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# Model 6514 System Electrometer

## Instruction Manual

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**3/04**

# Model 6514 System Electrometer
# Instruction Manual

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# Safety Precautions

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 manual for complete product specifications.

If the product is used in a manner not specified, the protection provided by the product 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 manual. 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, and perform safe installations and repairs of products. Only properly trained service personnel may perform installation and service procedures.

Keithley 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 Manual.

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 1000 volts, **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, make sure 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 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 indicates that the user should refer to the operating instructions located in the manual.

The  symbol on an instrument shows that it can source or measure 1000 volts or more, including the combined effect of normal and common mode voltages. Use standard safety precautions to avoid personal contact with these voltages.

The  symbol indicates a connection terminal to the equipment frame.

The **WARNING** heading in a 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 in a manual 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., 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

- **General information** — Covers general information that includes warranty information, contact information, safety symbols and terms, inspection, and available options and accessories.
- **System electrometer features** — Summarizes the features of Model 6514.
- **Front and rear panel familiarization** — Summarizes the controls and connectors of the instrument.
- **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 Model 6514.
- **Default settings** — Covers the five instrument setup configurations available to the user; three user defined, GPIB defaults, or factory defaults.
- **SCPI programming** — Explains how SCPI commands are presented in this manual.

# General information

## Warranty information

Warranty information is located at the front of this manual. Should your Model 6514 require warranty service, contact the Keithley representative or authorized repair facility in your area for further information. When returning the instrument for repair, be sure to fill out and include the service form at the back of this manual to provide the repair facility with the necessary 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 one of our Application Engineers 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 6514 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 6514 order:

- Model 6514 System Electrometer with line cord.
- Model 237-ALG-2 triax cable.
- Accessories as ordered.
- Certificate of calibration.
- Model 6514 Instruction Manual (P/N 6514-901-01).
- Manual Addenda (pertains to any improvements or changes concerning the instrument or manual).

If an additional manual is required, order the appropriate manual package. The manual packages include a manual and any pertinent addenda.

# Options and accessories

## Input cables, connectors and adapters

**Model 237-ALG-2** — This is a 6.6 ft (2-meter) low-noise triax cable terminated with a 3-slot male triax connector on one end and 3 alligator clips on the other. (One Model 237-ALG-2 is included).

**Model 237-BNC-TRX adapter** — This is a male BNC to 3-lug female triax connector (guard disconnected). It is used to terminate a triax cable with a BNC plug.

**Model 237-TRX-T adapter** — This is a 3-slot male to dual 3-lug female triax tee adapter for use with 7078-TRX triax cables.

**Model 237-TRX-TBC connector** — This is a 3-lug female triax bulkhead (internal mount) connector with cap for assembly of custom test fixtures and interface connections.

**Model 7078-TRX-TBC connector** — This is a 3-lug female triax bulkhead (external mount) connector with cap for assembly of custom test fixtures and interface connections.

**Model 7078-TRX-3, 7078-TRX-10 and Models 7078-TRX-20 triax cables** — These are low noise triax cables terminated at both ends with 3-slot male triax connectors. The -3 model is 3 ft (0.9m) in length, the -10 model is 10 ft (3m) in length, and the -20 model is 20 ft (6m) in length.

**CS-751 barrel adapter** — This is a barrel adapter that allows you to connect two triax cables together. Both ends of the adapter are terminated with 3-lug female triax connectors.

## GPIB and trigger link cables and adapters

**Models 7007-1 and 7007-2 shielded GPIB cables** — Connect Model 6514 to the GPIB bus using shielded cables and connectors to reduce electromagnetic interference (EMI). Model 7007-1 is lm long; Model 7007-2 is 2m long.

**Models 8501-1 and 8501-2 trigger link cables** — Connect Model 6514 to other instruments with Trigger Link connectors (e.g., Model 7001 Switch System). Model 8501-1 is lm long; Model 8501-2 is 2m long.

**Model 8502 trigger link adapter** — Lets you connect any of the six trigger link lines of Model 6514 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 two (External Trigger) of Model 6514 to instruments that use BNC trigger connectors. Model 8503 is lm long.

### Rack mount kits

**Model 4288-1 single fixed rack mount kit** — Mounts a single Model 6514 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, 6430, 6514, 6517 A, 7001) side-by-side in a standard 19-inch rack.

**Model 4288-4 side-by-side rack mount kit** — Mounts Model 6514 and a 5.25-inch instrument (Models 195A, 196, 220, 224, 230, 263, 595, 614, 617, 705, 740, 775A, 6512) side-by-side in a standard 19-inch rack.

### Carrying case

**Model 1050 padded carrying case** — A carrying case for Model 6514. Includes handles and shoulder strap.

## System electrometer features

Model 6514 is a 6½-digit high-performance system electrometer. It can measure voltage, current, resistance and charge. Details on its measurement capabilities are explained in Section 2 of this manual (see “Measurement Overview”).

Features of Model 6514 System Electrometer include:

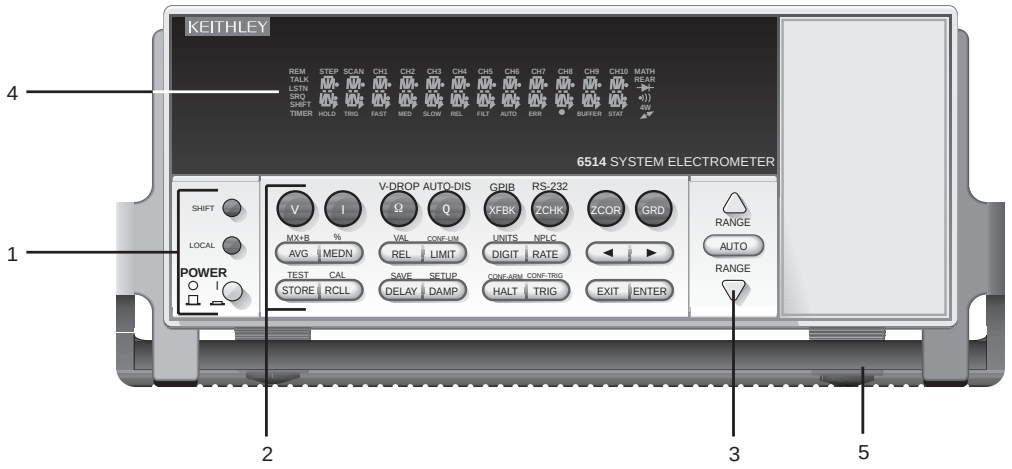
- **Setup storage** — Five instrument setups (three user, GPIB defaults and factory defaults) can be saved and recalled.
- **mX+b and percent** — These calculations provide mathematical manipulation of readings.
- **Relative** — Null offsets or establish baseline values.
- **Buffer** — Store up to 2500 readings in the internal buffer.
- **Limits** — Set up to two stages of high and low reading limits to test devices.
- **Digital I/O port** — Four output lines and one input line to control external circuitry. Use as an interface between limit tests and component handler.
- **Analog outputs** — Provides a 2V analog output for a full range input. Preamp out provides a driven guard for Volts, or can be used for external feedback measurements.
- **External feedback** — Extends the measurement capabilities of the electrometer; logarithmic currents, non-decade current ranges and non-standard charge ranges.
- **Remote interface** — Model 6514 can be controlled using the IEEE-488 interface (GPIB) or the RS-232 interface.
- **GPIB programming language** — When using the GPIB, the instrument can be programmed using the SCPI or DDC programming language.

# Front and rear panel familiarization

## Front panel summary

The front panel of Model 6514 is shown in Figure 1-1.

*Figure 1-1 Model 6514 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 GPIB remote mode. |
| POWER | Power switch. In position turns 6514 on (I), out position turns it off (O). |

### 2 Function and operation keys

**Top Row**

Unshifted

| | |
|---|---|
| V | Selects voltage measurement function. |
| I | Selects current measurement function. |
| Ω | Selects resistance measurement function. |
| Q | Selects charge measurement function. |
| XFBK | Enables/disables External Feedback. |
| ZCHK | Enables/disables Zero Check. |
| ZCOR | Enables/disables Zero Correct. |
| GRD | Enables/disables Guard. |

Shifted

| | |
|---|---|
| V-DROP | Enables/disables V-drop measurements for Ω function. |
| AUTO-DIS | Sets and enables/disables Auto Discharge for charge measurements. |
| GPIB | Configures and enables/disables GPIB interface. |
| RS-232 | Configures and enables/disables RS-232 interface. |

**Middle Row**

Unshifted

| | |
|---|---|
| AVG | Configures and enables/disables digital filter. |
| MEDN | Configures and enables/disables median filter. |
| REL | Enables/disables Relative (Rel). |
| LIMIT | Performs configured limit tests. |
| DIGIT | Sets display resolution. |
| RATE | Selects measurement rate. |
| ◀ and ▶ | Controls cursor position for making selections or editing values. |

Shifted

| | |
|---|---|
| MX+B | Configures and enables/disables mX+b math function. |
| % | Configures and enables/disables Percent math function. |
| VAL | Sets Rel value and enables Rel. |
| CONF-LIM | Configures limit tests. |
| UNITS | Selects engineering units for scientific notation for display readings. |
| NPLC | Set rate by setting PLC value. |

**Bottom Row**

Unshifted

| | |
|---|---|
| STORE | Sets the number of readings to store and enables the buffer. |
| RCLL | Displays stored readings (including maximum, minimum, peak-to-peak, average, and standard deviation). The ▲ and ▼ range keys scroll through the buffer, and the ◀ or ▶ key toggles between reading number and reading. |
| DELAY | Sets user delay between trigger and measurement. |
| DAMP | Enables/disables damping for current measurements. |
| HALT | Stops measurement process. Puts 6514 in idle state. |
| TRIG | Trigger measurement(s). Takes 6514 out of idle state. |
| EXIT | Cancels selection, moves back to measurement display. |
| ENTER | Accepts selection, moves to next choice or back to measurement display. |

Shifted

| | |
|---|---|
| TEST | Performs key-press test or display test. |
| CAL | Accesses calibration. |
| SAVE | Saves present setup to a memory location. |
| SETUP | Restores setup stored in a memory location, or to GPIB or factory defaults. |
| CONF-ARM | Configures Arm Layer of trigger model. |
| CONF-TRIG | Configures Trigger Layer of trigger model. |

## 3 Range keys

| | |
|---|---|
| ▲ | Selects the next higher voltage measurement range. |
| ▼ | Selects the next lower voltage measurement range. |
| AUTO | Enables/disables autorange. |

### 4 Display annunciators

| | |
|---|---|
| * (asterisk) | Readings being stored in buffer. |
| ↔ (more) | Indicates additional selections are available. |
| AUTO | Autorange enabled. |
| BUFFER | Recalling readings stored in buffer. |
| ERR | Questionable reading, or invalid cal step. |
| FAST | Fast (0.1 PLC) reading rate selected. |
| FILT | Filter enabled. |
| LSTN | Instrument addressed to listen over GPIB. |
| MATH | mX+b or Percent (%) calculation enabled. |
| MED | Medium (1 PLC) reading rate selected. |
| REL | Relative enabled for present measurement function. |
| REM | Instrument in GPIB remote mode. |
| SHIFT | Accessing a shifted key. |
| SLOW | Slow reading rate selected; 6 PLC for 60Hz or 5 PLC for 50Hz. |
| SRQ | Service request over GPIB. |
| STAT | Displaying buffer statistics. |
| TALK | Instrument addressed to talk over GPIB bus. |
| TIMER | Timer controlled triggering in use. |
| TRIG | External triggering (GPIB or trigger link) selected. |

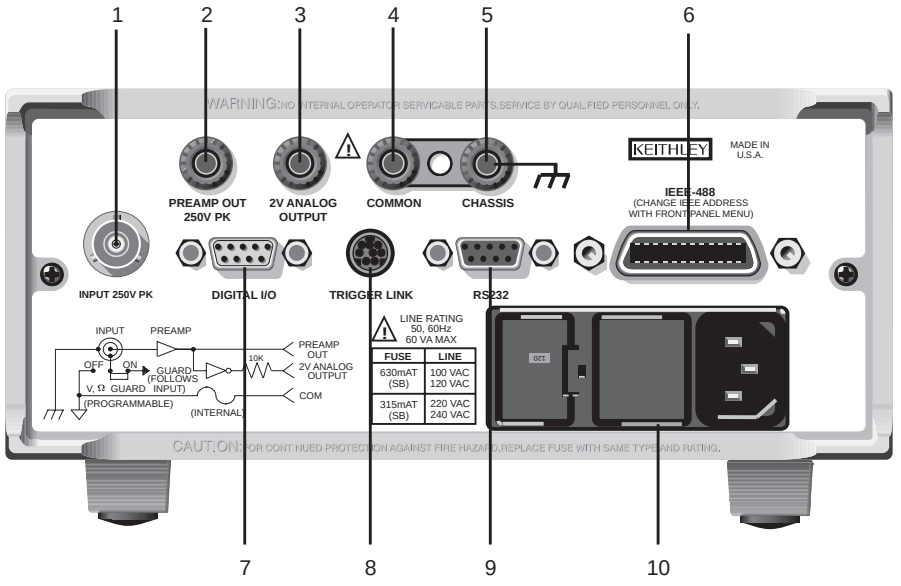
### 5 Handle

Pull out and rotate to desired position.

## Rear panel summary

The rear panel of Model 6514 is shown in Figure 1-2.

*Figure 1-2*
*Model 6514*
*rear panel*




### 1 INPUT

This standard 3-lug female triax connector is used to connect the signal to be measured to the input of Model 6514. Mates to a triax cable terminated with a 3-lug male triax connector.

### 2 PREAMP OUT

Provides a guard output for Volts measurements. Can be used as an inverting output or with external feedback for the Amps and Coulombs modes.

### 3 2V ANALOG OUTPUT

Provides a scaled DC output voltage. A full range input will result in a 2V analog output. For the volts function, the output is non-inverting.

### 4 COMMON

Use as input low, or the common for the 2V Analog Output and Preamp Out.

### 5 CHASSIS

This terminal is connected to the chassis of Model 6514 and to power line earth ground via the power line cord. For floating measurements (up to 500V peak), remove the ground link between COMMON and CHASSIS.

### 6 IEEE-488

Connector for IEEE-488 (GPIB) operation. Use a shielded cable, such as Models 7007-1 and 7007-2.

### 7 DIGITAL I/O

Male DB-9 connector for digital output lines and component handler signals.

### 8 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.

### 9 RS-232

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

### 10 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.

# Power-up

## Line power connection

Perform the following procedure to connect Model 6514 to line power and turn on the instrument.

1. Check to be sure the line voltage setting on the power module is correct for the operating voltage in your area. The line voltage setting is indicated in the window on the power module (see Figure 1-2). The upside-down 120 setting is for line voltages of 100/120VAC, and the upside-down 240 setting is for line voltages of 220/240VAC. The procedure to change the line voltage setting is provided in Section 20.

*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 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 Model 6514 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 (1) position.

## Line frequency selection

During the power-up sequence, the selected line frequency setting is displayed. The line frequency setting can be changed from the front panel by holding in the TRIG key during the power-up sequence. This action toggles between 50 and 60Hz. The command to remotely set line frequency is listed in Table 1-1.

### SCPI programming

*Table 1-1*
*SCPI commands - line frequency*

| Command | Description |
|---|---|
| SYSTem<br>:LFRequency <freq><br>:LFRequency? | SYSTem Subsystem:<br>Select power line frequency (in Hz); 50 or 60.<br>Read present line frequency setting. |

## Power-up sequence

The following power-up sequence occurs when the Model 6514 is turned on:

1. The Model 6514 performs self-tests on its EPROM and RAM with all digits and annunciators turned on. If a failure is detected, the instrument momentarily displays an error message and the ERR annunciator turns on. Error messages are listed in Appendix B.

*NOTE* *If a problem develops while the instrument is under warranty, return it to Keithley Instruments Inc., for repair.*

2. If the instrument passes the self-tests, the firmware revision levels are displayed. For example:
   6514 REV: A01
3. The detected line frequency is then displayed. For example:
   FREQ: 60Hz
4. Lastly, information on the selected remote interface is displayed:
   a. GPIB — If the GPIB is the selected interface, the instrument will display the selected language (SCPI or DDC) and primary address. Examples:
      SCPI ADDR: 14
      DDC ADDR: 14
   b. RS-232 — If RS-232 is the selected interface, the instrument will display the baud rate setting. For example:
      RS-232: 9600b

# Display

Readings can be displayed in engineering units or scientific notation (see "Units" in Section 6 for details). Annunciators indicate various states of operation. See "Front Panel Summary" (presented earlier in this section) for a complete listing of display annunciators.

*NOTE The Display and Keys Test allows you to test display digit segments and annunciators, and check the functionality of front panel keys. These tests are accessed by pressing SHIFT and then TEST. Refer to Section 20 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 B.

# Default settings

Model 6514 can be restored to one of five default setup configurations; factory (FACT), GPIB and three user-saved (USR0, USR1 and USR2). As shipped from the factory, Model 6514 powers up to the factory default settings. Factory default settings provide a general purpose setup for front panel operation, while the GPIB default settings do the same for remote operation. Factory and GPIB default settings are listed in Table 1-2.

For front panel operation, the instrument will power up to whichever default setup was last saved or restored. For example, if you save the present instrument setup as USR0, the instrument will subsequently power up to the USR0 setup.

*NOTE At the factory, the factory default setup is saved as the USR0, USR1 and USR2 setups.*

**Saving a user setup** — Perform the following steps to save a user setup:

1. Configure Model 6514 for the desired measurement application.
2. Press SHIFT and then SAVE to access the save setup menu.
3. Use the ▲ or ▼ key to display the desired memory location (0 = USR0, 1 = USR1, 2 = USR2).
4. Press ENTER.

**Restoring a setup** — Perform the following steps to restore a setup:

1. Press SHIFT and then SETUP to display the restore menu:
2. Use the ▲ or ▼ key to display the desired setup (FACT, GPIB, USR0, USR1 or USR2).
3. Press ENTER.

## Remote operation

**Saving and restoring user setups** — The *SAV and *RCL commands are used to save and recall user setups. These commands are documented in Section 14.

**Restoring factory or GPIB default setups** — The SYSTem:PRESet command returns Model 6514 to the factory defaults and the *RST command returns it to the GPIB defaults. The *RST command is documented in Section 14 and SYSTem:PRESet is covered in Section 16 (SYSTem Subsystem).

**Selecting power-on setup** — The SYSTem:POSetup command is used to select which setup to return to on power-up. The SYSTem:POSetup command is documented in Section 16 (SYSTem Subsystem).

*Table 1-2*
*Default settings*

| **Setting** | **Factory** | **GPIB** |
|---|---|---|
| Arm Layer (CONF-ARM): | | |
| Arm-In Source Event | IMM | IMM |
| Arm Count | INF | 1 |
| Input Trigger Link Line | 1 | 1 |
| Source Bypass | NEVER | NEVER |
| Output Trigger Link Line | 2 | 2 |
| Output Trigger | Off | Off |
| Auto Discharge | Off | Off |
| Level | 2e-6 | 2e-6 |
| Buffer (STORE): | Disabled | Disabled |
| Count | No effect | No effect |
| Digital Filter (AVG): | Off | Off |
| Count | 10 | 10 |
| Type | Moving | Moving |
| Display Resolution (DIGIT) | 5½-digits | 5½-digits |
| Function | Volts | Volts |
| Guard | Off | Off |
| GPIB: | No effect (On at factory) | No effect (On at factory) |
| Address | No effect (14 at factory) | No effect (14 at factory) |
| Language | No effect (SCPI at factory) | No effect (SCPI at factory) |

*Table 1-2 (cont.)*
*Default settings*

| **Setting** | **Factory** | **GPIB** |
|---|---|---|
| Limit Tests: | | |
| Limit 1 and Limit 2: | Disabled | Disabled |
| HI and LO Values | 1, -1 | 1, -1 |
| Digital Fail Output Patterns | 15 | 15 |
| Digital Output Pass Pattern | 15 | 15 |
| Auto-Clear | Off | Off |
| Delay | 0.00010 sec | 0.00010 sec |
| Output Clear Pattern | 15 | 15 |
| Line 4 Mode | End of Test | End of Test |
| Median Filter: | Off | Off |
| Rank | 1 | 1 |
| MX+B: | Disabled | Disabled |
| “M” Value | 1.0 | 1.0 |
| “B” Value | 0.0 | 0.0 |
| Units | MXB | MXB |
| Percent: | Disabled | Disabled |
| Reference | 1.0 | 1.0 |
| Range | 20V | Auto |
| Rate: | Slow | Slow |
| NPLC | 6.0 (60Hz) or 5.0 (50Hz) | 6.0 (60Hz) or 5.0 (50Hz) |
| Rel: | Off | Off |
| Rel Value (VAL) | 0.0 | 0.0 |
| RS-232: | No effect (Off at factory) | No effect (Off at factory) |
| All Settings | No effect | No effect |
| Trigger Layer (CONF-TRIG): | | |
| Trig-In Source Event | IMM | IMM |
| Trigger Count | 1 | 1 |
| Trigger Delay | 0 | 0 |
| Input Trigger Link Line | 1 | 1 |
| Source Bypass | NEVER | NEVER |
| Output Trigger Link Line | 2 | 2 |
| Units | No effect | No effect |
| V-Drop | Disabled | Disabled |
| Zero Check | Enabled | Enabled |
| Zero Correct | Disabled | Disabled |

# SCPI programming

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

*NOTE* *Except for Section 17, most SCPI 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 6514 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. When a query command is sent and Model 6514 is addressed to talk, the response message is sent to the computer.

*NOTE* *For complete details, see "Programming Syntax" in Section 12.*

# 2
# Measurement Concepts

- **Measurement overview** — Explains the basic measurement capabilities of Model 6514.
- **Performance considerations** — Covers a couple of considerations that affect overall performance; warm-up and autozero.
- **Connection fundamentals** — Covers fundamental information about connecting test circuits to the electrometer.
- **Zero check and zero correct** — Provides operation information on these two important aspects of the basic measurement process.
- **Measurement considerations** — Summarizes the various factors that affect low level measurements.

# Measurement overview

The basic measurement capabilities of Model 6514 are summarized in Table 2-1. Accuracy for each measurement function and range is listed in specifications (Appendix A).

*Table 2-1*
*Basic measurement capabilities*

| Function | Reading Range | Available Ranges |
|---|---|---|
| Volts | ±10uV to ±210V | 2V, 20V and 200V |
| Amps | ±100aA to ±21mA | 20pA, 200pA, 2nA, 20nA, 200nA, 2uA, 20uA, 200uA, 2mA and 20mA |
| Ohms | 10mΩ to 210GΩ | 2kΩ, 20kΩ, 200kΩ, 2MΩ, 20MΩ, 200MΩ, 2GΩ, 20GΩ and 200GΩ |
| Coulombs | 10fC to 21µC | 20nC, 200nC, 2µC, and 20µC |

# Performance considerations

## Warm-up period

Model 6514 can be used within one minute after it is turned on. However, the instrument should be turned on and allowed to warm up for at least one hour before use to achieve rated accuracy. If the instrument has been exposed to extreme temperatures, allow extra time for the internal temperature to stabilize.

## Autozero

To help maintain stability and accuracy over time and changes in temperature, the Model 6514 periodically measures internal voltages corresponding to offsets (zero) and amplifier gains. 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 and gain measurements are not performed. This increases measurement speed. However, the zero and gain 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.

Autozero cannot be disabled from the front panel, however, it can be enabled from the front panel by restoring factory or GPIB default conditions.

### SCPI programming

*Table 2-2*
*SCPI commands — autozero*

| Command | Description | Default |
|---|---|---|
| SYSTem | SYSTem Subsystem: | |
| :AZERo | | |
| [:STATe] <b> | Enable or disable autozero. | ON |

**Programming example**

The following command sequence will perform one zero corrected amps measurement:

```
SYST:AZER OFF              ' Disable autozero.
SYST:AZER ON               ' Enable autozero.
```

# Connection fundamentals

The following provides important fundamental information on input connections to Model 6514. Typical connection drawings are included with the various measurement procedures provided in subsequent sections of this manual.

## Input connector

The rear panel INPUT connector is a 3-lug female triax connector that will mate to a cable terminated with a male triax connector.

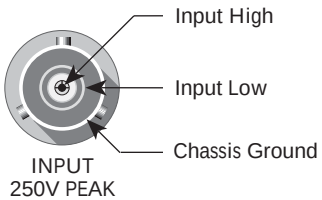
## Input configurations

As shown in Figure 2-1, the input connector can be configured in two ways. With guard off (Figure 2-1A), input low is connected to the inner shell of the connector. This configuration is used for Amps, Coulombs, unguarded Volts and unguarded Ohms measurements.

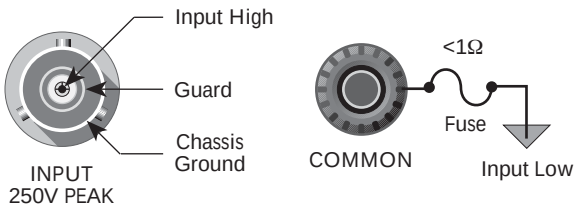
With guard on (Figure 2-1B), the driven guard is connected to the inner shell of the triax connector. Input low is accessed via the COMMON terminal through an internal 0.1Ω fuse. This configuration is used for guarded Volts and guarded Ohms measurements only. The GRD key toggles guard on and off.

*NOTE* *The state of guard (on or off) has no affect on the Amps and Coulombs functions. The unguarded configuration is always selected for the Amps and Coulombs functions.*

*Figure 2-1*
*Input connector configurations*




**A. Unguarded (GRD off)**




**B. Guarded (GRD on)**

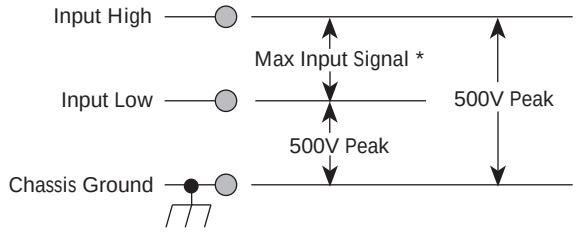
## Maximum input levels

The maximum input levels to Model 6514 are summarized in Figure 2-2.

*WARNING* **The maximum common-mode input voltage, which is the voltage between the input (HI or LO) and chassis ground, is 500V peak. Exceeding this value may create a shock hazard.**

*CAUTION* **Connecting PREAMP OUT, COMMON, or 2V ANALOG OUTPUT to earth while floating the input may damage the instrument.**

*Figure 2-2*
*Maximum input levels*




* Max Input Signal - 250V Peak, DC to 60Hz sine wave (10 seconds maximum in mA ranges).

## Low noise input cables

When making precision measurements, you should always use low noise cables. The following low noise cables are recommended for use with Model 6514:

- Model 237-ALG-2 — This 2-meter low noise triax cable mates directly to the input connector of Model 6514. The other end is terminated with three alligator clips. The clip with the red boot is input high, black boot is input low or guard, and the green boot is chassis ground.
- Model 7078-TRX-3 — This 3-foot low noise triax cable is terminated with a 3-slot triax connector on either end.
- Models 7078-TRX-10 and 7078-TRX-20 — Same as Model 7078-TRX-3 except that they are 10 feet and 20 feet in length.

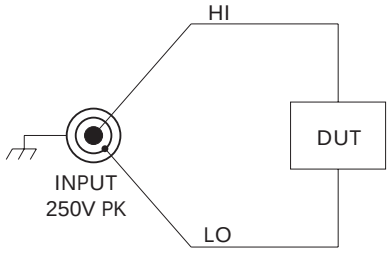
*NOTE* *As a general rule, always use the shortest possible cable for volts, amps and ohms measurements.*

# Basic connections to DUT

## Unguarded connections

Basic unguarded connections are shown in Figure 2-3, the DUT is the voltage, current, resistance or charge to be measured. Circuit high is connected to the center conductor of the input connector and circuit low is connected to the inner shell of the connector. For unguarded volts and ohms measurements, the driven guard (GRD) must be off.

*Figure 2-3*
*Basic connections for unguarded measurements*



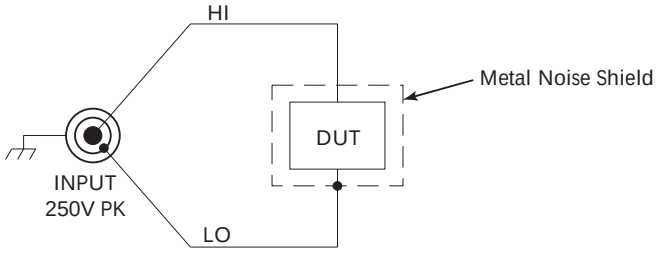

NOTE: For Volts and Ohms, GRD must be off.

**Noise and safety shields** — Figure 2-4 shows typical shielding for unguarded measurements. A noise shield is used to prevent unwanted signals from being induced on the electrometer input. Measurements that may benefit from effective shielding include unguarded volts and ohms, amps below 1uA, and low level coulombs.

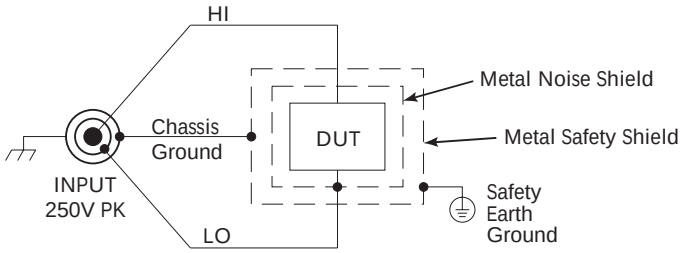
Typically, the noise shield is connected to electrometer input LO. However, better noise performance may be achieved by connecting the noise shield to both input LO and chassis ground. Electrometer LO can be connected to chassis ground by installing the ground link between the COMMON and CHASSIS binding posts.

A safety shield is required whenever a hazardous voltage (>30V) is present on the noise shield or when the test circuit (DUT) is floated above earth ground at a hazardous voltage level (see "Floating Measurements"). Connections for the safety shield is shown in Figure 2-4B. The metal safety shield must completely surround the noise shield or floating test circuit, and it must be connected to safety earth ground using #18 AWG or larger wire.

*Figure 2-4*
*Shielding for unguarded measurements*




**A. Noise Shield**




**B. Safety Shield**

## Guarded connections

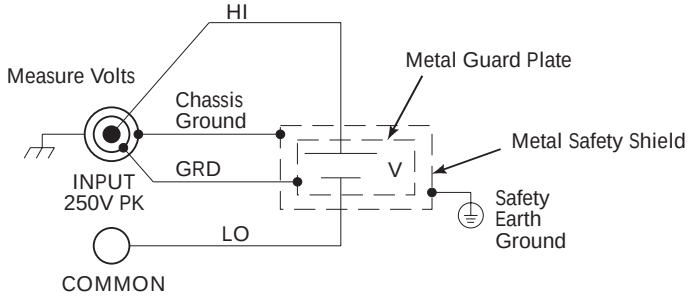
The basic guarded connections for volts and ohms are shown in Figure 2-5. For these measurements, circuit high is connected to the center conductor of the input connector while circuit low is connected to the COMMON banana jack terminal. With guard (GRD) on, the driven guard is available at the inner shell of the triax connector which is connected to the metal guard plate.

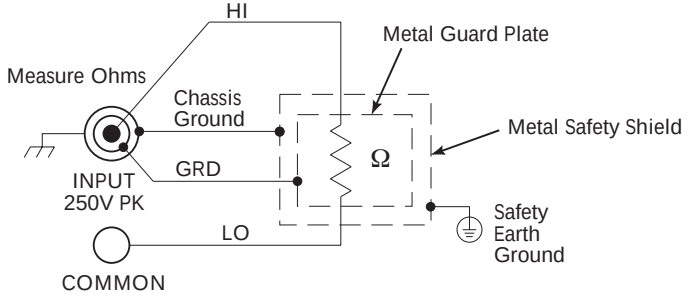
*WARNING* **The guard voltage is at the same potential as the input. Therefore, hazardous voltage on the input will also be present on the guard plate. To prevent electric shock, always use a metal safety shield (as shown in Figure 2-5) for guarded voltage measurements above 30Vrms (42V peak). The metal safety shield must be connected to safety earth ground using #18 AWG or larger wire.**

*WARNING* **With an open input, up to 250V peak may be present on the guard terminals while in Volts or Ohms. To prevent this, enable zero check whenever the input is open.**

The driven guard is used to eliminate leakage current and capacitance in high impedance circuits which could corrupt the volts or ohms measurement. The concept of guarding techniques are covered in Section 3.

*Figure 2-5*
*Basic connections for guarded measurements*



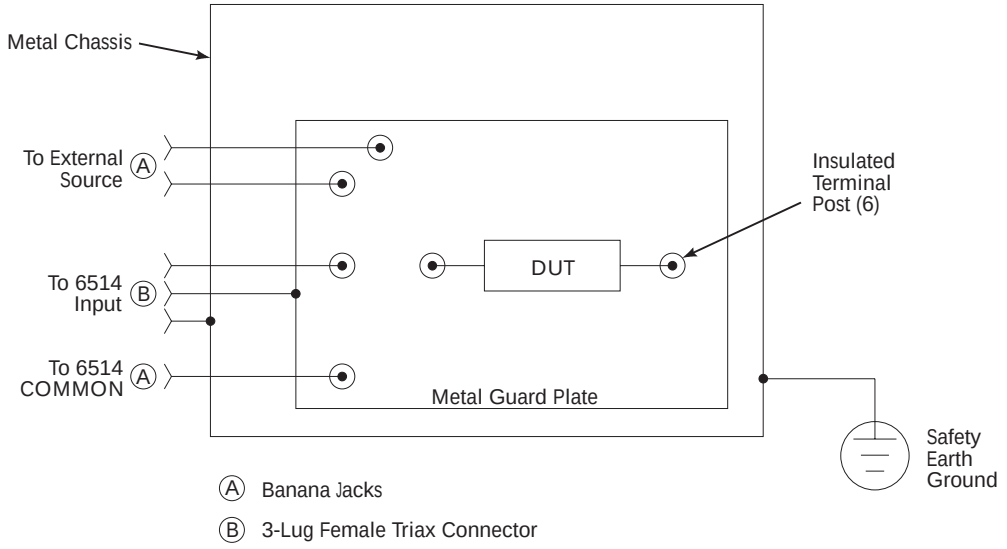




NOTE: GRD must be on.

## Test fixture

Whenever possible, use a shielded low leakage test fixture to make precision measurements. A general purpose test fixture is shown in Figure 2-6. This test fixture will accommodate a variety of connection requirements.

*Figure 2-6 General purpose test fixture*




### Test fixture chassis

- The chassis of the test fixture should be metal so that it can function as a shield for the DUT or test circuit. The metal chassis should be connected to chassis ground of Model 6514 via the triax cable.
- The test box must have a lid that closes to prevent contact with live circuitry.
- The test fixture must have a screw terminal that is used exclusively for connection to safety earth ground.

*WARNING* **To provide protection from shock hazards, the test fixture chassis must be properly connected to safety earth ground. A grounding wire (#18 AWG or larger) must be attached securely to the test fixture at a screw terminal designed for safety grounding. The other end of the ground wire must be attached to a known safety earth ground.**

### Guard plate

A metal guard plate will provide guarding or noise shielding for the DUT or test circuit. It will also serve as a mounting panel for DUT or test circuits. The guard plate must be insulated with 1000V spacing from the chassis of the test fixture.

## Connectors, terminals and internal wiring

Basic connector requirements include a 3-lug female triax connector, and three banana jacks. One banana jack is used to make the COMMON connection to the electrometer for guarded measurements. The other two banana jacks will accommodate connection to an external power supply. The banana jacks must be insulated from the chassis of the test fixture. The outer shell of the triax connector must be referenced to chassis ground. Therefore, DO NOT insulate the outer shell of the triax connector from the metal chassis of the test fixture.

DUT and test circuits are to be mounted on the guard plate using insulated terminals. To minimize leakage, select terminals that use virgin Teflon insulators.

Inside the test fixture, use an insulated wire to connect the inner shell of the triax connector to the guard plate. For unguarded measurements, the guard plate will serve as a noise shield. For the volts and ohms functions, turning GRD on will connect guard to the guard plate.

## Handling and cleaning test fixtures

Dust, body oil, solder flux, and other contaminants on connector and terminal insulators can significantly decrease the leakage resistance resulting in excessive leakage currents. Contaminants on DUT and test circuit components can create a leakage path. The leakage currents may be large enough to corrupt low-level measurements.

Handling tips:

- Do not touch the bodies of DUT or test circuit components. If you cannot handle them by their leads, use clean cotton gloves to install them in the test fixture.
- Do not touch any connector or terminal insulator.
- If installing a test circuit that is on a PC board, handle the board by the edges. Do not touch any board traces or components.

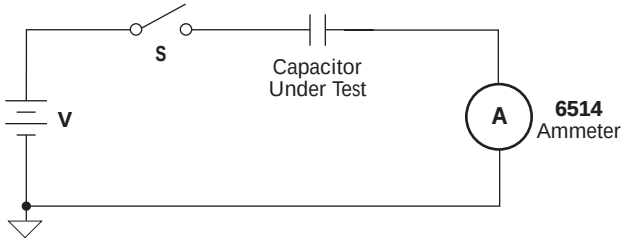
Cleaning tips:

- Use dry nitrogen gas to clean dust off connector and terminal insulators, DUT, and other test circuit components.
- If you have just built the test fixture, remove any solder flux using methanol along with clean foam-tipped swabs or a clean soft brush. Clean the areas as explained in the next tip.
- To clean contaminated areas, use methanol and clean foam-tipped swabs. After cleaning a large area, you may want to flush the area with methanol. Blow dry with dry nitrogen gas.
- After cleaning, the test fixture (and any other cleaned devices or test circuits) should be allowed to dry in a 50°C low-humidity environment for several hours.

## Input protection

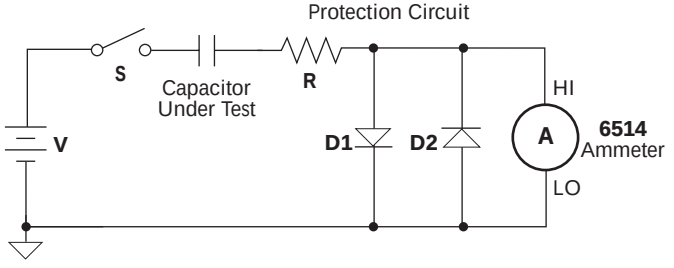
Model 6514 incorporates protection circuitry against nominal overload conditions. However, a high voltage (>250V) and resultant current surge could damage the input circuitry. A typical test circuit to measure the leakage current of a capacitor is shown in Figure 2-7. When Switch S is closed, an initial charging current will flow and the high voltage will be seen across the input of Model 6514.

*Figure 2-7*
*Capacitor test circuit without protection*




Adding a resistor and two diodes (1N3595) as shown in Figure 2-8 will provide considerable extra protection. The resistor must be large enough to limit the current through the diodes to 10mA or less, and be large enough to withstand the supply voltage. The protection circuit should be enclosed in a light-tight conductive shield.

*Figure 2-8*
*Capacitor test circuit with protection*



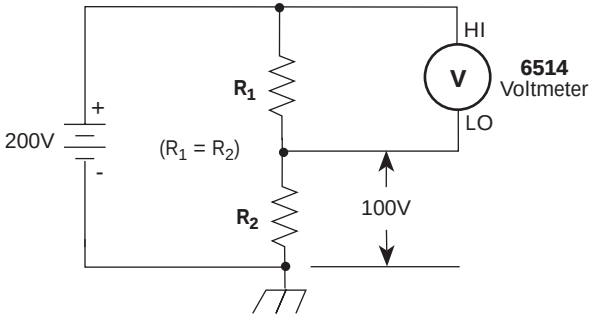

## Floating measurements

With the ground link between the COMMON and CHASSIS banana jack terminals removed, Model 6514 can perform floating measurements up to 500V above chassis ground. These measurements can result in safety concerns.

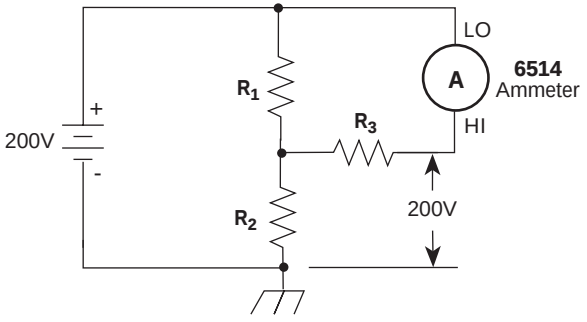
Figure 2-9 shows two examples where Model 6514 floats at a hazardous voltage level. In Figure 2-9A, a shock hazard (100V) exists between meter input LO and chassis ground. If meter input LO is connected to a noise shield, then the shock hazard will also be present on that shield.

In Figure 2-9B, a shock hazard (200V) exists between the meter input (HI and LO) and chassis ground. If meter LO is connected to a shield, then the shock hazard will also be present on that shield.

*Figure 2-9*
*Floating measurements*




**A. Voltage measurement**




**B. Current measurement**

*WARNING* **The maximum voltage (common-mode) between electrometer LO and chassis ground is 500V. Exceeding this value may create a shock hazard.**

*WARNING* **When floating input LO above 30V from earth (chassis) ground, hazardous voltage will be present at the analog outputs (PREAMP OUT and 2V ANALOG OUTPUT). Hazardous voltage may also be present when the input voltage exceeds 30V in the Volts function.**

*CAUTION* **Connecting PREAMP OUT, COMMON or 2V ANALOG OUTPUT to earth (chassis) ground while floating the input may damage the instrument.**

# Zero check and zero correct

Table 2-3 lists the display messages associated with zero check and zero correct. The two-character message is displayed along with the reading.

*Table 2-3*
*Display messages for zero check and zero correct*

| Display Message | Zero Check | Zero Correct |
|---|---|---|
| ZC | On | Off |
| ZZ | On | On |
| CZ | Off | On |

## Zero check

When zero check is enabled (on), the input amplifier is reconfigured to shunt the input signal to low as shown in Figure 2-10. With zero check enabled, it will remain enabled when a different function is selected. With zero check disabled, it will remain disabled when the volts, amps or coulombs function is selected.

*NOTE Zero check will always enable whenever the ohms function is selected.*

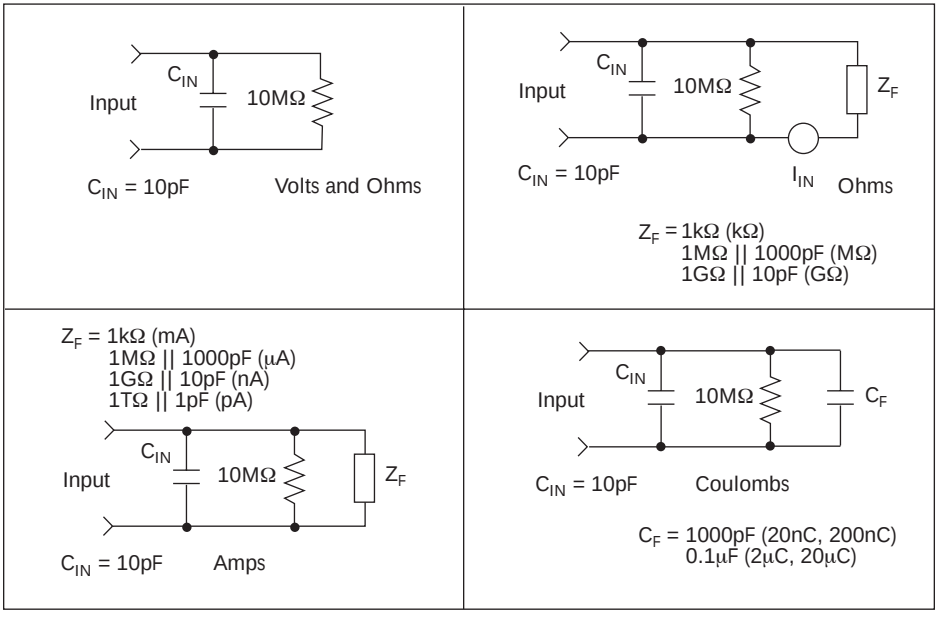
Zero check is enabled by pressing the ZCHK key. Pressing ZCHK a second time disables zero check.

*NOTE To ensure proper operation, always enable zero check before changing functions.*

For coulombs, enabling zero check dissipates the charge. That is, the charge reading is reset to zero. When zero check is disabled, a sudden change in the charge reading (zero check hop) occurs. This effect can be cancelled by enabling Relative (REL) immediately after zero check is disabled. Relative is explained in Section 7.

For volts, amps and ohms, leave zero check enabled when connecting or disconnecting input signals. For coulombs, disable zero check before connecting the input signal. If zero check is left enabled when you connect the input signal, the charge will dissipate through the 10MΩ resistor (see Figure 2-10).

*Figure 2-10 Equivalent input impedance with zero check enabled*




## Zero correct

Model 6514 has a zero correct feature to algebraically subtract the voltage offset term from the measurement. Perform the following steps to zero correct the volts or amps function:

*NOTE The ZCOR key toggles zero correct on and off. If zero correct is enabled ("ZZ" or "CZ" message displayed), press ZCOR to disable it.*

1. Select the volts (V) or amps (I) function.
2. Enable zero check ("ZC" message displayed).
3. Select the range that will be used for the measurement, or select the lowest range.
4. Press ZCOR to enable zero correct ("ZZ" message displayed).
5. Press ZCHK to disable zero check.
6. Readings can now be taken from the display. The "CZ" message indicates that the displayed reading is zero corrected.

*NOTES* *Zero check will enable whenever the ohms function is selected.*

*Model 6514 will remain zeroed even if it is upranged. If downranged, re-zero the instrument.*

*Model 6514 does not have to be re-zeroed as long as the ambient temperature remains stable.*

*Zero correction cancels the voltage offset term of the amplifier. With both zero check and zero correct enabled, the instrument may not display a perfectly zeroed reading.*

*If Model 6514 is operating at, or near $T_{CAL}$, zero correction will have very little affect. $T_{CAL}$ is the internal temperature of Model 6514 when it was last calibrated.*

## SCPI programming — zero check and zero correct

*Table 2-4*
*SCPI commands — zero check and zero correct*

| Commands | Description | Default | Ref |
|---|---|---|---|
| SYSTem | SYSTem Subsystem: | | |
| :ZCHeck <b> | Enable or disable zero check. | ON | |
| :ZCORrect | Zero correct: | | |
| [:STATe] <b> | Enable or disable zero correct. | OFF | A |
| :ACQuire | Acquire a new zero correct value. | | B |
| INITiate | Trigger a reading. | | B |

### A) SYSTem:ZCORrect[:STATe] <b>

This method to perform zero correction is consistent with the way it is performed from the front panel. That is, zero correction is performed while zero check is enabled:

```
SYST:ZCH  ON                    ' Enable zero check.
SYST:ZCOR  ON                   ' Perform zero correction.
```

A second method to perform zero correction is to first acquire the zero correct value (see Ref. B).

## B) SYSTem:ZCORrect:ACQuire

The zero correct value can only be acquired while zero check is enabled. The internal offset will become the correction value. Zero correction can then be performed with zero check disabled. This acquire method makes it convenient if you need to re-zero the selected function often.

The following command sequence uses the acquire method to zero correct the 2V range:

```
SYST:ZCH ON                    ' Enable zero check.
FUNC 'VOLT'                    ' Select Volts function.
VOLT:RANG 2                    ' Select 2V range.
INIT                           ' Trigger one reading.
SYST:ZCOR:ACQ                  ' Acquire zero correct value.
SYST:ZCH OFF                   ' Disable zero check.
SYST:ZCOR ON                   ' Perform zero correction.
```

The INITiate command in the above sequence is used to trigger a reading. This reading is the offset that is acquired as the zero correct value. See Section 9 for more information on INITiate.

*NOTE* *Sending the :ACQuire command while zero check is disabled will result in an error. The command will not be executed.*

# Input bias current and offset voltage calibration

The input bias current and offset voltage calibration procedures that follow should be performed periodically to actively cancel input bias current and offset voltage, optimizing measurement accuracy, particularly at low levels.

## Front panel

### Front panel input bias current calibration

1. Access the front panel calibration menu by pressing SHIFT then CAL.

*NOTE See Section 19 for details on other calibration menu selections.*

2. From the calibration menu, use the down RANGE key to display the following:
   CAL: IOFFSET
3. Press ENTER. The instrument will prompt for the triax shielding cap as follows:
   INPUT CAP
4. Connect a triax shielding cap to the rear panel INPUT jack. (Use a Keithley CAP-31 or equivalent.)
5. Press ENTER to complete input bias current calibration.
6. If you wish to perform front panel offset voltage calibration, proceed to Step 2 of the procedure below. Otherwise, press EXIT to return to normal display.

### Front panel offset voltage calibration

1. Access the front panel calibration menu by pressing SHIFT then CAL.
2. From the calibration menu, use the up or down RANGE key to display the following:
   CAL: VOFFSET
3. Press ENTER. The instrument will prompt for a short:
   INPUT SHORT
4. Connect a triax short to the rear panel INPUT jack. (Use the supplied Model 237-ALG-2 triax cable or equivalent with red and black alligator clips connected together.)
5. Press ENTER to complete offset voltage calibration.
6. Press EXIT to return to normal display.

## SCPI programming

Table 2-5 lists SCPI commands used for input bias current and offset voltage calibration.

*Table 2-5*
*SCPI commands — input bias current and offset voltage calibration*

| Commands | Description |
|---|---|
| :CALibration:UNPRotected:IOFFset | Input bias current calibration. |
| :CALibration:UNPRotected:VOFFset | Offset voltage calibration. |

### SCPI command input bias current calibration

1. Connect a triax shielding cap to the rear panel INPUT jack. (Use a Keithley CAP-31 or equivalent.)
2. Send the following command to perform input bias current calibration:
   :CAL:UNPR:IOFF
3. Allow the Model 6514 to complete the calibration process.

### SCPI command offset voltage calibration

1. Connect a triax short to the rear panel INPUT jack. (Use the supplied Model 237-ALG-2 triax cable or equivalent with red and black alligator clips connected together.)
2. Send the following command to perform offset voltage calibration:
   :CAL:UNPR:VOFF
3. Allow the Model 6514 to complete the calibration process.

# Measurement considerations

There are a variety of factors to consider when making low level measurements. These considerations are listed and summarized in Table 2-6. For comprehensive information on all measurement considerations, refer to the Low Level Measurements handbook, which is available from Keithley Instruments.

*Table 2-6*
*Summary of measurement considerations*

| **Considerations** | **Description** |
|---|---|
| *For V and Ω measurements:* | *See Section 3 for details* |
| Loading effects | Circuit loading caused by a high impedance voltage source. |
| Cable leakage resistance | For unguarded measurements, leakage resistance in the triax cable (between HI and LO) shunts the voltage to be measured. |
| Input capacitance (settling time) | At very high resistance levels, effects of cable capacitance can slow down measurement response time. |
| Guarding input cable | Eliminates the effects of leakage resistance for high impedance measurements and input capacitance when using a long input cable. |
| *For I measurements:* | *See Section 4 for details* |
| Input bias current | Offset current of Model 6514 could affect low current measurements. |
| Voltage burden | Offset voltage of Model 6514 could cause errors if it is high in relation to the voltage of the measured circuit. |
| Noise | Noise generated by source resistance and source capacitance. |
| *For Q measurements:* | *See Section 5 for details* |
| Input bias current | Offset current of Model 6514 is integrated along with the input signal, affecting the final reading. |
| External voltage source | Input current to Model 6514 should be limited to <1mA. |
| Zero check hop | Sudden change in the charge reading when zero check is turned off. |
| Auto-discharge hop | Sudden change in the charge reading when auto-discharge resets the charge reading to zero. |

*Table 2-6 (cont.)*
*Summary of measurement considerations*

| **Considerations** | **Description** |
|---|---|
| *For all measurements:* | *See Appendix C for details* |
| Ground loops | Multiple ground points can create error signals. |
| Triboelectric effects | Charge currents generated in a cable by friction between a conductor and the surrounding insulator (i.e. bending a triax cable). |
| Piezoelectric and stored charge effects | Currents generated by mechanical stress on certain insulating materials. |
| Electrochemical effects | Currents generated by the formation of chemical batteries on a circuit board caused by ionic contamination. |
| Humidity | Reduces insulation resistance on PC boards and test connection insulators. |
| Light | Light sensitive components must be tested in a light-free environment. |
| Electrostatic interference | Charge induced by bringing a charged object near your test circuit. |
| Magnetic fields | The presence of magnetic fields can generate EMF (voltage). |
| Electromagnetic interference (EMI) | EMI from external sources (i.e. radio and TV transmitters) can affect sensitive measurements. |

# 3
# Volts and Ohms Measurements

- **Measurement overview** — Summarizes the volts and ohms measurement capabilities of Model 6514.
- **Guarding** — Explains guarding and the benefits derived from it for high-impedance volts and ohms measurements.
- **Volts and ohms measurement procedure** — Provides the procedure to measure volts and ohms.
- **SCPI programming** — Covers the basic SCPI command used for the volts and ohms functions.
- **Volts and ohms measurement considerations** — Covers measurement considerations that apply to volts and ohms measurements.
- **Application** — Shows how to measure dielectric absorption of a capacitor.

# Measurement overview

**Volts measurements** — Model 6514 can make volts measurements from 10µV to 210V using three measurement ranges; 2V, 20V, and 200V.

**Ohms measurements** — Model 6514 makes ohms measurements by sourcing a test current and measuring the voltage drop across the DUT. The resistance reading is then calculated (R = V/1) and displayed. The electrometer can make ohms measurements from 10mΩ to 210GΩ using nine measurement ranges; 2kΩ, 20kΩ, 200kΩ, 2MΩ, 20MΩ, 200MΩ, 2GΩ, 20GΩ,and 200GΩ.

*NOTE Accuracy specifications for all measurement functions are provided in Appendix A.*

# Guarding

The purpose of guarding is to eliminate the effects of leakage resistance and capacitance, that can exist between input HI and input LO. This leakage resistance and capacitance could adversely affect high-impedance measurements.

## Test circuit leakage

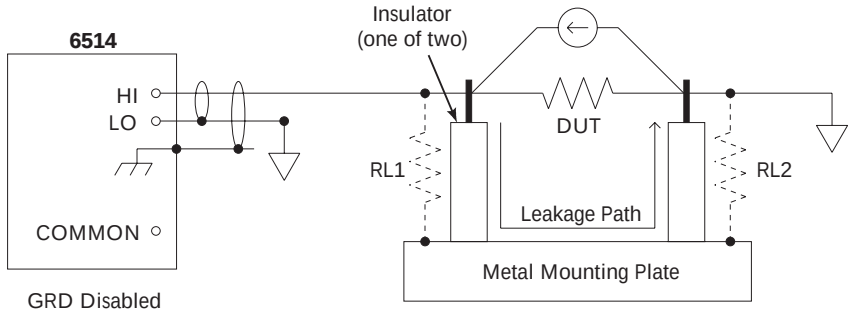
In a test circuit, leakage current can occur through the insulators of the terminals for the DUT (device under test). In Figure 3-1, the test circuit consists of a current source in series with the DUT. The objective is to make an accurate voltage measurement of the DUT.

In Figure 3-1A, a resistance leakage path through the insulators (RL1 and RL2) shunts current around the DUT. If this leakage current is high in comparison to the DUT current, significant measurement error will occur. To keep error <0.1%, the leakage resistance must be 1000 times greater than the resistance of the DUT. For example, if the nominal resistance of the DUT is 100MΩ, leakage resistance must be >100GΩ.

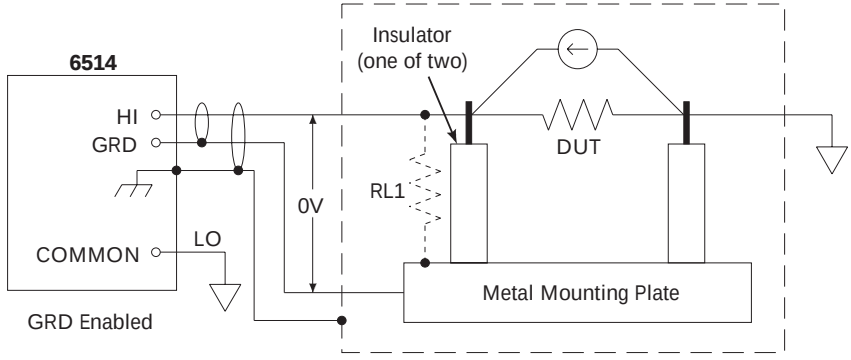
Figure 3-1B shows how to use guarding to eliminate the effects of leakage resistance. With GRD enabled, the driven guard, which is at the same potential as input HI, is connected to the metal mounting plate (now known as the guard plate). With both ends of RL1 at the same potential, current will not flow through the insulator. With no current leakage path, all current flows through the DUT allowing an accurate voltage measurement.

The above explanation also pertains to ohms measurements. The only difference is that the test current is provided by Model 6514.

*Figure 3-1*
*High-impedance voltage measurements*




**A. Unguarded**




**B. Guarded**

## Input cable leakage and capacitance

In a similar manner to leakage in the test circuit, leakage in the input cable could also corrupt high-impedance measurements. In the unguarded mode, leakage in a triax cable occurs between the center conductor (HI) and the inner shield (LO).

Inherently, an input cable has capacitance that is formed by the center conductor (HI), inner shield (LO) and the insulator between them. For high-impedance measurements, the RC time constant can significantly slow down measurement response.

To minimize the effects of cable leakage, and input capacitance, keep the input cable as short as possible and use guard. With guard enabled, the same potential is applied to both the center conductor and inner shield of the cable. This eliminates leakage current and capacitor charging/discharging.

*NOTE* *Detailed information on "Cable Leakage Resistance", "Input Capacitance (Settling Time)" and "Guarding Input Cables" is provided in "Volts and Ohms Measurement Considerations" (located in this section).*

# Volts and ohms measurement procedure

*CAUTION* **The maximum input voltage to Model 6514 is 250V peak. Exceeding this value may cause damage to the instrument that is not covered by the warranty.**

*WARNING* **The maximum common-mode input voltage, which is the voltage between the input (HI or LO) and chassis ground, is 500V peak. Exceeding this value may create a shock hazard.**

## Step 1 Enable zero check and select the volts (V) or ohms (Ω) function

Zero check should always be enabled before making function or connection changes. The ZCHK key toggles zero check on and off. When on, the "ZC" or "ZZ" message is displayed. See Section 2 for details on zero check.

The volts function is selected by pressing the V key, and the ohms function is selected by pressing the Ω key.

*NOTE* *Zero check will enable whenever the ohms function is selected.*

## Step 2 Enable or disable guard

The GRD key toggles the driven guard on and off. If performing unguarded measurements, press GRD until the "GUARD OFF" message is displayed. If performing guarded measurements, press GRD until the "GUARD ON" message is displayed.

*WARNING* **Hazardous voltage may be present on the inner shield of the triax cable when GRD is on. A metal safety shield connected to safety earth ground (as shown in Figure 3-5) must be used for voltage measurements at or above 30V.**

## Step 3 Perform zero correction (volts only)

To achieve optimum accuracy for low voltage measurements, it is recommended that you zero correct the electrometer. To do so, select the 2V range (which is the lowest range) and press the ZCOR key until the "ZZ" message is displayed. See Section 2 for details on zero correction.

## Step 4 Select a manual measurement range or enable auto range

Use the RANGE ▲ and ▼ keys to select a manual measurement range, or press AUTO to enable auto range. With auto range enabled, the instrument will automatically go to the most sensitive range to make the measurement. See Section 6 for details on range.

## Step 5 Connect the DUT to the electrometer

*NOTE* *Fundamental information on making connections to the electrometer input is provided in Section 2 ("Connection Fundamentals").*

*WARNING* **A metal safety shield is required whenever a hazardous voltage (>30V) is present on a noise shield or guard shield. As shown in Figures 3-2 and 3-3, the safety shield must be connected to safety earth ground using #18 AWG wire or larger.**

**Unguarded connections** — Connections for unguarded volts and ohms measurements are shown in Figure 3-2, where the DUT is the voltage or resistance to be measured. If a hazardous voltage (>30V) is present on the noise shield, or the test circuit is floating above earth ground at a hazardous voltage level, a safety shield must be used as shown.

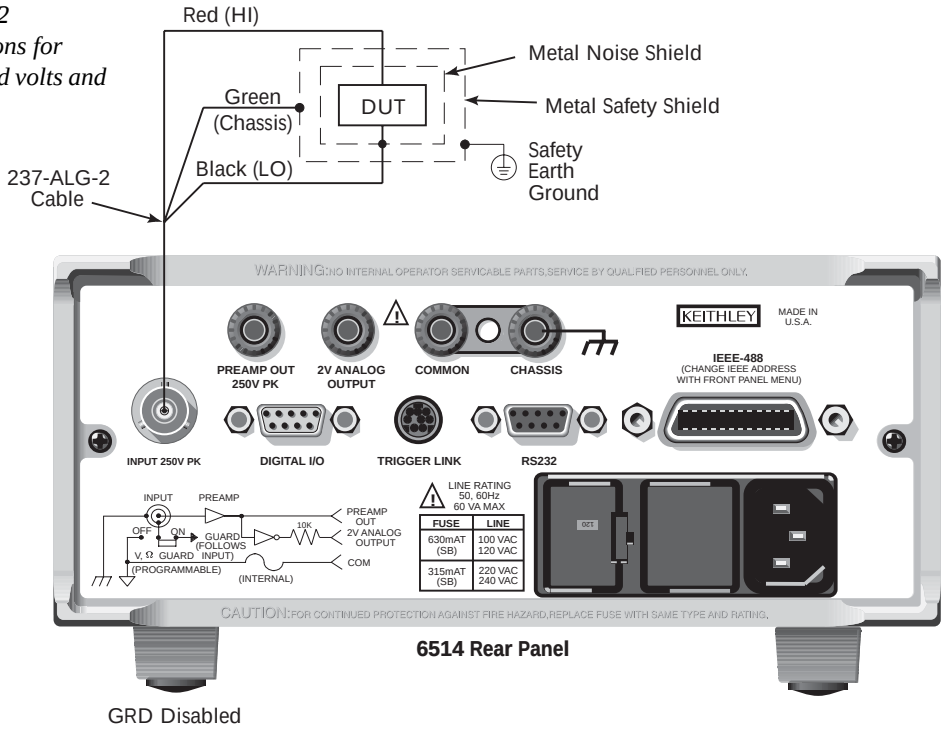
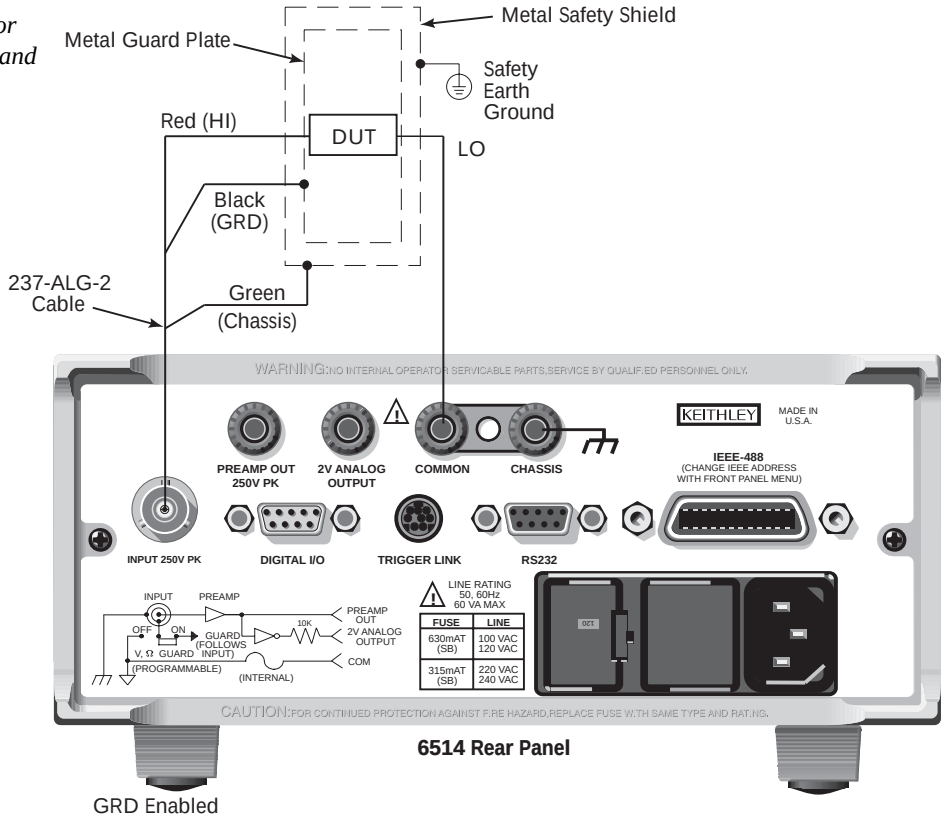



*Figure 3-2*
*Connections for unguarded volts and ohms*

**Guarded connections** — Connections for guarded volts and ohms measurements are shown in Figure 3-3. The driven guard (GRD) must be enabled for these measurements.

*WARNING* **With an open input, up to 250V peak may be present on the guard terminals while in Volts or Ohms. To prevent this, make sure zero check is enabled whenever the input is open.**

*Figure 3-3*
*Connections for guarded volts and ohms*




### Step 6 Disable zero check and take a reading from the display

## V-Drop and I-Source for ohms

Model 6514 performs ohms measurement by sourcing a known test current through the DUT and then measuring the voltage drop across it. The resistance reading is then calculated (R = V/I) and displayed.

While the electrometer is measuring ohms, the test current through the DUT and the voltage drop across it can be displayed as follows:

**V-Drop** — While displaying an ohms reading, press SHIFT and then Ω to display the voltage drop across the DUT. The "VΩ" message will indicate that a V-Drop reading is being displayed. To return to the normal ohms reading, again press SHIFT and then Ω.

**Test current** — While displaying an ohms or V-Drop reading, press the Ω key. The test current (ISRC) will be displayed for as long as you hold the key down.

*WARNING* **The ohms function has a 250V compliance. To prevent electric shock, always enable zero check to disable the test signal before making or breaking connections to DUT.**

# SCPI programming

*Table 3-1*
*SCPI commands — volts and ohms function*

| Commands | Description | Default | Ref |
|---|---|---|---|
| [SENSe] | SENSe Subystem: | | |
| :FUNCtion <name> | Select function; 'VOLTage' or 'RESistance'. | VOLT | A |
| :DATA? | Return latest "raw" reading. | | B |
| :VOLTage | | | |
| :GUARd <b> | Enable or disable guard. | OFF | C |
| :RESistance | | | |
| :GUARd <b> | Enable or disable guard. | OFF | C |
| | | | |
| INITiate | Trigger one or more readings. | | B |
| READ? | Trigger and return reading(s). | | B |

## A) SENSe:FUNCtion <name>

**Parameters**

| | |
|---|---|
| 'VOLTage' | Volts function |
| 'RESistance' | Ohms function |
| 'CURRent' | Amps function |
| 'CHARge' | Coulombs function |

Note that the parameter names are enclosed in single quotes ('). However, double quotes (") can instead be used. Each measurement function "remembers" its own unique range setting.

### B) SENSe:DATA?

This command does not trigger a reading. It simply returns the last "raw" reading string. It will not return the result of any instrument calculation. The reading reflects what is applied to the input.

To return a fresh (new) reading, you can send the INITiate command to trigger one or more readings before sending :DATA?. Details on INITiate are provided in Section 9.

While Model 6514 is busy performing measurements, the :DATA? command will not return the reading string until the instrument finishes and goes into the idle state.

*NOTES* *The format that the reading string is returned in is set by commands in the FORMat Subsystem (see Section 16).*

*If there is no reading available when :DATA? is sent, an error (-230) will occur.*

*The READ? command can be used to return "fresh" readings. This command triggers and returns the readings. See Section 15 for details.*

### C) :GUARd Commands

Either of the two guard commands (VOLTage:GUARd or RESistance:GUARd) can be used to control the state of guard.

## Programming example

The following command sequence will perform one zero corrected voltage measurement on the 2V range:

```
*RST                  ' Return to RST defaults.
SYST:ZCH ON           ' Enable zero check.
VOLT:GUAR ON          ' Enable guard.
FUNC 'VOLT'           ' Select Volts function.
VOLT:RANG 2           ' Select 2V range.
SYST:ZCOR ON          ' Perform zero correction.
SYST:ZCH OFF          ' Disable zero check.
READ?                 ' Trigger and return one reading.
```

# Volts and ohms measurement considerations

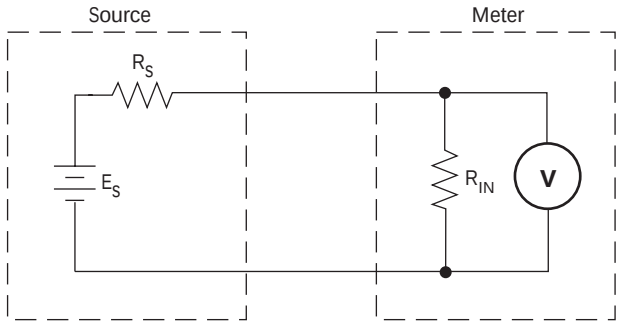
*NOTE* *Since Model 6514 uses the source I measure V (calculate R) technique to measure resistance, measurement considerations that apply to the volts function also apply to the ohms function.*

Some considerations for making accurate volts and ohms measurements are summarized as follows. Additional measurement considerations are covered in Appendix C. For comprehensive information on precision measurements, refer to the Low Level Measurements handbook, which is available from Keithley Instruments.

## Loading effects

Circuit loading can be detrimental to high-impedance voltage measurements. To see how meter loading can affect accuracy, refer to Figure 3-4. $R_S$ represents the resistance component of the source, while $R_{IN}$ represents the input resistance of the meter. The percent error due to loading can be calculated using the formula in the illustration. To keep the error under 0.1%, the input resistance ($R_{IN}$) must be about 1000 times the value of the source resistance ($R_S$). The input resistance of Model 6514 is >200TΩ. Therefore, to keep the error under 0.1%, the source resistance of the measured voltage must be <200GΩ.

*Figure 3-4*
*Meter loading*




## Cable leakage resistance

In an unguarded voltage measurement, leakage current occurs in the input triax cable between the center conductor (HI) and the inner shield (LO). This leakage resistance shunts the voltage source to be measured. If the resistance of the source is not significantly less than the leakage resistance of the cable, measurement errors will occur.

The effects of leakage resistance can be eliminated by using guard to make high impedance voltage measurements. See “Guarding Input Cable” for more information. In general, guarding should be used when DUT resistance is $10^9\Omega$ or greater.

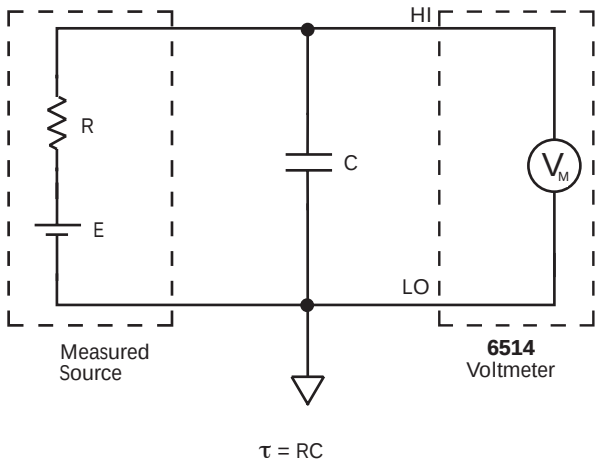
## Input capacitance (settling time)

The settling time of the circuit is particularly important when making volts measurements of a source that has high internal resistance (Figure 3-5A), or when making high-resistance ohms measurements (Figure 3-5B).

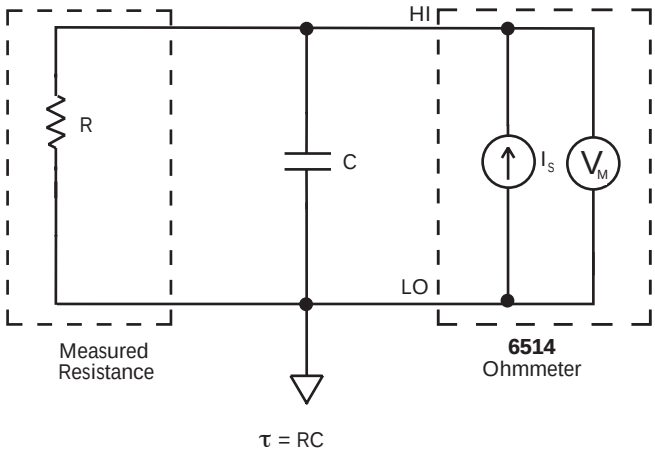
In both cases, the shunt capacitance (C) has to fully charge before an accurate voltage measurement can be made by $V_M$ of Model 6514. The time period for charging the capacitor is determined by the RC time constant (one time constant, $\tau$ = RC), and the familiar exponential curve of Figure 3-6 results. Therefore, it becomes necessary to wait four or five time constants to achieve an accurate reading. For example, if R = 100G( and the input cable has a nominal capacitance of 10pF, the RC time constant would be 1 second. If 1% accuracy is required, a single measurement would require at least five seconds.

There are two basic ways to minimize this problem: (1) keep capacitance in the system to an absolute minimum by keeping connecting cables as short as possible, and (2) use guarding. There is, however, a limit to how short the cable can be. Using guard can reduce these effects by up to a factor of 1000 (see “Guarding Input Cable”).

*Figure 3-5*
*Effects of input capacitance*

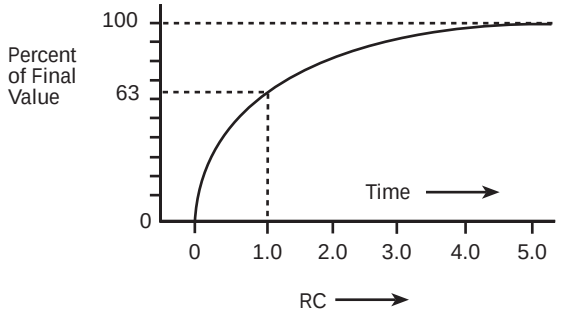



**A. High-Impedance Volts Measurement (Unguarded)**




**B. High-Impedance Ohms Measurement (Unguarded)**

*Figure 3-6*
*Settling time*

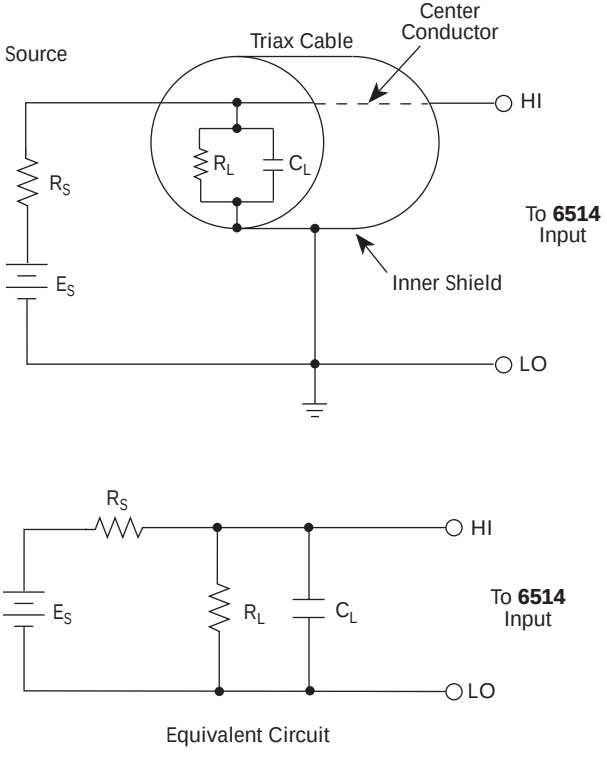



## Guarding input cable

Guarding should be used for high-impedance measurements and for low voltage measurements that use long input cables.

To better understand the concept of guarding, review the unguarded circuit shown in Figure 3-7. $E_S$ and $R_S$ represents the resistance and voltage components of the source, and $R_L$ and $C_L$ represents the leakage resistance and cable capacitance of the triax input cable. The equivalent circuit shows the divider that is formed. If $R_S$ is large enough, the divider will significantly attenuate the voltage seen at the input of Model 6514 (see "Cable Leakage Resistance"). Also, $R_S$ and the cable capacitance ($C_L$) could create a long RC time constant resulting in a slow measurement response (see "Input Capacitance").

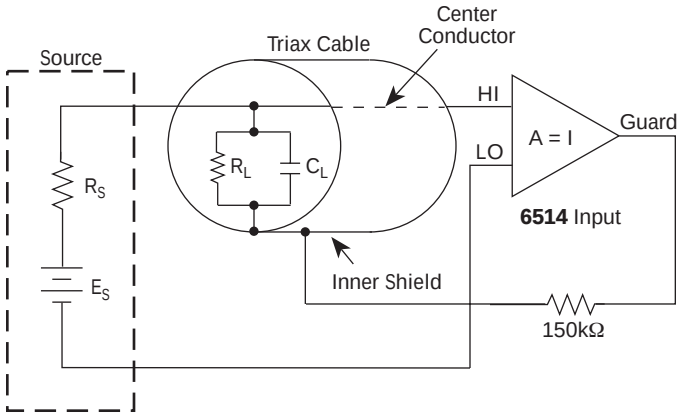
*Figure 3-7*
*Unguarded input cable*



Guarding the circuit minimizes these effects by driving the inner shield of the triax cable at signal potential, as shown in Figure 3-8. Here, a unity gain amplifier with a high input impedance and low output impedance is used. Since the center conductor (HI) and the inner shield (Guard) of the cable are at virtually the same potential, the potential across $R_L$ is zero, so no current flows. Also, with a zero potential across $C_L$, there is no capacitor charging process to slow down the measurement response.

For the volts and ohms functions, the input of Model 6514 places the driven guard on the inner shield of the triax cable when GRD is enabled.

*Figure 3-8*
*Guarded input cable*



# Application

## Capacitor dielectric absorption

Dielectric absorption occurs when randomly oriented permanent dipoles of molecules with a capacitor dielectric are aligned by an applied electric field. After a capacitor has been disconnected from a discharge circuit, a residual charge remains on the capacitor, and a voltage will be re-established across the capacitor terminals.

For timing and integrating applications, dielectric absorption (or a residual capacitor voltage) can seriously degrade the accuracy of the circuit. Thus, a capacitor's dielectric absorption must be known and compensated for in circuits where capacitance tolerance is a significant factor in circuit accuracy.

Dielectric absorption is not normally specified by a manufacturer since its importance is application dependent. The parameter can be defined as the capacitor's discharge current at a designated time following the initiation of a discharge cycle. The capacitor is typically charged up to the maximum voltage that will be applied. The measurement of the discharge current is usually made at a discharge time interval that will be used in the application of the device, or no longer than one minute. Acceptable capacitors have current levels below a required maximum limit.

Dielectric absorption can also be expressed as a percentage of residual voltage with respect to a charging voltage. This ratio is determined by charging the capacitor to the rated voltage. The capacitor is then discharged for a second time interval. Finally, the capacitor is open-circuited, and the residual voltage across the capacitor is measured after a third time constant.

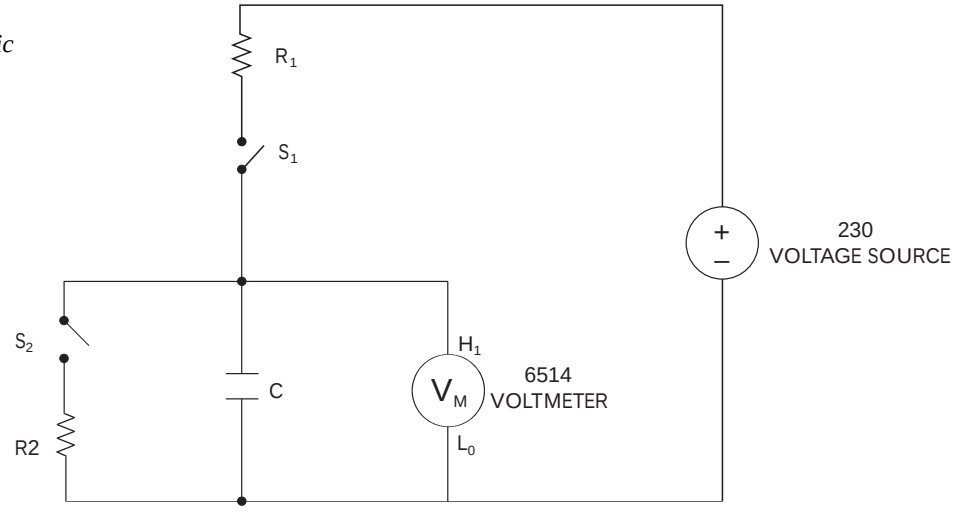
The Model 6514 is particularly useful in measuring dielectric absorption because it draws virtually no charge from the capacitor during the measurement, nor does it induce charge on the capacitor being measured.

The test circuit in Figure 3-9A uses Keithley Model 230 as a voltage source and Model 6514 to perform the voltage measurements. Figure 3-9B shows the voltage waveform across the capacitor during the three phases of the test.

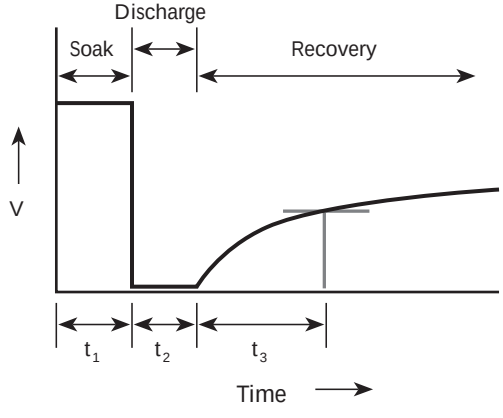
Initially, capacitor C is charged through $R_1$ for the required soak time ($t_1$ in Figure 3-9B). Soak time is typically one or two minutes, depending on the capacitor value. Next, the voltage source is turned off, and the capacitor is discharged through $R_2$ ($t_2$). The capacitor is allowed to sit for a few minutes with $S_2$ and $S_1$ open ($t_3$), and the residual voltage is then measured by Model 6514. Dielectric absorption is then calculated as follows:

% Dielectric Absorption = (Residual Voltage / Soak Voltage) × 100%

*Figure 3-9*
*Measuring dielectric absorption*




**A. Connections**




**B. Voltage Waveform**

# 4
# Amps Measurements

- **Measurement overview** — Summarizes the current measurement capabilities of Model 6514.
- **Amps measurement procedure** — Provides the procedure to measure amps.
- **High-Impedance measurement techniques** — Explains non-driven guarding techniques to eliminate leakage currents in high-impedance test circuits.
- **SCPI programming** — Covers the basic SCPI commands used for the amps function.
- **Amps measurement considerations** — Covers measurement considerations that apply to amps measurements.
- **Applications** — Covers applications to measure diode leakage current, capacitor leakage current, cable insulation resistance, and surface insulation resistance.

# Measurement overview

**Amps measurements** — Model 6514 can make amps measurements from 100aA to 21mA using 10 measurement ranges; 20pA, 200pA, 2nA, 20nA, 200nA, 2µA, 20µA, 200µA, 2mA, and 20mA.

**External feedback** — The external feedback mode of Model 6514 can be used to measure logarithmic currents, and re-configure the input to use non-decade current ranges. Measurements using the external feedback mode are covered in Section 11.

*NOTE* *Accuracy specifications for all measurement functions are provided in Appendix A.*

# Amps measurement procedure

*CAUTION* **The maximum input voltage and current to Model 6514 is 250V peak and 21mA. Exceeding either of these values may cause damage to the instrument that is not covered by the warranty.**

*WARNING* **The maximum common-mode input voltage, which is the voltage between the input (HI or LO) and chassis ground, is 500V peak. Exceeding this value may create a shock hazard.**

To achieve optimum precision for low-level current measurements, input bias current and voltage burden can be minimized by performing the offset correction procedures in Section 19. Information about these offsets are provided in "Current Measurement Considerations" (located in this section).

*NOTE* *After measuring high voltage or high ohms, it may take several minutes for the input current to drop to within specified limits. Input current can be verified by placing the protection cap on the input triax connector, and then installing the ground link between COMMON and CHASSIS ground. With the instrument on the 20pA range and zero check disabled, allow the reading to settle until the input bias current is within specifications. The specifications for input bias current are listed in Appendix A.*

Perform the following steps to measure current:

## Step 1 Enable zero check and select the amps (I) function

Zero check should always be enabled before making function or connection changes. The ZCHK key toggles zero check on and off. When on, the "ZC" or "ZZ" message is displayed. See Section 2 for details on zero check.

The amps function is selected by pressing the I key.

### Step 2 Perform zero correction

To achieve optimum accuracy for low current measurements, it is recommended that you zero correct the electrometer. To do so, select the 20pA range (which is the lowest range) and press the ZCOR key until the "ZZ" message is displayed. See Section 2 for details on zero correction.

### Step 3 Select a manual measurement range or enable auto range

Use the RANGE ▲ and ▼ keys to select a manual measurement range, or press AUTO to enable auto range. With auto range enabled, the instrument will automatically go to the most sensitive range to make the measurement. See Section 6 for details on range.

### Step 4 Connect the current to be measured to the electrometer

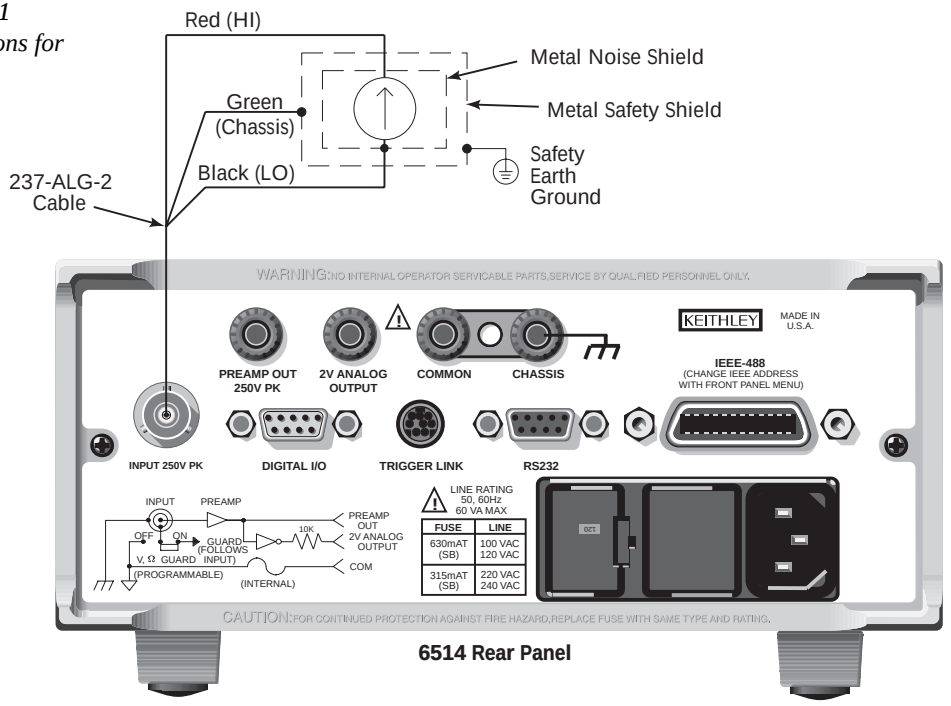
Basic connections for amps measurements are shown in Figure 4-1.

*NOTE* *Fundamental information on making connections to the electrometer input is provided in Section 2 ("Connection Fundamentals").*

*WARNING* **A safety shield is required whenever a hazardous voltage (>30V) is present on the noise shield. This can occur when the test circuit is floated above earth ground at a hazardous voltage level (see "Floating Measurements" in Section 2). Connections for the safety shield are shown in Figure 4-1. The metal safety shield must completely surround the noise shield or foating test circuit, and it must be connected to safety earth ground using #18 AWG or larger wire.**

*NOTE* *High-impedance current measurements require special measurement techniques. These connection techniques are covered in "High-Impedance Measurement Techniques" (located in this section).*

*Figure 4-1*
*Connections for amps*




**6514 Rear Panel**

### Step 5 Disable zero check and take a reading from the display

If the readings are noisy, you may want to use damping and/or filtering to reduce noise. Use filtering if the noise is caused by a noisy input signal and use damping if noise is caused by input capacitance. Filtering is covered in Section 6, and damping is discussed next.

## Damping

High capacitance seen at the input will increase reading noise. This capacitance can be attributed to a long input cable or to the capacitance of the source, or a combination of both. Enabling damping will reduce this type of noise for current measurements. However, damping will also slow down the response of the measurement.

Perform the following steps to enable or disable damping:

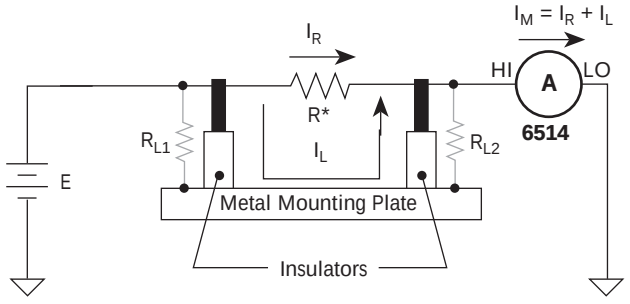
1. Press DAMP to display the present state of damping.
2. Use the ▲ or ▼ key to display ON or OFF.
3. Press ENTER.

# High impedance measurement techniques

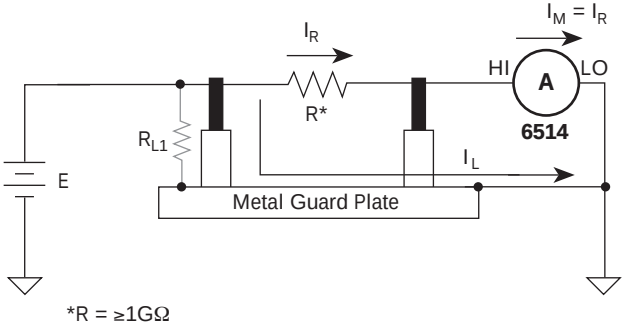
Significant leakage could occur across a high impedance (≥1GΩ) DUT through the insulators as shown in Figure 4-3A where $R_{L1}$ and $R_{L2}$ represent the leakage resistance. Instead of measuring just the current ($I_R$) through R, you are also measuring the leakage current ($I_L$). The current measured by the ammeter is $I_R + I_L$.

By connecting ammeter input LO to the metal mounting (guard) plate as shown in Figure 4-2B, the leakage current ($I_L$) is shunted to ammeter input LO and is not measured by the ammeter. Therefore, the ammeter only measures $I_R$.

*Figure 4-2*
*High impedance current measurements*




**A. Unguarded**




**B. Guarded**

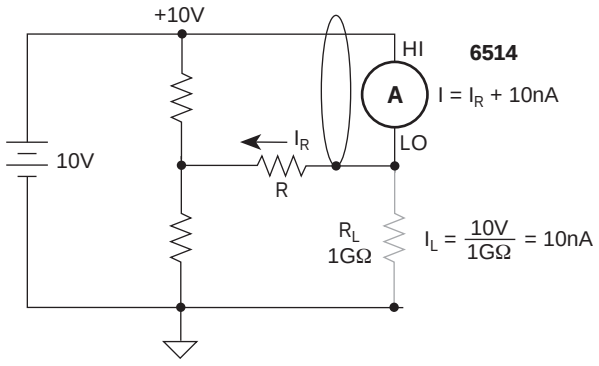
**Floating current measurements** — As discussed in Section 3 for volts measurements, guarding uses a conductor at essentially the same potential as input HI to drastically reduce leakage currents in high-impedance test circuits. No current can flow when there is a 0V drop across a leakage resistance.

For floating current measurements, ammeter input LO can be used as the guard since it totally surrounds input HI (via the input triax cable), and is at nearly the same potential as input HI. The actual voltage drop, known as voltage burden, depends on which measurement range is being used. The voltage burden values are listed in the specifications (Appendix A).

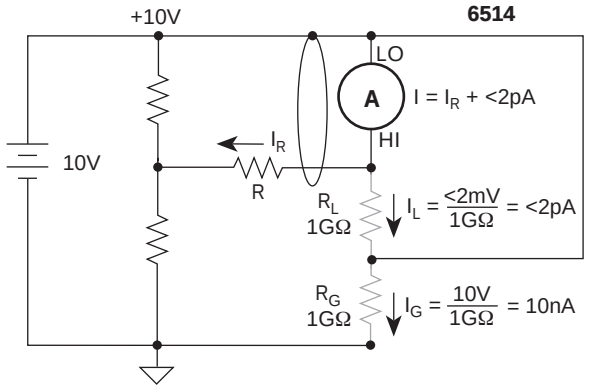
Figure 4-3A shows an unguarded floating current measurement in a high impedance circuit. The goal is to measure the current ($I_R$) through resistor R. However, a leakage path ($R_L$) exists from ammeter input LO to test circuit common. Since the ammeter drops essentially 0V, approximately 10V is dropped by $R_L$. The current through $R_L$ will be approximately 10nA (10V/1GΩ = 10nA). Therefore, the current that is measured by Model 6514 is the sum of the two currents ($I = I_R$ +10nA). Obviously, if $I_R$ is a low level current, then the 10nA leakage will corrupt the measurement.

Figure 4-3B shows the guarded version of the same circuit. Notice that the only difference is that the connections to the electrometer are reversed. Resistor $R_L$ now represents the leakage from ammeter input HI to ammeter input LO, and resistor $R_G$ represents the leakage from ammeter input LO (guard) to test circuit common. As previously mentioned, the ammeter drops almost 0V. If the actual voltage drop across the ammeter is <2mV, it then follows that there is a <2mV drop across $R_L$. Therefore, the current through $R_L$ is <2pA (<2mV/1GΩ = <2pA). The current that is being measured by Model 6514 is the sum of the two currents ($I = I_R$ + <2pA). The use of guarding reduced the leakage current from 10nA to <2pA. Note that the 10nA leakage current ($I_G$) from ammeter input LO to test circuit common still exists, but it is of no consequence since it is not measured by Model 6514.

*Figure 4-3*
*Floating current measurements*




**A. Unguarded**




**B. Guarded**

# SCPI programming

*Table 4-1*
*SCPI commands — amps function*

| Commands | Description | Default | Ref |
|---|---|---|---|
| [SENSe] | SENSe Subystem: | | |
| :FUNCtion 'CURrent' | Select Amps function. | VOLT | A |
| :DATA? | Return latest "raw" reading. | | B |
| :CURRent | | | |
| :DAMPing <b> | Enable or disable damping. | OFF | |
| INITiate | Trigger one or more readings. | | B |
| READ? | Trigger and return reading(s). | | B |

## A) SENSe:FUNCtion <name>

**Parameters**

| | |
|---|---|
| 'CURRent' | Amps function |
| 'VOLTage' | Volts function |
| 'RESistance' | Ohms function |
| 'CHARge' | Coulombs function |

Note that the parameter names are enclosed in single quotes ('). However, double quotes (") can instead be used. Each measurement function "remembers" its own unique range setting.

## B) SENSe:DATA?

This command does not trigger a reading. It simply returns the last "raw" reading string. It will not return the result of any instrument calculation. The reading reflects what is applied to the input.

To return a fresh (new) reading, you can send the INITiate command to trigger one or more readings before sending :DATA?. Details on INITiate are provided in Section 9.

While Model 6514 is busy performing measurements, the :DATA? command will not return the reading string until the instrument finishes and goes into the idle state.

*NOTES* *The format that the reading string is returned in is set by commands in the FORMat Subsystem (see Section 16).*

*If there is no reading available when :DATA? is sent, an error (-230) will occur.*

*The READ? command can be used to return "fresh" readings. This command triggers and returns the readings. See Section 15 for details.*

### Programming example

The following command sequence will perform one zero corrected amps measurement:

```
*RST                    ' Return 6514 to RST defaults.
SYST:ZCH ON             ' Enable zero check.
FUNC 'CURR'             ' Select the Amps function.
CURR:RANG 20e-12        ' Select the 20pA range.
SYST:ZCOR ON            ' Perform zero correction.
CURR:RANG:AUTO ON       ' Enable auto range.
SYST:ZCH OFF            ' Disable zero check.
READ?                   ' Trigger and return one reading.
```

## Amps measurement considerations

Some considerations for making accurate amps measurements are summarized as follows. Additional measurement considerations are covered in Appendix C. For comprehensive information on precision measurements, refer to the Low Level Measurements handbook, which is available from Keithley Instruments.

### Input bias current

An ideal ammeter would read 0A with an open input. In practice, however, ammeters do have some current that flows when the input is open. This current is known as the input bias (offset) current and may be large enough to corrupt low current measurements.

The input bias current for Model 6514 is listed in the specifications. Input bias current may be reduced by performing the current offset correction procedure explained in Section 19.

### Voltage burden

The input resistance of the ammeter causes a small voltage drop across the input terminals. This voltage is known as the voltage burden. If the voltage burden is large in relation to the voltage of the measured circuit, then significant measurement errors will occur.

Refer to Figure 4-4 to see how voltage burden affects current measurements. Assume $V_S$ is 5mV and $R_S$ is 5kΩ to configure a 1uA current source (5mV/5kΩ = 1μA). An ideal ammeter with zero voltage burden would measure the current source as follows:

$$I_M = \frac{E_S}{R_S} = \frac{5mV}{5k\Omega} = 1\mu A$$

In practice however, every ammeter has a voltage burden. If the voltage burden ($V_B$) is 1mV, the current will be measured as follows:

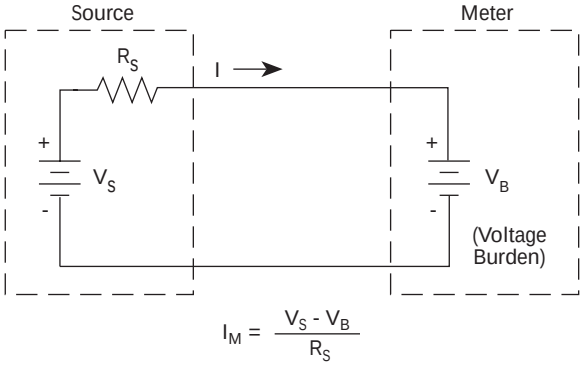
$$I_M = \frac{V_S - V_B}{R_S} = \frac{5mV - 1mV}{5k\Omega} = 0.8\mu A$$

The 1mV voltage burden caused a 20% measurement error. Percent error in a measured reading ($I_M$) due to voltage burden can be calculated as follows:

$$I_M\%error = \frac{100\%}{(V_S/V_B)}$$

The voltage burden of Model 6514 depends on the selected range (see specifications). Voltage burden may be reduced by performing the offset correction procedure in Section 19.

*Figure 4-4*
*Voltage burden considerations*




## Noise

Noise can seriously affect sensitive current measurements. The following paragraphs discuss how source resistance and input capacitance affect noise performance.

### Source resistance

The source resistance of the DUT will affect the noise performance of current measurements. As the source resistance is reduced, the noise gain of the ammeter will increase, as we will now discuss.

Figure 4-5 shows a simplified model of the feedback ammeter. $R_S$ and $C_S$ represents the source resistance and source capacitance, $V_S$ is the source voltage, and $V_{NOISE}$ is the noise voltage. Finally, $R_F$ and $C_F$ are the feedback resistance and capacitance respectively.

The source noise gain of the circuit can be given by the following equation:

$$\text{Output } V_{NOISE} = \text{Input } V_{NOISE}(1 + R_F/R_S)$$

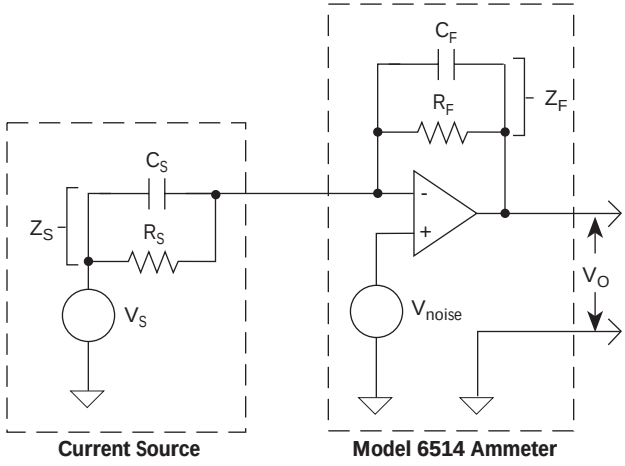
Note that as $R_S$ decreases in value, the output noise increases. For example, when $R_F = R_S$, the input noise is multiplied by a factor of two. Since decreasing the source resistance can have a detrimental effect on noise performance, there are usually minimum recommended source resistance values based on measurement range. Table 4-2 summarizes minimum recommended

source resistance values for various measurement ranges. Note that the recommended source resistance varies by measurement range because the $R_F$ value also depends on the measurement range.

*Table 4-2*
*Minimum recommended source resistance values*

| Range | Minimum Recommended Source Resistance |
|---|---|
| pA | 1GΩ to 100GΩ |
| nA | 1MΩ to 100MΩ |
| µA | 1kΩ to 100kΩ |
| mA | 1Ω to 100Ω |

*Figure 4-5*
*Source resistance and capacitance*



## Source capacitance

DUT source capacitance will also affect the noise performance of the Model 6514 ammeter. In general, as source capacitance increases, the noise also increases. To see how changes in source capacitance can affect noise gain, again refer to the simplified ammeter model in Figure 4-5. The elements of interest for this discussion are the capacitance, $C_S$ and the feedback capacitance $C_F$. Taking into account the capacitive reactance of these two elements, the previous noise gain formula must be modified as follows:

$$\text{Output } V_{NOISE} = \text{Input } V_{NOISE}(1 + Z_F/Z_S)$$

Here, $Z_F$ represents the feedback impedance made up of $C_F$ and $R_F$, while $Z_S$ is the source impedance formed by $R_S$ and $C_S$. Furthermore,

$$Z_F = \frac{R_F}{\sqrt{[(2\pi f R_F C_F)^2 + 1]}}$$

and,

$$Z_S = \frac{R_S}{\sqrt{[(2\pi f R_S C_S)^2 + 1]}}$$

Note that as $C_S$ increases in value, $Z_S$ decreases in value, thereby increasing the noise gain. Again, at the point where $Z_S = Z_F$, the input noise is amplified by a factor of two.

The maximum value of source capacitance ($C_S$) for Model 6514 ammeter is 10,000pF. You can, however, usually measure at higher source capacitance values by inserting a resistor in series with the ammeter input, but remember that any series resistance will increase the voltage burden by a factor of $I_{IN}$ $R_{SERIES}$. For example, the range of resistance listed in Table 4-2 will result in voltage burden values in range of 1mV to 1V. A useful alternative to a series resistor is a series diode, or two diodes in parallel back-to-back. The diodes can be small-signal types and should be in a light-tight enclosure.

# Applications

The following applications require an external voltage source. The Keithley Model 230 voltage source is fully programmable and can source up to 100V at 100mA.

With the proper use of external triggering between Models 6514 and 230, the tests can be automated. All of the applications require a bias time or delay, which can be provided by the delay feature of Model 6514. When Model 6514 is triggered, a measurement will not be performed until the delay period expires.

*NOTE External triggering and delay are covered in Section 9.*

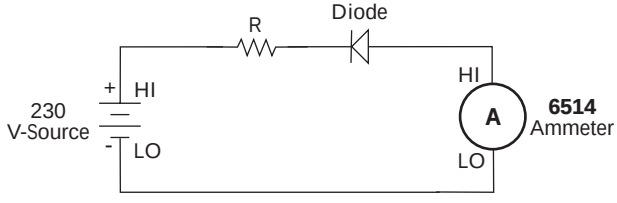
## Diode leakage current

Figure 4-6 shows how to measure the leakage current for a diode. By sourcing a positive voltage, the leakage current through the diode will be measured. Note that if you source a negative voltage, you will forward bias the diode. Resistor R is used to limit current in the event that the diode shorts out or it becomes forward biased. Select a value of R that will limit current to 20mA or less.

A profile for leakage current can be developed by measuring current at various voltage levels. For example, you can program Model 230 to source from 1 to 10V in 1V steps. With the proper use of external triggering, Model 6514 will perform a current measurement on each voltage step. To ensure that the voltage is settled before each current measurement, you can program Model 6514 for a delay. For example, if you program Model 6514 for a one second delay, each measurement will be performed after the voltage step is allowed to settle for one second. The current measurements can be stored in the buffer.

*NOTE Buffer operation is covered in Section 8.*

*Figure 4-6*
*Connections; diode leakage current test*



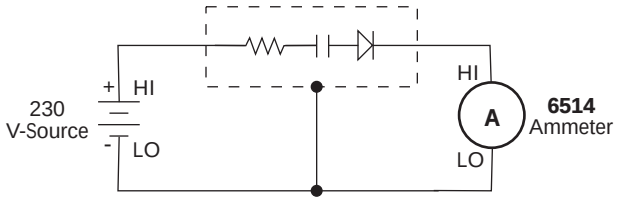

Equivalent Circuit

## Capacitor leakage current

Figure 4-7 shows how to measure the leakage current for a capacitor. The magnitude of the leakage is dependent on the type of dielectric and the applied voltage. A resistor and a diode are used to limit noise for the measurement.

For this test, a fixed bias voltage is to be applied to the capacitor for a specified time to allow the capacitor to fully charge (current decays exponentially with time). The leakage current is then measured. After the measurement, the voltage source is set to output 0V for a specified time to allow the capacitor to discharge.

*Figure 4-7*
*Connections; capacitor leakage current test*




Equivalent Circuit

## Cable insulation resistance

*NOTE* *For this test, Model 6514 uses the source voltage, measure current method to determine resistance. Once a current measurement is performed, resistance can be calculated.*

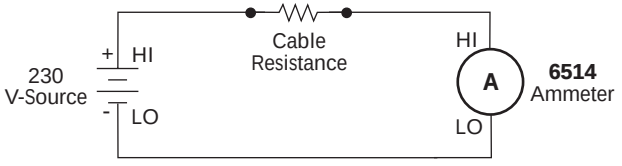
Figure 4-8 shows how to measure the insulation resistance of a cable. The resistance of the insulator between the shield and the inner conductor is being measured. The cable sample should be kept as short as possible to minimize input capacitance to the ammeter.

For this test a fixed bias voltage is applied across the insulator for a specified time to allow the charging effects of cable capacitance to stabilize. The current is then measured. Cable resistance (R) can then be calculated as follows:

$R = V/I$

where; V is the sourced bias voltage
I is the measured current

*Figure 4-8*
*Connections; cable insulation resistance test*




Equivalent Circuit

## Surface insulation resistance (SIR)

*NOTE* *For this test, Model 6514 uses the source voltage, measure current method to determine resistance. Once a current measurement is performed, resistance can be calculated.*

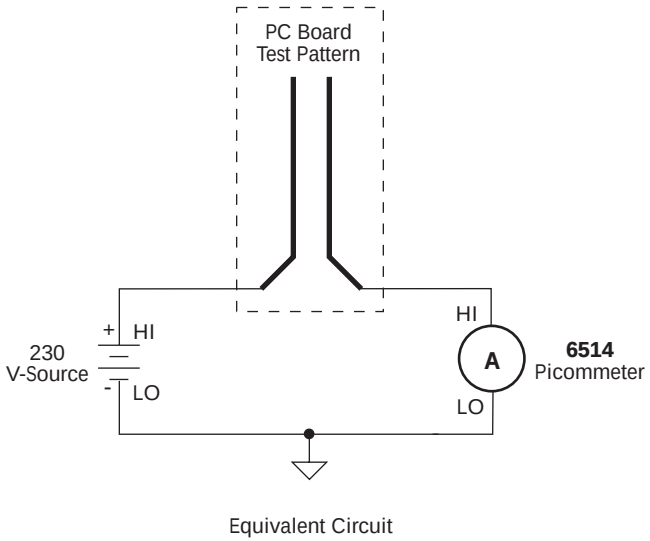
Figure 4-9 shows how to measure the insulation resistance between PC board traces. Note that the drawing shows a "Y" test pattern for the measurement. This is a typical test pattern for SIR tests.

A bias voltage (typically 50V) is applied to the test pattern for a specified time (typically one second) to polarize the test pattern. The test voltage (typically 100V) is then applied and, after a specified time (typically one second), Model 6514 measures the current. Surface insulation resistance can now be calculated as follows:

SIR = V/I

where; V is the sourced test voltage
I is the measured current

*Figure 4-9*
*Connections; surface insulation resistance test*



# 5
# Coulombs Measurements

- **Measurement overview** — Summarizes the charge measurement capabilities of the Model 6514.
- **Auto discharge** — Explains how to use the auto discharge feature of Model 6514.
- **Coulombs measurement procedure** — Provides the procedure to measure coulombs.
- **SCPI programming** — Covers the basic SCPI commands used for the coulombs function.
- **Amps measurement considerations** — Covers measurement considerations that apply to coulombs measurements.
- **Application** — Summarizes an application to measure capacitance.

# Measurement overview

**Coulombs measurements** — Model 6514 can make coulombs measurements from 10fC to 2.1µC using four measurement ranges; 20nC, 200nC, 2µC, and 20µC.

In the coulombs function, an accurately known capacitor is placed in the feedback loop of the amplifier so that the voltage developed is proportional to the integral of the input current in accordance with the following formula:

$$V = \frac{1}{C}\int i\,dt = \frac{Q}{C}$$

Where; V is the voltage
C is the known capacitance
Q is the charge

The voltage is scaled and displayed as charge.

**External feedback** — The external feedback mode of Model 6514 can be used to measure non-standard charge ranges. Measurements using the external feedback mode are covered in Section 11.

*NOTE Accuracy specifications for all measurement functions are provided in Appendix A.*

# Auto discharge

Model 6514 has an auto discharge feature for the coulombs function. When enabled, auto discharge resets the charge reading to zero when the specified charge level is reached. After the integrator resets, the charge measurement process simply restarts at zero. The charge reading resets every time the specified charge level is reached.

When auto discharge is disabled, you can use zero check to reset the integrator.

Perform the following steps to set an auto discharge level and enable it:

1. Press SHIFT and then AUTO-DIS to display the present auto discharge level.
2. Use the cursor keys (◀ and ▶) and ( ▲ and ▼) to enter a discharge level. To change polarity, place the cursor on the "+" or "-" sign and press ▲ or ▼. To change range, place the cursor on the range indicator and use the ▲ and ▼ keys.
3. With the desired auto discharge level displayed, press ENTER.

*NOTE Pressing SHIFT and then AUTO-DIS a second time disables auto discharge ("DISCHRG OFF" displayed briefly).*

# Coulombs measurement procedure

*CAUTION* **The maximum input voltage and current to Model 6514 is 250V peak and 21mA. Exceeding either of these values may cause damage to the instrument that is not covered by the warranty.**

*WARNING* **The maximum common-mode input voltage, which is the voltage between the input (HI or LO) and chassis ground, is 500V peak. Exceeding this value may create a shock hazard.**

*NOTE* *After measuring high voltage in the volts function, it may take several minutes for input current to drop to within specified limits. Input current can be verified by placing the protection cap on the input triax connector, and then installing the ground link between COMMON and CHASSIS ground. With the instrument on the 20pA range and zero check disabled, allow the reading to settle until the input bias current is within specifications. The specifications for input bias current are listed in Appendix A.*

Perform the following steps to measure charge:

## Step 1 Enable zero check and select the coulombs (Q) function

Zero check should always be enabled before making function or connection changes. The ZCHK key toggles zero check on and off. When on, the "ZC" or "ZZ" message is displayed. See Section 2 for details on zero check.

The coulombs function is selected by pressing the Q key.

## Step 2 Select a manual measurement range or enable auto range.

Use the RANGE ▲ and ▼ keys to select a manual measurement range, or press AUTO to enable auto range. With auto range enabled, the instrument will auto range between the HIGH range group (2µC and 20µC) or the LOW range group (20nC and 200nC). To select the HIGH range group, press SHIFT and then the RANGE ▲ key. To select the LOW range group, press SHIFT and then the RANGE ▼ key. See Section 6 for details on range.

## Step 3 If desired, set and enable auto discharge

See "Auto Discharge" to set an auto discharge level and enable it.

## Step 4 Connect the input cable to Model 6514 (open input)

Make sure that the test circuit is not connected to the input.

## Step 5 Disable zero check and press the REL key

When zero check is turned off, a charge may be induced on the input. Pressing the REL key zeroes the display. See "Zero Check Hop" in "Coulombs Measurement Considerations" (in this section). Details on Relative are provided in Section 7.

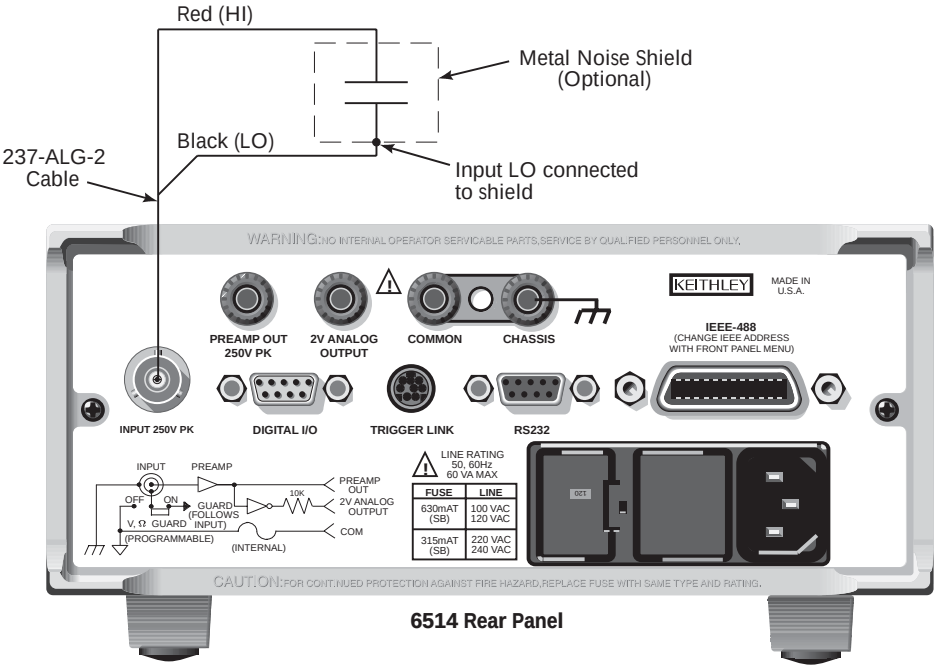
*NOTE* *If the zeroed reading drifts significantly after REL is enabled, disable REL and toggle zero check on and off until drift is minimized. Enable zero check and repeat Step 5.*

## Step 6 Connect the charge to be measured to the electrometer

Basic connections for amps measurements are shown in Figure 5-1.

*NOTE* *See "Connection Basics" in Section 2 for fundamental information on making connections to the electrometer input.*

*Figure 5-1*
*Typical connections for coulombs*




## Step 7 Take the charge reading from the display

If using auto discharge, use the REL key to zero the display when the integrator resets. Remember that Rel was enabled in Step 5. Therefore, you will have to press REL twice. The first press disables Rel, and the second press re-enables it to zero the display. See "Auto Discharge Hop" in "Coulombs Measurement Considerations" (in this section).

# SCPI programming

*Table 5-1*
*SCPI commands — coulombs function*

| Commands | Description | Default | Ref |
|---|---|---|---|
| [SENSe] | SENSe Subystem: | | |
| :FUNCtion 'CHARge' | Select coulombs function. | VOLT | A |
| :DATA? | Return latest "raw" reading. | | B |
| :CHARge | | | |
| :ADIScharge | Auto discharge: | | |
| [:STATe] <b> | Enable or disable auto discharge. | OFF | |
| :LEVel <NRf> | Set auto discharge level; -2.1e-5 to 2.1e-5. | 2e-6 | |
| INITiate | Trigger one or more readings. | | B |
| READ? | Trigger and return reading(s). | | B |

## A) SENSe:FUNCtion <name>

**Parameters**

| | |
|---|---|
| 'CHARge' | Coulombs function |
| 'CURRent' | Amps function |
| 'VOLTage' | Volts function |
| 'RESistance' | Ohms function |

Note that the parameter names are enclosed in single quotes ('). However, double quotes (") can instead be used. Each measurement function "remembers" its own unique range setting.

## B) SENSe:DATA?

This command does not trigger a reading. It simply returns the last "raw" reading string. It will not return the result of any instrument calculation. The reading reflects what is applied to the input.

To return a fresh (new) reading, you can send the INITiate command to trigger one or more readings before sending :DATA?. Details on INITiate are provided in Section 9.

While Model 6514 is busy performing measurements, the :DATA? command will not return the reading string until the instrument finishes and goes into the idle state.

*NOTES* *The format that the reading string is returned in is set by commands in the FORMat Subsystem (see Section 16).*

*If there is no reading available when :DATA? is sent, an error (-230) will occur.*

*The READ? command can be used to return "fresh" readings. This command triggers and returns the readings. See Section 15 for details.*

### Programming example

The following command sequence will perform one coulombs measurement:

```
*RST                        ' Return 6514 to RST defaults.
SYST:ZCH ON                 ' Enable zero check.
FUNC 'CHAR'                 ' Select the Coulombs function.
CHAR:RANG:AUTO ON           ' Enable auto range.
                            ' Connect input cable.
SYST:ZCH OFF                ' Disable zero check.
CALC2:NULL:STAT ON          ' Enable Rel to zero the display.
                            ' Connect charge circuit to DUT.
READ?                       ' Trigger and return one reading.
```

## Coulombs measurement considerations

Some considerations for making accurate Coulombs measurements are summarized as follows. Additional measurement considerations are covered in Appendix C. For comprehensive information on precision measurements, refer to the Low Level Measurements handbook, which is available from Keithley Instruments.

### Input bias current

A primary consideration when making charge measurements is the input bias (offset) current of the integrating amplifier. Any such current is integrated along with the input signal and reflected in the final reading. Model 6514 has a maximum input bias of 4fA for charge at $T_{CAL}$ (temperature at time of calibration). This input offset translates into a charge of 4fC per second at the $T_{CAL}$ temperature. This value must be subtracted from the final reading to obtain the correct value.

Input bias current may be reduced by performing the offset correction procedure explained in Section 19.

### External voltage source

When using an external voltage source, the input current should be limited to less than 1mA by placing a resistor in series with the high input lead. The value of this resistor should be at least:

$R = 1000 \times V$ (ohms)

where; V is the voltage across the resistor, or the compliance of the current being integrated.

### Zero check hop and auto discharge hop

Using the zero check feature (going from the enabled state to the disabled state) causes a sudden change in the charge reading and is known as zero check hop. This sudden change in charge also occurs when the auto discharge feature resets the charge reading to zero. This hop in charge can be eliminated by taking a reading the instant zero check is disabled or when an auto discharge occurs, and subtracting it from all subsequent readings. A better way to deal with this hop in charge is to enable Rel immediately after zero check is disabled or when auto discharge resets the charge reading. This action nulls out the charge reading caused by the hop.

# Application

## Capacitance measurements

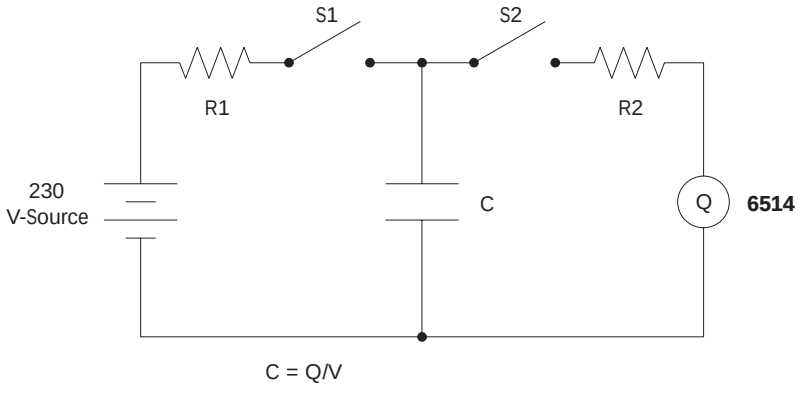
Figure 5-2 shows a general test circuit to measure a capacitor (C). Resistors R1 and R2 are used to limit current. Select a value for R1 that will limit current to ≤100mA, and select a value for R2 that will limit current to ≤20mA.

When switch S1 is closed, the Keithley Model 230 voltage source charges the capacitor. After waiting sufficient time for the capacitor to fully charge, open switch S1 and close switch S2 to measure the charge. The capacitance can now be calculated as follows:

$C = Q/V$

where; C is the capacitance (in farads)
Q is the measured charge (in coulombs)
V is the voltage used to charge the capacitor

*Figure 5-2 Measuring capacitors*



# 6
# Range, Units, Digits, Rate, and Filters

- **Range, units, and digits** — Provides details on measurement range, reading units, and display resolution selection. Includes the SCPI commands for remote operation.
- **Rate** — Provides details on reading rate selection. Includes the SCPI commands for remote operation.
- **Filters** — Explains how to configure and control the digital and median filters. Includes the SCPI commands for remote operation.

# Range, units, and digits

## Range

The ranges for each measurement function are listed in Table 6-1. The range setting (fixed or AUTO) is remembered by each function.

*Table 6-1*
*Measurement ranges*

| V | I | Ω | Q |
|---|---|---|---|
| 2V | 20pA | 2kΩ | 20nC |
| 20V | 200pA | 20kΩ | 200nC |
| 200V | 2nA | 200kΩ | 2µC |
| | 20nA | 2MΩ | 20µC |
| | 200nA | 20MΩ | |
| | 2uA | 200MΩ | |
| | 20uA | 2GΩ | |
| | 200uA | 20GΩ | |
| | 2mA | 200GΩ | |
| | 20mA | | |

The full scale readings for every measurement range are 5% over range. For example, on the 20V range, the maximum input voltage is ± 21V. Input values that exceed the maximum readings cause the overflow message (“OVERFL0W”) to be displayed.

### Manual ranging

To select a range, press the RANGE ▲ or ▼ key. The instrument changes one range per key-press. The selected range is displayed momentarily. If the instrument displays the “OVER-FLOW” message on a particular range, select a higher range until an on-range reading is dis-played. Use the lowest range possible without causing an overflow to ensure best accuracy and resolution.

### Autoranging

When using autorange, the instrument automatically goes to the most sensitive available range to measure the applied signal. Up-ranging occurs at 105% of range, while down-ranging occurs at the range value. For example, if on the 20V range, the instrument will go up to the 200V range when the input signal exceeds 21V. While on the 200V range, the instrument will go down to the 20V range when the input level goes to 20V.

The AUTO key toggles the instrument between manual ranging and autoranging. The AUTO annunciator turns on when autoranging is selected. To disable autoranging, press AUTO or the RANGE ▲ or ▼ key. Pressing AUTO to disable autoranging leaves the instrument on the present range.

Every time an autorange occurs, a search for every available range of the selected function is performed. The time it takes to perform the search could slow down range change speed significantly. For V, I and ( measurements, upper and/or lower autorange limits can be set to reduce search time. For Q measurements, the instrument will only autorange between the two higher charge ranges (high range group), or between the two lower charge ranges (low range group).

*NOTE* *Range limits and groups are not in effect for manual ranging. Every range is accessible with manual range selection.*

**Autorange limits for V, I and Ω**

Search time for V, I and Ω can be reduced by setting upper and/or lower autorange limits. For example, if you know the maximum input will be around 1µA, you can set the upper current range limit to 2µA. This eliminates the 20µA, 200µA, 2mA and 20mA ranges from the search, therefore, increasing the range change speed. Should the input exceed 2.1µA, the "OVERFLOW" message will be displayed.

Perform the following steps to set upper and/or lower autorange limits.

1. Select the V, I or Ω function.
2. Press SHIFT and then one of the following RANGE keys:
   a. Press the RANGE ▲ key to display the present UPPER range limit.
   b. Press the RANGE ▼ key to display the present LOWER range limit.
3. Use the RANGE ▲ and ▼ keys to display the desired limit.
4. Press ENTER.

*NOTE* *If you attempt to select an incompatible range limit, it will be ignored and "TOO LARGE" or "TOO SMALL" will be displayed briefly. For example, if the lower range limit is 20V, trying to set the upper limit to 2V will result in the "TOO SMALL" error.*

**Autorange groups for Q**

To optimize range change speed for charge measurements, the instrument will only autorange between two ranges. With the high range group selected, the instrument can only autorange between the 2µC and 20µC ranges. With the low range group selected, the instrument can only autorange between the 20nC and 200nC ranges.

If the HIGH range group is presently selected and the instrument is on the 20nC or 200nC range (autorange disabled), pressing the AUTO range key will initially select the 2µA range and then enable autorange. If the range group is then changed to LOW, the instrument will initially go to the 200nC range with autorange enabled. Therefore, the instrument will always stay within the selected range group with autorange enabled.

*NOTE* *With the low range group selected, the "OVERFLOW" message will be displayed when the input signal exceeds 210nC.*

Perform the following steps to select autorange group for Q:

1. Select the Q function.
2. Press Shift and then one of the follow RANGE keys:
   a. Press the RANGE ▲ key to select the HIGH range group (2µC and 20µC).
   b. Press the RANGE ▼ key to select the LOW range group (20nC and 200nC).

## Units

Readings can be displayed using engineering (ENG) units (i.e. 1.236 MΩ) or scientific (SCI) notation (i.e. 1.236E+06Ω). Perform the following steps to change the units setting:

1. Press SHIFT and then DIGIT to display the present units setting (ENG or SCI).
2. Press the RANGE ▲ or ▼ key to display the desired units setting.
3. Press ENTER.

*NOTE* *1. The units setting can only be changed from the front panel (no remote operation).*
*2. Scientific notation provides more resolution on small values than engineering units.*

## Digits

The DIGIT key sets display resolution for Model 6514. Display resolution can be set from 3½ to 6½ digits. This single global setting affects display resolution for all measurement functions.

To set display resolution, press (and release) the DIGIT key until the desired number of digits is displayed.

*NOTE* *Changing the integration rate changes display resolution, but changing display resolution does not change the rate setting (see RATE for details).*

## SCPI programming - range and digits

*Table 6-2*
*SCPI commands — range and digits*

| Commands | Description | Default |
|---|---|---|
| *For Range:* | | |
| [:SENSe] | SENSe Subsystem: | |
| :VOLTage | Measure voltage: | |
| :RANGe | Range selection: | |
| [:UPPer] <n> | Specify expected reading; -210 to 210 (V). | 20V |
| : AUTO <b> | Enable or disable autorange. | (see Note) |
| :ULIMit <n> | Specify upper range limit for autorange; -210 to 210 (V). | 200V |
| :LLIMit <n> | Specify lower range limit for autorange; -210 to 210 (V). | 2V |

*Table 6-2 (cont.)*
*SCPI commands — range and digits*

| Commands | Description | Default |
|---|---|---|
| :CURRent | Measure current: | |
| :RANGe | Range selection: | |
| [:UPPer] <n> | Specify expected reading; -0.021 to 0.021 (A). | 200µA |
| : AUTO <b> | Enable or disable autorange. | (see Note) |
| :ULIMit <n> | Specify upper range limit for autorange; -0.021 to 0.021 (A). | 20mA |
| :LLIMit <n> | Specify lower range limit for autorange; -0.021 to 0.021 (A). | 20pA |
| :RESistance | Measure resistance: | |
| :RANGe | Range selection: | |
| [:UPPer] <n> | Specify expected reading; 0 to 2.1e11 (Ω). | 200kΩ |
| : AUTO <b> | Enable or disable autorange. | (see Note) |
| :ULIMit <n> | Specify upper range limit for autorange; 0 to 2.1e11 (Ω). | 200GΩ |
| :LLIMit <n> | Specify lower range limit for autorange; 0 to 2.1e11 (Ω). | 2kΩ |
| :CHARge | Measure charge: | |
| :RANGe | Range selection: | |
| [:UPPer] <n> | Specify expected reading; -21e-6 to 21e-6 (C). | 200nC |
| : AUTO <b> | Enable or disable autorange. | (see Note) |
| :LGRoup <name> | Select autorange group; HIGH or LOW | HIGH |
| *For Digits:* | | |
| DISPlay | DISPlay Subsystem: | |
| :DIGITs <n> | Set display resolution; 4 to 7, where:<br>4 = 3½-digit resolution<br>5 = 4½-digit resolution<br>6 = 5½-digit resolution<br>7 = 6½-digit resolution<br><br>Note: Rational numbers can be used. For example, to set 4 resolution, send a value of 4.5 (the 6514 rounds it to 5). | 6 |

Note: *RST default is ON and SYSTem:PRESet default is OFF.

## Programming example — range and digits

The following command sequence selects the 200V range and sets display resolution to 3:

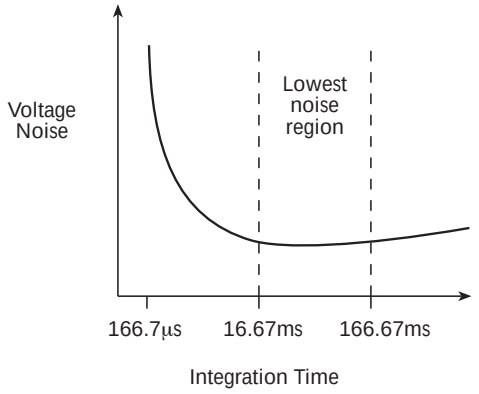
```
*RST                    ' Restore RST defaults.
VOLT:RANG 200           ' Set V function to 200V range.
DISP:DIG 3.5            ' Set display resolution to 3½ digits.
```

# Rate

The RATE key selects the integration time of the A/D converter. This is the period of time the input signal is measured. 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 a 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, Model 6514 has a parabola-like shape for its speed vs. noise characteristics and is shown in Figure 6-1. Model 6514 is optimized for the 1 PLC to 10 PLC reading rate. At these speeds (lowest noise region in the graph), Model 6514 will make corrections for its own internal drift and still be fast enough to settle a step response <100ms.

*Figure 6-1*
*Speed vs. noise characteristics*




The rate setting is global for all measurement functions. Therefore, it does not matter what function is presently selected when you set rate.

There are two ways to set rate. You can select slow, medium, or fast by using the RATE key, or you can set the number of power cycles from the NPLC menu that is accessed by pressing SHIFT and then NPLC.

**Rate Key** — The RATE key selections are explained as follows:

- SLOW — Selects the slowest front panel integration time (6 PLC for 60 Hz or 5 PLC for 50 Hz) and sets display resolution to 5½-digit resolution. The SLOW rate provides better noise performance at the expense of speed.
- MED — Selects the medium integration time (1 PLC) and sets display resolution to 5½-digit resolution. Select the MED rate when a compromise between noise performance and speed is acceptable.
- FAST — Selects the fastest front panel integration time (0.1 PLC) and sets display resolution to 4½-digit resolution. Select the FAST rate if speed is of primary importance (at the expense of increased reading noise).

To change the rate setting, press (and release) the RATE key until the desired rate annunciator (SLOW, MED or FAST) is displayed.

**NPLC Menu** — From this menu you can set rate by setting the PLC value. Perform the following steps to set NPLC:

1. Press SHIFT and then NPLC to display the present PLC value.
2. Use the ◄, ►, ▲, and ▼ keys to display the desired PLC value (0.01 to 10).
3. Press ENTER.

*NOTE* *The SLOW, MED or FAST annunciator will only turn on if the set PLC value corresponds exactly to the slow (5 or 6 PLC), medium (1 PLC) or fast (0.1 PLC) integration rate. For example, with the integration rate set to 2 PLC, none of the rate annunciators will turn on.*

## SCPI programming — rate

As shown in Table 6-3, there are four commands to set rate. However, since the rate setting is global and affects all measurement functions, it doesn't matter which command you use to set it.

*Table 6-3*
*SCPI commands — rate*

| Command | Description | Default |
|---|---|---|
| [:SENSe] | SENSe Subsystem: | |
| :VOLTage | | |
| :NPLCycles <n> | Specify integration rate; 0.01 to 10 (PLCs) | 6.0 (60Hz)<br>5.0 (50Hz) |
| :CURRent | | |
| :NPLCycles <n> | Specify integration rate; 0.01 to 10 (PLCs) | 6.0 (60Hz)<br>5.0 (50Hz) |
| :RESistance | | |
| :NPLCycles <n> | Specify integration rate; 0.01 to 10 (PLCs) | 6.0 (60Hz)<br>5.0 (50Hz) |
| :CHARge | | |
| :NPLCycles <n> | Specify integration rate; 0.01 to 10 (PLCs) | 6.0 (60Hz)<br>5.0 (50Hz) |

### Programming example — rate

The following command sets the integration rate for all measurement functions to 2 PLC:

```
VOLT:NPLC 2              ' Set integration rate to 2 PLC.
```

# Filters

Filtering stabilizes noisy measurements caused by noisy input signals. The Model 6514 uses two types of filters: median and digital. The displayed, stored or transmitted reading is simply the result of the filtering processes. Note that both the median and digital filters can be in effect at the same time.

With both filters enabled, the median filter operation is performed first. After the median filter yields a reading, it is sent to the stack of the digital filter. Therefore, a filtered reading will not be displayed until both filter operations are completed.

The settings for the filter are global. Therefore, the filter configuration applies to all four measurement functions. The MEDN key is used to configure and control the median filter, and the AVG key is used to configure and control the digital filter. When either the median or digital filter is enabled, the FILT annunciator is on.

## Median filter

The median filter is used to determine the "middle-most" reading from a group of readings that are arranged according to size. For example, assume the following readings:

20V, 1V, 3V

The readings are re-arranged in an ascending order as follows:

1V, 3V, 20V

From the above readings, it is apparent that 3V is the median (middle-most) reading. The number of sample readings used for the median calculation is determined by the selected rank (1 to 5) as follows:

Sample readings = $(2 \times R) + 1$

where; R is the selected rank (1 to 5)

For example, a rank of 5 will use the last 11 readings to determine the median; $(2 \times 5) + 1 = 11$. Each new reading replaces the oldest reading, and the median is then determined from the updated sample of readings.

**Median filter operation** — The median filter operates as a moving type filter. For example, if the median filter is configured to sample 11 readings (Rank 5), the first filtered reading will be calculated (and displayed) after 11 readings are acquired and placed in its filter stack. Each subsequent reading will then be added to the stack (oldest reading discarded) and another median filter reading will be calculated and displayed. The median filter operation will reset (start over) whenever the Zero Check operation is performed or the function is changed.

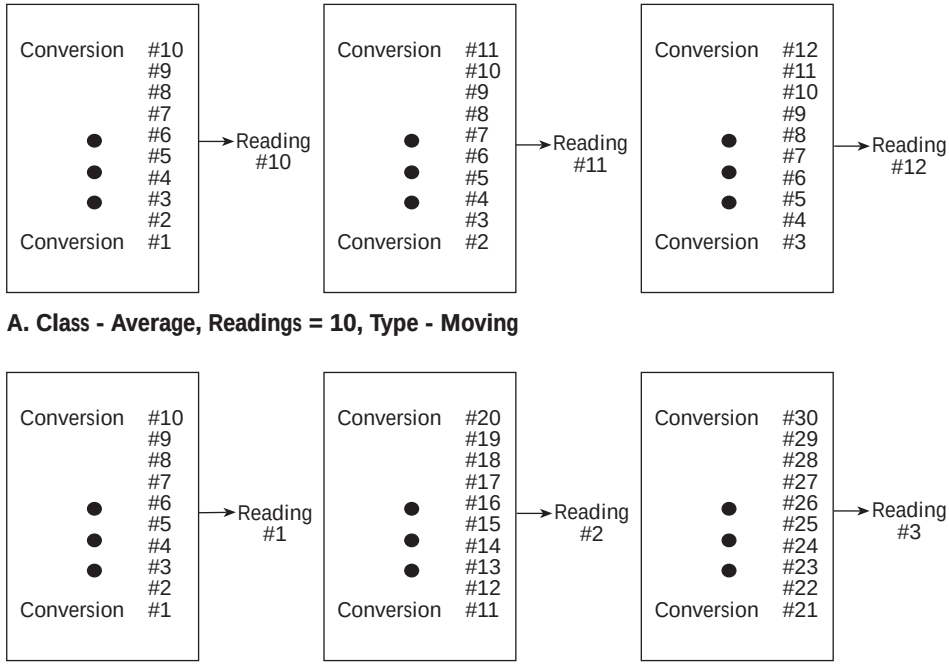
### Median filter configuration control

The MEDN key is a toggle-action key. It will either disable the median filter (displays “MEDIAN OFF”), or access the configuration menu to enable the median filter.

1. Press the MEDN key to display the present filter rank.
2. Use the RANGE ▲ or ▼ key to display the desired rank (1 to 5) and press ENTER.

## Digital filter

*Figure 6-2 Digital filter types; moving and repeating*




### Digital filter types

The digital filter can be either a moving or repeating type. Filter types are compared in Figure 6-2.

**Moving Filter** - Every time a reading conversion occurs, the readings in the stack are averaged to yield a single filtered reading. The stack type is first-in, first-out. After the stack fills, the newest reading conversion replaces the oldest. Note that the instrument does not wait for the stack to fill before releasing readings.

**Repeating Filter** - Takes a selected number of reading conversions, averages them, and yields a reading. It then flushes its stack and starts over.

### Response time

The various filter parameters have the following effects on the time needed to display, store, or output a filtered reading:

- Filter type: The time to the first reading is the same for both types, but thereafter, the moving mode yields a faster reading than repeating mode.
- Number of reading conversions: Speed and accuracy are tradeoffs.

### Operation consideration

- The digital filter operation will reset (start over) whenever the zero check operation is performed or the function is changed.

### Digital filter configuration and control

The AVG key is a toggle-action key. It will either disable the digital filter (display "AVERAGE OFF"), or access the configuration menu to enable the digital filter.

*NOTE* *For the following procedure, use the ◀ and ▶ keys and the RANGE ▲ and ▼ keys to set values. The ◀ and ▶ keys provide cursor control, while the ▲ and ▼ keys increment and decrement the value.*

1. Press the AVG key to display the present number of reading conversions to average (filter count).
2. Key in desired filter count value (1 to 100) and press ENTER. The present filter type (repeating or moving) is displayed.
3. Use the ▲ or ▼ key to display the desired filter type (REPEAT or MOVNG AV) and press ENTER.

## SCPI programming — filters

*Table 6-4*
*SCPI commands — filters*

| Commands | Description | Default |
|---|---|---|
| *For median filter:* | | |
| [:SENSe[1]] | SENSe Subsystem: | |
| :MEDian | Median Filter: | |
| :RANK <n> | Specify filter rank; 1 to 5. | 1 |
| [:STATe] <b> | Enable or disable median filter. | OFF |
| | | |
| *For digital filter:* | | |
| [:SENSe[1]] | SENSe Subsystem: | |
| :AVERage | Digital Filter: | |
| :TCONtrol <name> | Select filter control; MOVing or REPeat. | REP |
| :COUNt <n> | Specify filter count; 1 to 100. | 10 |
| [:STATe] <b> | Enable or disable digital filter. | OFF |

## Programming example

The following command sequence configures and enables both filters:

```
' Median Filter:
MED:RANK 5                ' Set rank to 5.
MED ON                    ' Enable median filter.

' Digital Filter:
AVER:COUN 20              ' Set filter count to 20.
AVER:TCON MOV             ' Select moving filter.
AVER ON                   ' Enable digital filter.
```

# 7 Relative, mX+b and Percent (%)

- **Relative** — Explains how to null an offset or establish a baseline value. Includes the SCPI commands for remote operation.
- **mX+b and percent (%)** — Covers these two basic math operations, and includes the SCPI commands for remote operation.

# Relative

Relative (Rel) nulls an offset or subtracts a baseline reading from present and future readings. When a Rel value is established, subsequent readings will be the difference between the actual input and the Rel value.

Displayed (Rel'ed) Reading = Actual Input - Rel Value

A Rel value is the same for all measurement ranges. For example, a Rel value of 1 is 1V on the 2V range, 1V on the 20V range, and 1V on the 200V range. Note that function changes disables Rel.

When a Rel value is larger than the selected range, the display is formatted to accommodate the Rel'ed reading. However, this does not increase the maximum allowable input for that range. An over-range input signal will still cause the display to overflow. For example, on the 20V range, Model 6514 still overflows for a 20.1V input.

*NOTE Rel can be used on the result of the percent (%) or mX+b calculations. However, Rel will disable whenever a math function is enabled or disabled.*

## Setting and controlling relative

From the front panel, there are two ways to set the Rel value. You can use the input reading as the Rel value or you can manually key in the Rel value.

### REL key

When the REL key is used to enable Rel, the present display reading is used as the Rel value. Perform the following steps to set a Rel value:

1. Display the reading you want as the Rel value. This could be a zero offset reading that you want to null out, or it could be an applied level that you want to use as a baseline.
2. Press REL. The REL annunciator turns on and subsequent readings will be the difference between the actual input and the Rel value.
3. To disable REL, press the REL key a second time or select a different measurement function. The REL annunciator turns off.

*NOTE When Rel is disabled, the Rel value is remembered and can be reinstated from the VAL key.*

### VAL key

The SHIFT-VAL key sequence displays the present Rel value. From this display you can enable Rel using that Rel value or you can key in a different Rel value.

1. Press SHIFT and then VAL to display the present Rel value.
2. To change the Rel value, use the ◀, ▶, ▲ and ▼ keys to change the value. To change polarity, place the cursor on the polarity sign and press ▲ or ▼. To change range, place the cursor on the range symbol (at the end of the reading) and use the ▲ and ▼ keys (see Table 7-1).
3. With the desired Rel value displayed, press ENTER to enable Rel.

*Table 7-1*
*Range symbols for rel values*

| Symbol | Prefix | Exponent |
|---|---|---|
| P | pico- | $10^{-12}$ |
| N | nano- | $10^{-9}$ |
| µ | micro- | $10^{-6}$ |
| m | milli- | $10^{-3}$ |
| ^ | (none) | $10^{0}$ |
| K | kilo- | $10^{3}$ |
| M | mega- | $10^{6}$ |
| G | giga- | $10^{9}$ |
| T | tera- | $10^{12}$ |

## SCPI programming — relative

*Table 7-2*
*SCPI commands — relative (null)*

| Commands | Description | Default | Ref |
|---|---|---|---|
| CALCulate2 | CALCulate2 Subsystem: | | |
| :FEED <name> | Specify reading to Rel; SENSe[1] or CALCulate[1]. | SENS | A |
| :NULL | Configure and control Relative. | | |
| :ACQuire | Use input signal as Rel value. | | |
| :OFFSet <NRf> | Specify Rel value; -9.999999e20 to 9.999999e20. | 0.0 | |
| :STATe <b> | Enable or disable Rel. | OFF | |
| :DATA? | Return Rel'ed readings triggered by INITiate. | | B |
| :LATest? | Return only the latest Rel'ed reading. | | B |
| INITiate | Trigger one or more readings. | | |

### A) :FEED <name> Specify reading to Rel

With SENSe[1] selected, the Rel operation will be performed on the input signal. With CALCulate[1] selected, the Rel operation will be performed on the result of the Percent (%) or mX+b calculation.

### B) :DATA? and :DATA:LATest?

With Rel enabled, these commands will return one or more Rel'ed readings. They will not trigger fresh (new) readings. Use the INITiate command to trigger new readings (see Section 9 for details on INITiate).

If the instrument is programmed to perform a finite number of measurements, the :DATA? command will return all the Rel'ed readings after the last reading is taken. The :DATA:LATest? command will only return the last (latest) Rel'ed reading.

If the instrument is programmed to perform an infinite number of measurements (arm count or trigger count set to infinite), you cannot use the :DATA? command to return Rel'ed readings. However, you can use the :DATA:LATest? command to return the last Rel'ed reading after aborting the measurement process. After sending the INITiate command to start the measurement process, use the ABORt command to abort the measurement process, then use :DATA:LATest? to return to the last Rel'ed reading.

### Programming example — relative

This program fragment establishes a 1V baseline for voltage measurements:

```
FUNC 'VOLT'              ' Select V function.
CALC2:NULL:OFFS 1        ' Set Rel value of 1V.
CALC2:NULL:STAT ON       ' Enable Rel.
CALC2:FEED SENS          ' Rel input signal.
INIT                     ' Trigger reading(s).
CALC2:DATA?              ' Request Rel'ed reading.
```

# mX+b and percent (%)

## mX+b

This math operation manipulates normal display readings (X) mathematically according to the following calculation:

Y = mX+b

where: X is the normal display reading
m and b are user-entered constants for scale factor and offset
Y is the displayed result

To configure and control the mX+b calculation, perform the following steps:

1. Press SHIFT and then MX+B to display the present scale factor:
   M: +1.0000000 ^ (factory default)
2. Key in a scale factor value. The ◄ and ► keys control cursor position and the ▲ and ▼ range keys increment and decrement the digit value. To change range, place the cursor

on the range symbol and use the ▲ and ▼ keys. With the cursor on the polarity sign, the ▲ and ▼ keys toggle polarity.

*NOTE Range symbols are defined in Table 7-1*

3. Press ENTER to enter the M value and display the offset (B) value:
   B: +00.000000 P (factory default)
4. Key in the offset value.
5. Press ENTER to enter the B value and display the three-character UNITS designator:
   UNITS: MXB (factory default)
6. Use the ◄ and ► cursor keys, and the ▲ and ▼ keys if you wish to change the units designator. Each character can be any letter in the alphabet (A through Z).
7. 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.
8. To disable mX+b, again press SHIFT and then MX+B. The MATH annunciator will turn off.

## Percent (%)

This math function determines percent deviation from a specified reference value. The percent calculation is performed as follows:

$$\text{Percent} = \frac{\text{Input}}{\text{Reference}} \times 100\%$$

where: Input is the normal display reading
Reference is the user entered constant
Percent is the displayed result

To configure and control the percent calculation, perform the following steps:

1. Press SHIFT and then % to display the present reference value:
   REF: +1.000000 ^ (factory default)
2. Key in a reference value. The ◄ and ► keys control cursor position and the ▲ and ▼ range keys increment and decrement the digit value. To change range, place the cursor on the range symbol and use the ▲ and ▼ keys. With the cursor on the polarity sign, the ▲ and ▼ keys toggle polarity.
3. 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.
4. To disable percent, again press SHIFT and then %. The MATH annunciator will turn off.

*NOTES 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 %).*

*Rel can be used on the result of the mX+b or percent math operation. Note however that Rel will disable whenever a math function is enabled or disabled. See "Relative" for details on using Rel.*

## SCPI programming — mX+b and percent

*Table 7-3*
*SCPI commands — mX+b and percent*

| Commands | Description | Default | Ref |
|---|---|---|---|
| CALCulate[1] | CALCulate1 Subsystem: | | |
| :FORMat <name> | Select calculation; MXB or PERCent. | MXB | |
| :KMATh | Path to configure mX+b and percent: | | |
| :MMFactor <n> | Specify scale factor (M) for mX+b; -9.99999e20 to 9.99999e20. | 1.0 | |
| :MBFactor <n> | Specify offset (B) for mX+b; -9.99999e20 to 9.99999e20. | 0.0 | |
| :MUNits <name> | Specify units for mX+b; 3 characters “A” through “Z”. | MXB | |
| :PERCent | Percent: | 1.0 | |
| :REFerence <n> | Specify reference value; -9.99999e20 to 9.99999e20. | | |
| :ACQuire | Use input signal as reference value. | | |
| :STATe <b> | Enable or disable the selected calculation. | OFF | |
| :DATA? | Returns all CALC1 results triggered by the INITiate. | | A |
| :DATA:LATest? | Returns only the latest CALC1 reading. | | A |

### A) :DATA? and :DATA:LATest?

The INITiate command must be sent to trigger the measurements and calculations. The number of calculations depend on how many measurements the instrument is programmed to perform.

If the instrument is programmed to perform a finite number of measurements, the :DATA? command will return all the CALC1 readings after the last reading is taken. The :DATA:LATest? command will only return the last (latest) CALC1 reading.

If the instrument is programmed to perform an infinite number of measurements (arm count or trigger count set to infinite), you cannot use the :DATA? command to return CALC1 readings. However, you can use the :DATA:LATest? command to return the last CALC1 reading after aborting the measurement process. After sending the INITiate command to start the measurement process, use the ABORt command to abort the measurement process, then use :DATA:LATest? to return the last CALC1 reading.

### Programming example — mX+b

This command sequence performs a single mX+b calculation and displays the result on the computer CRT:

```
*RST                    ‘ Restores RST defaults.
CALC:FORM MXB           ‘ Selects mX+b calculation.
CALC:KMAT:MMF 2         ‘ Sets scale factor (M) to 2.
CALC:KMAT:MBF 0.5       ‘ Sets offset (B) to 0.5.
CALC:STAT ON            ‘ Enables calculation.
INIT                    ‘ Perform one measurement and
                          calculate mX+b.
CALC:DATA?              ‘ Request mX+b result.
```

# 8 Buffer

- **Buffer operations** — Explains how to store and recall readings including buffer statistics.
- **SCPI programming** — Covers the SCPI commands used to control buffer operations.

# Buffer operations

Model 6514 has a buffer to store from one to 2500 readings. It also stores overflow readings. Each reading has a timestamp. The timestamp for each reading is referenced to the time the measure/store process is started. In addition, recalled data includes statistical information (maximum, minimum, peak-to-peak, average and standard deviation).

The buffer fills with the specified number of readings and stops. Readings are placed in the buffer after any math operations are performed. Math operations include relative, mX+b, percent, or limits.

Buffered data is overwritten each time the storage operation is selected. The data is volatile; it is not saved through a power cycle.

Measurement function changes are permissible during the storage process. Note however, that the statistics will be based on the readings of the different measurement functions.

## Store

Perform the following steps to store readings:

1. Set up the instrument for the desired configuration.
2. Press the STORE key.
3. Use the cursor keys ◄ and ►, and the RANGE keys ▲ and ▼ to set the number of readings to store (1 to 2500).
4. Press ENTER to enable the buffer. If in the immediate trigger mode, the storage process will start immediately. If in the external input trigger mode, each input trigger (or press of TRIG key) will store a reading. See Section 9 for information on triggering.

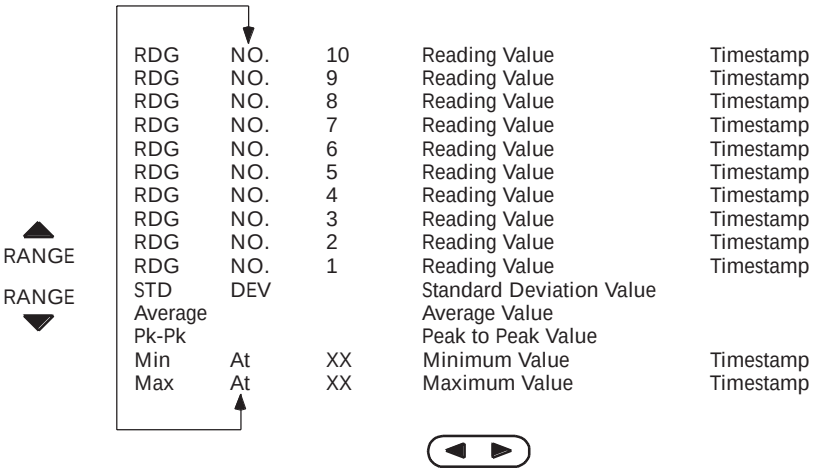
*NOTE* *The asterisk (*) annunciator turns on to indicate that the data storage operation is enabled. It will turn off when the storage process is finished (buffer full).*

## Recall

Perform the following steps to view stored readings and buffer statistics:

1. Press RCLL. The message “RDG NO. 1” is displayed. Note that the arrow annunciator (↔) also turns on to indicate that additional data is available for viewing.
2. As shown in Figure 8-1, use the RANGE keys ▲ and ▼ and the cursor keys ◄, ► to navigate through the reading numbers, reading values, timestamps, and buffer statistics.
3. To return to the normal display, press EXIT.

*Figure 8-1*
*Buffer locations*




## Buffer statistics

- **MIN** and **MAX** provides the minimum and maximum readings stored in the buffer. It also indicates the buffer location of these readings.
- The **PK-PK (peak-to-peak)** value is the difference between the maximum and minimum readings stored in the buffer:
  PK-PK = MAX - MIN
- **Average** is the mean of the buffer readings. Mean is calculated as follows:

$$y = \frac{\sum_{i=1}^{n} X_i}{n}$$

Where: $X_i$ is a stored reading
n is the number of stored readings

- The **STD DEV** value is the standard deviation of the buffered readings. Standard deviation is calculated as follows:

$$y = \sqrt{\frac{\sum_{i=1}^{n} X_i^2 - \left(\frac{1}{n}\left(\sum_{i=1}^{n} X_i\right)^2\right)}{n-1}}$$

Where: $X_i$ is a stored reading
n is the number of stored readings

# SCPI programming

Commands associated with buffer operation are listed in Table 8-1. The TRACe commands are used to store and recall readings in the buffer. The FORMat:ELEMents command is used to specify which data elements to include in the response message for TRACe:DATA? (which is the command to read the buffer). The CALCulate3 commands are used to obtain statistics from the buffer data.

*NOTE The Model 6514 uses IEEE-754 floating point format for statistics calculations.*

*Table 8-1*
*SCPI commands — buffer*

| Commands | Description | Default | Ref |
|---|---|---|---|
| :TRACe | TRACe Subsystem: | See Note | |
| :CLEar | Clear readings from buffer. | | |
| :FREE? | Query bytes available and bytes in use. | | A |
| :POINts <n> | Specify number of readings to store; 1 to 2500. | 100 | |
| :ACTual? | Returns number of readings actually stored in buffer. | | |
| :FEED <name> | Select source of readings; SENSe[1], CALCulate[1] or CALCulate2. | SENS1 | B |
| :CONTrol <name> | Select buffer control mode; NEVer or NEXT. | NEV | C |
| :TSTamp | Timestamp: | | |
| :FORMat <name> | Select timestamp format; ABSolute or DELTa. | ABS | D |
| :DATA? | Read all readings in buffer. | | E |
| :FORMat | FORMat Subsystem: | | Sec 16 |
| :ELEMents <list> | Specify data elements for :TRACe:DATA? response message; READing, TIME and STATus. | All 3 | F |
| :CALCulate3 | CALCulate3 Subsystem: | | |
| :FORMat <name> | Select buffer statistic; MINimum, MAXimum, MEAN, SDEViation or PKPK. | MEAN | G |
| :DATA? | Read the selected buffer statistic. | | H |

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

## A) TRACe:FREE?

Two values, separated by commas, are returned. The first value indicates how many bytes of memory are available, and the second value indicates how many bytes are reserved to store readings.

### B) TRACe:FEED <name>

Name parameters:

- SENSe — Raw input readings are stored in the buffer.
- CALCulate1 — The results of the mX+b or percent (%) calculation are stored in the buffer. See Section 7 for information on mX+b and percent.
- CALCulate2 — Test limit or Rel readings are stored in the buffer. See Section 10 for information on limit tests.

### C) TRACe:FEED:CONTrol <name>

Name parameters:

- NEXT — Enables the buffer and turns on the asterisk (*) annunciator. After the buffer stores the specified number of readings, the asterisk annunciator turns off.
- NEVer — Disables the buffer.

### D) TRACe:TSTamp:FORMat <name>

Name parameters:

- ABSolute — Each timestamp is referenced to the first reading stored in the buffer.
- DELTa — Timestamps provide the time between each buffer reading.
- The timestamp data element can be included with each buffer reading (see Ref F).

### E) TRACe:DATA?

1. The response message will include one to three data elements for each stored reading. Use the FORMat:ELEMents command (see Ref F) to specify the elements.
2. Reading an empty buffer will result in the “ERROR: -230” display message.
3. Buffer data can be sent in the binary format. See the FORMat Subsystem in Section 16 for details.

### F) FORMat:ELEMents <list>

1. List parameters:
   - READing —Includes the buffer reading in each data string.
   - TIME — Includes the timestamp for each reading. Timestamp can be in the absolute or delta format (see Ref D).
   - STATus — Includes a status word for each reading. It provides status information on instrument operation. See “FORMat Subsystem” in Section 16 for details.
2. At least one data element must be in the list. Listed elements must be separated by a comma (i.e. FORMat:ELEMents READing, TIME). Elements not listed will not accompany the response message for TRACe:DATA?.

### G) CALCulate3:FORMat <name>

This command selects the statistic to be returned by CALCulate3:DATA? (see Ref H). Name parameters:

- MINimum — Select the lowest reading stored in the buffer.
- MAXimum — Select the largest reading stored in the buffer.
- MEAN — Select the mean average statistic for the readings stored in the buffer.
- SDEViation — Select the standard deviation statistic for the readings stored in the buffer.
- PKPK — Select the peak-to-peak statistic for readings stored in the buffer. Peak-to-Peak is calculated as follows: PKPK = MAXimum - MINimum.

### H) CALCulate3:DATA?

1. If the number of data points in the buffer is one or none, CALCulate3:DATA? will result in an error (-230).
2. If there is a lot of data in the buffer, some statistic operations may take too long and cause a bus time-out error. To avoid this, send calc3:data? and then wait for the MAV (message available) bit in the Status Byte Register to set before addressing the Model 6514 talk (see Section 13).

## Programming example

The following program fragment stores 20 readings into the buffer and then calculates the mean average on the buffer readings:

```
' Select data elements:
*RST                      ' Return 6514 to RST defaults.
FORM:ELEM READ,TIME       ' Select reading and timestamp.

' Store and Recall Readings:
TRAC:POIN 20              ' Set buffer size to 20.
TRAC:FEED SENS            ' Store raw input readings.
TRAC:FEED:CONT NEXT       ' Start storing readings.
TRAC:DATA?                ' Request all stored readings.

' Acquire Mean Statistic for Buffer Readings:
CALC3:FORM MEAN           ' Select mean statistic.
CALC3:DATA?               ' Request mean statistic.
```

# 9
# Triggering

- **Trigger models** — Explains the various components of the trigger models, which control the triggering operations of the instrument. Also explains how to configure the trigger model from the front panel.
- **SCPI programming** — Includes the commands used to configure the trigger model, and the commands to control the measurement process.
- **External triggering** — Explains external triggering which allows Model 6514 to trigger other instruments, and be triggered by other instruments.

# Trigger models

The flowcharts in Figures 9-1 and 9-2 summarize triggering for Model 6514. They are called trigger models because they are modeled after the SCPI commands to control triggering (operation).

*Figure 9-1 Trigger model — front panel operation*

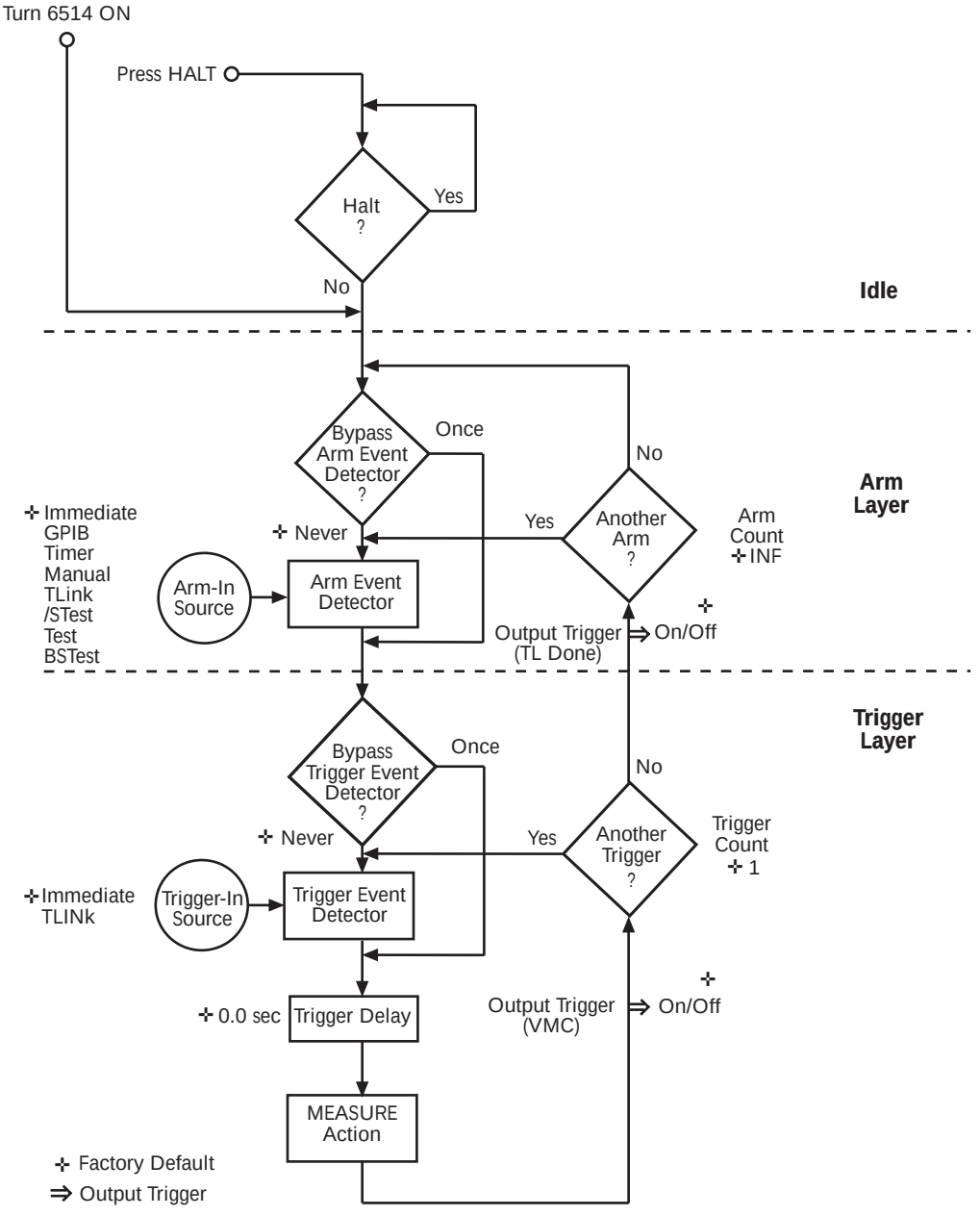
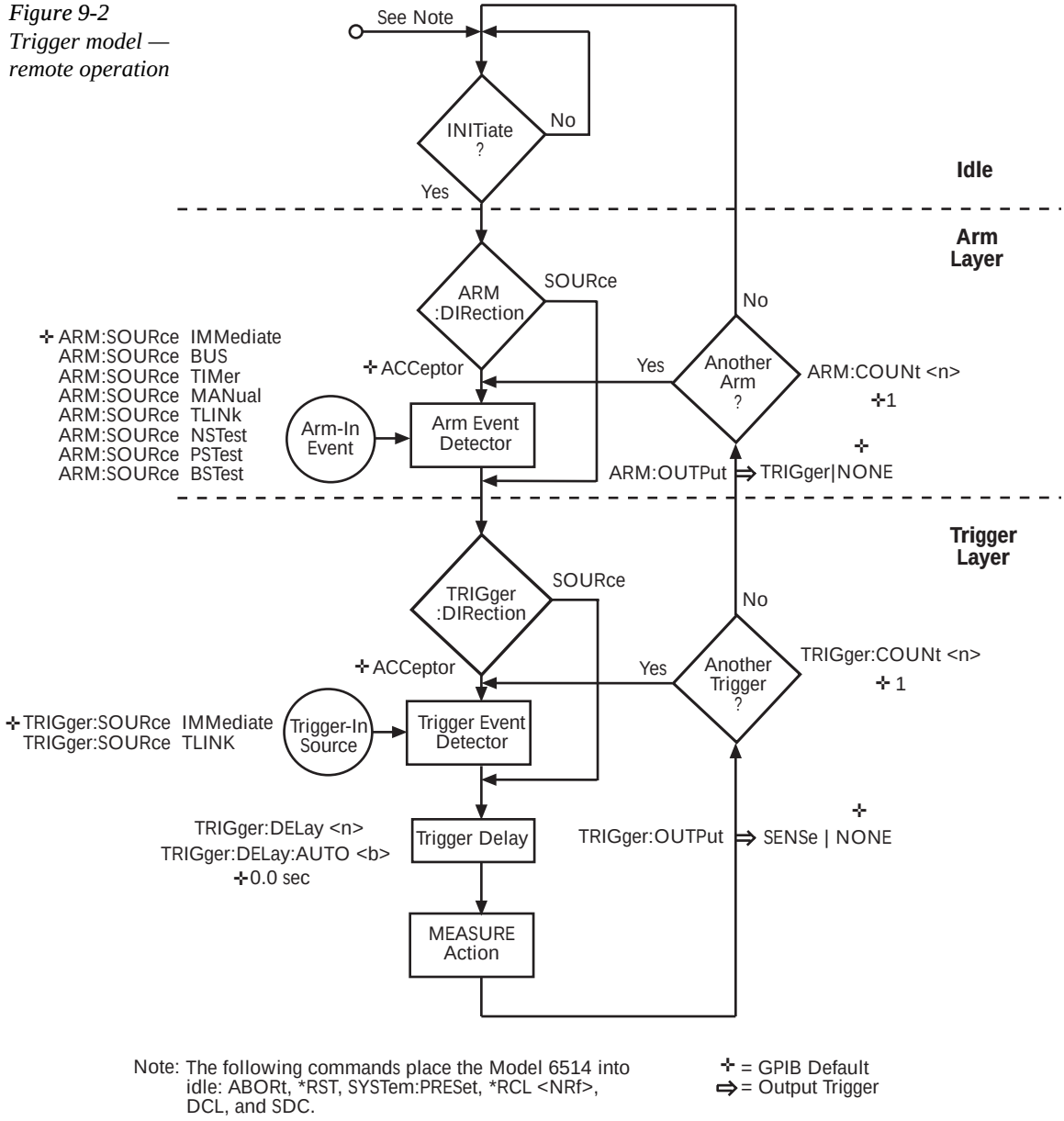


*Figure 9-2*
*Trigger model — remote operation*




Note: The following commands place the Model 6514 into idle: ABORt, *RST, SYSTem:PRESet, *RCL <NRf>, DCL, and SDC.

✣ = GPIB Default
⇨ = Output Trigger

The only difference between front panel operation (Figure 9-1) and remote operation (Figure 9-2) is within the idle state of the instrument. Nomenclature in Figure 9-1 relates to the various names used for configuration menu items, while Figure 9-2 provides the SCPI commands to control operation.

## Idle and initiate

While in the idle state, the instrument cannot perform measurements. While in idle, the reading remains frozen or dashes replace the reading (i.e. -.------ V). Once Model 6514 is taken out of idle, operation proceeds through the trigger model.

**Front panel operation** — As shown in Figure 9-1, Model 6514 immediately leaves the idle state when it is turned on. Typically, operation remains in the arm and trigger layers of the trigger model. However, Model 6514 can be put into the idle state at any time by pressing the HALT key. To take the instrument out of idle, press the TRIG key. Other front panel keys can instead be pressed, but they may change the setup.

**Remote operation** — As shown in Figure 9-2, an initiate command is required to take the instrument out of idle. The following commands perform an initiate operation:

- INITiate
- READ?
- MEASure?

While operating within the trigger model (not in idle), most commands will not be executed until the instrument completes all of its programmed operations and returns to the idle state. The IFC, SDC and DCL commands can be executed under any circumstance while operating within the trigger model. They will abort any other command or query.

The following commands can be executed while operating within the trigger model except when a READ? or MEASure? is being processed.

- ABORt
- SYSTem:PRESet
- *TRG or GET
- *RST
- *RCL <NRf>

*NOTE* *For fastest response, use SDC or DCL to return to idle (see Section 12 for details on general bus commands).*

## Trigger model operation

Once the instrument is taken out of idle, operation proceeds through the trigger model to perform a measurement (measure action).

*NOTE* *The following discussion focuses on the front panel trigger model (Figure 9-1). However, equivalent SCPI commands are included where appropriate.*

### Event detectors and control sources

A control source holds up operation until the programmed event occurs and is detected. Note that there are two detector bypasses. A bypass around a detector is only enabled if the appropri-

ate TLink control source is selected. See TLink control source (Arm-In and Trigger-In) as follows for details.

**Arm-In source** — The Arm-In control sources are explained as follows:

- **Immediate** (ARM:SOURce IMMediate) — Event detection for the arm layer is satisfied immediately allowing operation to continue on into the trigger layer.
- **GPIB** (ARM:SOURce BUS) — Event detection for the arm layer is satisfied when a bus trigger (GET or *TRG) is received by Model 6514.
- **Timer** (ARM:SOURce TIMer) — Event detection for the arm layer is immediately satisfied after the instrument leaves the idle state. Detection for each subsequent pass is satisfied when the programmed timer interval elapses. The timer resets to its initial state when the instrument goes back into idle.
- **Manual** (ARM:SOURce MANual) — Event detection for the arm layer is satisfied by pressing the TRIG key. Model 6514 must be in the local mode for it to respond to the TRIG key. Press LOCAL or send LOCAL 14 over the bus to place Model 6514 in local.
- **TLink** (ARM:SOURce TLINk) — Event detection for the arm layer is satisfied when an input trigger via the TRIGGER LINK connector is received by Model 6514. Note that if the source bypass is set to ONCE (ARM:DIRection SOURce), operation will initially loop around the source detector after the instrument leaves the idle state. Detection for each subsequent pass is satisfied by an input trigger. The bypass resets when the instrument goes into idle.
- **/STest** (ARM:SOURce NSTest) — Event detection for the arm layer is satisfied when a negative going pulse (via the SOT line of the Digital I/O) is received from a component handle (see “Limit Testing” in Section 10).
- **Test** (ARM:SOURce PSTest) — Event detection for the arm layer is satisfied when a positive going pulse (via the SOT line of the Digital I/O) is received from a component handle (see “Limit Testing” in Section 10).
- **BSTest** (ARM:SOURce BSTest) — Event detection for the arm layer is satisfied when either a positive-going or a negative-going pulse (via the SOT line of the Digital I/O) is received from a component handler (see “Limit Testing” in Section 10).

**Trigger-In source** — The Trigger-In control sources are explained as follow:

- **Immediate** (TRIGger:SOURce IMMediate) — Event detection for the trigger layer is satisfied immediately allowing operation to continue on to perform a measurement.
- **TLink** (TRIGger:SOURce TLINk) — Event detection for the trigger layer is satisfied when an input trigger via the TRIGGER LINK connector is received by Model 6514. Note that if the source bypass is set to ONCE (TRIGger:DIRection SOURce), operation will loop around the source detector on the initial pass through the arm layer. Detection for each subsequent pass is satisfied by an input trigger. The bypass resets when Model 6514 leaves the trigger layer.

## Trigger delay

A programmable delay is available after event detection. It can be set manually (0 to 999.9998 seconds) or an auto delay can be used. With auto delay selected, the Model 6514 automatically sets delay according to function and range. The auto delay settings are listed in Table 9-1.

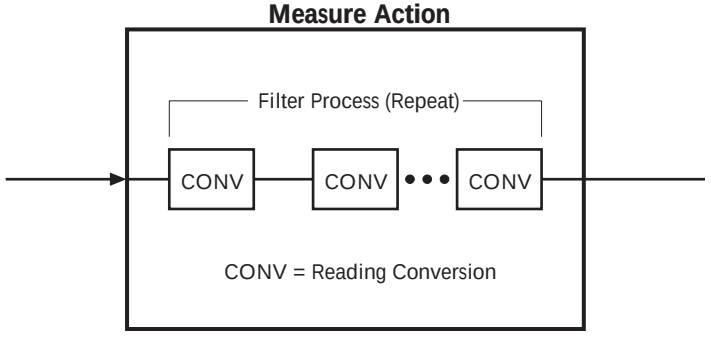
*Table 9-1*
*Auto delay settings*

| Volts | | Amps | | Ohms | | Coulombs | |
|---|---|---|---|---|---|---|---|
| **Range** | **Delay** | **Range** | **Delay** | **Range** | **Delay** | **Range** | **Delay** |
| 2V | 5ms | 20pA | 2500ms | 2kΩ | 5ms | 20nC | 3ms |
| 20V | 3ms | 200pA | 2500ms | 20kΩ | 1ms | 200nC | 3ms |
| 200V | 2ms | 2nA | 10ms | 200kΩ | 1ms | 2μC | 3ms |
| | | 20nA | 10ms | 2MΩ | 10ms | 20μC | 3ms |
| | | 200nA | 10ms | 20MΩ | 10ms | | |
| | | 2μA | 10ms | 200MΩ | 10ms | | |
| | | 20μA | 5ms | 2GΩ | 50ms | | |
| | | 200μA | 5ms | 20GΩ | 50ms | | |
| | | 2mA | 1ms | 200GΩ | 50ms | | |
| | | 20mA | 0.5ms | | | | |

## Measure action

The measure action block of the trigger model is where a measurement is performed. However, if the repeating filter is enabled (see Figure 9-3), the instrument samples the specified number of reading conversions to yield single filtered reading. Only one reading conversion is performed if the digital filter is disabled, or after the specified number of reading conversions for a moving average filter is reached.

*Figure 9-3*
*Measure action block of trigger model*




## Output triggers

Model 6514 can send out an output trigger (via the rear panel TRIGGER LINK connector) right after the measure action and/or when operation leaves the trigger layer. An output trigger can be used to trigger another instrument to perform an operation (e.g., select the next output step for a source).

### Counters

Programmable counters are used to repeat operations within the trigger model layers. For example, if the trigger count is set for 10, operation will keep looping around in the trigger layer until 10 measurements are performed. If the arm count is set to 2, operation will then loop back through the arm layer and go back into the trigger layer to perform 10 more measurements.

## Trigger model configuration — front panel

*NOTE* *See "SCPI Programming" (Table 9-2) for the SCPI commands to configure the trigger model.*

There are two separate configuration menus to configure the trigger model; one for the arm layer and one for the trigger layer. Note that trigger delay can be set from either the trigger layer configuration menu or from the DELAY key.

Once in a menu structure, use the ▲ and ▼ keys to display menu items. Use the cursor (◀ and ▶) and the ▲ and ▼ keys to key in values. A menu item or value is selected by pressing ENTER. Use the EXIT key to exit from the menu.

**Arm layer configuration menu** — The configuration menu for the arm layer is structured as follows. Bullets denote the main items of the menu. To access the menu, press SHIFT and then CONF-ARM.

- **ARM-IN** — Select the Arm-in control source:
  **IMM** (Immediate), **GPIB**, **TIMER**(1), **MAN** (Manual), **TLINK**(2), **/STEST**, **TEST**, or **BSTEST**.
  1. TIMER — You will be prompted to enter the timer interval (in hour, minute, second format). The TIMER annunciator will turn on. The minimum timer setting is 0.001 seconds.
  2. TLINK — Select the input trigger link line (1 to 6). You will then be prompted to enable (ONCE) or disable (NEVER) the source bypass.
- **ARM-OUT** — Configure the output trigger:
  **LINE** — Select the output trigger link line (1 to 6).
  **EVENT** — Enable (ON) or disable (OFF) the trigger layer done output trigger.
- **COUNT** — Set a finite (FIN) arm count (1 to 2500), or select infinite (INF) arm count.

*NOTE* *Input trigger and output trigger cannot share the same Trigger Link line. Defaults set line 1 as the input and line 2 as the output.*

**Trigger layer configuration menu** — The configuration menu for the trigger layer is structured as follows. Bullets denote the main items of the menu. To access the menu, press SHIFT and then CONF-TRIG.

- **TRIG-IN** — Select the Trig-In control source:
  **IMM** (Immediate), or **TLINK**. After selecting TLINK, select the input trigger link line (1 to 6). You will then be prompted to enable (ONCE) or disable (NEVER) the source bypass.

- **TRIG-OUT** — Configure output triggers:
  **LINE** — Select the output trigger link line (1 to 6).
  **VMC** — Enable (ON) or disable (OFF) the VMC (voltmeter complete) output trigger.
- **DELAY** — Configure the trigger delay of the trigger layer:
  **MAN** — Manually set the delay (0 to 999.9998 seconds).
  **AUTO** — Selects auto delay. The delay is set according to function/range (see Table 9-1).
- **COUNT** — Set a finite (FIN) trigger count (1 to 2500), or select infinite (INF) trigger count.

*NOTE* *Input trigger and output trigger cannot share the same trigger link line. Defaults set line 1 as the input and line 2 as the output.*

**DELAY Menu** — To access the menu for trigger delay, press the DELAY key.

- **DELAY** — Configure the trigger delay of the trigger layer:
  **MAN** — Manually set the delay (0 to 999.9998 seconds).
  **AUTO** — Selects auto delay. The delay is set according to function/range (see Table 9-1).

# SCPI programming

*Table 9-2*
*SCPI commands — triggering*

| Command | Description | Default | Ref |
|---|---|---|---|
| ABORt | Reset trigger system (goes to idle state). | | A |
| INITiate | Initiate one trigger cycle. | | B |
| FETch? | Request latest reading. | | B |
| READ? | Trigger and request a “fresh” reading. | | B |
| | | | |
| ARM[:SEQuence[1]] | Arm Layer: | | |
| [:LAYer[1]] | | | |
| :SOURce <name> | Select control source; IMMediate, TIMer, BUS, TLINk, STESt, PSTest, NSTest, BSTest, or MANual. | IMM | C |
| :COUNt <n> | Set measure count; 1 to 2500, or INF (infinite). | 1 | |
| :TIMer <n> | Set timer interval; 0.001 to 99999.999 (sec). | 0.1 | |
| [:TCONfigure] | | | |
| :DIRection <name> | Enable (SOURce) or disable (ACCeptor) bypass. | ACC | D |
| [:ASYNchronous] | Configure input/output triggers: | | |
| :ILINe <NRf> | Select input trigger line; 1, 2, 3, 4, 5 or 6. | 1 | E |
| :OLINe <NRf> | Select output trigger line; 1, 2, 3, 4, 5 or 6. | 2 | E |
| :OUTPut <name> | Output trigger (TRIGger) or not at all (NONE). | NONE | |
| | | | |
| TRIGger[:SEQuence[1]] | Trigger Layer: | | |
| :SOURce <name> | Select control source; IMMediate or TLINk. | IMM | |
| :COUNt <n> | Set measure count; 1 to 2500, or INF (infinite). | 1 | |
| :DELay <n> | Set trigger delay; 0 to 999.9998 (sec). | 0.0 | |
| :AUTO <b> | Enable or disable auto delay. | OFF | |
| [:TCONfigure] | | | |
| :DIRection <name> | Enable (SOURce) or disable (ACCeptor) bypass. | ACC | D |
| [:ASYNchronous] | Configure input/output triggers: | | |
| :ILINe <NRf> | Select input trigger line; 1, 2, 3, 4, 5 or 6. | 1 | E |
| :OLINe <NRf> | Select output trigger line; 1, 2, 3, 4, 5 or 6. | 2 | E |
| :OUTPut <name> | Output trigger after measurement (SENSe) or not at all (NONE). | NONE | |
| :TRIGger:CLEar | Clear pending input trigger. | NONE | F |

### A) ABORt

If operation has been started by the INITiate command, ABORt will cancel all operations and immediately return to the instrument to the idle state. If operation has been started by READ? (or MEASure?), ABORt has no affect.

### B) INITiate

1. After sending this command to take the instrument out of idle, the instrument will perform one or more measurements and then return to idle. The FETch? command can then be used to read the last reading that was measured.
2. If INITiate is sent while the instrument is operating within the trigger model, it will not execute until the operation returns to the idle state.
3. One alternative to using INITiate, is to use the READ? command. When READ? is sent, the instrument is taken out of idle and all readings that are taken are returned (see Section 15 for details on READ?).

### C) ARM:SOURce <name>

With the TIMer control source selected, use the ARM:TIMer command to set the timer interval.

### D) DIRection <name>

The source bypass can only be used if the TLINk control source is selected.

### E) ILINe <name> and OLINe <name>

Input trigger and output trigger cannot share the same trigger link line. Defaults set line 1 as the input and line 2 as the output.

### F) :TRIGger:CLEar

When this action command is sent, any pending (latched) input triggers are cleared immediately. When the Model 6514 is being latched by another instrument, it may inadvertently receive and latch input triggers that do not get executed. These pending triggers could adversely affect subsequent operation.

When using external triggering, it is recommended that TRIGger:CLEar be sent after sending the ABORt command and at the beginning of a program before sending an initiate command (See “INITiate” command).

## Programming example

The following command sequence will trigger and return 10 readings.

```
*RST                          ‘ Return 6514 to RST defaults.
ARM:SOURce IMMediate          ‘ Set arm control source Immediate.
ARM:COUNt 1                   ‘ Set arm count to 1.
TRIGger:SOURce IMMediate      ‘ Set trigger control source
                                Immediate.
TRIGger:COUNt 10              ‘ Set trigger count to 10.
READ?                         ‘ Trigger and return 10 readings.
```

# External triggering

Input and output triggers are received and sent via the rear panel TRIGGER LINK connector. The trigger link has six lines. At the factory, line #2 is selected for output triggers and line #1 is selected for input triggers. These input/output assignments can be changed as previously explained in this section. The connector pinout is shown in Figure 9-4.

*Figure 9-4*
*Trigger link connection operation*

Rear Panel Pinout



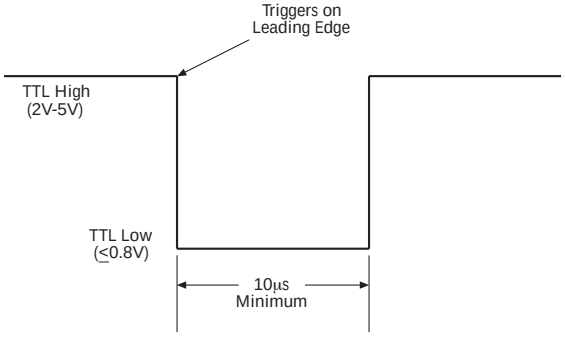

Trigger Link

| Pin Number | Description |
|---|---|
| 1 | Trigger Link 1 |
| 2 | Trigger Link 2 |
| 3 | Trigger Link 3 |
| 4 | Trigger Link 4 |
| 5 | Trigger Link 5 |
| 6 | Trigger Link 6 |
| 7 | Ground |
| 8 | Ground |

## Input trigger requirements

An input trigger is used to satisfy event detection for a trigger model layer that is using the TLINK control source. The input requires a falling-edge, TTL compatible pulse with the specifications shown in Figure 9-5.

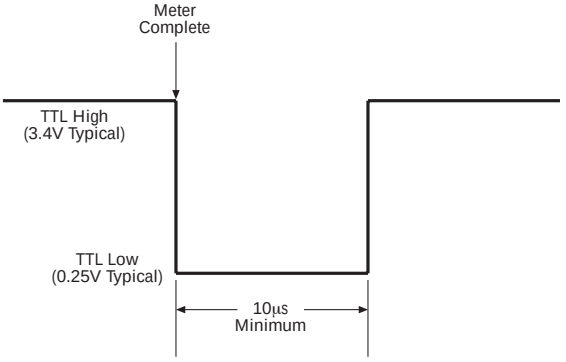
*Figure 9-5*
*Trigger link input pulse specifications*



## Output trigger specifications

Model 6514 can be programmed to output a trigger immediately after a measurement and/or when operation leaves the trigger layer of the trigger model. The output trigger provides a TTL-compatible output pulse that can be used to trigger other instruments. The specifications for this trigger pulse are shown in Figure 9-6. A trigger link line can source 1mA and sink up to 50mA.

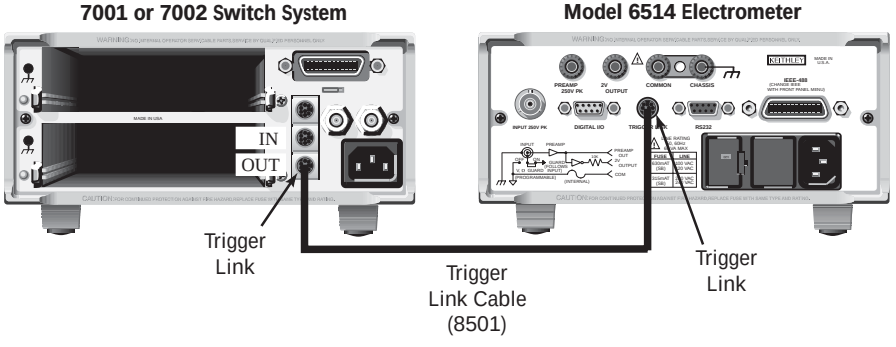
*Figure 9-6*
*Trigger link output pulse specifications*




## External trigger example

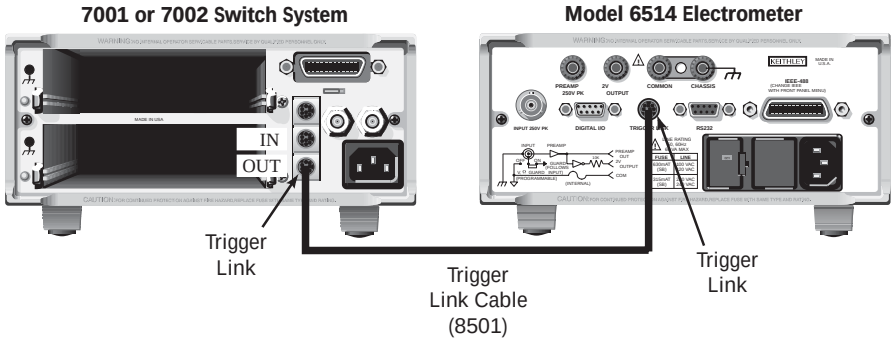
In a simple test system, you may want to close a switching channel and measure the resistance of a DUT connected to that channel. Such a test system is shown in Figure 9-7, which uses a Model 6514 to measure 10 DUTs switched by a Model 7011 multiplexer card in a Model 7001 or 7002 switch system.

*Figure 9-7*
*DUT test system*



The trigger link connections for this test system are shown in Figure 9-8. The trigger link of Model 6514 is connected to the trigger link (IN or OUT) of the switching mainframe. Note that with the default trigger settings of the switching mainframe, line #1 is an input and line #2 is an output.

*Figure 9-8 Trigger link connections*




For this example, Model 6514 and switching mainframe are configured as follows:

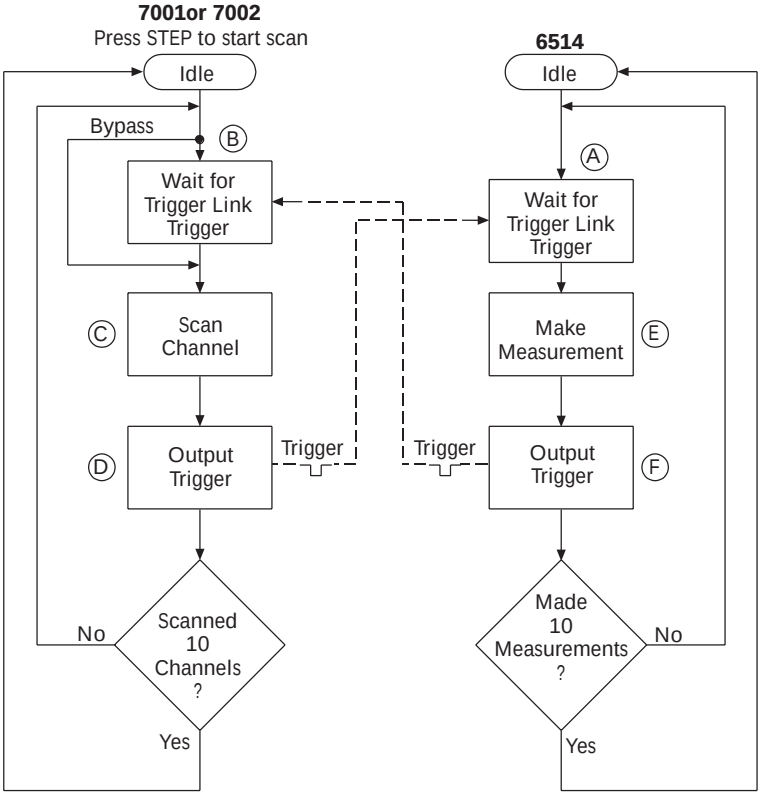
| **Model 6514** | **Switching Mainframe** |
|---|---|
| Factory Defaults Restored | Factory Defaults Restored |
| Trig-In Event = TLink | Scan List = 1!1-1!10 |
| Trigger Input Line = #2 | Number of Scans 1 |
| Trigger Output Line = #1 | Channel Spacing = TrigLink |
| Trigger Output Event = ON | |
| Trigger Count = 10 | |
| Trigger Delay = Auto | |

To store readings in Model 6514 buffer, press STORE and set the buffer size to 10. When ENTER is pressed, the asterisk (*) annunciator turns on to indicate the buffer is enabled (see Section 8 for details on buffer operation).

To start the test, press STEP on the switching mainframe to take it out of idle and start the scan. The switching mainframes output pulse triggers Model 6514 to take a reading and store it. Model 6514 then sends an output trigger pulse to the switching mainframe to close the next channel. This process continues until all 10 channels are scanned, measured and stored.

Details of this testing process are explained in the following paragraphs and are referenced to the operation model shown in Figure 9-9.

*Figure 9-9*
*Operation model for triggering example*




a. Operation of Model 6514 starts at point A in the flowchart, where it waits for an external trigger.

b. Pressing STEP takes Model 7001/2 out of idle and places operation at point B in the flowchart.

c. For the first pass through Model, the scanner does not wait at point B. Instead, it closes the first channel (point C).

d. After the relay settles, Model 7001/2 outputs a trigger pulse. Since the instrument is programmed to scan 10 channels, operation loops back to point B, where it waits for an input trigger.

e. and f. With Model 6514 at point A, the output trigger pulse from Model 7001/2 triggers a measurement of DUT #1 (point E). After the measurement is complete, Model 6514 outputs a trigger pulse and then loops back to point A, where it waits for another input trigger.

The trigger applied to Model 7001/2 from Model 6514 closes the next channel in the scan, which then triggers Model 6514 to measure that DUT. This process continues until all 10 channels are scanned and measured.

# 10
# Limit Tests

- **Limit testing** — Explains the basic Limit 1 and Limit 2 testing operations.
- **Binning** — Explains how to use a component handler to perform binning operations.
- **Front panel operation** — Explains how to configure and run tests from the front panel.
- **SCPI programming** — Covers the SCPI commands for remote operation.

# Limit testing

As shown in Figure 10-1, there are two limit tests that can be performed on a DUT. Limit 1 is used as the wide pass band and Limit 2 is used as the narrow pass band. It is up to the user to specify limits that conform to this pass band relationship.

*Figure 10-1*
*Limit tests*

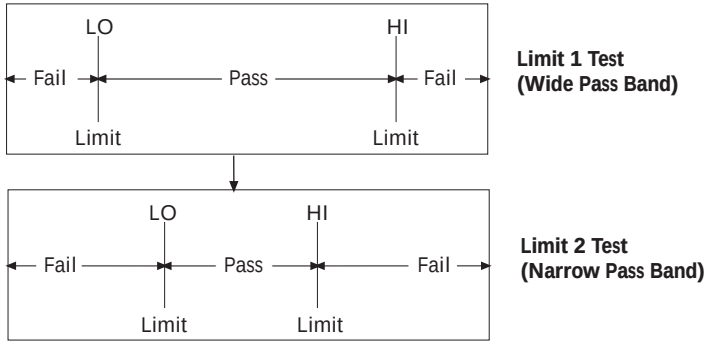
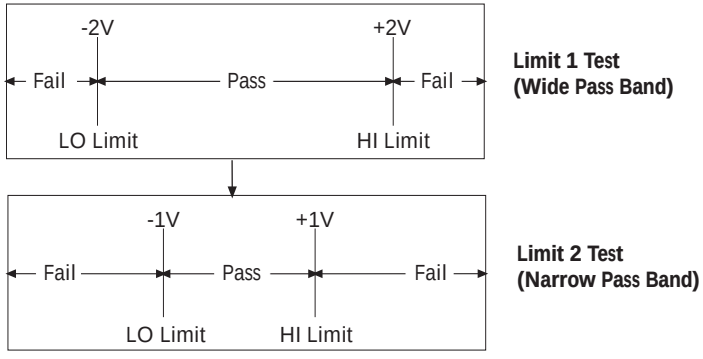



Figure 10-2 shows an example where the HI and LO limits for limit 1 are ±2V, and the Hi and LO limits for limit 2 are ±1V. A 0V reading passes both limit 1 and limit 2 tests. A +1.5V reading passes limit 1 but fails limit 2. A +2.5V reading fails both limit 1 and limit 2.

*Figure 10-2*
*Limit tests example*




The 2-stage limit testing process is shown in Figure 10-3. If limit 1fails, the “L1” message is displayed and the test is finished. Limit 2 is not tested because the pass band relationship between the two stages implies that if limit 1 fails, limit 2 must also fail. If limit 1 passes, the limit 2 test is performed. If limit 2 fails, the “L2” message is displayed. If both limit 1 and limit 2 pass, the “OK” message is displayed. The display messages for limit tests are summarized in Table 10-1.

A test is only performed if it is enabled. Therefore, you can perform a single-stage test or a 2-stage test. In the flowchart (Figure 10-3), operation simply proceeds through a disabled test.

*Figure 10-3*
*Operation model for limit test*

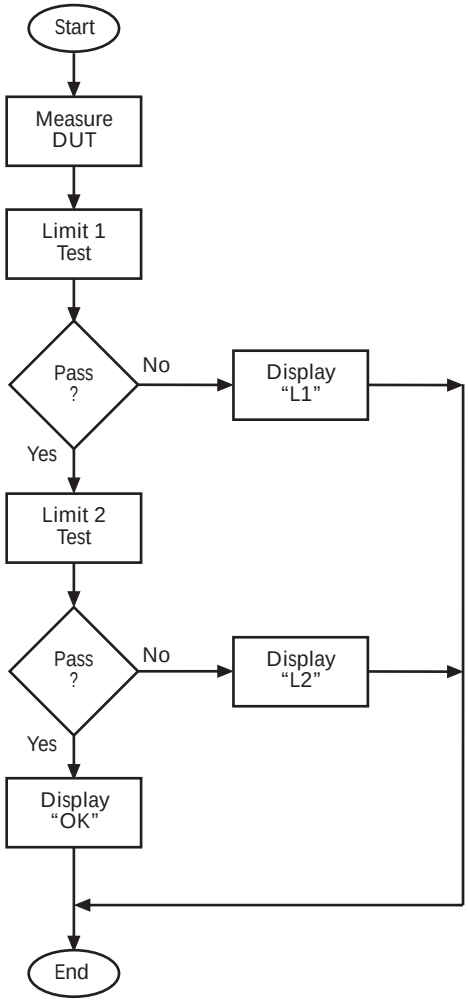



*Table 10-1*
*Test limit display messages*

| **Display Message** | **Limit 1 Test Result** | **Limit 2 Test Result** |
|---|---|---|
| :OK | Pass | Pass |
| :L1 | Fail | Not Performed |
| :L2 | Pass | Fail |

*NOTES* *Display messages indicate which test or tests have failed, but they do not indicate which limit (HI or LO) has failed. When using remote operation, you can determine which limit failed by reading the measurement event register. See Ref B for the FAIL? commands in Table 10-2.*

*Relative (Rel), mX+b and percent can be used with limit testing. The tests will be done on the result of the math operation (not the input values). These math operations are covered in Section 7.*

**Application** — A typical application for a 2-stage limit test is to sort a batch of DUT according to tolerance. For example, you may want to sort resistors (all having the same nominal value) into three groups, 1%, 5%, and >5%. The limits for limit 1 would be the 5% tolerances, and the limits for limit 2 would be the 1% tolerances. If a resistor passes both tests, it belongs in the 1% group. If it passes limit 1, but fails limit 2, it belongs in the 5% group. If it fails both tests, it belongs in the >5% group.

# Binning

Even though no additional equipment is required to perform limit tests on the DUT, Model 6514 can be used with a component handler to perform binning operations. Based on the outcome of a test, the component handler will place the DUT in the assigned bin.

Figure 10-4 shows a basic binning system. After all programmed testing on the DUT is completed, the appropriate digital output pattern is sent to the component handler, which then places the DUT in the appropriate bin. The component handler selects the next DUT, and the testing process is repeated.

*Figure 10-4*
*Binning system*

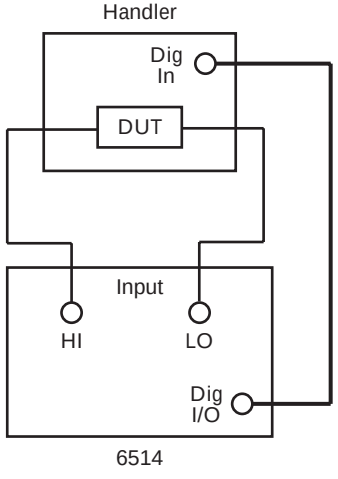
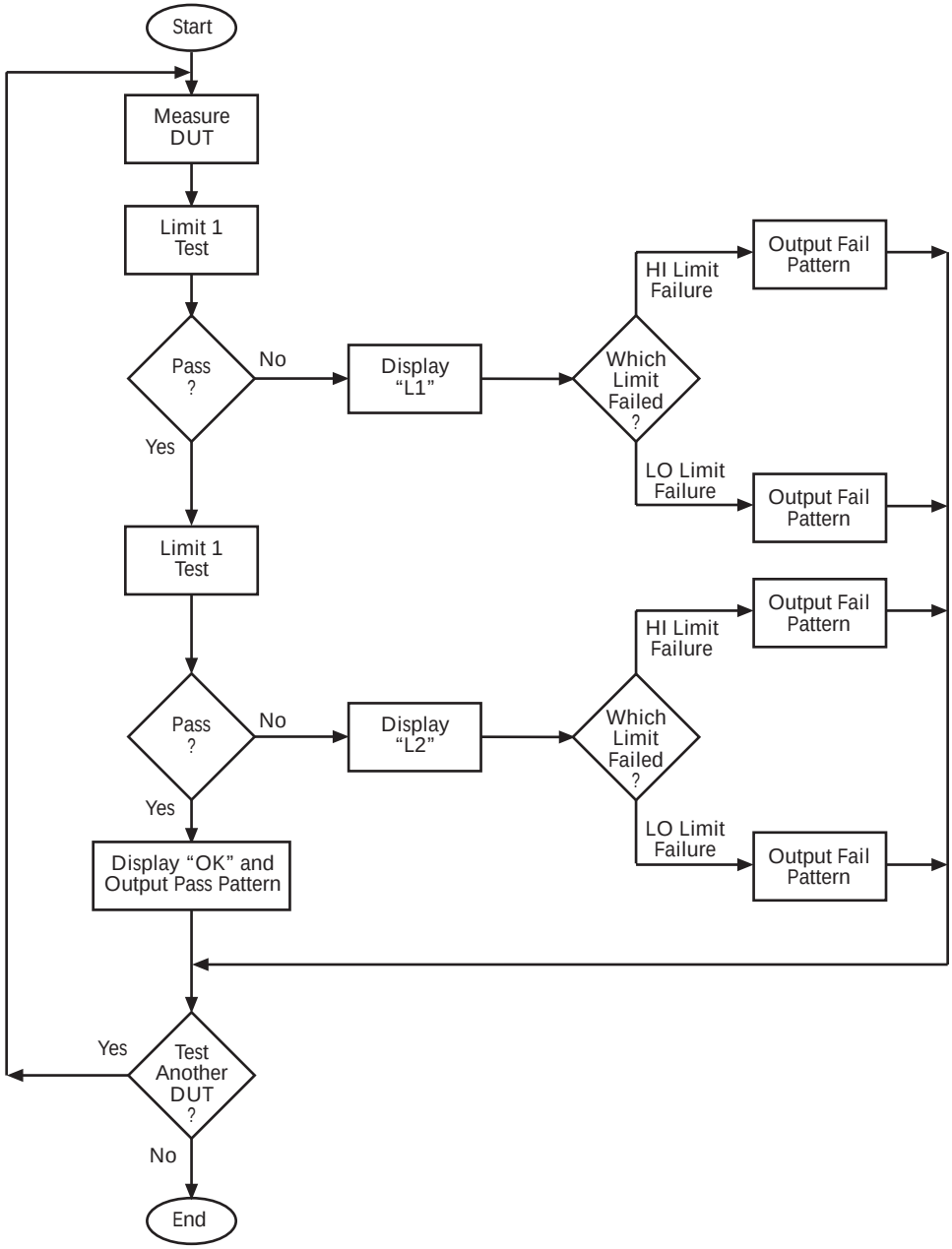


Figure 10-5 shows the basic limit testing flowchart expanded to include binning. Notice that there are five possible output patterns (one pass pattern and four fail patterns), but only one will be sent to the component handler for each DUT that is tested.

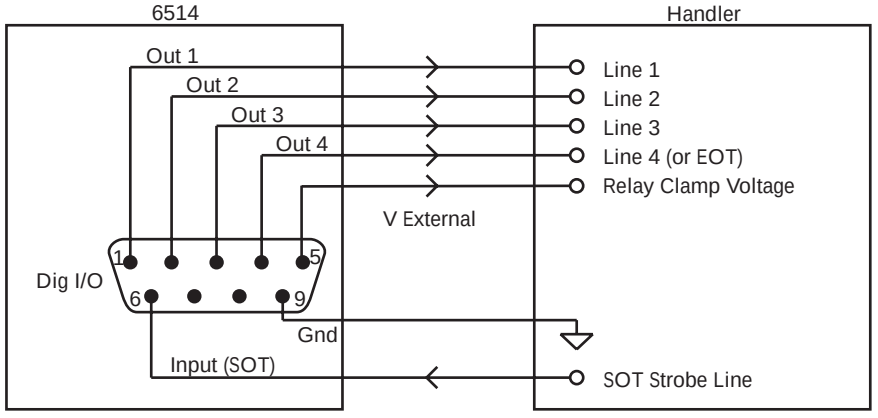
*Figure 10-5*
*Operation model for limit testing with binning*



## Component handler interface

Model 6514 is interfaced to a component handler via the Digital I/O port as shown in Figure 10-6. The I/O port has four lines for output signals and one line for input signals. The input line is used to start the test and the output lines are used to send the test pass/fail signal(s) to the component handler to perform the binning operation.

*Figure 10-6*
*Handler interface connections*




The digital I/O lines are available at the DB-9 connector on the rear panel of Model 6514. A custom cable using a standard female DB-9 connector is required for connection to Model 6514.

### Start of test

The SOT (start of test) line of the Digital I/O is used to control the start of the testing process. When /STest is the selected arm-in event for the arm layer of the trigger model, the testing process will start when the SOT line is pulled low. When test is the selected arm-in event, the test will start when the SOT line is pulled high. Section 9 provides details on trigger model configuration.

*NOTE* *If you do not wish to use the SOT line to start the test, you can use the immediate arm-in event. The testing process will start as soon as the LIMIT key is pressed (assuming one or both limit tests are enabled).*

The component handler will either maintain the SOT line high or low. This is its “not ready” condition. When the component handler is ready (DUT properly position in the handler), it will either pull the SOT line low or high to start the test.

### Digital output patterns

Model 6514 uses digital output bit patterns to communicate test results to the component handler. For each limit test, unique fail patterns are used for the HI and LO limits. A pass pattern is used to indicate that there were no errors. After a test is finished, the appropriate output pattern is sent to the component handler. The handler decodes the bit pattern and places the DUT in the appropriate bin.

Model 6514 can be used with either of the two basic types of handlers. When used with a category pulse handler, Model 6514 pulses one of the four handler lines. The handler then places the DUT into the bin assigned to the pulsed line.

When used with a category register handler, Model 6514 outputs a bit pattern to three handler lines. After Model 6514 sends the end-of-test (EOT) strobe pulse to the fourth handler line, the handler places the DUT into the bin assigned to that bit pattern.

## Component handler types

Model 6514 can accommodate two different types of component handlers; category pulse, and category register.

### Category pulse component handler

When using this type of handler, Model 6514 pulses one of the four handler lines when a pass or fail condition occurs. The handler then places the DUT in the bin assigned to that pulsed line. When interfacing to this type of handler, a maximum of four component handler bins are supported.

If the handler requires low-going pulses, then the four digital output lines of Model 6514 must be initially set to high. This initial HI, HI, HI, HI clear pattern on the output lines represents a "no action" condition for the handler since it is waiting for one of the lines to go low. A line goes low when the defined fail or pass pattern sets it low. For example, if you want a particular test failure to pulse line #4 of the handler, the defined fail pattern has to be HI, HI, HI, LO. When the failure occurs, line #4 will be pulled low, and the DUT will be placed in the bin assigned to that pulsed line.

If the handler requires a high-going pulse, the four digital output lines of Model 6514 must initially be set low. The LO, LO, LO, LO clear pattern represents the "no action" condition for the handler. When one of those lines are pulled high by a defined pass or fail bit pattern (i.e., LO, LO, LO, HI), the DUT will be placed in the bit assigned to that pulsed line.

### Category register component handler

When using this type of handler, Model 6514 sends a bit pattern to three handler lines when a pass or fail condition occurs. This bit pattern determines the bin assignment for the DUT. With the pass/fail pattern on the output, line #4 is then pulsed. This EOT (end-of-test) pulse latches the bit pattern into the register of the handler, which places the DUT in the assigned bin. When interfacing to this type of handler, a maximum of eight component handler bins are supported.

If the handler requires a low-going EOT pulse, line #4 of the digital output must initially be set high. When the EOT line is pulsed low, the binning operation occurs. When using the CONFIG LIMITS MENU to define pass/fail bit patterns, line #4 must be set low. If, for example, the required fail pattern by the handler is HI, LO, HI, then you must define the fail pattern of the test to be HI, LO, HI, LO. When the test fails, the HI, LO, HI bit pattern is sent to the handler. When line #4 goes LO, the bit pattern is latched into the register of the handler, and the binning operation occurs.

Conversely, if the handler requires a high-going EOT pulse, the EOT line of the digital output must initially be set low (off). When the EOT line is pulsed high, the binning operation occurs.

### Line 4 mode

When using a category pulse component handler, Model 6514 must be set to the Busy or /Busy mode. In the Busy mode, the idle state for line 4 is LO. When the test starts (SOT line pulsed), line 4 goes HI (busy state). After the test is finished, it goes back to LO. For the /Busy mode, the idle state for line 4 is HI and busy state is LO.

When using a catagory register component handler, Model 6514 must be set for the End of Test mode. In this mode, Model 6514 sends the EOT pulse to the component handler as previously explained.

## Digital output clear pattern

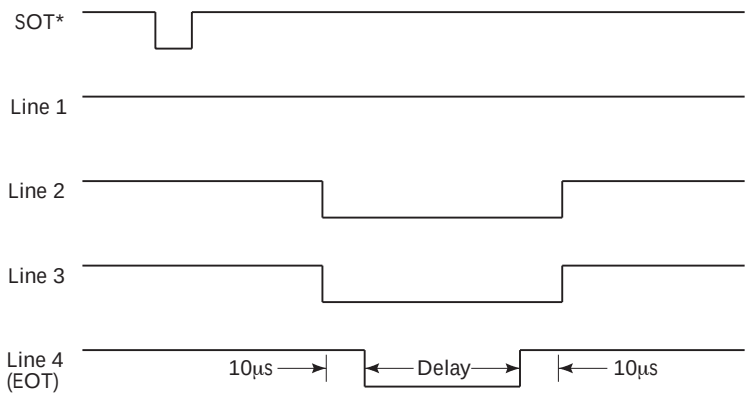
After every binning operation, the digital output needs to be reset to a clear pattern, which serves as a "no action" condition for the component handler.

Model 6514 can be programmed to automatically clear the digital output after the pass or fail pattern is sent. With auto-clear, you must specify the required pulse width (delay) for the pass or fail pattern. When not using auto-clear, you must return the digital output to its clear pattern.

*NOTE* *With the Busy line 4 mode selected, the clear state of line 4 is LO, regardless of the configured clear pattern. With the /Busy mode selected, the clear state of line 4 is HI.*

Auto-Clear timing — The following example timing diagram (Figure 10-7) and discussion explain the relationship between the digital output lines for auto-clear.

*Figure 10-7 Digital output auto-clear timing example*




* With the SOT line being pulsed low (as shown), /START TEST must be the selected arm event for the trigger model. If the SOT line is instead pulsed high by the handler, START TEST must be the selected arm event.

Initially, the four digital output lines are cleared (in this case, they are all set high). Limit tests start when the start-of-test (SOT) pulse is received from the component handler. When the testing process is finished, the pass or fail pattern is applied to the digital output. As shown in the diagram, lines 2, 3, and 4 go low while line 1 remains high.

The pulse width (delay) of the pass/fail pattern can be set from 0 to 60 sec (10µsec resolution) as required by the component handler. Note that the delay specifies the pulse width of line 4. The pulse width of lines 1, 2, and 3 is actually 20µsec longer. Line 4 is skewed because it is used as the end-of-test (EOT) strobe by category register component handlers. Lines 1, 2, and 3 establish the bit pattern and then 10µsec later the SOT strobe "tells" the handler to read the bit pattern and perform the binning operation. This 10µsec offset is used to make sure the correct bit pattern is read by the handler.

After the pass/fail is read by the handler, the digital output returns to the clear pattern.

# Front panel operation

## Limit test configuration

Most aspects of limit testing are configured from the limit configuration menu. When using a component handler, the "start of test" (/STest, Test or Immediate) option is set from the arm layer configuration menu.

Once in a menu structure, use the ▲ and ▼ keys to display menu items. Use the cursor ◀ and ▶ and the ▲ and ▼ keys to key in values. To change polarity of a value, place the cursor on "+" or "-" and press ▲ and ▼. To change range for the value, place the cursor on the range symbol and use the ▲ and ▼ keys (P = pico, $_N$ = nano, μ = micro, m = milli, ^ = x1, K = kilo, M = mega, G = giga, T = tera). A menu item or value is selected by pressing ENTER.

**Digital output bit patterns** — An output pattern is set by selecting a decimal value (0 to 15) that corresponds to the 4-bit BCD pattern of the output. To determine the output pattern value, add up the decimal weight values for the desired HI lines:

| Output HI Line: | Out 4 | Out 3 | Out 2 | Out 1 |
|---|---|---|---|---|
| Decimal Weight: | 8 | 4 | 2 | 1 |

For example, to set an output pattern to 0101 (lines 3 and 1 HI), set the output value to 5 (4 +1).

### Limits configuration menu

The configuration menu for limits is structured as follows. Bullets denote the main items of the menu. To access the menu, press SHIFT and then CONF-LIM.

- **LIMIT 1** — Configure limit 1 test:
  **CONTROL** — Enable or disable limit 1 test.
  **HILIM** — Set the HI limit (-9.999999T to +9.999999T), and set the "fail" digital output bit pattern (0 to 15).
  **LOLIM** — Set the LO limit (-9.999999T to +9.999999T), and set the "fail" digital output bit pattern (0 to 15).
- **LIMIT 2** — Configure limit 2 test:
  **CONTROL** — Enable or disable limit 2 test.
  **HILIM** — Set the HI limit (-9.999999T to +9.999999T), and set the "fail" digital output bit pattern (0 to 15).
  **LOLIM** — Set the LO limit (-9.999999T to +9.999999T), and set the "fail" digital output bit pattern (0 to 15).
- **PASS** — Set the digital output bit pattern for the "all tests pass" condition (0 to 15).
- **DIG CLR** (Digital Clear):
  **AUTO CLR** — Enable or disable auto-clear for the digital output.
  **DEL** (Delay) — Set the pass/fail pattern pulse width (0 to 60 sec with 10μsec resolution).
  **DIGOUT** — Set the digital output clear pattern (0 to 15).

- **LIN4MOD** (Line 4 Mode):
  **ENDOFTST** (End of Test) — With this mode, Model 6514 will pulse the EOT line when the test is finished. Use with catagory register component handlers.
  **/BUSY** and **BUSY** — Pulls line 4 LO (/Busy) or HI (Busy) while the test is in process. Use with catagory pulse component handlers.

### Arm layer configuration menu

When using a component handler, the "start of test" option is selected from the Arm-In menu item of the arm layer configuration menu. To access the menu, press SHIFT and then CONF-ARM.

- **ARM-IN** — Select the "start of test" option:
  **IMM** (Immediate) — Test starts when LIMIT key is pressed.
  **TEST** — Test starts when the handler pulls the SOT line of the Digital I/O high.
  **/STEST** — Test starts when the handler pulls the SOT line of the Digital I/O low.

*NOTE* *The other arm-in control sources are seldom used with component handlers, but are available.*

## Perform limit tests

### Step 1 Configure test system

As previously explained, testing the system could be as simple as connecting a DUT to Model 6514 or could employ the use of a component handler for binning operations.

### Step 2 Configure measurement

Configure Model 6514 for the desired measurement as covered in the previous sections of this manual.

### Step 3 Configure limit tests

Configure Model 6514 for the limit tests as explained in "Limit Test Configuration".

### Step 4 Start testing process

To enable the limit tests, press the LIMIT key. If the SOT line of the Digital I/O port is being used by a component handler, the test process will not start until the handler pulses the SOT line. Otherwise, the testing process will start when LIMIT is pressed.

### Step 5 Stop testing process

The testing process can be terminated at any time by again pressing the LIMIT key. When using a component handler, the testing process will stop after the last DUT is tested.

# SCPI programming

*Table 10-2*
*SCPI commands — limit tests*

| Command | Description | Default | Ref |
|---|---|---|---|
| :CALCulate2 | CALCulate2 Subsystem: | | |
| :FEED <name> | Select input path for limit testing; CALCulate[1] or SENSe[1]. | SENS | A |
| :LIMit[1] | Limit 1 Testing: | | |
| :UPPer | Configure upper limit: | | |
| [:DATA] <n> | Set limit; -9.99999e20 to 9.99999e20. | 1.0 | |
| :SOURce2 <NDN> or <NRf> | Specify 4-bit output “fail” pattern. | 15 | B |
| :LOWer | Configure lower limit: | | |
| [:DATA] <n> | Set limit; -9.99999e20 to 9.99999e20. | -1.0 | |
| :SOURce2 <NDN> or <NRf> | Specify 4-bit output “fail” pattern. | 15 | B |
| :STATe <b> | Enable or disable Limit 1 test. | OFF | |
| :FAIL? | Return result of Limit 1 test; 0 (pass) or 1(fail). | | C |
| :LIMit2 | Limit 2 Testing: | | |
| :UPPer | Configure upper limit: | | |
| [:DATA] <n> | Set limit; -9.99999e20 to 9.99999e20. | 1.0 | |
| :SOURce2 <NDN> or <NRf> | Specify 4-bit output “fail” pattern. | 15 | B |
| :LOWer | Configure lower limit: | | |
| [:DATA] <n> | Set limit; -9.99999e20 to 9.99999e20. | -1.0 | |
| :SOURce2 <NDN> or <NRf> | Specify 4-bit output “fail” pattern. | 15 | |
| :STATe <b> | Enable or disable Limit 2 test. | OFF | |
| :FAIL? | Return result of Limit 2 test; 0 (pass) or 1(fail). | | C |
| :CLIMits | Composite Limits: | | |
| :CLEar | Clear I/O port and restore it back to SOURce2:TTL settings: | | |
| [:IMMediate] | Clears I/O port immediately. | | |
| :AUTO <b> | When enabled, I/O port clears when :INITiate sent. | ON | |
| :PASS | Define “pass” digital output pattern. | | |
| :SOURce2 <NDN> or <NRf> | Specify 4-bit pass pattern (no failures). | 15 | B |
| :NULL | Configure and control Rel: | | Sec 7 |
| :OFFSet <NRf> | Specify Rel value; -9.999999e20 to 9.999999e20. | 0.0 | |
| :STATe <b> | Enable or disable Rel. | OFF | |
| :DATA? | Return CALC2 reading(s) triggered by INITiate. | | D |
| :LATest? | Return last (latest) CALC2 reading. | | D |

*Table 10-2 (cont.)*
*SCPI commands — limit tests*

| Command | Description | Default | Ref |
|---|---|---|---|
| :SOURce2 | SOURce2 Subsystem: | | |
| :TTL <NDN> or <NRf> | Specify 4-bit digital output clear pattern. | 15 | B |
| :CLEar | Clear I/O port (return output to TTL pattern): | | |
| [:IMMediate] | Clear I/O port immediately. | | |
| :AUTO <b> | Enable or disable auto-clear. | OFF | |
| :DELay <n> | Specify delay (pulse-width) for pass/fail pattern; 0 to 60 (sec). | 0.0001 | |
| :TTL4 | Line 4 Mode configuration: | | |
| :MODE <name> | Select output line 4 mode; EOTest or BUSY. | EOT | |
| :BSTate <ttl> | Select active TTL level for busy; 1 (HI) or 0 (LO). | 0 | |
| | Trigger Subystem: | | Sec 9 |
| ARM | Arm Layer: | | |
| :SOURce <name> | Select control source; NSTest, PSTest or IMMediate. | IMM | E |
| INITiate | Initiation one trigger cycle. | | D |
| FORMat | FORMat subsystem: | | |
| :SOURce2 <name> | Select data format for reading output patterns: | ASC | |
| | <name> = ASCii — Decimal format | | |
| | HEXadecimal — Hexadecimal format | | |
| | OCTal — Octal format | | |
| | BINary — Binary format | | |

## A) FEED <name>

Name parameters:

- CALCulate1 — Limit tests will be performed on the result of a math calculation (mX+b or percent).
- SENSe — Limit tests will be performed on the input signal. Note however, that Rel can be used on the result of a math calculation as well as the input signal. Limit tests will be performed on the result of the Rel operation (see CALCulate2:NULL). Details on relative, mX+b and percent are provided in Section 7.

## B) <NDN> and <NRf> parameters

| | | |
|---|---|---|
| <NDN> | = #Bxxxx | Binary format (each x = 1 or 0) |
| | = #Hx | Hexadecimal format (x = 0 to F) |
| | = #Qxx | Octal format (x = 0 to 17) |
| <NRf> | = 0 to 15 | Decimal format |

An output pattern is set by sending a parameter value that corresponds to the 4-bit BCD pattern of the output. The parameter value can be sent in the binary, decimal, hexadecimal, or octal format. For example, if you wish to set lines 4, 2, and 1 HI, the binary parameter value would

be 1011. To use one of the other formats, convert the binary number to its decimal, hexadecimal, or octal equivalent:

Binary 1011 = Decimal 11 = Hexadecimal B = Octal 13

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 to set an output pattern to 1101 (lines 4, 3 and 1 set HI):

| | |
|---|---|
| #b1101 | Binary format (<NDN> parameter type) |
| #hD | Hexadecimal format (<NDN> parameter type) |
| #q15 | Octal format (<NDN> parameter type) |
| 13 | Decimal format (<NRf> parameter type) |

*NOTE* *When a query command to read a programmed output pattern (i.e., CALC2:LIM:UPP:SOUR2?) is sent, the format for the returned value is determined by the presently selected response message format for output patterns (see FORMat:SOURce2 command in Table 10-2).*

## C) FAIL?

In the event of a failure, you can read the measurement event register to determine which limit (upper or lower) failed. See Section 13 to program and read the measurement event register.

## D) DATA?

The INITiate command must be sent to perform the programmed number of measurements. If the instrument is programmed to perform a finite number of measurements, the :DATA? command will return all the CALC2 readings after the last reading is taken. The :DATA:LATest? command will only return the last (latest) CALC2 reading.

If the instrument is programmed to perform an infinite number of measurements (arm count or trigger count set to infinite), you cannot use the :DATA? command to return CALC2 readings. However, you can use the :DATA:LATest? command to return the last CALC2 reading after aborting the measurement process. After sending the INITiate command to start the measurement process, use the ABORt command to abort the measurement process, then use :DATA:LATest? to return the last CALC2 reading.

Sending :DATA? or :DATA:LATest? without first sending INITiate will return “old” readings, or cause an error (-220) if limit is not enabled or there are no readings available.

## E) ARM:SOURce <name>

Typical “start of test” options:

- IMMediate — Test starts when LIMIT key is pressed.
- NSTest — Test starts when component handler pulls the SOT line low.
- PSTest — Test starts when component handler pulls the SOT line high.

## Programming example

The following command sequence will test DUT using the limit tests example shown in Figure 10-2.

```
*RST                    ' Restore RST defaults (Volts function).
CALC2:LIM:UPP 2         ' Set upper limit for Limit 1 (2V).
CALC2:LIM:LOW -2        ' Set lower limit for Limit 1 (-2V).
CALC2:LIM:STAT ON       ' Enable Limit 1 test.
CALC2:LIM2:UPP 1        ' Set upper limit for Limit 2 (1V).
CALC2:LIM2:LOW -1       ' Set lower limit for Limit 2 (-1V).
CALC2:LIM2:STAT ON      ' Enable Limit 2 test.
                        ' Connect DUT to input.
INIT                    ' Perform tests on DUT (one measure-
                         ment).
CALC2:LIM:FAIL?         ' Return result of Limit 1 test.
CALC2:LIM2:FAIL?        ' Return result of Limit 2 test.
```

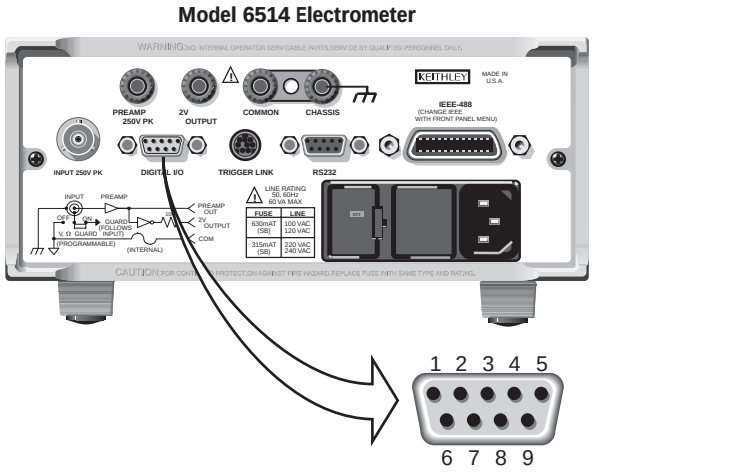
# 11
# Digital I/O, Analog Outputs, and External Feedback

- **Digital I/O port** — Explains how to use the digital I/O port to control external circuitry.
- **Analog outputs** — Covers the 2V analog output and preamp out.
- **External feedback** — Explains how to use the external feedback mode to perform charge and current measurements.

# Digital I/O port

Model 6517A's Digital I/O port is a male DB-9 connector located on the rear panel. The ports location and pin designations are shown in Figure 11-1. The four active-low, digital output lines and one input line are used to control external circuitry.

*Figure 11-1*
*Digital I/O port*




1 = Digital Output #1
2 = Digital Output #2
3 = Digital Output #3
4 = Digital Output #4 (EOT*)
5 = VEXT
6 = SOT*
7 = Not Used
8 = Not Used
9 = Digital Ground

* Start of Test (SOT) and End of Test (EOT) are used for Limit Tests (see Section 10).

Typical applications for the digital I/O port include the following:

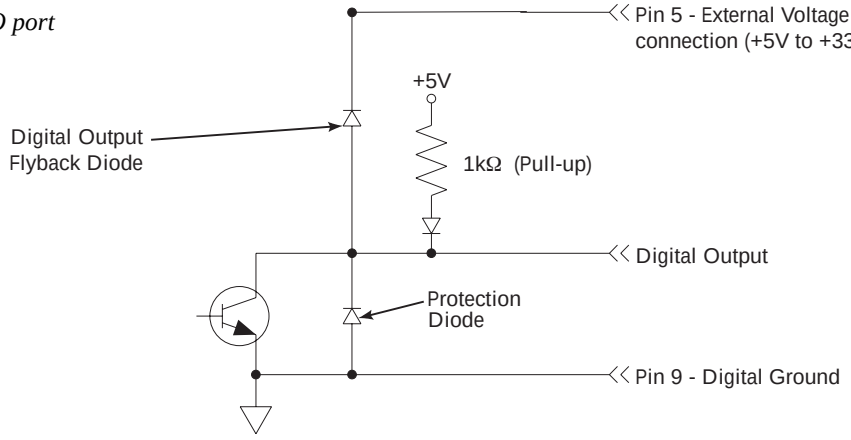
- **Component handler control** — When performing limit tests, a component handler can be used to sort DUT into bins. The digital I/O of Model 6514 serves as the interface between the limit tests and the component handler. Via the digital input line (pin 6), the component handler can tell Model 6514 when it is ready for the test. Via the digital output lines, Model 6514 sends digital output patterns to the component handler and tells it when the test is finished. A digital output pattern determines which bin the DUT belongs in.

*NOTE* *Information on using the digital I/O to control a component handler for limit tests is provided in Section 10.*

- **External device control** — Each digital output can be used as a control switch for an external device (i.e. relay) circuit. Each output line can sink up to 500mA. Drive voltage is provided by an external source (+5V to +33V).
- **Logic Control** — The four digital outputs can be used as inputs to logic devices.

The simplified schematic for the digital outputs are shown in Figure 11-2. Note that this illustration shows the schematic for one digital output. All four digital output circuits are identical.

*Figure 11-2 Digital I/O port simplified schematic*




## Sink mode — controlling external devices

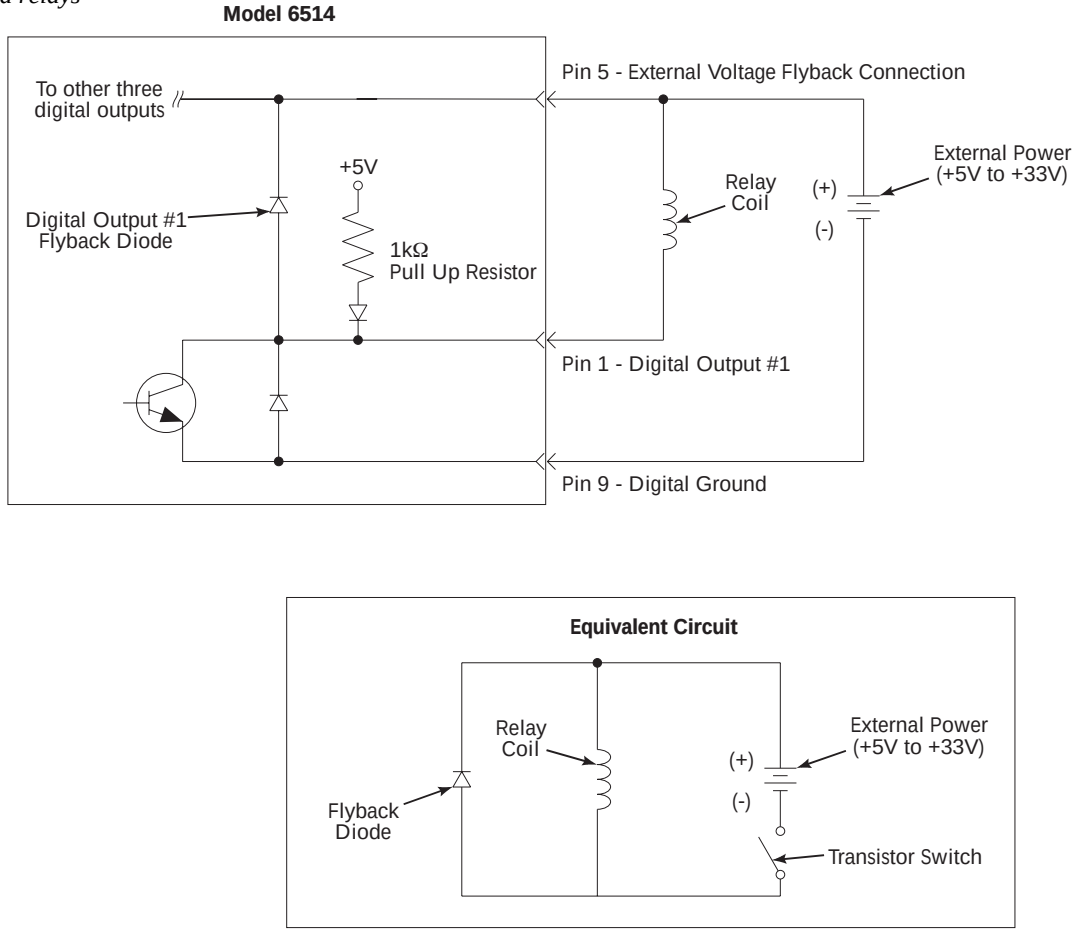
Each output can be operated from an external supply (voltage range from +5V to +33V applied through the external device being driven). The high current sink capacity of the output driver allows direct control of relays, solenoids, and lamps (no additional circuitry needed).

As shown in Figure 11-2, each of the four digital, open-collector outputs includes a built-in pull up resistor to +5V. The output transistor is capable of sinking 500mA 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 5 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 500mA.

*CAUTION* **Do not exceed +33V maximum voltage on pin 5 of the digital I/O port, and do not use any output line to sink >500mA. 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 11-3. Other externally powered devices can be similarly connected by replacing the relay with the device. When the output line is set LO (0V), the output transistor sinks current through the external device. In the HI state, the output transistor is off (transistor switch open). This interrupts current flow through the external device.

*Figure 11-3*
*Controlling externally powered relays*



## Source mode — logic control

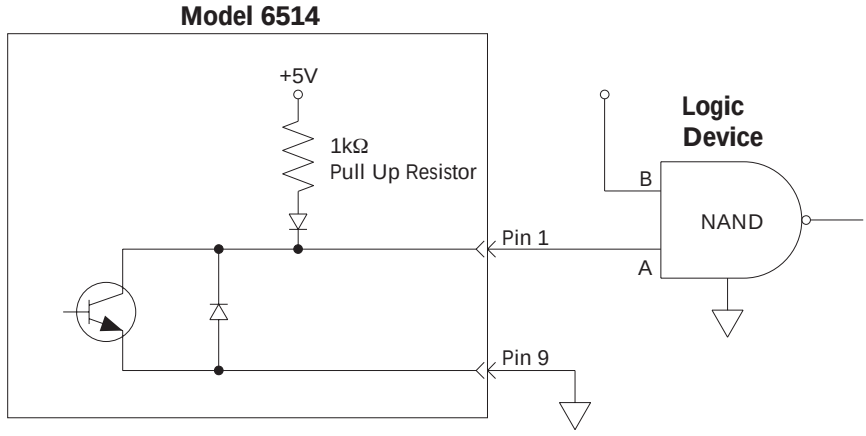
The digital outputs can be used as logic inputs to active TTL, low-power TTL, or CMOS inputs. For this mode of operation, the output lines can source up to 2mA.

*CAUTION* **Each output line can source up to 2mA. Exceeding 2mA may cause damage to Model 6514 that is not covered by the warranty.**

Figure 11-4 shows how to connect a logic device to one of the output lines. When the output line is set HI, the transistor will turn off (transistor switch open) to provide a reliable logic high output (>3.75V). When the output line is set LO, 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 HI.

*Figure 11-4*
*NAND gate control*




## Setting digital output lines

Digital output lines are set by selecting a decimal value (0 to 15) that corresponds to the 4-bit BCD pattern of the output. To determine the value, add up the decimal weight values for the desired HI lines:

| Output HI Line: | Out 4 | Out 3 | Out 2 | Out 1 |
|---|---|---|---|---|
| Decimal Weight: | 8 | 4 | 2 | 1 |

For example, to set output lines 3 and 1 HI (0101 bit pattern), set the output value to 5 (4 +1).

Perform the following steps to set the digital output pattern from the front panel:

1. Press SHIFT and then CONF-LIM to access the limits menu.
2. Press the ▲ or ▼ until "LIMIT:PASS" is displayed.
3. Press ENTER. The present digital output pattern value will be displayed.
4. Use the ◄, ►, ▲ and ▼ keys to display the desired output pattern value (0 to 15), and press ENTER.
5. Press EXIT to return to the normal display state.

## SCPI programming — digital output pattern

*Table 11-1*
*SCPI commands — digital outputs*

| Command | Description | Default |
|---|---|---|
| SOURce2 | SOURce2 Subsystem: | |
| :TTL <NRf> or <NDN> | Specify 4-bit digital output pattern (see "Parameter Values"). | 15 |
| :TTL? | Query the digital output pattern. The value returned is in the decimal format. | |
| Parameter Values (see Note): | | |
| <NRf> = 0 to 15 | Decimal format | |
| <NDN> = #Bxxxx | Binary format (each x = 1 or 0) | |
| = #Hx | Hexadecimal format (x = 0 to F) | |
| = #Qxx | Octal format (x = 0 to 17) | |

Note: The <NDN> parameter type can be used to set the output pattern using non-decimal values. Convert the decimal value to its binary, hexadecimal or octal equivalent and include the appropriate header (#B, #H or #Q). For example, to set output lines 4 and 2 HI using the binary format, send SOURce2:TTL #B1010. More information about the <NDN> parameter type is provided in Section 13 (see "Programming Enable Registers").

### Programming example

The following command sequence sets output lines 4 and 2 HI, and output lines 3 and 1 LO.

```
SOUR2:TTL 10              ' Set output lines 4 and 2 HI.
SOUR2:TTL?                ' Request output pattern value.
```

# Analog outputs

Model 6514 has two analog outputs on the rear panel. The 2V ANALOG OUTPUT provides a scaled ±2V output with a value of ±2V corresponding to full-range input. The PREAMP OUT is especially useful in situations requiring buffering. These two analog outputs are discussed in the following paragraphs.

*WARNING* **When floating input low above 30V RMS from earth ground, hazardous voltage will be present at the analog outputs. Hazardous voltage may also be present when the input voltage exceeds 30V RMS in the volts function, or when input currents exceed 30pA in the amps function.**

*CAUTION* **Connecting PREAMP OUT, COMMON, or 2V ANALOG OUTPUT to earth while floating the input may damage the instrument.**

## 2V analog output

The 2V analog output provides a scaled ±2V output that is non-inverting in the volts mode. Connections for using this output are shown in Figure 11-5. For a full-range input (i.e. 2V on the 2V range), the output will be 2V. Example analog outputs are listed in Table 11-2.

The 2V analog output signal is not corrected during calibration. Gain errors of up to 15% may appear at this output, depending on function and range.

The output impedance is 10kΩ. To minimize the effects of loading, the input impedance of the device connected to the 2V analog output should be as high as possible. For example, for a device that has an input impedance of 10MΩ, the error due to loading will be approximately 0.1%.

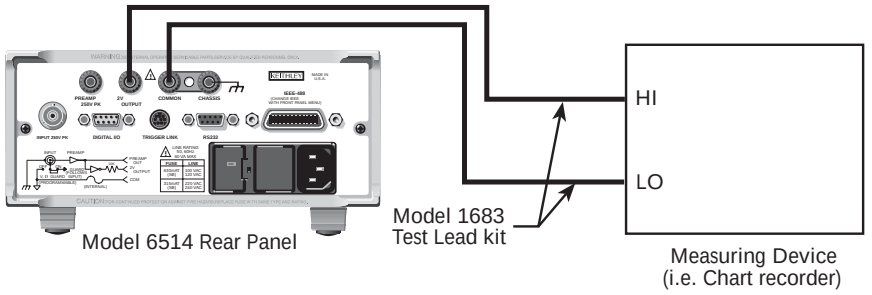
*NOTE* *Rel and the result of mX+b or percent have no affect on the analog output. The 2V analog output is scaled only to the actual input.*

*Table 11-2*
*Example 2V analog output values*

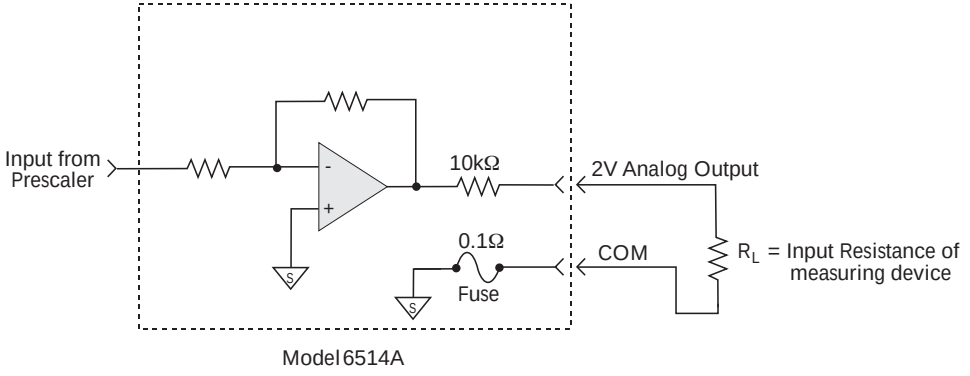
| Range | Applied signal | Analog output value (nominal)* |
|---|---|---|
| 20pA | 10.5pA | -1.05V |
| 2uA | -1.65µA | 1.65V |
| 200mV | 140mV | 1.4V |
| 200V | -36V | -0.36V |
| 200kΩ | 175kΩ | 1.75V |
| 20nC | 19nC | -1.9V |

* Output values are within ±15% of nominal value.

*Figure 11-5*
*Typical 2V analog output connections*




**A. Connections**

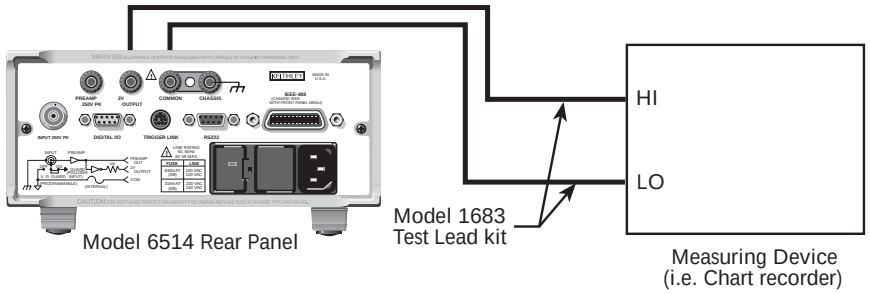



**B. Equivalent Circuit**

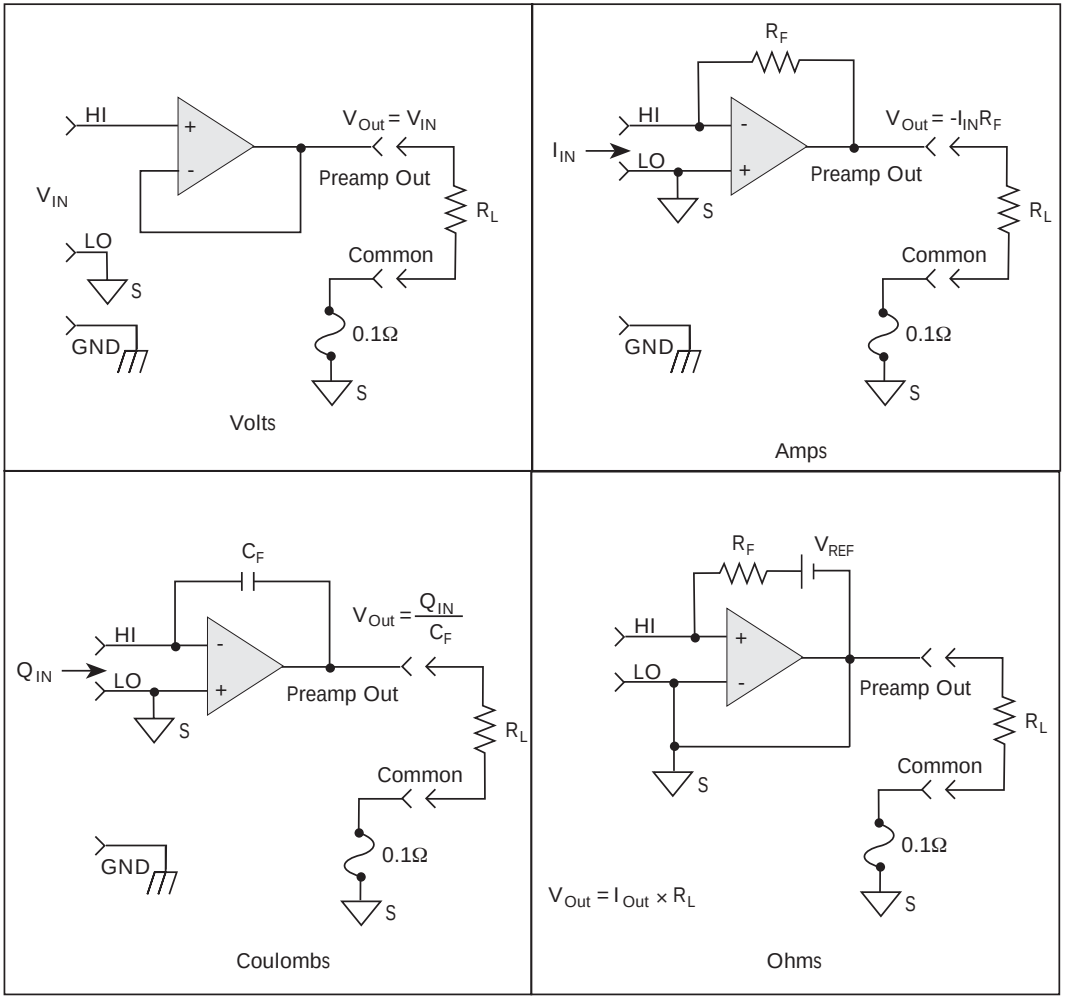
## Preamp out

The preamp output of Model 6514 follows the signal amplitude applied to the input terminal The preamp output provides a guard output for volts measurements. It can be used as an inverting output or with external feedback in the amps and coulombs modes. Connections and equivalent circuits for the preamp output are shown in Figure 11-6. Full-range outputs for the various functions and ranges are listed in Table 11-3.

*Figure 11-6 Typical preamp out connections*




**A. Connections**




**B. Equivalent Circuit**

Since the preamp output signal is not corrected during calibration, gain error of up to 15% may appear at this output, depending on function and range selection. For all volts ranges, preamp output accuracy is typically 10ppm.

*WARNING* **High voltage may be present between the preamp output and common terminals depending on the input signal (see Table 11-3).**

*CAUTION* **Connecting preamp output, common, or 2V analog output to earth while floating the input may damage the instrument.**

*Table 11-3*
*Full-range preamp out values*

| Function | Range | Full-range value |
|---|---|---|
| Volts | 2V | 2V |
| | 20V | 20V |
| | 200V | 200V |
| Amps | 2nA, 2µA, 2mA | 2V |
| | 20pA, 20nA, 20µA, 20mA | 20V |
| | 200pA, 200nA, 200µA | 200V |
| Ohms | 2kΩ, 2MΩ, 2GΩ | 2V |
| | 20kΩ, 20MΩ, 20GΩ | 20V |
| | 200kΩ, 200MΩ, 200GΩ | 200V |
| Coulombs | 20nC, 2µC | 20V |
| | 200nC, 20µC | 200V |

Note that the preamp out output resistance is 1Ω. The output resistance appears between input low and analog output low to keep the resistor out of the loop when using external feedback elements. To keep loading errors under 0.1%, the device connected to the preamp output should have a minimum input impedance of 100k.

*CAUTION* **To prevent damage to Model 6514, do not connect a device to preamp out that will draw more than ±100µA. For example, at 200V, the impedance connected to preamp out must be at least 2MΩ (200V/100µA = 2MΩ).**

# External feedback

The external feedback function provides a means to extend the capabilities of Model 6514 electrometer to such uses as logarithmic currents, non-decade current ranges, as well as non-standard coulombs ranges. The following paragraphs discuss the basic electrometer input circuitry and methods to implement these functions.

## Electrometer input circuitry

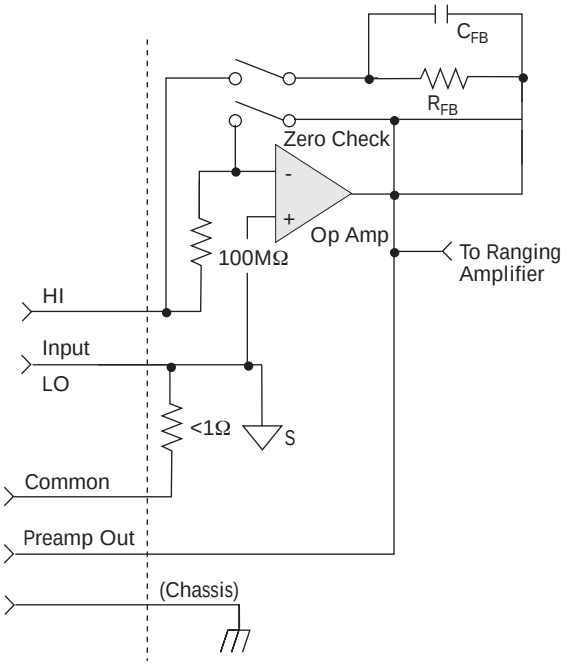
A simplified diagram of the electrometer input in the external feedback mode is shown in Figure 11-7. An input current applied to the inverting (-) input of the op amp is nulled by a current feedback through the internal feedback network made up of $R_{FB}$ and $C_{FB}$. Because the output of the op amp appears at the preamp out, this internal network can be replaced by an external network connected between the preamp output and input HI connections. When using external feedback, the following factors must be taken into account:

1. The maximum current value that can be supplied by the preamp output is 20mA in amps and ohms (1mA in volts). The maximum voltage span in external feedback is ±20V.
2. The input impedance in the external feedback mode is given by the relationship $Z_{IN} = Z_{FB}/A_V$, where: $Z_{FB}$ is the impedance of the external feedback network, and $A_V$ is the open-loop gain of the electrometer (typically greater than $55\times10^6$). Note that the input impedance is $Z_{IN} = 10M\Omega \parallel Z_{FB}$ when zero check is enabled.
3. The voltage at the preamp out terminal is given by the formula:

   V = -IZFB

4. Any feedback elements should be housed in a suitable shielded enclosure (see “Shielded Fixture Construction” below). Insulators connected to input HI should be made of Teflon or other high-quality insulating material and should be thoroughly cleaned to maintain the high input impedance and low input current of Model 6514. If these insulators become contaminated, they can be cleaned with methanol and then with clean, pressurized air.

*Figure 11-7*
*Electrometer input circuitry (external feedback mode)*




## Shielded fixture construction

Since shielding is so critical for proper operation of external feedback, it is recommended that a shielded fixture similar to the one shown in Figure 11-8 be used to house the feedback element. The fixture is constructed of a commercially available shielded fixture modified with the standard BNC connectors replaced with triaxial female connectors. For convenience, a banana jack can be mounted on the box to make the necessary preamp out connection.

Alternately, a wire could be run through a rubber grommet mounted in a hole in the side of the box. Note that input low is connected to chassis ground within the shielded box. This connection can be made by using a small solder lug secured with a screw.

## Non-standard coulombs ranges

The Model 6514 has four coulombs ranges allowing it to measure charge between 10fC and 20µC. Charge measurements greater than 20µC can be obtained by placing the instrument in the external feedback mode and measuring the voltage across an external feedback capacitor. See the following subheading "External feedback procedure" for instructions.

Charge is related to capacitance and voltage by the formula:

$Q = CV$

where: Q = the charge in coulombs
C = the capacitance in farads
V = the voltage in volts.

Model 6514 display will read the charge directly in units determined by the value of C. For example, a 10µF capacitor will result in a displayed reading of 10µC/V.

In practice, the feedback capacitor should be greater than 100pF for feedback stability and of suitable dielectric material to ensure low leakage and low dielectric absorption. Polystyrene, polypropylene, and Teflon dielectric capacitors are examples of capacitor types with these desirable characteristics. The capacitor should be mounted in a shielded fixture like the one in Figure 11-8.

To discharge the external feedback capacitor, enable zero check. The discharge time constant will be given by: $t = (10M\Omega)(C_{FB})$. Allow five time constants for discharge to within 1% of final value.

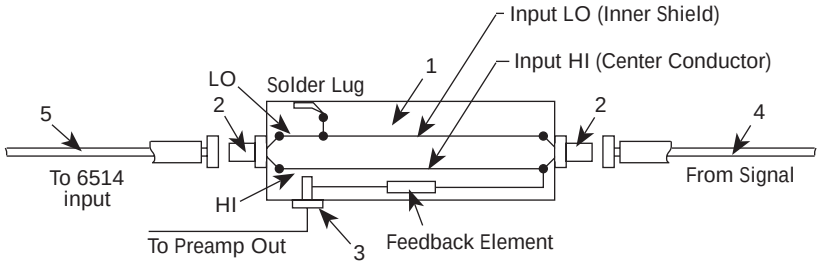
## External feedback procedure

Use the following procedure to operate Model 6514 in the external feedback mode.

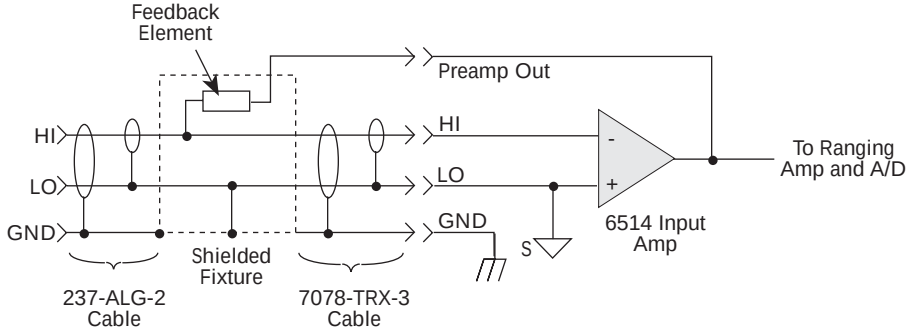
1. Enable zero check.
2. Connect the feedback element between the preamp out terminal and the input HI terminal.
3. Enable external feedback as follows:
   a. Press the XFBK key to access the external feedback menu.
   b. Press the ▲ or ▼ key to select ON and press ENTER.
4. Press the V key to select the volts function.
5. Disable zero check. The "XF" message will be displayed to indicate that the instrument is in the external feedback mode. The display will show the voltage measured at the output of the input preamplifier (PREAMP OUT).

*NOTE To disable external feedback, press XFBK and select the OFF option.*

*Figure 11-8*
*Shielded fixture construction*




**A. Construction**




**B. Equivalent Circuits**

| Parts List | | |
|---|---|---|
| Item | Description | MFR Part Number |
| 1 | Shielded Fixture | Pomona #2390 |
| 2 | Female Triaxial | Keithley 7078-TRX-TBC |
| 3 | Banana Jack | Keithley BI-9-2 |
| 4 | Triaxial Cable | Keithley 237-ALG-2 |
| 5 | Triaxial Cable | Keithley 7078-TRX-3 |

## Logarithmic currents

The use of a diode junction in the external feedback path permits a logarithmic current-to-voltage conversion. This relationship for a junction diode is given by the equation:

$V = mkT/q \ln(I/I_O) + I_{RB}$

where; q = unit of charge ($1.6022 \times 10^{-19}$)
k = Boltzmann's constant ($1.3806 \times 10^{-23}$)
T = temperature (K).

The limitations in this equation center on the factors $I_O$, m, and RB. $I_O$ is the extrapolated current for $V_O$. An empirical proportional constant, m, accounts for the different character current conduction (recombination and diffusion mechanisms) within the junction, typically varying between 1 and 2. Finally, RB constitutes the ohmic bulk resistance of the diode junction material. $I_O$ and RB limit the usefulness of the junction diode at low and high currents respectively. The factor m introduces non-linearity's between those two extremes. Because of these limitations, most diodes have a limited range of logarithmic behavior.

A solution to these constraints is to use a transistor configured as a "transdiode" in the feedback path, as shown in Figure 11-9. Analyzing the transistor in this configuration leads to the relationship:

$V = kT/q[\ln(I/I_O) - \ln(h_{FE}/(1 + h_{FE}))]$

where; $h_{FE}$ is the current gain of the transistor.

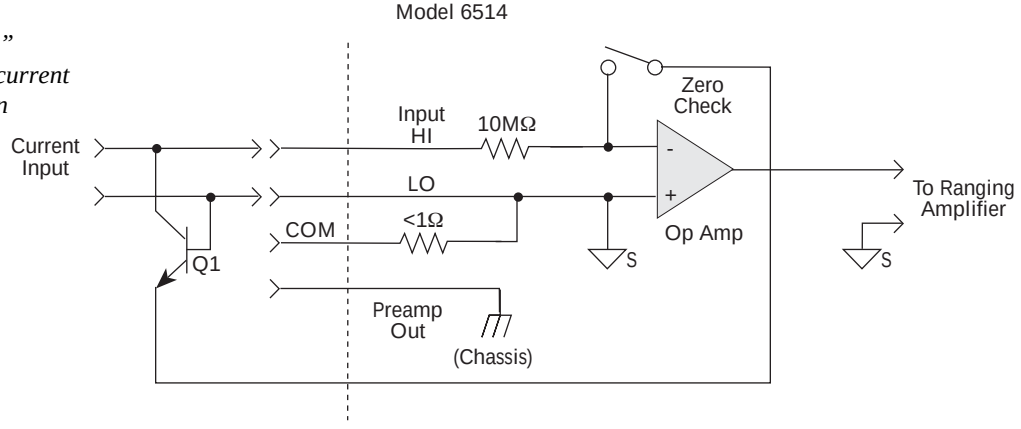



*Figure 11-9*
*"Transdiode" logarithmic current configuration*

From this equation, proper selection of Q1 would require a device with high current gain ($h_{FE}$), which is maintained over a wide range of emitter currents. Suitable devices for this application include Analog Devices AD812 and Precision Monolithics MAT-01. Use the enclosure in Figure 11-8 to shield the device.

Frequency compensation/stabilization is accomplished by adding a feedback capacitor, $C_{FB}$. The value of this capacitor depends on the particular transistor being used and the maximum current level expected. Compensation at maximum current is required because the dynamic impedance will be minimum at this point. It should be noted that the response speed at lower currents will be compromised due to the increasing dynamic impedance, which is given by the following formula:

Using the above transistors, a minimum RC time constant of 100µsec at maximum input current would be used. At $I_{IN}$ (max) of 100µA, this value would correspond to 0.4µF. Note that at 100nA, this value would increase the RC response time constant to 100msec. A minimum capacitance of 100pF is recommended.

Although the input signal to this particular circuit is assumed to be a current, conversion to voltage input could be performed by placing a shunt resistor across the input. However, the nominal voltage burden of 1mV must be considered as an error signal that must be taken into account.

Further processing of the current response can be achieved by using the suppress feature. For example, REL could be enabled with a reference input current applied. For all subsequent currents, the natural logarithm of the ratio of the measured current to the suppressed current would then be displayed:

$$\begin{aligned} V_{DISP} &= V_{REL}\ kT/q\ (\ln (I_{READ}/I_O) - \ln (I_{REL}/I_O)) \\ &= kT/q\ (\ln (I_{READ}/I_{REL})) \\ &= 0.26/I\ (\ln (I_{READ}/I_{REL}))\ @\ 25^{\circ}C \end{aligned}$$

*NOTE* *The circuit topology of Figure 11-9 works for positive input currents only. For bipolar input signals, an external offset bias must be applied, or use a PNP transistor for Q1.*

## Non-decade current gains

Model 6514 electrometer input uses internal decade resistance feedback networks for the current ranges. In some applications, non-decade current gains may be desirable. As shown in Figure 11-10, an external feedback resistor, $R_{FB}$, can be used to serve this purpose. Limitations on the magnitude of the feedback current require that the value of $R_{FB}$ be greater than $10^2\Omega$.

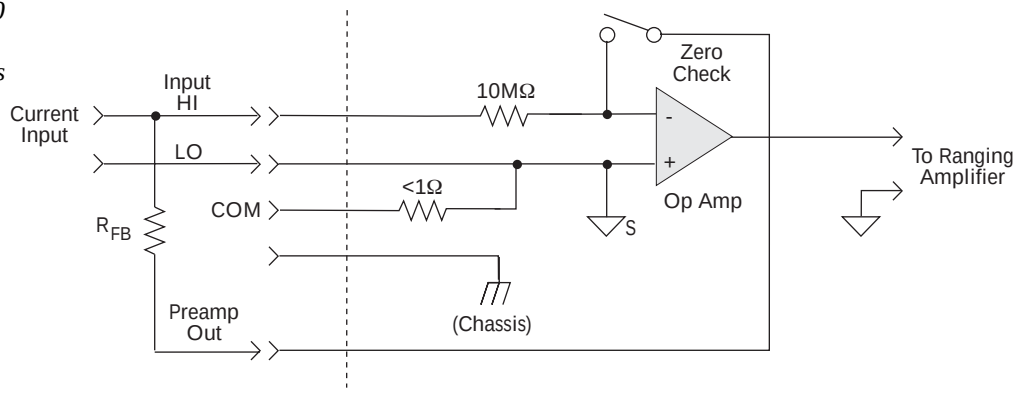



*Figure 11-10 Non-decade current gains*

## SCPI programming — external feedback

*Table 11-4*
*SCPI commands — external feedback*

| Commands | Description | Ref | Default |
|---|---|---|---|
| [SENSe] | SENSe Subsystem: | | |
| :VOLTage | Volts configuration: | | |
| :XFEedback <b> | Enable or disable external feedback. | | Off |
| :FUNCtion VOLTage | Select Volts function. | Sec 3 | |
| SYSTem | SYSTem Subsystem: | | |
| :ZCHeck <b> | Enable or disable zero check. | Sec 2 | On |

### Programming example — external feedback

The following command sequence configures Model 6514 to perform measurements using the external feedback mode:

```
SYST:ZCH ON            ' Enable zero check.
VOLT:XFE ON            ' Enable external feedback.
FUNC 'VOLT'            ' Select Volts function.
SYST:ZCH OFF           ' Disable zero check.
READ?                  ' Trigger measurement(s) and request
                       reading(s).
```

# 12
# Remote Operation

- **Selecting and configuring an interface** — Explains how to select and configure an interface; GPIB or RS-232.
- **GPIB operation and reference** — Covers the following GPIB topics:
  GPIB Bus Standards
  GPIB Bus Connections
  Primary Address Selection
  General Bus Commands
  Front Panel GPIB Operation
  Programming Syntax
- **RS-232 interface reference** — Provides basic reference information for the RS-232 interface and explains how to make connections to the computer.

# Selecting and configuring an interface

## Interfaces

Model 6514 supports two built-in remote interfaces:

- GPIB interface
- RS-232 interface

You can use only one interface at a time. At the factory, the GPIB bus is selected. You can select the interface only from the front panel. The interface selection is stored in non-volatile memory; it does not change when power has been off or after a remote interface reset.

**GPIB interface** — The GPIB is the IEEE-488 interface. Model 6514 must be assigned to unique address. At the factory the address is set to 14, but can be set to any value from 0 to 30. However, the address must not conflict with the address assigned to other instruments in the system. You can use either the SCPI or DDC language to program the instrument.

**RS-232 interface** — When using the RS-232 interface, you must set baud rate, data bits, parity, terminator and flow control. For the RS-232 interface, you can only use the SCPI language to program the instrument.

## Languages

For the GPIB interface, there are two programming languages to choose from:

- SCPI language
- DDC language

*NOTE* *For the RS-232 interface, only the SCPI language can be used to program the instrument. When the RS-232 interface is selected, it automatically defaults to SCPI.*

**SCPI language** — Standard Commands for Programmable Instrument (SCPI) is fully supported by the GPIB and RS-232 interfaces. Always calibrate Model 6514 using the SCPI language.

**DDC language** — Model 6514 implements most DDCs (device-dependent commands) available in the Keithley Models 6512, 617, and 617 HIQ electrometers. The commands are provided in Appendix D. See the appropriate instruction manual for details on operation.

## Interface selection and configuration procedures

When you select (enable) the GPIB interface, the RS-232 interface disables. Conversely, selecting (enabling) the RS-232 interface disables the GPIB interface.

*NOTE When an interface is enabled (on) or disabled (off), the instrument will exit from the menu structure and perform the power-on sequence.*

## GPIB interface

The GPIB interface is selected and configured from the GPIB menu structure. From this menu, you can enable or disable the GPIB interface, and check or change the following settings:

- Primary address (0 to 30)
- Language (SCPI or DDC)

**Selecting GPIB interface** — Press SHIFT and then GPIB to access the GPIB menu. The present status (on or off) of the GPIB interface is displayed. If the GPIB is already enabled (on), proceed to step 1 of "Checking/Changing GPIB Settings" to check and/or change the settings. Perform the following steps to enable (select) the GPIB interface:

1. Place the cursor on the OFF setting by pressing the ◄ or ► key.
2. Press the ▲ or ▼ key to toggle the setting to ON.
3. Press ENTER. The instrument will exit the menu structure and perform the power-on sequence.

**Checking/changing GPIB settings** — Press SHIFT and then GPIB to access the GPIB menu and perform the following steps:

1. Use the ▲ or ▼ key to display the present address (ADDR) and language (LANG) settings. If these settings are correct, press EXIT to exit the menu. Otherwise, continue on to change one or both settings.
2. Use ▲ or ▼ to display the primary address (ADDR). To retain this address, press ENTER. To change the GPIB address:
   a. Press the ◄ or ► key to move the cursor over to the address value field.
   b. Use the ◄, ►, ▲ and ▼ keys to display a valid address value (0 to 30).
   c. Press ENTER. The present programming language setting is then displayed.
3. To retain the displayed programming language (LANG), press ENTER. To change the programming language:
   a. Press ◄ or ► to move the cursor over to the language setting.
   b. Press ▲ or ▼ to display the desired language setting (SCPI or DDC).
   c. Press ENTER. The unit will reset.

## RS-232 interface

The RS-232 interface is selected and configured from the RS-232 menu structure. From this menu, you can enable or disable the RS-232 interface, and check or change the following settings:

- Baud rate (57.6K, 38.4k, 19.2k, 9600, 4800, 2400, 1200, 600 or 300)
- Data bits (7 or 8)
- Parity (none, odd or even)
- Terminator (CR, LF, CRLF or LFCR)
- Flow control (none or Xon/Xoff)

*NOTE See "RS-232 Interface Reference" (located at the end of this section) for information on these settings and connections to the computer.*

**Selecting RS-232 interface** — Press SHIFT and then RS-232 to access the RS-232 menu. The present status (on or off) of the RS-232 interface is displayed. If it is already enabled (on), proceed to step 1 of "Checking/Changing RS-232 Settings" to check and/or change the settings. Perform the following steps to enable (select) the RS-232 interface:

1. Place the cursor on the OFF setting by pressing the ◄ or ► key.
2. Press the ▲ or ▼ key to toggle the setting to ON.
3. Press ENTER. The instrument will exit the menu structure and perform the power-on sequence.

**Checking/changing RS-232 settings** — Press SHIFT and then RS-232 to access the RS-232 menu and perform the following steps:

1. Use the ▲ or ▼ key to display the RS-232 settings. If these settings are correct, press EXIT to exit the menu. Otherwise, continue on to change one or more settings.
2. Use the ▲ or ▼ key to display the baud rate (BAUD). To retain this baud rate, press ENTER. To change the baud rate:
   a. Press the ◄ or ► key to move the cursor over to the baud rate value.
   b. Use the ▲ or ▼ key to display the desired baud rate (300 to 57.6k).
   c. Press ENTER. The data bits setting is then displayed.
3. To retain the displayed data bits setting (BITS), press ENTER. To change the data bits setting:
   a. Press the ◄ or ► key to move the cursor over to the data bits value.
   b. Use the ▲ or ▼ key to display the desired number of data bits (8 or 7).
   c. Press ENTER. The parity setting is then displayed.
4. To retain the displayed parity setting (PARITY), press ENTER. To change the parity setting:
   a. Press ◄ or ► to move the cursor over to the parity setting.
   b. Use ▲ or ▼ to display the desired parity (NONE, ODD or EVEN).
   c. Press ENTER. The terminator is then displayed.
5. To retain the displayed terminator (TX TERM), press ENTER. To change the terminator:
   a. Press ◄ or ► (to move the cursor over to the terminator setting.
   b. Use ▲ or ▼ to display the desired terminator (LFCR, CR, CRLF or LF).
   c. Press ENTER. The flow control setting is then displayed.
6. To retain the displayed flow control setting (FLOW), press ENTER. To change the flow control setting:
   a. Press ◄ or ► to move the cursor over to the flow control setting.
   b. Use ▲ or ▼ to display the desired flow control setting (NONE or XonXoff).
   c. Press ENTER.

*NOTE Only the SCPI language can be used with the RS-232 interface. The instrument defaults to the SCPI language when the RS-232 interface is selected (enabled).*

# GPIB operation and reference

## GPIB bus standards

The GPIB bus is the IEEE-488 instrumentation data bus with hardware and programming standards originally adopted by the IEEE (Institute of Electrical and Electronic Engineers) in 1975. Model 6514 conforms to these standards:

- IEEE-488.1-1987
- IEEE-488.2-1992

This standard defines a syntax for sending data to and from instruments, how an instrument interprets this data, what registers should exist to record the state of the instrument, and a group of common commands.

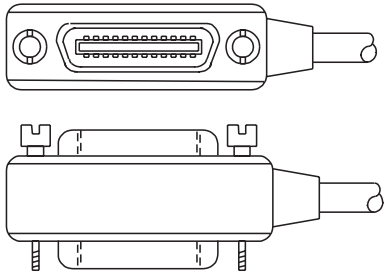
- SCPI 1996.0 (Standard Commands for Programmable Instruments)

This standard defines a command language protocol. It goes one step further than IEEE-488.2-1992 and defines a standard set of commands to control every programmable aspect of an instrument.

## GPIB bus connections

To connect Model 6514 to the GPIB bus, use a cable equipped with standard IEEE-488 connectors as shown in Figure 12-1.

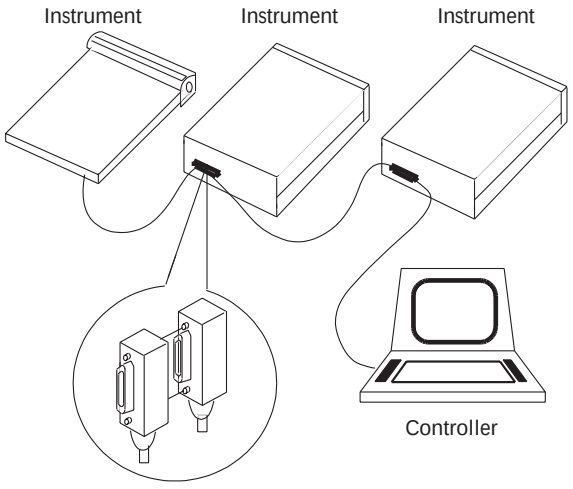
*Figure 12-1*
*IEEE-488 connector*



To allow many parallel connections to one instrument, stack the connector. Two screws are located on each connector to ensure that connections remain secure. Current standards call for metric threads, which are identified with dark-colored screws. Earlier versions had different screws, which were silver-colored. Do not use these types of connectors on Model 6514, because it is designed for metric threads.

Figure 12-2 shows a typical connecting scheme for a multi-unit test system.

*Figure 12-2*
*IEEE-488 connections*



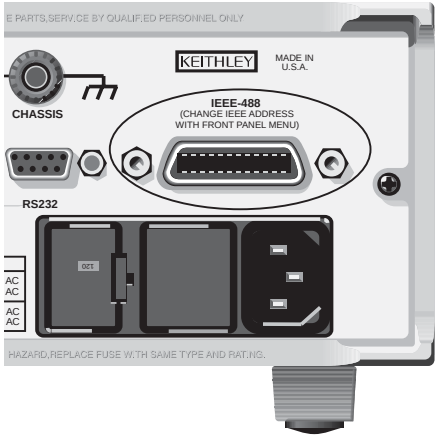

To avoid possible mechanical damage, stack no more than three connectors on any one unit.

*NOTE* *To minimize interference caused by electromagnetic radiation, use only shielded IEEE-488 cables. Available shielded cables from Keithley are Models 7007-1 and 7007-2.*

To connect Model 6514 to the IEEE-488 bus, follow these steps:

1. Line up the cable connector with the connector located on the rear panel. The connector is designed so that it will fit only one way. Figure 12-3 shows the location of the IEEE-488 connector.

*Figure 12-3*
*IEEE-488 connector location*




2. Tighten the screws securely, making sure not to over tighten them.
3. Connect any additional connectors from other instruments as required for your application.
4. Make sure that the other end of the cable is properly connected to the controller. Most controllers are equipped with an IEEE-488 style connector, but a few may require a different type of connecting cable. See your controllers instruction manual for information about properly connecting to the IEEE-488 bus.

*NOTE* *You can only have 15 devices connected to an IEEE-488 bus, including the controller. The maximum cable length is either 20 meters or two meters times the number of devices, whichever is less. Not observing these limits may cause erratic bus operation.*

## Primary address selection

Model 6514 ships from the factory with a GPIB address of 14. When the instrument powers up, it momentarily displays the primary address. You can set the address to a value of 0-30. Do not assign the same address to another device or to a controller that is on the same GPIB bus.

Usually controller addresses are 0 or 21, but see the controllers instruction manual for details. Make sure the address of the controller is the same as that specified in the controllers programming language.

The primary address is checked or changed from the GPIB menu, which is accessed by pressing SHIFT and then GPIB. Press the ▲ or ▼ key to display the present address (i.e. ADDR: 14).

To change the GPIB address:

1. Press SHIFT and then GPIB to access the GPIB configuration menu.
2. Use the ▲ or ▼ key to display the present address (i.e. ADDR: 14).
3. Use the ◀, ▶, ▲ and ▼ keys to display a valid address value and press ENTER.
4. Return to the main display by pressing EXIT.

# General bus commands

## Commands and associated statements

General commands are those commands, such as DCL, that have the same general meaning regardless of the instrument. Table 12-1 lists the general bus commands.

*Table 12-1*
*General bus commands*

| Command | Effect on Model 6514 |
|---|---|
| REN | Goes into remote when next addressed to listen. |
| IFC | Reset interface; all devices go into talker and listener idle states. |
| LLO | LOCAL key locked out. |
| GTL | Cancel remote; restore front panel operation for Model 6514. |
| DCL | Return all devices to known conditions. |
| SDC | Returns Model 6514 to known conditions. |
| GET | Initiates a trigger. |
| SPE, SPD | Serial polls Model 6514. |

## REN (remote enable)

The remote enable command is sent to Model 6514 by the controller to set up the instrument for remote operation. Generally, the instrument should be placed in the remote mode before you attempt to program it over the bus. Simply setting REN true does not actually place the instrument in the remote state. You must address the instrument to listen after setting REN true before it goes into remote.

Note that the instrument does not have to be in remote to be a talker.

Also, note that all front panel controls except for LOCAL and POWER are inoperative while the instrument is in remote. You can restore normal front panel operation by pressing the LOCAL key.

### IFC (interface clear)

The IFC command is sent by the controller to place all instruments on the bus in the local, talker, listener idle states. Model 6514 responds to the IFC command by canceling front panel TALK or LSTN lights, if the instrument was previously placed in one of those states. Note that this command does not affect the status of the instrument; settings, data, and event registers are not changed.

To send the IFC command, the controller must set the IFC line true for a minimum of 100µs.

### LLO (local lockout)

Use the LLO command to prevent local operation of the instrument. After the unit receives LLO, all its front panel controls except the POWER are inoperative. In this state, pressing the LOCAL will not restore control to the front panel. The GTL command restores control to the front panel.

### GTL (go to local)

Use the GTL command to put a remote mode instrument into local mode. The GTL command also restores front panel key operation.

### DCL (device clear)

Use the DCL command to clear the GPIB interface and return it to a known state. Note that the DCL command is not an addressed command, so all instruments equipped to implement DCL will do so simultaneously.

When Model 6514 receives a DCL command, it clears the input buffer and output queue, cancels deferred commands, and clears any command that prevents the processing of any other device command. A DCL does not affect instrument settings and stored data.

### SDC (selective device clear)

The SDC command is an addressed command that performs essentially the same function as the DCL command. However, since each device must be individually addressed, the SDC command provides a method to clear only selected instruments instead of clearing all instruments simultaneously, as is the case with DCL.

### GET (group execute trigger)

GET is a GPIB trigger that is used as an event to control operation. Model 6514 reacts to this trigger if it is the programmed control source. The control source is programmed from the SCPI TRIGger subsystem.

### SPE, SPD (serial polling)

Use the serial polling sequence to obtain Model 6514 serial poll byte. The serial poll byte contains important information about internal functions. Generally, the serial polling sequence is used by the controller to determine which of several instruments has requested service with the SRQ line. However, the serial polling sequence may be performed at any time to obtain the status byte from Model 6514.

## Front panel GPIB operation

The following paragraphs describe aspects of the front panel that are part of GPIB operation, including messages, status indicators, and the LOCAL key.

### Error and status messages

See Appendix B for a list of error and status messages associated with IEEE-488 programming. The instrument can be programmed to generate an SRQ, and command queries can be performed to check for specific error conditions.

### GPIB status indicators

The REM (remote), TALK (talk), LSTN (listen), and SRQ (service request) annunciators show the GPIB bus status. Each of these indicators is described below.

- REM — This indicator shows when the instrument is in the remote state. REM does not necessarily indicate the state of the REM line, as the instrument must be addressed to listen with REM true before the REM indicator turns on. 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.
- TALK — This indicator is on when the instrument is in the talker active state. Place the unit in the talk state by addressing it to talk with the correct MTA (My Talk Address) command. TALK is off when the unit is in the talker idle state. Place the unit in the talker idle state by sending a UNT (Untalk) command, addressing it to listen, or sending the IFC (Interface Clear) command.
- LSTN — This indicator is on when Model 6514 is in the listener active state, which is activated by addressing the instrument to listen with the correct MLA (My Listen Address) command. LSTN is off when the unit is in the listener idle state. Place the unit in the listener idle state by sending UNL (Unlisten), addressing it to talk, or sending the IFC (Interface Clear) command over the bus.
- 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 ceased to exist.

### 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 LLO (Local Lockout) command is in effect, the LOCAL key is also inoperative.

# Programming syntax

The following paragraphs cover syntax for both common commands and SCPI commands. For more information, see the IEEE- 488.2 and SCPI standards.

## 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. |
| :DISPlay:ENABle <b> | Parameter <b> required. |
| :SYSTem:PRESet | No parameter used. |

Put at least one space between the command word and the parameter.

- 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 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.

  :DISPlay:ENABle ON Enable the display

  <name> Name parameter — Select a parameter name from a listed group.

  <name> = NEVer
  = NEXT

  :CALCulate:FORMat MXB Select Mx + B calculation

  <NRf> Numeric representation format — A number that can be expressed as an integer (e.g., 8) a real number (e.g., 23.6) or an exponent (2.3E6).

  :TRACe:POINts 20 Set buffer size to 20

<NDN> Non-decimal numeric — A non-decimal value that can be used to program status enable registers. A unique header identifies the format; #B (binary), #H (hexadecimal) and #Q (octal). See “Programming Enable Registers” in Section 13 for details.

| | |
|---|---|
| *SRE #B10001 | Set bits B0 and B4 of Service Request Enable Register |

<n> Numeric value — Can consist of an NRf number or one of the following name parameters: DEFault, MINimum, or 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.

| | |
|---|---|
| :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 999999.999 sec. |

- Angle brackets < > — Used to denote a parameter type. Do not include the brackets in the program message.

  :DISPlay:ENABle <b>

  The <b> indicates that a Boolean type parameter is required. Thus, to enable the display, you must send the command with the ON or 1 parameter as follows.

  :DISPlay:ENABle ON or 1

## Query commands

The query command requests 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.

| | |
|---|---|
| :ARM: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.

| | |
|---|---|
| :ARM:TIMer? DEFault | Queries the *RST default value |
| :ARM:TIMer? MINimum | Queries the lowest allowable value |
| :ARM: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 tables in this manual use the long-form version. However, the short-form version is indicated by upper case characters.

| | |
|---|---|
| :SYSTem:PRESet | long-form |
| :SYST:PRES | short form |
| :SYSTem:PRES | long-form and short-form combination |

Note that each command word must be in either long-form or short-form. 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.

  :auto = :auto

These rules apply to command words that exceed four letters:

- If the fourth letter of the command word is a vowel, delete it and all the letters after it.

  immediate = :imm

- If the fourth letter of the command word is a consonant, retain it but drop all the letters after it.

  :format = :form

- If the command contains a question mark (?) or a non-optional number included in the command word, you must include it in the short-form version.

  :delay? = :del?

- Command words or characters that are enclosed in brackets ([ ]) are optional and need not be included in the program message.

## 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 simply a three letter acronym preceded by an asterisk (*). The following SCPI commands from the STATus subsystem are used to help explain how command words are structured to formulate program messages.

| Command structure | |
|---|---|
| :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 entered 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.
- The colon (:) at the beginning of a program message is optional and need not be used.

  :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.
- When the path pointer detects a colon (:) that immediately follows a semicolon (;), it resets to the root level.
- The path pointer can only move down. It cannot be moved up a level. Executing a command at a higher level requires that you start over at the root command.

**Using common commands 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.

:stat:oper:enab <NRf>; *ESE <NRf>

**Program Message Terminator (PMT)**

Each program message must be terminated with an LF (line feed), EOI (end or identify), or an LF+EOI. The bus will hang if your computer does not provide this termination. The following example shows how a program message must be terminated:

:trac:poin 10 <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.
- For fastest command execution:
  1. Do not use optional command words (i.e., [:SENSE [1]]).
  2. Do not use the colon (:) at the beginning of a program message.
  3. Always use the short-form versions of commands and parameters.
  4. Minimize the amount of “white” space in command strings.
  5. Keep numeric parameters simple (i.e., 1 vs. 1.000e + 00).
  6. Use all upper-case.

## 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. When Model 6514 is addressed to talk, the response message is sent from the output queue to the computer.

### Multiple response messages

If you send more than one query command in the same program message (see "Multiple Command Messages"), the multiple response messages for all the queries is sent to the computer when Model 6514 is addressed to talk. The responses are sent in the order that 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) and EOI (end or identify). 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.** Always tell Model 6514 what to send to the computer.
The following two steps must always be performed to send information from the instrument other computer:
1. Send the appropriate query command(s) in a program message.
2. Address Model 6514 to talk.

**Rule 2.** The complete response message must be received by the computer before another program message can be sent to Model 6514.

# RS-232 interface reference

## Sending and receiving data

The RS-232 interface transfers data using seven or eight data bits and one stop bit. Parity selections include none, odd or even.

## RS-232 settings

The procedure to select and configure the RS-232 interface is provided in "Selecting and Configuring an Interface" located at the beginning of this section. Make sure the controller you connect to Model 6514 also uses these settings.

*NOTE* *You can break data transmissions by sending a ^C or ^X character string to Model 6514. This clears any pending operation and discards any pending output.*

### Baud rate

The baud rate is the rate at which Model 6514 and the programming terminal communicate. You can choose from one of the following rates: 57.6k, 38.4k, 19.2k, 9600, 4800, 2400, 1200, 600 or 300.

Make sure that the programming terminal that you are connecting to Model 6514 can support the baud rate you selected. Both Model 6514 and the other device must be configured for the same baud rate.

### Data and stop bits

The RS-232 can be set to transfer data using seven or eight data bits and one stop bit.

### Parity

Parity for the RS-232 interface can be set to none, even or odd.

### Terminator

Model 6514 can be configured to terminate each program message that it transmits to the controller with any of the following combinations of <CR> and <LF>:

- LF line feed
- CR carriage return
- LFCR line feed, carriage return
- CRLF carriage return, line feed

### Flow control (signal handshaking)

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. Model 6514 does not support hardware handshaking (flow control).

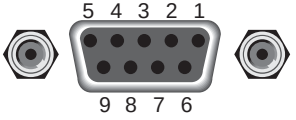
Software flow control is in the form of X_ON and X_OFF characters and is enabled when XonXoFF is selected from the RS232 FLOW menu. When the input queue of Model 6514 becomes more than 3/4 full, the instrument issues an X_OFF command. The control program should respond to this and stop sending characters until Model 6514 issues the X_ON, which it will do once its input buffer has dropped below half-full. Model 6514 recognizes X_ON and X_OFF sent from the controller. An X_OFF will cause Model 6514 to stop outputting characters until it sees an X_ON. Incoming commands are processed after the <CR> character is received from the controller.

If NONE is the selected flow control, then there will be no signal handshaking between the controller and Model 6514. Data will be lost if transmitted before the receiving device is ready.

## RS-232 connections

The RS-232 serial port can be connected to the serial port of a controller (i.e., personal 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), and signal ground (GND) lines of the RS-232 standard. It does not use the hardware handshaking lines CTS and RTS. Figure 12-4 shows the rear panel connector for the RS-232 interface, and Table 12-2 shows the pinout for the connector.

*Figure 12-4*
*RS-232 interface connector*




**RS232**
Rear Panel 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). Table 12-3 provides pinout identification for the 9-pin (DB-9) or 25-pin (DB-25) serial port connector on the computer (PC).

*Table 12-2*
*RS-232 connector pinout*

| Pin number | Description |
|---|---|
| 1 | DCD, data carrier detect |
| 2 | TXD, transmit data |
| 3 | RXD, receive data |
| 4 | DTR, data terminal ready |
| 5 | GND, signal ground |
| 6 | DSR, data set ready |
| 7 | RTS, ready to send |
| 8 | CTS, clear to send |
| 9 | No connections |

RTS and CTS are tied together.
DCD, DTR, and DSR are tied together.

*Table 12-3*
*PC serial port pinout*

| Signal | DB-9 pin number | DB-25 pin number |
|---|---|---|
| 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 B for RS-232 error messages.

# 13
# Status Structure

- **Overview** — Provides an operational overview of the status structure for Model 6514.
- **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

Model 6514 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 13-1. The heart of the status structure is the status byte register. This register can be read by the users test program to determine if a service request (SRQ) has occurred, and what event caused it.

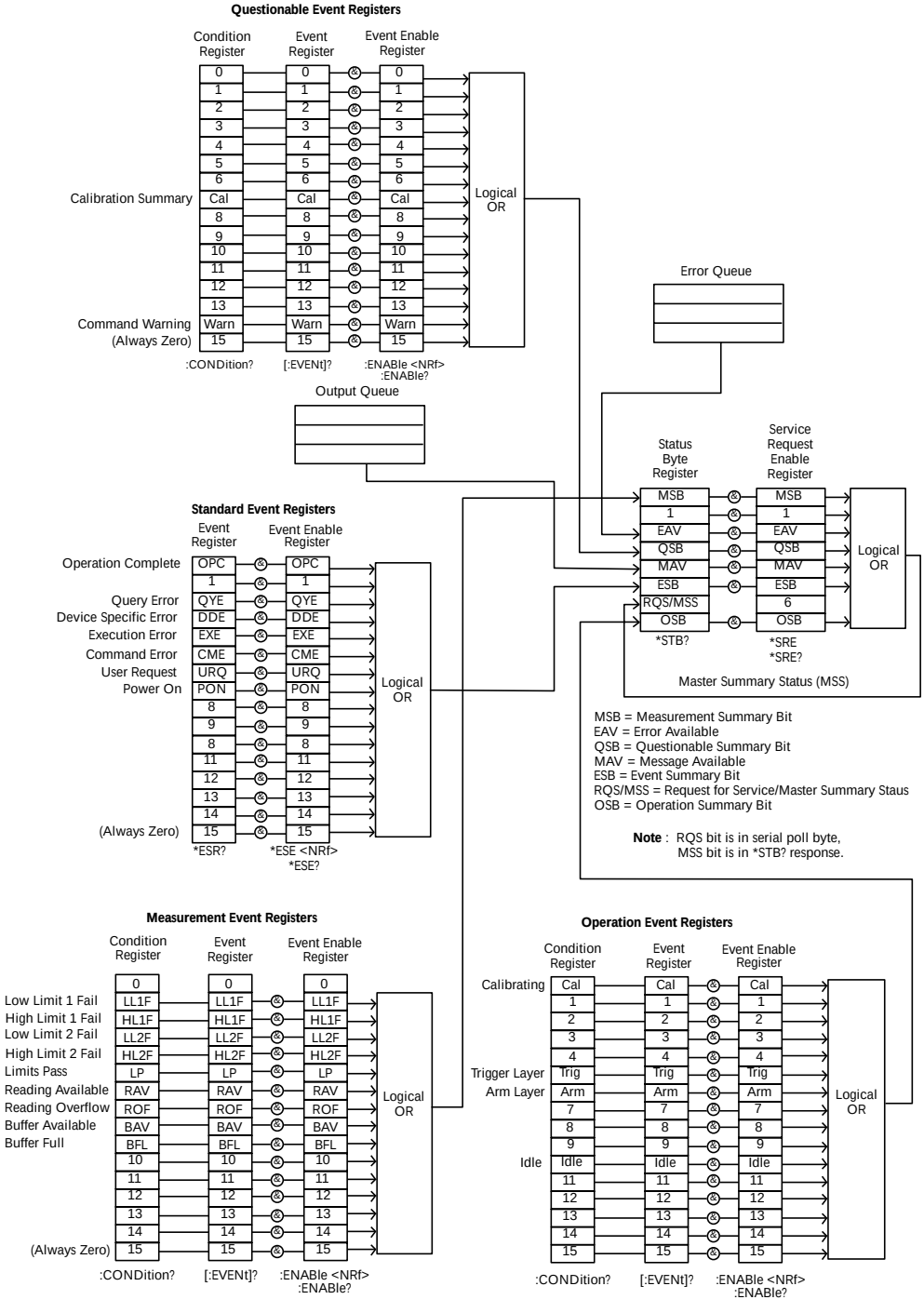
**Status byte and SRQ** — The status byte register receives the summary bits of four status register sets and two queues. The register sets and queues monitor the various instrument events. When an enabled event occurs, it sets a summary bit in the status byte register. When a summary bit of the status 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** — Model 6514 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 13-1*
*6514 status mode structure*



# Clearing registers and queues

When Model 6514 is turned on, the bits of all registers in the status structure are clear (reset to 0) and the two queues are empty. Commands to reset the event and event enable registers, and the error queue are listed in Table 13-1. 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 13-1*
*Common and SCPI commands — reset registers and clear queues*

| Commands | Description | Ref |
|---|---|---|
| *To reset registers:* | | |
| *CLS | Reset all bits of the following event registers to 0:<br>Standard event register<br>Operation event register<br>Measurement event register<br>Questionable event register | Note 1 |
| STATus<br>:PRESet | STATus subsystem:<br>Reset all bits of the following enable registers to 0:<br>Operation event enable register<br>Measurement event enable register<br>Questionable event enable register | Note 1 |
| *To clear error queue:* | | |
| *CLS | Clear all messages from error queue | Note 2 |
| STATus<br>:QUEue<br>:CLEar | STATus subsystem:<br>Error queue:<br>Clear messages from error queue | Note 3 |
| SYSTem<br>:ERRor<br>:CLEar | SYSTem subsystem:<br>Error queue:<br>Clear messages from error queue | Note 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”).
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 (see Tables 13-3 and 13-6).

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 (see Figure 13-2) 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 13-2 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).

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 | 1's and 0's |
| Hexadecimal | 0 through 9 and A through F |
| Octal | 0 through 7 |

*Figure 13-2*
*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 | 0/1 | 0/1 | 0/1 | 0/1 | 0/1 | 0/1 | 0/1 | 0/1 |
| Decimal Weights | 32768 ($2^{15}$) | 16384 ($2^{14}$) | 8192 ($2^{13}$) | 4096 ($2^{12}$) | 2048 ($2^{11}$) | 1024 ($2^{10}$) | 512 ($2^9$) | 256 ($2^8$) |

## 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 (see Tables 13-3 through 13-6).

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, B3, 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 13-2).

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

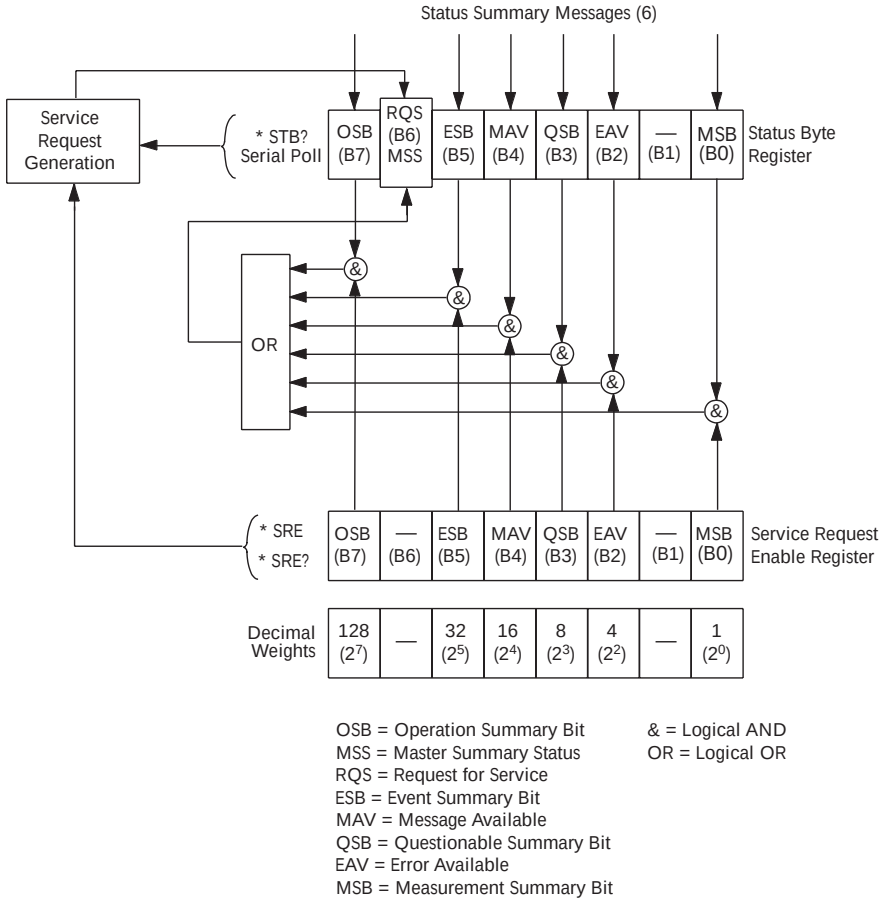
*Table 13-2*
*SCPI command — data formats for reading status registers*

| Command | Description | Default |
|---|---|---|
| :FORMat | FORMat subsystem | |
| :SREGister <name> | Select data format for reading status registers:<br><name> = ASCii — Decimal format<br>HEXadecimal — Hexadecimal format<br>OCTal — Octal format<br>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 13-3 shows the structure of these registers.

*Figure 13-3*
*Status byte and service request*




## 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 status (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, request service (RQS)/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.

Depending on how it is used, bit B6 of the status byte register is either the request for service (RQS) bit or the master summary status (MSS) bit:

- When using the serial poll sequence of Model 6514 to obtain the status byte (a.k.a. serial poll byte), B6 is the RQS bit. See “serial polling and SRQ” for details on using the serial poll sequence.
- When using the *STB? command (see Table 13-3) to read the status byte, B6 is the MSS bit.

## 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 (RQS/MSS) by the status summary message bits (B0, B2, B3, B4, B5, and B7) of the status byte register. As shown in Figure 13-3, 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/RQS 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 (i.e. *SRE 0). The commands to program and read the SRQ enable register are listed in Table 13-6.

## Serial polling and SRQ

Any enabled event summary bit that goes from 0 to 1 will set bit B6 and generate an SRQ (service request). In your test program, you can periodically read the status byte to check if an SRQ has occurred and what caused it. If an SRQ occurs, the program can, for example, branch to an appropriate subroutine that will service the request.

Typically, SRQs are managed by the serial poll sequence of Model 6514. If an SRQ does not occur, bit B6 (RQS) of the status byte register will remain cleared, and the program will simply proceed normally after the serial poll is performed. If an SRQ does occur, bit B6 of the status byte register will set, and the program can branch to a service subroutine when the SRQ is detected by the serial poll.

The serial poll automatically resets RQS of the status byte register. This allows subsequent serial polls to monitor bit B6 for an SRQ occurrence generated by other event types. After a serial poll, the same event can cause another SRQ, even if the event register that caused the first SRQ has not been cleared.

The serial poll does not clear MSS. The MSS bit stays set until all status byte summary bits are reset.

### SPE, SPD (serial polling)

The SPE, SPD general bus command is used to serial poll Model 6514. Serial polling obtains the serial poll byte (status byte). Typically, serial polling is used by the controller to determine which of several instruments has requested service with the SRQ line.

## 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 13-3. 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 (i.e. *SRE 0).*

*Table 13-3*
*Common commands — status byte and service request enable registers*

| Command | Description | Default |
|---|---|---|
| *STB? | Read status byte register. | |
| *SRE <NDN> or <NRf> | Program the service request enable register:<br><NDN> = #Bxx…x Binary format (each x = 1 or 0)<br>= #Hx Hexadecimal format (x = 0 to FF)<br>= #Qx Octal format (x = 0 to 377)<br><NRf> = 0 to 255 Decimal format | (Note) |
| *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 first command of 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 using the binary format (which directly indicates which bits are set). The command to select format (FORMat:SREGister) is documented in Table 13-2. To determine the exact nature of the error, you will have to read the error queue (see "Queues").

```
*CLS                    ‘ Clear Error Queue.
*SRE 4                  ‘ Enable EAV.
FORM:SREG BIN           ‘ Select binary format.
BadCommand              ‘ Generate error.
*STB?                   ‘ Read Status Byte Register.
```

*NOTE* *An example program to demonstrate serial polling (Generating SRQ on buffer full) is provided in Appendix E.*

# Status register sets

As shown in Figure 13-1, there are four status register sets in the status structure of Model 6514; standard event status, operation event status, measurement event status, and questionable event status.

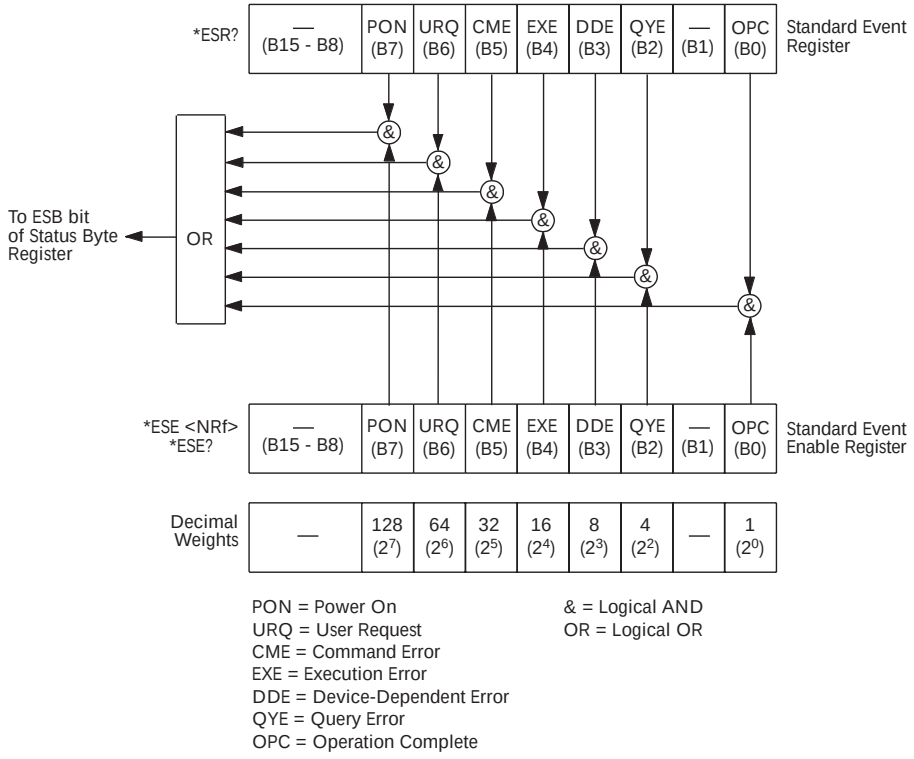
## Register bit descriptions

### Standard event status

The used bits of the standard event register (shown in Figure 13-4) are described as follows:

- **Bit B0, operation complete** — Set bit indicates that all pending selected device operations are completed and Model 6514 is ready to accept new commands. This bit only sets in response to the *OPC? query command. See Section 14 for details on *OPC and *OPC?.
- **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 due to some internal condition.
- **Bit B4, execution error (EXE)** — Set bit indicates that Model 6514 detected an error while trying to execute a command.
- **Bit B5, command error (CME)** — Set bit indicates that a command error has occurred. Command errors include:
  - → IEEE-488.2 syntax error — Model 6514 received a message that does not follow the defined syntax of the IEEE-488.2 standard.
  - → Semantic error — Model 6514 received a command that was misspelled or received an optional IEEE-488.2 command that is 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 Model 6514 front panel was pressed.
- **Bit B7, power ON (PON)** — Set bit indicates that Model 6514 has been turned off and turned back on since the last time this register has been read.

*Figure 13-4*
*Standard event status*

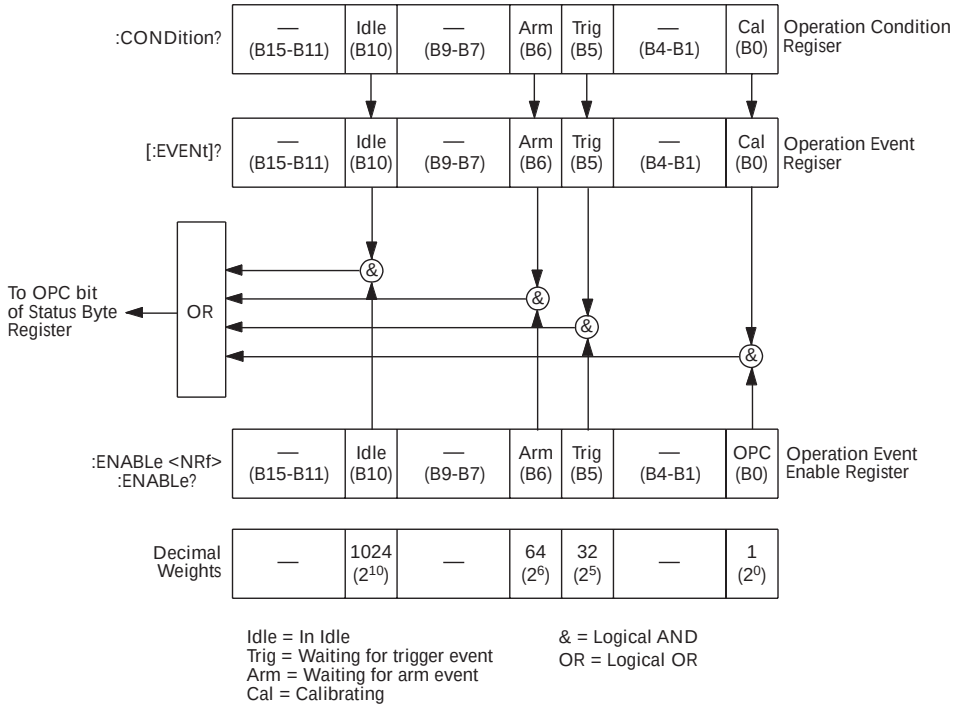


## Operation event status

The used bits of the operation event register (shown in Figure 13-5) are described as follows:

- **Bit B0, calibrating** — Set bit indicates that Model 6514 is calibrating.
- **Bit B5, waiting for trigger event (Trig)** — Set bit indicates that Model 6514 is in the trigger layer waiting for a TLINK trigger event to occur.
- **Bit B6, waiting for arm event (Arm)** — Set bit indicates that Model 6514 is in the arm layer waiting for an arm event to occur.
- **Bit B10, idle state (Idle)** — Set bit indicates Model 6514 is in the idle state.

*Figure 13-5*
*Operation event status*

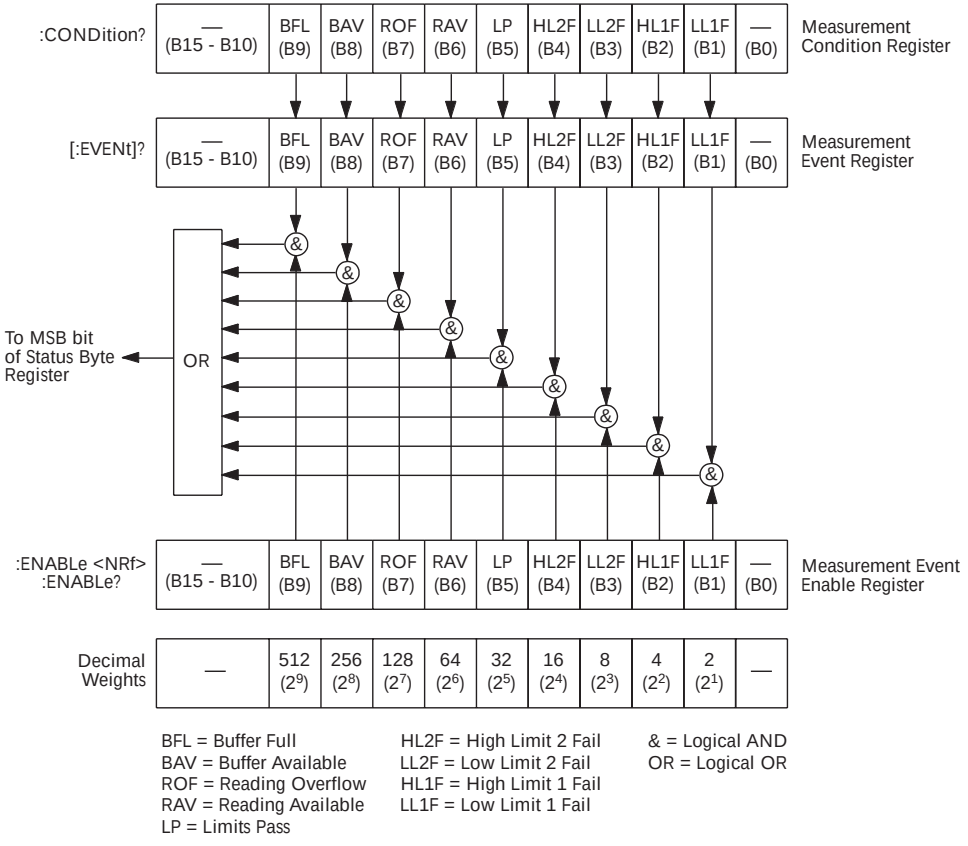


## Measurement event status

The used bits of the measurement event register (shown in Figure 13-6) are described as follows:

- **Bit B1, low limit 1 fail (LL1F)** — Set bit indicates that the low limit 1 test has failed.
- **Bit B2, high limit 1 fail (HL1F)** — Set bit indicates that the high limit 1 test has failed.
- **Bit B3, low limit 2 fail (LL2F)** — Set bit indicates that the low limit 2 test has failed.
- **Bit B4, high limit 2 fail (HL2F)** — Set bit indicates that the high limit 2 test has failed.
- **Bit B5, limits pass (LP)** — Set bit indicates that all limit tests passed.
- **Bit B6, reading available (RAV)** — Set bit indicates that a reading was taken and processed.
- **Bit B7, reading overflow (ROF)** — Set bit indicates that the volts, amps, ohms or coulombs reading exceeds the selected measurement range of Model 6514.
- **Bit B8, buffer available (BAV)** — Set bit indicates that there are at least two readings in the buffer.
- **Bit B9, buffer full (BFL)** — Set bit indicates that the buffer is full.

*Figure 13-6 Measurement event status*

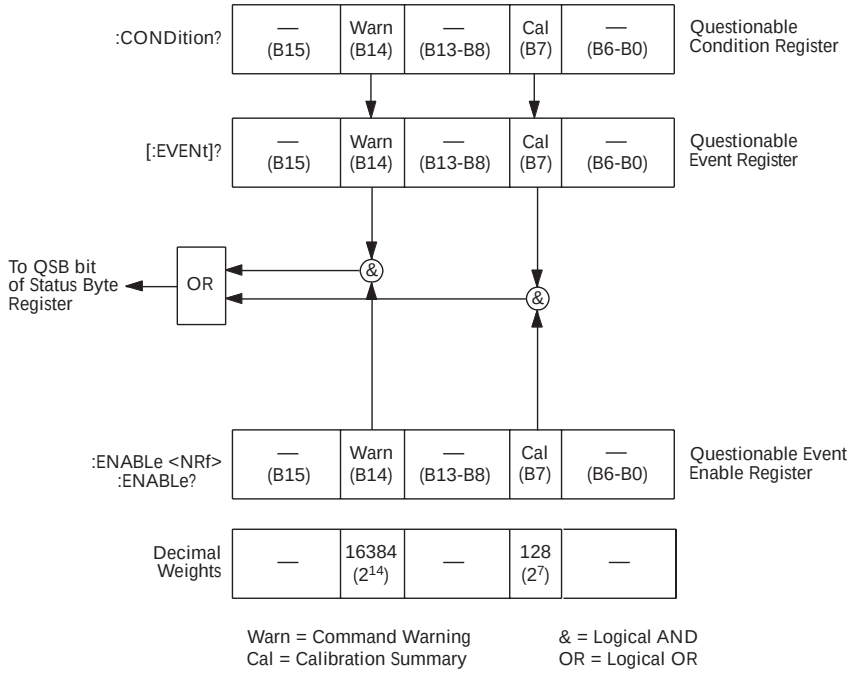


### Questionable event status

The used bits of the questionable event register (shown in Figure 13-7) are described as follows:

- **Bit B7, calibration summary (Cal)** — Set bit indicates that an invalid calibration constant was detected during the power-up sequence. This error will clear after successful calibration of Model 6514.
- **Bit B14, command warning (Warn)** — Set bit indicates that a signal oriented measurement command parameter has been ignored.

*Figure 13-7*
*Questionable event status*




## Condition registers

As Figure 13-1 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 Model 6514 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 13-4. For details on reading registers, see “Reading registers”.

*Table 13-4*
*Common and SCPI commands — condition registers*

| Command | Description |
|---|---|
| STATus | STATus subsystem: |
| :OPERation:CONDition? | Read operation condition register. |
| :MEASurement:CONDition? | Read measurement condition register. |
| :QUEStionable:CONDition? | Read questionable condition register. |

## Event registers

As Figure 13-1 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 13-5. For details on reading registers, see “Reading registers”.

*Table 13-5*
*Common and SCPI commands — event registers*

| Command | Description |
|---|---|
| *ESR? | Read standard event status register. |
| STATus | STATus subsystem: |
| :OPERation:[:EVENt]? | Read operation event register. |
| :MEASurement:[:EVENt]? | Read measurement event register. |
| :QUEStionable:[:EVENt]? | Read questionable event register. |

Note: Power-up and *CLS resets all bits of all event registers to 0. STATus:PRESet has no effect.

## Event enable registers

As Figure 13-1 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 13-6. For details on programming and reading registers, see "Programming enable registers" and "Reading registers".

*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 13-6*
*Common and SCPI commands — event enable registers*

| **Command** | **Description** |
|---|---|
| *ESE <NDN> or <NRf> | Program standard event enable register (see "*Parameters*"). |
| *ESE? | Read standard event enable register. |
| | |
| STATus | STATus subsystem: |
| :OPERation | Operation event enable register: |
| :ENABle <NDN> or <NRf> | Program enable register (see "*Parameters*"). |
| :ENABle? | Read enable register. |
| :MEASurement | Measurement event enable register: |
| :ENABle <NDN> or <NRf> | Program enable register (see "*Parameters*"). |
| :ENABle? | Read enable register. |
| :QUEStionable | Questionable event enable register: |
| :ENABle <NDN> or <NRf> | Program enable register (see "*Parameters*"). |
| :ENABle? | Read measurement event enable register: |
| *Parameters:* | |
| <NDN> = #Bxx…x | Binary format (each x = 1 or 0) |
| = #Hx | Hexadecimal format (x = 0 to FFFF) |
| = #Qx | Octal format (x = 0 to 177777) |
| <NRf> = 0 to 65535 | Decimal format |

Note: Power-up and STATus:PRESet resets all bits of all enable registers to 0. *CLS has no effect.

### Programming example — program and read registers

This command sequence programs and reads the measurement registers. Registers are read using the binary format (which directly indicates which bits are set). The command to select format (FORMat:SREGister) is documented in Table 13-2.

```
FORM:SREG BIN          ‘ Select binary format to read registers.
STAT:MEAS:ENAB 512     ‘ Enable BFL (buffer full).
STAT:MEAS:COND?        ‘ Read Measurement Condition Register.
STAT:MEAS?             ‘ Read Measurement Event Register.
```

# Queues

Model 6514 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.

Model 6514 status model (Figure 13-1) 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.

A message is read from the output queue by addressing Model 6514 to talk after the appropriate query is sent.

## 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 13-7. When you read a single 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 Appendix B. As shown in Table 13-7, there are commands to read the entire message (code and message) or the code only.

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 13-7, 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 13-7*
*SCPI commands — error queue*

| Command | Description | Default |
|---|---|---|
| STATus | STATus subsystem: | |
| :QUEue | Read error queue: | (Note 1) |
| [:NEXT]? | Read and clear oldest error/status (code and message). | |
| :ENABle <list> | Specify error and status messages for error queue. | (Note 2) |
| :ENABle? | Read the enabled messages. | |
| :DISable <list> | Specify messages not to be placed in queue. | (Note 2) |
| :DISable? | Read the disabled messages. | |
| :CLEar | Clear messages from error queue. | |
| | | |
| SYSTem | SYSTem subsystem: | |
| :ERRor | Read error queue: | (Note 1) |
| [:NEXT]? | Read and clear oldest error/status (code and message). | |
| :ALL? | Read and clear all errors/status (code and message). | |
| :COUNt? | Read the number of messages in queue. | |
| :CODE | Code numbers only: | |
| [:NEXT]? | Read and clear oldest error/status (code only). | |
| :ALL? | Read and clear all errors/status (codes only). | |
| :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 command reads the error queue:

```
STAT:QUE?                ' Read Error Queue.
```

# 14
# Common Commands

Common commands (summarized in Table 14-1) 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 14-1*
*IEEE-488.2 common commands and queries*

| Mnemonic | Name | Description | Ref |
|---|---|---|---|
| *CLS | Clear status | Clears all event registers and error queue. | Sec 13 |
| *ESE <NRf> | Event enable command | Program the standard event enable register. | Sec 13 |
| *ESE? | Event enable query | Read the standard event enable register. | Sec 13 |
| *ESR? | Event status register query | Read the standard event enable register and clear it. | Sec 13 |
| *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. | B |
| *OPT? | Option query | The value 5156 is returned if the Model 5156 calibration source is connected to the Model 6514. The value 0 is returned if the Model 5156 is not connected. | |
| *RCL <NRf> | Recall command | Returns Model 6514 to the user-saved setup. | C |
| *RST | Reset command | Returns Model 6514 to the *RST default conditions. | D |
| *SAV <NRf> | Save command | Saves the present setup as the user-saved setup. | C |
| *SRE <NRf> | Service request enable command | Programs the service request enable register. | Sec 13 |
| *SRE? | Service request enable query | Reads the service request enable register. | Sec 13 |
| *STB? | Status byte query | Reads the status byte register. | Sec 13 |
| *TRG | Trigger command | Sends a bus trigger to Model 6514. | E |
| *TST? | Self-test query | Performs a checksum test on ROM and returns the result. | F |
| *WAI | Wait-to-continue command | Wait until all previous commands are executed. | G |

## 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 INC., MODEL 6514, xxxxxxx, yyyyy/zzzzz/w

Where: xxxxxxx is the serial number.
yyyyy/zzzzz is the firmware revision levels of the digital board ROM and display board ROM. Note that yyyyy also provides build date and time information.
w is the board revision level.

### B) OPC — operation complete
Sets OPC bit

### OPC? — operation complete query
Places a "1" in output queue

When *OPC is sent, the OPC bit in the standard event register will set after all pending command operations are complete. When *OPC? is sent, an ASCII "1" is placed in the output queue after all pending command operations are complete.

Typically, either one of these commands is sent after the INITiate command. The INITiate command is used to take the instrument out of idle in order to perform measurements. While operating within the trigger model layers, all sent commands (except DCL, SDC, IFC, SYSTem:PRESet, *RST, GET and ABORt) will not execute.

After all programmed operations are completed, the instrument returns to the idle state at which time all pending commands (including *OPC and/or *OPC?) are executed. After the last pending command is executed, the OPC bit and/or an ASCII "1" is placed in the output queue.

**Programming example** — The following command sequence will perform 10 measurements. After the measurements are completed (in approximately 10 seconds), an ASCII "1" will be placed in the output queue.

```
*RST                    ' Return 6514 to RST defaults (idle).
TRIG:DEL 1              ' Set trigger delay for 1 second.
ARM:COUN 10             ' Program for 5 measurements and stop.
INIT                    ' Start measurements.
*OPC?                   ' Send *OPC?.
```

### C) 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

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. Three setup configurations can be saved and recalled.

Model 6514 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.

**Programming example:**

```
*SAV 2   ' Save present setup in memory location 2.
*RST     ' Set 6514 to RST defaults.
*RCL 2   ' Return (recall) 6514 to setup stored in memory location 2.
```

### D) RST — reset
Return Model 6514 to RST defaults

When the *RST command is sent, Model 6514 performs the following operations:

1. Returns Model 6514 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.

### E) TRG — trigger

Send bus trigger to Model 6514

Use the *TRG command to issue a GPIB trigger to Model 6514. It has the same effect as a group execute trigger (GET).

Use the *TRG command as an event to control operation. Model 6514 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 covered in Section 9.*

**Programming example** — The following command sequence configures Model 6514 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.

```
*RST                    ' Restore RST defaults.
ARM:SOUR BUS            ' Select BUS control source.
ARM:COUN INF            ' Set arm layer count to infinite.
INIT                    ' Take 6514 out of idle.
*TRG                    ' Trigger one measurement.
```

### F) 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. When Model 6514 is addressed to talk, 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.

### G) WAI — wait-to-continue

Wait until previous commands are completed

Effectively, the *WAI command is a No-Op (no operation) for Model 6514 and thus, does not need to be used.

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.

The *WAI command is used 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.

# 15
# 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 15-1.

*NOTE The readings acquired by these commands depend on which data elements are selected (see "FORMat Subsystem" in Section 16 for details).*

*Table 15-1*
*Signal oriented measurement command summary*

| Command | Description | Ref |
|---|---|---|
| CONFigure:<function> | Places Model 6514 in a "one-shot" measurement mode for the specified function. | A |
| CONFigure? | Queries the selected function. | |
| FETCh? | Requests the latest reading(s). | B |
| READ? | Performs an INITiate and a :FETCh?. | C |
| MEASure[:<function>]? | Performs a CONFigure:<function>, and a :READ?. | D |

## A) CONFigure:<function> Configure Model 6514 for "one-shot" measurements

| | | |
|---|---|---|
| <function> = | VOLTage[:DC] | Configure voltage |
| | CURRent[:DC] | Configure current |
| | RESistance | Configure resistance |
| | CHARge | Configure charge |

This command configures the instrument for "one-shot" measurements on the specified function. Each subsequent READ? command will then trigger a single measurement and acquire the reading (see READ? for details).

If the instrument is in idle, this command will execute immediately. If the instrument is not in idle, execution of the command will execute when the operation returns to the idle state.

When this command is executed, Model 6514 will be configured as follows:

- The specified function is selected.
- All controls related to the selected function are defaulted to the *RST values.
- The event control sources of the trigger model are set to immediate.
- The arm and trigger count values of the trigger model are set to one.
- The delay of the trigger model is set to zero.
- Model 6514 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.

This command is automatically asserted when the :MEASure? command is sent.

**Programming example** — The following command sequence selects and configures Model 6514 for "one-shot" measurements. Each subsequent READ? triggers a single measurement and requests the reading.

```
CONF:VOLT                ' Perform CONFigure operations.
READ?                    ' Trigger measurement and request reading.
```

### B) FETCh? Request latest reading

This command requests the latest post-processed readings. After sending this command and addressing Model 6514 to talk, the readings are 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 group of readings. Note that this command can repeatedly return the same readings. Until there is a new reading(s), this command continues to return the old reading(s). If your application requires a "fresh" reading, use the :READ? command.

This command is automatically asserted when the :READ? or :MEASure? command is sent.

### C) READ? Trigger measurement(s) and request reading(s)

This command is used to trigger and acquire readings. The number of readings depends on how the trigger model is configured. For example, if configured for 20 measurements (arm count 1, trigger count 20), 20 sets of readings will be acquired.

When this command is sent, the following commands execute in the order they are presented:

- INITiate
- FETCh?

If the instrument is in the idle state, INITiate takes the instrument out of idle to perform the programmed number measurements. If the instrument is not in the idle state, execution of this command will wait until it goes back into idle.

The FETCh? command is executed to acquire the reading(s). The readings are sent to the computer when Model 6514 is addressed to talk.

*NOTE* *If the instrument is programmed to perform an infinite number of measurements (arm count or trigger count set to infinite), you cannot use the READ? command to trigger and acquire readings. Use INITiate to start (trigger) the measurement process, send ABORt to abort the measurement process, and then use SENSe:DATA[:LATest]? to return the last (latest) reading.*

### D) MEASure[:<function>]? Configure and perform "one-shot" measurement

| | | | |
|---|---|---|---|
| <function> | = | VOLTage[:DC] | Measure voltage |
| | | CURRent[:DC] | Measure current |
| | | RESistance | Measure resistance |
| | | CHARge | Measure charge |

This command combines all of the other signal oriented measurement commands to perform a "one-shot" measurement and acquire the reading.

When this command is sent, the following commands execute in the order that they are presented.

- CONFigure:<function>
- READ?

When :CONFigure is executed, the instrument goes into a "one-shot" measurement mode. See CONFigure for details.

When READ? is executed, its operations will then be performed. In general, an INITiate is executed to perform the measurement and a FETch? is executed to acquire the reading. See :READ? for details.

*NOTE* *If you send MEASure? (no measurement function specified), the operations of CONFigure will apply to the presently selected function.*

# 16
# DISPlay, FORMat, and SYSTem

- **DISPlay subsystem** — Covers the SCPI commands that are used to control the display.
- **FORMat subsystem** — Covers the SCPI commands to configure the format that readings are sent over the bus.
- **SYSTem subsystem** — Covers miscellaneous SCPI commands.

# DISPlay subsystem

*Table 16-1*
*SCPI commands — display*

| Command | Description | Default | Ref |
|---|---|---|---|
| :DISPlay | | | |
| :DIGits <n> | Set display resolution; 4 to 7. | 6 | Sec 6 |
| :ENABle <b> | Turn front panel display on or off. | (see Note) | A |
| [:WINDow[1]] | Path to control user text messages: | | |
| :TEXT | | (see Note) | |
| [:DATA] <a> | Define ASCII message "a" (up to 12 characters). | | B |
| :STATe <b> | Enable or disable text message mode. | | C |

Note: *RST and SYSTem:PRESet have no effect on the display circuitry and user-defined text messages.

## A) DISPlay:ENABle <b>

With front panel circuitry turned off, the instrument operates at a higher speed. While disabled, the display is frozen and all front panel controls (except LOCAL) are disabled. Normal display operations can be resumed by using :ENABle to enable the display, pressing the LOCAL key, or cycling power.

## B) DISPlay:TEXT[:DATA] <a>

| | | |
|---|---|---|
| Message Types: | String | 'aa…a' or "aa…a" |
| | Indefinite Block | #0aa…a |
| | Definite Block | #XYaa…a |

where; Y = number of characters in message (up to 12)
X = number of digits that make up Y (1 or 2)

The display message can be up to 12 characters (ASCII) long. A space is counted as a character. Excess message characters result in an error. Note that for the string type, the message must be enclosed by single or double quotes.

An indefinite block message must be the only command in the program message, or the last command in the program message. If you include a command after an indefinite block message (on the same line), it will be treated as part of the message and is displayed instead of executed.

### C) DISPlay:TEXT:STATe <b>

When the text message mode is enabled, a defined message is displayed. When disabled, the message is removed from the display.

**GPIB operation** — A user-defined message remains displayed only as long as the instrument is in remote. Taking the instrument out of remote (by pressing LOCAL or sending the GTL (go to local) command) or cycling power cancels the message and disables the text message mode.

**RS-232 operation** — A user-defined message can be cancelled by sending SYSTem:LOCal, pressing LOCAL, or cycling power.

# FORMat subsystem

The commands in this subsystem are used to select the format for transferring data over the bus.

*Table 16-2*
*SCPI commands — data format*

| Command | Description | Default | Ref |
|---|---|---|---|
| :FORMat | | | |
| [:DATA] <type>[,<length>] | Specify data format; ASCii, REAL, 32 or SREal. | ASCii | A |
| :ELEMents <item list> | Specify data elements; READing, TIME, and STATus. | All 3 | B |
| :BORDer <name> | Specify byte order; NORMal or SWAPped. | (see Note) | C |
| :SREGister <name> | Select data format for reading status registers; ASCii, HEXadecimal, OCTal, or BINary. | ASC | Sec 13 |
| :SOURce2 <name> | Select data format for reading output patterns: ASCii, HEXadecimal, OCTal, or BINary. | ASC | Sec 10 |

Note: *RST default is NORMal. SYSTem:PRESet default is SWAPped.

## A) FORMat[:DATA] <type>[,<length>]

**Parameters**

| | | |
|---|---|---|
| ASCii | = | ASCII format |
| REAL, 32 | = | Binary IEEE-754 single precision format |
| SREal | = | Binary IEEE-754 single precision format |

*NOTE* *<length> is not used for the ASCii or SREal parameters. It is optional for the REAL parameter. If you do not use <length> with REAL, <length> defaults to 32 (single precision format). The double precision format (<length> = 64) is not supported by Model 6514.*

The response to READ?, FETCh?, MEASure?, TRACe:DATA?, CALC1:DATA? or CALC2:DATA? over the GPIB can be returned in either the ASCii or binary format. All other queries are returned in ASCii, regardless of the selected format. Over the RS-232 interface, only the ASCII format is allowed.

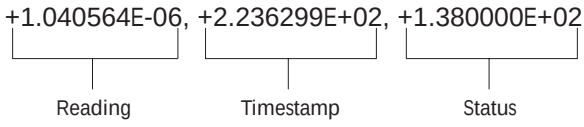
*NOTE* *Regardless of which data format for output strings is selected, the instrument will only respond to input commands using the ASCII format.*

### ASCII data format

The ASCII data format is in a direct readable form for the operator. Most BASIC languages easily convert ASCII mantissa and exponent to other formats. However, some speed is compromised to accommodate the conversion. Figure 16-1 shows an example ASCII string that includes all the data elements. See :ELEMents for information on the data elements.

Figure 16-1 also shows the byte order of the data string. Data elements not specified by the :ELEMents command are simply not included in the string.

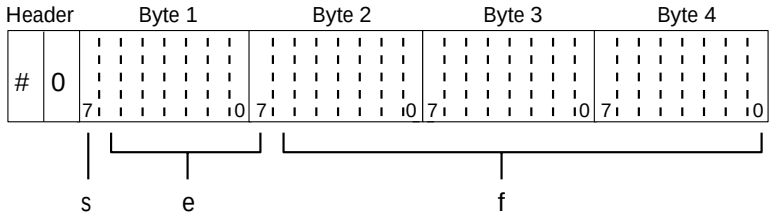
*Figure 16-1*
*ASCII data format*




**IEEE-754 single precision format**

REAL 32 or SREal will select the binary IEEE-754 single precision data format. Figure 16-2 shows the normal byte order format for each data element. For example, if all three data elements are selected, the data string for each reading conversion is made up of three 4-byte data blocks. Note that the data string for each reading conversion is preceded by a 2-byte header that is the binary equivalent of an ASCII # sign and 0. Figure 16-2 does not show the byte for the terminator that is attached to the end of each data string. Note that the byte order of the data string can be sent in reverse order (see :BORDer).

*Figure 16-2*
*IEEE-754 single precision data format (32 data bits)*




s = sign bit (0 = positive, 1 = negative)
e = exponent bits (8)
f = fraction bits (23)

Normal byte order shown. For swapped byte order, bytes sent in reverse order: Header, Byte 4, Byte 3 Byte 2, Byte 1.

The header and terminator are sent only once for each READ?.

During binary transfers, never un-talk Model 6514 until after the data is read (input) to the computer. Also, to avoid erratic operation, the readings of the data string (and terminator) should be acquired in one piece. The header (#0) can be read separately before the rest of the string.

The number of bytes to be transferred can be calculated as follows:

Bytes = 2 + (Rdgs x 4) + 1

where; 2 is the number of bytes for the header (#0).
Rdgs is the product of the number of selected data elements, arm count and trigger count.
4 is the number of bytes for each reading.
1 is the byte for the terminator.

For example, assume the instrument is configured to perform 10 measurements and send them to the computer using the binary format:

Bytes = 2 + (10 x 4) + 1
= 43

## B) FORMat:ELEMents <item list>

**Parameters**

| | | |
|---|---|---|
| READing | = | Voltage, current, resistance or charge reading |
| TIME | = | Timestamp |
| STATus | = | Status information |

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 ":ELEMents READing, TIME, STATus" to include all elements in the data string. The elements for the ASCii format are shown in Figure 16-1.

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. The timestamp operates as a timer that starts at zero seconds when the instrument is turned on, or when the timestamp is reset (SYSTem:TIME:RESet). After 99,999.99 seconds, the timer resets back to zero and starts over.

For buffer readings, timestamp can be referenced to the first reading stored in the buffer (absolute format) which is timestamped at 0 seconds, or to the time between each stored reading (delta format). The TRACe:TSTamp:FORMat command is used to select the timestamp format.

**Status** — The status word provides information about Model 6514 operation. The 16-bit status word is sent in decimal form. The decimal value has to be converted to the binary equivalent to determine the state of each bit in the word. For example, if the returned status value is 9, the binary equivalent is 00000001001. Bits 0 and 3 are set. The bits are explained as follows:

Bit 0 (OFLO) - Set to 1 if measurement performed while in over-range (overflowed reading).
Bit 1 (Filter) - Set to 1 when measurement performed with the averaging filter enabled.
Bit 2 (Math) - Set to 1 when measurement performed with CALC1 enabled.
Bit 3 (Null) - Set to 1 if null for CALC2 is enabled.
Bit 4 (Limits) - Set to 1 if a limit test (CALC2) is enabled.
Bits 5 and 6 (Limit Results) - Provides limit test results:

| Bit 6 | Bit 5 | |
|---|---|---|
| 0 | 0 | All limit tests passed |
| 0 | 1 | CALC2:LIM1 test failed |
| 1 | 0 | CALC2:LIM2 test failed |

Bits 7 and 8 (Measure) - Provides measurement status:

| Bit 8 | Bit 7 | |
|---|---|---|
| 0 | 0 | Voltage function selected |
| 0 | 1 | Current function selected |
| 1 | 0 | Resistance function selected |
| 1 | 1 | Charge function selected |

Bit 9 (Zero Check) - Set to 1 when zero check is enabled.

Bit 10 (Zero Correct) - Set to 1 when zero correct is enabled.

**Example** — The ASCII data string in Figure 16-1 contains all three data elements. The status value of 138 has a binary equivalent of 01001010, which indicates that bits B1, B3, and B7 are set. Therefore, the reading is 1.04056uA with null (REL) and the AVG filter enabled. The reading was taken 223.6299 seconds after the instrument was turned on.

## C) FORMat:BORDer <name>

**Parameters**

| | | |
|---|---|---|
| NORMal | = | Normal byte order for IEEE-754 binary format |
| SWAPped | = | Reverse byte order for IEEE-754 binary format |

For normal byte order, the data format for each element is sent as follows:

Byte 1 Byte 2 Byte 3 Byte 4

For reverse byte order, data is sent as follows:

Byte 4 Byte 3 Byte 2 Byte 1

The "#0" header (see Figure 16-2) is not affected by this command. The header is always sent at the beginning of the data string for each measurement conversion.

The ASCII data format can only be sent in the normal byte order. The SWAPped selection is ignored when the ASCII format is selected.

*NOTE The SWAPped byte order must be used when transmitting binary data to any IBM PC.*

# SYSTem subsystem

*Table 16-3*
*SCPI commands — system*

| Command | Description | Default | Ref |
|---|---|---|---|
| :SYSTem | | | |
| :ZCHeck <b> | Enable or disable zero check. | ON | Sec 2 |
| :ZCORrect | Zero correct: | | Sec 2 |
| [:STATe] <b> | Enable or disable zero correct. | OFF | |
| :ACQuire | Acquire a new zero correct value. | | |
| :PRESet | Return to SYSTem:PRESet defaults. | | A |
| :LFRequency <freq> | Select power line frequency; 50 or 60 (Hz). | | Sec 1 |
| :AZERo | Path to control autozero: | | Sec 2 |
| [:STATe] <b> | Enable or disable autozero. | ON | |
| :TIME | Timestamp: | | |
| :RESet | Reset timestamp to 0 seconds. | | B |
| :POSetup <name> | Select power-on setup; RST, PRESet or SAVx (where x = 0 to 4). | | C |
| :VERSion? | Query SCPI revision level. | | D |
| :ERRor | Read messages in error queue: | (see Note ) | Sec 13 |
| [:NEXT]? | Return and clear oldest error (code and message). | | |
| :ALL? | Return and clear all errors (code and message). | | |
| :COUNt? | Return the number of errors. | | |
| :CODE | Error code numbers only: | | |
| [:NEXT]? | Return and clear oldest error (code only). | | |
| :ALL? | Return and clear all errors (codes only). | | |
| :CLEar | Clear messages from error queue. | | Sec 13 |
| :KEY <NRf> | Simulate key-press; see Figure 16-3. | | E |
| | *RS-232 interface:* | | Sec 12 |
| :LOCal | Take Model 6514 out of remote (RS-232 only). | | |
| :REMote | Put Model 6514 in remote (RS-232 only). | | |
| :RWLock | Enable or disable local lockout (RS-232 only). | | |

Note: Clearing the error queue - power-up and *CLS clears the error queue. *RST, SYSTem:PRESet, and STATus:PRESet have no effect on the error queue.

### A) SYSTem:PRESet

Returns the instrument to states optimized for front panel operation. SYSTem:PRESet defaults are listed in the SCPI tables in Section 17.

### B) SYSTem:TIME:RESet

Resets the absolute timestamp to 0 seconds. The timestamp also resets when power is cycled, or after the instrument is on for 99,999.99 seconds. The TRACe:TSTamp:FORMat command is used to select the absolute timestamp. See Section 8 (Buffer) for details.

### C) SYSTem:POSetup <name>

| **Parameters** | | |
|---|---|---|
| | RST | Power-up to *RST defaults |
| | PRESet | Power-up to SYSTem:PRESet defaults |
| | SAVx | Power-up to setup stored in memory (x = memory location 0, 1, 2, 3 or 4) |

The *RST and SYSTem:DEFaults are listed in the SCPI tables in the Section 17. A setup is saved in memory using the *SAV command. See Section 14 (Common Commands) for details.

### D) SYSTem:VERSion

Read the version of the SCPI standard being used by Model 6514. Example response message: 1996.0.

### E) SYSTem:KEY <NRf>

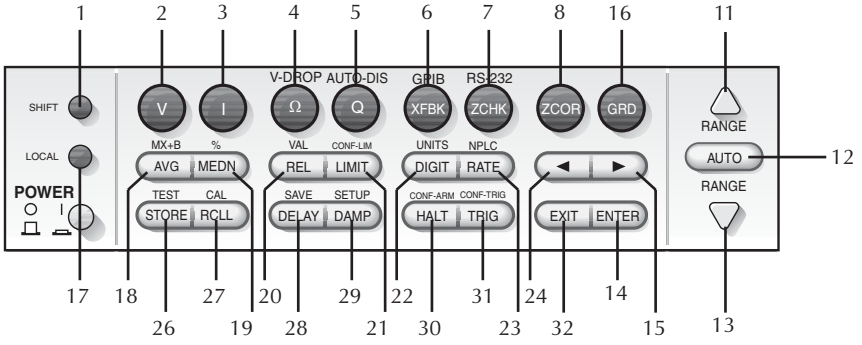
**Parameters**

| | | | | | |
|---|---|---|---|---|---|
| 1 | = | SHIFT key | 17 | = | LOCAL key |
| 2 | = | V key | 18 | = | AVG key |
| 3 | = | I key | 19 | = | MEDIAN key |
| 4 | = | Ω key | 20 | = | REL key |
| 5 | = | Q key | 21 | = | LIMIT key |
| 6 | = | XFDBK key | 22 | = | DIGIT key |
| 7 | = | ZCHECK key | 23 | = | RATE key |
| 8 | = | ZCOR key | 24 | = | Cursor left arrow key |
| 9 | = | ------- | 25 | = | ------- |
| 10 | = | ------- | 26 | = | STORE key |
| 11 | = | RANGE up arrow key | 27 | = | RECALL key |
| 12 | = | AUTO key | 28 | = | DELAY key |
| 13 | = | RANGE down arrow key | 29 | = | DAMP key |
| 14 | = | ENTER key | 30 | = | HALT key |
| 15 | = | Cursor right arrow key | 31 | = | TRIG key |
| 16 | = | GRD 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 “V” key: SYSTem:KEY 2. The key-press codes are also shown in Figure 16-3.

The queue for the :KEY? query command can only hold one key-press. When :KEY? is sent and Model 6514 is addressed to talk, the key-press code number for the last key pressed (either physically or with :KEY) is sent to the computer.

*Figure 16-3*
*Key-press codes*



# 17
# SCPI Reference Tables


- **Table 17-1** — CALCulate command summary
- **Table 17-2** — DISPlay command summary
- **Table 17-3** — FORMat command summary
- **Table 17-4** — SENSe command summary
- **Table 17-5** — SOURce command summary
- **Table 17-6** — STATus command summary
- **Table 17-7** — SYSTem command summary
- **Table 17-8** — TRACe command summary
- **Table 17-9** — TRIGger 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 indicated 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 — Refers you to the section (Sec) that provides operation information for that command or command subsystem.
- SCPI — A checkmark (√) indicates that the command and its parameters are SCPI confirmed. An unmarked command indicates that it is a 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 17-1*
*CALCulate command summary*

| Command | Description | Default parameter | Ref | SCPI |
|---|---|---|---|---|
| :CALCulate[1] | Path to configure and control CALC1 calculations. | | Sec 7 | √ |
| :FORMat <name> | Select math format; MXB or PERCent. | MXB | | √ |
| :FORMat? | Query math format. | | | √ |
| :KMATh | Configure math calculations: | | | |
| :MMFactor <NRf> | Set “m” for mX+b calculation; -9.99999e20 to 9.99999e20. | 1.0 | | |
| :MMFactor? | Query “m” factor. | | | |
| :MBFactor <NRf> | Set “b” for mX+b calculation; -9.99999e20 to 9.99999e20. | 0.0 | | |
| :MBFactor? | Query “b” factor. | | | |
| :MUNits <name> | Specify units for mX+b result; 3 letters (A - Z). | “MXB” | | |
| :MUNits? | Query units. | | | |
| :PERCent | Configure percent math calculation: | | | |
| [:REFerence] <NRf> | Specify reference value; -9.99999e20 to 9.99999e20. | 1.0 | | |
| :ACQuire | Use input signal as reference value. | | | |
| :PERCent? | Query reference value. | | | |
| :STATe <b> | Enable or disable CALC1 calculation. | OFF | | √ |

*Table 17-1 (cont.)*
*CALCulate command summary*

*NOTE The <NDN> and <NRf> parameter values for the :SOURce2 command are provided at the end of this table.*

| Command | Description | Default parameter | Ref | SCPI |
|---|---|---|---|---|
| :STATe? | Query state of CALC1 calculation. | | | √ |
| :DATA? | Return all CALC1 results triggered by INITiate. | | | √ |
| :LATest? | Return last (latest) reading. | | | |
| :CALCulate2 | Path to configure and control limit testing (CALC2): | | Sec 10 | √ |
| :FEED <name> | Select input path for limit testing; CALCulate[1] or SENSe[1]. | SENS | | √ |
| :FEED? | Query input path for limit tests. | | | √ |
| :LIMit[1] | Limit 1 Testing: | | | √ |
| :UPPer | Configure upper limit: | | | √ |
| [:DATA] <n> | Set limit; -9.99999e20 to 9.99999e20. | 1.0 | | √ |
| [:DATA]? | Query upper limit. | | | √ |
| :SOURce2 <NDN> or <NRf> | Specify 4-bit output “fail” pattern. | 15 | | √ |
| :SOURce2? | Query output pattern value. | | | √ |
| :LOWer | Configure lower limit: | | | √ |
| [:DATA] <n> | Set limit; -9.99999e20 to 9.99999e20. | -1.0 | | √ |
| [:DATA]? | Query lower limit. | | | √ |
| :SOURce2 <NDN> or <NRf> | Specify 4-bit output “fail” pattern. | 15 | | √ |
| :SOURce2? | Query output pattern value. | | | √ |
| :STATe <b> | Enable or disable limit 1 test. | OFF | | √ |
| :STATe? | Query state of limit 1 test. | | | √ |
| :FAIL? | Return result of limit 1 test; 0 (pass) or 1 (fail). | | | √ |
| :LIMit2 | Limit 2 Testing: | | | √ |
| :UPPer | Configure upper limit: | | | √ |
| [:DATA] <n> | Set limit; -9.99999e20 to 9.99999e20. | 1.0 | | √ |
| [:DATA]? | Query upper limit. | | | √ |
| :SOURce2 <NDN> or <NRf> | Specify 4-bit output “fail” pattern. | 15 | | √ |
| :SOURce2? | Query output pattern value. | | | √ |
| :LOWer | Configure lower limit: | | | √ |
| [:DATA] <n> | Set limit; -9.99999e20 to 9.99999e20. | -1.0 | | √ |
| [:DATA]? | Query lower limit. | | | √ |
| :SOURce2 <NDN> or <NRf> | Specify 4-bit output “fail” pattern. | 15 | | √ |

*Table 17-1 (cont.)*
*CALCulate command summary*

| Command | Description | Default parameter | Ref | SCPI |
|---|---|---|---|---|
| :SOURce2? | Query output pattern value. | | | √ |
| :STATe <b> | Enable or disable limit 2 test. | OFF | | √ |
| :STATe? | Query state of limit 2 test. | | | √ |
| :FAIL? | Return result of limit 2 test; 0 (pass) or 1 (fail). | | | √ |
| :CLIMits | Composite Limits: | | | |
| :CLEar | Clear I/O port and restore it back to SOURce2:TTL settings: | | | |
| [:IMMediate] | Clears I/O port immediately. | | | |
| :AUTO <b> | When enabled, I/O port clears when :INITiate sent. | ON | | |
| :AUTO? | Query state of auto-clear. | | | |
| :PASS | Define “pass” digital output pattern. | | | |
| :SOURce2 <NDN> or <NRf> | Specify 4-bit pass pattern (no failures). | 15 | | |
| :SOURce2? | Query “pass” output pattern. | | | |
| :NULL | Configure and control Rel: | | | √ |
| :ACQuire | Use input signal as Rel value. | | | |
| :OFFSet <NRf> | Specify Rel value; -9.999999e20 to 9.999999e20. | 0.0 | | √ |
| :OFFSet? | Query Rel value. | | | √ |
| :STATe <b> | Enable or disable Rel. | OFF | | √ |
| :STATe? | Query state of Rel. | | | √ |
| :DATA? | Return all CALC2 readings triggered by INITiate. | | | √ |
| :LATest? | Return only the last (latest) reading. | | | |
| :CALCulate3 | Path to configure and control CALC3 calculations on buffer data: | | Sec 8 | √ |
| :FORMat <name> | Select buffer statistic; MEAN, SDEViation, Maximum, MINimum or PKPK. | MEAN | | √ |
| :FORMat? | Query selected statistic. | | | √ |
| :DATA? | Read the selected buffer statistic. | | | √ |

**:SOURce2 <NDN> and <NRf> parameters:**

| | |
|---|---|
| <NDN> = #Bxxxx | Binary format (each x = 1 or 0) |
| = #Hx | Hexadecimal format (x = 0 to F) |
| = #Qxx | Octal format (x = 0 to 17) |
| <NRf> = 0 to 15 | Decimal format |

*Table 17-2*
*DISPlay command summary*

| Command | Description | Default parameter | Ref | SCPI |
|---|---|---|---|---|
| :DISPlay | | | Sec 16 | |
| :DIGits <n> | Set display resolution; 4 to 7. | 6 | Sec 6 | |
| :DIGits? | Query display resolution. | | | |
| :ENABle <b> | Turn front panel display on or off. | (Note 1) | | √ |
| :ENABle? | Query display state. | | | √ |
| [:WINDow[1]] | Path to control user text messages: | | | √ |
| :TEXT | | (Note 2) | | √ |
| [:DATA] <a> | Define ASCII message “a” (up to 12 characters). | | | √ |
| [:DATA]? | Read text message. | | | √ |
| :STATe <b> | Enable or disable text message mode. | (Note 3) | | √ |
| :STATe? | Query state of text message mode. | | | √ |

Notes:
1. *RST and SYSTem:PRESet have no effect on the display circuitry. Pressing LOCAL or cycling power enables (ON) the display circuit.
2. *RST and SYSTem:PRESet have no effect on a user-defined message. Pressing LOCAL or cycling power cancels all user-defined messages.
3. *RST and SYSTem:PRESet have no effect on the state of the message mode. Pressing LOCAL or cycling power disables (OFF) the message mode.

*Table 17-3*
*FORMat command summary*

| Command | Description | Default parameter | Ref | SCPI |
|---|---|---|---|---|
| :FORMat | | | Sec 16 | |
| [:DATA] <type>[,<length>] | Specify data format; ASCii, REAL, 32, or SREal. | ASC | | √ |
| [:DATA]? | Query data format. | | | √ |
| :ELEMents <item list> | Specify data elements; READing, TIME, and STATus. | All 3 | | |
| :ELEMents? | Query data format elements. | | | |
| :BORDer <name> | Specify byte order; NORMal or SWAPped. | (see Note) | | √ |
| :BORDer? | Query byte order. | | | √ |
| :SREGister <name> | Select data format for reading status registers; ASCii, HEXadecimal, OCTal, or BINary. | ASC | Sec 13 | |
| :SREGister? | Query format for reading event registers. | | | |
| :SOURce2 <name> | Select data format for reading output patterns: ASCii, HEXadecimal, OCTal, or BINary. | ASC | Sec 10 | |
| :SOURce2? | Query format for reading output patterns. | | | |

Note: *RST default is NORMal. SYSTem:PRESet default is SWAPped.

*Table 17-4*
*SENSe command summary*

| Command | Description | Default parameter | Ref | SCPI |
|---|---|---|---|---|
| [:SENSe[1]] | | | | |
| :FUNCtion <name> | Select function; 'VOLTage[:DC]', 'CURRent[:DC]', 'RESistance' or 'CHARge'. | 'VOLT' | Secs 3, 4, 5 | √ |
| :FUNCtion? | Query measurement function. | | | √ |
| :DATA | Path to return instrument readings: | | Secs 3, 4, 5 | √ |
| [:LATest]? | Return the last instrument reading. | | | √ |
| :VOLTage[:DC] | Path to configure volts function: | | | √ |
| :NPLCycles <NRf> | Set integration rate in line cycles (PLC); 0.01 to 10. | 6 (60Hz) 5 (50Hz) | Sec 6 | √ |
| :NPLCycles? | Query NPLC. | | | √ |
| :RANGe | Configure measurement range: | | Sec 6 | √ |
| [:UPPer] <NRf> | Select range; -210 to 210 (volts). | 21 | | √ |
| [:UPPer]? | Query range value. | | | √ |
| :AUTO <b> | Enable or disable autorange. | (see Note) | | √ |
| :ULIMit <NRf> | Select autorange upper limit; -210 to 210 (volts). | 210 | | |
| :ULIMit? | Query upper limit for autorange. | | | |
| :LLIMit <NRf> | Select autorange lower limit; -210 to 210 (volts). | 2.1 | | |
| :LLIMit? | Query lower limit for autorange. | | | |
| :AUTO? | Query state of autorange. | | | √ |
| :GUARd <b> | Enable or disable driven guard. | OFF | Sec 3 | |
| :GUARd? | Query state of driven guard. | | | |
| :XFEedback <b> | Enable or disable external feedback. | OFF | Sec 11 | |
| :XFEedback? | Query state of external feedback. | | | |
| :CURRent[:DC] | Path to configure amps function: | | | √ |
| :NPLCycles <NRf> | Set integration rate in line cycles (PLC); 0.01 to 10. | 6 (60Hz) 5 (50Hz) | Sec 6 | √ |
| :NPLCycles? | Query NPLC. | | | √ |
| :RANGe | Configure measurement range: | | Sec 6 | √ |
| [:UPPer] <NRf> | Select range; -0.021 to 0.021 (amps). | 2.1e-4 | | √ |
| [:UPPer]? | Query range value. | | | √ |
| :AUTO <b> | Enable or disable autorange. | (see Note) | | √ |

*Table 17-4 (cont.)*
*SENSe command summary*

| Command | Description | Default parameter | Ref | SCPI |
|---|---|---|---|---|
| :ULIMit <NRf> | Select autorange upper limit; -0.021 to 0.021 (amps). | 2.1e-2 | | |
| :ULIMit? | Query upper limit for autorange. | | | |
| :LLIMit <NRf> | Select autorange lower limit; -0.021 to 0.021 (amps). | 2.1e-11 | | |
| :LLIMit? | Query lower limit for autorange. | | | |
| :AUTO? | Query state of autorange. | | | √ |
| :DAMPing <b> | Enable or disable current damping. | OFF | Sec 4 | |
| :DAMPing? | Query state of damping | | | |
| :RESistance | Path to configure ohms function: | | | √ |
| :NPLCycles <NRf> | Set integration rate in line cycles (PLC); 0.01 to 10. | 6 (60Hz)<br>5 (50Hz) | Sec 6 | √ |
| :NPLCycles? | Query NPLC. | | | √ |
| :RANGe | Configure measurement range: | | Sec 6 | √ |
| [:UPPer] <NRf> | Select range; 0 to 2.1e11 (ohms). | 2.1e5 | | √ |
| [:UPPer]? | Query range value. | | | √ |
| :AUTO <b> | Enable or disable autorange. | (see Note) | | √ |
| :ULIMit <NRf> | Select autorange upper limit; -2.1e11 to 2.1e11 (ohms). | 2.1e11 | | |
| :ULIMit? | Query upper limit for autorange. | | | |
| :LLIMit <NRf> | Select autorange lower limit; -2.1e11 to 2.1e11 (ohms). | 2.1e3 | | |
| :LLIMit? | Query lower limit for autorange. | | | |
| :AUTO? | Query state of autorange. | | | √ |
| :GUARd <b> | Enable or disable driven guard. | OFF | Sec 3 | |
| :GUARd? | Query state of driven guard. | | | |
| :CHARge | Path to configure coulombs function: | | | √ |
| :NPLCycles <NRf> | Set integration rate in line cycles (PLC); 0.01 to 10. | 6 (60Hz)<br>5 (50Hz) | Sec 6 | √ |
| :NPLCycles? | Query NPLC. | | | √ |
| :RANGe | Configure measurement range: | | Sec 6 | √ |
| [:UPPer] <NRf> | Select range; -21e-6 to 21e-6 (coulombs). | 2.1e-6 | | √ |
| [:UPPer]? | Query range value. | | | √ |
| :AUTO <b> | Enable or disable autorange. | (see Note) | | √ |

*Table 17-4 (cont.)*
*SENSe command summary*

| Command | Description | Default parameter | Ref | SCPI |
|---|---|---|---|---|
| :LGRoup <name> | Specify autorange limit; HIGH or LOW. | HIGH | | |
| :LGRoup? | Query upper limit for autorange. | | | |
| :AUTO? | Query state of autorange. | | | √ |
| :ADIScharge | Path for auto discharge: | | Sec 5 | |
| :LEVel <NRf> | Set auto discharge level; -21e-6 to 21e-6. | 2e-6 | | |
| :LEVel? | Query auto discharge level. | | | |
| [:STATe] <b> | Enable or disable auto discharge. | OFF | | |
| [:STATe]? | Query state of auto discharge. | | | |
| | | | | |
| :AVERage | Path to control the Digital Filter: | | Sec 6 | |
| :TCONtrol <name> | Select filter control; MOVing or REPeat. | REP | | |
| :TCONtrol? | Query filter control. | | | |
| :COUNt <n> | Specify filter count; 2 to 100. | 10 | | |
| :COUNt? | Query filter count. | | | |
| [:STATe] <b> | Enable or disable digital filter. | OFF | | |
| [:STATe]? | Query state of digital filter. | | | |
| :MEDian | Path to control median filter: | | Sec 6 | |
| :RANK <NRf> | Specify “n” for rank; 1 to 5 (rank = 2n+1). | 1 | | |
| :RANK? | Query rank. | | | |
| [:STATe] <b> | Enable or disable median filter. | OFF | | |
| [:STATe]? | Query state of median filter. | | | |

Note: *RST default is ON and SYSTem:PRESet default is OFF.

*Table 17-5*
*SOURce command summary*

| Command | Description | Default parameter | Ref | SCPI |
|---|---|---|---|---|
| :SOURce2 | | | Sec 10 | |
| :TTL | Program I/O port: | | | |
| [:LEVel] <NDN> or <NRf> | Specify 4-bit digital output pattern. | 15 | | |
| [:LEVel]? | Query output value. | | | |
| :CLEar | Clear I/O port (return output to TTL pattern): | | | |
| [:IMMediate] | Clear I/O port immediately. | | | |
| :AUTO <b> | Enable or disable auto-clear. | OFF | | |
| :AUTO? | Query state of auto-clear. | | | |
| :DELay <n> | Specify delay (pulse-width) for pass/fail pattern; 0 to 60 (sec). | 0.0001 | | |
| :DELay? | Query delay. | | | |
| :TTL4 | Line 4 mode configuration: | | | |
| :MODE <name> | Select output line 4 mode; EOTest or BUSY. | EOT | | |
| :MODE? | Query line 4 mode. | | | |
| :BSTate <ttl> | Select active TTL level for busy; 1 (HI) or 0 (LO). | 0 | | |
| :BSTate? | Query busy level. | | | |
| **<NDN> and <NRf> parameters:** | | | | |
| <NDN> = #Bxxx | Binary format (each x = 1 or 0) | | | |
| = #Hx | Hexadecimal format (x = 0 to F) | | | |
| = #Qx | Octal format (x = 0 to 17) | | | |
| <NRf> = 0 to 15 | Decimal format | | | |

*Table 17-6*
*STATus command summary*

| Command | Description | Default parameter | Ref | SCPI |
|---|---|---|---|---|
| :STATus | | (Note 1) | Sec 13 | √ |
| :MEASurement | Measurement event registers: | | | |
| [:EVENt]? | Read the event register. | (Note 2) | | |
| :ENABle <NDN> or <NRf> | Program the enable register. | (Note 3) | | |
| :ENABle? | Read the enable register. | | | |
| :CONDition? | Read the condition register. | | | |
| :OPERation | Operation event registers: | | | √ |
| [:EVENt]? | Read the event register. | (Note 2) | | √ |

*Table 17-6 (cont.)*
*STATus command summary*

| Command | Description | Default parameter | Ref | SCPI |
|---|---|---|---|---|
| :ENABle <NDN> or <NRf> | Program the enable register. | (Note 3) | | √ |
| :ENABle? | Read the enable register. | | | √ |
| :CONDition? | Read the condition register. | | | √ |
| :QUEStionable | Questionable event registers: | | | √ |
| [:EVENt]? | Read the event register. | (Note 2) | | √ |
| :ENABle <NDN> or <NRf> | Program the enable register. | (Note 3) | | √ |
| :ENABle? | Read the enable register. | | | √ |
| :CONDition? | Read the condition register. | | | √ |
| :PRESet | Return status registers to default states. | | | √ |
| :QUEue | Read error queue: | | | √ |
| [:NEXT]? | Read and clear oldest error/status (code and message). | (Note 4) | | √ |
| :ENABle <list> | Specify error and status messages for error 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 | Clear messages from error queue. | | | |

*Parameters:*

| | | |
|---|---|---|
| <NDN> = | #Bxx…x | Binary format (each x = 1 or 0) |
| = | #Hx | Hexadecimal format (x = 0 to FFFF) |
| = | #Qx | Octal format (x = 0 to 177777) |
| <NRf> = | 0 to 65535 | Decimal format |
| <list> = | (100:200, -224) | Example of a range and single entry (+100 through +200 and -224) |

Notes:
1. Commands in this subsystem are not affected by *RST or 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. STATus:PRESet has no effect.
3. Enable registers — Power-up and STATus:PRESet clears all bits. *CLS has no effect.
4. Error queue — Power-up and *CLS empties the error queue. STATus:PRESet has no effect.
5. Error queue messages — Power-up enables error messages and disables status messages. *CLS and STATus:PRESet have no effect.

*Table 17-7*
*SYSTem command summary*

| Command | Description | Default parameter | Ref | SCPI |
|---|---|---|---|---|
| :SYSTem | | | Sec 16 | |
| :ZCHeck <b> | Enable or disable zero check. | ON | Sec 2 | |
| :ZCHeck? | Query state of zero check. | | | |
| :ZCORrect | Zero correct: | | Sec 2 | |
| [:STATe] <b> | Enable or disable zero correct. | OFF | | |
| [:STATe]? | Query state of zero correct. | | | |
| :ACQuire | Acquire a new zero correct value. | | | |
| :PRESet | Return to SYSTem:PRESet defaults. | | | √ |
| :LFRequency <freq> | Select power line frequency; 50 or 60 (Hz). | | Sec 1 | |
| :LFRequency? | | | | |
| :AZERo | Path to control autozero: | | Sec 2 | √ |
| [:STATe] <b> | Enable or disable autozero. | ON | | √ |
| [:STATe]? | Query state of autozero. | | | √ |
| :TIME | Timestamp: | | | |
| :RESet | Reset timestamp to 0 seconds. | | | |
| :POSetup <name> | Select power-on setup; RST, PRESet, or SAVx (where x = 0 to 4). | | | |
| :POSetup? | Query power-on setup. | | | |
| :VERSion? | Query SCPI revision level. | | | √ |
| :ERRor | Read error queue: | (see Note ) | Sec 13 | √ |
| [:NEXT]? | Read and clear oldest error/status (code and message). | | | |
| :ALL? | Read and clear all errors/status (code and message). | | | |
| :COUNt? | Read the number of messages in queue. | | | |
| :CODE | Code numbers only: | | | |
| [:NEXT]? | Read and clear oldest error/status (code only). | | | |
| :ALL? | Read and clear all errors/status (codes only). | | | |
| :CLEar | Clear messages from error queue. | | Sec 13 | |
| :KEY <NRf> | Simulate key-press; see Figure 16-3. | | | √ |
| :KEY? | Query the last “pressed” key. | | | √ |

*Table 17-7 (cont.)*
*SYSTem command summary*

| Command | Description | Default parameter | Ref | SCPI |
|---|---|---|---|---|
| | *RS-232 interface:* | | Sec 12 | |
| :LOCal | Take Model 6514 out of remote (RS-232 only). | | | |
| :REMote | Put Model 6514 in remote (RS-232 only). | | | |
| :RWLock | Enable or disable local lockout (RS-232 only). | | | |

Note: Clearing the error queue - Power-up and *CLS clears the error queue. *RST, SYSTem:PRESet, and STATus:PRESet have no effect on the error queue.

*Table 17-8*
*TRACe command summary*

| Command | Description | Default parameter | Ref | SCPI |
|---|---|---|---|---|
| :TRACe\|:DATA | Use :TRACe or :DATA as root command. | (see Note) | Sec 8 | √ |
| :DATA? | Read the contents of the buffer (data store). | | | √ |
| :CLEar | Clear readings from buffer. | | | |
| :FREE? | Query bytes available and bytes in use. | | | √ |
| :POINts <n> | Specify size of buffer; 1 to 2500. | 100 | | √ |
| :ACTual? | Query number of readings stored in buffer. | | | |
| :POINts? | Query buffer size. | | | √ |
| :FEED <name> | Select source of readings for buffer; SENSe[1], CALCulate[1], or CALCulate2. | SENS1 | | √ |
| :CONTrol <name> | Select buffer control mode; NEXT or NEVer. | NEV | | √ |
| :CONTrol? | Query buffer control mode. | | | √ |
| :FEED? | Query source of readings for buffer. | | | √ |
| :TSTamp | Timestamp: | | | |
| :FORMat <name> | Select timestamp format; ABSolute or DELta. | ABS | | |
| :FORMat? | Query timestamp format. | | | |

Note: SYSTem:PRESet and *RST have no effect on the commands in this subsystem. The listed defaults are power-on defaults.

*Table 17-9*
*TRIGger command summary*

| Command | Description | Default parameter | Ref | SCPI |
|---|---|---|---|---|
| :INITiate | Path to initiate measurement cycle(s): | | Sec 9 | √ |
| [:IMMediate] | Initiate one trigger cycle. | | | √ |
| :ABORt | Reset trigger system (goes to idle state). | | | √ |
| :ARM[:SEQuence[1]] | Path to configure arm layer: | | | √ |
| [:LAYer[1]] | | | | |
| :SOURce <name> | Select control source; IMMediate, TIMer, BUS, TLINk, STESt, PSTest, NSTest, BSTest, or MANual. | IMMediate | | √ |
| :SOURce? | Query arm control source. | | | √ |
| :COUNt <n> | Set measure count; 1 to 2500, or INF (infinite). | 1 | | √ |
| :COUNt? | Query measure count. | | | √ |
| :TIMer <n> | Set timer interval; 0.001 to 99999.999 (sec). | 0.100 | | √ |
| :TIMer? | Query timer interval. | | | √ |
| [:TCONfigure] | | | | √ |
| :DIRection <name> | Enable (SOURce) or disable (ACCeptor) bypass. | ACCeptor | | √ |
| :DIRection? | Query arm source bypass. | | | √ |
| [:ASYNchronous] | Configure input/output triggers: | | | |
| :ILINe <NRf> | Select input trigger line; 1, 2, 3, 4, 5, or 6. | 1 | | |
| :ILINe? | Query input trigger line. | | | |
| :OLINe <NRf> | Select output trigger line; 1, 2, 3, 4, 5, or 6. | 2 | | |
| :OLINe? | Query output trigger line. | | | |
| :OUTPut <name> | Output trigger (TRIGger) or not at all (NONE). | NONE | | |
| :OUTPut? | Query output trigger status. | | | |
| :TRIGger[:SEQuence[1]] | Path to configure trigger layer: | | | √ |
| :SOURce <name> | Select control source; IMMediate or TLINk. | IMMediate | | √ |
| :SOURce? | Query trigger control source. | | | √ |
| :COUNt <n> | Set measure count; 1 to 2500, or INF (infinite). | 1 | | √ |
| :COUNt? | Query measure count. | | | √ |
| :DELay <n> | Set trigger delay; 0 to 999.9999 (sec). | 0.0 | | √ |
| :AUTO <b> | Enable or disable auto delay. | OFF | | √ |
| :AUTO? | Query state of auto delay. | | | √ |
| :DELay? | Query delay value. | | | √ |

*Table 17-9 (cont.)*
*TRIGger command summary*

| Command | Description | Default parameter | Ref | SCPI |
|---|---|---|---|---|
| :TRIGger:CLEar | Clear input triggers immediately. | | | |
| [:TCONfigure] | | | | √ |
| :DIRection <name> | Enable (SOURce) or disable (ACCeptor) bypass. | ACCeptor | | √ |
| :DIRection? | Query trigger source bypass. | | | √ |
| [:ASYNchronous] | Configure input/output triggers: | | | |
| :ILINe <NRf> | Select input trigger line; 1, 2, 3, 4, 5, or 6. | 1 | | |
| :ILINe? | Query input trigger line. | | | |
| :OLINe <NRf> | Select output trigger line; 1, 2, 3, 4, 5, or 6. | 2 | | |
| :OLINe? | Query output trigger line. | | | |
| :OUTPut <name> | Output trigger after measurement (SENSe) or not at all (NONE). | NONE | | |
| :OUTPut? | Query output trigger status. | | | |

# 18
# Performance Verification

# Introduction

Use the procedures in this section to verify that Model 6514 accuracy is within the limits stated in the instrument's one-year accuracy specifications. You can perform these verification procedures:

- When you first receive the instrument make sure that it was not damaged during shipment.
- Verify that the unit meets factory specifications.
- Determine if calibration is required.
- Following calibration, make sure it was performed properly.

*WARNING* **The information in this section is intended only for qualified service personnel. Do not attempt these procedures unless you are qualified to do so. Some of these procedures may expose you to hazardous voltages, which could cause personal injury or death if contacted. Use standard safety precautions when working with hazardous voltages.**

*NOTE* *If the instrument is still under warranty, and its performance is outside specified limits, contact your Keithley representative, or the factory, to determine the correct course of action.*

# Verification test requirements

Be sure that you perform the verification tests:

- Under the proper environmental conditions.
- After the specified warm-up period.
- Using the correct line voltage.
- Using the proper test equipment.
- Using the specified test signals and reading limits.

## Environmental conditions

Conduct your performance verification procedures in a test environment with:

- An ambient temperature of (18-28˚C) 65-82˚F.
- A relative humidity of less than 70% unless otherwise noted.

## Warm-up period

Allow Model 6514 to warm up for at least one hour before conducting the verification procedures. If the instrument has been subjected to temperature extremes (those outside the ranges stated above), allow additional time for the instrument's internal temperature to stabilize. Typically, allow one extra hour to stabilize a unit that is (10˚C) 18˚F outside the specified temperature range.

Allow the test equipment to warm up for the minimum time specified by the manufacturer.

## Line power

Model 6514 requires a line voltage of 100/120 VAC or 220/240 VAC at a line frequency of 50 or 60Hz. Verification tests must be performed within this range.

# Recommended test equipment

Table 18-1 summarizes recommended verification equipment. You can use alternate equipment, but keep in mind that test equipment accuracy will add to the uncertainty of each measurement. Generally, the test equipment should have accuracy or uncertainty at least four times better than corresponding Model 6514 specifications.

*Table 18-1*
*Recommended verification equipment*

| **Description** | **Manufacturer/model** | **Specifications** |
|---|---|---|
| Calibrator | Fluke 5700A | DC voltage:[1]<br>2V: 7ppm<br>20V: 5ppm<br>200V: 7ppm<br><br>DC current:[1]<br>20µA: 550ppm<br>200µA: 100ppm<br>2mA: 55ppm<br>20mA: 55ppm |
| Resistance calibrator | Fluke 5450A | Nominal resistance:[1]<br>1.9kΩ: 8ppm<br>19kΩ: 7.5ppm<br>190kΩ: 8.5ppm<br>1.9MΩ: 11.5ppm<br>19MΩ: 30ppm<br>100MΩ: 120ppm |
| Electrometer calibration standard | Keithley Model 5156 | Nominal resistance:[2]<br>100MΩ: 200ppm<br>1GΩ: 300ppm<br>10GΩ: 400ppm<br>100GΩ: 500ppm<br><br>Nominal capacitance:[2]<br>1nF: 1,000ppm<br>100nF: 1,000ppm |

Notes:
1. 90-day, 23˚ ±5˚C full-range accuracy specifications shown,
2. 23˚ ±3˚C accuracy of characterization.
3. Connect red and black clips to make triax short.

*Table 18-1 (cont.)*
*Recommended verification equipment*

| Description | Manufacturer/model | Specifications |
|---|---|---|
| Triax cable | Keithley 7024-3 | |
| Low-noise coax cable | Keithley 4801 | |
| Triax-to-alligator clip cable[3] | Keithley 237-ALG-2 | |
| Triax-to-BNC adapter | Keithley 7078-TRX-BNC | |
| Triax shielding cap | Keithley CAP-31 | |
| BNC-to-double banana plug adapter | Pomona 1269 | |

Notes:
1. 90-day, 23˚ ±5˚C full-range accuracy specifications shown,
2. 23˚ ±3˚C accuracy of characterization.
3. Connect red and black clips to make triax short.

# Verification limits

The verification limits stated in this section have been calculated using only Model 6514 one-year accuracy specifications, and they do **not** include test equipment uncertainty. If a particular measurement falls outside the allowable range, recalculate new limits based on Model 6514 specifications and corresponding test equipment specifications.

## Example reading limits calculation

As an example of how verification limits are calculated, assume you are testing the 20V range using a 20V input value. Using Model 6514 20V range accuracy specification of ±(0.025% of reading + 3 counts), the calculated reading limits are:

Reading limits = 20V ±[(20V × 0.025%) + 300μV]
= 20V ±(0.005 + 0.0003)
= 20V ±0.0053V
= 19.9947V to 20.0053V

## Recalculating resistance reading limits

When verifying resistance measurement accuracy, it will probably be necessary to recalculate resistance limits based on the actual resistance values. You can calculate new reading limits in the same manner described above, but be sure to use the actual calibration resistance values and Model 6514 ohms accuracy specifications for your calculations.

As an example, assume that you are testing the 20kΩ range, and that the actual value of the nominal 19kΩ calibrator resistor is 19.1kΩ. Using Model 6514 20kΩ range accuracy specifications of ±(0.15% of reading + 3 counts), the recalculated reading limits are:

Reading limits = 19.1kΩ ±[(19.1kΩ × 0.15%) + 0.3Ω]
= 19.1kΩ ±29Ω
= 19.0710kΩ to 19.1290kΩ

# Calibrator voltage calculations

When verifying the 20pA-2µA current ranges and all charge ranges, you must calculate the actual calibrator voltages from the desired current or charge values and the characterized Model 5156 Calibration Standard resistor and capacitor values.

## Current calculations

Calibrator voltages required for verification currents are calculated as follows:

$$V = IR$$

Where: V = required calibrator voltage
I = verification current
R = actual standard resistor value

For example, assume you are calibrating the 20pA range using an actual 100.5GΩ standard resistor value. The actual calibrator voltage is: 20pA × 100.5GΩ = 2.01V.

## Charge calculations

Calibrator voltages for verification charge values are calculated as follows:

$$V = Q/C$$

Where: V = required calibrator voltage
Q = verification current
C = actual standard resistor value

For example, the required calibrator voltage for a 200nC range verification charge value with a 99.5nF standard capacitance value is: 200nC/99.5nF = 2.01005V.

# Performing the verification test procedures

## Test summary

- Volts measurement accuracy
- Amps measurement accuracy
- Ohms measurement accuracy
- Coulombs measurement accuracy

If Model 6514 is not within specifications and not under warranty, see the calibration procedures in Section 19 for information on calibrating the unit.

## Test considerations

When performing the verification procedures:

- Restore Model 6514 factory front panel defaults and perform input bias current and voltage offset calibration as outlined below.
- Make sure that the test equipment is properly warmed up and properly connected to Model 6514 INPUT jack.
- Be sure test equipment is set up for the proper function and range.
- Allow the input signal to settle before making a measurement.
- Do not connect test equipment to Model 6514 through a scanner, multiplexer, or other switching equipment.

*WARNING* **The maximum common-mode voltage (voltage between analog common and chassis ground) is 500V peak, DC to 60Hz sine wave. Exceeding this value may cause a breakdown in insulation, creating a shock hazard.**

*CAUTION* **The maximum input voltage is 250V peak, DC to 60Hz sine wave. Exceeding this voltage may result in instrument damage.**

# Restoring factory defaults

Before performing *each* verification procedure, restore the instrument to its factory front panel defaults as follows:

1. Press SHIFT then SETUP. The instrument will display the following prompt:
   RESTORE: FACT
2. Using either RANGE key, select FACT, then restore the factory default conditions by pressing ENTER.

*NOTE* *You can use either RANGE key to select among FACT, GPIB, and USR setups. Be sure to use FACT defaults for the verification procedures.*

# Input bias current and offset voltage calibration

Before performing the performance verification procedures, perform input bias current and offset voltage calibration as outlined below. Note that these offsets will be lost if power is cycled unless you save them first.

## Offset voltage calibration

1. From the calibration menu, use the down RANGE key to display the following:
   CAL: VOFFSET
2. Press ENTER. The instrument will prompt for a short:
   INPUT SHORT
3. Connect the triax short (triax cable with red and alligator black clips connected together) to the rear panel INPUT jack.
4. Press ENTER to complete offset voltage calibration. The unit will display the following message:
   CALIBRATING

## Input bias current calibration

1. Turn on the power, and allow a one-hour warm-up period before calibrating input bias current or offset voltage.
2. Restore factory defaults as outlined above.
3. Press SHIFT then CAL, and note that the unit displays the following:
   CAL: RUN
4. Use the down RANGE key to display the following:
   CAL: IOFFSET
5. Press ENTER. The instrument will prompt for an open input:
   INPUT CAP

6. Connect the triax shielding cap to the rear panel INPUT jack.
7. Press ENTER to complete input bias current calibration. The unit will display the following message: CALIBRATING

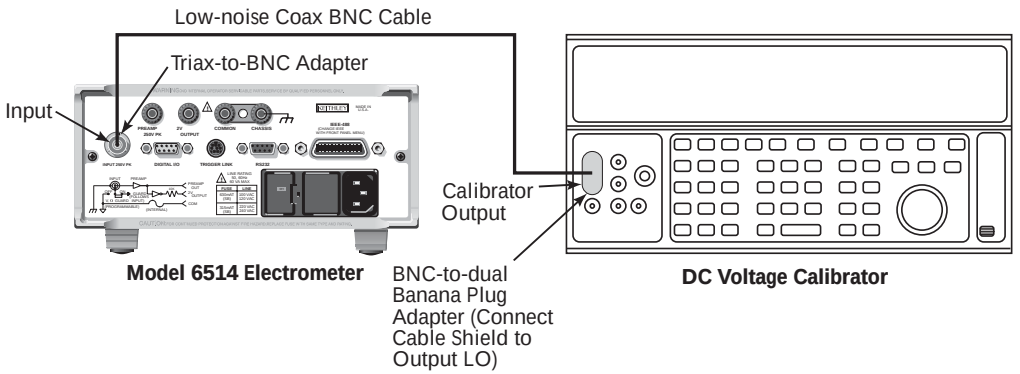
# Volts measurement accuracy

Follow the steps below to verify that Model 6514 volts function measurement accuracy is within specified limits. The test involves applying accurate DC voltages and then verifying that Model 6514 voltage readings are within required limits.

*WARNING* **Hazardous voltages are used in the following procedures. Always place the calibrator in standby before changing test connections.**

1. With the power off, connect the voltage calibrator to Model 6514 INPUT jack, as shown in Figure 18-1. Use the appropriate triax-to-BNC, low-noise coaxial cable, and BNC-to-dual banana plug adapters where shown.

*Figure 18-1 Connections for volts verification*




2. Turn on the power and allow a one-hour warm-up period. Restore factory defaults and perform offset calibration as outlined above.
3. Select the DC volts function on Model 6514 by pressing the V key, and set the calibrator to output DC volts.
4. Select Model 6514 2V range with the down RANGE key.
5. Make sure zero check is enabled (press ZCHECK), then zero correct the instrument with ZCOR. Disable zero check.
6. Set the calibrator voltage to 0.0000V, and turn on the output.
7. Enable REL on Model 6514. Leave REL enabled for the remainder of the test.

8. Verify voltage measurement accuracy for each of the voltages listed in Table 18-2. For each test point:
   - Select the correct Model 6514 measurement range.
   - Set the calibrator voltage to the indicated value.
   - Verify that Model 6514 voltage reading is within the limits given in the table.
9. Repeat the procedure for negative source voltages with the same magnitudes as those listed in Table 18-2.

*Table 18-2*
*Voltage measurement accuracy reading limits*

| **Model 6514 range** | **Calibrator voltage** | **Model 6514 volts reading limits (1 Year, 18˚C-28˚C)** |
|---|---|---|
| 2V | 2.00000V | 1.99946 to 2.00054V |
| 20V | 20.0000V | 19.9947 to 20.0053V |
| 200V | 200.000V | 199.877 to 200.123V |

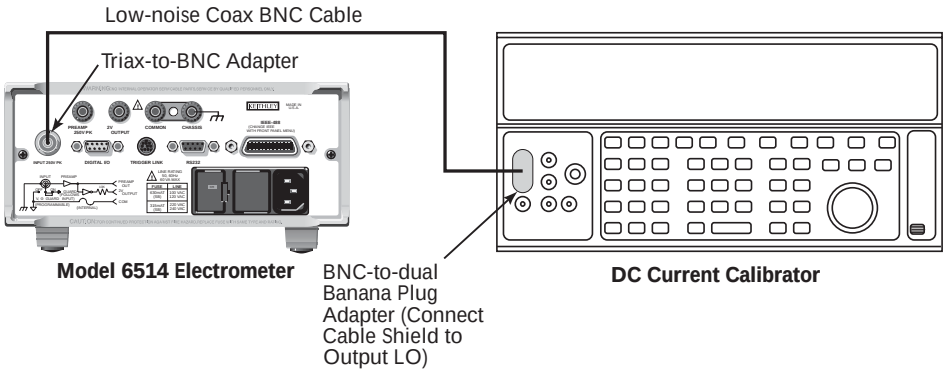
# Amps measurement accuracy

Follow the steps below to verify that Model 6514 amps function measurement accuracy is within specified limits. The test involves applying accurate DC currents and then verifying that Model 6514 current readings are within required limits.

## 20µA-20mA range accuracy

1. Connect the current calibrator to Model 6514 INPUT jack, as shown in Figure 18-2. Use the appropriate triax-to-BNC, low-noise coaxial cable, and BNC-to-dual banana plug adapters where shown.

*Figure 18-2 Connections for 20µA-20mA range verification*




2. Select Model 6514 DC amps function with the I key, and set the calibrator to output DC current.
3. Set Model 6514 to the 20µA range using the up or down RANGE key.
4. With zero check enabled, zero correct Model 6514, then disable zero check.
5. Set the calibrator current to 0.0000µA, and make sure the output is turned on.
6. Enable Model 6514 REL mode. Leave REL enabled for the remainder of the test.
7. Verify current measurement accuracy for each of the currents listed in Table 18-3. For each test point:
   - Select the correct Model 6514 measurement range.
   - Set the calibrator current to the indicated value.
   - Verify that Model 6514 current reading is within the limits given in the table.

8. Repeat the procedure for negative source currents with the same magnitudes as those listed in Table 18-3.

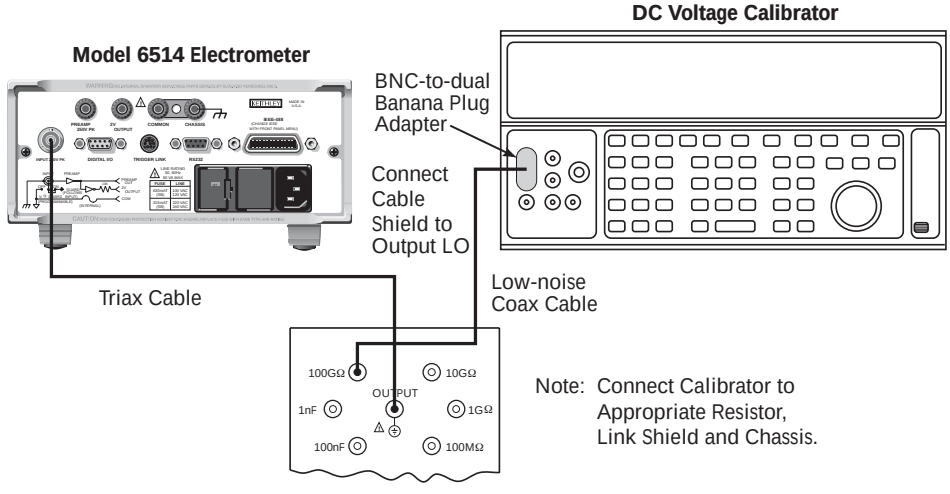
*Table 18-3*
*20µA-20mA range current measurement accuracy reading limits*

| Model 6514 range | Calibrator current | Model 6514 amps reading limits (1 Year, 18˚C-28˚C) |
|---|---|---|
| 20µA | 20.0000µA | 19.9795 to 20.0205µA |
| 200µA | 200.000µA | 199.795 to 200.205µA |
| 2mA | 2.00000mA | 1.99790 to 2.00210mA |
| 20mA | 20.0000mA | 19.9795 to 20.0205mA |

## 20pA-2µA range accuracy

1. Connect the voltage calibrator and Model 5156 Electrometer Calibration Standard to Model 6514 INPUT jack, as shown in Figure 18-3. Initially make connections to the 100GΩ resistor in the calibration standard.

*Figure 18-3*
*Connections for 20pA-20µA range verification*




2. Select the DC amps function on Model 6514, and set the calibrator to output DC voltage.
3. Set Model 6514 to the 20pA range.
4. With zero check enabled, zero correct the instrument, then disable zero check.
5. Set the calibrator voltage to 0.0000V, and make sure the output is turned on.
6. Enable Model 6514 REL mode. Leave REL enabled for the remainder of the test.

7. Verify current measurement accuracy for each of the currents listed in Table 18-4. For each test point:
   - Make connections to the indicated calibration standard resistor.
   - Select the correct Model 6514 measurement range.
   - Calculate the actual required calibrator voltage: V = IR, where I is the desired applied current, and R is the actual standard resistor value.
   - Set the calibrator to the calculated voltage.
   - Verify that Model 6514 current reading is within the reading limits listed in the table.
8. Repeat the procedure for negative source currents with the same magnitudes as those listed in Table 18-4.

*Table 18-4*
*20pA-2µA range current measurement accuracy reading limits*

| **Model 6514 range** | **Nominal calibrator voltage** | **Calibration standard resistor[1]** | **Applied current** | **Actual voltage[2]** | **Model 6514 amps reading limits (1 Year, 18˚C-28˚C)** |
|---|---|---|---|---|---|
| 20pA | 2V | 100GΩ | 20.0000pA | _____V | 19.7970 to 20.2030pA |
| 200pA | 2V | 10GΩ | 200.000pA | _____V | 197.995 to 202.005pA |
| 2nA | 2V | 1GΩ | 2.00000nA | _____V | 1.99570 to 2.00430nA |
| 20nA | 2V | 100MΩ | 20.0000nA | _____V | 19.9595 to 20.0405nA |
| 200nA | 20V | 100MΩ | 200.000nA | _____V | 199.595 to 200.405nA |
| 2µA | 200V | 100MΩ | 2.00000µA | _____V | 1.99790 to 2.00210µA |

[1] Nominal resistance values shown. Use actual characterized value for calculations.
[2] Calculate actual calibrator voltage as follows: V = IR, where I is desired applied current, and R is actual standard resistance value.

# Ohms measurement accuracy

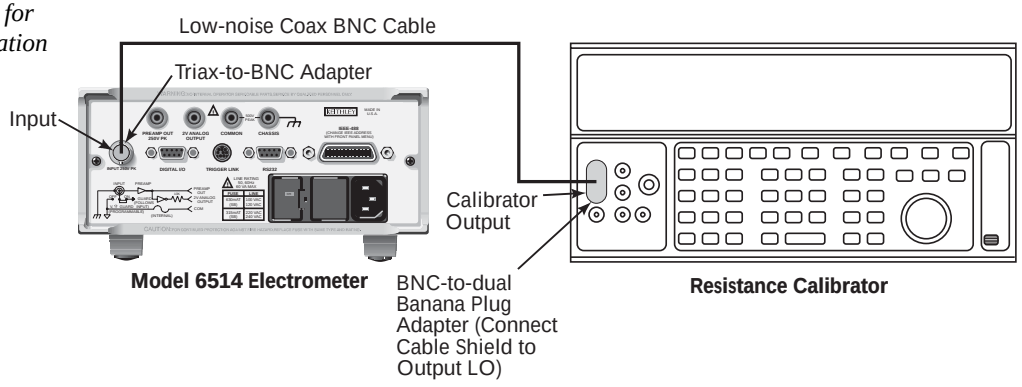
Follow the steps below to verify that Model 6514 ohms function measurement accuracy is within specified limits. This procedure involves applying accurate resistances from a resistance calibrator or standard and then verifying that Model 6514 resistance measurements are within required limits.

*WARNING* **With the ohms function selected, the Model 6514 can output an open-circuit voltage up to 250V. Place the unit in zero check when leads are not connected.**

## 2kΩ-20MΩ range accuracy

1. Connect the resistance calibrator to Model 6514 INPUT jack, as shown in Figure 18-4.

*Figure 18-4 Connections for ohms verification (2kΩ-20MΩ ranges)*




2. Select Model 6514 ohms function by pressing the Ω key, and set the calibrator to the resistance function.
3. With zero check enabled, zero correct the instrument, then disable zero check.
4. Output 0Ω from the calibrator, and then press REL.

5. Verify resistance measurement accuracy for the 2kΩ-20MΩ ranges as listed in Table 18-5. For each test point:

   - Select the correct Model 6514 measurement range.
   - Set the calibrator resistance to the indicated value.
   - If the calibrator resistance differs from the nominal value, recalculate new reading limits based on the resistance and Model 6514 accuracy specifications.
   - Verify that Model 6514 resistance reading is within the required reading limits.

*Table 18-5*
*2kΩ-20MΩ range resistance measurement accuracy limits*

| **Model 6514 range** | **Calibrator resistance[1]** | **Model 6514 ohms reading limits (1 Year, 18˚C-28˚C)[2]** |
|---|---|---|
| 2kΩ | 1.9kΩ | 1.89610 to 1.90390kΩ |
| 20kΩ | 19kΩ | 18.9712 to 19.0288kΩ |
| 200kΩ | 190kΩ | 189.522 to 190.478kΩ |
| 2MΩ | 1.9MΩ | 1.89525 to 1.90475MΩ |
| 20MΩ | 19MΩ | 18.9617 to 19.0383MΩ |

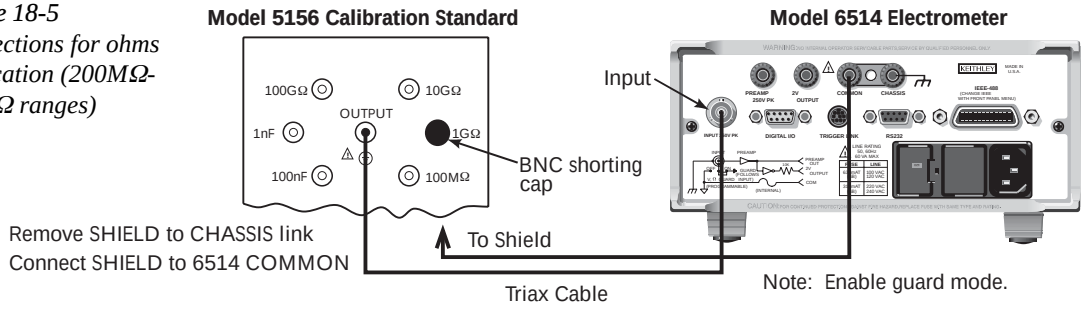
[1] Nominal resistance values.
[2] Reading limits based on Model 6514 accuracy specifications and nominal resistance values. If actual resistance values differ from nominal values shown, recalculate reading limits using actual calibrator resistance values and Model 6514 one-year accuracy specifications. See *Verification limits* earlier in this section for details.

## 200MΩ-200GΩ range accuracy

1. Connect Model 5156 Electrometer Calibration Standard to Model 6514, as shown in Figure 18-5. Initially, connect the BNC shorting cap to the 100MΩ resistance jack. Be sure to remove the link between SHIELD and CHASSIS, and connect Model 5156 CHASSIS jack to Model 6514 COMMON terminal.

*WARNING* **Hazardous voltage may be present on Model 5156 SHIELD and OUTPUT jacks.**

*Figure 18-5*
*Connections for ohms verification (200MΩ-200GΩ ranges)*




2. Select Model 6514 ohms function with the Ω key.
3. Using the GRD key, enable Model 6514 guard mode.
4. Verify resistance measurement accuracy for the 200MΩ-200GΩ ranges as listed in Table 18-6. For each test point:
   - Select the correct Model 6514 measurement range.
   - Connect the BNC shorting cap to select the appropriate standard resistor.
   - If the standard resistance differs from the nominal value, recalculate new reading limits based on the resistance and Model 6514 accuracy specifications.
   - Verify that Model 6514 resistance reading is within the required reading limits.

*Table 18-6*
*200MΩ-200GΩ resistance measurement accuracy limits*

| Model 6514 range | Standard resistance[1] | Model 6514 ohms reading limits (1 Year, 18˚C-28˚C)[2] |
|---|---|---|
| 200MΩ | 100MΩ | 99.697 to 100.303MΩ |
| 2GΩ | 1GΩ | 0.98496 to 1.01504GΩ |
| 20GΩ | 10GΩ | 9.8497 to 10.1503GΩ |
| 200GΩ | 100GΩ | 98.497 to 101.503GΩ |

[1] Nominal resistance values.

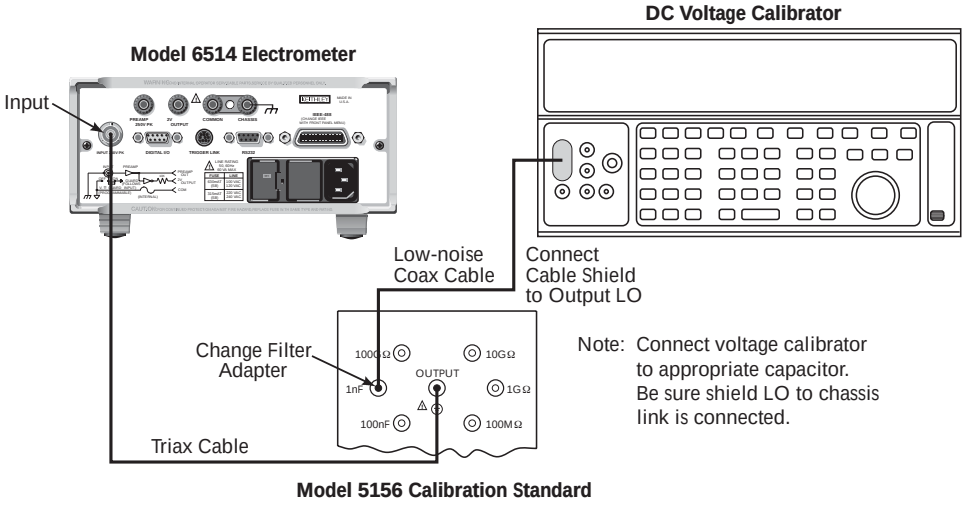
[2] Reading limits based on Model 6514 accuracy specifications and nominal resistance values. If actual resistance values differ from nominal values shown, recalculate reading limits using actual standard resistance values and Model 6514 one-year accuracy specifications. See *Verification limits* earlier in this section for details.

# Coulombs measurement accuracy

Follow the steps below to verify that Model 6514 coulombs function measurement accuracy is within specified limits. The test involves applying accurate charge values and then verifying that Model 6514 readings are within required limits.

1. Connect the voltage calibrator and Model 5156 Electrometer Calibration Standard to Model 6514 INPUT jack, as shown in Figure 18-6. Be sure to use the charge filter as indicated. Initially, make connections to the 1nF capacitor, and be sure the link between SHIELD and CHASSIS is installed.

*Figure 18-6 Connections for coulombs verification*




2. Using the GRD key, make sure Model 6514 guard mode is disabled.
3. Select Model 6514 coulombs function by pressing the Q key, and set the calibrator to the DC volts function.
4. With zero check enabled, zero correct the instrument, then disable zero check.
5. Set the calibrator voltage to 0.0000V, and turn on its output.
6. Enable the REL mode, and leave REL enabled for the remainder of the test.

7. Verify charge measurement accuracy for each of the values listed in Table 18-7. For each test point:
   - Select the correct Model 6514 measurement range.
   - Make connections to the correct standard capacitor.
   - Calculate the required voltage from the desired charge and actual standard capacitance value: V = Q/C.
   - Disable zero check.
   - Set the calibrator voltage to the calculated value.
   - Verify that Model 6514 charge reading is within the required limits.
   - Enable zero check to discharge the capacitor.

*Table 18-7*
*Coulombs measurement accuracy reading limits*

| **Model 6514 range** | **Nominal calibrator voltage** | **Standard capacitor[1]** | **Applied charge** | **Actual voltage[2]** | **Model 6514 coulombs reading limits (1 Year, 18˚C-28˚C)** |
|---|---|---|---|---|---|
| 20nC | 20V | 1nF | 20.0000nC | _____V | 19.9915 to 20.0805nC |
| 200nC | 200V | 1nF | 200.000nC | _____V | 199.195 to 200.805nC |
| 2µC | 20V | 100nF | 2.00000µC | _____V | 1.97995 to 202.02005µC |
| 20µC | 200V | 100nF | 20.0000µC | _____V | 19.7995 to 20.2005µC |

[1] Nominal values.
[2] Calculate actual voltage from applied charge and actual capacitance value: V = Q/C.

# 19
# Calibration

# Introduction

Use the procedures in this section to calibrate Model 6514. These procedures require accurate test equipment to source precise DC voltages, currents, resistances and charge values.

*WARNING* **The information in this section is intended only for qualified service personnel. Do not attempt these procedures unless you are qualified to do so. These procedures may expose you to hazardous voltages which could cause severe injury or death.**

# Environmental conditions

## Temperature and relative humidity

Conduct the calibration procedures at an ambient temperature of 18-28˚C (65-82˚F) with relative humidity of less than 70% unless otherwise noted.

## Warm-up period

Allow Model 6514 to warm up for at least one hour before performing calibration.

If the instrument has been subjected to temperature extremes (those outside the ranges stated above), allow additional time for the instrument's internal temperature to stabilize. Typically, allow one extra hour to stabilize a unit that is 10˚C (18˚F) outside the specified temperature range.

Also, allow the test equipment to warm up for the minimum time specified by the manufacturer.

## Line power

Model 6514 requires a line voltage of 100/120 VAC or 220/240 VAC at a line frequency of 50 or 60Hz. The instrument must be calibrated while operating from a line voltage within this range.

# Calibration considerations

When performing the calibration procedures:

- Make sure that the test equipment is properly warmed up and connected to Model 6514 INPUT jack.
- Always allow the source signal to settle before calibrating each point.
- Do not connect test equipment to Model 6514 through a scanner or other switching equipment.
- If an error occurs during calibration, Model 6514 will generate an appropriate error message.

*WARNING* **The maximum common-mode voltage (voltage between common and chassis ground) is 500V peak. DC to 60Hz sine wave. Exceeding this value may cause a breakdown in insulation, creating a shock hazard.**

*CAUTION* **The maximum input voltage is 250V peak, DC to 60Hz sine wave. Exceeding this voltage may result in instrument damage.**

## Calibration cycle

Perform calibration at least once a year to ensure the unit meets or exceeds its specifications.

# Recommended calibration equipment

Table 19-1 lists the recommended equipment for the calibration procedures. You can use alternate equipment, but keep in mind that test equipment uncertainty will affect calibration accuracy. Calibration equipment should have accuracy specifications at least four times better than corresponding Model 6514 specifications.

*Table 19-1*
*Recommended calibration equipment*

| Description | Manufacturer/model | Specifications |
|---|---|---|
| Calibrator | Fluke 5700A | DC voltage:[1]<br>2V: 7ppm<br>20V: 5ppm<br>200V: 7ppm<br><br>DC current:[1]<br>20µA: 550ppm<br>200µA: 100ppm<br>2mA: 55ppm<br>20mA: 55ppm |
| Resistance calibrator | Fluke 5450A | Nominal resistance:[1]<br>1.9kΩ: 8ppm<br>1.9MΩ: 11.5ppm |
| Calibration standard | Keithley Model 5156 | Nominal resistance:[2]<br>100MΩ: 200ppm<br>1GΩ: 300ppm<br>10GΩ: 400ppm<br>100GΩ: 500ppm<br><br>Nominal capacitance:[2]<br>1nF: 1,000ppm<br>100nF: 1,000ppm |
| Triax cable | Keithley 7024-3 | |
| Low-noise coax cable | Keithley 4801 | |
| Triax-to-alligator clip cable[3] | Keithley 237-ALG-2 | |
| Triax-to-BNC adapter | Keithley 7078-TRX-BNC | |
| Triax shielding cap | Keithley CAP-31 | |
| BNC-to-double banana plug adapter | Pomona 1269 | |

[1] 90-day, 23˚ ±5˚C full-range accuracy specifications shown.
[2] 23˚ ±3˚C accuracy of characterization.
[3] Short red and black clips to make triax short.

# Calibration errors

Model 6514 checks for errors after each calibration step, minimizing the possibility that improper calibration may occur due to operator error. If an error is detected during calibration, the instrument will display an appropriate error message. The unit will then prompt you to repeat the calibration step that caused the error.

# Calibration menu

You can access the calibration menu by pressing SHIFT then CAL. The various selections are summarized in Table 19-2. Use the up or down RANGE key to scroll through these selections.

*Table 19-2*
*Calibration menu*

| **Menu item*** | **Description** |
|---|---|
| RUN | Calibrates present function and range. |
| COUNT | Displays calibration count. |
| IOFFSET | Performs input bias current calibration. |
| VOFFSET | Performs offset voltage calibration. |
| DATES | Displays calibration and due dates. |
| UNLOCK | Unlocks calibration using code. |
| LOCK | Locks cal, exits to the main menu. |
| SAVE | Saves calibration constants. |

* Press SHIFT then CAL to access. Use up or down RANGE to scroll through selections.

# Aborting calibration

You can abort the calibration procedure at any time by pressing the EXIT key.

# Current and charge calculations

When calibrating the 20pA-2μA current ranges and all charge ranges, you must calculate the actual current or charge values from the applied calibrator voltages and the characterized Model 5156 Calibration Standard resistor and capacitor values. You can either calculate these values manually (as in this section) or automatically as covered below.

## Manual calculations

### Current calculations

Calibration currents are calculated as follows:

$I = V/R$

Where: I = calibration current
V = calibrator voltage
R = actual standard resistor value

For example, assume you are calibrating the 20pA range using a 2V calibrator voltage with an actual 100.5GΩ standard resistor value. The actual calibration current is: 2V/100.5GΩ = 19.9004pA.

### Charge calculations

Calibration charge values are calculated as follows:

$Q = CV$

Where: Q = calibration charge
C = actual standard capacitance value
V = calibrator voltage

For example, the 200nC range calibration charge value using 2V with a 99.5nF standard capacitance value is: 2V × 99.5nF = 199nC.

## Automatic calculations

As an alternative to manual calculations, you can use a computer to read the standard values from Model 5156 via remote programming commands, and then have the computer perform the calculations. See Appendix H for details. Note that you can use the *OPT? command (Section 14) to determine if the Model 5156 is properly connected.

# Calibration procedure

The calibration procedure should be performed in the following order:

- Preparing for calibration
- Offset voltage and input bias current calibration
- Volts calibration
- Amps calibration
- Coulombs calibration
- Ohms calibration
- Entering calibration dates and saving calibration
- Locking out calibration

*NOTE Ohms calibration must be done last to allow charge to bleed off internal insulators.*

## Preparing for calibration

1. Turn on Model 6514 and the calibrator, and allow them to warm up for at least one hour before performing calibration.
2. Press SHIFT then CAL. The instrument will display the following:
   CAL: RUN
3. Use the up or down RANGE key to display the following:
   CAL: UNLOCK
4. Press ENTER. The instrument will prompt for the calibration code:
   CODE?
5. Enter the current calibration code on the display. (Factory default: 006514.) Use the up and down RANGE keys to select the letter or number, and use the left and right arrow keys to choose the position. Press ENTER to complete the process, and the unit will display:
   NEW CODE? N
6. With N displayed, press ENTER.

## Input bias current and offset voltage calibration

Before performing the remaining calibration steps, perform input bias current and offset voltage calibration as outlined below.

### Offset voltage calibration

1. From the calibration menu, use the up or down RANGE key to display the following:
   CAL: VOFFSET
2. Press ENTER. The instrument will prompt for a short:
   INPUT SHORT

3. Connect the triax short (triax cable with red and black alligator clips connected together) to the rear panel INPUT jack.
4. Press ENTER to complete offset voltage calibration.

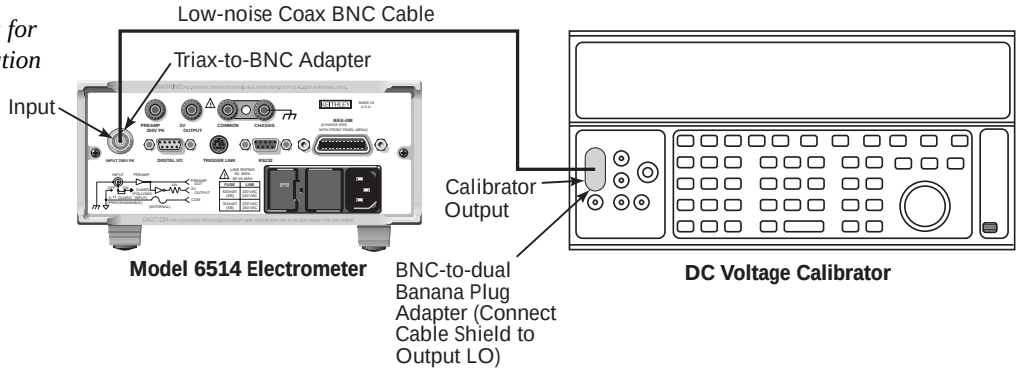
### Input bias current calibration

1. From the calibration menu, use the down RANGE key to display the following:
   CAL: IOFFSET
2. Press ENTER. The instrument will prompt for an open input:
   INPUT CAP
3. Connect the triax shielding cap to the rear panel INPUT jack.
4. Press ENTER to complete input bias current calibration.

## Volts calibration

1. Connect the voltage calibrator to Model 6514 INPUT jack, as shown in Figure 19-1. Be sure to use the low-noise coaxial cable and appropriate adapters as shown.

*Figure 19-1*
*Connections for volts calibration*




2. Select Model 6514 volts function by pressing the V key, and set the calibrator to output DC volts.
3. Select Model 6514 2V range and make sure the calibrator output is turned on.
4. Press SHIFT then CAL to access the calibration menu. The unit will display the following:
   CAL:RUN
5. Press ENTER. The unit will prompt for the zero calibration point:
   2V ZERO
6. Connect a triax short to the INPUT jack, and then press ENTER.
7. The unit will prompt for the +2V cal point:
   +2V CAL

8. Press ENTER. The unit will display the following for the positive full-scale calibration voltage:
   2.000000 DCV
9. Set the calibrator output voltage to +2.000000V, then adjust Model 6514 display to agree with that value.

*NOTE* *If your calibrator cannot source the recommended calibration values, use the closest values, then set Model 6514 display to agree with the calibrator signal levels. Use the up and down RANGE keys to select the digit value, and use the left and right arrow keys to choose the digit position.*

10. Press ENTER. The unit will prompt for the negative full-scale calibration point:
    -2V CAL
11. Press ENTER. The Model 6514 will prompt for the negative full-scale calibration voltage:
    -2.000000 VDC
12. Set the calibrator output voltage to -2.000000V, then adjust the display to agree with the calibrator voltage. Press ENTER to complete calibration of the present range.
13. Press EXIT to return to normal display.
14. Repeat steps 3 through 13 for the 20V and 200V ranges using Table 19-3 as a guide.

*Table 19-3*
*Volts calibration summary*

| **Model 6514 range** | **Calibrator voltages*** |
|---|---|
| 2V | Triax short |
| | +2.000000V |
| | -2.000000V |
| 20V | Triax short |
| | +20.00000V |
| | -20.00000V |
| 200V | Triax short |
| | +200.0000V |
| | -200.0000V |

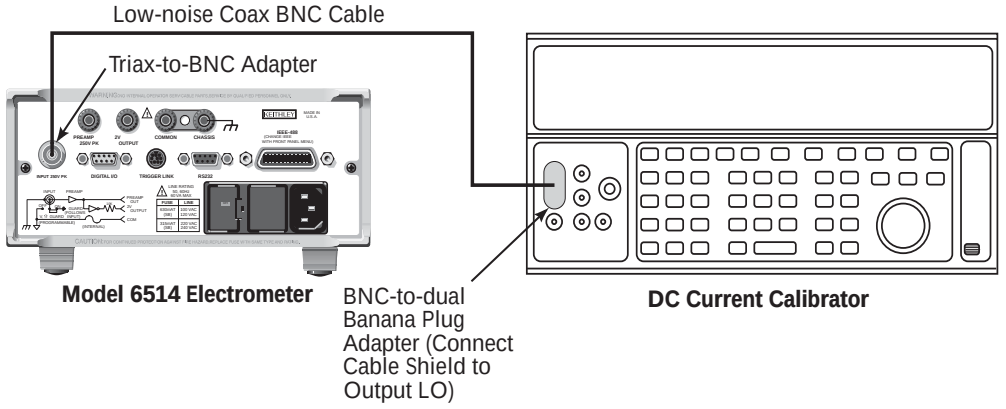
* Calibrate zero, positive full-scale, and negative full-scale for each range.

# Amps calibration

## 20µA-20mA range calibration

1. Connect the triax shielding cap to the Model 6514 INPUT jack.

*Figure 19-2 Connections for 20µA-20mA range calibration*




2. Select Model 6514 amps function by pressing the I key, and set the calibrator to output DC current.
3. Select Model 6514 20µA range, and make sure the calibrator output is turned on.
4. Press SHIFT then CAL, then press ENTER at the CAL: RUN prompt. The unit will prompt for the zero calibration point:

   20µA ZERO
5. Connect the triax shielding cap to the INPUT jack, allow 15 seconds for settling, and then press ENTER.
6. Connect the current calibrator to the Model 6514 INPUT jack, as shown in Figure 19-2.
7. The unit will prompt for the positive full-scale cal point:

   +20µA CAL
8. Press ENTER. The unit will prompt for the positive full-scale current:

   20.00000 µA
9. Set the calibrator current to +20.00000µA, then adjust the display to agree with the calibrator current. Allow 15 seconds for settling.
10. Press ENTER. The unit will prompt for the negative full-scale calibration point:

    -20µA CAL
11. Press ENTER. Model 6514 will prompt for the negative full-scale calibration current:

    -20.00000 µA
12. Set the calibrator output to —20.00000µA, then adjust the display to agree with the calibrator value. Allow 15 seconds for settling, then press ENTER to complete calibration of the present range.
13. Press EXIT to return to normal display.
14. Repeat steps 1 through 13 for the 200µA through 20mA ranges using Table 19-4 as a guide.

*Table 19-4*
*20*µA-20mA range amps calibration summary

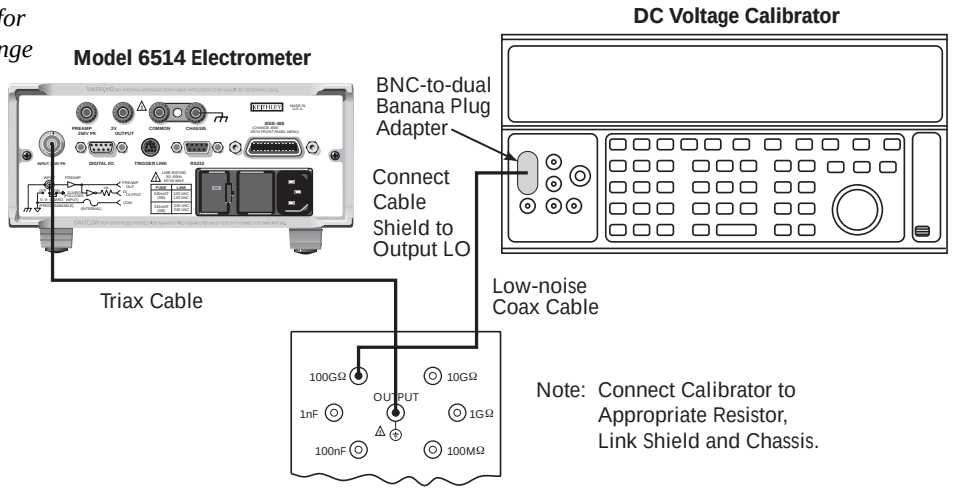
| Model 6514 range | Calibrator currents* | Settling time** |
|---|---|---|
| 20µA | 0µA | >15 sec. |
| | +20.00000µA | >15 sec. |
| | -20.00000µA | >15 sec. |
| 200µA | 0µA | >15 sec. |
| | +200.0000µA | >15 sec. |
| | -200.0000µA | >15 sec. |
| 2mA | 0mA | >15 sec. |
| | +2.000000mA | >15 sec. |
| | -2.000000mA | >15 sec. |
| 20mA | 0mA | >15 sec. |
| | +20.00000mA | >15 sec. |
| | -20.00000mA | >15 sec. |

* Calibrate zero, positive full-scale, and negative full-scale for each range. Triax cap used for zero cal points.
** Allow calibration signal to settle for indicated time before calibrating each point.

## 20pA-2µA range calibration

1. Connect the triax shielding cap to the Model 6514 INPUT jack.

*Figure 19-3*
*Connections for 20pA-2µA range calibration*



2. Select the amps function on Model 6514.
3. Select Model 6514 20pA range.
4. Press SHIFT then CAL, then press ENTER at the CAL: RUN prompt. The unit will prompt for the zero calibration point:

   20PA ZERO
5. Allow the settling time listed in Table 19-5, then press ENTER.
6. The instrument will prompt for the positive full-scale calibration point:

   +20PA CAL
7. Connect the voltage calibrator and Model 5156 Electrometer Calibration standard to the Model 6514 INPUT jack, as shown in Figure 19-3. Initially, make connections to the 100GΩ resistance.
8. Press ENTER. The instrument will prompt a full-scale calibration current:

   20.00000 PA
9. Set the calibrator voltage to +2.000000V. Calculate the actual calibration current from the calibrator voltage and the actual standard resistor value: I = V/R. Adjust Model 6514 display to agree with the calculated current. Allow the settling time listed in Table 19-5, then press ENTER.
10. Model 6514 will prompt for the negative full-scale calibration point:

    -20PA CAL
11. Press ENTER. The instrument will prompt for the negative full-scale current:

    -20.00000 PA
12. Set the calibrator output voltage to -2.000000V, then calculate the calibration current from the calibrator voltage and standard resistor value: I = V/R. Adjust Model 6514 display to agree with the calculated current. Allow the settling time listed in Table 19-5, then press ENTER to complete calibration of the present range.
13. Press EXIT to return to normal display.
14. Repeat steps 1 through 13 for the 200pA through 2μA ranges using Table 19-5 as a guide. Be sure to make connections to the correct standard resistor.

*Table 19-5*
*20pA-2µA range amps calibration summary*

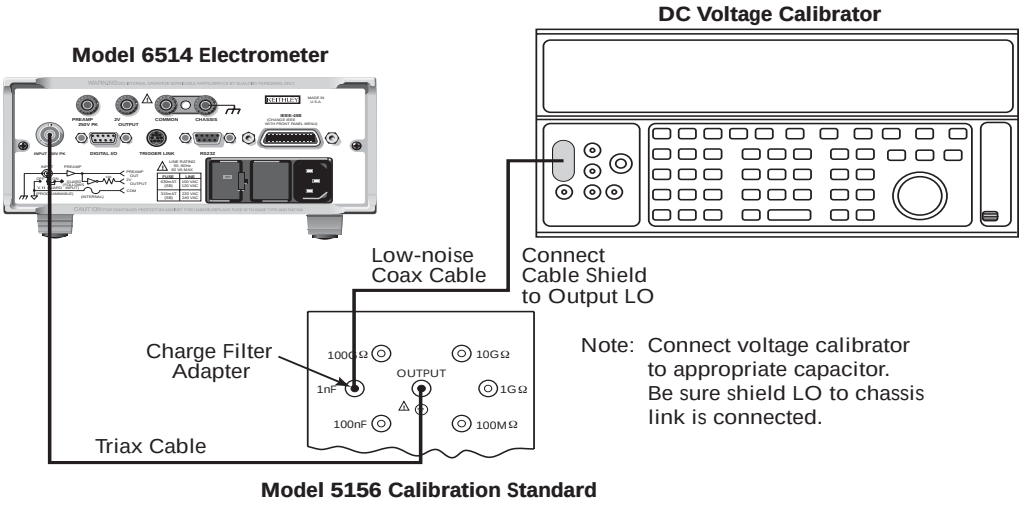
| Model 6514 range | Calibrator voltages | Standard resistor[1] | Calibration currents[2] | Settling time[3] |
|---|---|---|---|---|
| 20pA | | 100GΩ | 0pA | > 2 min. |
| | +2.000000V | 100GΩ | +20pA | > 2 min. |
| | -2.000000V | 100GΩ | -20pA | > 2 min. |
| 200pA | | 10GΩ | 0pA | > 2 min. |
| | +2.000000V | 10GΩ | +200pA | > 2 min. |
| | -2.000000V | 10GΩ | -200pA | > 2 min. |
| 2nA | | 1GΩ | 0nA | > 15 sec. |
| | +2.000000V | 1GΩ | +2nA | > 15 sec. |
| | -2.000000V | 1GΩ | -2nA | > 15 sec. |
| 20nA | | 1GΩ | 0nA | > 15 sec. |
| | +20.00000V | 1GΩ | +20nA | > 15 sec. |
| | -20.00000V | 1GΩ | -20nA | > 15 sec. |
| 200nA | | 100MΩ | 0nA | > 15 sec. |
| | +20.00000V | 100MΩ | +200nA | > 15 sec. |
| | -20.00000V | 100MΩ | -200nA | > 15 sec. |
| 2µA | | 100MΩ | 0µA | > 15 sec. |
| | +200.0000V | 100MΩ | +2µA | > 15 sec. |
| | -200.0000V | 100MΩ | -2µA | > 15 sec. |

[1] Nominal resistance values.
[2] Nominal currents. Calculate actual currents from calibrator voltage and actual standard resistor value: I = V/R. Calibrate zero, positive full-scale, and negative full-scale for each range. Triax cap used for zero cal points.
[3] Allow calibration signal to settle for indicated time before calibrating each point.

## Coulombs calibration

1. Connect the voltage calibrator and Model 5156 Calibration Standard to Model 6514 INPUT jack, as shown in Figure 19-4. Initially, make connections to the 1nF capacitor. Also be sure to connect the link between SHIELD and CHASSIS.

*Figure19-4 Connections for coulombs*




2. Select Model 6514 coulombs function by pressing the Q key, and set the calibrator to output volts.
3. Using the GRD key, disable Model 6514 guard mode.
4. Select Model 6514 20nC range, make sure the calibrator output is turned on and set the output to 0V.
5. Press SHIFT then CAL, then press ENTER at the CAL: RUN prompt. The unit will prompt for the positive full-scale calibration point:

   +20nC CAL
6. Press ENTER. The unit will prompt for the positive full-scale calibration value:

   20.0000nC
7. Set the calibrator voltage to +20.00000V. Compute the actual charge from the calibrator voltage and actual capacitance value: Q = CV. Adjust Model 6514 display to agree with that charge value, then press ENTER.
8. Model 6514 will prompt for the zero calibration point:

   2nC ZERO
9. Press ENTER to complete zero calibration for the present range and then set the calibrator to output 0V. Model 6514 will next prompt for the negative full-scale calibration point:

   -20nC CAL

10. Press ENTER. Model 6514 will prompt for the negative full-scale charge value: -20.0000nC
11. Set the calibrator output voltage to -20.00000V. Calculate the actual charge from the calibrator voltage and actual standard capacitor value: Q = CV. Adjust Model 6514 display to agree with the calculated charge value, then press ENTER to complete calibration of the present range.
12. Press EXIT to return to normal display.
13. Repeat steps 4 through 12 for the 200nC through 20µC ranges using Table 19-6 as a guide.

*Table 19-6*
*Coulombs calibration summary*

| **Model 6514 range** | **Calibrator voltage** | **Standard capacitance[1]** | **Calibration charge[2]** |
|---|---|---|---|
| 20nC | +20.00000V | 1nF | +20nC |
| | -20.00000V | 1nF | -20nC |
| 200nC | +200.0000V | 1nF | +200nC |
| | -200.0000V | 1nF | -200nC |
| 2µC | +20.00000V | 100nF | +2µC |
| | -20.00000V | 100nF | -2µC |
| 20µC | +200.0000V | 100nF | +20µC |
| | -200.0000V | 100nF | -20µC |

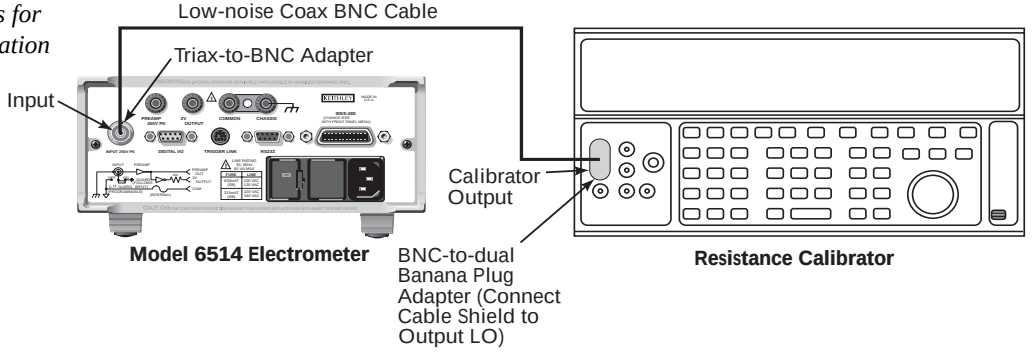
[1] Nominal value.
[2] Based on nominal capacitance values. Calculate actual charge from calibrator voltage and actual standard capacitance value: Q = CV. Calibrate positive full-scale, and negative full-scale values for each range.

## Ohms calibration

*NOTE Calibration is required only for the 2kΩ, 2MΩ, and the 2GΩ ranges. However, other ranges may also be calibrated using appropriate calibration resistances if desired. Volts should be calibrated before ohms.*

1. Connect the triax short to the INPUT jack (triax alligator cable with red and black leads connected together).

*Figure 19-5 Connections for ohms calibration (2kΩ and 2MΩ ranges)*




2. Select Model 6514 ohms function by pressing the Ω key.
3. Select Model 6514 2kΩ range.
4. Press SHIFT then CAL. At the CAL:RUN prompt, press ENTER. The unit will prompt as follows:

   2KOHM ZERO

*NOTE Zero calibration is performed only on the 2kΩ range.*

5. Press ENTER. The unit will prompt for the calibration resistance:

   INPUT 2KOHM

6. Press ENTER. The unit will prompt for the actual resistance:
   2.000000KOHM
7. Connect the resistance calibrator to the Model 6514 INPUT jack, as shown in Figure 19-5.
8. Select the 1.9kΩ calibrator resistance.
9. Adjust Model 6514 display to agree with the actual calibration resistance, then press ENTER to complete calibration of the present range.
10. Press EXIT to return to normal display.
11. Repeat steps 3 through 10 for the 2MΩ range using the 1.9MΩ calibrator resistance. (See Table 19-7.)

12. Disconnect the resistance calibrator, and connect the 1GΩ calibration standard resistor to Model 6514 INPUT jack, as shown in Figure 19-6. Be sure to remove the link between Model 5156 SHIELD and CHASSIS terminals. Also connect Model 5156 CHASSIS terminal to Model 6514 COMMON jack.

*WARNING* **Hazardous voltages may be present on Model 5156 SHIELD and OUTPUT terminals.**

13. Using the GRD key, enable Model 6514 guard mode.
14. Repeat steps 3 through 10 for the 2GΩ range. Be sure to set Model 6514 display to the actual standard resistance value.

*Figure 19-6*
*Connections for ohms calibration (2GΩ range)*

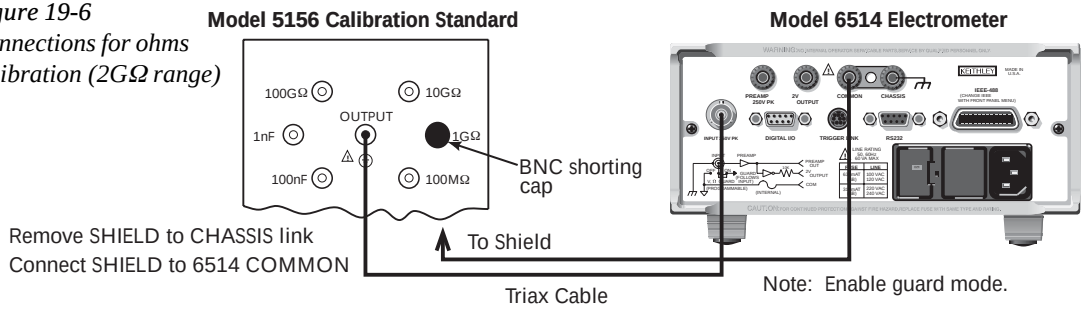



*Table 19-7*
*Ohms calibration summary*

| Model 6514 range | Calibration resistance* |
|---|---|
| 2kΩ** | 1.9kΩ |
| 2MΩ | 1.9MΩ |
| 2GΩ | 1GΩ |

* Nominal values. Use actual values for calibration. Use resistance calibrator for 2kΩ and 2MΩ ranges. Use calibration standard resistor for 1GΩ range.

** Zero also calibrated on 2kΩ range.

## Entering calibration dates and saving calibration

*NOTE* *For temporary calibration without saving new calibration constants, proceed to Locking out calibration.*

1. Press SHIFT then CAL to access the calibration menu.
2. Use either RANGE key to display the following:
   CAL: DATES
3. Press ENTER. The unit will display:
   DATE: 06/15/98
4. Use the arrow and RANGE keys to set the date, then press ENTER. The unit will then prompt for the calibration due date:
   NDUE: 06/15/99
5. Set the due date as desired, then press ENTER.
6. Select CAL: SAVE from the calibration menu, then press ENTER. The unit will prompt as follows:
   SAVE CAL?YES
7. With the YES prompt displayed, press ENTER to save and lock out calibration. The unit will display:
   CAL SAVED

*NOTE* *Calibration will also be locked out once saved.*

## Locking out calibration

Use the following procedure to lock out calibration without saving new calibration constants:

1. Press SHIFT then CAL, then use the up RANGE key to display the following:
   CAL: LOCK
2. Press ENTER. The instrument will display the following message:
   CAL LOCKED.

# Changing the calibration code

Follow the steps below to change the calibration code:

1. Press SHIFT then CAL. The instrument will display the following:
   CAL: RUN
2. Use the up or down RANGE key to display the following:
   CAL: UNLOCK
3. Press ENTER. The instrument will prompt for the present calibration code:
   CODE?

4. Enter the present calibration code on the display. (Factory default: 006514.) Use the up and down RANGE keys to select the letter or number, and use the left and right arrow keys to choose the position. Press ENTER to complete the process, and the unit will display:
   NEW CODE? Y/N
5. Select Y, then press ENTER. The unit will prompt for the new code:
   CODE? 000000
6. Enter the new code, then press ENTER.
7. Using the LOCK selection in the calibration menu, lock out calibration after changing the code.

# Resetting the calibration code

If you forget the calibration code, you can unlock calibration by shorting together the CAL pads, which are located on the display circuit board inside the unit. Doing so will also reset the code to the factory default (006514).

# Displaying calibration dates

To display calibration dates at any time:

1. From normal display, press SHIFT then CAL. The unit will display the following:
   CAL: RUN
2. Use either RANGE key to select CAL: DATES, then press ENTER. Model 6514 will display the last calibration date, for example:
   DATE: 06/15/98
3. Press ENTER to view the calibration due date, for example:
   NDUE: 06/15/99
4. Press EXIT to return to normal display.

# Displaying the calibration count

To display the calibration count at any time:

1. From normal display, press SHIFT then CAL. The unit will display the following:
   CAL: RUN
2. Use either RANGE key to select CAL:COUNT from the calibration menu, then press ENTER. For example:
   COUNT: 1
3. Press EXIT to return to normal display.

# 20
# Routine Maintenance

# Introduction

The information in this section deals with routine type maintenance that can be performed by the operator and includes procedures for setting the line voltage and replacing the line fuse, and running the front panel tests.

# Setting line voltage and replacing line fuse

*WARNING* **Disconnect the line cord at the rear panel, and remove all test leads connected to the instrument (front and rear) before replacing the line fuse.**

The power line fuse is located in the power module next to the AC power receptacle (see Figure 20-1). If the line voltage must be changed, or if the line fuse requires replacement, perform the following steps:

1. Place the tip of a flat-blade screwdriver into the power module by the fuse holder assembly (see Figure 20-1). Gently push in and to the left. 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 20-1.

*CAUTION* **For continued protection against fire or instrument damage, replace the fuse only with the type and rating listed. If the instrument repeatedly blows fuses, it will require servicing.**

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 inverted in the window.
4. Install the fuse holder assembly into the power module by pushing it in until it locks in place.

*Figure 20-1*
*Power module*

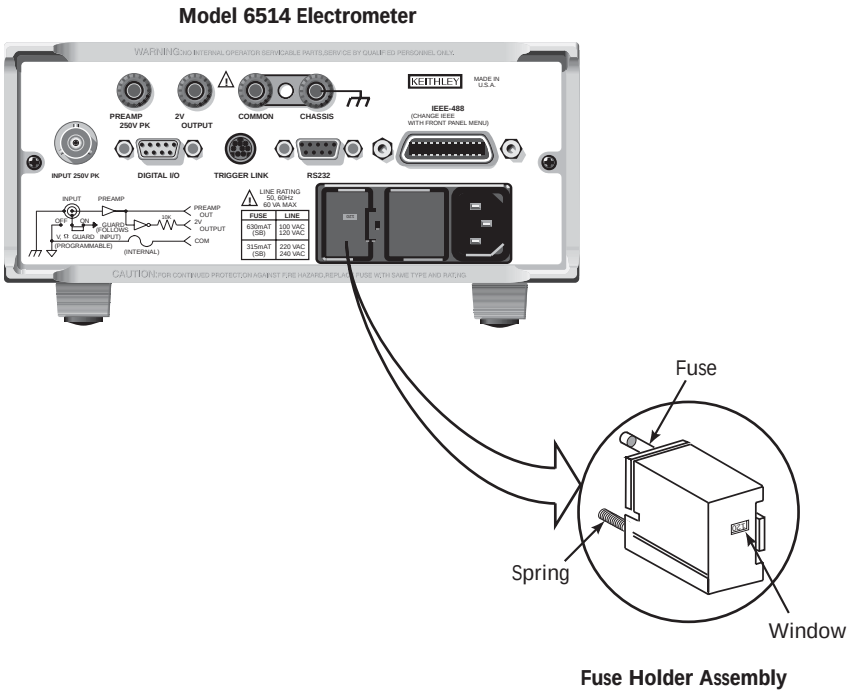



*Table 20-1*
*Power line fuse*

| **Line voltage** | **Rating** | **Keithley part no.** |
|---|---|---|
| 100/120V | 0.63A, 250V, 5x20mm, slow blow | FU-106-.630 |
| 220/240V | 0..315A, 250V, 5x20mm, slow-blow | FU-106-.315 |

## Front panel tests

The front panel tests are summarized in Table 20-2. To run a test, simply press SHIFT then TEST, then scroll through the menu choices and press ENTER.

*Table 20-2*
*Front panel tests*

| Test | Description |
|---|---|
| DISP | Test display |
| KEY | Test front panel keys |

## DISP test

The display test allows you to verify that each segment and annunciator in the vacuum fluorescent display is working properly. Perform the following steps to run the display test:

1. Press SHIFT and then TEST to access the self-test options.
2. Use the up or down RANGE key to display "TEST: DISP".
3. Press ENTER to start the test. There are four parts to the display test. Each time ENTER is pressed, the next part of the test sequence is selected. The four parts of the test sequence are as follows:
   - All annunciators are displayed.
   - The segments of each digit are sequentially displayed.
   - The 12 digits (and annunciators) are sequentially displayed.
   - The annunciators located at either end of the display are sequentially displayed.
4. When finished, abort the display test by pressing EXIT. The instrument returns to normal operation.

## KEY test

The KEY test allows you to check the functionality of each front panel key. Perform the following steps to run the KEY test:

1. Press SHIFT and then TEST to access the self-test options.
2. Use the up or down RANGE key to display "TEST: KEY".
3. Press ENTER to start the test. When a key is pressed, the label name for that key is displayed to indicate that it is functioning properly. When the key is released, the message "NO KEY PRESS" is displayed.
4. Pressing EXIT tests the EXIT key. However, the second consecutive press of EXIT aborts the test and returns the instrument to normal operation.

# A
# Specifications

## VOLTS

| RANGE | 5½ DIGIT RESOLUTION | ACCURACY (1 Year)[1] 18°–28°C ±(%rdg+counts) | TEMPERATURE COEFFICIENT 0°–18°C & 28°–50°C ±(%rdg+counts)/°C |
|---|---|---|---|
| 2 V | 10 µV | 0.025 + 4 | 0.003 + 2 |
| 20 V | 100 µV | 0.025 + 3 | 0.002 + 1 |
| 200 V | 1mV | 0.06 + 3 | 0.002 + 1 |

**Note:**
[1] When properly zeroed, 5½-digit. Rate: Slow (100ms integration time).

**NMRR:** 60dB on 2V, 20V, >55dB on 200V, at 50Hz or 60Hz ±0.1%.

**CMRR:** >120dB at DC, 50Hz or 60Hz.

**INPUT IMPEDANCE:** >200TΩ in parallel with 20pF, < 2pF guarded (10MΩ with zero check on).

**SMALL SIGNAL BANDWIDTH AT PREAMP OUTPUT:** Typically 100kHz (–3dB).

## AMPS

| RANGE | 5½ DIGIT RESOLUTION | ACCURACY (1 Year)[1] 18°–28°C ±(%rdg+counts) | TEMPERATURE COEFFICIENT 0°–18°C & 28°–50°C ±(%rdg+counts)/°C |
|---|---|---|---|
| 20 pA | 100 aA[2] | 1 + 30 | 0.1 + 5 |
| 200 pA | 1 fA[2] | 1 + 5 | 0.1 + 1 |
| 2 nA | 10 fA | 0.2 + 30 | 0.1 + 2 |
| 20 nA | 100 fA | 0.2 + 5 | 0.03 + 1 |
| 200 nA | 1 pA | 0.2 + 5 | 0.03 + 1 |
| 2 µA | 10 pA | 0.1 + 10 | 0.005 + 2 |
| 20 µA | 100 pA | 0.1 + 5 | 0.005 + 1 |
| 200 µA | 1 nA | 0.1 + 5 | 0.005 + 1 |
| 2 mA | 10 nA | 0.1 + 10 | 0.008 + 2 |
| 20 mA | 100 nA | 0.1 + 5 | 0.008 + 1 |

**Notes:**
[1] When properly zeroed, 5½-digit. Rate: Slow (100ms integration time).
[2] aA $=10^{-18}$A, fA$=10^{-15}$A.

**INPUT BIAS CURRENT:** <3fA at $T_{CAL}$ (user adjustable). Temperature coefficient = 0.5fA/°C .

**INPUT BIAS CURRENT NOISE:** <750aA p-p (capped input), 0.1Hz to 10Hz bandwidth, damping on. Digital filter = 40 readings.

**INPUT VOLTAGE BURDEN at $T_{CAL}$ ±1°C** (user adjustable)**:**

<20µV on 20pA, 2nA, 20nA, 2µA, 20µA ranges.
<100µV on 200pA, 200nA, 200µA ranges.
<2mV on 2mA range.
<4mV on 20mA range.

**TEMPERATURE COEFFICIENT OF INPUT VOLTAGE BURDEN:** <10µV/°C on pA, nA, µA ranges.

**PREAMP SETTLING TIME (to 10% of final value):** 2.5s typical on pA ranges, damping off, 3s typical on pA ranges damping on, 15ms on nA ranges, 5ms on µA and mA ranges.

**NMRR:** >95dB on pA, 60dB on nA, µA, and mA ranges at 50Hz or 60Hz ±0.1%. Digital Filter = 40.

## OHMS

| RANGE | 5½-DIGIT RESOLUTION | ACCURACY (1Year)[1] 18°–28°C ±(% rdg+counts) | TEMPERATURE COEFFICIENT 0°–18°C & 28°–50°C ±(% rdg+counts)/°C | TEST CURRENT (nominal) |
|---|---|---|---|---|
| 2 kΩ | 10 mΩ | 0.20+ 10 | 0.01 + 2 | 0.9 mA |
| 20 kΩ | 100 mΩ | 0.15+ 3 | 0.01 + 1 | 0.9 mA |
| 200 kΩ | 1 Ω | 0.25+ 3 | 0.01 + 1 | 0.9 mA |
| 2 MΩ | 10 Ω | 0.25+ 4 | 0.02 + 2 | 0.9 µA |
| 20 MΩ | 100 Ω | 0.25+ 3 | 0.02 + 1 | 0.9 µA |
| 200 MΩ | 1 kΩ | 0.30+ 3 | 0.02 + 1 | 0.9 µA |
| 2 GΩ | 10 kΩ | 1.5 + 4 | 0.04 + 2 | 0.9 nA |
| 20 GΩ | 100 kΩ | 1.5 + 3 | 0.04 + 1 | 0.9 nA |
| 200 GΩ | 1 MΩ | 1.5 + 3 | 0.04 + 1 | 0.9 nA |

[1] When properly zeroed, 5½ digit. Rate: Slow (100ms integration time).

**MAXIMUM OPEN CIRCUIT VOLTAGE:** 250VDC.

**PREAMP SETTLING TIME (To 10% of final reading with <100pF input capacitance):** 2kΩ through 200kΩ: 2ms; 20MΩ through 200MΩ: 90ms. 2GΩ through 200GΩ: 1s.

## COULOMBS

| RANGE | 6½ DIGIT RESOLUTION | ACCURACY (1 Year)[1,2] 18°–28°C ±(%rdg+counts) | TEMPERATURE COEFFICIENT 0°–18°C & 28°–50°C ±(%rdg+counts)/°C |
|---|---|---|---|
| 20 nC | 10 fC | 0.4 + 50 | 0.04 + 10 |
| 200 nC | 100 fC | 0.4 + 50 | 0.04 + 10 |
| 2 µC | 1 pC | 1 + 50 | 0.05 + 10 |
| 20 µC | 10 pC | 1 + 50 | 0.05 + 10 |

**Notes:**

[1] Charge acquisition time must be <1000s, derate 2% for each additional 10,000s.

[2] When properly zeroed, 6½ digit. Rate: Slow (100ms integration time).

**INPUT BIAS CURRENT:** <4fA at $T_{CAL}$. Temperature coefficient = 0.5fA/°C.

## IEEE-488 BUS IMPLEMENTATION

**MULTILINE COMMANDS:** DCL, LLO, SDC, GET, GTL, UNT, UNL, SPE, SPD.

**IMPLEMENTATION:** SCPI (IEEE-488.2, SCPI-1996.0); DDC (IEEE-488.1).

**UNILINE COMMANDS:** IFC, REN, EOI, SRQ, ATN.

**INTERFACE FUNCTIONS:** SH1, AH1, T5, TE0, L4, LE0, SR1, RL1, PP0, DC1, DT1, C0, E1.

**PROGRAMMABLE PARAMETERS:** Function, Range, Zero Check, Zero Correct, EOI (DDC mode only), Trigger, Terminator (DDC mode only), Data Storage 2500 Storage, Calibration (SCPI mode only), Display Format, SRQ, REL, Output Format, Guard, V-offset Cal, I-offset Cal.

**ADDRESS MODES:** TALK ONLY and ADDRESSABLE.

**LANGUAGE EMULATION:** 6512, 617, 617HIQ emulation via DDC mode.

**TRIGGER TO READING DONE:** 150ms typical, with external trigger.

**RS-232 IMPLEMENTATION:**

**Supports**: SCPI 1996.0.
**Baud Rates:** 300, 600, 1200, 2400, 4800, 9600, 19.2k, 38.4k, 57.6k.
**Protocols:** Xon/Xoff, 7 or 8 bit ASCII, parity-odd/even/none.
**Connector:** DB-9 TXD/RXD/GND.

## GENERAL

**DISPLAY:** 6½-digit vacuum fluorescent.

**OVERRANGE INDICATION:** Display reads "OVRFLOW".

**RANGING:** Automatic or manual.

**CONVERSION TIME:** Selectable 0.01 PLC to 10 PLC.

**PROGRAMS:** Provide front panel access to IEEE address, choice of engineering units or scientific notation, and digital calibration.

**MAXIMUM INPUT:** 250V peak, DC to 60Hz sine wave; 10s per minute maximum on mA ranges.

**MAXIMUM COMMON MODE VOLTAGE (DC to 60Hz sine wave):** Electrometer, 500V peak;

**ISOLATION (Meter COMMON to chassis):** Typically $10^{10}\Omega$ in parallel with 500pF.

**INPUT CONNECTOR:** Three lug triaxial on rear panel.

**2V ANALOG OUTPUT:** 2V for full range input. Inverting in Amps and Coulombs mode. Output impedance 10kΩ.

**PREAMP OUTPUT:** Provides a guard output for Volts measurements. Can be used as an inverting output or with external feedback in Amps and Coulombs modes.

**DIGITAL INTERFACE:**
**Handler Interface:** Start of test, end of test, 3 category bits.
**Digital I/O:** 1 Trigger input, 4 outputs with 500mA sink capability.
**Connector:** 9 Pin D subminiature, male pins.

**EMC:** Conforms with European Union Directive 89/336/EEC EN55011, EN50082-1, EN61000-3-2, EN61000-3-3, FCC part 15 class B.

**SAFETY:** Conforms with European Union Directive 73/23/EEC EN61010-1.

**GUARD:** Switchable voltage and ohm guard available.

**TRIGGER LINE:** Available, see manual for usage.

**READING STORAGE:** 2500 readings.

**READING RATE:**

| | |
|---|---|
| To internal buffer | 1200 readings/second[1] |
| To IEEE-488 bus | 500 readings/second[1,3] |
| To front panel | 17 readings/second at 60Hz;[2] |
| | 15 readings/second at 50Hz[2] |

**Notes:**
[1] 0.01 PLC, digital filters off, front panel off, auto zero off.
[2] 1.00 PLC, digital filters off.
[3] Binary transfer mode.

**DIGITAL FILTER:** Median and averaging (selectable from 2 to 100 readings).

**DAMPING:** User selectable on Amps function.

**ENVIRONMENT:**
**Operating:** 0°–50°C; relative humidity 70% non-condensing, up to 35°C.
**Storage:** –25° to +65°C.

**WARM-UP:** 1 hour to rated accuracy (see manual for recommended procedure).

**POWER:** 90–125V or 210–250V, 50–60Hz, 60VA.

**PHYSICAL:**
**Case Dimensions:** 90mm high × 214mm wide × 369mm deep (3½ in. × 8⅜ in. × 14⁹⁄₁₆ in.).
**Working Dimensions:** From front of case to rear including power cord and IEEE-488 connector: 15.5 inches.
**Net Weight:** <4.6 kg (<10.1 lbs).
**Shipping Weight:** <9.5 kg (<21 lbs).

# B
# Status and Error Messages

*Table B-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 | EE |
| -362 | Framing error in program message | EE |
| -361 | Parity error in program message | EE |
| -360 | Communications error | EE |
| -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 |
| -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 B-1 (cont.)*
*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 |
| | Measurement events: | |
| +101 | Low limit 1 failed | SE |
| +102 | High limit 1 failed | SE |
| +103 | Low limit 2 failed | SE |
| +104 | High limit 2 failed | SE |
| +105 | Active limit tests passed | SE |
| +106 | Reading available | SE |

*Table B-1 (cont.)*
*Status and error messages*

| Number | Description | Event |
|---|---|---|
| +107 | Reading overflow | SE |
| +108 | Buffer available | SE |
| +109 | Buffer full | SE |
| | | |
| | Standard events: | |
| +200 | Operation complete | SE |
| | | |
| | Operation events: | |
| +300 | Device calibrating | SE |
| +303 | Device sweeping | SE |
| +305 | Waiting in trigger layer | SE |
| +306 | Waiting in arm layer | SE |
| +310 | Re-entering the idle layer | SE |
| | | |
| | Questionable events: | |
| +408 | Questionable calibration | SE |
| +414 | Command warning | SE |
| | | |
| | Calibration errors: | |
| +500 | Date of calibration not set | EE |
| +501 | Next date of calibration not set | EE |
| +502 | Calibration data invalid | EE |
| +507 | Measurement offset data invalid | EE |
| +508 | Measurement gain data invalid | EE |
| +509 | Not permitted with cal locked | EE |
| +510 | Not permitted with cal un-locked | EE |
| +511 | Voltage offset not converging | EE |
| +512 | Current offset not converging | EE |
| | | |
| | Lost data errors: | |
| +602 | GPIB address lost | EE |
| +603 | Power-on state lost | EE |
| +604 | DC calibration data lost | EE |
| +605 | Calibration dates lost | EE |
| +606 | GPIB communication language lost | EE |
| | | |
| | Communication errors: | |
| +700 | Invalid system communication | EE |
| +701 | ASCII only with RS-232 | EE |

*Table B-1 (cont.)*
*Status and error messages*

| Number | Description | Event |
|---|---|---|
| | Additional (more informative) command execution errors: | |
| +800 | Illegal with storage active | EE |
| +801 | Insufficient vector data | EE |
| +804 | Expression list full | EE |
| +805 | Undefined expression exists | EE |
| +806 | Expression not found | EE |
| +807 | Definition not allowed | EE |
| +808 | Expression cannot be deleted | EE |
| +811 | Not an operator or number | EE |
| +812 | Mismatched parentheses | EE |
| +813 | Not a number of data handle | EE |
| +814 | Mismatched brackets | EE |
| +815 | Too many parentheses | EE |
| +816 | Entire expression not parsed | EE |
| +817 | Unknown token | EE |
| +818 | Error parsing mantissa | EE |
| +819 | Error parsing exponent | EE |
| +820 | Error parsing value | EE |
| +821 | Invalid data handle index | EE |
| +830 | Invalid with INFinite ARM:COUNT | EE |
| +831 | Invalid with INFinite TRIG:COUNT | EE |
| +900 | Internal system error | EE |
| | DDC Status Model: | |
| +950 | Rdg overflow | SE |
| +951 | Rdg ready | SE |
| +952 | Buffer full | SE |
| +953 | IDDC error | EE |
| +954 | IDDCO error | EE |
| +955 | Trig overrun | EE |
| +956 | No remote | EE |
| +957 | Number error | EE |
| +958 | DDC ready | SE |
| +960 | DDC Mode IDDC Error | EE |
| +961 | DDC Mode IDDCO Error | EE |

*Table B-1 (cont.)*
*Status and error messages*

| Number | Description | Event |
|---|---|---|
| | Keithley 6512 Serial Poll Byte Events: | |
| +962 | DDC Ready | SE |
| +963 | DDC Reading Done | SE |
| +965 | DDC Buffer Full | SE |
| +966 | DDC Reading overflow | SE |

EE = error event
SE = status event
SYS = system error event
NOTE: Errors and status messages with a positive number are instrument-dependent. Negative errors are reserved by SCPI.

*NOTE: SCPI-confirmed messages are described in Volume 2: Command Reference of the Standard Commands for Programmable Instruments. Refer to the :SYSTem:ERRor? command.*

# C
# General Measurement Considerations

# Measurement considerations

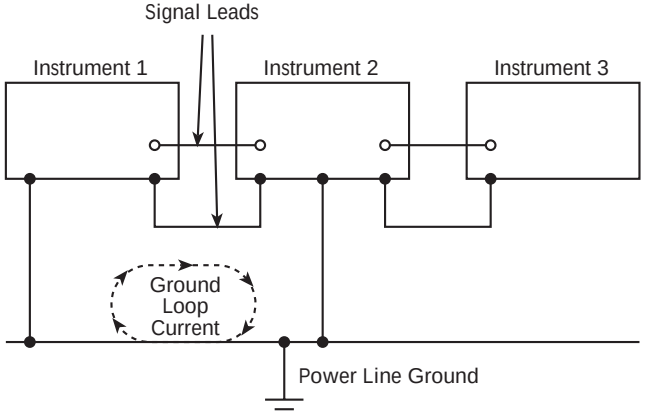
The following measurement considerations apply to all precision measurements. Measurement considerations that are unique to a particular measurement function are covered in Sections 3, 4, and 5. Table 2-5 (located at the end of Section 2) lists all measurement considerations, and indicates where to find detailed information on them.

For comprehensive information on all measurement considerations, refer to the Low Level Measurements handbook, which is available from Keithley.

## Ground loops

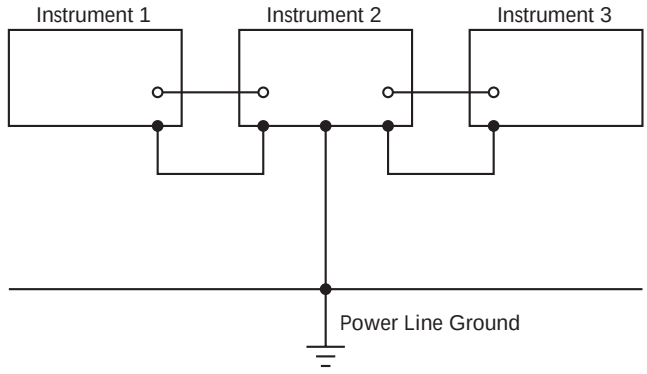
Ground loops that occur in multiple-instrument test setups can create error signals that cause erratic or erroneous measurements. The configuration shown in Figure C-1 introduces errors in two ways. Large ground currents flowing in one of the wires will encounter small resistances, either in the wires, or at the connecting points. This small resistance results in voltage drops that can affect the measurement. Even if the ground loop currents are small, magnetic flux cutting across the large loops formed by the ground leads can induce sufficient voltages to disturb sensitive measurements.

*Figure C-1*
*Power line ground loops*



To prevent ground loops, instruments should be connected to ground at only a single point, as shown in Figure C-2. Note that only a single instrument is connected directly to power line ground. Experimentation is the best way to determine an acceptable arrangement. For this purpose, measuring instruments should be placed on their lowest ranges. The configuration that results in the lowest noise signal is the one that should be used.

*Figure C-2*
*Eliminating ground loops*




## Triboelectric effects

Triboelectric currents are generated by charges created between a conductor and an insulator due to friction. Here, free electrons rub off the conductor and create a charge imbalance that causes the current flow. For example, bending a triaxial cable causes friction between the center conductor (HI) and its surrounding insulator resulting in triboelectric currents. Triboelectric currents can be minimized as follows:

- Use “low noise” cables. These cables are specially designed to minimize charge generation and use graphite to reduce friction. The Keithley Model 7078-TRX triax cables are low noise.
- Use the shortest cables possible, and secure them (i.e., taping or tying) to a non-vibrating surface to keep them from moving.

## Piezoelectric and stored charge effects

Piezoelectric currents are generated when mechanical stress is applied to certain insulating materials (i.e., crystalline). In some plastics, pockets of stored charge cause the material to behave in a similar manner.

When building test fixtures, choose good insulating materials and make connecting structures as rigid as possible. Make sure there are no mechanical stresses on the insulators.

## Electrochemical effects

Error currents also arise from electrochemical effects when ionic chemicals create weak batteries on a circuit board. These batteries could generate a few nanoamps of current between conductors. Ionic contamination may be the result of body oils, salts or solder flux. The problem is further enhanced by high humidity (moisture) that decreases insulation resistance.

When building test fixtures, select insulators that resist water absorption, and use the fixture in a moderate humidity environment. Also, be sure that all insulators are kept clean and free of contamination. See “Handling and Cleaning Test Fixtures” in Section 2 for cleaning tips.

## Humidity

Excess humidity can reduce insulation resistance on PC boards and in test connection insulators. Reduction in insulation resistance can, of course, seriously affect high-impedance measurements. Also, humidity (moisture) can combine with contaminants to produce offset currents caused by electrochemical effects (see (Electrochemical Effects). To minimize the effects of moisture, keep humidity to a minimum (ideally <50%), and keep components and connectors in the test system clean. See “Handling and Cleaning Test Fixtures” in Section 2 for cleaning tips.

## Light

Some components, such as semiconductor junctions and MOS capacitors on semiconductor wafers, are excellent light detectors. Consequently, these components must be tested in a light-free environment. While many test fixtures provide adequate light protection, others may allow sufficient light penetration to affect the test results. Areas to check for light leaks include doors and door hinges, tubing entry points, and connectors or connector panels.

## Electrostatic interference

Electrostatic interference occurs when a electrically charged object is brought near an uncharged object, thus inducing a charge on the previously uncharged object. Usually, effects of such electrostatic action are not noticeable because low impedance levels allow the induced charge to dissipate quickly. However, the high impedance levels of many measurements do not allow these charges to decay rapidly, and erroneous or unstable readings may result. These erroneous or unstable readings may be caused in the following ways:

1. DC electrostatic field can cause undetected errors or noise in the reading.
2. AC electrostatic fields can cause errors by driving the input preamplifier into saturation, or through rectification that produces DC errors.

Electrostatic interference is first recognizable when hand or body movements near the experiment cause fluctuations in the reading. Pick-up from AC fields can also be detected by observing the electrometer preamp output on an oscilloscope. Line frequency signals on the output are an indication that electrostatic interference is present. Means of minimizing electrostatic interference include:

1. Shielding. Possibilities include: a shielded room, a shielded booth, shielding the sensitive circuit, and using shielded cable. The shield should always be connected to a solid connector that is connected to signal low. If circuit low is floated above ground, observe safety precautions, and avoid touching the shield. Meshed screen or loosely braided cable could be inadequate for high impedances, or in string fields. Note, however, that shielding can increase capacitance in the measuring circuit, possibly slowing down response time.
2. Reduction of electrostatic fields. Moving power lines or other sources away from the experiment reduces the amount of electrostatic interference seen in the measurement.

## Magnetic fields

A magnetic field passing through a loop in a test circuit will generate a magnetic EMF (voltage) that is proportional to the strength of the field, the loop area, and the rate at which these factors are changing. Magnetic fields can be minimized by following these guidelines:

- Locate the test circuit as far away as possible from such magnetic field sources as motors, transformers and magnets.
- Avoid moving any part of the test circuit within the magnetic field.
- Minimize the loop area by keeping leads as short as possible and twisting them together.

## Electromagnetic Interference (EMI)

The electromagnetic interference characteristics of the Model 6514 comply with the electromagnetic compatibility (EMC) requirements of the European Union as denoted by the CE mark. However, it is still possible for sensitive measurements to be affected by external sources. In these instances, special precautions may be required in the measurement setup.

Sources of EMI include:

- Radio and TV broadcast transmitters.
- Communications transmitters, including cellular phones and handheld radios.
- Devices incorporating microprocessors and high-speed digital circuits.
- Impulses sources as in the case of arcing in high-voltage environments.

The effect on instrument performance can be considerable if enough of the unwanted signal is present. The effects of EMI can be seen as an unusually large offset, or, in the case of impulse sources, erratic variations in the displayed reading.

The instrument and experiment should be kept as far away as possible from any EMI sources. Additional shielding of the instrument, experiment and test leads will often reduce EMI to an acceptable level. In extreme cases, a specially constructed screen room may be required to sufficiently attenuate the troublesome signal.

External filtering of the input signal path may be required. In some cases, a simple one-pole filter may be sufficient. In more difficult situations, multiple notch or band-stop filters, tuned to the offending frequency range, may be required. Connecting multiple capacitors of widely different values in parallel will maintain a low impedance across a wide frequency range. Keep in mind, however, that such filtering may have detrimental effects (such as increased response time) on the measurement.

# D
# DDC Emulation Commands

# DDC language

The Model 6514 can be configured to accept device-dependent commands (DDCs) of the Keithley Model 6512, 617, or 617 HIQ electrometer. The commands for controlling the Model 6514 with the DDC language are provided in Table D-1. For details on Model 6512, 617, and 617 HIQ operation, refer to the appropriate instruction manual.

Since the architecture of the Model 6514 differs from that of the other electrometers, some commands are different and cannot be used. Be sure to refer to the notes at the end of the table for information on command restrictions.

*CAUTION* **The DDC language is intended to be used only over the IEEE-488 bus. Using front panel controls in conjunction with this language may cause erratic operation. In this case, results cannot be guaranteed.**

*Table D-1*
*Device dependent command summary*

| Mode | Command | Description | Note |
|---|---|---|---|
| Calibration Value | none | A (calibration) commands not supported | |
| Reading Mode | B0 | Electrometer | |
| | B1 | Buffer reading | |
| | B2 | Maximum reading | |
| | B3 | Minimum reading | |
| Zero Check | C0 | Zero Check off | |
| | C1 | Zero Check on | |
| Function | F0 | Volts | |
| | F1 | Amps | |
| | F2 | Ohms | |
| | F3 | Coulombs | |
| | F4 | External Feedback | |
| Data Format | G0 | Reading with prefix (NDCV-1.23456E+00) | |
| | G1 | Reading without prefix (-1.23456E+00) | |
| | G2 | Reading with prefix and buffer suffix (if in B1) (NDCV-1.23456E+00+00,012) | |
| Hit Key | H0 | Manual trigger | |
| | Hn | Hit front panel key, where “n” = 1 to 32 (see Figure 16-3 for key press codes) | A |
| Buffer Size | In | Set buffer size, where “n” = 1 to 2500. | B |

*Table D-1 (cont.)*
*Device dependent command summary*

| Mode | Command | Description | Note |
|---|---|---|---|
| EOI and Bus Hold-off | K0 | Enable both EOI and bus hold-off on X | |
| | K1 | Disable EOI, enable bus hold-off on X | |
| | K2 | Enable EOI, disable bus hold-off on X | |
| | K3 | Disable both EOI and bus hold-off on X | |
| Store Calibration | none | L1 (store calibration) command not supported | |
| SRQ | M0 | Disable SRQ | |
| | M1 | Reading overflow | |
| | M2 | Buffer full | |
| | M8 | Reading done | |
| | M16 | Ready | |
| | M32 | Error | |
| Baseline Suppression (Rel) | N0 | Suppression (Rel) disabled | |
| | N1 | Suppression (Rel) enabled | |
| Digital Filter | P0 | Filter off | |
| | P1 | Filter off | |
| | Pn | Repeat Filter on, where filter size “n” = 2 to 100 | C |
| Data Store (Buffer) | Q0 | Conversion rate | |
| | Q1 | One reading per second | |
| | Q2 | One reading every 10 seconds | |
| | Q3 | One reading per minute | |
| | Q4 | One reading every 10 minutes | |
| | Q5 | One reading per hour | |
| | Q6 | Trigger mode | |
| | Q7 | Disabled | |

*Table D-1 (cont.)*
*Device dependent command summary*

| Mode | Command | Description | | | | | Note |
|---|---|---|---|---|---|---|---|
| Range | | **V** | **A** | **Ω** | **Q** | **XFdbk** | |
| | R0 | Auto | Auto | Auto | Auto | Auto | |
| | R1 | 2V | 20pA | 2kΩ | 20nC | 2V | |
| | R2 | 2V | 20pA | 20kΩ | 20nC | 2V | |
| | R3 | 20V | 200pA | 200kΩ | 20nC | 20V | |
| | R4 | 200V | 2nA | 2MΩ | 200nC | 200V | |
| | R5 | 200V | 20nA | 20MΩ | 2µC | 200V | |
| | R6 | 200V | 200nA | 200MΩ | 20µC | 200V | |
| | R7 | 200V | 2uA | 2GΩ | 20µC | 200V | |
| | R8 | 200V | 20uA | 20GΩ | 20µC | 200V | |
| | R9 | 200V | 200uA | 200GΩ | 20µC | 200V | |
| | R10 | 200V | 2mA | 200GΩ | 20µC | 200V | |
| | R11 | 200V | 20mA | 200GΩ | 20µC | 200V | |
| | R12 | Cancel Auto range for all functions | | | | | |
| Trigger Mode | T0 | Continuous, triggered by talk | | | | | |
| | T1 | One-shot, triggered by talk | | | | | |
| | T2 | Continuous, triggered by GET | | | | | |
| | T3 | One-shot, triggered by GET | | | | | |
| | T4 | Continuous, triggered by X | | | | | |
| | T5 | One-shot, triggered by X | | | | | |
| | T6 | Continuous, triggered by External Trigger | | | | | |
| | T7 | One-shot, triggered by External Trigger | | | | | |
| Status Word | U0 | Return status word: FRRCZNT0BG0QMMKYY*<br>*YY: := LFCR<br>=: CRLF<br>:0 LF<br>=0 CR<br>00 None | | | | | D |
| | U1 | Send error conditions | | | | | |
| | U2 | Send data conditions | | | | | E |
| | U3 | Buffer size and readings stored | | | | | F |
| Execute | X | Execute other device-dependent commands | | | | | F |

*Table D-1 (cont.)*
*Device dependent command summary*

| Mode | Command | Description | Note |
|---|---|---|---|
| Terminator | Y0 | LFCR (line feed, carriage return) | D |
| | Y1 | CRLF (carriage return, line feed) | |
| | Y2 | LF (line feed) | |
| | Y3 | CR (carriage return) | |
| | Y4 | None | |
| Zero Correct | Z0 | Zero Correct disabled | |
| | Z1 | Zero Correct enabled | |

A. The hit key command (Hn) is not used by the Models 6512, 617, and 617 HIQ. The hit command is similar to the SCPI SYSTem:KEY command (see Section 16 for details).
B. The buffer size command (In) is not used by the Models 6512, 617, and 617 HIQ. The buffer size command is similar to the SCPI TRACe:POINts command (see Section 8 for details).
C. The moving filter cannot be selected from the DDC language.
D. For the Models 6512, 617, and 617 HIQ, the terminator commands (Y) to set the terminator are different from the Y commands used by the Models 6512, 617, and 617 HIQ. Also note that the "YY" response to the U0 command is different.
E. For the Model 6514, the Buffer Full bit in the U2X status word does not get cleared until either the buffer is resized or buffer storage is reactivated. Note that requesting a buffer reading does not clear the U2 Buffer Full bit.
F. The U3 status command is not used by the Models 6512, 617, and 617 HIQ. The response message indicates the buffer size (In) and the actual number of readings stored in the buffer.

# E
# Example Programs

# Programming examples

All examples assume QuickBASIC version 4.5 or higher and a CEC IEEE-488 interface card with CEC driver version 2.11 or higher, with the Model 6514 at address 14 on the IEEE-488 bus.

## Changing function and range

The Model 6514 has independent range control for each of its four measurement functions. This means, for example, that autorange can be turned on for Volts while leaving it off for the rest of the functions.

Another difference is in the parameter for the range command. The parameter value for the :RANGe command is given as "the maximum value to measure". The instrument interprets this parameter and goes to the appropriate range. When you query the range with :RANGe?, the instrument sends back the full scale value of its present range.

Note that the Model 6514 rounds the range parameter to an integer before choosing the appropriate range. Sending VOLTage:RANGe 21.6 will set the Volts function to the 200V range. The parameter 21.6 is rounded to 22, which exceeds the 20V range.

The following program demonstrates range and function changes. A measurement will be taken while on the Amps and Ohms function:

```
  ‘ For QuickBASIC 4.5 and CEC PC488 interface card, edit the follow-
ing
  ‘ line where the QuickBASIC libraries are on your computer:
       ‘$INCLUDE: ‘c:\qb45\ieeeqb.bi’

  ‘ Initialize the CEC interface as address 21:
       CALL initialize(21, 0)

  ‘ Restore RST defaults:
       CALL SEND(14, “*rst”, status%)

  ‘ Set Amps for 20uA range and Ohms for 2MW range:
       CALL SEND(14, “curr:rang 20e-6”, status%)
       CALL SEND(14, “res:rang 2e6”, status%)
  ‘ Switch to Amps function and take reading. Each READ?
  ‘ will trigger one reading:
       CALL SEND(14, “func ‘curr’”, status%)
       CALL SEND(14, “read?”, status%)
       reading%$ = SPACE$(80)
       CALL ENTER(reading$, length%, 14, status%)
       PRINT reading$

  ‘ Switch to Ohms function and take reading:
       CALL SEND(14, “func ‘res’”, status%)
       CALL SEND(14, “read?”, status%)
       reading%$ = SPACE$(80)
       CALL ENTER(reading$, length%, 14, status%)
       PRINT reading$
```

## One-shot triggering

Other instruments generally have two types of triggering: one-shot and continuous. In one-shot, each activation of the selected trigger source causes one reading. In continuous, the instrument is idle until the trigger source is activated, at which time it begins taking readings at a specified rate. Typical trigger sources are:

- IEEE-488 talk
- IEEE-488 Group Execute Trigger (GET)
- "X" command
- External trigger (rear panel BNC)

Arming the instrument to respond to triggers is implicit in the non-SCPI voltmeters. Sending a command to a non-SCPI voltmeter to change any of the trigger controls causes the instrument to arm itself for triggers.

The SCPI trigger model implemented in the Model 6514 gives:

- Explicit control over the trigger source (the TRIGger subsystem).
- A way for completely disabling triggers.

Changing any of the settings in the TRIGger subsystem does not automatically arm the Model 6514 for triggers.

The following program sets up the Model 6514 to take one reading each time it receives an external trigger pulse.

```
' For QuickBASIC 4.5 and CEC PC488 interface card, edit
' the following line where the QuickBASIC libraries are
' on your computer:
' $INCLUDE: 'c:\qb45\ieeeqb.bi'

' Initialize the CEC interface as address 21:
CALL initialize(21, 0)

' Puts trigger model in idle state and configure for
' one-shot ' triggering:
CALL SEND(14, "*rst", status%)
CALL SEND(14, "trig:sour tlin; coun inf", status%)

' Take 6514 out of idle (ready for external input triggers):
CALL SEND(14, "init", status%)
```

After the Model 6514 receives the INITiate command, it stops at the control source in the trigger model, waiting for a trigger pulse. Each time a pulse arrives at the Trigger Link connector, the Model 6514 takes one reading. Because TRIGger:COUNt has been set to INFinity, the instrument never enters the idle state. You can send the ABORt command to put the instrument in the idle state, disabling triggers until another INITiate command is sent.

## Generating SRQ on buffer full

When your program must wait until the Model 6514 has completed an operation, it is more efficient to program the 6514 to assert the IEEE-488 SRQ line when it is finished, rather than repeatedly serial polling the instrument. An IEEE-488 controller will typically address the instrument to talk and then unaddress it each time it performs a serial poll. Repeated polling of the Model 6514 will generally reduce its overall reading throughput. Therefore, use the srq%() function call.

The Model 6514 provides a status bit for almost every operation it performs. It can be programmed to assert the IEEE-488 SRQ line whenever a status bit becomes true or false. The IEEE-488 controller (your computer) can examine the state of the SRQ line without performing a serial poll, thereby detecting when the 6514 has completed its task without interrupting it in the process.

The following example program segment sets up the Model 6514 to assert SRQ when the reading buffer has completely filled and then arms the reading buffer, initiates readings, and waits for the Model 6514 to indicate that the buffer is full.

This is not a complete program. The commands to configure the trigger model and the reading buffer (see the next example) are not shown. The example shown here can be modified for any event in the Model 6514 status reporting system.

```
‘ For QuickBASIC 4.5 and CEC PC488 interface card, edit
‘ the following line where the QuickBASIC libraries are
‘ on your computer:
‘ $INCLUDE: ‘c:\qb45\ieeeqb.bi’

‘ Initialize the CEC interface as address 21:
CALL initialize(21, 0)

‘ Reset STATus subsystem (not affected by *RST)
CALL SEND(14, "stat:pres;*cls", status%)

CALL SEND(14, "stat:meas:enab 512", status%)  'enable BFL
CALL SEND(14, "*sre 1"' status%)              'enable MSB
CALL SEND(14, "trac:feed:cont next", status%)

‘ Start everything
CALL SEND(14, "init", status%)

WaitSRQ:
IF (NOT(srq%()) THEN GOTO WaitSRQ
CALL SPOLL(14, poll%, status%)
IF (poll% AND 64)=0 THEN GOTO WaitSRQ
```

After the program has detected an asserted SRQ line, it serial polls the Model 6514 to determine if it is the device requesting service. This is necessary for two reasons:

- Serial polling the Model 6514 causes it to stop asserting the SRQ line.
- In test systems that have more than one IEEE-488 instrument programmed to assert SRQ, your program must determine which instrument is actually requesting service.

Once an event register has caused a service request, it cannot cause another service request until you clear it by reading it (in this case using STATus:MEASurement[:EVENt]?) or by sending the *CLS command.

## Storing readings in buffer

The reading buffer in the Model 6514 is flexible and capable. It has three controls, which are found in the TRACe susbsystem. There are commands to control:

- The size of the buffer (in readings).
  `TRACe:POINts <NRf>` Store up to 2000 readings.
- Where the data is coming from.
  `TRACe:FEED SENSe1` Store unprocessed readings.
  `TRACe:FEED CALCulate1` Store CALC1 (KMATh) results.
  `TRACe:FEED CALCulate2` Store CALC2 (limits) readings.
- Select buffer control mode.
  `TRACe:FEED:CONTrol NEVer` Immediately stop storing readings.
  `TRACe:FEED:CONTrol NEXT` Arm buffer, stop when buffer is full.

The following example program sets up the Model 6514 to take 20 readings as fast as it can into the buffer, and then reads the data back after the buffer has filled.

```
' Example program to demonstrate the reading buffer
' For QuickBASIC 4.5 and CEC PC488 interface card

' Edit the following line to where the QuickBASIC
' libraries are on your computer
' $INCLUDE: 'c:\qb45\ieeeqb.bi'

' Initialize the CEC interface as address 21
CALL initialize(21, 0)

' Reset controls and put trigger model in IDLE state
CALL SEND(14, "*rst", status%)

' Reset STATus subsystem (not affected by *RST)
CALL SEND(14, "stat:pres;*cls", status%)
CALL SEND(14, "stat:meas:enab 512", status%)  'enable BFL
CALL SEND(14, "*sre 1", status%)              'enable MSB
CALL SEND(14, "trig:coun 20", status%)

' TRACe subsystem is not affected by *RST
CALL SEND(14, "trac:poin 20", status%)
CALL SEND(14, "trac:feed sens1;feed:cont next", status%)

' Start everything
CALL SEND(14, "init", status%)

' Initialize reading$ while the 6514 is busy taking readings
reading$ = SPACE$(4000)

WaitSRQ:
IF (NOT(srq%)) THEN GOTO WaitSRQ
CALL SPOLL(14, poll%, status%)
```

```
IF (poll% AND 64)=0 THEN GOTO WaitSRQ

CALL SEND(14, "stat:meas?", status%)
CALL ENTER(S$, length%, 14, status%)

CALL SEND(14, "trac:data?", status%)
CALL ENTER(reading$, length%, 14, status%)
PRINT reading$
```

*NOTE: To repeat buffer storage, send the following command and then repeat the steps following the 'Start everything comment in the above example.*

```
CALL SEND(14, "feed:cont next", status%)
```

## Taking readings using the :READ? command

This programming example demonstrates a simple method for taking and displaying (on the computer CRT) a specified number of readings. The product of the arm count and trigger count determines the number of readings to take. The *RST default for both counters is one. Therefore, READ? will trigger and return one reading (1 × 1 = 1). If, for example, you want to take 10 readings, you can set one of the counters to 10, while keeping the other counter set to one. READ? will trigger and return 10 readings (10 × 1 = 10).

The following program takes 10 readings on the Volts function and displays them on the computer CRT.

```
' For QuickBASIC 4.5 and CEC PC488 interface card
' edit the following line to where the QuickBASIC libraries are
' on your computer
' $INCLUDE: 'c:\qb45\ieeeqb.bi

' Initialize the CEC interface as address 21
CALL initialize(21, 0)

' Reset controls, clear buffer and place 2182 in idle
CALL SEND(14, "*rst", status%)
CALL SEND(14, "trac:cle", status%)

CALL SEND(14, "trig:coun 10", status%)
CALL SEND(14, "form:elem read", status%)
CALL SEND(14, "read?", status%)
reading$ = SPACE$ (300)
CALL ENTER(reading$, length%, 14, status%)
PRINT reading$
```

## Controlling the Model 6514 via the RS-232 COM2 port

This example program illustrates the use of the Keithley Model 6514 interfaced to the RS-232 COM2 port. The Model 6514 is set up to take 100 readings at the fastest possible rate. The readings are taken, sent across the serial port, and displayed on the screen.

```
' Example program controlling the Model 6514 via the RS-232 COM2 port
' For QuickBASIC 4.5 and CEC PC488 interface card
RD$=SPACE$(1500)              ' Set string space
CLS                           ' CLear screen
PRINT "Set COM2 baud rate to 19200"
PRINT "Set 8 data bits, no parity, no flow control, and CR as Termina-
tor"

' Configure serial port parameters
ComOpen$="COM2:19200,N,8,1,ASC,CD0,CS0,DS0,LF,OP0,RS,TB8192,RB8192"
OPEN ComOpen$ FOR RANDOM AS #1

' Model 6514 setup commands
' Note Serial communications only operate with SCPI mode....
PRINT #1, "*RST"                ' RST defaults
PRINT #1, "*CLS"                ' Clear registers
PRINT #1, "VOLT:RANG 10"        ' 10V range
PRINT #1, "SYST:AZER OFF"       ' Disable autozero
PRINT #1, "AVER OFF"            ' Disable average filter
PRINT #1, "DISP:DIG 4"          ' 3½-digit resolution
PRINT #1, "FORM:ELEM READ"      ' Reading only
PRINT #1, "VOLT:NPLC 0.01"      ' NPLC = 0.01
PRINT #1, "TRIG:COUN 100"       ' 100 readings
PRINT #1, "DISP:ENAB OFF"       ' Turn off display
PRINT #1, "INIT"                ' Take 6514 out of idle
SLEEP 1                         ' Wait one second
PRINT #1, "READ?"               ' Perform measurements
LINE INPUT #1, RD$              ' Get data
PRINT RD$                       ' Display data on CRT
PRINT #1, "DISP:ENAB ON"        ' Turn on display
PRINT #1, "SYST:AZER ON"        ' Enable autozero

' Clean up and quit:
CLOSE #1                        ' Close file
CLEAR                           ' Clear interface
END
```

# F
# IEEE-488 Bus Overview

# Introduction

The IEEE-488 bus is a communication system between two or more electronic devices. A device can be either an instrument or a computer. When a computer is used on the bus, it serves as a supervisor of the communication exchange between all the devices and is known as the controller. Supervision by the controller consists of determining which device will talk and which device will listen. As a talker, a device will output information and as a listener, a device will receive information. To simplify the task of keeping track of the devices, a unique address number is assigned to each.

On the bus, only one device can talk at a time and is addressed to talk by the controller. The device that is talking is known as the active talker. The devices that need to listen to the talker are addressed to listen by the controller. Each listener is then referred to as an active listener. Devices that do not need to listen are instructed to unlisten. The reason for the unlisten instruction is to optimize the speed of bus information transfer since the task of listening takes up bus time.

Through the use of control lines, a handshake sequence takes place in the transfer process of information from a talker to a listener. This handshake sequence helps ensure the credibility of the information transfer. The basic handshake sequence between an active controller (talker) and a listener is as follows:

1. The listener indicates that it is ready to listen.
2. The talker places the byte of data on the bus and indicates that the data is available to the listener.
3. The listener, aware that the data is available, accepts the data and then indicates that the data has been accepted.
4. The talker, aware that the data has been accepted, stops sending data and indicates that data is not being sent.
5. The listener, aware that there is no data on the bus, indicates that it is ready for the next byte of data.

# Bus description

The IEEE-488 bus, which is also referred to as the GPIB (General Purpose Interface Bus), was designed as a parallel transfer medium to optimize data transfer without using an excessive number of bus lines. In keeping with this goal, the bus has only eight data lines that are used for both data and with most commands. Five bus management lines and three handshake lines round out the complement of bus signal lines

A typical setup for controlled operation is shown in Figure F-1. Generally, a system will contain one controller and a number of other instruments to which the commands are given. Device operation is categorized into three operators: controller, talker, and listener. The controller controls the instruments on the bus. The talker sends data while a listener receives data. Depending on the type of instrument, any particular device can be a talker only, a listener only, or both a talker and listener.

There are two categories of controllers: system controller and basic controller. Both are able to control other instruments, but only the system controller has the absolute authority in the system. In a system with more than one controller, only one controller may be active at any given time. Certain protocol is used to pass control from one controller to another.

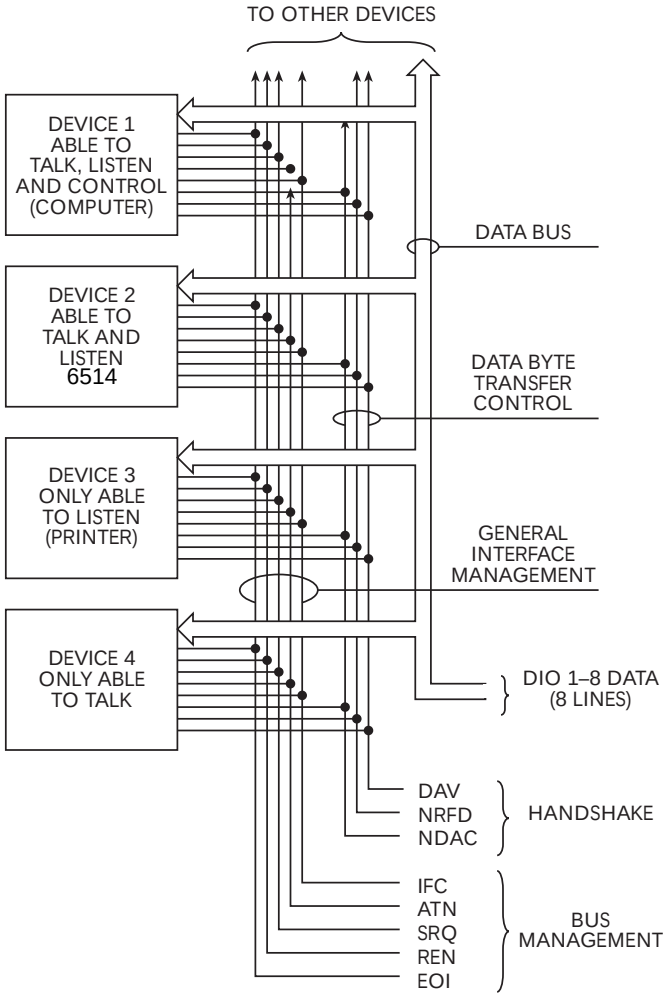
The IEEE-488 bus is limited to 15 devices, including the controller. Thus, any number of talkers and listeners up to that limit may be present on the bus at one time. Although several devices may be commanded to listen simultaneously, the bus can have only one active talker, or communications would be scrambled.

A device is placed in the talk or listen state by sending an appropriate talk or listen command. These talk and listen commands are derived from an instrument's primary address. The primary address may have any value between 0 and 31, and is generally set by rear panel DIP switches or programmed in from the front panel of the instrument. The actual listen address value sent out over the bus is obtained by ORing the primary address with $20. For example, if the primary address is $14, the actual listen address is $34 ($34 = $14 + $20). In a similar manner, the talk address is obtained by ORing the primary address with $40. With the present example, the talk address derived from a primary address of $14 would be $54 ($54 = $14 + $40).

The IEEE-488 standards also include another addressing mode called secondary addressing. Secondary addresses lie in the range of $60-$7F. Note, however, that many devices, including the Model 6514, do not use secondary addressing.

Once a device is addressed to talk or listen, the appropriate bus transactions take place. For example, if the instrument is addressed to talk, it places its data string on the bus one byte at a time. The controller reads the information, and the appropriate software can be used to direct the information to the desired location.

*Figure F-1*
*IEEE-488 bus configuration*



# Bus lines

The signal lines on the IEEE-488 bus are grouped into three different categories: data lines, management lines, and handshake lines. The data lines handle bus data and commands, while the management and handshake lines ensure that proper data transfer and operation takes place. Each bus line is active low, with approximately zero volts representing a logic 1 (true). The following paragraphs describe the operation of these lines.

## Data lines

The IEEE-488 bus uses eight data lines that transfer data one byte at a time. DIO1 (Data Input/Output) through DIO8 (Data Input/Output) are the eight data lines used to transmit both data and multiline commands and are bi-directional. The data lines operate with low true logic.

## Bus management lines

The five bus management lines help to ensure proper interface control and management. These lines are used to send the uniline commands.

ATN (Attention) — The ATN state determines how information on the data bus is to be interpreted.

IFC (Interface Clear) — The IFC line controls clearing of instruments from the bus.

REN (Remote Enable) — The REN line is used to place the instrument on the bus in the remote mode.

EOI (End or Identify) — The EOI line is used to mark the end of a multi-byte data transfer sequence.

SRQ (Service Request) — The SRQ line is used by devices when they require service from the controller.

## Handshake lines

The bus handshake lines operate in an interlocked sequence. This method ensures reliable data transmission regardless of the transfer rate. Generally, data transfer will occur at a rate determined by the slowest active device on the bus.

One of the three handshake lines is controlled by the source (the talker sending information), while the remaining two lines are controlled by accepting devices (the listener or listeners receiving the information). The three handshake lines are:

DAV (DATA VALID) — The source controls the state of the DAV line to indicate to any listening devices whether or not data bus information is valid.

NRFD (Not Ready For Data) — The acceptor controls the state of NRFD. It is used to signal to the transmitting device to hold off the byte transfer sequence until the accepting device is ready.

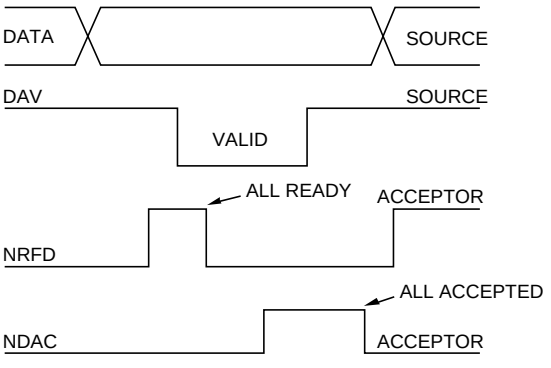
NDAC (Not Data Accepted) — NDAC is also controlled by the accepting device. The state of NDAC tells the source whether or not the device has accepted the data byte.

The complete handshake sequence for one data byte is shown in Figure F-2. Once data is placed on the data lines, the source checks to see that NRFD is high, indicating that all active devices are ready. At the same time, NDAC should be low from the previous byte transfer. If these conditions are not met, the source must wait until NDAC and NRFD have the correct status. If the source is a controller, NRFD and NDAC must be stable for at least 100ns after ATN is set true. Because of the possibility of a bus hang up, many controllers have time-out routines that display messages in case the transfer sequence stops for any reason.

Once all NDAC and NRFD are properly set, the source sets DAV low, indicating to accepting devices that the byte on the data lines is now valid. NRFD will then go low, and NDAC will go high once all devices have accepted the data. Each device will release NDAC at its own rate, but NDAC will not be released to go high until all devices have accepted the data byte.

The previous sequence is used to transfer both data, talk and listen addresses, as well as multiline commands. The state of the ATN line determines whether the data bus contains data, addresses, or commands as described in the following paragraphs.

*Figure F-2*
*IEEE-488 handshake sequence*



# Bus commands

The instrument may be given a number of special bus commands through the IEEE-488 interface. The following paragraphs briefly describe the purpose of the bus commands which are grouped into the following three categories.

1. Uniline commands — Sent by setting the associated bus lines true. For example, to assert REN (Remote Enable), the REN line would be set low (true).
2. Multiline commands — General bus commands which are sent over the data lines with the ATN line true (low).
3. Common commands — Commands that are common to all devices on the bus; sent with ATN high (false).
4. SCPI commands — Commands that are particular to each device on the bus; sent with ATN (false).

These bus commands and their general purpose are summarized in Table F-1.

*Table F-1*
*IEEE-488 bus command summary*

| **Command type** | **Command** | **State of ATN line** | **Comments** |
|---|---|---|---|
| Uniline | REN (Remote Enable) | X | Set up devices for remote operation. |
| | EOI | X | Marks end of transmission. |
| | IFC (Interface Clear) | X | Clears interface. |
| | ATN (Attention) | Low | Defines data bus contents. |
| | SRQ | X | Controlled by external device. |
| Multiline Universal | LLO (Local Lockout) | Low | Locks our local operation. |
| | DCL (Device Clear) | Low | Returns device to default conditions. |
| | SPE (Serial Enable) | Low | Enables serial polling. |
| | SPD (Serial Poll Disable) | Low | Disables serial polling. |
| Addressed | SDC (Selective Device Clear) | Low | Returns unit to default conditions. |
| | GTL (Go To Local) | Low | Returns device to local. |
| Unaddressed | UNL (Unlisten) | Low | Removes all listeners from the bus. |
| | UNT (Untalk) | Low | Removes any talkers from the bus. |
| Common | — | High | Programs IEEE-488.2 compatible instruments for common operations. |
| SCPI | — | High | Programs SCPI compatible instruments for particular operations. |

*Figure F-3 Command codes*

| $D_7$ $D_6$ $D_5$ $D_4$ | | | | | | X 0 0 0 | Command | X 0 0 1 | Command | X 0 1 0 | Primary Address | X 0 1 1 | Primary Address | X 1 0 0 | Primary Address | X 1 0 1 | Primary Address | X 1 1 0 | | X 1 1 1 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Bits** | $D_3$ ↓ | $D_2$ ↓ | $D_1$ ↓ | $D_0$ ↓ | Column→ Row ↓ | 0 (A) | 0 (B) | 1 (A) | 1 (B) | 2 (A) | 2 (B) | 3 (A) | 3(B) | 4 (A) | 4 (B) | 5 (A) | 5 (B) | 6 (A) | 6 (B) | 7 (A) | 7 (B) |
| | 0 | 0 | 0 | 0 | 0 | NUL | | DLE | | SP | 0 | 0 | 16 | @ | 0 | P | 16 | | | p | |
| | 0 | 0 | 0 | 1 | 1 | SOH | GTL | DC1 | LLO | ! | 1 | 1 | 17 | A | 1 | Q | 17 | a | | q | |
| | 0 | 0 | 1 | 0 | 2 | STX | | DC2 | | " | 2 | 2 | 18 | B | 2 | R | 18 | b | | r | |
| | 0 | 0 | 1 | 1 | 3 | ETX | | DC3 | | # | 3 | 3 | 19 | C | 3 | S | 19 | c | | s | |
| | 0 | 1 | 0 | 0 | 4 | EOT | SDC | DC4 | DCL | $ | 4 | 4 | 20 | D | 4 | T | 20 | d | | t | |
| | 0 | 1 | 0 | 1 | 5 | ENQ | PPC* | NAK | PPU* | % | 5 | 5 | 21 | E | 5 | U | 21 | e | | u | |
| | 0 | 1 | 1 | 0 | 6 | ACK | | SYN | | & | 6 | 6 | 22 | F | 6 | V | 22 | f | | v | |
| | 0 | 1 | 1 | 1 | 7 | BEL | | ETB | | ' | 7 | 7 | 23 | G | 7 | W | 23 | g | | w | |
| | 1 | 0 | 0 | 0 | 8 | BS | GET | CAN | SPE | ( | 8 | 8 | 24 | H | 8 | X | 24 | h | | x | |
| | 1 | 0 | 0 | 1 | 9 | HT | TCT* | EM | SPD | ) | 9 | 9 | 25 | I | 9 | Y | 25 | i | | y | |
| | 1 | 0 | 1 | 0 | 10 | LF | | SUB | | • | 10 | : | 26 | J | 10 | Z | 26 | j | | z | |
| | 1 | 0 | 1 | 1 | 11 | VT | | ESC | | + | 11 | ; | 27 | K | 11 | [ | 27 | k | | { | |
| | 1 | 1 | 0 | 0 | 12 | FF | | FS | | , | 12 | < | 28 | L | 12 | \ | 28 | l | | : | |
| | 1 | 1 | 0 | 1 | 13 | CR | | GS | | - | 13 | = | 29 | M | 13 | ] | 29 | m | | } | |
| | 1 | 1 | 1 | 0 | 14 | SO | | RS | | . | 14 | > | 30 | N | 14 | ∩ | 30 | n | | ≅ | |
| | 1 | 1 | 1 | 1 | 15 | SI | | US | | / | 15 | ? | UNL | O | 15 | — | UNT | o | | DEL | |

ADDRESSED COMMAND GROUP (ACG)

UNIVERSAL COMMAND GROUP (UCG)

LISTEN ADDRESS GROUP (LAG)

TALK ADDRESS GROUP (TAG)

PRIMARY COMMAND GROUP (PCG)

SECONDARY COMMAND GROUP (SDC)

*PPC (PARALLEL POLL CONFIGURE) PPU (PARALLEL POLL UNCONFIGURE), and TCT (TAKE CONTROL) not implemented by Model 6514.

Note: $D_0$ = DIO1 ... $D_7$ = DIO8; X = Don't Care.

## Addressed multiline commands

Addressed commands are multiline commands that must be preceded by the device listen address before that instrument will respond to the command in question. Note that only the addressed device will respond to these commands. Both the commands and the address preceding it are sent with ATN true.

SDC (Selective Device Clear) — The SDC command performs essentially the same function as the DCL command except that only the addressed device responds. Generally, instruments return to their power-up default conditions when responding to the SDC command.

GTL (Go To Local) — The GTL command is used to remove instruments from the remote mode. With some instruments, GTL also unlocks front panel controls if they were previously locked out with the LLO command.

GET (Group Execute Trigger) — The GET command is used to trigger devices to perform a specific action that depends on device configuration (for example, take a reading). Although GET is an addressed command, many devices respond to GET without addressing.

## Address commands

Addressed commands include two primary command groups and a secondary address group. ATN is true when these commands are asserted. The commands include:

LAG (Listen Address Group) — These listen commands are derived from an instrument's primary address and are used to address devices to listen. The actual command byte is obtained by ORing the primary address with $20.

TAG (Talk Address Group) — The talk commands are derived from the primary address by ORing the address with $40. Talk commands are used to address devices to talk.

SCG (Secondary Command Group) — Commands in this group provide additional addressing capabilities. Many devices (including the Model 6514) do not use these commands.

## Unaddress commands

The two unaddress commands are used by the controller to remove any talkers or listeners from the bus. ATN is true when these commands are asserted.

UNL (Unlisten) — Listeners are placed in the listener idle state by the UNL command.

UNT (Untalk) — Any previously commanded talkers will be placed in the talker idle state by the UNT command.

## Common commands

Common commands are commands that are common to all devices on the bus. These commands are designated and defined by the IEEE-488.2 standard.

Generally, these commands are sent as one or more ASCII characters that tell the device to perform a common operation, such as reset. The IEEE-488 bus treats these commands as data in that ATN is false when the commands are transmitted.

## SCPI commands

SCPI commands are commands that are particular to each device on the bus. These commands are designated by the instrument manufacturer and are based on the instrument model defined by the Standard Commands for Programmable Instruments (SCPI) Consortium's SCPI standard.

Generally, these commands are sent as one or more ASCII characters that tell the device to perform a particular operation, such as setting a range or closing a relay. The IEEE-488 bus treats these commands as data in that ATN is false when the commands are transmitted.

## Command codes

Command codes for the various commands that use the data lines are summarized in Figure F-3. Hexadecimal and the decimal values for the various commands are listed in Table F-2.

*Table F-2*
*Hexadecimal and decimal command codes*

| Command | Hex value | Decimal value |
|---|---|---|
| GTL | 01 | 1 |
| SDC | 04 | 4 |
| GET | 08 | 8 |
| LLO | 11 | 17 |
| DCL | 14 | 20 |
| SPE | 18 | 24 |
| SPD | 19 | 25 |
| LAG | 20-3F | 32-63 |
| TAG | 40-5F | 64-95 |
| SCG | 60-7F | 96-127 |
| UNL | 3F | 63 |
| UNT | 5F | 95 |

## Typical command sequences

For the various multiline commands, a specific bus sequence must take place to properly send the command. In particular, the correct listen address must be sent to the instrument before it will respond to addressed commands. Table F-3 lists a typical bus sequence for sending the addressed multiline commands. In this instance, the SDC command is being sent to the instrument. UNL is generally sent as part of the sequence to ensure that no other active listeners are present. Note that ATN is true for both the listen command and the SDC command byte itself.

*Table F-3*
*Typical bus sequence*

| Step | Command | ATN state | Data bus | | |
|---|---|---|---|---|---|
| | | | ASCII | Hex | Decimal |
| 1 | UNL | Set low | ? | 3F | 63 |
| 2 | LAG* | Stays low | . | 2E | 46 |
| 3 | SDC | Stays low | EOT | 04 | 4 |
| 4 | | Returns high | | | |

*Assumes primary address = 14.

Table F-4 gives a typical common command sequence. In this instance, ATN is true while the instrument is being addressed, but it is set high while sending the common command string.

*Table F-4*
*Typical addressed command sequence*

| Step | Command | ATN state | Data bus | | |
|---|---|---|---|---|---|
| | | | ASCII | Hex | Decimal |
| 1 | UNL | Set low | ? | 3F | 63 |
| 2 | LAG* | Stays low | . | 2E | 46 |
| 3 | Data | Set high | * | 2A | 42 |
| 4 | Data | Stays high | R | 52 | 82 |
| 5 | Data | Stays high | S | 53 | 83 |
| 6 | Data | Stays high | T | 54 | 84 |

*Assumes primary address = 14.

## IEEE command groups

Command groups supported by the Model 6514 are listed in Table F-5. Common commands and SCPI commands are not included in this list.

*Table F-5*
*IEEE command groups*

| | |
|---|---|
| **HANDSHAKE COMMAND GROUP** | |
| | NDAC = NOT DATA ACCEPTED<br>NRFD = NOT READY FOR DATA<br>DAV = DATA VALID |
| **UNIVERSAL COMMAND GROUP** | |
| | ATN = ATTENTION<br>DCL = DEVICE CLEAR<br>IFC = INTERFACE CLEAR<br>REN = REMOTE ENABLE<br>SPD = SERIAL POLL DISABLE<br>SPE = SERIAL POLL ENABLE |
| **ADDRESS COMMAND GROUP** | |
| LISTEN | LAG = LISTEN ADDRESS GROUP<br>MLA = MY LISTEN ADDRESS<br>UNL = UNLISTEN |
| TALK | TAG = TALK ADDRESS GROUP<br>MTA = MY TALK ADDRESS<br>UNT = UNTALK<br>OTA = OTHER TALK ADDRESS |
| **ADDRESSED COMMAND GROUP** | |
| | ACG = ADDRESSED COMMAND GROUP<br>GTL = GO TO LOCAL<br>SDC = SELECTIVE DEVICE CLEAR |
| **STATUS COMMAND GROUP** | |
| | RQS = REQUEST SERVICE<br>SRQ = SERIAL POLL REQUEST<br>STB = STATUS BYTE<br>EOI = END |

# Interface function codes

The interface function codes, which are part of the IEEE-488 standards, define an instrument's ability to support various interface functions and should not be confused with programming commands found elsewhere in this manual. The interface function codes for the Model 6514 are listed in Table F-6.

*Table F-6*
*Model 6514 interface function codes*

| Code | Interface function |
|---|---|
| SH1 | Source Handshake capability |
| AH1 | Acceptor Handshake capability |
| T5 | Talker (basic talker, talk-only, serial poll, unaddressed to talk on LAG) |
| L4 | Listener (basic listener, unaddressed to listen on TAG) |
| SR1 | Service Request capability |
| RL1 | Remote/Local capability |
| PP0 | No Parallel Poll capability |
| DC1 | Device Clear capability |
| DT1 | Device Trigger capability |
| C0 | No Controller capability |
| E1 | Open collector bus drivers |
| TE0 | No Extended Talker capability |
| LE0 | No Extended Listener capability |

The codes define Model 6514 capabilities as follows:

**SH (Source Handshake Function)** — SH1 defines the ability of the instrument to initiate the transfer of message/data over the data bus.

**AH (Acceptor Handshake Function)** — AH1 defines the ability of the instrument to guarantee proper reception of message/data transmitted over the data bus.

**T (Talker Function)** — The ability of the instrument to send data over the bus to other devices is provided by the T function. Instrument talker capabilities (T5) exist only after the instrument has been addressed to talk.

**L (Listener Function)** — The ability for the instrument to receive device-dependent data over the bus from other devices is provided by the L function. Listener capabilities (L4) of the instrument exist only after it has been addressed to listen.

**SR (Service Request Function)** — SR1 defines the ability of the instrument to request service from the controller.

**RL (Remote-Local Function)** — RL1 defines the ability of the instrument to be placed in the remote or local modes.

**PP (Parallel Poll Function)** — The instrument does not have parallel polling capabilities (PP0).

**DC (Device Clear Function)** — DC1 defines the ability of the instrument to be cleared (initialized).

**DT (Device Trigger Function)** — DTI defines the ability of the Model 6514 to have readings triggered.

**C (Controller Function)** — The instrument does not have controller capabilities (C0).

**TE (Extended Talker Function)** — The instrument does not have extended talker capabilities (TE0).

**LE (Extended Listener Function)** — The instrument does not have extended listener capabilities (LE0).

**E (Bus Driver Type)** — The instrument has open-collector bus drivers (E1).

# G
# IEEE-488 and SCPI Conformance Information

# Introduction

The IEEE-488.2 standard requires specific information about how the Model 6514 implements the standard. Paragraph 4.9 of the IEEE-488.2 standard (Std 488.2-1987) lists the documentation requirements. Table G-1 provides a summary of the requirements and provides the information or references the manual for that information. Table G-2 lists the coupled commands used by the Model 6514.

The Model 6514 complies with SCPI version 1991.0. Tables 17-1 through 17-9 list the SCPI confirmed commands and the non-SCPI commands implemented by the Model 6514.

*Table G-1*
*IEEE-488 documentation requirements*

| | **Requirements** | **Description or reference** |
|---|---|---|
| (1) | IEEE-488 Interface Function Codes. | See Appendix F. |
| (2) | Behavior of 6514 when the address is set outside the range 0-30. | Cannot enter an invalid address. |
| (3) | Behavior of 6514 when valid address is entered. | Address changes and bus resets. |
| (4) | Power-On Setup Conditions. | Determine by :SYSTem:POSetup (Section 16). |
| (5) | Message Exchange Options: | |
| (a) | Input buffer size. | 2048 bytes. |
| (b) | Queries that return more than one response message unit. | None. |
| (c) | Queries that generate a response when parsed. | All queries (Common Commands and SCPI). |
| (d) | Queries that generate a response when read. | None. |
| (e) | Coupled commands. | See Table G-2. |
| (6) | Functional elements required for SCPI commands. | Contained in SCPI command subsystems tables (see Tables 17-1 through 17-9). |
| (7) | Buffer size limitations for block data. | Block display messages: 12 characters max, |
| (8) | Syntax restrictions. | See Programming Syntax in Section 12. |
| (9) | Response syntax for every query command. | See Programming Syntax in Section 12. |
| (10) | Device-to-device message transfer that does not follow rules of the standard. | None. |
| (11) | Block data response size. | See Display Subsystem in Section 16. |
| (12) | Common Commands implemented by 6514. | See Common Commands in Section 14. |
| (13) | Calibration query information. | Section 19 |
| (14) | Trigger macro for *DDT. | Not applicable. |

*Table G-1 (cont.)*
*IEEE-488 documentation requirements*

| | **Requirements** | **Description or reference** |
|---|---|---|
| (15) | Macro information | Not applicable. |
| (16) | Response to *IDN (identification). | See Common Commands in Section 14. |
| (17) | Storage area for *PUD and *PUD? | Not applicable. |
| (18) | Resource description for *RDT and *RDT? | Not applicable. |
| (19) | Effects of *RST, *RCL and *SAV. | See Common Commands in Section 14. |
| (20) | *TST information. | See Common Commands in Section 14. |
| (21) | Status register structure. | See Status Structure in Section 13. |
| (22) | Sequential or overlapped commands. | All are sequential except :INIT which is overlapped. |
| (23) | Operation complete messages. | *OPC, *OPC? and *WAI; see Common Commands in Section 14. |

*Table G-2*
*Coupled commands*

| **Sending** | **Changes** | **To** |
|---|---|---|
| CALC1:FORM:KMAT:PERC:ACQ | CALC1:FORM:KMAT:PERC:REF <n> | Acquired value |
| CALC2:NULL:ACQ | CALC2:NULL:OFFS <n> | Acquired value |
| VOLT:RANG:UPP <n> | VOLT:RANG:AUTO <b> | OFF |
| CURR:RANG:UPP <n> | CURR:RANG:AUTO <b> | OFF |
| RES:RANG:UPP <n> | RES:RANG:AUTO <b> | OFF |
| CHAR:RANG:UPP <n> | CHAR:RANG:AUTO <b> | OFF |
| VOLT:NPLC <n> | CURR:NPLC <n> | Volts PLC value |
| | RES:NPLC <n> | Volts PLC value |
| | CHAR:NPLC <n> | Volts PLC value |
| CURR:NPLC <n> | VOLT:NPLC <n> | Amps PLC value |
| | RES:NPLC <n> | Amps PLC value |
| | CHAR:NPLC <n> | Amps PLC value |
| RES:NPLC <n> | VOLT:NPLC <n> | Ohms PLC value |
| | CURR:NPLC <n> | Ohms PLC value |
| | CHAR:NPLC <n> | Ohms PLC value |
| CHAR:NPLC <n> | VOLT:NPLC <n> | Charge PLC value |
| | CURR:NPLC <n> | Charge PLC value |
| | RES:NPLC <n> | Charge PLC value |
| TRAC:POIN <n> | TRAC:FEED:CONT <name> | NEV |
| TRAC:CLE | TRAC:FEED:CONT <name> TRAC:CLE | NEV |
| CHAR:RANG:AUTO:LGR <n><br>CHAR:RANG:AUTO ON | CHAR:RANG:UPP <n> | If autorange = ON then:<br>2µC if old range <2nC<br>and LRG = UPPer or<br>200nC if old range >200nC<br>and LGR = LOWer |

# H
# Calibration Options

# Introduction

This appendix contains information on reading Model 5156 Electrometer Calibration Standard values as well as a summary of Model 6514 remote calibration commands. See Section 19 for complete calibration information.

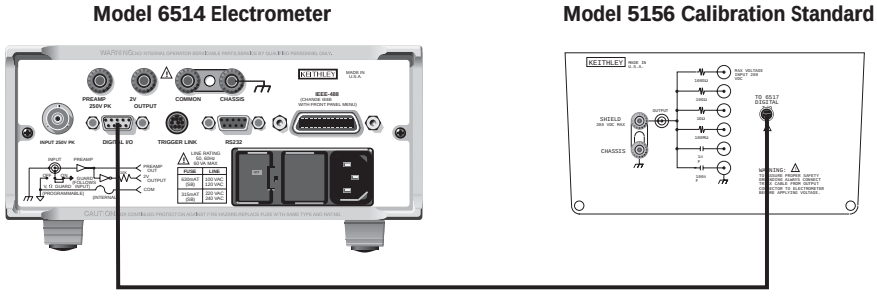
# Reading calibration standard values

Instead of manually computing calibration currents and charge values, you can read out Model 5156 Electrometer Calibration standard values via remote, then use a computer to calculate those values.

## Data transfer connections

Figure H-1 shows data transfer connections. Connect the Model 6514 DIGITAL I/O connector to the Model 5156 TO 6517 DIGITAL I/O connector using the optional Keithley CA-199-1A data transfer cable. Also connect the Model 6514 to the GPIB or RS-232 port of the host computer (not shown).

*Figure H-1*
*Data transfer connections*



## Example program

The program below demonstrates how to read back and display calibration standard values. To use this program, you will need the following:

- IBM PC compatible computer.
- Microsoft QBasic (supplied with DOS 5 – 6.22).
- CEC or Keithley IEEE-488 interface card installed in the computer.
- Installed CECHP.EXE driver (supplied with above interface card).

```
' Program to read Model 5156 standard values via Model 6514.
' 6514 primary address = 14.
OPEN "IEEE" FOR OUTPUT AS #1              ' Open IEEE-488 output path.
OPEN "IEEE" FOR INPUT AS #2               ' Open IEEE-488 input path.
PRINT #1, "INTERM CRLF"                   ' Set input terminator.
PRINT #1, "OUTTERM LF"                    ' Set output terminator.
PRINT #1, "REMOTE 14"                     ' Put 6514 in remote.
CLS
PRINT "Model 5156 Calibration Standard values:"
PRINT #1, "OUTPUT 14;:CAL:UNPR:KI5156?"   ' Query 5156 standard values.
PRINT #1, "ENTER 14"
INPUT #2, R100G, R10G, R1G, R100M, C1NF, C100NF
PRINT #1, "LOCAL 14"
CLOSE
PRINT "100 G ohm value:"; R100G
PRINT "10 G ohm value:"; R10G
PRINT "1 G ohm value:"; R1G
PRINT "100 M ohm value:"; R100M
PRINT "1 nF value:"; C1NF
PRINT "100 nF value:"; C100NF
END
```

# Remote calibration

## Calibration commands

Table H-1 summarizes Model 6514 calibration commands.

*Table H-1*
*Calibration commands*

| Command | Description |
|---|---|
| :CALibration | |
| :PROTected | |
| :CODE '<code>' | Eight character code/password used to enable or unlock calibration. (Default: KI006514.) |
| :CODE? | Calibration code query. |
| :LOCK | Lock out further calibration. |
| :LOCK? | Return 1 if calibration is locked, 0 otherwise. |
| :SENSe <NRf> | Calibrate active function and range. |
| :DATA? | Query measurement cal constants. |
| :SAVE | Save all calibration data to non-volatile memory. |
| :DATE <NRf, NRf, NRf> | Year, Month, Day when cal was last performed. |
| :DATE? | Query last cal date. |
| :NDUE <NRf, NRf, NRf> | Year, Month, Day when 6514 is due for re-cal. |
| :NDUE? | Query cal due date. |
| :COUNt? | Returns how many times a 6514 has been calibrated. |
| :UNPRotected | |
| :VOFFset | Voltage Offset correction. |
| :IOFFset | Current Offset correction. |

## Remote calibration overview

The steps below outline the general procedure for calibrating the Model 6514 using remote commands. Refer to Section 19 for details on calibration steps, calibration points, and test equipment connections.

1. Send the following command to unlock calibration:

   :CAL:PROT:CODE 'KI006514'

   Note that the above command uses the factory default code.

2. Perform current and voltage offset correction by sending the following commands:

   :CAL:UNPR:IOFF

   :CAL:UNPR:VOFF

   Be sure the appropriate connections are made to the INPUT jack before sending each command (cap for IOFF; short for VOFF).

3. Send the appropriate commands to select the function and range to be calibrated. For example, the following commands select the volts function and the 2V range:

   :SENS:FUNC 'VOLT'

   :SENS:VOLT:RANG 2

4. Make appropriate connections, then send the commands for each calibration point for the selected function and range. For example, send the following commands for the 2V range:

   :CAL:PROT:SENS 0

   :CAL:PROT:SENS 2

   :CAL:PROT:SENS –2

*NOTE* *Be sure the appropriate calibration signal is applied to the INPUT jack before sending the command for each calibration point. See Section 19 for details.*

5. Repeat steps 3 and 4 for each function and range.
6. After all functions and ranges are calibrated, send the commands to program the calibration dates; for example:

   :CAL:PROT:DATE 1998,12,15

   :CAL:PROT:NDUE 1999,12,15

7. Finally, send the following commands to save calibration constants and then lock out calibration:

   :CAL:PROT:SAVE

   :CAL:PROT:LOCK

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Zero correct 2-14

# Service Form

**Model No.** _____ **Serial No.** _____ **Date** _____

**Name and Telephone No.** _____

**Company** _____

List all control settings, describe problem and check boxes that apply to problem. _____

_____

_____

❑ Intermittent ❑ Analog output follows display ❑ Particular range or function bad; specify

_____

❑ IEEE failure ❑ Obvious problem on power-up ❑ Batteries and fuses are OK

❑ Front panel operational ❑ All ranges or functions are bad ❑ Checked all cables

Display or output (check one)

❑ Drifts ❑ Unable to zero ❑ Unstable

❑ Overload ❑ Will not read applied input

❑ Calibration only ❑ Certificate of calibration required ❑ Data required

(attach any additional sheets as necessary)

Show a block diagram of your measurement including all instruments connected (whether power is turned on or not). Also, describe signal source.

Where is the measurement being performed? (factory, controlled laboratory, out-of-doors, etc.)_____

_____

What power line voltage is used?_____ Ambient temperature?_____ °F

Relative humidity? _____Other? _____

Any additional information. (If special modifications have been made by the user, please describe.)

_____

_____

Be sure to include your name and phone number on this service form.

Specifications are subject to change without notice.
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