mode, the INIT:CONT ON command can be sent to enable continuous initiation. However, if the sample count is >1, a setting conflict error (-221) will occur. Set the sample count to 1 (SAMP:COUN 1) and then send INIT:CONT ON.

Scanning

For remote operation, scanning is normally performed with continuous initiation disabled (INIT:CONT OFF). The sample count (SAMP:COUNt) specifies the number of channels to scan and store in the buffers (sample buffer and data store); the trigger count (TRIG:COUNt) specifies the number of scans to perform. Note that if the trigger count is >1, the data for each subsequent scan will overwrite the data stored in the sample buffer and data store.

Once the scan is properly configured, INIT or READ? will start the scan. READ? also returns the scanned readings (data arrays) from the sample buffer or the CALC1 block if Math is enabled. FETCh? will not start a scan, but it will return the readings already stored.

While the scan is in process, SENS:DATA? and CALC1:DATA? commands can be used to return the latest data array. When used after the scan is finished, they will return the data array for the last stored reading.

E
Measurement Considerations

Measurement considerations

Low-level voltage measurements made using the Model 2701 can be adversely affected by various types of noise or other unwanted signals that can make it very difficult to obtain accurate voltage readings. Some of the phenomena that can cause unwanted noise include thermoelectric effects (thermocouple action), source resistance noise, magnetic fields, and radio frequency interference. The following paragraphs discuss the most important of these effects and ways to minimize them.

NOTE For comprehensive information on low-level measurements, see the "Low Level Measurements" handbook, which is available from Keithley.

Thermoelectric potentials

Thermoelectric potentials (thermal EMFs) are small electric potentials generated by differences in temperature at the junction of dissimilar metals. The following paragraphs discuss how such thermals are generated and ways to minimize their effects.

Thermoelectric coefficients

As shown in Table E-1, the magnitude of thermal EMFs generated depends on the particular materials involved. Best results are obtained with clean copper-to-copper connections as indicated in the table.

Table E-1
Material thermoelectric coefficients

Material	Thermoelectric potential
Copper-Copper	0.2µV/°C
Copper-Silver	0.3µV/°C
Copper-Gold	0.3µV/°C
Copper-Cadmium/Tin	0.3µV/°C
Copper-Lead/Tin	1–3µV/°C
Copper-Kovar	40µV/°C
Copper-Silicon	400µV/°C
Copper-Copper Oxide	1000µV/°C

Thermoelectric generation

Figure E-1 shows a representation of how thermal EMFs are generated. The test leads are made of the A material, while the source under test is the B material. The temperatures between the junctions are shown as T_1 and T_2. To determine the thermal EMF generated, the following relationship may be used:

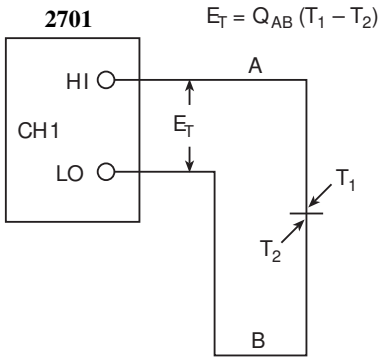
$$E_T = Q_{AB} (T_1 - T_2)$$

where: E_T = Generated thermal EMF
Q_{AB} = Thermoelectric coefficient of material A with respect to material B (μV/°C)
T_1 = Temperature of B junction (°C or K)
T_2 = Temperature of A junction (°C or K)

In the unlikely event that the two junction temperatures are identical, no thermal EMFs will be generated. More often, the two junction temperatures will differ and considerable thermal EMFs will be generated.

A typical test setup will probably have several copper-to-copper junctions. As pointed out earlier, each junction can have a thermoelectric coefficient as high as 0.2μV/°C. Since the two materials will frequently have a several degree temperature differential, it is easy to see how thermal potentials of several microvolts can be generated even if reasonable precautions are taken.

Figure E-1
Thermal EMF generation



Minimizing thermal EMFs

To minimize thermal EMFs, use only copper wires, lugs, and test leads for the entire test setup. Also, it is imperative that all connecting surfaces are kept clean and free of oxides. As noted in Table E-1, copper-to-copper oxide junctions can result in thermal EMFs as high as 1mV/°C.

Even when low-thermal cables and connections are used, thermal EMFs can still be a problem in some cases. It is especially important to keep the two materials forming the junction at the same temperature. Keeping the two junctions close together is one way to minimize such thermal problems. Also, keep all junctions away from air currents; in some cases, it may be necessary to thermally insulate sensitive junctions to minimize temperature variations. When a Cu–Cu connection is made, sufficient pressure must be applied to ensure the connection is gas tight to prevent future oxidation.

In some cases, connecting the two thermal junctions together with good thermal contact to a common heat sink may be required. Unfortunately, most good electrical insulators are poor conductors of heat. In cases where such low thermal conductivity may be a problem, special insulators that combine high electrical insulating properties with high thermal conductivity may be used. Some examples of these materials include hard anodized aluminum, sapphire, and diamond.

Nulling residual thermal offsets

Even if all reasonable precautions are taken, some residual thermal offsets may still be present. These offsets can be minimized by using the Model 2701 Relative feature to null them out. To do so, place the instrument on the 3mV range and short the end of the connecting cable nearest the measured source (first disconnect the cable from the source to avoid shorting out the source). After allowing the reading to settle, press the front panel REL button to null the offset. Select the appropriate range and make your measurement as usual.

Source resistance noise

Noise present in the source resistance is often the limiting factor in the ultimate resolution and accuracy of Model 2701 measurements. The following paragraphs discuss the generation of Johnson noise as well as ways to minimize such noise.

Johnson noise equation

The amount of noise present in a given resistance is defined by the Johnson noise equation as follows:

$$E_{RMS} = \sqrt{4kTRF}$$

where: E_{RMS} = rms value of the noise voltage
k = Boltzmann's constant (1.38×10^{-23}J/K)
T = Temperature (K)
R = Source resistance (ohms)
F = Noise bandwidth (Hz)

At a room temperature of 293K (20°C), the above equation simplifies to:

$$E_{RMS} = 1.27 \times 10^{-10}\sqrt{RF}$$

Since the peak to peak noise is five times the rms value 99% of the time, the peak to peak noise can be equated as follows:

$$E_{p-p} = 6.35 \times 10^{-10}\sqrt{RF}$$

For example, with a source resistance of 10kΩ, the noise over a 0.5Hz bandwidth at room temperature will be:

$$E_{p-p} = 6.35 \times 10^{-10}\sqrt{(10 \times 10^{3})(0.5)}$$

$$E_{p-p} = 45nV$$

Minimizing source resistance noise

From the above examples, it is obvious that noise can be reduced in several ways: (1) lower the temperature, (2) reduce the source resistance, and (3) narrow the bandwidth. Of these three, lowering the resistance is the least practical because the signal voltage will be reduced more than the noise. For example, decreasing the resistance of a current shunt by a factor of 100 will also reduce the voltage by a factor of 100, but the noise will be decreased only by a factor of 10.

Very often, cooling the source is the only practical method available to reduce noise. Again, however, the available reduction is not as large as it might seem because the reduction is related to the square root of the change in temperature. For example, to cut the noise in half, the temperature must be decreased from 293K to 73.25K, a four-fold decrease.

Magnetic fields

When a conductor loop cuts through magnetic lines of force, a very small current is generated. This phenomenon will frequently cause unwanted signals to occur in the test leads of a test system. If the conductor has sufficient length or cross-sectional area, even weak magnetic fields such as those of the earth can create sufficient signals to affect low-level measurements.

Three ways to reduce these effects are: (1) reduce the lengths of the connecting cables, (2) minimize the exposed circuit area, and (3) change the orientation of the leads or cables. In extreme cases, magnetic shielding may be required. Special metal with high permeability at low flux densities (such as mu metal) is effective at reducing these effects.

Even when the conductor is stationary, magnetically-induced signals may still be a problem. Fields can be produced by various sources, such as the AC power line voltage. Large inductors such as power transformers can generate substantial magnetic fields, so care must be taken to keep the Model 2701 voltage source and connecting cables a good distance away from these potential noise sources.

Radio frequency interference

RFI (Radio Frequency Interference) is a general term used to describe electromagnetic interference over a wide range of frequencies across the spectrum. Such RFI can be particularly troublesome at low signal levels, but it can also affect measurements at high levels if the fields are of sufficient magnitude.

RFI can be caused by steady-state sources, such as radio signals, TV signals, or some types of electronic equipment (microprocessors, high speed digital circuits, etc.), or it can result from impulse sources, as in the case of arcing in high-voltage environments. In either case, the effect on the measurement can be considerable if enough of the unwanted signal is present.

RFI can be minimized in several ways. The most obvious method is to keep the Model 2701 voltage source and signal leads as far away from the RFI source as possible. Additional shielding of the instrument, signal leads, sources, and other measuring instruments will often reduce RFI to an acceptable level. In extreme cases, a specially-constructed screen room may be required to sufficiently attenuate the troublesome signal.

The Model 2701 digital filter may help to reduce RFI effects in some situations. In some cases, additional external filtering may also be required. Keep in mind, however, that filtering may have detrimental effects such as increased settling time on the desired signal.

Ground loops

When two or more instruments are connected together, care must be taken to avoid unwanted signals caused by ground loops. Ground loops usually occur when sensitive instrumentation is connected to other instrumentation with more than one signal return path, such as power line ground. As shown in Figure E-2, the resulting ground loop causes current to flow through the instrument LO signal leads and then back through power line ground. This circulating current develops a small but undesirable voltage between the LO terminals of the two instruments. This voltage will be added to the source voltage, affecting the accuracy of the measurement.

Figure E-2
Power line ground loops

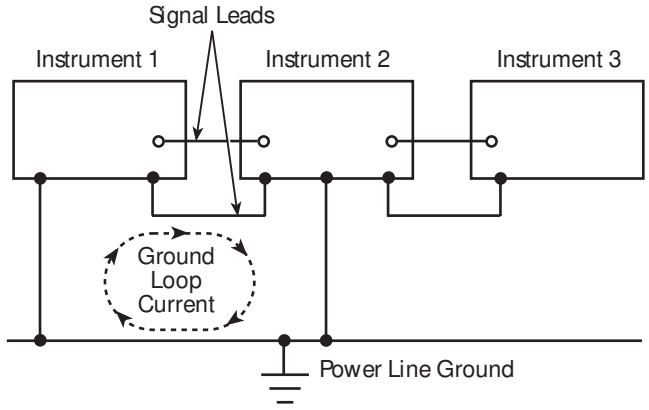
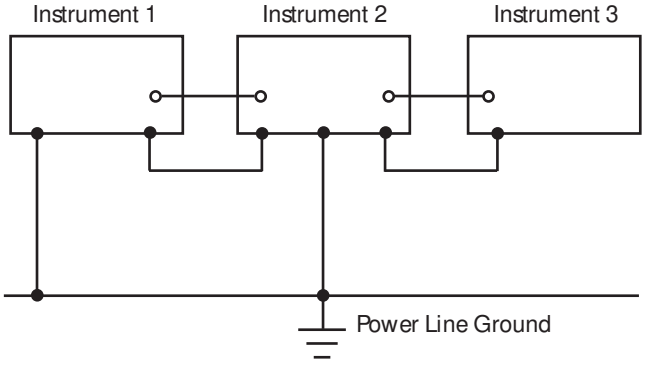


Figure E-3 shows how to connect several instruments together to eliminate this type of ground loop problem. Here, only one instrument is connected to power line ground.

Ground loops are not normally a problem with instruments like the Model 2701 that have isolated LO terminals. However, all instruments in the test setup may not be designed in this manner. When in doubt, consult the manual for all instrumentation in the test setup.

Figure E-3
Eliminating ground loops



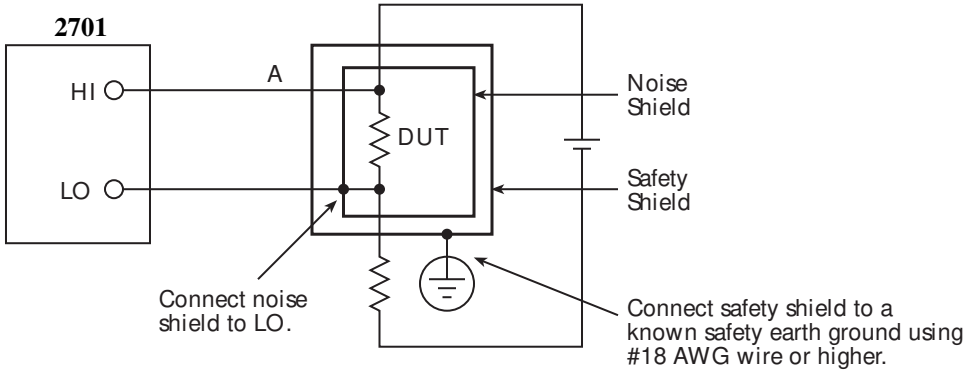
Shielding

WARNING Do not float input LO more than 30V rms, 42.4V peak above earth ground with an exposed shield connected to input LO. To avoid a possible shock hazard, surround the LO shield with a second safety shield that is insulated from the inner shield. Connect this safety shield to safety earth ground using #18 AWG minimum wire before use.

Proper shielding of all signal paths and sources being measured is important to minimize noise pickup in virtually any low-level measurement situation. Otherwise, interference from such noise sources as line frequency and RF fields can seriously corrupt measurements, rendering experimental data virtually useless.

In order to minimize noise, a closed metal shield surrounding the source may be necessary, as shown in the example of Figure E-4. This shield should be connected to input LO in most cases, although better noise performance may result with the shield connected to chassis ground in some situations.

Figure E-4
Shielding example



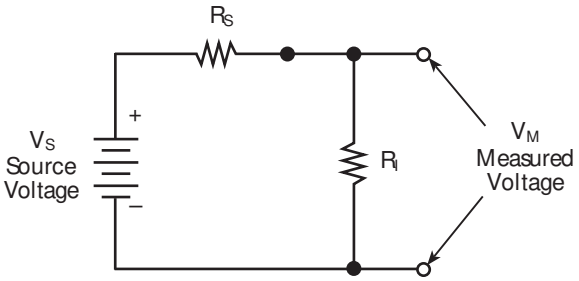
WARNING: Safety shield required when floating noise shield >30V rms above chassis ground.

Meter loading

Loading of the voltage source by the Model 2701 becomes a consideration for high source resistance values. As the source resistance increases, the error caused by meter loading increases.

Figure E-5 shows the method used to determine the percent error due to meter loading. The voltage source, V_S, has a source resistance, R_S, while the input resistance of the Model 2701 is R_I and the voltage measured by the nanovoltmeter is V_M.

Figure E-5
Meter loading



The voltage actually measured by the meter is attenuated by the voltage divider action of R_S and R_I, and it can be calculated as follows:

$$V_M = \frac{V_S R_L}{R_I + R_S}$$

This relationship can be modified to directly compute for percent error:

$$\text{Percent error} = \frac{100 R_S}{R_I + R_S}$$

From the above equation, it is obvious that the input resistance of the Model 2701 must be at least 999 times the value of source resistance if loading error is to be kept to within 0.1%.

F
Temperature Equations

- Thermocouple equation — Documents the ITS-90 inverse function polynomial and the coefficients to calculate thermocouple temperature.
- Thermistor equation — Documents the Steinhart-Hart equation which is used to calculate thermistor temperature.
- RTD equation — Documents the Callendar-Van Dusen equation which is used to calculate the temperature vs. resistance readings listed in the RTD reference tables.

Thermocouple equation

The Model 2701 uses the ITS-90 inverse function coefficients for the polynomial to calculate thermocouple temperature. The Model 2701 measures the thermocouple voltage and then calculates temperature (in °C) as follows:

$t_{90} = c_0 + c_1E + c_2E^2 + c_3E^3 \ldots\ c_iE^i$

where: t_{90} is the calculated temperature in °C.
c_0, c_1, c_2, c_3 ... c_i are the coefficients for the thermocouple type.
E is the thermocouple voltage in microvolts (µV).

The coefficients for each thermocouple type are listed in Table F-1 through Table F-8.

Table F-1
Type B inverse function polynomial

	250ºC to 700ºC (291µV to 2,431µV)	700ºC to 1,820ºC (2,431µV to 13,820µV)
c_0 =	$9.842\,332\,1 \times 10^{1}$	$2.131\,507\,1\,1 \times 10^{2}$
c_1 =	$6.997\,150\,0 \times 10^{-1}$	$2.851\,050\,4\,1 \times 10^{-1}$
c_2 =	$-8.476\,530\,4 \times 10^{-4}$	$-5.274\,288\,7\,1 \times 10^{-5}$
c_3 =	$1.005\,264\,4 \times 10^{-6}$	$9.916\,080\,4\,1 \times 10^{-9}$
c_4 =	$-8.334\,595\,2 \times 10^{-10}$	$-1.296\,530\,3\,1 \times 10^{-12}$
c_5 =	$4.550\,854\,2 \times 10^{-13}$	$1.119\,587\,0\,1 \times 10^{-16}$
c_6 =	$-1.552\,303\,7 \times 10^{-16}$	$-6.062\,519\,9\,1 \times 10^{-21}$
c_7 =	$2.988\,675\,0 \times 10^{-20}$	$1.866\,169\,6\,1 \times 10^{-25}$
c_8 =	$-2.474\,286\,0 \times 10^{-24}$	$-2.487\,858\,5\,1 \times 10^{-30}$
Error:	0.03°C to -0.02°C	0.02°C to -0.01°C
$t_{90} = c_0 + c_1E + c_2E^2 + c_3E^3 \ldots\ c_iE^i$ where: t_{90} is the calculated temperature in °C. E is the measured voltage in microvolts.		

Table F-2
Type E inverse function polynomial

	-200°C to 0°C (-8,825µV to 0µV)	0°C to 1,000°C (0µV to 76,373µV)
c_0 =	0.0	0.0
c_1 =	$1.697\,728\,8 \times 10^{-2}$	$1.705\,703\,5 \times 10^{-2}$
c_2 =	$-4.351\,497\,0 \times 10^{-7}$	$-2.330\,175\,9 \times 10^{-7}$
c_3 =	$-1.585\,969\,7 \times 10^{-10}$	$6.543\,558\,5 \times 10^{-12}$
c_4 =	$-9.250\,287\,1 \times 10^{-14}$	$-7.356\,274\,9 \times 10^{-17}$
c_5 =	$-2.608\,431\,4 \times 10^{-17}$	$-1.789\,600\,1 \times 10^{-21}$
c_6 =	$-4.136\,019\,9 \times 10^{-21}$	$8.403\,616\,5 \times 10^{-26}$
c_7 =	$-3.403\,403\,0 \times 10^{-25}$	$-1.373\,587\,9 \times 10^{-30}$
c_8 =	$-1.156\,486\,0 \times 10^{-29}$	$1.062\,982\,3 \times 10^{-35}$
c_9 =		$-3.244\,708\,7 \times 10^{-41}$
Error:	0.03°C to -0.01°C	0.02°C to -0.02°C
$t_{90} = c_0 + c_1E + c_2E^2 + c_3E^3 \ldots\ c_iE^i$ where: t_{90} is the calculated temperature in °C. E is the measured voltage in microvolts.		

Table F-3
Type J inverse function polynomial

	-210°C to 0°C (-8,095µV to 0µV)	0°C to 760°C (0µV to 42,919µV)	760°C to 1,200°C (42,919µV to 69,553µV)
c_0 =	0.0	0.0	$-3.113\,581\,87 \times 10^{3}$
c_1 =	$1.952\,826\,8 \times 10^{-2}$	$1.978\,425 \times 10^{-2}$	$3.005\,436\,84 \times 10^{-1}$
c_2 =	$-1.228\,618\,5 \times 10^{-6}$	$-2.001\,204 \times 10^{-7}$	$-9.947\,732\,30 \times 10^{-6}$
c_3 =	$-1.075\,217\,8 \times 10^{-9}$	$1.036\,969 \times 10^{-11}$	$1.702\,766\,30 \times 10^{-10}$
c_4 =	$-5.908\,693\,3 \times 10^{-13}$	$-2.549\,687 \times 10^{-16}$	$-1.430\,334\,68 \times 10^{-15}$
c_5 =	$-1.725\,671\,3 \times 10^{-16}$	$3.585\,153 \times 10^{-21}$	$4.738\,860\,84 \times 10^{-21}$
c_6 =	$-2.813\,151\,3 \times 10^{-20}$	$-5.344\,285 \times 10^{-26}$	
c_7 =	$-2.396\,337\,0 \times 10^{-24}$	$5.099\,890 \times 10^{-31}$	
c_8 =	$-8.382\,332\,1 \times 10^{-29}$		
Error:	0.03°C to -0.05°C	0.04°C to -0.04°C	0.03°C to -0.05°C
$t_{90} = c_0 + c_1E + c_2E^2 + c_3E^3 \ldots\ c_iE^i$ where: t_{90} is the calculated temperature in °C. E is the measured voltage in microvolts.			

Table F-4
Type K inverse function polynomial

	-200°C to 0°C (-5,891µV to 0µV)	0°C to 500°C (0µV to 20,644µV)	500°C to 1,372°C (20,644µV to 54,886µV)
c_0 =	0.0	0.0	$-1.318\ 058 \times 10^{2}$
c_1 =	$2.517\ 346\ 2 \times 10^{-2}$	$2.508\ 355\ 2 \times 10^{-2}$	$4.830\ 222 \times 10^{-2}$
c_2 =	$-1.166\ 287\ 8 \times 10^{-6}$	$7.860\ 106\ 2 \times 10^{-8}$	$-1.646\ 031 \times 10^{-6}$
c_3 =	$-1.083\ 363\ 8 \times 10^{-9}$	$-2.503\ 131\ 2 \times 10^{-10}$	$5.464\ 731 \times 10^{-11}$
c_4 =	$-8.977\ 354\ 0 \times 10^{-13}$	$8.315\ 270\ 2 \times 10^{-14}$	$-9.650\ 715 \times 10^{-16}$
c_5 =	$-3.734\ 237\ 7 \times 10^{-16}$	$-1.228\ 034\ 2 \times 10^{-17}$	$8.802\ 193 \times 10^{-21}$
c_6 =	$-8.663\ 264\ 3 \times 10^{-20}$	$9.804\ 036\ 2 \times 10^{-22}$	$-3.110\ 810 \times 10^{-26}$
c_7 =	$-1.045\ 059\ 8 \times 10^{-23}$	$-4.413\ 030\ 2 \times 10^{-26}$	
c_8 =	$-5.192\ 057\ 7 \times 10^{-28}$	$1.057\ 734\ 2 \times 10^{-30}$	
c_9 =		$-1.052\ 755\ 2 \times 10^{-35}$	
Error:	0.04°C to -0.02°C	0.04°C to -0.05°C	0.06°C to -0.05°C

$t_{90} = c_0 + c_1E + c_2E^2 + c_3E^3 \ldots\ c_iE^i$
where: t_{90} is the calculated temperature in °C. E is the measured voltage in microvolts.

Table F-5
Type N inverse function polynomial

	-200°C to 0°C (-3,990µV to 0µV)	0°C to 600°C (0uV to 20,613µV)	600°C to 1,300°C (20,613µV to 47,513µV)
c_0 =	0.0	0.0	$1.972\ 485 \times 10^{1}$
c_1 =	$3.843\ 684\ 7 \times 10^{-2}$	$3.868\ 96 \times 10^{-2}$	$3.300\ 943 \times 10^{-2}$
c_2 =	$1.101\ 048\ 5 \times 10^{-6}$	$-1.082\ 67 \times 10^{-6}$	$-3.915\ 159 \times 10^{-7}$
c_3 =	$5.222\ 931\ 2 \times 10^{-9}$	$4.702\ 05 \times 10^{-11}$	$9.855\ 391 \times 10^{-12}$
c_4 =	$7.206\ 052\ 5 \times 10^{-12}$	$-2.121\ 69 \times 10^{-18}$	$-1.274\ 371 \times 10^{-16}$
c_5 =	$5.848\ 858\ 6 \times 10^{-15}$	$-1.172\ 72 \times 10^{-19}$	$7.767\ 022 \times 10^{-22}$
c_6 =	$2.775\ 491\ 6 \times 10^{-18}$	$5.392\ 80 \times 10^{-24}$	
c_7 =	$7.707\ 516\ 6 \times 10^{-22}$	$-7.981\ 56 \times 10^{-29}$	
c_8 =	$1.158\ 266\ 5 \times 10^{-25}$		
c_9 =	$7.313\ 886\ 8 \times 10^{-30}$		
Error:	0.03°C to -0.02°C	0.03°C to -0.02°C	0.02°C to -0.04°C

$t_{90} = c_0 + c_1E + c_2E^2 + c_3E^3 \ldots\ c_iE^i$
where: t_{90} is the calculated temperature in °C. E is the measured voltage in microvolts.

Table F-6
Type R inverse function polynomial

	-50°C to 250°C (-226µV to 1,923µV)	250°C to 1,200°C (1,923µV to 13,228µV)	1,064°C to 1,664.5°C (11,361µV to 19,739µV)	1,664.5°C to 1,768.1°C (19,739µV to 21,103µV)
c_0 =	0.0	$1.334\,584\,505 \times 10^{1}$	$-8.199\,599\,416 \times 10^{1}$	$3.406\,177\,836 \times 10^{4}$
c_1 =	$1.889\,138\,0 \times 10^{-1}$	$1.472\,644\,573 \times 10^{-1}$	$1.553\,962\,042 \times 10^{-1}$	-7.023 729 171
c_2 =	$-9.383\,529\,0 \times 10^{-5}$	$-1.844\,024\,844 \times 10^{-5}$	$-8.342\,197\,663 \times 10^{-6}$	$5.582\,903\,813 \times 10^{-4}$
c_3 =	$1.306\,861\,9 \times 10^{-7}$	$4.031\,129\,726 \times 10^{-9}$	$4.279\,433\,549 \times 10^{-10}$	$-1.952\,394\,635 \times 10^{-8}$
c_4 =	$-2.270\,358\,0 \times 10^{-10}$	$-6.249\,428\,360 \times 10^{-13}$	$-1.191\,577\,910 \times 10^{-14}$	$2.560\,740\,231 \times 10^{-13}$
c_5 =	$3.514\,565\,9 \times 10^{-13}$	$6.468\,412\,046 \times 10^{-17}$	$1.492\,290\,091 \times 10^{-19}$	
c_6 =	$-3.895\,390\,0 \times 10^{-16}$	$-4.458\,750\,426 \times 10^{-21}$		
c_7 =	$2.823\,947\,1 \times 10^{-19}$	$1.994\,710\,149 \times 10^{-25}$		
c_8 =	$-1.260\,728\,1 \times 10^{-22}$	$-5.313\,401\,790 \times 10^{-30}$		
c_9 =	$3.135\,361\,1 \times 10^{-26}$	$6.481\,976\,217 \times 10^{-35}$		
c_{10} =	$-3.318\,776\,9 \times 10^{-30}$			
Error:	0.02°C to -0.02°C	0.005°C to -0.005°C	0.001°C to -0.0005°C	0.002°C to -0.001°C

$t_{90} = c_0 + c_1E + c_2E^2 + c_3E^3 \ldots\ c_iE^i$
where: t_{90} is the calculated temperature in °C. E is the measured voltage in microvolts.

Table F-7
Type S inverse function polynomial

	-50°C to 250°C (-235µV to 1,874µV)	250°C to 1,200°C (1,874µV to 11,950µV)	1,064°C to 1,664.5°C (10,332µV to 17,536µV)	1,664.5°C to 1,768.1°C (17,536µV to 18,693µV)
c_0 =	0.0	$1.291\,509\,199 \times 10^{1}$	$-8.087\,801\,117 \times 10^{1}$	$5.333\,875\,126 \times 10^{4}$
c_1 =	$1.849\,494\,60 \times 10^{-1}$	$1.466\,298\,863 \times 10^{-1}$	$1.621\,573\,104 \times 10^{-1}$	$-1.235\,892\,298 \times 10^{1}$
c_2 =	$-8.005\,050\,62 \times 10^{-5}$	$-1.534\,713\,402 \times 10^{-5}$	$-8.536\,869\,453 \times 10^{-6}$	$1.092\,657\,613 \times 10^{-3}$
c_3 =	$1.022\,374\,30 \times 10^{-7}$	$3.145\,945\,973 \times 10^{-9}$	$4.719\,686\,976 \times 10^{-10}$	$-4.265\,693\,686 \times 10^{-8}$
c_4 =	$-1.522\,485\,92 \times 10^{-10}$	$-4.163\,257\,839 \times 10^{-13}$	$-1.441\,693\,666 \times 10^{-14}$	$6.247\,205\,420 \times 10^{-13}$
c_5 =	$1.888\,213\,43 \times 10^{-13}$	$3.187\,963\,771 \times 10^{-17}$	$2.081\,618\,890 \times 10^{-19}$	
c_6 =	$-1.590\,859\,41 \times 10^{-16}$	$-1.291\,637\,500 \times 10^{-21}$		
c_7 =	$8.230\,278\,80 \times 10^{-20}$	$2.183\,475\,087 \times 10^{-26}$		
c_8 =	$-2.341\,819\,44 \times 10^{-23}$	$-1.447\,379\,511 \times 10^{-31}$		
c_9 =	$2.797\,862\,60 \times 10^{-27}$	$8.211\,272\,125 \times 10^{-36}$		
Error:	0.02°C to -0.02°C	0.01°C to -0.01°C	0.0002°C to -0.0002°C	0.002°C to -0.002°C

$t_{90} = c_0 + c_1E + c_2E^2 + c_3E^3 \ldots\ c_iE^i$
where: t_{90} is the calculated temperature in °C. E is the measured voltage in microvolts.

Table F-8
Type T inverse function polynomial

	-200°C to 0°C (-5,603µV to 0µV)	0°C to 400°C (0µV to 20,872µV)
c_0 =	0.0	0.0
c_1 =	$2.594\ 919\ 2 \times 10^{-2}$	$2.592\ 800 \times 10^{-2}$
c_2 =	$-2.131\ 696\ 7 \times 10^{-7}$	$-7.602\ 961 \times 10^{-7}$
c_3 =	$7.901\ 869\ 2 \times 10^{-10}$	$4.637\ 791 \times 10^{-11}$
c_4 =	$4.252\ 777\ 7 \times 10^{-13}$	$-2.165\ 394 \times 10^{-15}$
c_5 =	$1.330\ 447\ 3 \times 10^{-16}$	$6.048\ 144 \times 10^{-20}$
c_6 =	$2.024\ 144\ 6 \times 10^{-20}$	$-7.293\ 422 \times 10^{-25}$
c_7 =	$1.266\ 817\ 1 \times 10^{-24}$	
Error:	0.04°C to -0.02°C	0.03°C to -0.03°C

$t_{90} = c_0 + c_1E + c_2E^2 + c_3E^3 \ldots\ c_iE^i$
where: t_{90} is the calculated temperature in °C.
E is the measured voltage in microvolts.

Thermistor equation

Temperature (in Kelvin) is calculated using the Steinhart-Hart equation as follows:

$$T_K = \frac{1}{A + (B\ln R) + [C(\ln R)^3]}$$

where: T_K is the calculated temperature in Kelvin.
lnR is the natural log of the measured resistance of the thermistor.
A, B, and C are the curve fitting constants. The constants for the three thermistor types used by the Model 2701 are listed in Table F-9.

Table F-9
Model 2701 curve fitting constants for thermistors

Constant	2252Ω at 25°C (Series 44004)	5000Ω at 25°C (Series 44007)	10kΩ at 25°C (Series 44006)
A	0.0014733	0.001288	0.0010295
B	0.0002372	0.0002356	0.0002391
C	1.074e-7	9.557e-8	1.568e-7

Selecting a thermistor — The thermistor manufacturers specified curve fitting values (A, B, and C) may not be exactly the same as the ones used by the Model 2701. If they are not exactly the same, perform the following steps to select a thermistor to use with the Model 2701:

NOTE *The specified thermistor temperature measurement accuracy of the Model 2701 (see Appendix A) is based on the curve fitting constants listed in Table F-9. If the thermistor manufacturer's curve fitting constants are not exactly the same as the ones listed in Table F-9, accuracy will be affected.*

1. Choose the thermistor type to be used; 2252Ω, 5kΩ, or 10kΩ
2. Compare the A, B, and C constants from the thermistor manufacturer with those used by the Model 2701 (see Table F-9).
3. Select a thermistor that closely matches the A, B, and C constants in Table F-9.
4. Analyze the differences between the two sets of curve fitting constants to determine the affect on measurement accuracy.

Converting K to °C — The temperature in Kelvin can be converted to °C as follows:

$$T_{°C} = T_K - 273.15$$

where: $T_{°C}$ is the temperature in °C.
T_K is the calculated Kelvin temperature.

Example — Calculate the temperature for a Series 44007 thermistor that measures 5kΩ (R):

lnR = ln(5000) = 8.5172
A = 0.001288
B = 0.0002356
C = 9.557e-8

T_K = 1 / {A + (BlnR) + [(C)(lnR)^3]}
= 1 / {0.001288 + [(0.0002356)(8.5172)] + [(9.557e-8)(8.5172^3)]}
= 1 / (0.001288 + 0.002007 + 0.000059)
= 1 / 0.003354
= 298.15

$T_{°C}$ = T_K - 273.15
= 298.15 - 273.15
= 25°C

RTD equations

The temperature vs. resistance readings listed in the RTD reference tables are calculated using the Callendar-Van Dusen equation. There are two equations based on different temperature ranges. There is an equation for the -200° to 0°C range and one for the 0° to 630°C range.

Equation for -200° to 0°C temperature range

$R_{RTD} = R_0 [1 + AT + BT^2 + CT^3(T-100)]$

where: R_{RTD} is the calculated resistance of the RTD
R_0 is the known RTD resistance at 0°C
T is the temperature in °C

A = alpha [1 + (delta/100)]
B = -1 (alpha)(delta)(1e-4)
C = -1 (alpha)(beta)(1e-8)

The alpha, beta, and delta values are listed in Table F-10.

Equation for 0° to 630°C temperature range

$R_{RTD} = R_0 (1 + AT + BT^2)$

where: R_{RTD} is the calculated resistance of the RTD
R_0 is the known RTD resistance at 0°C
T is the temperature in °C

A = alpha [1 + (delta/100)]
B = -1 (alpha)(delta)(1e-4)

The alpha and delta values are listed in Table F-10.

RTD parameters for equations

The RTD parameters for the Callendar-Van Dusen equations are listed in Table F-10.

Table F-10
RTD parameters

Type	Standard	Alpha	Beta	Delta	¾ at 0°C
PT100	ITS-90	0.00385055	0.10863	1.49990	100¾
D100	ITS-90	0.003920	0.10630	1.49710	100¾
F100	ITS-90	0.003900	0.11000	1.49589	100¾
PT385	IPTS-68	0.003850	0.11100	1.50700	100¾
PT3916	IPTS-68	0.003916	0.11600	1.50594	100¾

Example 1

Calculate the resistance of a PT100 RTD at 100°C (T). The following R_0 (Ω at 0°C), alpha, and delta values are used for the PT100 RTD (Table F-10):

T = 100°C
R_0 (Ω at 0°C) = 100Ω
alpha = 0.003850
delta = 1.49990

Using the above alpha and delta values, A and B are calculated as follows:

A = 0.00385 [1 + (1.4999/100)]
= 0.00385 (1.014999)
= 0.003907746

B = -1 (0.00385)(1.4999)(1e-4)
= -1 (0.005774615)(1e-4)
= -5.774615e-7

The resistance of the RTD at 100°C (R_{100}) is then calculated as follows:

$R_{100} = R_0 [1 + AT + BT^2]$
$= 100 \{1 + [(0.003907746)(100)] + [(-5.774615e-7)(100^2)]\}$
$= 100 [1 + 0.3907746 + (-0.005774615)]$
$= 100 (1.385)$
$= 138.5\Omega$

Example 2

Calculate the resistance of a D100 RTD at -100°C (T). The following R_0 (Ω at 0°C), alpha, beta, and delta values are used for the D100 RTD (Table F-10):

T = -100°C
R_0 (Ω at 0°C) = 100¾
alpha = 0.003920
beta = 0.10630
delta = 1.49710

Using the above alpha and delta values, A and B are calculated as follows:

A = 0.003920 [1 + (1.49710/100)]
= 0.003920 (1.014971)
= 0.003978686

B = -1 (0.003920)(1.49710)(1e-4)
= -1 (0.005868632)(1e-4)
= -5.868632e-7

C = -1 (0.003920)(0.10630)(1e-8)
= -1 (0.000416696)(1e-8)
= -4.16696e-12

The resistance of the RTD at -100°C (R_{100}) is then calculated as follows:

$R_{100} = R_0 [1 + AT + BT^2 + CT^3(T-100)]$
= 100 {1 + [(0.003978686)(-100)] + [(-5.868632e-7)(-100^2)] + [(-4.16696e-12)(-100^3)](-100-100)}
= 100 [1 + (-0.3978686) + (-0.005868632) + (0.000833392)]
= 100 (0.5954294)
= 59.54294Ω

G
KE2700 Instrument Driver Examples

Introduction

An IVI style Instrument Driver is provided with the Models 2700, 2701, and 2750. The driver supports programming in LabView, LabWindows CVI, Visual Basic, and C,

Test examples provided by the KE2700 Instrument Driver are listed in Table G-1 and Table G-2. Some of the examples demonstrate the simple command sequence examples that are used throughout this manual. These examples include a reference to appropriate manual section in the "References" column of the tables.

Visual Basic and CVI (C) examples

Table G-1 lists the Visual Basic and CVI (C) examples and "Use Cases" that are provided with the KE2700 Instrument Driver. By default, Visual Basic examples are installed in \Program Files\Keithley Instruments\KE2700\Examples\VB and CVI examples are installed in \Program Files\Keithley Instruments\KE2700\Examples\CVI.

Table G-1
Visual Basic and CVI (C) examples

Name	Manual Reference	Brief Description
Advance1	None	Use Case 1 — 40-channel scan using 7708 module: • 30 channels DCV (10V range). • 10 channels type T thermocouple temperature. • Measurement speed (rate) – 1 plc. • Filter – Disabled (no filtering). • Buffer – Store 160 reading strings. Buffer elements include reading, channel #, and real time clock. • Triggering – Timer scan; 40 channels every one minute. • Data retrieval – SRQ when buffer ¼, ½, ¾, and full.
Advance2	None	Use Case 2 — 40-channel scan using 7708 module: • 30 channels DCV (15 on 100mV range, 15 on 10V range). • 9 channels ACV (1V range). • 1 channel 4-wire RTD temperature. • Measurement speed (rate) – 1 plc. • Filter – Disabled (no filtering). • Buffer – Store 160 reading strings. Buffer elements include reading only. • Triggering – Timer scan; 40 channels every one minute. • Data retrieval – SRQ when buffer ¼, ½, ¾, and full.

Advance3	None	Use Case 3 — Two scans using 7708 module:
		• 40 channel DCV (1V range) scan.
		• 20 channel Ω4 scan:
		  • Models 2700 and 2701 – 100Ω range.
		  • Model 2750 – 10Ω range, dry-circuit ohms enabled.
		• Measurement speed (rate) – 0.1 plc.
		• DCV input divider – Enabled (10MΩ input impedance).
		• Filter – Disabled (no filtering).
		• Buffer – Store 40 DCV reading strings, 20 Ω4 reading strings. Buffer elements include reading only.
		• Limits (DCV scan) – Limit 1 (all channels) = 20mV, Master Latch enabled.
		• Triggering – Bus control source.
		• Data retrieval – SRQ if limit fails.

Table G-1 (continued)
Visual Basic and CVI (C) examples

Name	Manual Reference	Brief Description

Advance4	None	Use Case 4 — Two scans using 7708 module:
		• 40 channel DCV scan (1V range). Configuration saved in User Setup 1.
		• 20 channel Ω4 scan. Configuration saved in User Setup 2.
		  • Models 2700 and 2701 – 100Ω range.
		  • Model 2750 – 10Ω range, dry-circuit ohms enabled.
		• Setup 1 or Setup 2 recalled to perform scan.
		• Measurement speed (rate) – 0.1 plc.
		• DCV input divider – Enabled (10MΩ input impedance).
		• Filter – Disabled (no filtering).
		• Buffer – Store 40 DCV reading strings, 20 Ω4 reading strings. Buffer elements include reading only.
		• Limits (DCV scan) – Limit 1 (all channels) = 20mV, Master Latch enabled.
		• Triggering – Bus control source.
		• Data retrieval – SRQ if limit fails.

Advance5	None	Use Case 5 — 32-channel scan using 7701 module: • Common-side 4-wire ohms measurements (CSIDe mode). • Dry-circuit ohms option for Model 2750. • Install jumpers to connect Input Hi and Sense Hi directly to DUT (common-side bus). • Install jumpers to connect channel 35 to Sense Lo and Input Lo. • Buffer – Store 32 reading strings. Buffer elements include reading only. • Triggering – Immediate control source. • Data retrieval – SRQ when buffer full.

Table G-1 (continued)
Visual Basic and CVI (C) examples

Name	Manual Reference	Brief Description
Advance6	None	Use Case 6 — Scan 160 channels using 7703 module (see ***NOTE***): • Type K thermocouple (TC) temperature measurements. • Reference junction – Simulated. • Measurement speed (rate) – 0.01 plc. • Filter – Disabled (no filtering). • Buffer – Store 160 reading strings. Buffer elements include reading and channel #. • Triggering – Bus control source. • Data retrieval – Continuously store data into buffer. Retrieve data for every 32 readings. ***NOTE***: When using a module that has a built-in cold junction, use the Internal reference junction. Keep in mind that the buffer and data retrieval will have to be modified to accommodate the number of scanned channels. Modules that have cold junction include: 7700 and 7706 modules – 20 available TC channels 7708 module – 40 available TC channels

Advance7	None	Use Case 7 — Ten 40-channel scans using 7702 module:
		• Channel 1 uses an external reference junction.
		  • Measurement speed (rate) – 1 plc.
		  • Filter – Repeat, 25 readings.
		• Channels 2 through 40 are connected to type K thermocouples.
		  • Measurement speed (rate) – 1 plc.
		  • Filter – Disabled (no filtering).
		  • Open thermocouple detection – Enabled.
		• Buffer – Store 400 reading strings. Buffer elements include reading, real time clock, and channel #.
		• Triggering – Bus control source.
		• Data retrieval – SRQ when buffer ¼, ½, ¾, and full.

Table G-1 (continued)
Visual Basic and CVI (C) examples

Name	Manual Reference	Brief Description

Advance8	None	Use Case 8 — 7706 module in slot 1 and 7702 module in slot 2:
		• 7706 module:
		  • Output analog output values to analog output channels.
		  • Output digital output values to digital output channels.
		• 7702 module:
		  • Scan 120 DCV channels.
		  • Measurement speed (rate) – 1 plc.
		  • Filter – Disabled (no filtering).
		  • Math – mX+b, m = 0.555, b = -17.778.
		  • Limits – Limit 1 (all channels) = 100, Limit 2 = 180.
		• Buffer – Store 320 reading strings. Buffer elements include reading, channel #, and limit code.
		• Triggering – Bus control source, trigger delay 0.125 seconds.
		• Data retrieval – SRQ when buffer ¼, ½, ¾, and full.

Analout	See 7706 packing list	Demonstrates setting the output value of the analog output channels of the 7706 module.
AOCalibration	See 7706 packing list	Demonstrates how to remotely calibrate the analog output channels of the 7706 module.
BufStats	Page 6-15 (Prog Ex.)	Demonstrates calculating the mean of 20 readings.
BusTrg	Page 12-7 (*TRG Prog Ex.)	Demonstrates use of bus triggering.
CloseChannels	Page 2-21 (Remote Prog Ex.)	Demonstrates closing channels – multiple channel operation.
ConfigChan	Page 3-58 (Ex. 4)	Demonstrates configuring channels.
CTMMV	Page 3-57 (Ex. 1)	Demonstrates continuous AC volts measurement.
Digits	Page 4-7 (Ex. 1 & 2)	Demonstrates setting display resolution.
Digout	See 7706 packing list	Demonstrates setting the digital outputs on a 7706 module.
Get1Reading	None	Demonstrates retrieving one reading from the instrument.
Limits	Page 9-14	Demonstrates limits and digital outputs.
Linear	Page 5-14 (Ex. 1)	Demonstrates an mX+b linear calculation.
MAFilter	Page 4-22 (Ex. 1)	Demonstrates moving filter use.

Table G-1 (continued)
Visual Basic and CVI (C) examples

Name	Manual Reference	Brief Description
MultiRange	Page 4-5 (Ex. 1 & 2)	Demonstrates various range and function settings.
Ohmm	Page 3-57 (Ex. 2)	Demonstrates measuring offset compensated ohms in one-shot trigger mode.
Percent	Page 5-14 (Ex. 2)	Demonstrates percent calculation.
PollSQR	Page 11-10 (Prog Ex.)	Demonstrates serial poll operation and use of SRQs.
Prmr	Page 11-19 (Prog Ex.)	Demonstrates reading the measurement condition and event registers.
RAFilter	Page 4-22 (Ex. 2)	Demonstrates use of repeating filter.
RateBandwidth	Page 4-13 (Ex. 1 & 2)	Demonstrates rate and bandwidth settings.
Ratio1	Page 5-19 (Ex. 1)	Demonstrates ratio calculation.
Ratio2	Page 5-19 (Ex. 2)	Demonstrates ratio and channel average functions.
ReadError-Queue	Page 11-23 (Prog Ex.)	Demonstrates reading the error queue.
Relative1	Page 5-6 (Ex. 1)	Demonstrates acquiring and using a relative reference reading.
Relative2	Page 5-6 (Ex. 2)	Demonstrates setting a relative reference value.
Relative3	Page 5-6 (Ex. 3)	Demonstrates zero correction using relative value.
ScanChan	Page 7-32 (Prog Ex.)	Demonstrates scanning 10 channels.
Simple1	None	Use Case 1 — 30-channel scan using 7708 module: • 30 channels DCV (10V range). • 10 channels type T thermocouple temperature. • Measurement speed (rate) – 1 plc. • Filter – Disabled (no filtering). • Buffer – Store 120 reading strings. Buffer elements include reading only. • Triggering – Bus control source.

Table G-1 (continued)
Visual Basic and CVI (C) examples

Name	Manual Reference	Brief Description
Simple2	None	Use Case 2 — 40-channel scan using 7708 module: • 30 channels DCV (15 on 100mV range, 15 on 10V range). • 9 channels ACV (1V range). • 1 channel 4-wire RTD temperature. • Measurement speed (rate) – 1 plc. • Filter – Disabled (no filtering). • Buffer – Store 120 reading strings. Buffer elements include reading only. • Triggering – Bus control source.

Simple3	None	Use Case 3 — Two scans using 7708 module:
		• 40 channel DCV (1V range) scan.
		• 20 channel Ω4 scan:
		  • Models 2700 and 2701 – 100Ω range.
		  • Model 2750 – 10Ω range, dry-circuit ohms enabled.
		• Measurement speed (rate) – 0.1 plc.
		• DCV input divider – Enabled (10MΩ input impedance).
		• Filter – Disabled (no filtering).
		• Buffer – Store 40 DCV reading strings, 20 Ω4 reading strings. Buffer elements include reading only.
		• Limits (DCV scan) – Limit 1 (all channels) = 20mV, Master Latch enabled.
		• Triggering – Bus control source.

Table G-1 (continued)
Visual Basic and CVI (C) examples

Name	Manual Reference	Brief Description

Simple4	None	Use Case 4 — Two scans using 7708 module:
		• 40 channel DCV scan (1V range). Configuration saved in User Setup 1.
		• 20 channel Ω4 scan. Configuration saved in User Setup 2.
		  • Models 2700 and 2701 – 100Ω range.
		  • Model 2750 – 10Ω range, dry-circuit ohms enabled.
		• Setup 1 or Setup 2 recalled to perform scan.
		• Measurement speed (rate) – 0.1 plc.
		• DCV input divider – Enabled (10MΩ input impedance).
		• Filter – Disabled (no filtering).
		• Buffer – Store 40 DCV reading strings, 20 Ω4 reading strings. Buffer elements include reading only.
		• Limits (DCV scan) – Limit 1 (all channels) = 20mV, Master Latch enabled.
		• Triggering – Bus control source.

Simple5	None	Use Case 5 — 32-channel scan using 7701 module. • Common-side 4-wire ohms measurements (CSIDe mode). • Dry-circuit ohms option for Model 2750. • Install jumpers to connect Input Hi and Sense Hi directly to DUT (common-side bus). • Install jumpers to connect channel 35 to Sense Lo and Input Lo. • Buffer – Store 32 reading strings. Buffer elements include reading only. • Triggering – Immediate control source.

Table G-1 (continued)
Visual Basic and CVI (C) examples

Name	Manual Reference	Brief Description
Simple6	None	Use Case 6 — Scan 160 channels using 7703 module (see ***NOTE***): • Type K thermocouple (TC) temperature measurements. • Reference junction – Simulated. • Measurement speed (rate) – 0.01 plc. • Filter – Disabled (no filtering). • Buffer – Store 160 reading strings. Buffer elements include reading only. • Triggering – Bus control source. ***NOTE***: When using a module that has a built-in cold junction, use the Internal reference junction. Keep in mind that the buffer will have to be modified to accommodate the number of scanned channels. Modules that have cold junction include: 7700 and 7706 modules – 20 available TC channels 7708 module – 40 available TC channels

Simple7	None	Use Case 7 — Ten 40-channel scans using 7702 module:
		• Channel 1 uses an external reference junction.
		  • Measurement speed (rate) – 1 plc.
		  • Filter – Repeat, 25 readings.
		• Channels 2 through 40 are connected to type K thermocouples.
		  • Measurement speed (rate) – 1 plc.
		  • Filter – Disabled (no filtering).
		• Buffer – Store 400 reading strings. Buffer elements include reading only.
		• Triggering – Bus control source.

Table G-1 (continued)
Visual Basic and CVI (C) examples

Name	Manual Reference	Brief Description

Simple8	None	Use Case 8 — 7706 module in slot 1 and 7702 module in slot 2:
		• 7706 module:
		  • Output analog output values to analog output channels.
		  • Output digital output values to digital output channels.
		• 7702 module:
		  • Scan 120 DCV channels.
		  • Measurement speed (rate) – 1 plc.
		  • Filter – Disabled (no filtering).
		• Buffer – Store 320 reading strings. Buffer elements include reading only.
		• Triggering – Bus control source, trigger delay 0.125 seconds.

SOPC	Page 12-4	Demonstrates operation complete query (*OPC?).
SrSetup	Page 12-6	Demonstrates saving and recalling user setup.
TCalibration	7706	Demonstrates 7706 temperature calibration.
TCTemperature	None	Demonstrates temperature measurement.
Totalizer	7706	Demonstrates reading the 7706 totalizer.
TrigReadings	Page 8-20	Demonstrates instrument triggering.
VoltdB1	Page 5-21 (Ex. 1)	Demonstrates DCV dB measurement with 1V 0dB level.
VoltdB2	Page 5-21 (Ex. 2)	Demonstrates ACV dB measurement with 10V 0dB level.

LabVIEW examples

Table G-2 lists the LabVIEW examples and "Use Cases" that are provided with the KE2700 Instrument Driver. LabVIEW examples are provided in the file: Examples.llb. Use cases are provided in the file: Use Cases.llb. By default, these are installed in the Program Files\National Instruments\LabView X\instr.lib\KE2700 directory.

In addition to the examples, numerous supporting VIs are included in the library file.

Table G-2
LabVIEW examples

Name	Manual Reference	Brief Description
Read multi-point from channels	None	Demonstrates configuring and reading multiple data points from switching module channels.
Read multi-point from front panel	None	Demonstrates configuring and reading multiple data points from the front panel input.
Read single point from switching module channel	None	Demonstrates configuring and reading a single data point from switching module channels.
Read single point from front panel	None	Demonstrates configuring and reading a single data point from the front panel input.
Advance1	None	Use Case 1 — 40-channel scan using 7708 module: • 30 channels DCV (10V range). • 10 channels type T thermocouple temperature. • Measurement speed (rate) – 1 plc. • Filter – Disabled (no filtering). • Buffer – Store 160 reading strings. Buffer elements include reading, channel #, and real time clock. • Triggering – Timer scan; 40 channels every one minute. • Data retrieval – SRQ when buffer ¼, ½, ¾, and full.

Table G-2 (continued)
LabVIEW examples

Name	Manual Reference	Brief Description
Advance2	None	Use Case 2 — 40-channel scan using 7708 module: • 30 channels DCV (15 on 100mV range, 15 on 10V range). • 9 channels ACV (1V range). • 1 channel 4-wire RTD temperature. • Measurement speed (rate) – 1 plc. • Filter – Disabled (no filtering). • Buffer – Store 160 reading strings. Buffer elements include reading only. • Triggering – Timer scan; 40 channels every one minute. • Data retrieval – SRQ when buffer ¼, ½, ¾, and full.

Advance3	None	Use Case 3 — Two scans using 7708 module:
		• 40 channel DCV (1V range) scan.
		• 20 channel Ω4 scan:
		  • Models 2700 and 2701 – 100Ω range.
		  • Model 2750 – 10Ω range, dry-circuit ohms enabled.
		• Measurement speed (rate) – 0.1 plc.
		• DCV input divider – Enabled (10MΩ input impedance).
		• Filter – Disabled (no filtering).
		• Buffer – Store 40 DCV reading strings, 20 Ω4 reading strings. Buffer elements include reading only.
		• Limits (DCV scan) – Limit 1 (all channels) = 20mV, Master Latch enabled.
		• Triggering – Bus control source.
		• Data retrieval – SRQ if limit fails.

Table G-2 (continued)
LabVIEW examples

Name	Manual Reference	Brief Description

Advance4	None	Use Case 4 — Two scans using 7708 module:
		• 40 channel DCV scan (1V range). Configuration saved in User Setup 1.
		• 20 channel Ω4 scan. Configuration saved in User Setup 2.
		  • Models 2700 and 2701 – 100Ω range.
		  • Model 2750 – 10Ω range, dry-circuit ohms enabled.
		• Setup 1 or Setup 2 recalled to perform scan.
		• Measurement speed (rate) – 0.1 plc.
		• DCV input divider – Enabled (10MΩ input impedance).
		• Filter – Disabled (no filtering).
		• Buffer – Store 40 DCV reading strings, 20 Ω4 reading strings. Buffer elements include reading only.
		• Limits (DCV scan) – Limit 1 (all channels) = 20mV, Master Latch enabled.
		• Triggering – Bus control source.
		• Data retrieval – SRQ if limit fails.

Advance5	None	Use Case 5 — 32-channel scan using 7701 module: • Common-side 4-wire ohms measurements (CSIDe mode). • Dry-circuit ohms option for Model 2750. • Install jumpers to connect Input Hi and Sense Hi directly to DUT (common-side bus). • Install jumpers to connect channel 35 to Sense Lo and Input Lo. • Buffer – Store 32 reading strings. Buffer elements include reading only. • Triggering – Immediate control source. • Data retrieval – SRQ when buffer full.

Table G-2 (continued)
LabVIEW examples

Name	Manual Reference	Brief Description
Advance6	None	Use Case 6 — Scan 160 channels using 7703 module (see ***NOTE***): • Type K thermocouple (TC) temperature measurements. • Reference junction – Simulated. • Measurement speed (rate) – 0.01 plc. • Filter – Disabled (no filtering). • Buffer – Store 160 reading strings. Buffer elements include reading and channel #. • Triggering – Bus control source. • Data retrieval – Continuously store data into buffer. Retrieve data for every 32 readings. ***NOTE***: When using a module that has a built-in cold junction, use the Internal reference junction. Keep in mind that the buffer and data retrieval will have to be modified to accommodate the number of scanned channels. Modules that have cold junction include: 7700 and 7706 modules – 20 available TC channels 7708 module – 40 available TC channels

Advance7	None	Use Case 7 — Ten 40-channel scans using 7702 module:
		• Channel 1 uses an external reference junction.
		  • Measurement speed (rate) – 1 plc.
		  • Filter – Repeat, 25 readings.
		• Channels 2 through 40 are connected to type K thermocouples.
		  • Measurement speed (rate) – 1 plc.
		  • Filter – Disabled (no filtering).
		  • Open thermocouple detection – Enabled.
		• Buffer – Store 400 reading strings. Buffer elements include reading, real time clock, and channel #.
		• Triggering – Bus control source.
		• Data retrieval – SRQ when buffer ¼, ½, ¾, and full.

Table G-2 (continued)
LabVIEW examples

Name	Manual Reference	Brief Description

Advance8	None	Use Case 8 — 7706 module in slot 1 and 7702 module in slot 2:
		• 7706 module:
		  • Output analog output values to analog output channels.
		  • Output digital output values to digital output channels.
		• 7702 module:
		  • Scan 120 DCV channels.
		  • Measurement speed (rate) – 1 plc.
		  • Filter – Disabled (no filtering).
		  • Math – mX+b, m = 0.555, b = -17.778.
		  • Limits – Limit 1 (all channels) = 100, Limit 2 = 180.
		• Buffer – Store 320 reading strings. Buffer elements include reading, channel #, and limit code.
		• Triggering – Bus control source, trigger delay 0.125 seconds.
		• Data retrieval – SRQ when buffer ¼, ½, ¾, and full.

Simple1	None	Use Case 1 — 30-channel scan using 7708 module: • 30 channels DCV (10V range). • 10 channels type T thermocouple temperature. • Measurement speed (rate) – 1 plc. • Filter – Disabled (no filtering). • Buffer – Store 120 reading strings. Buffer elements include reading only. • Triggering – Bus control source.
Simple2	None	Use Case 2 — 40-channel scan using 7708 module: • 30 channels DCV (15 on 100mV range, 15 on 10V range). • 9 channels ACV (1V range). • 1 channel 4-wire RTD temperature. • Measurement speed (rate) – 1 plc. • Filter – Disabled (no filtering). • Buffer – Store 120 reading strings. Buffer elements include reading only. • Triggering – Bus control source.

Table G-2 (continued)
LabVIEW examples

Name	Manual Reference	Brief Description

Simple3	None	Use Case 3 — Two scans using 7708 module:
		• 40 channel DCV (1V range) scan.
		• 20 channel Ω4 scan:
		  • Models 2700 and 2701 – 100Ω range.
		  • Model 2750 – 10Ω range, dry-circuit ohms enabled.
		• Measurement speed (rate) – 0.1 plc.
		• DCV input divider – Enabled (10MΩ input impedance).
		• Filter – Disabled (no filtering).
		• Buffer – Store 40 DCV reading strings, 20 Ω4 reading strings. Buffer elements include reading only.
		• Limits (DCV scan) – Limit 1 (all channels) = 20mV, Master Latch enabled.
		• Triggering – Bus control source.

Simple4	None	Use Case 4 — Two scans using 7708 module:
		• 40 channel DCV scan (1V range). Configuration saved in User Setup 1.
		• 20 channel Ω4 scan. Configuration saved in User Setup 2.
		  • Models 2700 and 2701 – 100Ω range.
		  • Model 2750 – 10Ω range, dry-circuit ohms enabled.
		• Setup 1 or Setup 2 recalled to perform scan.
		• Measurement speed (rate) – 0.1 plc.
		• DCV input divider – Enabled (10MΩ input impedance).
		• Filter – Disabled (no filtering).
		• Buffer – Store 40 DCV reading strings, 20 Ω4 reading strings. Buffer elements include reading only.
		• Limits (DCV scan) – Limit 1 (all channels) = 20mV, Master Latch enabled.
		• Triggering – Bus control source.

Table G-2 (continued)
LabVIEW examples

Name	Manual Reference	Brief Description
Simple5	None	Use Case 5 — 32-channel scan using 7701 module. • Common-side 4-wire ohms measurements (CSIDe mode). • Dry-circuit ohms option for Model 2750. • Install jumpers to connect Input Hi and Sense Hi directly to DUT (common-side bus). • Install jumpers to connect channel 35 to Sense Lo and Input Lo. • Buffer – Store 32 reading strings. Buffer elements include reading only. • Triggering – Immediate control source.
Simple6	None	Use Case 6 — Scan 160 channels using 7703 module (see ***NOTE***): • Type K thermocouple (TC) temperature measurements. • Reference junction – Simulated. • Measurement speed (rate) – 0.01 plc. • Filter – Disabled (no filtering). • Buffer – Store 160 reading strings. Buffer elements include reading only. • Triggering – Bus control source. ***NOTE:*** When using a module that has a built-in cold junction, use the Internal reference junction. Keep in mind that the buffer will have to be modified to accommodate the number of scanned channels. Modules that have cold junction include: 7700 and 7706 modules – 20 available TC channels 7708 module – 40 available TC channels

Table G-2 (continued)
LabVIEW examples

Name	Manual Reference	Brief Description

Simple7	None	Use Case 7 — Ten 40-channel scans using 7702 module:
		• Channel 1 uses an external reference junction.
		  • Measurement speed (rate) – 1 plc.
		  • Filter – Repeat, 25 readings.
		• Channels 2 through 40 are connected to type K thermocouples.
		  • Measurement speed (rate) – 1 plc.
		  • Filter – Disabled (no filtering).
		• Buffer – Store 400 reading strings. Buffer elements include reading only.
		• Triggering – Bus control source.

Simple8	None	Use Case 8 — 7706 module in slot 1 and 7702 module in slot 2:
		• 7706 module:
		  • Output analog output values to analog output channels.
		  • Output digital output values to digital output channels.
		• 7702 module:
		  • Scan 120 DCV channels.
		  • Measurement speed (rate) – 1 plc.
		  • Filter – Disabled (no filtering).
		• Buffer – Store 320 reading strings. Buffer elements include reading only.
		• Triggering – Bus control source, trigger delay 0.125 seconds.

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