

Model 6487 Picoammeter/Voltage Source

Reference Manual

6487-901-01 Rev. D October 2020



6487-901-01

A Greater Measure of Confidence

KEITHLEY
A Tektronix Company

**Model 6487 Picoammeter / Voltage Source
Reference Manual**

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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 nonhazardous voltages, there are situations where hazardous conditions may be present.

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

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

The types of product users are:

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

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

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

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

Keithley products are designed for use with electrical signals that are measurement, control, and data I/O connections, with low transient overvoltages, and must not be directly connected to mains voltage or to voltage sources with high transient overvoltages. Measurement Category II (as referenced in IEC 60664) connections require protection for high transient overvoltages often associated with local AC mains connections. Certain Keithley measuring instruments may be connected to mains. These instruments will be marked as category II or higher.

Unless explicitly allowed in the specifications, operating manual, and instrument labels, do not connect any instrument to mains.

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 30 V RMS, 42.4 V peak, or 60 VDC 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 V, no conductive part of the circuit may be exposed.

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

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

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

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

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

For safety, instruments and accessories must be used in accordance with the operating instructions. If the instruments or accessories are used in a manner not specified in the operating instructions, the protection provided by the equipment may be impaired.

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

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

Chassis connections must only be used as shield connections for measuring circuits, NOT as protective earth (safety 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 protective earth (safety ground) using the wire recommended in the user documentation.

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

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

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

The  symbol indicates a connection terminal to the equipment frame.

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

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

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

The **CAUTION** heading with the  symbol in the user documentation explains hazards that could result in moderate or minor injury or damage the instrument. Always read the associated information very carefully before performing the indicated procedure. Damage to the instrument 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. Standard fuses with applicable national safety approvals may be used if the rating and type are the same. The detachable mains power cord provided with the instrument may only be replaced with a similarly rated power cord. 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 to maintain accuracy and functionality of the product). If you are unsure about the applicability of a replacement component, call a Keithley office for information.

Unless otherwise noted in product-specific literature, Keithley instruments are designed to operate indoors only, in the following environment: Altitude at or below 2,000 m (6,562 ft); temperature 0 °C to 50 °C (32 °F to 122 °F); and pollution degree 1 or 2.

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

Safety precaution revision as of June 2017.

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Section 1

Introduction

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Welcome

The 6487 is a high resolution bus-programmable (RS-232 and IEEE-488) picoammeter. The 6487 has eight current measurement ranges from 20 mA to 2 nA.

The 6487 also has a built-in \pm 500 V dc voltage source and an ohms function that includes an alternating voltage mode for enhanced high resistance measurement accuracy.

Extended warranty

Additional years of warranty coverage are available on many products. These valuable contracts protect you from unbudgeted service expenses and provide additional years of protection at a fraction of the price of a repair. Extended warranties are available on new and existing products. Contact your local Keithley Instruments office, sales partner, or distributor for details.

Contact information

If you have any questions after you review the information in this documentation, please contact your local Keithley Instruments office, sales partner, or distributor. You can also call the Tektronix corporate headquarters (toll-free inside the U.S. and Canada only) at 1-800-833-9200. For worldwide contact numbers, visit tek.com/contact-us.

General information

Warranty information is located at the front of this manual. Should your 6487 require warranty service, contact the Keithley Instruments 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.

Unpacking and inspection

The 6487 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. Before removing the 6487 from the bag, observe the following handling precautions.

Handling precautions

- Always grasp the 6487 by the covers.
- After removing the 6487 from its anti-static bag, inspect it for any obvious signs of physical damage. Report any such damage to the shipping agent immediately.
- When the 6487 is not installed and connected, keep the unit in its anti-static bag and store it in the original packing carton.

Package contents

- Model 6487 Picoammeter with line cord
- Protective triaxial shield cap (CAP-31)
- 7078-TRX-3 triaxial cable
- Model 8607 1 kV Source banana cable set
- CS-459 4-Pin Female interlock connector
- Accessories as ordered
- Certificate of calibration

Additional references

While reading this document, you may find it helpful to consult the following documentation for reference:

- Model 6487 User's Manual: Available from the [tek.com](#) website.
- Low-Level Measurements handbook: Available from the [tek.com](#) website.

Power-up

Line power connection

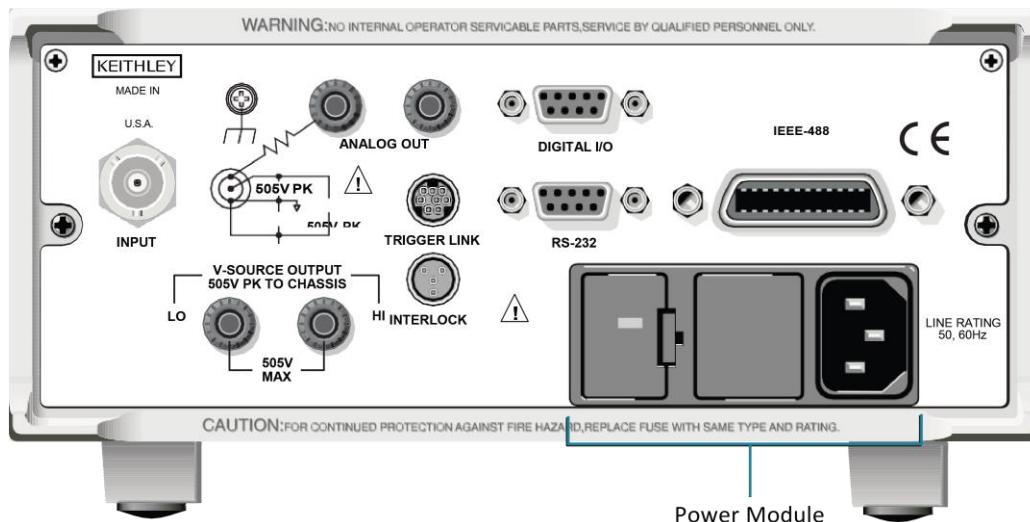
To connect the Model 6487 to line power and turn on the instrument:

1. Check to see that the line voltage indicated in the window of the fuse holder assembly is correct for the operating voltage in your area.

CAUTION

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

Figure 1: Rear panel



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

WARNING

The power cord supplied with the 2601B-PULSE contains a separate protective earth (safety ground) wire for use with grounded outlets. When proper connections are made, the instrument chassis is connected to power-line ground through the ground wire in the power cord. In addition, a chassis ground connection is provided through a screw on the rear panel. This terminal should be connected to a known protective earth. In the event of a failure, not using a properly grounded protective earth and grounded outlet may result in personal injury or death due to electric shock. Do not replace detachable mains supply cords with inadequately rated cords. Failure to use properly rated cords 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 (I) position.

WARNING

Hazardous voltages may be present in the test system. To prevent injury or death, remove power from the instrument or test system and discharge any energy storage components (for example, capacitors or cables) before changing any connections that might allow contact with an uninsulated conductor.

Line frequency

The 6487 operates at line frequencies of 50 Hz or 60 Hz. When auto detect is enabled (factory default), line frequencies are automatically sensed and set accordingly, therefore there are no switches to set. Use the :SYSTem:LFREquency? command (query) to read the line frequency. The factory default setting is Auto-Detect enabled.

If the power line is noisy, auto detect may not be able to lock in on a frequency. If this occurs, set the frequency manually. This may be accomplished using the front panel or over the bus.

Front panel procedure

To set the line frequency from the front panel:

1. Press **MENU**.
2. Scroll to the **LFREQ:** menu item using the up and down **RANGE** keys. The present settings are displayed.
3. Press the right arrow cursor key.
4. Use the up and down **RANGE** keys to scroll to the desired line frequency: **AUTOXX 50** or **AUTOXX 60**.
5. Press **ENTER**.

SCPI programming - line frequency

Command	Description
<code>SYSTem :LFREquency <freq> :AUTO :AUTO? [:STATE] [:STATE] ? :LFREquency?</code>	<code>SYSTem subsystem: Set power line frequency (in Hz) to 50 or 60. Turn automatic frequency detection ON or OFF. Read the present automatic detected line frequency state (1 = on, 0 = off). Read present line frequency setting.</code>

Power-up sequence

The following power-up sequence occurs when the Model 6487 is turned on.

1. The 6487 performs EPROM and RAM self-tests with all digits and annunciators turned on. If a failure is detected, the instrument displays an error message and the ERR annunciator turns on.
2. If the instrument passes the self-tests, the firmware revision levels are displayed. For example:

6487 A01

3. After the firmware revision levels are displayed, the detected line frequency is displayed. For example:

FREQ: 60Hz

4. After the detected line frequency is displayed, information on the selected remote interface is displayed:
 - a. If the GPIB is the selected interface, the instrument will display the selected language (SCPI, 488.1, or DDC) and primary address.

SCPI ADDR: 22

DDC ADDR: 22

b. If RS-232 is the selected interface, the instrument will display the baud rate setting.

RS-232: 9600b

5. If the factory setup is selected as the power-on setup, the unit is placed in the default reading mode after the communication information is displayed. If a setup other than FACTory is selected, the configured setup will be displayed. For example, if the USR1 setup (User Setup #1) is selected:

USING USR1

To configure the power-on set up:

1. From the PWR-ON: menu, press **CONFIG** and then **SETUP**.
2. Use the up and down **RANGE** keys to scroll through the menu items.
3. Press **ENTER** to select or **EXIT** to quit without changing power-on setup.

Front panel operation

The following figure shows the front panel of the 6487. The controls, indicators, and display are described later in this section of the manual.

Figure 2: Front panel



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 for either status or errors.

Messages, both status and error, are held in queues. For information on retrieving messages from queues, see [Status structure](#) (on page 10-1).

Default settings

The 6487 can be restored to one of five setup configurations:

- Factory default (FACT)
- Three user-saved setups (USR0, USR1, and USR2)
- Bus default (GPIB).

As shipped from the factory, the 6487 powers up to the factory default settings. Factory default settings provide a general purpose setup for front panel operation, while the bus default (GPIB) settings do the same for remote operation.

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

NOTE

At the factory, the factory default setup is saved into the USR0, USR1, and USR2 setups.

Front panel setup operation

To save a user setup:

1. Configure the 6487 for the desired measurement application.
2. Press **SAVE** to access the save setup menu.
3. Use the up or down **RANGE** key to display the desired memory location (0 = USR0, 1 = USR1, 2 = USR2).
4. Press **ENTER**.

To restore any setup:

1. Press **SETUP** to display the restore menu:
2. Use the up or down **RANGE** key to display the desired setup (FACT, USR0, USR1, USR2, or GPIB).
3. Press **ENTER**.

To select power-on setup:

1. Press **CONFIG** and then **SETUP** to display the power-on menu.
2. Use the up or down **RANGE** key to display the desired setup (FACT, USR0, USR1, USR2, or GPIB).
3. Press **ENTER**.

Remote setup operation

Saving and restoring user setups

The *SAV and *RCL commands are used to save and recall user setups. These commands are documented in [Common commands](#) (on page 11-1).

Restoring factory or GPIB default setups

The SYSTem:PRESet command returns the 6487 to the factory defaults and the *RST command returns it to the GPIB defaults. The *RST command is documented in [Common commands](#) (on page 11-1) and SYSTem:PRESet is covered in [DISPlay, FORMat, and SYSTem](#) (on page 13-1).

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 [DISPlay, FORMat, and SYSTem](#) (on page 13-1).

Setting	Factory (:SYStem:PRESet)	GPIB (*RST)
Arm Layer (CONFIG ARM): Arm-In Source Event Arm Count Input Trigger Link Line Source Bypass Output Trigger Link Line Output Trigger	IMM INF 1 NEVER 2 Off	* 1 * * * *
Buffer (STORE): Count	Disabled No effect	*
Damping (DAMP)	On	*
Digital Filter (FILT): Count Type	Off 10 Moving	*
Display Resolution (DIGITS)	5H-digits	*
Format byte order	Swapped	Normal
Function	Amps	*
GPIB: Address Language	No effect (On at factory) No effect (22 at factory) No effect (SCPI at factory)	*
Limit Tests: Limit 1 and Limit 2: HI and LO Values	Disabled 1, -1	*
Log (MATH)	OFF	*
Median Filter (FILT): Rank	Off 1	*
MX+B (MATH): "M" Value "B" Value Units	Disabled 1.0 0.0 X	*
M/X+B (MATH) "M" Value "B" Value Units	Disabled 1.0 0.0 X	*
Ohms Mode	Normal	*
Range	AUTO	*
Rate: NPLC	Slow 6.0 (60 Hz) or 5.0 (50 Hz)	*
Rel: Rel Value (VAL)	Off 0.0	*
RS-232: All Settings	No effect (Off at factory) No effect	*

Setting	Factory (:SYStem:PRESet)	GPIB (*RST)
Trigger Layer (CONFIG TRIG): Trig-In Source Event Trigger Count Trigger Delay Input Trigger Link Line Source Bypass 	IMM 1 0 1 NEVER 2	*
Units	No effect	*
Voltage Source: Operate Amplitude Range Current Limit 10 V Range Interlock Sweeps: Start Voltage Stop Voltage Step Voltage Center Voltage Span Voltage Delay	Off 0 V 10 V 25 mA Off 0 V 10 V 1 V 5 V 10 V 1 s	*
Zero Check	Enabled	*
Zero Correct	Disabled	*

*This factory (:SYStem:PRESet) and bus (*RST) GPIB defaults are the same. Bus settings that are different from factory reset are as shown.

Menus

Main menus

Many aspects of operation are configured through the main menus summarized in the next table. Refer to the section listed in the next table for in-depth information. To access the main menus, press the **MENU** key. Use the up and down **RANGE** keys to scroll through the menu items and the left and right keys to change options. Press **ENTER** to save any changes made and leave the menu. Press **EXIT** to leave the menu without saving changes.

NOTE

The **MENU** key is used to access the menu structure. However, if in remote for IEEE-488 bus operation (**REM** annunciator is lit), pressing the menu key has no effect. Press the **LOCAL** key to place the unit in local operation, then press the **MENU** key to access the menu items.

See the following table for the main menu structure.

Menu item	Description
CAL	Provides path to the following calibration submenu items: VOFFSET, COUNT, RUN, VSRC-RUN, DATES, UNLOCK, LOCK, and SAVE. See reference section for verification and calibration information.
TSTAMP	Timestamp format can be ABSolute or DELTa.
UNITS	Readings can be displayed in ENGINEering units or SCIENTific notation.
TEST	Run display or key tests.
SNUM	Displays the units serial number.
LFREQ	Line frequency can be manually set to 50 Hz, 60 Hz, or AUTOMATICally set. The number after AUTO indicates present detected frequency value.

Configuration menus

Many keys have configuration menus that allow you to configure various 6487 operating modes. The following table summarizes the various configuration menus. To access a configuration menu, press **CONFIG** and then the corresponding front panel key.

Key	Description
I Ü	Configure normal or alternating voltage ohms modes.
MATH	Set up MX + B, M/X + B, and LOG math functions.
FILT	Configure median and average filters.
REL	Enter relative value.
OPER	Select DC or SWEEP mode, set source amplitude and current limit.
COMM	Configure GPIB or RS-232 interface.
TRIG	Configure trigger parameters.
LIMIT	Set up and enable limit tests.
RATE	Set integration rate in number of power line cycles (NPLCs).
SETUP	Select power-on setup.
STORE	Select number of readings to store in buffer.
RANGE (arrow up)	Set upper auto range limit.
RANGE (arrow down)	Set lower auto range limit.

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.

Most SCPI tables in this manual do not include most optional command words and query commands. Optional command words and query commands are summarized as follows.

Optional command words

The 6487 accepts optional command words to conform with the IEEE-488.2 and SCPI standards. Any command word that is enclosed in brackets ([]) is optional and does not need to be included in the program message. For example:

```
:INITiate[:IMMediate]
```

These brackets indicate that :IMMediate is implied and does not have to be used. The above command can be sent as either :INITiate or :INITiate:IMMediate.

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 the 6487 is addressed to talk, the response message is sent to the computer. For example:

```
:ARM:TIMER?
```

This is a command that queries the timer interval

Section 2

Measurement concepts and connections

In this section:

Connection fundamentals	2-1
Basic connections to the DUT.....	2-3
Using a test fixture	2-7
Interlock	2-13
Analog output.....	2-15
Measurement considerations	2-17

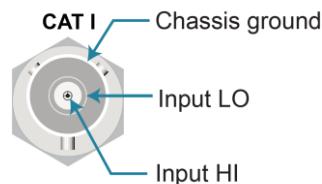
Connection fundamentals

The following provides important fundamental information on input connections to the 6487.

Input connector

The rear panel INPUT connector is a three-lug female triaxial connector. Make connections using a male terminated triaxial cable.

Figure 3: Triaxial input connector



Voltage source output connectors

The rear panel V-SOURCE OUTPUT HI and LO connectors are used to connect the voltage source to the DUT. The voltage source is primarily used for ohms measurements but can also be used for standalone source operation.

Maximum input levels

The maximum input levels to the 6487 are summarized in the following figure.

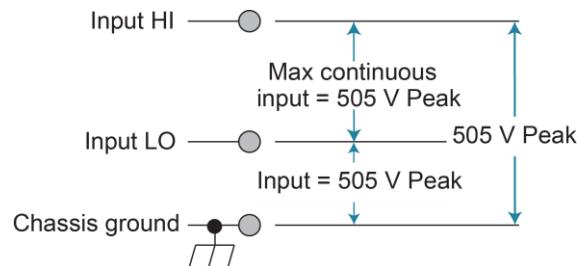
WARNING

The maximum safe voltage between the voltage source or ammeter common and chassis ground (common mode voltage) is 505 V peak. Exceeding this voltage can create a shock hazard.

CAUTION

Maximum continuous input voltage is 505 V peak.

Figure 4: Maximum input levels



Low-noise input cables

When making precision measurements, you should always use low-noise cables in the shortest practical length for INPUT connections.

The following low-noise cables are recommended for use with the 6487:

- **Model 237-ALG-2 Triaxial Cable:** This 2 m (6.6 ft) low-noise triaxial cable is terminated with a three-slot male triaxial connector on one end and three alligator clips on the other end.
- **Models 7078-TRX-3, 7078-TRX-5, 7078-TRX-10, 7078-TRX-12, and 7078-TRX-20 Triaxial Cables:** These are low- noise triaxial cables terminated at both ends with three-slot male triaxial connectors. The trailing numbers of each cable model refers to its length in feet.

Voltage source test leads

When using the voltage source, the test leads must be rated for 505 V minimum and should include safety sheaths. These test leads are recommended for use with the 6487:

Model 8606 High Performance Probe Tip Kit: Consists of two spade lugs, two alligator clips, and two spring hook test probes. (The spade lugs and alligator clips are rated at 30 V_{RMS}, 42.4 V peak; the test probes are rated at 1000 V.) These components are designed to be used with high performance test leads terminated with banana plugs, such as the Model 8607 High Performance Banana Cables.

Model 8607 High Performance Banana Cables: Consists of two high voltage (1000 V) banana cables. The cables are terminated with banana plugs that have retractable sheaths.

WARNING

Use only test leads with reinforced insulation and a minimum rating of 1010 V peak for connections to the voltage source to avoid a possible shock hazard.

Basic connections to the DUT

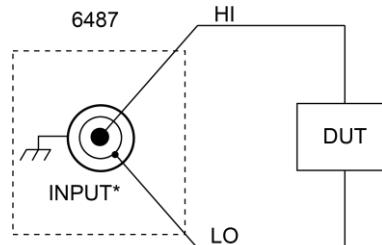
WARNING

Hazardous voltages may be present in the test system. To prevent injury or death, remove power from the instrument or test system and discharge any energy storage components (for example, capacitors or cables) before changing any connections that might allow contact with an uninsulated conductor.

Current measurement connections

Basic connections for current measurements are shown in the following figure. The DUT is the current to be measured. Circuit high is connected to the center conductor of the input connector and circuit low is connected to input LO (inner shield).

Figure 5: Basic current measurement connections



* Maximum Continuous Input: 505 V Peak

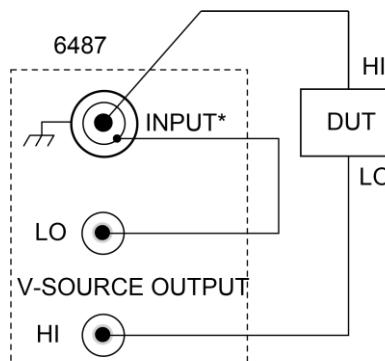
CAUTION

Current limiting resistors are required for DUTs capable of forcing voltages 505 V or greater. Damage to the instrument may result if voltages greater than 505 V are forced on input HI.

Ohms measurement connections

Basic connections for ohms measurements are shown in the following figure. The DUT is the resistance to be measured. Circuit high is connected to the center conductor of the INPUT connector and circuit low is connected to the V-SOURCE OUTPUT HI terminal. Note that INPUT LO and V-SOURCE OUTPUT LO are connected together externally.

Figure 6: Basic ohms connections



* Maximum continuous input: 505 V peak

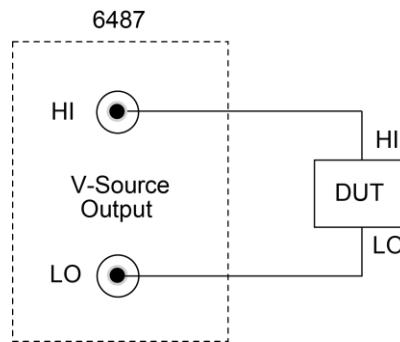
Voltage source connections

Basic connections for using the voltage source independently are shown in the following figure. The DUT is the load for the voltage source. DUT high is connected to V-SOURCE OUTPUT HI and DUT LO is connected to V-SOURCE OUTPUT LO.

CAUTION

Do not connect external sources to the 6487 voltage source. External sources may damage the 6487 voltage source.

Figure 7: Basic voltage source connections



Voltages greater than 505 V

When making very high resistance measurements, it may be necessary to use an external voltage source with voltages greater than the maximum tolerable input voltage of 505 V. In the event that the resistance to be measured becomes shorted or an incorrect value of resistance is inserted in the test setup, the voltage source can permanently damage the 6487. To prevent this damage, the following steps should be taken as a precaution.

To prevent accidental damage, a series resistor should be added to the test setup. The minimum value of this series resistor depends on the lowest current range to be used in the measurement. If it will not be necessary to use the lower measurement ranges, a smaller series resistor can be used, reducing the effect it will have on measurement accuracy. The lowest necessary measurement range can be determined from the measurement range accuracy specifications, the applied voltage, and largest resistance desired to measure. If using auto range, program the 6487 to not use its lowest ranges when autoranging.

To set the auto range lower limit from the front panel:

1. Press the **CONFIG** key.
2. Press the down **RANGE** key.
3. Use the up and down **RANGE** keys to scroll through the available lower limit settings.
4. Press **ENTER** to save the displayed value as the lower limit. Press **EXIT** to return to the previous setting.
5. To set the auto range lower limit over the bus, use **[CURRENT] :RANGE:AUTO:LLIMit**.
6. Use the following formula to determine the minimum resistance for current-limiting resistors:

$$\text{MinR}_{\text{series}} = \left(\frac{\text{SourceVoltage} - 505 \text{ V}}{505 \text{ V}} \right) R_{\text{in}}$$

Lowest range	R_{in}
2 nA or 20 nA	11 MΩ
200 nA or 2 μA	3.5 MΩ
20 μA or 200 μA	50 kΩ
2 mA or 20 mA	510 Ω

The series limiting resistor should have a minimum power rating of:

$$\text{MinPowerRating} = \text{SourceVoltage}^2 / R_{\text{series}}$$

For example, if measuring 100 GΩ resistances using an external voltage source of 750 V and the lowest necessary current range of 20 nA, the minimum series resistance that will prevent damage in the case of a shorted resistor would be:

$$\text{minimum } R_{\text{series}} = (750 \text{ V} - 505 \text{ V}) / 505 \text{ V} / 11 \text{ MΩ} = 12.25 \text{ MΩ}$$

$$\text{minimum power rating} = (750 \text{ V})^2 / 14 \text{ MΩ} = 41 \text{ mW}$$

NOTE

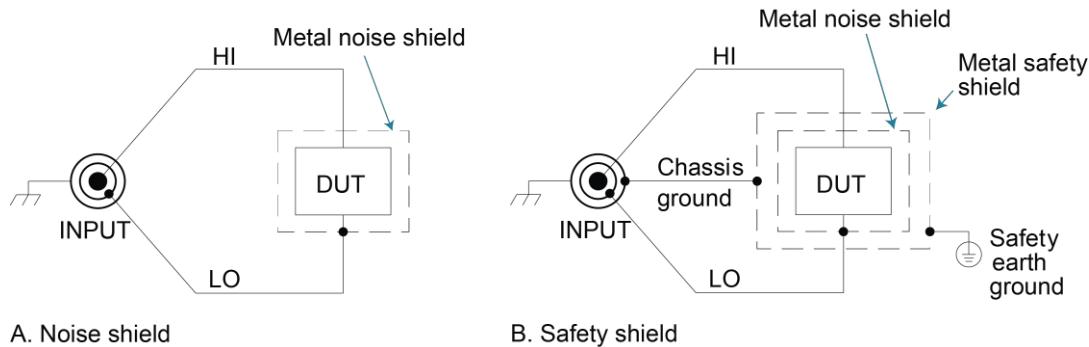
The 12.25 MΩ in series will increase the measured resistance to 100.012 GΩ

The 6487 can be programmed to calculate the resistance and subtract the series resistance. Using the M/X+B function, in the example above, you would set M to 500, B to -14e6, and the units character to Ω.

Noise and safety shields

The next graphic shows typical measurement shielding. A noise shield is used to prevent unwanted signals from being induced on the picoammeter input. Amps measurements below 1 μA may benefit from effective shielding. Typically, the noise shield is connected to picoammeter input LO. Additionally, the following figures show an added safety shield connected to earth ground and the 6487 chassis. This type of shielding should be used whenever hazardous voltages will be present in the test circuit.

Figure 8: Shielding for measurements (unguarded)



CAUTION

The LO to chassis breakdown voltage is 505 V. Exceeding this voltage may cause damage to the instrument.

Using a test fixture

Whenever possible, use a shielded low-leakage test fixture to make precision measurements and for safety when high voltages (> 30 V) are used.

⚠ WARNING

To provide protection from shock hazards, an enclosure should be provided that surrounds all live parts.

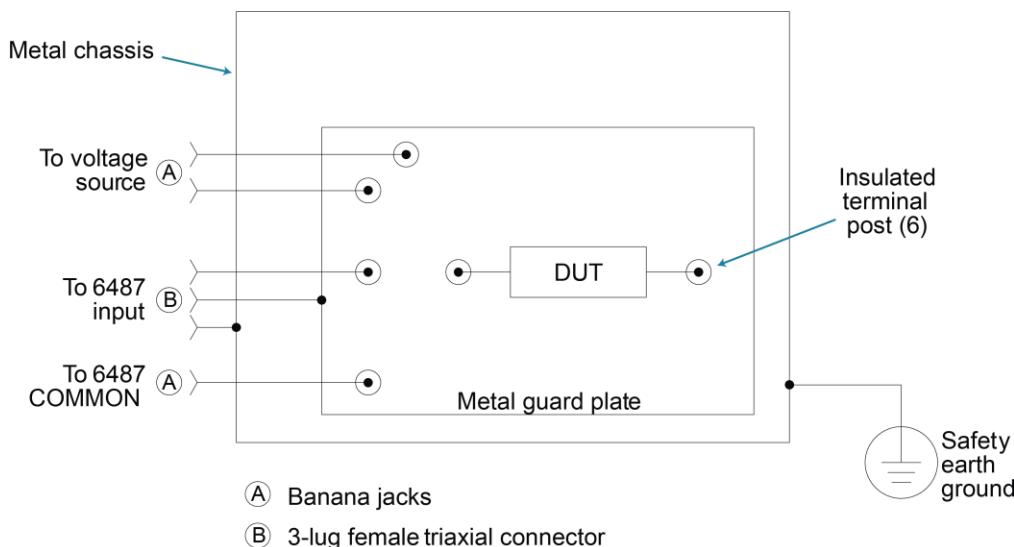
Nonconductive enclosures must be constructed of materials that are suitably rated for flammability and the voltage and temperature requirements of the test circuit. Connect the enclosure of all metal test fixtures to protective earth (safety ground). See your specific test fixture for information. Nonconductive test fixtures must be rated to double the maximum capability of the test equipment in the system.

For metallic enclosures, the test fixture chassis must be properly connected to protective earth (safety ground). A grounding wire (16 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 protective earth (safety ground).

General purpose test fixture

A general purpose test fixture is shown in the next graphic. This test fixture will accommodate a variety of connection requirements.

Figure 9: 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 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 appropriate spacing from the chassis of the test fixture commensurate with the external source used.

Connectors, terminals, and internal wiring

Basic connector requirements include a female triaxial connector and two banana jacks. The banana jacks provide for connection to the power supply (either the internal voltage source or an external power supply). The banana jacks must be insulated from the 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 shell of the triaxial connector to the guard plate (the guard plate will serve as a noise shield).

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 body of a DUT or a test circuit component. If you can not 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, then clean the area as described in the following 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, allow the test fixture and any other cleaned devices or test circuits to dry in a 50° C, low-humidity environment for several hours.

Model 8009 resistivity test fixture

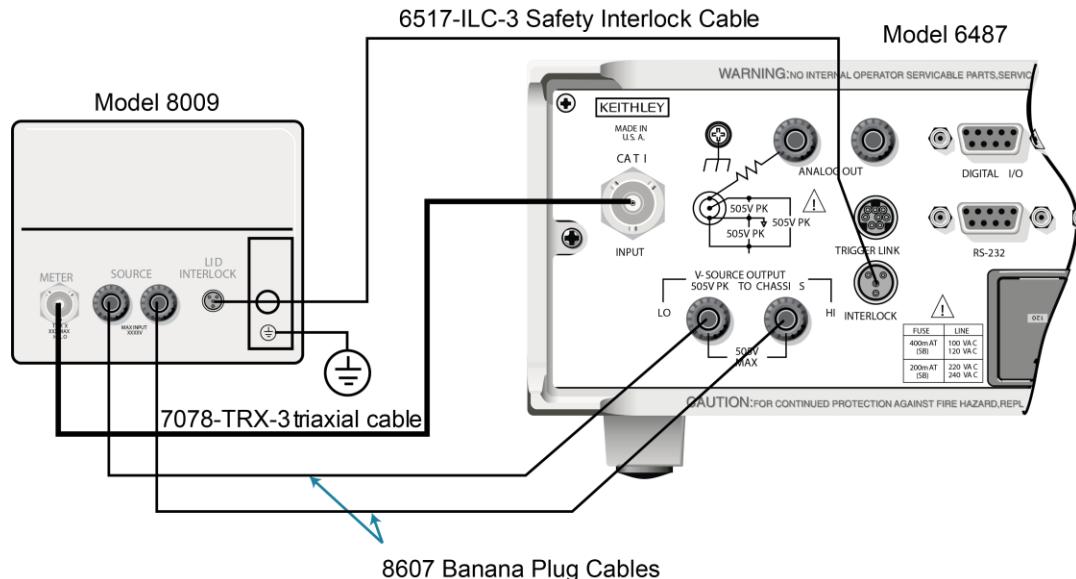
This test fixture allows volume resistivity in the range from 10^3 to 10^{18} $\Omega\text{-cm}$ and surface resistivity in the range from 10^3 to 10^{17} $\Omega\text{-sq}$. Features include:

- A 3-lug triaxial connector and dual binding posts.
- Guarded electrodes that can accommodate samples up to 64 mm thick and 102 mm x 102mm (1/8 in. thick and 4 in. x 4 in).
- Screw terminal on the test fixture for safety earth ground.
- A safety interlock.

When the safety interlock is engaged, the V-source goes into a high impedance state when the lid of the test fixture is opened. Note that this could leave a charged device in the fixture.

For typical connections to the 6487, refer to the following figure.

Figure 10: Typical connections to the Model 6487 using the 8009 test fixture



NOTE

Connect fixture ground to safety earth ground using safety ground wire supplied with the test fixture.

Floating measurements

⚠️ WARNING

Before attempting floating measurements, make sure to have a thorough understanding of any dangers involved. Take adequate precautions before connecting any instruments or power sources. Also, make sure to read and understand information contained in [Connection fundamentals](#) (on page 2-1). Death or injury due to electrical shock can result if adequate safety measures are not taken.

If it is possible for the DUT or external supply to present more than 505 V to the input HI, it is imperative that the connection between input LO and the external voltage source be sufficiently low impedance and capable of carrying the short-circuit current of the source, in order that the LO not exceed 505 V.

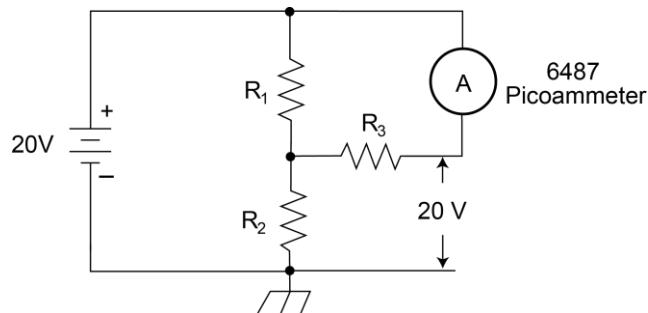
CAUTION

Connecting COMMON or ANALOG OUT to earth while floating the input may damage the instrument.

The LO-to-chassis breakdown voltage is 505 V. Exceeding this voltage may cause damage to the instrument.

The following figure shows an example where the 6487 floats.

Figure 11: Floating measurements



Interlock

The 6487 has a built-in interlock that works in conjunction with the voltage source. The interlock prevents the voltage source from being operated on the 50 V and 500 V ranges, and optionally on the 10 V range, to ensure safe operation.

The 6487 has a hardware safety interlock. For safety reasons, the 50 V or 500 V voltage source ranges must have external, normally-open switches connected to pins 1 and 2 of the interlock connector. The switch must then be closed to enable voltage output on these ranges.

The 487 uses a 3-pin DIN interlock connector, while the 6487 uses a 4-pin DIN for the interlock connection. The Model 487 interlock prevents voltage source output only with the Model 236-ILC-3 cable connected. Without the cable connected, the 487 allows voltage source output on the 50 V or 500 V ranges. The 6487 will prevent voltage source output for the 50 V or 500 V ranges unless pins 1 and 2 are connected through an external switch by the customer. The 6487 will allow the 10 V range output by factory default without the external interlock connection, but it can be configured to require the external interlock connection.

With 6487 front panel operation, an open interlock will display "CLOSE INTLCK" as an error message when attempting to operate the voltage source on the 50 V and 500 V ranges. The 6487 in the 487 DDC emulation mode displays "IDDCO ERROR" on the front panel when an "O1" command is sent. The 487 displays "INTERLOCK" for the same condition. The "U9" voltage source error status word functions the same for either the 487 or 6487 in DDC emulation mode.

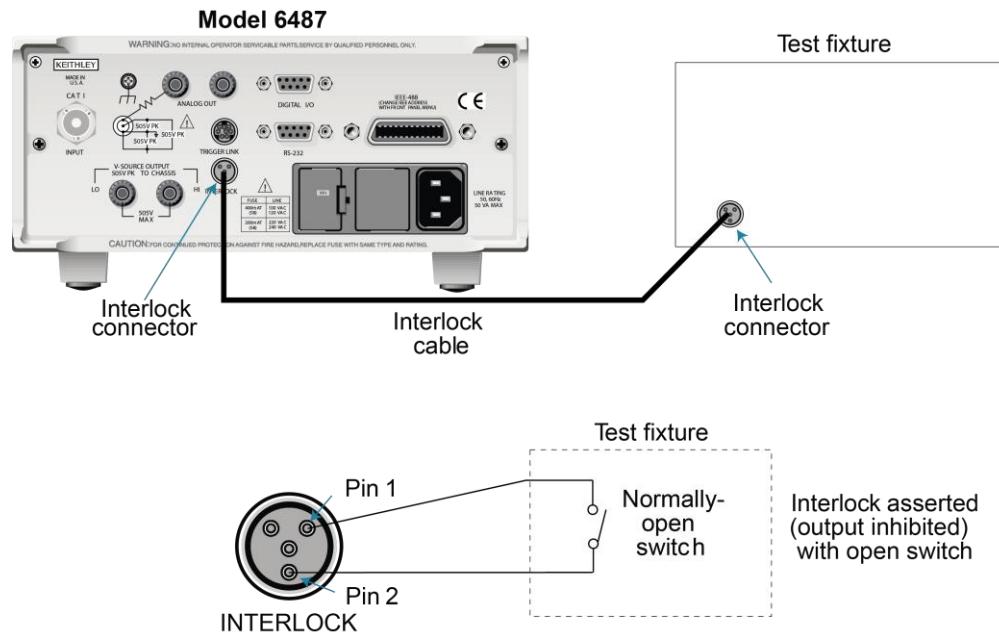
Interlock connections

The next graphic shows interlock connections and the pin diagram of the INTERLOCK connector. Typically, the INTERLOCK connector is connected to the same type of connector on the test fixture. A normally-open switch is connected to pins 1 and 2 of the INTERLOCK connector as shown. When the switch is open, the interlock is asserted and the voltage source cannot be placed in operate on the 50 V or 500 V voltage source ranges, and optionally for the 10 V range.

⚠ WARNING

If the voltage source is operating when the interlock is asserted, the voltage source will change to a high impedance state, possibly leaving charged DUT capacitance.

Figure 12: Interlock connections



Interlock operation

The interlock is always operational for the 50 V and 500 V voltage source ranges. To enable the voltage source output, pins 1 and 2 of the INTERLOCK connector must be shorted together. For the 10 V range, the interlock is optional and can be controlled with interlock programming.

Interlock programming

The next table summarizes the commands associated with controlling the 10 V range interlock and determining if the interlock is asserted. For example, to enable the 10 V range interlock, send `SOURce[1]:VOLTage:INTerlock[:STATe] ON`.

Command	Description	Default
<code>SOURce[1]:VOLTage:INTerlock[:STATe]:FAIL?</code>	SOURce1 subsystem: Interlock control: Enable or disable 10 V range interlock.* Query if interlock is asserted:** 1 = asserted; source cannot be turned on.	OFF

* Interlock is always enabled for 50 V and 500 V ranges and cannot be programmed.
** Query can be used for all three source ranges: 10 V, 50 V, and 500 V.

Analog output

The 6487 has an analog output on the rear panel. The ANALOG OUT provides a scaled, inverting ± 2 V output. A full-scale reading corresponds to ± 2 V output.

WARNING

The maximum safe voltage between the voltage source or ammeter and chassis ground (common mode voltage) is 505 V dc. Exceeding this voltage can create a shock hazard.

CAUTION

Connecting COMMON or ANALOG OUT to earth while floating the input may damage the instrument.

NOTE

Analog outputs will be at same voltages as applied to the triaxial shell.

Connections for using this output are shown in the next figure. For a full-scale input (for example, 2 mA on the 2 mA range), the output will be -2 V. Example analog outputs are listed in the table following the graphic.

The 2 V analog output signal is not corrected during calibration. Gain errors of up to 2.5% may appear at this output, depending on range.

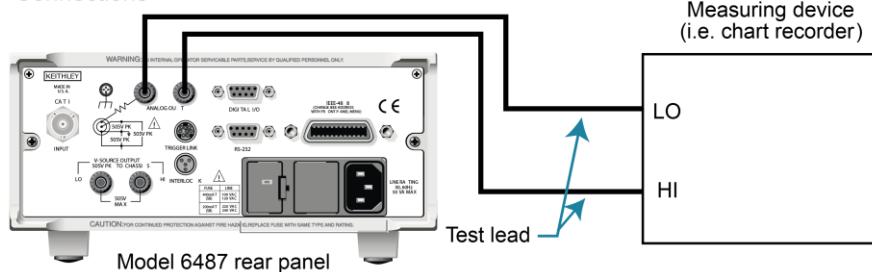
The output impedance is < 100 Ω. To minimize the effects of loading, the input impedance of the device connected to the ANALOG OUT should be as high as possible. For example, for a device that has an input impedance of 1 MΩ, the error due to loading will be approximately 0.01%. High capacitance connected to the analog output will increase the rise time.

An internal 1 kΩ resistance is connected between COM and analog common for protection. The effects of this resistance on analog output accuracy are negligible.

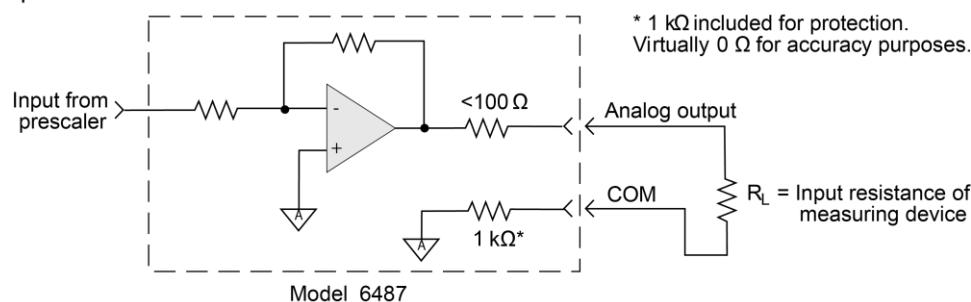
Rel and the result of $mX+b$, $m/X+b$, or LOG have no affect on the analog output. The 2 V analog output is scaled only to the actual input.

Figure 13: Typical analog output connections

A. Connections



B. Equivalent circuit



Range	Applied signal	Analog output value (nominal)*
20 nA	10.5 nA	-1.05 V
2 mA	-1.65 mA	1.65 V

* Output values are within $\pm(2.5\% + 2 \text{ mV})$ of nominal value.

Measurement considerations

There are a variety of factors to consider when making low-level measurements. These considerations are summarized in the following table. For comprehensive information on all measurement considerations, refer to the Low Level Measurements handbook, available from tek.com.

Considerations	Description
Input bias current	Offset current of the 6487 could affect low current measurements.
Voltage burden	Offset voltage of the 6487 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.
Ground loops	See the 6487 User's Manual for details
Triboelectric effects	Multiple ground points can create error signals.
Piezoelectric and stored charge effects	Charge currents generated in a cable by friction between a conductor and the surrounding insulator (i.e. bending a triaxial cable).
Electrochemical effects	Currents generated by mechanical stress on certain insulating materials.
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.

Section 3

Measurement and sourcing voltage

In this section:

Measurement overview	3-1
Performance considerations	3-2
Current measurements	3-7
Ohms measurements.....	3-12
Voltage source operation	3-17
Alternating voltage ohms mode.....	3-24

Measurement overview

Current measurements

The basic current measurement capabilities of the 6487 are summarized in the next table. Accuracy for each measurement function and range is listed in the instrument specifications, available from tek.com.

Range	Maximum reading	5 1/2-digit resolution
2 nA	±2.1 nA	10 fA
20 nA	±21 nA	100 fA
200 nA	±210 nA	1 pA
2 nA	±2.1 µA	10 pA
20 nA	±21 µA	100 pA
200 nA	±210 µA	1 nA
2 nA	±2.1 mA	10 nA
20 nA	±21 mA	100 nA

Voltage source

The basic voltage source output capabilities of the 6487 are summarized in the next table. Accuracy specifications are listed in the instrument specifications.

Range	Maximum output	Step size
10 V	±10.1 V	200 µV
50 V	±50.5 V	1 mV
500 V	±505 V	10 mV

Performance considerations

Warm-up period

The 6487 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.

Voltage offset correction

Voltage offset correction should be performed periodically to null input amplifier offsets.

To perform voltage offset correction:

1. Press the **MENU** key.
2. Select **CAL**, then press **ENTER**. The unit will display **CAL: VOFFSET**.
3. Press **ENTER**. The instrument will display **INPUT CAP**
4. Connect the triaxial shielding cap to the INPUT jack.
5. Press **ENTER** to complete voltage offset correction.
6. Press **EXIT** to return to normal display.
7. To perform remote correction, connect the triaxial shielding cap to the INPUT, then send **CALibration:UNPProtected:VOFFset**.

Autozero

To help maintain stability and accuracy over time and changes in temperature, the 6487 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 up to three times. However, the zero and gain reference points can eventually drift resulting in inaccurate readings of the input signal. It is recommended that autozero only be disabled for short periods of time.

To disable autozero from the front panel, press the **AZERO** key. This button toggles autozero on and off. It can also be enabled by restoring factory or GPIB default conditions. When autozero is enabled, a colon will be displayed after the reading.

For example:

Autozero disabled: 0.00258 nA +00.0

Autozero enabled: 0.00258 nA: +00.0

SCPI programming - autozero

The following are the SCPI autozero commands.

Command	Description	Default
SYSTem :AZERO [:STATE] 	SYSTem subsystem: Enable or disable autozero.	ON

SYSTem:AZERo[:STATe]

Sending this command over the bus does not update the display while in remote. To verify the **AZERO** state, send the query. The displayed autozero state will be updated when the instrument is placed back in local.

The following examples enable or disable the autozero feature:

SYST:AZER ON: Enable autozero.

SYST:AZER OFF: Disable autozero.

SYST:AZER?: Query autozero. 1 = on, 0 = off

Zero check and zero correct

Zero check

When zero check is enabled (on), the input amplifier is reconfigured to shunt the input signal to low with the input impedance.

NOTE

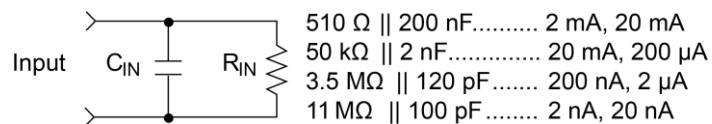
The **ZCHK** key toggles zero check on and off. If zero check is enabled (**ZEROCHK** displayed), press **ZCHK** to disable it.

From the front panel, enable or disable zero check by pressing the **ZCHK** key.

NOTE

Leave zero check enabled when connecting or disconnecting input signals.

Figure 14: Equivalent input impedance with zero check enabled



Zero correct

NOTE

The 6487 saves a single Zero Correct value. For best results, acquire a new Zero Correct value after changing to the desired range.

The 6487 has a zero correct feature to algebraically subtract the voltage offset term from the measurement.

NOTE

The **REL** key toggles zero correct on and off if zero check is enabled. The **MON** annunciator turns on when zero correct is enabled.

To zero correct the measurement:

1. Enable zero check. ZEROCHK is displayed.
2. Select the range that will be used for the measurement or select the lowest range.
3. Press **REL** to enable zero correct. ZCORRECT ON is displayed briefly.
4. Press **ZCHK** to disable zero check.
5. Readings can now be taken from the display. The **MON** annunciator indicates that the displayed reading is zero corrected.

NOTE

The 6487 will remain zero corrected even if it is upranged. If downranged, re-zero the instrument. The instrument does not have to be re-zero corrected 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 the 6487 is operating at or near TCAL, zero correction will have very little effect. TCAL is the internal temperature of the 6487 when it was last calibrated.

SCPI programming - zero check and zero correct

The following are the SCPI zero check and zero correct commands.

Command	Description	Default	Ref
SYS tem :ZC heck [:STATe] 	SYS tem subsystem: Zero check: Enable or disable zero check. When zero check is on, the instrument displays ZEROCHK.	ON	

**SYSTem:ZCORrect[:STATe] **

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. The zero correct state can be turned on and off repeatedly without requiring a new value. If no ACQ has been performed since the most recent reset, zero is used for the ACQ value.

SYSTem:ZCORrect:ACQuire**NOTE**

Before sending a SYST:ZCOR:ACQ command, send a SYST:ZCOR:STAT OFF command. Failure to do so may create a greater chance of obtaining an incorrect zero correct value, particularly if your last zero correction was accomplished on a different range.

The following command sequence uses the acquire method to zero correct the 200 μ A range.

Command	Comments
*RST	Set instrument to known default conditions in one-shot trigger mode.
SYST:ZCH ON	Enable zero check.
CURR:RANG 2E-4	Set instrument to 200 μ A range.
INIT	Trigger one reading.
SYST:ZCOR:STAT OFF	Turn zero correct off.
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.

NOTE

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

**SYSTem:ZCORrect[:STATe] **

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. The zero correct state can be turned on and off repeatedly without requiring a new value. If no ACQ has been performed since the most recent reset, zero is used for the ACQ value.

SYSTem:ZCORrect:ACQuire

The zero correct value can only be acquired while zero check is enabled and zero correct state is off. The internal offset measured at that moment will become the correction value. Zero correction can then be applied and zero check disabled. This acquire method makes it convenient if you need to re-zero the instrument often.

NOTE

Before sending a SYST:ZCOR:ACQ command, send a SYST:ZCOR:STAT OFF command. Failure to do so means that you have a higher chance of getting a bad zero correct value, particularly if your last zero correction was accomplished on a different range.

The following command sequence uses the acquire method to zero correct the 200 μ A range:

```
*RST           ' Set instrument to known default
               ' conditions in one-shot trigger mode.
SYST:ZCH ON   ' Enable zero check.
CURR:RANG 2E-4 ' Set instrument to 200  $\mu$ A range.
INIT          ' Trigger one reading.
SYST:ZCOR:STAT OFF ' Turn zero correct off.
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 [Triggering](#) (on page 7-1) 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.

Current measurements

Procedure

WARNING

The maximum safe voltage between picoammeter LO and chassis ground (common mode voltage) is 505 V. The 6487 does not internally limit the LO to chassis voltage. Exceeding 505 V can create a shock hazard.

If it is possible for the DUT or external supply to present more than 505 V to the input HI, it is imperative that the connection between input LO and the external voltage source be sufficiently low impedance and capable of carrying the short-circuit current of the source, in order that the LO not exceed 505 V.

CAUTION

The LO to chassis breakdown voltage is 505 V. Exceeding this voltage may cause damage to the instrument.

The maximum input voltage and current to the 6487 is 505 V peak and 21 mA. Exceeding either of these values may cause damage to the instrument that is not covered by the warranty.

To achieve optimum precision for low-level current measurements, input bias current and voltage burden can be minimized by performing the offset correction procedure. See [Measurement considerations](#) (on page 23-1) for more information.

NOTE

After overloading with high voltage, 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 connector and then use the ground link to connect COMMON and CHASSIS ground. With the instrument on the 2 nA range and zero check disabled, allow the reading to settle until the input bias current is within specifications.

Step 1. Select current function

Press the **I | Ω** key to make sure the current function is selected.

Step 2. Enable zero check

Zero check should always be enabled before making connection changes. The **ZCHK** key toggles zero check on and off. ZEROCHK is displayed when active.

Step 3. Perform zero correction

To achieve optimum accuracy for low current measurements, it is recommended that you zero correct the picoammeter:

To zero correct the picoammeter:

1. Select the 2 nA range.
2. Press the **REL** key so that the **MON** annunciator is on.

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

Use the **RANGE** arrow keys to select a manual measurement range or press **AUTO** to enable auto range. With auto range enabled, the instrument will automatically select the most sensitive range to make the measurement. See [Range, units, digits, rate, and filters](#) (on page 4-1) for more information.

Step 5. Connect the current to be measured to the picoammeter

⚠ WARNING

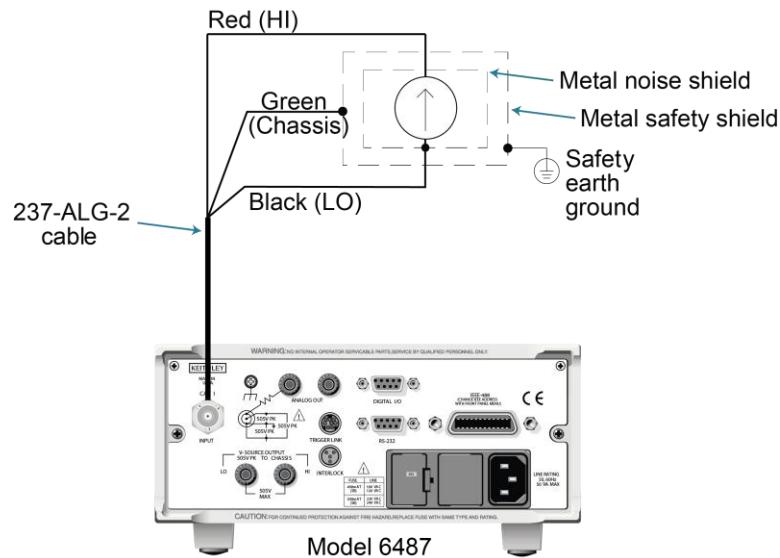
A safety shield is advisable whenever floating measurements are being made (see [Floating measurements](#) (on page 2-12)). The metal safety shield must completely surround the noise shield or floating test circuit and it must be connected to safety earth ground using #18 AWG or larger wire.

NOTE

When not making floating measurements, it is recommended that you ground measurement LO at only one place in the circuit, such as with the ground link connection on the rear panel of the 6487.

Fundamental information on making connections to the picoammeter input is provided in [Measurement Concepts and Connections](#) (on page 2-1).

Figure 15: Connections for amps



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

If the readings are noisy, you may want to use filtering to reduce noise. Use filtering if the noise is caused by a noisy input signal. Filtering is covered in [Range, units, digits, rate, and filters](#) (on page 4-1).

SCPI programming - current measurements

The following are the SCPI current measurement commands.

Command	Description	Default	Ref
SENSe :DATA? :FUNCTION 'CURRent' INITiate READ?	SENSe subsystem: Return latest raw reading. Select current function. Trigger one or more readings. Trigger and return readings.	CURR	A B C D

SENSe:DATA?

This command does not trigger a reading. It 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. While the 6487 is busy performing measurements, the :DATA? command will not return the reading string until the instrument finishes and goes into the idle state.

NOTE

The format that the reading string is returned in is set by commands in [DISPlay, FORMat, and SYSTem](#) (on page 13-1). If there is no reading available when :DATA? is sent, an error (-230) will occur.

FUNCTION 'CURRent'

Use this command to select the current function instead of the ohms function.

INITiate

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 [Triggering](#) (on page 7-1).

READ?

The READ? command can be used to return new readings. This command triggers and returns the readings. See [SCPI signal-oriented measurement commands](#) (on page 12-1) for more information.

Programming example - current measurements

Command	Comments
*RST	Return 6487 to RST defaults.
FUNC 'CURR'	Select current function.
SYST:ZCH ON	Enable zero check.
CURR:RANG 2e-9	Select the 2 nA range.
INIT	Trigger reading to be used as zero correction.
SYST:ZCOR:STAT OFF	Turn zero correct off.
SYST:ZCOR:ACQ	Use last reading taken as zero correct value.
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.

Ohms measurements

Overview

To measure ohms with the 6487, set up the voltage source to the desired range, value, and current limit (see [Voltage source operation](#) (on page 3-17)), choose an appropriate current measurement range (or use autorange), and enable the ohms function.

With the ohms function enabled, the 6487 calculates the measured resistance from the voltage source value and the measured current. When setting up the voltage source, choose the highest voltage value as possible for maximum current, keeping in mind such factors as the power dissipation and voltage coefficient of the resistance being tested.

NOTE

Ohms measurements can be made using either the DC or alternating voltage modes. See [Alternating voltage ohms mode](#) (on page 3-24).

Procedure

WARNING

Always turn off power to the 6487 before changing voltage source connections to avoid a possible shock hazard.

Step 1. Set up voltage source

- a. Press either of the **V-SOURCE** adjustment keys, then use the **RANGE** key to set the voltage source range.
- b. Set the voltage and current limit to the desired values using the cursor and **RANGE** keys.

Step 2. Perform zero correction

To achieve optimum accuracy for high resistance measurements, zero correct the picoammeter before enabling the ohms function. Make sure that zero check and the 2 nA range are selected, then press the **REL** key to perform zero correction. **MON** is displayed when zero correct is enabled.

Step 3. Select a manual current range or enable auto range

Use the manual **RANGE** keys to select a manual measurement range or press **AUTO** to enable auto range. When using manual ranging, choose an appropriate value based on the voltage source setting and the expected measured resistance.

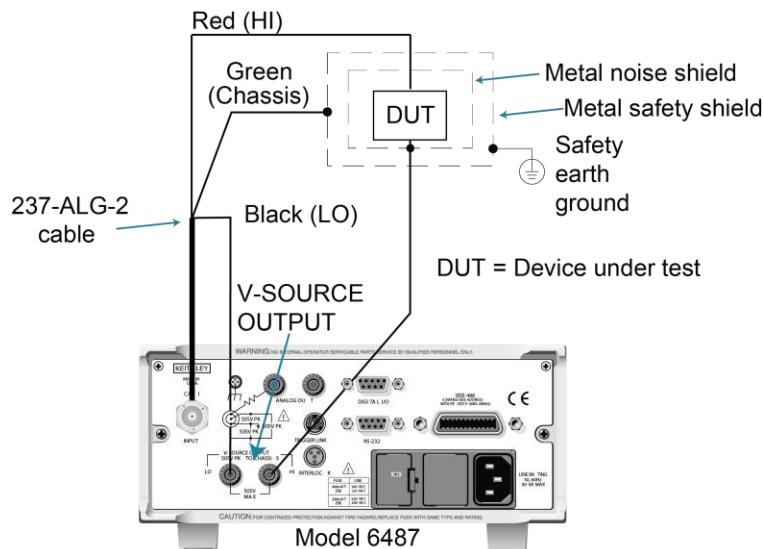
Step 4. Connect the resistance to be measured to the picoammeter

Basic connections for ohms measurements are shown in the next figure. Note that both the picoammeter INPUT and the V-SOURCE OUTPUT jacks are connected to the resistance under test.

⚠ WARNING

A safety shield is advisable whenever measurements are being made with voltages over 30 V dc. 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 16: Connections for ohms measurements



Step 5. Select ohms function

Press the **I | Ω** key to make sure the ohms function is selected.

Step 6. Turn on voltage source

Press the **OPER** key to turn on the voltage source output. VOLTAGE SOURCE OPERATE is displayed.

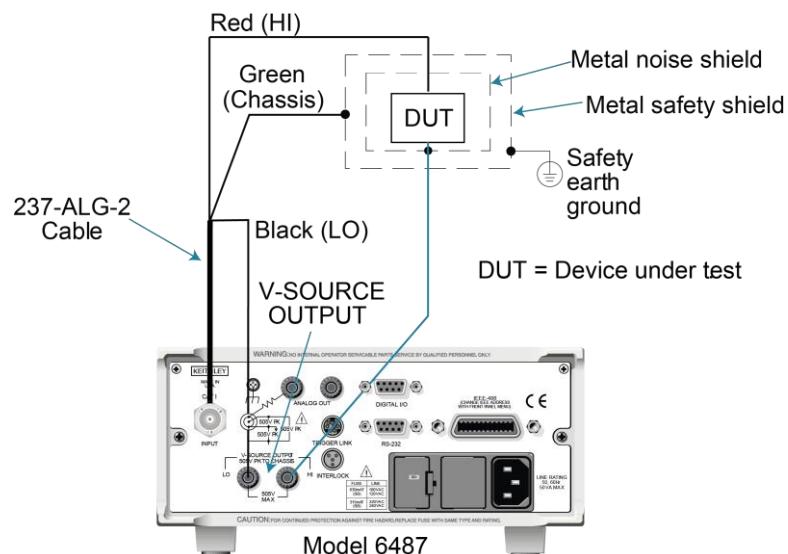
Step 7. Disable zero check and take a reading from the display

Press **ZCHK** to disable zero check and display readings. If the readings are noisy, use filtering to reduce noise.

NOTE

For any ohms measurements, the ohms reading is invalid and unknown if the voltage source is in compliance. Therefore, a value of -9.9e+36 will be returned over the GPIB and the message I-LIMIT will be displayed on the front panel for both normal readings and buffer recall readings for any ohms readings where the voltage source went into compliance.

Figure 17: Connections for ohms measurements



SCPI programming - ohms measurements

The following are SCPI ohms measurement commands.

Commands*	Description	Default
Measurements:		
[SENSe[1]]	SENSe[1] subsystem:	
[:CURRent[:DC]]		
:OHMS 	Enable or disable ohms function.	OFF
:RANGE <n>	Select manual current range (-0.021 to 0.021A).	
:AUTO 	Enable or disable auto current range.	ON
Sourcing voltage:		
SOURce[1]	SOURce[1] subsystem:	
:VOLTage	Voltage source commands:	
[:LEVel]		
[:IMMediate]		
[:AMPLitude] <NRf>	Set output voltage (-505 V to +505 V).	0 V
:RANGE <NRf>	Set voltage source range (10, 50, or 500).	10 V
:ILIMit <NRf>	Set current limit (25µA, 250µA, 2.5mA, or 25mA).	25 mA
:STATE 	Turn voltage source output on or off.	OFF
READ?	Trigger and return reading(s).	

* Zero correct and zero check commands not included.

[SENSe[1]][:CURRent[:DC]]:OHMS

Use this command to turn the ohms function on or off. When the ohms function is enabled, the 6487 calculates the reading from the measured current and the voltage source setting. Additional OHMS commands control the alternate voltage ohms mode as described in [Alternating voltage ohms mode \(on page 3-24\)](#).

SOURce[1]:VOLTage

These commands select the voltage source range, set the source level and current limit, and turn the source output on and off. Additional voltage source commands control voltage sweeps. See [Buffer and sweeps \(on page 6-1\)](#) for details.

Programming example - ohms measurements

The following command sequence will perform one zero-corrected resistance measurement:

Command	Comments
*RST	' Return 6487 to GPIB defaults.
FORM:ELEM READ,UNIT	' Measurement, units elements only.
SYST:ZCH ON	' Enable zero check.
RANG 2e-9	' Select the 2nA range.
INIT	' Trigger reading to be used as zero' correction.
SYST:ZCOR:ACQ	' Use last reading taken as zero ' correct value.
SYST:ZCOR ON	' Perform zero correction.
RANG:AUTO ON	' Enable auto current range.
SOUR:VOLT:RANG 10	' Select 10V source range.
SOUR:VOLT 10	' Set voltage source output to 10V.
SOUR:VOLT:ILIM 2.5e-3	' Set current limit to 2.5mA.
SENS:OHMS ON	' Enable ohms function.
SOUR:VOLT:STAT ON	' Put voltage source in operate.
SYST:ZCH OFF	' Disable zero check.
READ?	' Trigger and return one reading.

Voltage source operation

Voltage source edit keys

The **V-SOURCE** up and down keys operate in the same manner as the **RANGE** up and down keys if they are not being used to change the voltage source values. The **AUTO** key acts as a shortcut to set the **V-SOURCE** to **0 V**.

Configuring the voltage source

To set up the voltage source:

1. Press **CONFIG** then **OPER**.
2. Select either the **DC** mode for normal operation or **SWEEP** for voltage sweeps. Press **ENTER**.
3. After the mode is selected, the reading disappears and is replaced with a full-resolution value of the voltage source with the left-most position highlighted for editing.
4. Use the **RANGE** up and down keys to change the voltage source range and indicate the range selected (10 V, 50 V, or 500 V).
5. Enter the desired voltage source value, then press **ENTER**. Voltage values are changed immediately from this configuration by pressing the arrow keys. The arrow keys are used to select the digit being edited and the **V-SOURCE** up and down keys change the value. The digits will not increment beyond the limit for the present source range with subsequent source arrow key presses.

NOTE

The **V-SOURCE** up and down keys will operate in the same manner as the **RANGE** up and down keys if they are not being used to change the voltage source values.

6. After the voltage value and range is selected, press **ENTER** to advance to the current limit display and select the desired current limit. The current limit display offers different choices depending on the source rang (see the next table) . Pressing **ENTER** or **EXIT** from this display returns you to the normal readings display.

Source range	Selectable current limit			
10.0000 V	25 µA	250 µA	2.5 mA	25 mA
50.000 V	25 µA	250 µA	2.5 mA	
500.00 V	25 µA	250 µA	2.5 mA	

Sourcing voltage

WARNING

Always turn off the instrument power before changing voltage source connections to avoid a possible shock hazard.

To source voltage:

Step 1. Set up voltage source

- a. Press either of the **V-SOURCE** adjustment keys, then use the **RANGE** key to set the voltage source range.
- b. Set the voltage and current limit to the desired values using the cursor and **RANGE** keys.

Step 2. Connect the load to the source output

Basic connections for sourcing voltage are shown in the next figure.

WARNING

A safety shield is advisable whenever measurements are being made with voltages over 30 V dc. Connections for the safety shield are shown in the next figure. 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.

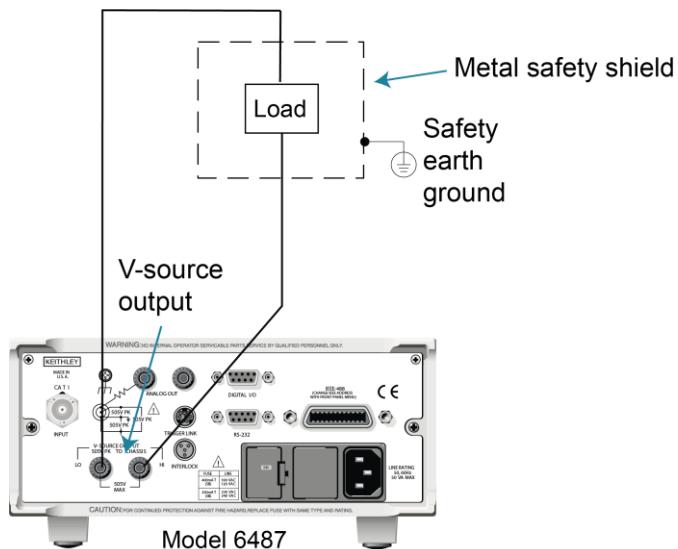
3. Turn on the voltage source

Press the **OPER** key to turn on the voltage source output. The VOLTAGE SOURCE OPERATE indicator will turn on.

CAUTION

Do not connect external sources to the 6487 voltage source. External sources may damage the 6487 voltage source.

Figure 18: Connections for sourcing voltage



Operate considerations

OPER (operate) key

The **OPER** (operate) key will function to turn the voltage source off, even if the instrument is operating under remote control (**REM** annunciator on), assuming that the **LLO** (Local Lockout) function has not been employed. While in remote, the **OPER** key will only turn the source off. To turn it on, the 6487 must be in local mode.

Voltage source off state

The voltage source is not in a high-impedance state when it is turned off. Rather, it is in a state that acts just like the voltage source was programmed to 0 V on the selected range. It will enter this state on power-up after the VOLTAGE SOURCE OPERATE illuminator is displayed.

The safety interlock will cause the voltage source to go into a high-impedance state instead of 0 V output and the source will stay in the high-impedance state until the operate state is changed to on. The exception is the 10 V range, where the interlock is optional. The OPERATE light and front panel display do not indicate the difference between 0 V output and high-impedance output caused by an open interlock. The interlock status is available by query via remote.

Compliance indication

At any time, it is possible that the voltage source will go into compliance. Should this situation occur, the OCOMP annunciator will flash and the displayed voltage value for readings of less than 6½ digits will alternate between showing the value and displaying CMPL. If you are in a menu where the voltage source value is not shown on the right-most four characters of the display, only the flashing OCOMP annunciator will be shown.

Open interlock indication

If the interlock is asserted (opened) while the unit is on 50 V or 500 V range, the voltage source will also technically be in compliance. However, there will be no indication of that status over the front panel or in the status registers. The open interlock takes precedence.

SCPI commands - voltage source

Commands	Description	Default
SOURce[1] :VOLTage [:LEVel] [:IMMEDIATE] [:AMPLitude] <NRf>	SOURce[1] subsystem: Voltage source commands: Set output voltage level (-505 V to +505 V).	
:RANGE <NRf>	Set voltage source range (10 V, 50 V, or 500 V).	0 V
:ILIMIT <NRf>	Set current limit (25 μ A, 250 μ A, 2.5 mA, or 25 mA).*	10 V
:STATE 	Turn voltage source output on or off.	25 mA
:INTerlock 	Enable or disable interlock for 10 V range.**	OFF
:FAIL?	Query interlock state (1 = asserted, and source output cannot be turned on).	OFF

* 25 mA not available for 50 V and 500 V ranges

** See [Interlock operation](#) (on page 2-14).

[:LEVel] [:IMMEDIATE] [:AMPLitude] <NRf>

Use this command to set the voltage source output level from -505 V to 505 V. Note that if the STATE is on, then the voltage will change as soon as this command is processed. Sending a value outside of the present range will generate Error -222 "Parameter Out of Range". To go to a higher value, change the source range.

RANGe <NRf>

This command selects the range. If you choose a range lower than the current level, the level will be changed to the maximum value for that range. The range selected will be the one that best accommodates the value sent. A value of 10.01, for example, will select the 50 V range.

ILIMit <NRf>

Use this command to set the voltage source current limit to 25 μ A, 250 μ A, 2.5 mA, or 25 mA. The maximum current limit for the 50 V and 500 V ranges is 2.5 mA.

STATe

This command turns the voltage source output on or off. However, the voltage source output cannot be turned on if the interlock is asserted. When the voltage source is turned off, the source will be a low-impedance 0 V source (limited to approximately 1 mA) and will discharge small capacitances.

INTerlock

These commands control the interlock for the 10 V range and query whether or not the interlock is asserted. Note that for the 50 V and 500 V ranges, this setting is ignored since the interlock is directly tied to the hardware and cannot be bypassed. Therefore, this command has no effect when the source is on any range other than the 10 V range.

Attempting to turn off the interlock state while on the 50 V or 500 V ranges will generate a -221 "Settings Conflict" error. Upranging from the 10 V range will always cause the interlock to be enabled. When you range back down to the 10 V range, the interlock state will be reset to what it was when you left the 10 V range. See [Measurement concepts and connections](#) (on page 2-1) for additional interlock details.

WARNING

When the interlock is asserted, the voltage source will change to a high-impedance state. This situation could leave any connected device charged to the last programmed voltage.

Programming example — voltage

The following command sequence will output 5 V on the 10 V range with a 2.5 mA limit:

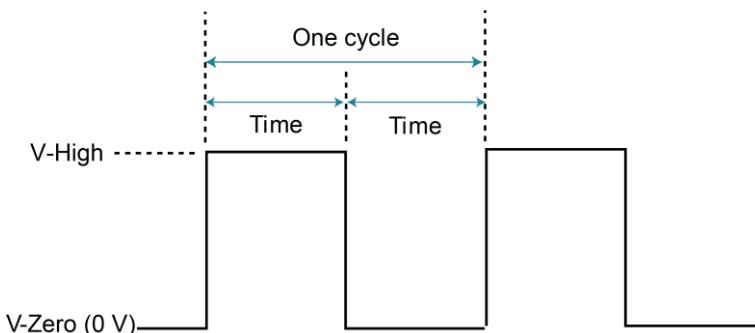
Command	Comments
*RST	' Return 6487 to GPIB defaults.
SOUR:VOLT:RANG 10	' Select 10V source range.
SOUR:VOLT 5	' Set voltage source output to 5.
SOUR:VOLT:ILIM 2.5e-3	' Set current limit to 2.5mA.
SOUR:VOLT:STAT ON	' Put voltage source in operate.

Alternating voltage ohms mode

Overview

Ohms can be measured in DC (normal) or alternating voltage (A-V). The alternating voltage ohms method is especially useful when the resistance or device being measured exhibits high background currents or high noise currents. These are typical problems seen when measuring high resistances, devices with moderate to high capacitance, or when adequate shielding is unavailable. By measuring current differences caused by a change in applied voltage, the alternating voltage method greatly reduces effects of currents that are not caused by the applied voltage, i.e., not resistive current. The A-V mode consists of switching the source level between 0 V and a user-selected value. See the following figure.

Figure 19: Alternating voltage ohms



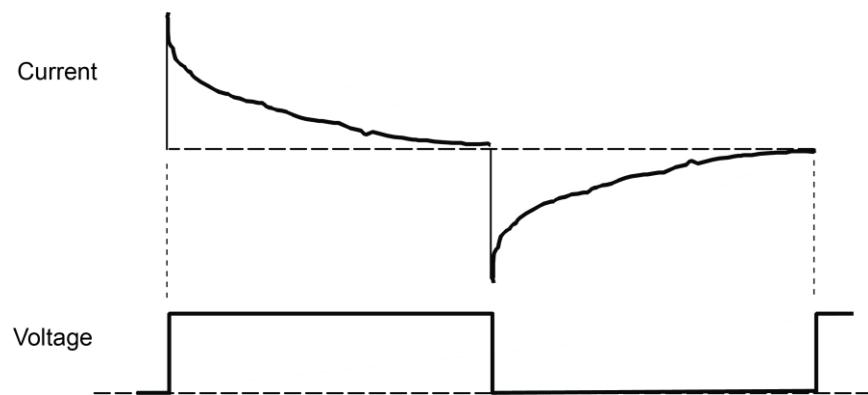
During each phase, one or several readings are collected into separate buffers for that phase, designated V-High and V-Zero. A third buffer is created by subtracting the n-th reading of the V-Zero buffer from its counterpart in the V-High buffer and storing these differences in a buffer designated V-Delta. Both from the front panel and remotely, A-V ohms readings always come from the V-Delta buffer. For more information, see [One-shot measurements](#) (on page 3-29).

The purpose of the alternating voltage ohms mode is to improve the accuracy and repeatability of very high resistance measurements, which are subject to errors from background currents in the test setup. By taking two current measurements, one at a specific step voltage and a second at 0 V, these background currents can be largely nulled out and the resistance calculated from the source voltage and measured current is closer to the actual DUT resistance. Data stored in the buffer can also be averaged to improve repeatability.

Key test parameters for A-V ohms include the step voltage, measurement time, and the number of test cycles. The optimum step voltage value depends on the measured resistance and desired current. The measurement time must be carefully chosen to assure adequate settling during both the step-voltage (V-High) and 0 V (V-Zero) phases of the measurement. The number of cycles to measure and average is often a compromise between improvement in repeatability and the overall measurement time.

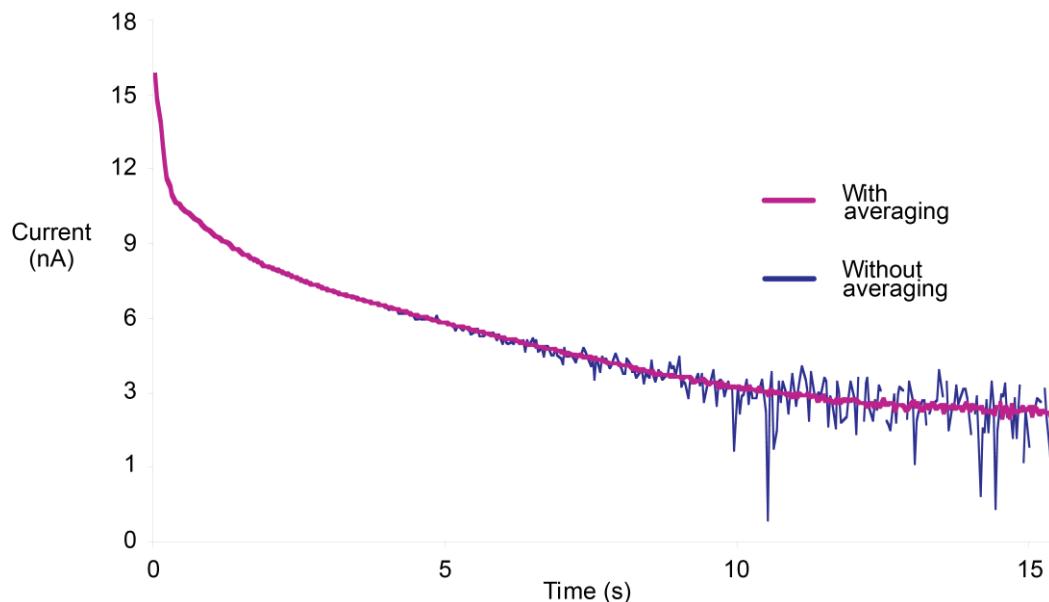
The next figure shows a comparison of the A-V voltage and the resulting current. When the voltage first makes a transition from low to high or high to low, the current initially increases to maximum and then decays. The decay period depends on the RC time constant (τ) of the circuit being tested.

Figure 20: A-V voltage and current



The next figure demonstrates the advantages of A-V ohms. The decaying curve shows how current decays over time without averaging, while the current plot at the bottom shows substantially improved results due to averaging of the A-V readings.

Figure 21: Averaged A-V current



Storing A-V ohms readings

Follow the steps below to setup and use the A-V ohms mode.

NOTE

The following procedure assumes that the 6487 is connected to the DUT.

Before starting the configuration process for A-V ohms, make sure the 6487 is on a current measurement range high enough to not overflow with the applied V-HI value. Autorange is turned off while A-V ohms is running.

Menu Item	Description	Default
V-HI	High source voltage value (-505 V to 505 V).	10 V
TIME	Time for each A-V phase.	15 s*
ONE-SHOT	Enable (YES) or disable (NO) one shot mode (one reading per phase).	YES
CYCLES	Number of A-V cycles (one high and low step): 1 to 9999.	3
AUTOCLEAR	Enable (Y) or disable (N) buffer auto clear with A-V ohms.	Y

* Default depends on integration time when entering A-V ohms menu: 15 s for 1 PLC or greater, 1s for 0.1 PLC, and 0.1s for 0.02 PLC.

To store A-V ohms readings:

1. Press **CONFIG**, then **I | Ω** to access the ohms configuration menu.
2. Select **ALT-VOL**, then press **ENTER**. The unit will prompt for the high voltage value:

V-HI : +10.0000

NOTE

If you have "regular" readings in the buffer, you will be prompted to clear the buffer. Use **CONFIG > STOR 0000 RDGs > ENTER** to clear.

3. Enter the desired high voltage level, then press **ENTER**. The unit will prompt for the time that the voltage source value will be at each phase in the A-V cycle:

TIME: 15.00 s

4. Enter the desired time, then press **ENTER**. The 6487 will prompt for the one-shot mode:

ONE-SHOT: YES

5. Select either **YES** or **NO**.

- a. Selecting **YES** will make one current measurement at the end of each phase and two measurements per cycle to make the V-Delta buffer and return a single reading of the cycle V-Delta measurements averaged together.
- b. Selecting **NO** will make current measurements continuously during each phase to make a V-Delta buffer of each cycle, with the points per cycle determined by the integration rate and the **TIME** specified, and will return the average decay curve (averaging the V-Delta waveforms of the cycles together, as in the "Averaged A-V current" graphic in [Overview](#) (on page 3-24)):

CYCLES: 0003

NOTE

See [One-shot measurements](#) (on page 3-29) and [OHMS:AVOLtage:ONEshot](#) (on page 3-38) for additional details.

6. Press **ENTER**. The unit will prompt for the number of A-V cycles.
7. Set the desired number of A-V cycles, then press **ENTER**. The unit will prompt you as to whether or not you wish to clear the buffer automatically when a new A-V measurement is started:

AUTOCLEAR: Y

8. Select **Y** or **N**, then press **ENTER**.
9. At this point, the voltage source is in operate at 0 V and the unit displays the message **TRIG TO STRT**.
10. To start storing A-V ohms readings, press the **TRIG** key. The asterisk (*) character will turn on to indicate the A-V readings are being stored. It will turn off when storage is complete.

NOTE

To halt the A-V process, press the **EXIT** key once. The voltage source turns off and **I|Ω TO REARM** message will display. A second press of the **EXIT** key takes you back to the normal reading display. From this reading display, you can still press **I|Ω** once and the A-V ohms sequence will again be armed.

Alternatively from this reading display, press **CONFIG > I|Ω** and change the selection back to **NORMAL** to take regular (not A-V) ohms readings.

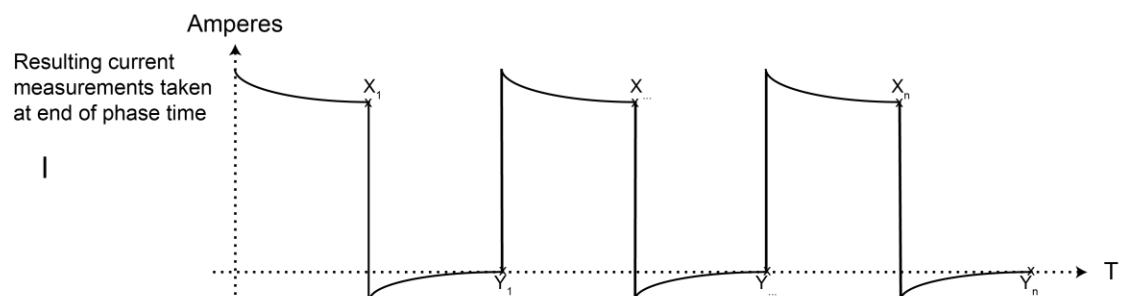
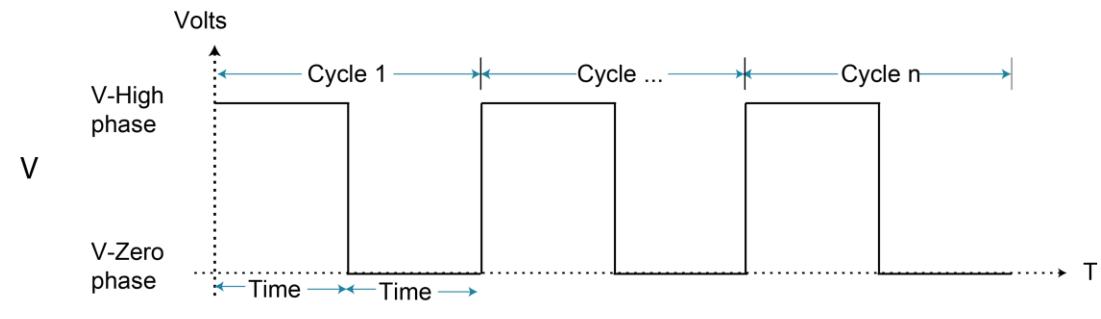
Pressing the **EXIT** or **OPER** key while A-V ohms is in progress will cause the message **I | Ω TO REARM** to appear.

One-shot measurements

The following figure illustrates a measurement when the one-shot A-V ohms mode is enabled.

See [OHMS:AVOLTage:ONEShot](#) (on page 3-38) for more information.

Figure 22: One-shot set to YES



$$\left. \begin{array}{l} \text{V-High buffer} = [X_1, X_{\dots}, X_n] \\ \text{V-Zero buffer} = [Y_1, Y_{\dots}, Y_n] \end{array} \right\} \text{V-Delta buffer} = [X_1 - Y_1, X_{\dots} - Y_{\dots}, X_n - Y_n] = [Z_1, Z_{\dots}, Z_n]$$

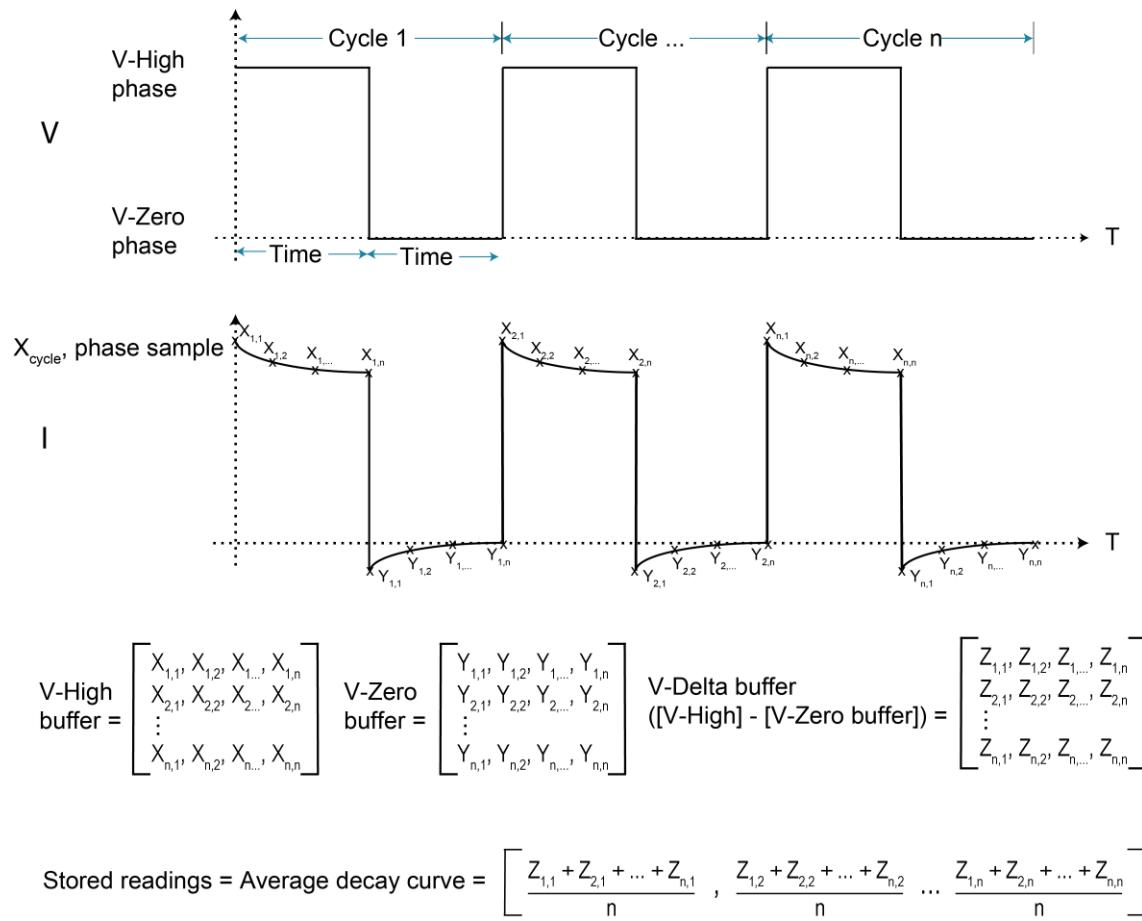
$$\text{Displayed readings} = \text{Average of V-Delta buffer} = \frac{Z_1 + Z_{\dots} + Z_n}{n}$$

One matrix element represents one cycle and a sample number.

The following figure illustrates a measurement when the one-shot A-V ohms mode is disabled.

See [OHMS:AVOLtage:ONEShot](#) (on page 3-38) for more information.

Figure 23: One-shot set to NO

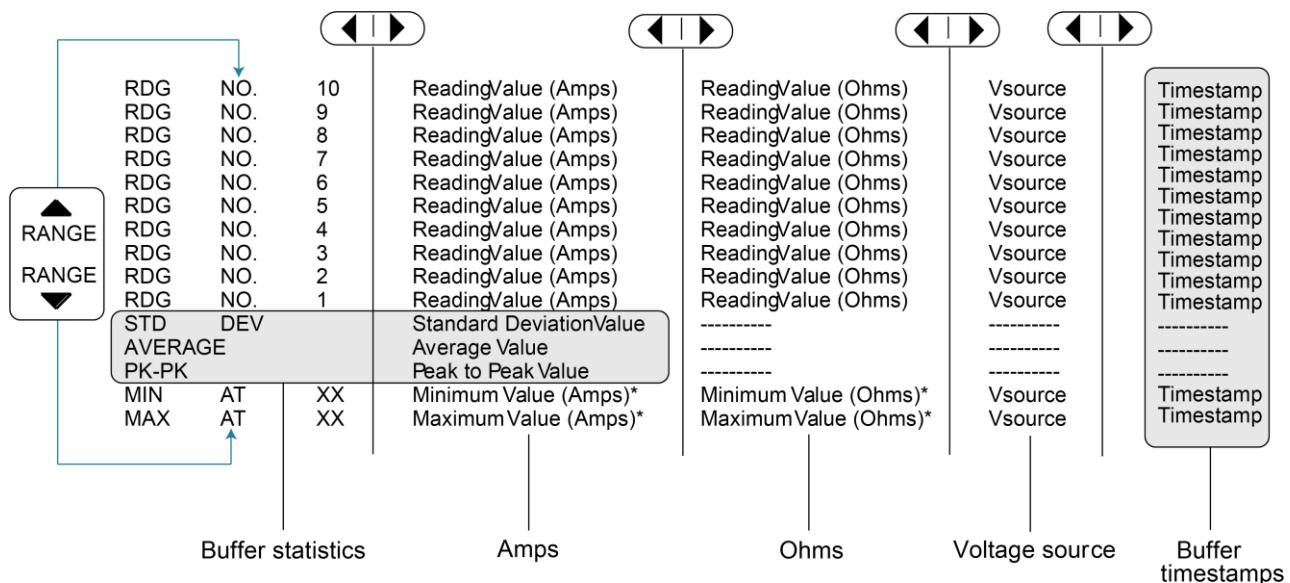


One matrix element represents one cycle and a sample number.

Recalling A-V ohms readings

From the front panel, you can view both amps and ohms A-V readings during the recall process. To do so, press the **RECALL** key, then use the left and right arrow keys to cycle among amps, ohms, voltage source, and time values for each reading. Use the **RANGE** up and down arrow keys to cycle through individual readings or buffer statistics, which are calculated on the basis of the amps readings. See the following figure.

Figure 24: A-V ohms reading recall sequence



*Maximum current will result in minimum ohms and vice-versa.

The MIN value applies to the minimum amps (maximum ohms) reading.

The MAX value applies to the maximum amps (minimum ohms) reading.

Note that the maximum current will result in a minimum ohms reading and vice versa. The MIN reading applies to the minimum current (maximum ohms), while the MAX reading applies to the maximum current (minimum ohms).

Expressing the standard deviation in ohms is not meaningful; therefore it cannot be viewed in ohms and will always show a blank ("-----"). The same applies for the P_k-P_k display. Average will be converted to ohms.

Operating considerations

Range

The ranges for current measurements are listed in the next table.

nA	mA	mA
2 nA	2 mA	2 mA
20 nA	20 mA	20 mA
200 nA	200 mA	

The full scale readings for every measurement range are 5 % over range. For example, on the 20 μ A range, the maximum input current is $\pm 21 \mu$ A. Input values that exceed the maximum readings cause the overflow message (OVRFLOW) to be displayed.

Filtering

The median and average filters are not used in the A-V ohms mode. Once the A-V ohms process is complete, the state of the filters will be restored.

Rate and autozero

During A-V ohms, integration rates are restricted to either 0.02 PLC, 0.1 PLC, 1 PLC, 6 PLC, or 60 PLC. Autozero is turned off but restored after completion if it was previously on. If the integration rate is set to any other value, it will be set to the closest of these settings. However, the original integration rate will not be restored at the conclusion of the A-V ohms cycle.

Integration times of 0.02 PLC and 0.1 PLC will automatically cause the display to be disabled during the A-V ohms run. After the desired number of cycles has completed (or an OHMS:AVOL:ABORT command is received), the display will be restored.

Triggering considerations

When A-V ohms is selected, the ARM-IN trigger source is forced to TIMER and the time interval selected will be slightly higher than that required for the A/D integration. For example, at 1 PLC the integration time is 16.67 ms, so sending the OHM:AVOL:ARM command will set the ARM-IN timer interval to 18 ms. See the following table. Likewise, the ARM-IN count will be set to INFinite.

When exiting A-V ohms with an AVOL:OHMS:ABOR command or when the desired number of cycles has completed, the previous trigger model settings will be restored.

See [Triggering](#) (on page 7-1) for more information.

PLC	50 Hz measurement interval (milliseconds)	60 Hz measurement interval (milliseconds)
0.02	0002	0002
0.1	0004	0004
1	0022	0018
5 (50 Hz) 6 (60 Hz)	0102	0102
50 (50 Hz) 60 (60 Hz)	1002	1002

Trigger state after A/V ohms

Once an A-V ohms reading sequence has been completed, the instrument will be left in the trigger IDLE state. If you are operating remotely (GPIB or RS-232), over the front panel, normal readings will resume after completing A-V ohms (although the "I/Q TO REARM" message will obscure these readings until you press **EXIT**). Send an INIT:IMM command to resume taking readings. See [Triggering](#) (on page 7-1) for more information.

Normal ohms with A-V ohms

Normal ohms (SENS:OHMS:STAT) is not compatible with A-V ohms since the latter relies on differences between current measurements in time. Therefore, the **I | Ω** key is ignored and the SENS:OHMS:STAT command is rejected with an error +850 "Not Allowed with A-V Ohms" while A-V ohms is armed.

Buffer operation

The same memory space is used for the regular 3,000 point buffer as for the three A-V ohms buffers. If there are already readings in the buffer, attempting to arm A-V ohms readings results in a -225 "Out of Memory" error. To avoid inadvertently writing over any desired readings, either send a TRAC:CLEar command over the bus or attempt to store 0 readings to manually clear the buffer from the front panel. From the front panel, attempting to select A-V ohms from the **CONFIG -> OHMS** menu will generate the message "CLEAR BUFFER" if there are already readings in the buffer.

If the buffer has stored A-V ohms readings, you will be given the "CLEAR BUFFER" prompt so that you do not inadvertently write over the A-V ohms data you have collected.

When working remotely, sending the TRAC:FEED:CONT NEXT command while there are A-V ohms readings in the buffer will result in a -225 "Out of Memory" error. Send TRAC:CLEar to clear out the buffer before attempting to store buffer readings.

Command restrictions

While a sweep is in progress, most voltage source control commands, trigger model commands, and buffer (TRACe subsystem) commands are locked out. Sending any of the commands listed below generates the error code +840 "Not allowed with sweep on":

```
SOUR:VOLT[:LEV][:IMM][:AMPL]
SOUR:VOLT:STATE
SOUR:VOLT:RANGE
ARM:SEQ1:COUN
ARM:SEQ1:SOUR
ARM:SEQ1:TIM
TRIG:SEQ1:COUN
TRIG:SEQ1:SOUR
TRIG:SEQ1:DEL
TRIG:SEQ1:DEL:AUTO
TRAC:FEED
TRAC:FEED:CONT
TRAC:POIN
TRAC:CLE
TRAC:TST:FORM
```

SENS:CURR:DC:NPLC

Over the front panel, pressing any key (for example **RATE**) that would change one of the settings associated with this command will automatically cause the buffer to be cleared if the following conditions are true:

- There are A-V ohms readings present in the buffer.
- SENS:CURR:OHMS:AVOL:CLE:AUTO is set to OFF.
- The front panel ohms mode is set for ALT-VOL.

If the buffer is cleared by one of these key presses, a "BUF CLEARED" message will be displayed. Regardless of whether the buffer gets cleared by the key press (it does not, for instance, if the OHMS:AVOL:CLE:AUTO setting is true), you also will have to re-enter the **CONFIG-> I | Ω** menu to select a new time interval before making another A-V ohms run from the front panel.

Interlock

Attempting to run A-V ohms from the front panel while the interlock is open and failing will result in the error message "CLOSE INTLCK" being displayed. If trying to run remotely with the :ARM command the error event +802 "Output Blocked by Interlock" is generated.

SCPI commands — A-V ohms

Command	Description	Default
To make measurements: [SENSe[1]] [:CURRent [:DC]] :OHMS :AVOLTage [:ARM] [:ARM]? :ABORT :VOLTage <NRf> :TIME <NRf> :POINTs? :ONEShot :CYCLes <NRf> :UNITS <name> :CLEar :AUTO :BCount? :BCount?	SENSe[1] subsystem: Current measurement commands: Ohms mode commands: Path to A-V ohms commands: Arm A-V ohms mode. Query if A-V ohms is armed. (1 = armed). Abort A-V ohms mode. Set high voltage value (-505 V to 505 V). Set time interval for each phase. Query number of points. Enable or disable one-shot mode. Set number of A-V cycles (1 to 9999). Select AMPS or OHMS units. Clear A-V ohms buffer. Enable/disable A-V buffer auto clear. Query number of A-V points.	10 V 15 s* ON 3 AMPS ON

To access A/V readings: TRACe :DATA? [BUFFER] :MODE? CALCulate3 :FORMAT <name> :DATA?	TRACe subsystem: Request data from BUFFER. Query buffer mode: DC or AVOLTage. CALCulate3 Subsystem: Select buffer statistic; MINimum, MAXimum, MEAN, SDEViation, or PKPK. Read the selected buffer statistic.	BUFFER MEAN
---	---	----------------

* Default depends on integration rate: 15 s for 1 PLC or greater, 1 s for 0.1 PLC, and 0.1 s for 0.02 PLC.

OHMS:AVOLTage[:ARM]

This command arms the A-V ohms mode. Once this command is sent, the next INIT command starts A-V readings. Sending this command, if there are normal readings in the buffer, results in error -225 "Out of Memory". Use TRAC:CLEar to clear out the buffer. If there are A-V ohms readings in the A-V buffers, this command will automatically clear those buffers in preparation for the next run if the OHMS:AVOL:CLEAR:AUTO state is true. Note that arming the A-V ohms mode will also set the source value to zero and turn operate on.

The ARM command is not allowed if the picoammeter is in auto range (CURR:RANG:AUTO ON); attempting to send the ARM command if autoranging results in error +852 "No A-V ohms with Autorange". If the combination of integration time and programmed TIME interval would result in more than the maximum 1,000 readings per phase, error +853 "Too Many A-V Ohms Readings" is returned.

The :ARM? query returns 1 if A-V ohms has been armed even if the unit is still in the idle state.

NOTE

No commands except for INIT should be sent after sending the OHMS:AVOL:ARM command.

OHMS:AVOLTage:ABORT

This command closes the A-V buffer and resets the source value back to 0 V. The source is also placed in standby.

OHMS:AVOLTage:VOLTage <NRf>

This command sets the positive voltage. During each A-V cycle, the voltage source level alternates between 0 V and this programmed value.

OHMS:AVOLtage:TIME <NRf>

This command sets the time interval in seconds that the source will be in each phase. The number of readings collected per phase will be determined by the integration period and trigger delay, if any. Note that changing the time will clear out any A-V buffer data that has been collected regardless of whether CLEar:AUTO is enabled or not. Sending a time value that would result in more than the maximum of 1000 readings per phase based on the present integration time will result in error +853 "Too Many A-V Ohms Readings". The default time interval depends on the integration time selected.

60 Hz					
	0.02 PLC	0.1 PLC	1 PLC	6 PLC	60 PLC
Time (ms)	2	4	18	102	1002
50 Hz					
	0.02 PLC	0.1 PLC	1 PLC	5 PLC	50 PLC
Time (ms)	2	4	22	102	1002

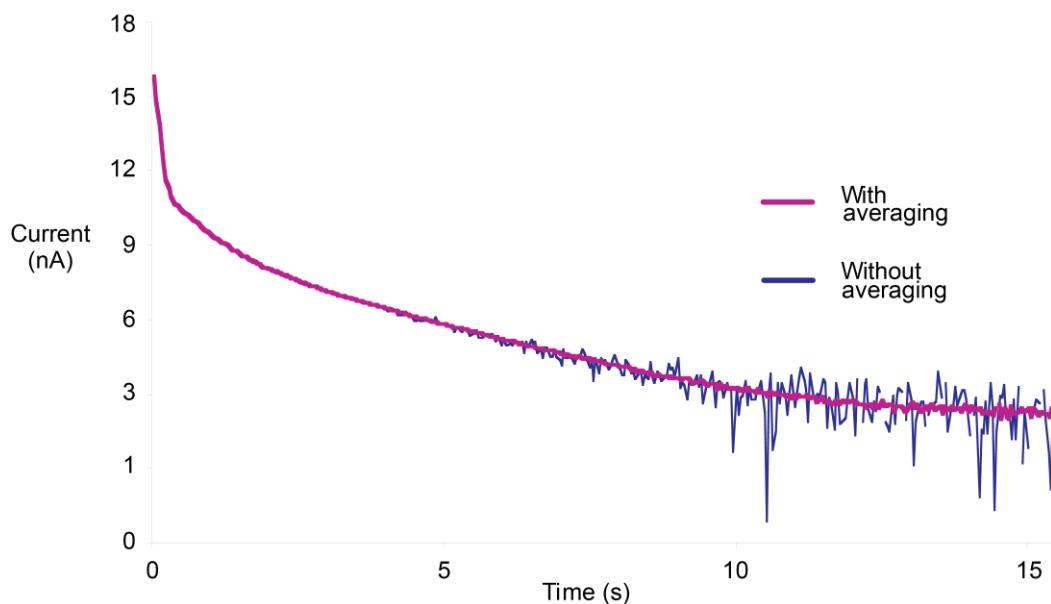
OHMS:AVOLtage:POINts?

This query returns the number of points per phase based on the user-supplied TIME value above. If the number of points would be greater than the maximum of 1,000 (for example, if you had set a new integration rate but had not changed the AVOL:TIME value), then -999 will be returned. A -999 return value indicates that you cannot send the OHMS:AVOL:ARM command until you adjust either the time interval or the integration rate to obtain a valid number of points.

OHMS:AVOLTage:ONEShot

This command controls the one-shot A-V ohms mode. If the one-shot mode is **ON**, then only a single reading is collected for each voltage phase at the end of the **TIME** interval given above for each cycle and only one reading is returned by averaging V-Delta of each cycle. If one-shot mode is **OFF**, then an average waveform of all the cycle's V-Delta is returned, as in the following figure.

Figure 25: Averaged A-V current



See [One-shot measurements](#) (on page 3-29) for more information.

OHMS:AVOLTage:CYCLes <NRf>

This command sets the number of cycles to run A-V ohms. A cycle is defined as one V-High and one V-Zero step.

OHMS:AVOLTage:UNITS <name>

This command sets either amperes or ohms for the the A-V ohms returned and stored readings.

OHMS:AVOLTage:CLEAR

CLEAR manually clears the A-V ohms buffers. TRAC:CLEAR will also do the same thing. AUTO ON enables A-V ohms auto-clear. If enabled, arming the next A-V ohms run will clear out the buffers. If disabled, subsequent A-V ohms runs will get averaged in with the saved readings.

OHMS:AVOLtage:BCount?

This query returns the number of V-High and V-Low cycles that have been averaged to result in the data stored in the A-V ohms buffer.

TRACe:DATA? [BUFFER]

This query returns data either from the normal buffer or the A-V ohms buffer. If A-V ohms is not on and no A-V ohms readings have been collected, normal buffer readings will be returned. If A-V ohms readings have been collected, A-V ohms readings will be returned.

TRACe:MODE?

This query returns the type of data stored in the buffer (either DC or AVOLTage).

Programming example — A-V ohms measurements

The following command sequence will perform A-V ohms measurements with a 5 V high value, 10 s per phase, and 5 A-V cycles:

```
*RST           ' Return 6487 to GPIB defaults.
TRAC:CLE      ' Clear buffer of all readings.
RANG 20e-3    ' Select 20mA range (turn off auto).
OHMS:AVOL:VOLT 5   ' Set high voltage to 5V.
OHMS:AVOL:ONES OFF  ' Disable one-shot mode.
OHMS:AVOL:CLE:AUTO ON  ' Enable buffer auto clear.
OHMS:AVOL:TIME 10   ' Set time per phase to 10s. (A)
OHMS:AVOL:CYCL 5    ' Set number of A-V cycles to 5. (B)
OHMS:AVOL:UNIT OHMS  ' Select ohms units.
SYST:ZCH OFF    ' Disable zero check.
OHMS:AVOL:ARM     ' Arm A-V ohms, turn on source.
INIT           ' Trigger A-V readings.
                ' Wait for time [(A) × 2] × cycles (B)
                ' before requesting readings. 100s in
                ' this example.
TRAC:DATA?      ' Request data from A-V ohms buffer.
```

Section 4

Range, units, digits, rate, and filters

In this section:

Range, units, and digits	4-1
Rate	4-5
Damping.....	4-6
Filters	4-7

Range, units, and digits

Range

The ranges for current measurements are listed in the following table.

nA	µA	mA
2 nA	2	2 mA
20 nA	20	20 mA
200 nA	200	

The full scale readings for every measurement range are 5% over range. For example, on the 20 µA range, the maximum input current is $\pm 21 \mu\text{A}$. Input values that exceed the maximum readings cause the overflow message (OVRFLOW) to be displayed.

Manual ranging

To select a range, press the **RANGE** up or down key. The instrument changes one range per press. If the instrument displays the OVRFLOW message on a particular range, select a higher range until an on-range reading is displayed. Use the lowest range possible without causing an overflow to 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 20 µA range, the instrument will go up to the 200 µA range when the input signal exceeds 21 µA. While on the 200 µA range, the instrument will go down to the 20 µA range when the input level goes below 20 µA.

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** up or down key. Pressing **AUTO** to disable autoranging leaves the instrument on the present range.

Each 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 the range change speed significantly. Setting upper and/or lower autorange limits can reduce search time.

NOTE

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

Autorange limits

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

To set upper and lower autorange limits:

1. Press **CONFIG** key (CONFIGURE : will be displayed).
2. Display the desired limit.
 - a. Press the **RANGE** up key to display the present **UPPER** range limit.
 - b. Press the **RANGE** down key to display the present **LOWER** range limit.
3. Scroll through the available range limits using the up or down **RANGE** key.
4. Press **ENTER** when the desired range is flashing.

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 20 μ A, setting the upper limit to 2 μ A will display the TOO SMALL error.

Units

NOTE

Changing the display resolution is not allowed if displaying readings in scientific notation.

Readings can be displayed using engineering (ENG) or scientific (SCI) notation. Perform the following steps to change the units setting:

1. Press **MENU** key.
 2. Scroll down to the **UNITS** item using the up or down **RANGE** key.
 3. Press **ENTER** to select setting.
 4. Use the up or down key to display the desired units setting.
 5. Press **ENTER**.
 6. Press **EXIT** to return to normal display.
-

NOTE

The units setting can only be changed from the front panel. Scientific notation provides more resolution on small values than engineering units.

Digits

The **DIGITS** key sets display resolution for the 6487. Display resolution can be set from 3½ to 6½ digits. This single global setting affects display resolution for all measurement ranges.

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

NOTE

Changing the integration rate does not change display resolution. Changing display resolution does not change the rate setting.

The voltage source value will not be displayed with the 6½ digit setting.

SCPI programming for range and digits

Commands	Description	Default
<pre>[:CURRent] :RANGE [:UPPer] <n> : AUTO :ULIMit <n> :LLIMit <n> For Digits: DISPlay :DIGits <n></pre>	<p>Measure current: Range selection: Specify expected reading; -0.021 to 0.021 A.</p> <p>Enable or disable autorange. Specify upper range limit for autorange: -0.021 to 0.021 A.</p> <p>Specify lower range limit for autorange: -0.021 to 0.021 A.</p> <p>DISPlay subsystem: Set display resolution: 4 to 7, where <n> of: 4 = 3½ digit resolution 5 = 4½ digit resolution 6 = 5½ digit resolution 7 = 6½ digit resolution</p> <p>Rational numbers can be used. For example, to set 5 resolution send a value of 4.5. The 6487 rounds it to 5.</p>	200 µA ON 20 mA 2 nA 6

Programming example — range and digits

The following command sequence selects the 20 mA range and sets display resolution to 3:

Command	Comments
*RST	' Restore RST defaults .
CURR:RANG 0.02	' Set to 20 mA range.
DISP:DIG 3.5	' Set display resolution to 3H digits.

The following table lists the instrument ranges and values

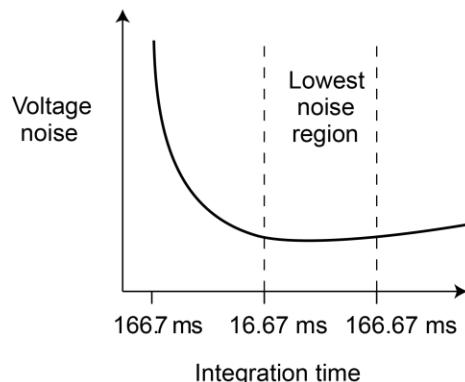
Range	<n> value	Display (5H digit resolution)
20 mA	2E-2 or 0.02	00.0000 mA
2 mA	2E-3 or 0.002	0.00000 mA
200 µA	2E-4 or 0.0002	000.000 µA
20 µA	2E-5 or 0.00002	00.0000 µA
2 µA	2E-6 or 0.000002	0.00000 µA
200 nA	2E-7 or 0.0000002	000.000 nA
20 nA	2E-8 or 0.00000002	00.0000 nA
2 nA	2E-9 or 0.000000002	0.00000 nA

Rate

The **RATE** key selects the integration time of the analog-to-digital 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 (NPLCs), where 1 PLC for 60 Hz is 16.67 ms (1/60) and 1 PLC for 50 Hz (and 400 Hz) is 20 ms (1/50).

Generally, the 6487 has a parabola-like shape for its speed vs. noise characteristics and is shown in the next figure. The 6487 is optimized for the 1 PLC to 10 PLC reading rate. At these speeds, the 6487 will make corrections for its own internal drift and still be fast enough to settle a step response <100 ms.

Figure 26: Speed versus noise characteristics



The rate setting is global for all ranges. Therefore, it does not matter what range is selected when you set the rate.

There are two ways to set the 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 **CONFIG / LOCAL** (while in LOCAL) and then **RATE**.

The available **RATE** key selections are as follows:

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

Press the **RATE** key until the desired rate is displayed.

To set the NPLC:

1. Press **CONFIG / LOCAL** and then **RATE** to display the present PLC value.
2. Use the arrow keys to adjust to the desired PLC value. Valid values are:
60 Hz operation: 0.01 to 60
50 Hz operation: 0.01 to 50
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 for the respective frequency of 50 or 60 Hz), 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 are displayed.

SCPI programming — rate

The following table contains the path and the command to set the rate.

Command	Description	Default
[:SENSe] [:CURRent] :NPLCycles <n>	SENSe subsystem: Specify integration rate: 0.01 (PLCs) to 60.0 (60 Hz) or 50.0 (50 Hz)	6.0 (60 Hz) 5.0 (50 Hz)

Programming example - rate

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

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

Damping

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

NOTE

Use damping to reduce noise caused by input capacitance. Use filtering to reduce noise caused by a noisy input signal.

To toggle damping on or off, press the **DAMP** key. **DAMP ON** or **DAMP OFF** will be displayed to indicate the present state of damping. Note that the **FILT** annunciator is used for both the analog damping filter and the two types of digital filters.

Command	Description	Default
[:SENSe] [:CURRent] :DAMPing [:STATe] [:STATe] ?	SENSe subsystem: Path to current functions Control damping (analog filter) Enable or disable damping filter Query damping filter state	ON

Filters

Filtering stabilizes erratic measurements caused by noisy input signals. The 6487 uses median and digital filters. The displayed, stored, or transmitted reading is simply the result of the filtering processes. Note that both the median and digital filters can be used 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. The **FILT** key is used to control both filters. When either the median or digital filter is enabled, the **FILT** annunciator is on. Note that the **FILT** annunciator is used for both the digital filters and the analog damping filter.

Median filter

The median filter is used to determine the reading at the midpoint of a group of readings that are arranged according to size. For example, assume the following readings:

20 mA, 1 mA, 3 mA

The readings are rearranged in an ascending order as follows:

1 mA, 3 mA, 20 mA

From the above readings, it is apparent that 3 mA 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:

$$\text{Sample readings} = (2^R) + 1$$

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;
 $(2^5) + 1 = 11$. Each new reading replaces the oldest reading and the median is then determined from the updated sample of readings.

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 range is changed.

Median filter control

To configure the median filter:

1. Press the **CONFIG** key.
2. Press the **FILT** key.
3. Select **MEDIAN**, then press **ENTER**.
4. Change the display to **MEDIAN ON**, then press **ENTER**.
5. The present rank will be displayed.
6. Use the **RANGE** keys to display the desired rank.
7. Press **ENTER** to set. To return to the previously set value, press **EXIT** instead of **ENTER**.

Digital filter

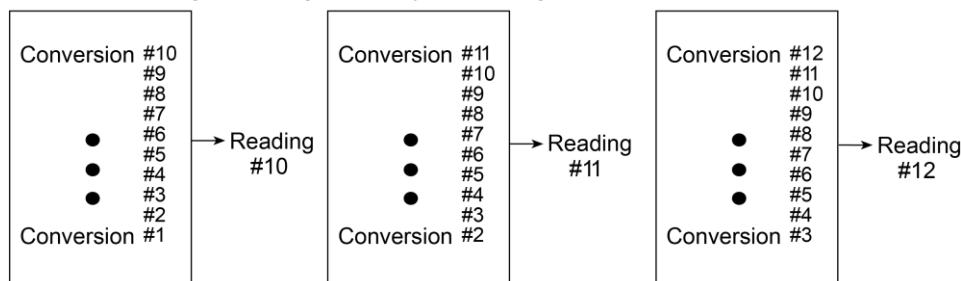
An additional filter parameter is type, either moving or repeating.

Moving filter: Each 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.

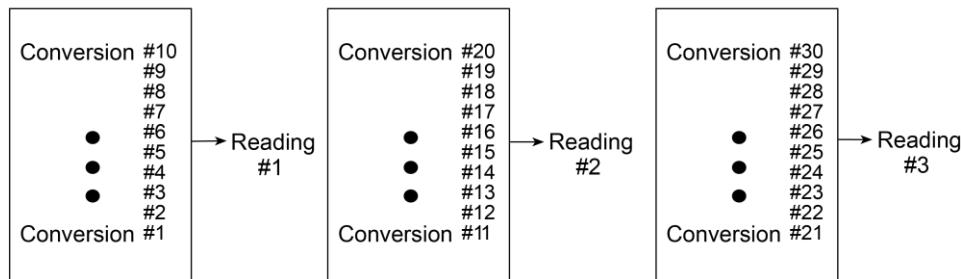
Repeating filter: Takes a selected number of reading conversions, averages them, and yields a reading. It then flushes its stack and starts over.

Figure 27: Moving and repeating digital filter types

A. Class - Average, readings = 10. Type: Moving



B. Class - Average, readings = 10. Type: Repeating



Response time

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

NOTE

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

To configure the average filter:

1. Press **CONFIG > FILT**.
2. Set the display to AVERAGE ON, then press **ENTER**. The present number of reading conversions to average (filter count) will be displayed.
3. Set the filter count (2 to 100):
 - Use the **RANGE** and arrow keys to display the desired filter count value at the **RDGS** prompt.
 - Press **ENTER** to set.
4. Set the filter type:
 - Use the **RANGE** keys to display the desired filter type at the **TYPE:** prompt.
 - Press **ENTER** to set.

SCPI programming — filters

The following table contains SCPI commands for filters.

Command	Description	Default
For median filter: [:SENSe[1]] :MEDian :RANK <n> [:STATe] 	SENSe subsystem: Median Filter: Specify filter rank: 1 to 5. Enable or disable median filter.	1 OFF
For digital filter: [:SENSe[1]] :AVERage :TCONTrol <name> :COUNT <n> [:STATe] 	SENSe Subsystem: Digital filter: Select filter control: MOVing or REpeat. Specify filter count: 2 to 100. Enable or disable digital filter.	MOV 10 OFF

Programming example - rate

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.
```

Section 5

Relative, mX+b, m/X+b, and log

In this section:

Relative.....	5-1
mX+b, m/X+b (reciprocal), and logarithmic	5-4

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 reading = Actual input - rel value

A Rel value is the same for all measurement ranges. For example, a Rel value of 1E-6 is 1 μ A on the 2 μ A range. It is also 1 μ A on the 20 μ A range and the 200 μ A range. Note changing ranges does not disable Rel.

When a Rel value is larger than the selected range, the display is formatted to accommodate the reading. However, this does not increase the maximum allowable input for that range. An overrange input signal will still cause the display to overflow. For example, on the 20 μ A range, the 6487 overflows for a 21 μ A input.

NOTE

Rel can be used on the result of the mX+b, m/X+b, or LOG calculations. However, Rel will be disabled whenever a math function is enabled or disabled.

Setting and controlling relative

From the front panel, you can use the input reading as the Rel value or you can manually enter the value.

REL key

When the **REL** key is used to enable Rel, the present display reading is used as the Rel value.

To set a Rel value:

1. Disable zero check by pressing **ZCHK**.
2. 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.
3. Press **REL**. The **REL** annunciator turns on and subsequent readings will be the difference between the actual input and the Rel value.
4. To disable Rel, press the **REL** key a second time or select a different measurement function.

NOTE

When Rel is disabled, the Rel value is remembered. To reinstate the previous Rel value, press **CONFIG > REL > ENTER**. If the **REL** is disabled and then **REL** is pressed again, it will determine and set a new null value. With zero check enabled, the **REL** key controls zero correct, not relative.

Displaying or manually entering REL

Press **CONFIG** and then **REL** to display the present Rel value. This displayed value can be enabled by pressing **ENTER**, or a different Rel value can be entered and enabled.

1. Press **CONFIG** and then **REL**. The present Rel value will be displayed.
2. To change the Rel value, use the **RANGE** and cursor keys and change the value. To change Rel polarity, place the cursor on the polarity sign and press either manual **RANGE** key. To change the Rel range, place the cursor on the range symbol (at the end of the reading) and use the manual **RANGE** keys.
3. With the desired Rel value displayed, press **ENTER** to enable Rel.

The following table lists the range symbols for Rel values.

Symbol	Prefix	Exponent
p	pico-	10^{-12}
n	nano-	10^{-9}
μ	micro-	10^{-6}
m	milli-	10^{-3}
\wedge	(none)	10^0
K	kilo-	10^3
M	mega-	10^6
G	giga-	10^9
T	tera-	10^{12}

SCPI programming — relative

Command	Description	Default
CALCulate2	Path to configure and control limit testing (CALC2):	
:FEED <name>	Specify reading to Rel: SENSe[1] or CALCulate[1].	SENS1
:NULL	Configure and control Relative.	
:ACQuire	Use input signal as Rel value.	
:OFFSet <NRf>	Specify Rel value: -9.999999e20 to 9.999999e20.	
:STATe 	Enable or disable Rel.	0.0
:DATA?	Return readings triggered by INITiate.	OFF
:DATA:LATest?	Return only the latest reading.	
INITiate	Trigger one or more readings.	

:FEED <name>

When SENSe[1] is selected, the Rel operation is performed on the input signal. When CALCulate[1] is selected, the Rel operation is performed on the result of the mX+b or m/X+b calculation.

:STATe

This command toggles the state of Rel without acquiring new values. This operation is different than the **REL** key on the front panel (which toggles the Rel state), as the front panel key acquires new values when pressed (unless **CONFIG** is pressed first). If a NULL value has not been acquired before enabling Rel, 0.000000E+00 is used.

:DATA? and :DATA:LATest?

With Rel enabled, these commands will return one or more readings, but they will not trigger new readings. Use the INITiate command to trigger new readings.

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

Programming example — relative

This program fragment establishes a 1 μ A baseline for measurements:

Command	Comments
CALC2:NULL:OFFS 1e-6	' Set Rel value of 1 μ A.
CALC2:NULL:STAT ON	' Enable Rel.
CALC2:FEED SENS	' Rel input signal.
SYST:ZCH OFF	' Turn off zero check.
INIT	' Trigger reading(s).
CALC2:DATA?	' Request Rel'ed reading.

mX+b, m/X+b (reciprocal), and logarithmic

mX+b and m/X+b

The following math operations manipulate normal display readings (X) according to the following calculations:

$$Y = mX+b$$

$$Y = m/X+b$$

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

NOTE

Changing the m or b for mX+b also changes it for m/X+b.

Configuring and controlling mX+b and m/X+b

NOTE

Enabling or disabling math disables Rel (if Rel is enabled).

To configure and control either of these math calculations:

1. Press **CONFIG > MATH** to enter the math configuration menu.
2. Using the manual **RANGE** keys, select either **MATH: mX+B** or **MATH: M/X+B**, then press **ENTER** to select the desired function and display the present scale factor:
M: +1.000000 ^ (factory default)
3. Key in a scale factor value. The left and right arrow keys control cursor position and the up and down **RANGE** keys increment and decrement the digit value. To change range, place the cursor on the range symbol and use the up and down keys. With the cursor on the polarity sign, the up and down keys toggle polarity.
4. Press **ENTER** to input the M value and display the offset (B) value: B: +0.000000 P (factory default).
5. Enter the offset value.
6. Press **ENTER** to set the B value and display the one-character UNITS designator:
UNITS: X (factory default)

NOTE

The configuration for mX+b calculations consists of a units designator, a value for M, and a value for B. This configuration is used for both the mX+b and the m/X +b calculations. Therefore, changing either configuration (of the mX+b or the m/X+b calculation) also changes the other calculation's configuration.

7. To change the units designator, press the right arrow key and use the manual RANGE keys. The character can be any letter in the alphabet.
8. Press **ENTER**.
9. To enable math, press the **MATH** key. The **MATH** annunciator and the units designator will turn on and the result of the calculation will be displayed.

Logarithmic

This calculation converts input readings to logarithm base 10 values. The calculation is performed as follows:

$$\log_{10}X = Y$$

where: X is the input reading
 y is the logarithmic result

For example: Assume that exactly 1 mA is being measured by the 6487.

$$\log_{10}1.000000 \text{ ma} = -3$$

NOTE

This calculation uses the absolute value of the normal input reading, as the log of a negative number cannot be computed.

To control the log function:

NOTE

Enabling or disabling math disables Rel (if Rel is enabled).

1. Press **CONFIG > MATH** to enter the math configuration menu.
2. Using either manual **RANGE** key, select **MATH: LOG10**, then press **ENTER** to select the log function.
3. To enable math, press the **MATH** key from normal display. The **MATH** annunciator and the **L** designator will turn on and the result of the calculation will be displayed.

SCPI programming — mX+b, m/X+b, and log

Command	Description	Default
CALCulate[1] :FORMat <name> :KMATh :MMFactor <n> :MBFactor <n> :MUNits <name> :STATE :DATA? :DATA:LATest?	CALCulate1 subsystem: Select calculation: MXB, RECiprocal, or LOG10. Path to configure mX+b and m/X+b: Specify scale factor (M) for mX+b and m/X+b: -9.99999e20 to 9.99999e20. Specify offset (B) for mX+b and m/X+b: -9.99999e20 to 9.99999e20. Specify units for mX+b or m/x+b result: 1 character: A-Z, '['=Ω, '\''=°, ']'=%. Enable or disable the selected calculation. Returns all CALC1 results triggered by the INITiate. Returns only the latest CALC1 reading.	MXB 1.0 0.0 "X" OFF

:FORMat <name>

This command selects the desired math function in the same manner as the front panel **CONFIG MATH** menu. Functions names include **MXB** ($mX + b$), **RECiprocal** ($m/X + b$), and **LOG10**.

:KMATh

Use these commands to set the **M** (scale factor), **B** (offset), and units for the $MX + B$ and reciprocal math functions.

: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 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 stop 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, using X as the units designator, and displays the result:

Command	Comments
*RST	'Restore RST defaults.
CALC:FORM MXB	'Select mX+b calculation.
CALC:KMAT:MMF 2e-3	'Set scale factor (M) to 2e-3.
CALC:KMAT:MBF 5e-4	'Set offset (B) to 5e-4.
CALC:KMAT:MUN 'X'	'Select X as units.
CALC:STAT ON	'Enable calculation.
SYST:ZCH OFF	'Disable zero check.
INIT	'Perform one measurement and 'calculate mX+b.
CALC:DATA?	'Request mX+b result.

Section 6

Buffer and sweeps

In this section:

Store	6-1
Buffer operations.....	6-2
Recall.....	6-2
Buffer timestamps	6-3
Buffer statistics.....	6-4
SCPI programming	6-5
Programming example.....	6-8
Voltage sweeps.....	6-8

Store

To store readings:

1. Set up the instrument for the desired configuration.
2. Press **CONFIG**. CONFIGURE : is displayed.
3. Press **STORE**. The present buffer size (in readings) is displayed.
4. Use the cursor left and right keys and the **RANGE** up and down arrow keys to set the number of readings to store (1 to 3000).
5. Press **ENTER** to save the buffer size, then press the **STORE** key. 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.

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).

Buffer operations

The 6487 has a buffer to store from one to 3000 readings. It also stores overflow readings and the voltage source value. Each reading has a timestamp. The timestamp for each reading is referenced to the time the measure/store process is started. 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 filters and/or math operations have been performed. Math operations include relative, $mX+b$, $m/X+b$, LOG, or limit tests.

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

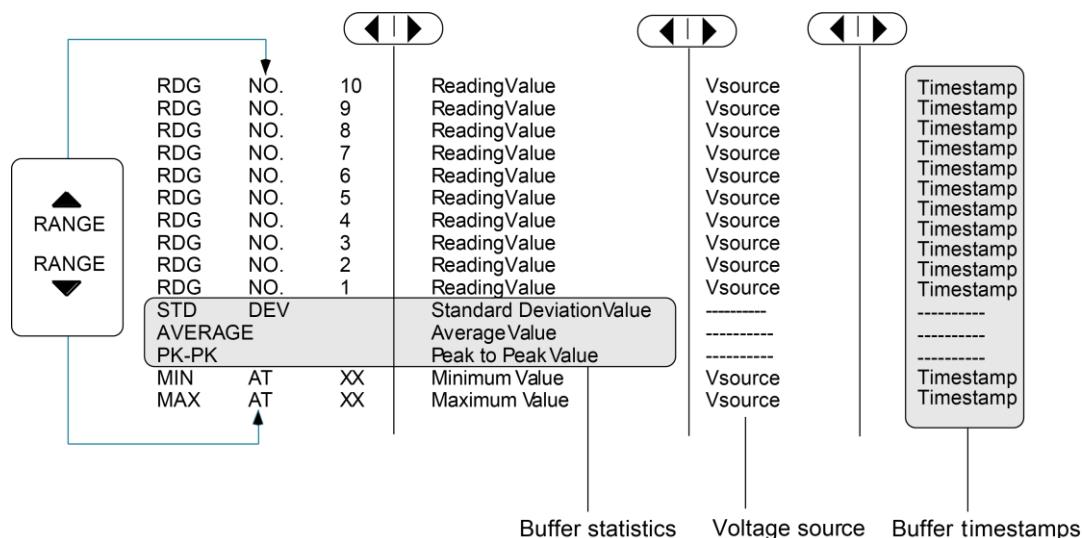
Measurement function changes are permissible during the storage process. The statistics are based on the readings of the different measurement functions.

Recall

To view stored readings and buffer statistics:

1. Press **RECALL**. 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. Use the **RANGE** up and down keys and the cursor left and right keys to navigate through the reading numbers and buffer statistics, reading values, voltage source values, and timestamps. For information on how to set buffer timestamps, see [Buffer timestamps](#) (on page 6-3).
3. Press **EXIT** to return to the normal display.

Figure 28: Buffer locations



Buffer timestamps

You can use the TSTAMP: menu item to change the timestamp format.

To access the menu:

1. Press **MENU**.
2. Scroll to the TSTAMP: menu item using the **RANGE** up and down keys.
3. Press **ENTER**.
4. Using the **RANGE** up and down keys, choose **ABS** (absolute) or **DELT** (delta).
 - **ABS**: each timestamp is referenced to the first reading stored in the buffer. The first reading always has a timestamp of 0000000.0000.
 - **DELT**: each timestamp provides the time between the readings.

Buffer statistics

MIN and **MAX** provide 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:

$$\text{PK-PK} = \text{MAX} - \text{MIN}$$

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:

Equation 1: Buffer statistics 2

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

Where: **X_i** is a stored reading
n is the number of stored readings
Avg is the mean of the buffer readings

NOTE

If any readings stored in the buffer are the result of an overflow or overvoltage condition, the buffer statistics calculation will not be performed. Buffer recall via front panel operation will show a series of dashes in place of the requested buffer statistics value. In remote operation, the corresponding buffer statistics will be represented by the value +9.91e37.

SCPI programming

Commands associated with buffer operation are listed in the next table.

NOTE

The 6487 uses the IEEE-754 floating point format for statistics calculations.

When programming the buffer via remote, the trigger count set with the TRIG:COUN command should normally equal the number of buffer readings to store set with TRAC:POIN.

If the voltage source was in compliance when the reading was acquired, the recalled front panel SRC: display will show the voltage value dimmed. Over the GPIB, a value of -999 returned for the voltage source element indicates that the source was in compliance.

For any ohms measurements, the ohms reading is invalid and unknown if the voltage source is in compliance. Therefore, a value of -9.9e+36 will be returned over the GPIB, and I-LIMIT will be displayed on the front panel for both normal readings and buffer recall readings for any ohms readings where the voltage source went into compliance.

Command	Description	Default
:TRACe	TRACe subsystem:	*
:CLEar	Clear readings from buffer.	
:FREE?	Query bytes available and bytes in use.	
:POINTs <n>	Specify number of readings to store: 1 to 3000.	100
:ACTual?	Returns number of readings actually stored in buffer.	
:FEED <name>	Select source of readings: SENSe[1], CALCulate[1], or CALCulate2.	SENS1
:CONTrol <name>	Select buffer control mode: NEVER or NEXT.	NEV
:TSTamp	Timestamp:	
:FORMAT <name>	Select timestamp format: ABSolute or DELTa.	ABS
:DATA?	Read all readings in buffer.	
:MODE?	Query the type of data (DC or AVOL) stored in the buffer.	
:FORMAT	FORMAT subsystem:	
:ELEMENTs <list>	Specify data elements for :TRACe:DATA? response message: READING, UNITS, VSOURCE, TIME, STATUS, ALL, or DEFault (all elements except VSOURCE).	All except VSO

Command	Description	Default
:CALCulate3	CALCulate3 subsystem:	
:FORMAT <name>	Select buffer statistic: MINimum, MAXimum, MEAN, SDEVIation, or PKPK.	MEAN
:DATA?	Read the selected buffer statistic.	

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

:TRACe:FREE?

Two comma-separated values 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.

:TRACe:FEED <name>

Name parameters:

- SENSe: Raw input readings are stored in the buffer.
- CALCulate1: The results of the mX+b, m/X+b, or log calculation are stored in the buffer.
- CALCulate2: Test limit or Rel readings are stored in the buffer.

: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.

: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.

:TRACe:DATA?

- The response message will include one to four data elements for each stored reading. Use the FORMat:ELEMents command to specify the elements.
- Reading an empty buffer will result in the "ERROR: -230" display message.
- Buffer data can be sent in the binary format.

:FORMat:ELEMents <list>

List parameters:

- READING: Includes the buffer reading in each data string.
- UNITS: Identifies amps, ohms, or math units.
- VSOURCE: Includes voltage source value in each reading string.
- TIME: Includes the timestamp for each reading. Timestamp can be in the absolute or delta format.
- STATus: Includes a status word for each reading. It provides status information on instrument operation.
- DEFault: All except VSOURCE.
- ALL: Includes all reading elements.

At least one data element must be in the list. Listed elements must be separated by a comma. Elements not listed will not accompany the response message for TRACe:DATA?. Data in the response message will be in order of the listed data elements set by this command.

:CALCulate3:FORMat <name>

This command selects the statistic returned by CALCulate3:DATA?.

- 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: $PKPK = MAXimum - MINimum$.

:CALCulate3:DATA?

If the number of data points in the buffer is one or none, CALCulate3:DATA? will result in an error (-230).

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 6487.

Programming example

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

Command	Comments
' Select data elements:	
*RST	' Return 6487 to RST defaults.
FORM:ELEM READ,TIME	' Select reading and timestamp.
' Store and Recall Readings:	
TRIG:COUN 20	' Set trigger model to take 20 readings.
TRAC:POIN 20	' Set buffer size to 20.
TRAC:FEED SENS	' Store raw input readings.
TRAC:FEED:CONT NEXT	' Start storing readings.
SYST:ZCH OFF	' Disable zero check.
INIT	' Trigger readings setup to SRQ on ' buffer full.
TRAC:DATA?	' Request all stored readings.
' Acquire Mean Statistic for Buffer Readings:	
CALC3:FORM MEAN	' Select mean statistic.
CALC3:DATA?	' Request mean statistic.

Voltage sweeps

The 6487 voltage source can be used to generate voltage sweeps from a start voltage to a stop voltage at discrete step voltages. Readings are stored in the buffer for later recall, one set of readings per voltage step.

Overview

A voltage sweep is performed from a start voltage to a stop voltage at discrete step voltages. At each step voltage:

- The source voltage is set to the new value.
- The unit waits for the programmed delay period.
- The reading is taken and stored in the buffer for later recall.

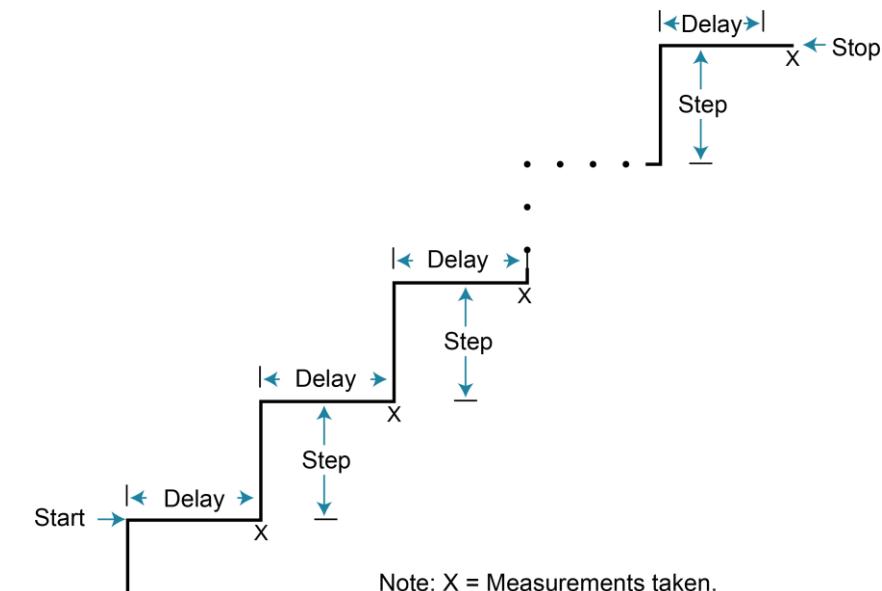
Note that sweeps can be positive-going or negative-going by programming the start and stop voltages accordingly, but the programmed step voltage is always positive.

The front panel sweep parameters are not error checked until you have entered a **STEP** value. If there are too many points, the error message "TOO MANY PTS" appears, and you will be taken back to the start (STRT) value entry menu.

Likewise, a step size larger than the (stop-start) interval results in the message "STEP TOO BIG".

Note that as long as the front panel **V-MODE** setting is **SWEEP**, the **TRIG** key will function to initiate sweeps rather than as a trigger source. To return the **TRIG** key to its normal behavior, use **CONFIG - > OPER** to set **V-MODE** back to DC.

Figure 29: Voltage sweeps



Sweep operation

To generate sweeps from the front panel:

1. Press **CONFIG** then **OPER**. The unit will prompt for **DC** or **SWEEP** operation.
2. Select **SWEEP**, then press **ENTER**. The unit will prompt for the **STRT** (start) voltage.
3. Using the manual **RANGE** and cursor keys, enter the desired start voltage, then press **ENTER**.
4. Enter the stop voltage, then press **ENTER**.
5. Enter the step voltage, then press **ENTER**.
6. Enter the delay period, then press **ENTER**.
7. Press **TRIG** to start the sweep. The SCAN annunciator will be on to show the sweep is armed.

The voltage source will be placed in operate, the sweep will be performed, and readings will be stored in the buffer for later recall. To abort a sweep in progress, press the **EXIT** key.

The following table lists the sweep parameter menu selections.

Sweep Menu	Description	Default
STRT	Start voltage (-505 V to 505 V).	0 V
STOP	Stop voltage (-505 V to 505 V).	10 V
STEP	Step voltage (-505 V to 505 V).	1 V
DEL	Delay between source and measure (0 s to 999.9999 s).	1 s

Recalling sweep data

To recall sweep data, press the **RECALL** key, and then use the manual **RANGE** and cursor keys to display readings. See [Recall](#) (on page 6-2) for more information.

Operating considerations

Buffer

The reading (TRACe) buffer is cleared at the start of the sweep and readings collected during the sweep are placed into the buffer. The voltage source value is stored as a reading element.

Source range

The source range will be fixed at the lowest range required to properly handle all points in the sweep. For example, a 10-point sweep from +2 V to +11 V in 1 V steps will start on the 50 V range and remain on the 50 V range for all points in the sweep.

Sweep direction

Sweeps can go in either direction, but the **STEP** is an absolute value and is always positive. It can range from zero to the value of (START – STOP).

Command restrictions

While a sweep is in progress, most voltage source control commands, trigger model commands, and buffer (TRACe subsystem) commands are locked out. Sending any of the commands listed below generates the error code +840 Not allowed with sweep on:

```
SOUR:VOLT[:LEV][:IMM][:AMPL]
SOUR:VOLT:STATE
SOUR:VOLT:RANGE
ARM:SEQ1:COUN
ARM:SEQ1:SOUR
ARM:SEQ1:TIM
TRIG:SEQ1:COUN
TRIG:SEQ1:SOUR
TRIG:SEQ1:DEL
TRIG:SEQ1:DEL:AUTO
TRAC:FEED
TRAC:FEED:CONT
TRAC:POIN
TRAC:CLE
TRAC:TST:FORM
```

Sweep example

For a linear sweep from -25 V to +25 V in 5 V steps, the sweep parameters would be set as follows:

- Start: -25
- Stop: 25
- Step: 5

This sweep will have 11 points corresponding to the voltage source values -25, -20, -15, -10, -5, 0, 5, 10, 15, 20, and 25. Changing the step to 7 V results in values of -25, -18, -11, -4, 3, 10, 17, and 24, which shows that only complete steps are executed.

SCPI programming — sweeps

Interlock

Attempting to initialize a sweep over the front panel while the interlock is open and failing will result in the error message "CLOSE INTLCK" being displayed. If trying to arm remotely with the SOUR:VOLT:SWE:INIT command, the error event +802 "Output Blocked by Interlock" is generated.

Trigger model

Sweeps do not change any of the trigger model settings other than to internally perform the equivalent of an ABORT command and return to the Idle layer when the SOUR:VOLT:SWE:INIT command is received. Trigger and arm counts, sources, and delays are exactly what they were before the sweep was started. The only difference is that the sweep delay is added between the setting of the source to the new value and the acquisition of the reading. The implications of this fact are that you must have the trigger and arm counts properly set before sending the SOUR:VOLT:SWE:INIT command.

Example A

```
*RST  
SYST:ZCH OFF  
SOUR:VOLT:SWE:STAR 0  
SOUR:VOLT:SWE:STOP 10  
SOUR:VOLT:SWE:STEP 1  
SOUR:VOLT:SWE:DEL 2  
SOUR:VOLT:SWE:INIT  
INIT:IMM
```

Because the *RST command sets the **ARM** and **TRIG** layer counts both to 1, INIT:IMM will take only a single reading in the sweep. After each INIT:IMM command arrives, the source will jump to the new voltage, there is a two-second delay, then the reading is collected.

Example B

```
*RST
SYST:ZCH OFF
ARM:COUN INF
SOUR:VOLT:SWE:STAR 0
SOUR:VOLT:SWE:STOP 10
SOUR:VOLT:SWE:STEP 1
SOUR:VOLT:SWE:DEL 2
SOUR:VOLT:SWE:INIT
INIT:IMM
```

This example is the same as before except that a setting for the **ARM** layer count to infinite has been added. Now, after the **INIT:IMM** is received, the sweep will begin and all 11 points will be collected with no further commands required. Each point will be spaced roughly two seconds apart (slightly longer due to the fact that the command sequence leaves Autozero on). Once the sweep is complete, the source will go to 0 V and will be turned off, but readings will continue to be taken since the **ARM** count is infinite. These readings will no longer be separated by the two-second sweep delay, but instead will be collected at the normal (Slow, 6 PLC) rate.

Status model

Bit 3 of the Operation Condition Register is used to indicate that a sweep is in progress. It will be set true when the **SOUR:VOLT:SWE:INIT** command is received and it remains high until either the last sweep point is completed or a **SOUR:VOLT:SWE:ABOR** command is received.

Command	Description	Default
SOURce[1] :VOLTage :SWEep :START <NRf> :STOP <NRf> :STEP <NRf> :CENTer <NRf> :SPAN <NRf> :DELay <NRf> :INITiate :ABORT :STATE? INITiate	<p>SOURce1 subsystem:</p> <p>Voltage source commands: Sweep commands Set start voltage: -505V to 505V. Program stop voltage: -505V to 505V. Program step voltage: -505V to 505V. Program center voltage: -505V to 505V. Program span voltage: -505V to 505V. Set delay: 0 to 999.9999s. Arm sweep, put source in operate. Abort sweep, put source in standby.</p> <p>Query if sweep running: 1 = sweep in progress.</p> <p>Trigger sweep.</p>	0 V 10 V 1 V 5 V 10 V 1 s

:VOLTage:SWEep:STARt <NRf>

This command programs the start voltage, which is the initial setting of the voltage source during the sweep.

:VOLTage:SWEep:STOP <NRf>

This command programs the stop voltage, which is the final setting of the voltage source during the sweep.

:VOLTage:SWEep:STEP <NRf>

This command programs the step voltage. In cases where there are not an exact number of steps between the start and stop point, the last step will be truncated. Step sizes larger than the (stop - start) interval will generate Error -842 "Sweep step size too large". Step sizes that will result in a sweep with more than the 3,000 point buffer maximum or below the minimum source resolution for the source range required by the sweep will also generate Error +841 "Sweep step size too small". The **STEP** size is an absolute value, so the lower limit is zero and the upper limit is restricted by the **START** and **STOP** settings.

:VOLTage:SWEep:CENTER <NRf>

This command enters the mid-point of the sweep. Note that **CENTER** and **SPAN** are related to **START** and **STOP**. These commands are another way to define the sweep.

:VOLTage:SWEep:SPAN <NRf>

This command enters the total span of the sweep. **CENTER** and **SPAN** are coupled with **START** and **STOP**.

:VOLTage:SWEep:DELay <NRf>

This command programs the delay period that the 6487 waits after sourcing the voltage before starting to take the measurement at each step.

:VOLTage:SWEep:INITiate

This command places the voltage source in operate and begins sweep operation with the next trigger. Once the sweep is triggered, the buffer is opened and the unit begins saving readings. Error checking is held off until the SOUR:VOLT:SWEep:INIT command is sent. A step size that is too small and would result in more than 3,000 points in the sweep generates Error +841 "Sweep step size too small". If the step size exceeds the interval (STOP - START), Error +842 "Sweep step size too large" is generated.

:VOLTage:SWEep:ABORt

This command immediately places the voltage source in standby (Operate off), cancels buffer storage, and restores the trigger model to its prior settings before the sweep.

:VOLTage:SWEep:STATe?

This query provides a means to determine whether or not a sweep is still running. A returned value of 1 indicates that the sweep is still in progress, while a value of 0 shows that no sweep is active.

Programming example

The following command sequence performs a sweep from 1 V to 10 V in 1 V increments and recalls all readings:

Command	Comments
*RST	' Return 6487 to RST defaults.
SOUR:VOLT:SWE:STAR 1	' Start voltage = 1V.
SOUR:VOLT:SWE:STOP 10	' Stop voltage = 10V.
SOUR:VOLT:SWE:STEP 1	' Step voltage = 1V.
SOUR:VOLT:SWE:DEL 0.1	' 0.1s delay.
ARM:COUN INF	' Reset arm count.
FORM:ELEM READ,VSO	' Select reading, voltage source data.
SOUR:VOLT:SWE:INIT	' Arm sweep, put source in operate.
SYST:ZCH OFF	' Turn off zero check.
INIT	' Trigger sweep.
TRAC:DATA?	' Request all stored sweep readings.

Section 7

Triggering

In this section:

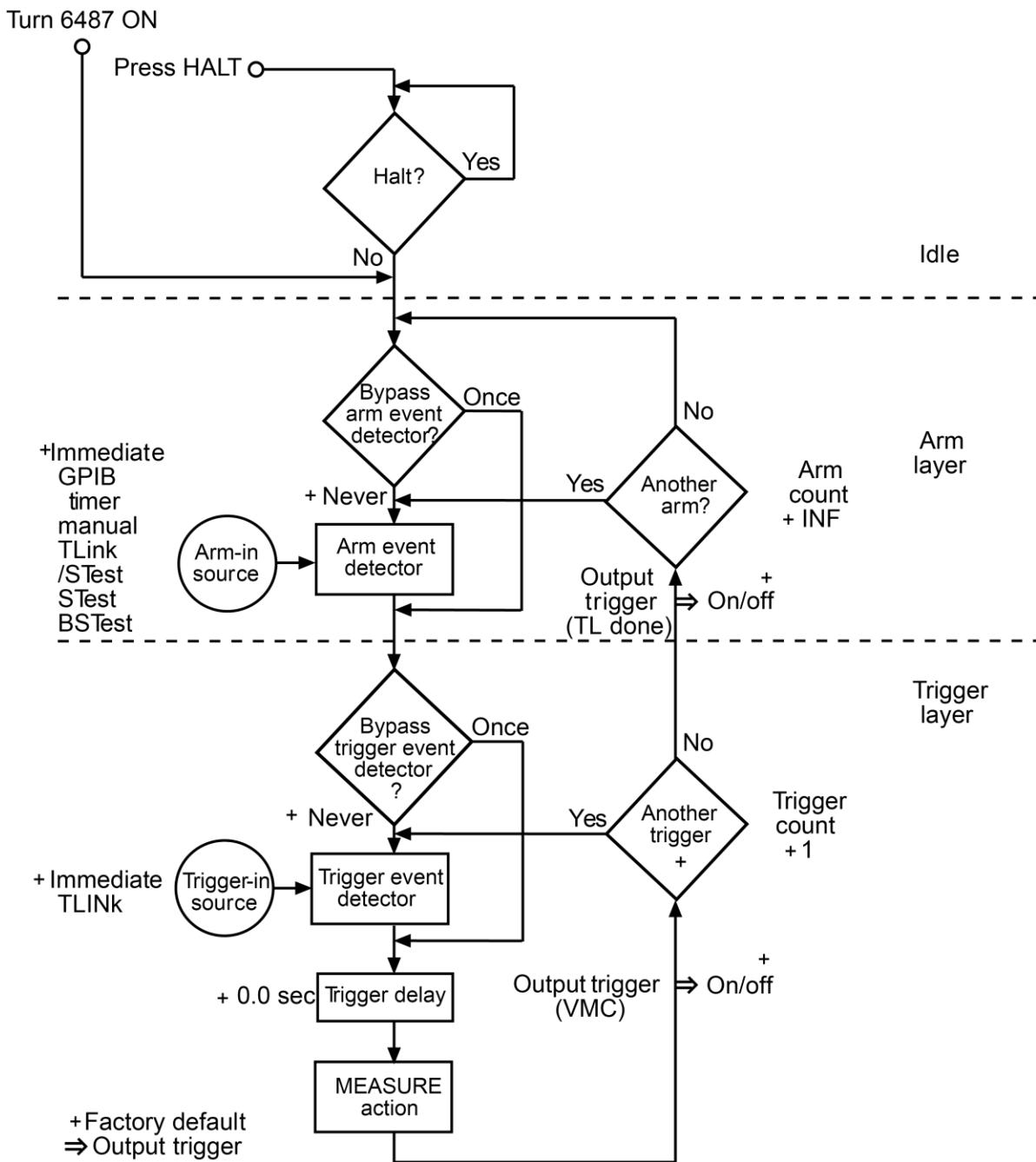
Trigger models	7-1
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Trigger models

The following flowcharts summarize triggering for the Model 6487. They are called trigger models because they are modeled after the SCPI commands to control triggering (operation).

The difference between front panel operation and remote operation is within the idle state of the instrument. Nomenclature in the front panel flowchart refers to the various names used for configuration menu items while the second flowchart provides the SCPI commands to control operation.

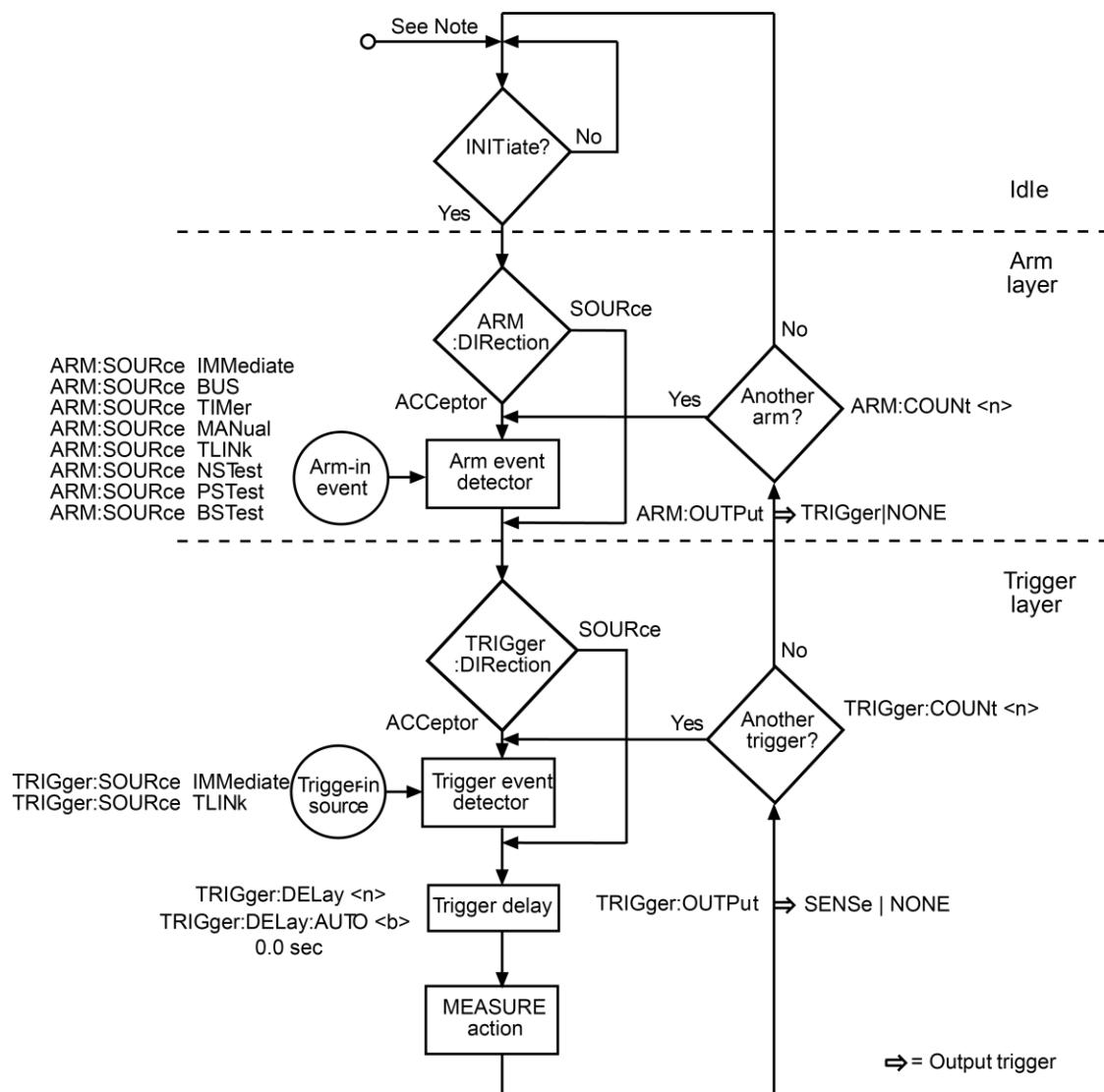
Figure 30: Trigger model, front panel operation



NOTE

The following commands place the 6487 into idle: ABORT, *RST, SYSTem:PRESet, *RCL <NRf>, DCL, and SDC.

Figure 31: Trigger model, remote operation



Idle, initiate, and operation

While in the idle state, the instrument cannot perform measurements. While in idle, the reading remains frozen or dashes replace the reading. For example, –.----- A. Once the 6487 idle state is removed, operation proceeds through the trigger model.

In front panel operation, the 6487 immediately leaves the idle state when it is turned on. Typically, operation remains in the arm and trigger layers of the trigger model. However, the 6487 can be put into the idle state at any time by selecting **HALT** in the trigger configuration menu. To take the instrument out of idle, press the **TRIG** key.

In remote operation, 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.

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 appropriate TLink control source is selected.

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 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 the Model 6487.
- **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. The 6487 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 the 6487 in local mode.
- **TLink** (ARM:SOURce TLINK): Event detection for the arm layer is satisfied when an input trigger via the TRIGGER LINK connector is received by the 6487. 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 handler.
- **STest** (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 handler.
- **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.

The Trigger-In control sources are explained as follows:

- **Immediate** (TRIGGER:SOURce IMMEDIATE): Event detection for the trigger layer is satisfied immediately allowing operation to continue 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 the 6487. 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 the 6487 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 6487 automatically sets delay according to range. The auto delay settings are listed in the following table.

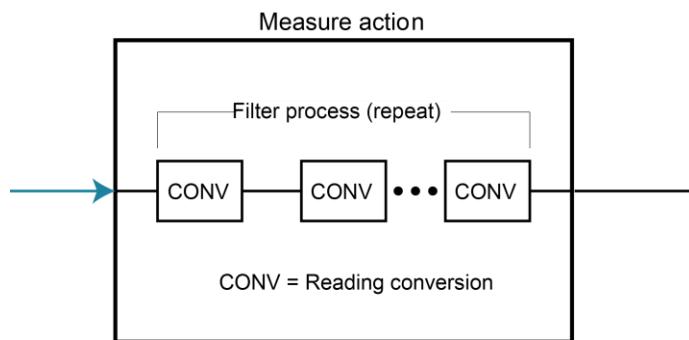
Range	Delay
2 nA	10 ms
20 nA	10 ms
200 nA	10 ms
2 μ A	10 ms
20 μ A	5 ms
200 μ A	5 ms
2 mA	1 ms
20 mA	0.5 ms

Measure action

The measure action block of the trigger model is where a measurement is performed. However, if the repeating filter is enabled, the instrument samples the specified number of reading conversions to yield a 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.

If a voltage sweep is active, one measure action per voltage step is performed.

Figure 32: Measure action block of trigger model



Output triggers

The 6487 can send out an output trigger from the rear panel TRIGGER LINK connector right after the measure action or when operation leaves the trigger layer. An output trigger can be used to trigger another instrument to perform an operation. For example, to 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, the operation will loop in the trigger layer until ten 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 ten additional measurements.

Trigger model configuration — front panel

NOTE

See [SCPI Programming](#) (on page 7-9) for the SCPI commands to configure the trigger model over the bus.

To configure both the **TRIG** and **ARM** layers of the trigger model, press **CONFIG** and then **TRIG**.

NOTE

When done configuring the trigger level, press **ENTER** to confirm value and then use the **EXIT** key to save changes and leave trigger model configuration.

Once in trigger model configuration mode, use the **RANGE** keys to display either the **trigger** layer or the **ARM** layer menus. Press **ENTER** to select the desired menu, then use the **RANGE** keys to display menu items. Use the cursor keys to key in values. You can select a menu item or value by pressing **ENTER**. Use the **EXIT** key to exit from the menu, saving all changes.

Menu	Description
CONFIG	Path to TRIG and ARM menu.
- TRIG	Path to TRIG layer sub-menus.
-- COUNT	Set TRIG measure count. Specify an INF inite measure count or specify a FIN ite measure count from 1 to 2048.
-- DELAY	Set trigger delay. Specify trigger delay from 0 to 999.9998 sec. Enable auto delay.
-- TRIG-OUT	Configure output triggers. Select the output trigger link line. Set a trigger link value from 1 to 6. Select VMC (voltmeter complete) output trigger. Enable or disable VMC.
-- TRIG-IN	Path to control source. Set the TRIG-IN control source. Set control source to IMM EDIATE. Set control source to TLINK . Set a TLINK value from 1 to 6. Set control source to EVENT . Enable (set to ONCE) or disable (set to NEVER).
- HALT	Stops triggering. Press TRIG to resume.
- ARM	Path to ARM layer submenus.
-- ARM-IN	Path to ARM-IN control source. Set control source to IMM EDIATE. Set control source to GPIB . Set control source to TIMER . Set the timer from 0.001 s to 27 h, 46 m, and 39.992 s.
-- MAN	Set control source to MAN UAL. Set control source to TLINK . Set a TLINK value from 1 to 6. Set control source to EVENT . Enable (set to ONCE) or disable (set to NEVER). Set control to negative pulse on SOT line. Set control to positive pulse on SOT line. Set control to positive or negative pulse on SOT line.
- ARM-OUT	Path to ARM-OUT trigger.
-- LINE	Set the output trigger link line. Set a trigger link value from 1 to 6.
-- EVENT	Set Trigger Layer Done event.
-- T - L - DONE	Enable or disable Trigger Layer Done.
-- COUNT	Set ARM measure count. Specify an INF inite measure count. Specify a FIN ite measure count from 1 to 2048.

NOTE

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

SCPI programming

The following table is a list of SCPI commands for triggering.

Command	Description	Default
ABORT	Reset trigger system (goes to idle state).	
INITiate	Initiate one trigger cycle.	
FETCh?	Request latest reading.	
READ?	Trigger and request a "fresh" reading.	
ARM[:SEQUence[1]] [:LAYER[1]]	Arm layer:	
:SOURCE <name>	Select control source: IMMEDIATE, TIMER, BUS, MANUAL, TLINK, PSTEST, NSTEST, or BSTEST.	IMM
:COUNT <n>	Set a measure count from 1 to 2048, or INF (infinite).	1
:TIMER <n>	Set timer interval from 0.001 to 99999.999 s.	0.1
[:TCONfigure]		
:DIRECTION <name>	Enable (SOURCE) or disable (ACCEPTOR) bypass.	ACC
[:ASYNchronous]	Configure input/output triggers:	
:ILINE <NRf>	Select input trigger line, 1 through 6.	1
:OLINE <NRf>	Select output trigger line, 1 through 6.	2
:OUTPUT <name>	Output trigger (TRIGGER) or not at all (NONE).	NONE
TRIGGER	Trigger layer:	
:CLEAR	Clear pending input trigger immediately.	
[:SEQUence[1]]	Trigger path.	
:SOURCE <name>	Select control source, IMMEDIATE or TLINK.	IMM
:COUNT <n>	Set measure count, 1 to 2048 or INF (infinite).	1
:DELAY <n>	Set trigger delay, 0 to 999.9998 (s).	0.0
:AUTO 	Enable or disable auto delay.	OFF
[:TCONfigure]		
:DIRECTION <name>	Enable (SOURCE) or disable (ACCEPTOR) bypass.	ACC
[:ASYNchronous]	Configure input/output triggers:	
:ILINE <NRf>	Select input trigger line, 1 through 6.	1
:OLINE <NRf>	Select output trigger line, 1 through 6.	2
:OUTPUT <name>	Output trigger after measurement (SENSe) or not at all (NONE).	NONE

ABORt

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

INITiate, FETCh, and READ?

After sending the `INITiate` 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.

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.

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.

ARM:SOURce <name>

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

ARM:DIRECTION <name>

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

ARM:ILINe <NRf> and ARM:OLINe <NRf>

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:CLEar

When this action command is sent, any pending (latched) input triggers are cleared immediately.

When the picoammeter 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.

Programming example

The following command sequence will trigger and return 10 readings.

Command	Comments
*RST	' Return 6487 to RST defaults.
ARM:SOUR IMM	' Set arm control source Immediate.
ARM:COUN 1	' Set arm count to 1.
TRIG:SOUR IMM	' Set trigger control source Immediate.
TRIG:COUN 10	' Set trigger count to 10.
SYST:ZCH OFF	' Disable zero check.
READ?	' Trigger and return 10 readings.

External triggering

The rear panel TRIGGER LINK connector provides a connection point for input and output triggers from the rear panel. 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 and output assignments can be changed. The connector pinouts are shown in the following figure.

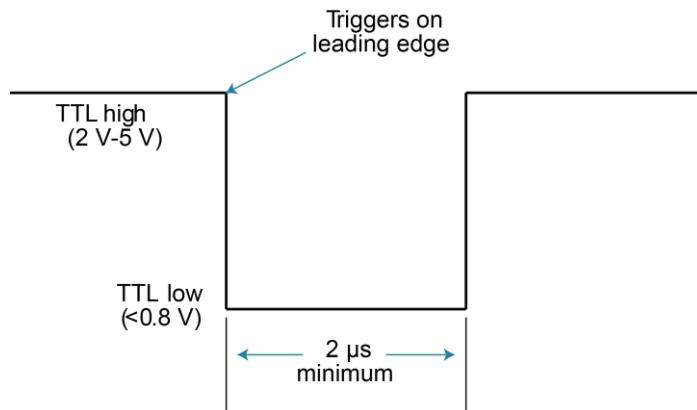
Figure 33: TRIGGER LINK pinouts

Rear panel pinout	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
Trigger link	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 the next figure.

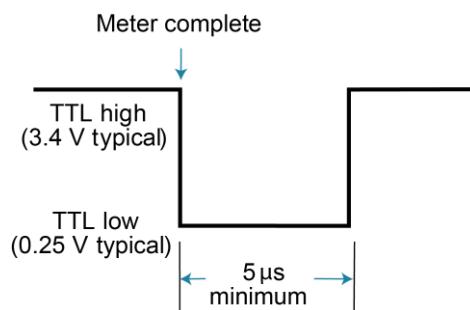
Figure 34: Trigger link input pulse specifications



Output trigger specifications

The 6487 can be programmed to output a trigger immediately after a measurement 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 the next figure. A trigger link line can source 1 mA and sink up to 50 mA.

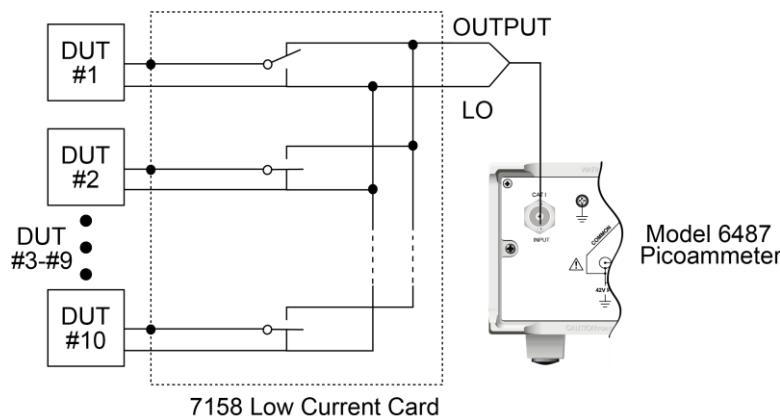
Figure 35: Trigger link output specifications



External trigger example

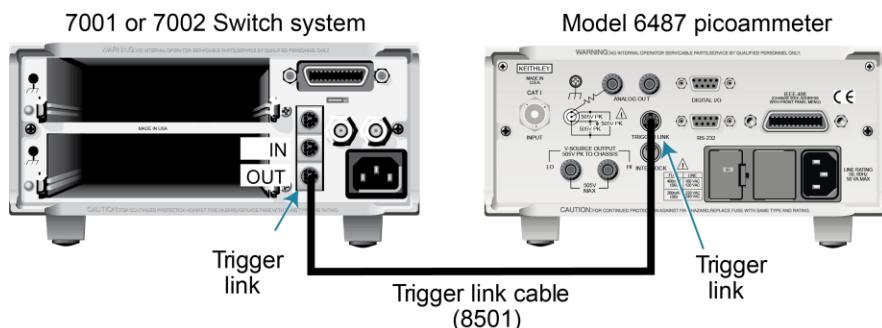
In a simple test system, you may want to close a switching channel and measure the current from a DUT connected to that channel. Such a test system is shown in the next figure. This example uses a 6487 to measure 10 DUTs switched by a Model 7158 low current card in a Model 7001 or 7002 switch system.

Figure 36: Simple test system with 10 DUTs



The trigger link connections for this test system are shown in the next figure. The trigger link of the 6487 is connected to the trigger link (IN or OUT) of the switching mainframe. With the default trigger settings of the switching mainframe, line 1 is an input and line 2 is an output.

Figure 37: Trigger link connections



For this example, the Model 6487 and switching mainframe are configured as follows:

Model 6487	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	

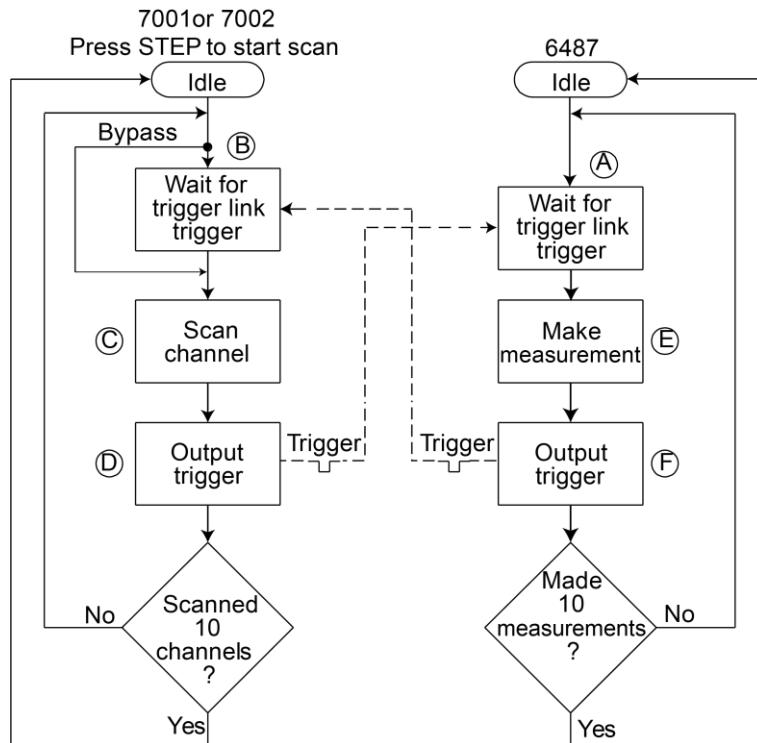
To store readings in the 6487 buffer:

1. Press **CONFIG** and then **STORE**.
2. Set the buffer size to 10 using the **RANGE** and cursor keys.
3. Press **ENTER**.

The next time **STORE** is pressed, the asterisk (*) annunciator turns on to indicate that the buffer is enabled. See the 6487 User's Manual (6487-900-01) for buffer details.

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 the 6487 to take a reading and store it. The 6487 then sends an output trigger pulse to the switching mainframe to close the next channel. This continues until all 10 channels are scanned, measured, and stored.

Figure 38: Example of an operational model for triggering



Details of this testing process are as follows:

- A. Operation of the Model 6487 starts at point A in the flowchart where it waits for an external trigger.
- B. Pressing STEP takes the 7001/7002 out of idle and places operation at point B in the flowchart.
- C. For the first pass through the 7001/7002, the scanner does not wait at point B. Instead, it closes the first channel (point C).
- D. After the relay settles, the 7001/7002 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 the 6487 at point A, the output trigger pulse from Model 7001/7002 triggers a measurement of DUT #1 (point E). When the measurement is complete, the 6487 outputs a trigger pulse and then loops back to point A where it waits for another input trigger.

The trigger applied to the 7001/7002 from the 6487 closes the next channel in the scan, which then triggers the 6487 to measure that DUT. This process continues until all 10 channels are scanned and measured.

Section 8

Limit tests and digital I/O

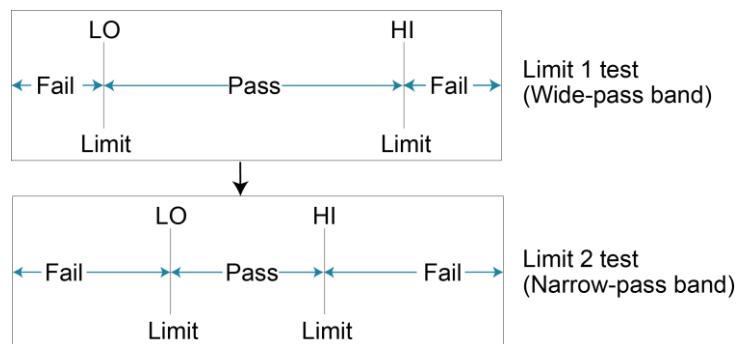
In this section:

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Performing limit tests	8-17
SCPI programming — limit tests	8-18

Limit testing

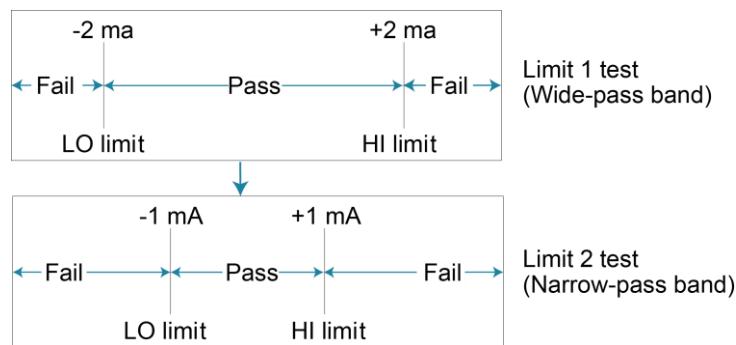
There are two limit tests can be performed on a DUT. Limit 1 is used as the wide-pass band and limit 2 is used as the narrow-pass band. It is up to the user to specify limits that conform to this pass band relationship.

Figure 39: Limit tests



The next figure shows an example where the HI and LO limits for limit 1 are ± 2 mA and the HI and LO limits for limit 2 are ± 1 mA. A 0 mA reading passes both limit 1 and limit 2 tests. A +1.5 mA reading passes limit 1 but fails limit 2. A +2.5 mA reading fails both limit 1 and Limit 2.

Figure 40: Limit test example



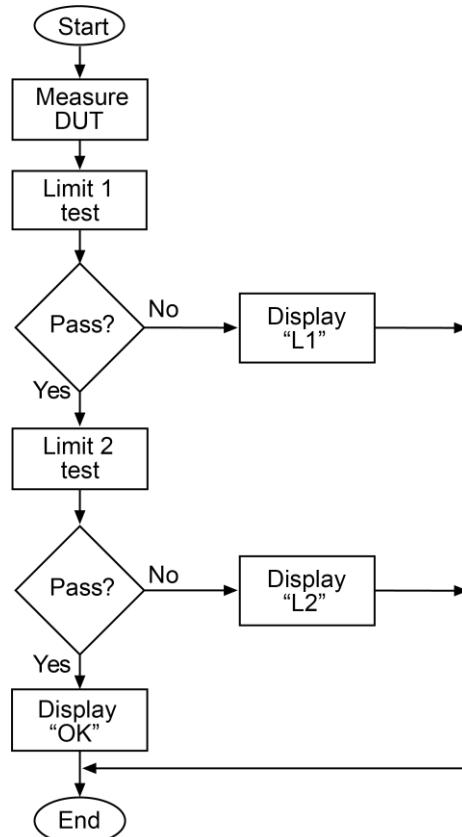
The two-stage limit testing process is shown in the next figure. If limit 1 fails, the L1 message is displayed and the test is finished. Limit 2 is not tested because the pass band relationship between the two stages implies that if limit 1 fails, limit 2 must also fail. If limit 1 passes, the limit 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.

NOTE

When limit tests are enabled, the voltage source value display is not visible, but it can still be viewed by using the CONFIG V-SOURCE menu or by pressing the V-SOURCE up or down arrow keys.

A test is only performed if it is enabled. You can perform a single-stage test or a two-stage test. In the flowchart, operation proceeds through a disabled test.

Figure 41: Operation model for limit test



NOTE

Display messages indicate which test or tests have failed, but they do not indicate whether the HI or LO limit has failed. When using remote operation, you can determine which limit failed by reading the measurement event register.

Relative (Rel), mX+b, m/X+b, and log can be used with limit testing. The tests will be done on the result of the math operation (not the input values).

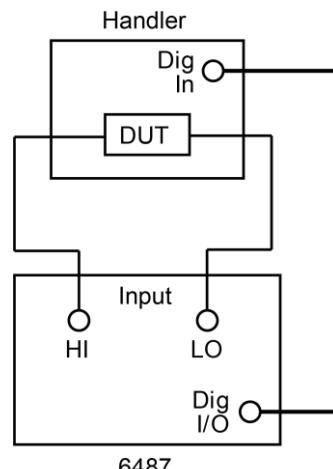
A typical application for a two-stage limit test is sorting a batch of DUTs according to tolerance. For example, you may want to sort diodes (all having the same nominal value) into three groups of 1%, 5%, and > 5%. The limits for limit 1 would be the 5 % tolerances and the limits for limit 2 would be the 1% tolerances. If a diode 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, the 6487 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.

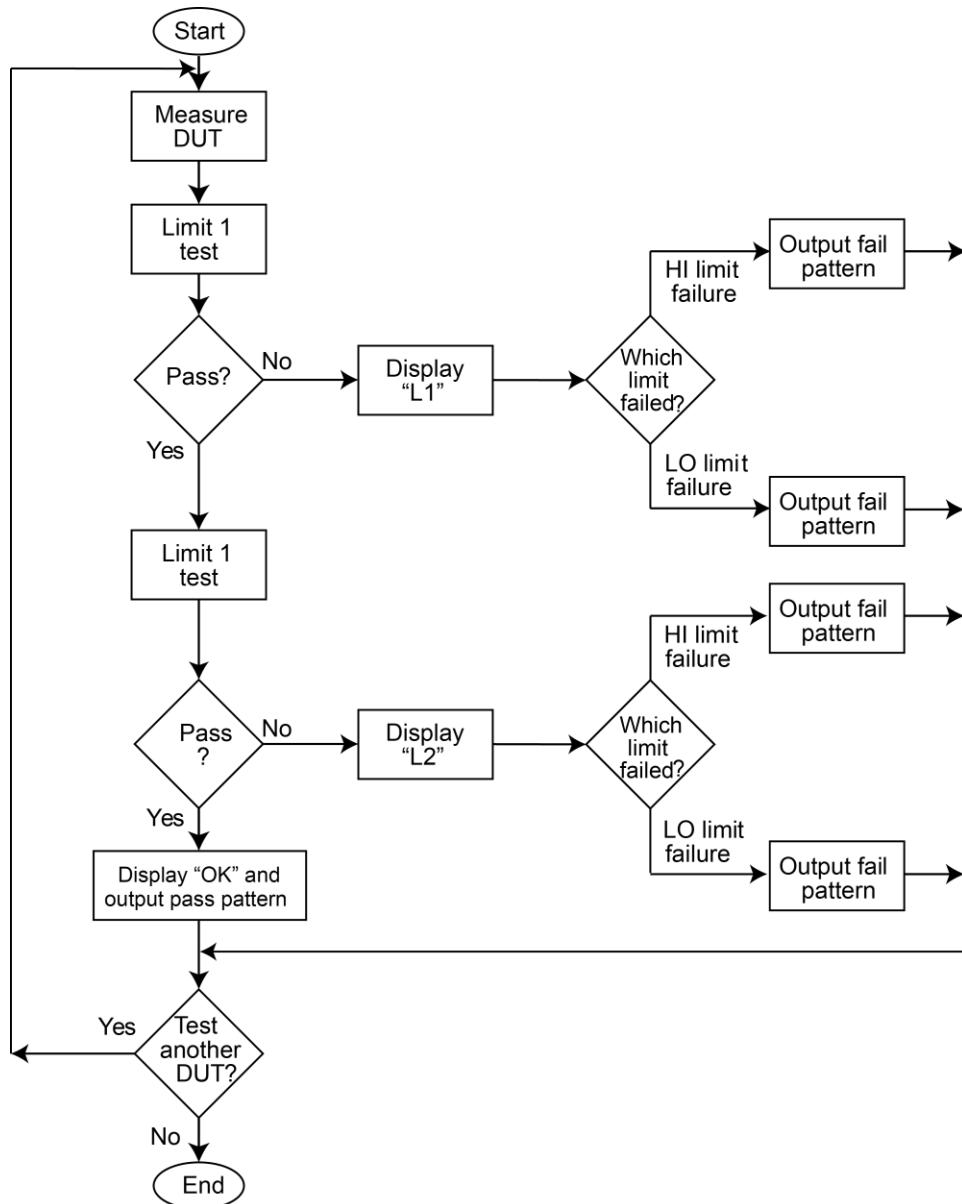
The next figure shows a basic binning system. After all programmed testing on the DUT is completed, the appropriate digital output pattern is sent to the component handler, which then places the DUT in the appropriate bin. The component handler selects the next DUT and the testing process is repeated.

Figure 42: Binning system



The next figure 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.

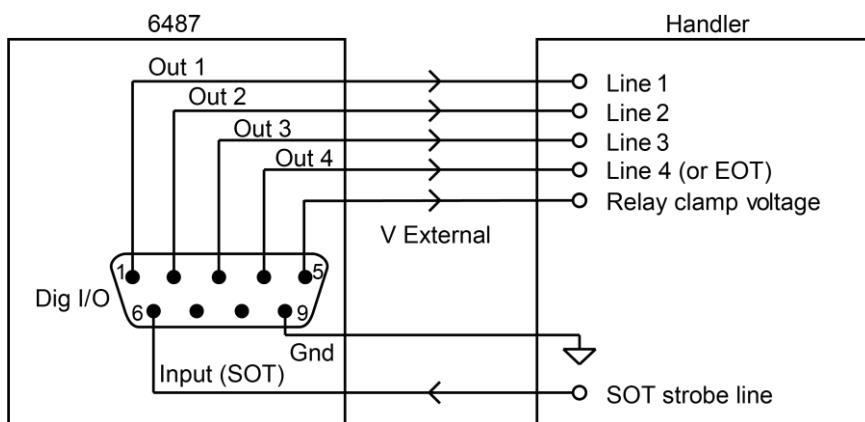
Figure 43: Operation model for limit testing with binning



Component handler interface

The 6487 uses the Digital I/O port to interface with a component handler. The 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 or fail signal to the component handler to perform the binning operation. A cable with a female DB-9 connector is required.

Figure 44: Handler interface connections



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 `STest` is the selected arm-in event, the test will start when the SOT line is pulled high. When `BSTest` is the selected arm-in event, the test will start when the SOT line is pulled either high or low.

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. When the component handler is ready (the DUT is properly positioned in the handler), it will either pull the SOT line low or high to start the test.

Digital output patterns

The 6487 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.

The 6487 can be used with either of the two basic types of handlers. When used with a category pulse handler, the 6487 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, the 6487 outputs a bit pattern to three handler lines. After the 6487 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

The 6487 can accommodate category pulse and category register component handlers.

Category pulse component handler

When using this type of handler, the 6487 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 the 6487 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 the 6487 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, the 6487 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, the 6487 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 category register component handler, the 6487 must be set for the End of Test mode. In this mode, the 6487 sends the EOT pulse to the component handler.

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.

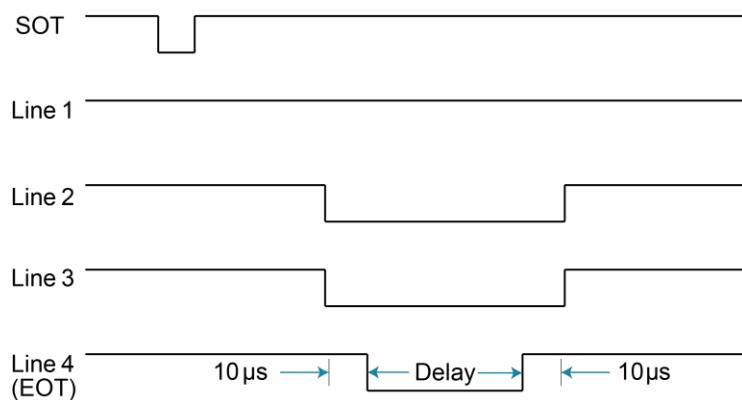
The 6487 can be programmed to automatically clear the digital output after the pass or fail pattern is sent. With auto-clear, you must specify the required pulse width (delay) for the pass or fail pattern. When not using auto-clear, you must return the digital output to its clear pattern.

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.

The following example timing diagram and discussion explain the relationship between the digital output lines for auto-clear timing. With the SOT line being pulsed low, /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.

Figure 45: Digital output auto-clear timing example



Initially, the four digital output lines are cleared. Limit tests start when the 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 previous figure, lines 2, 3, and 4 go low while line 1 remains high.

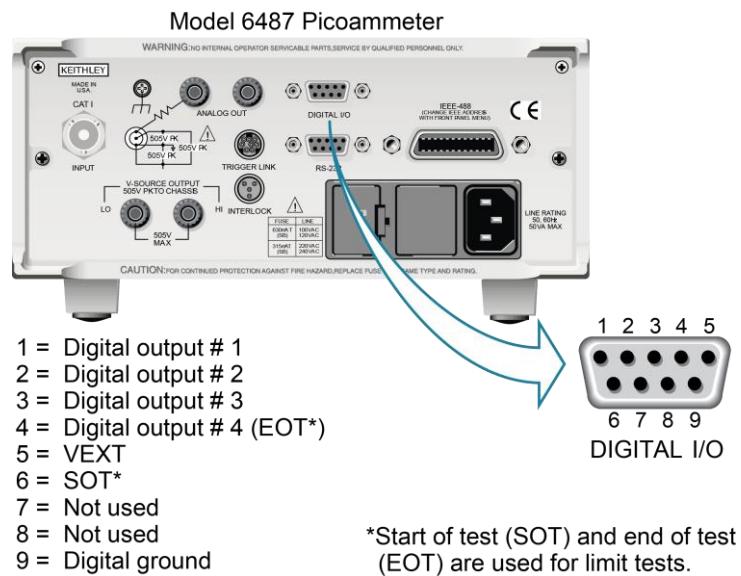
The pulse width (delay) of the pass/fail pattern can be set from 0 to 60 sec (10 µs resolution) as required by the component handler. Note that the delay specifies the pulse width of line 4. The pulse width of lines 1, 2, and 3 is actually 20 µs longer. Line 4 is skewed because it is used as the End-Of-Test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

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

Digital I/O port

The Digital I/O port of the 6487 is a male DB-9 connector located on the rear panel. The port location and pin designations are shown in the next figure. The four active-low, digital output lines and one input line are used to control external circuitry.

Figure 46: Digital I/O port

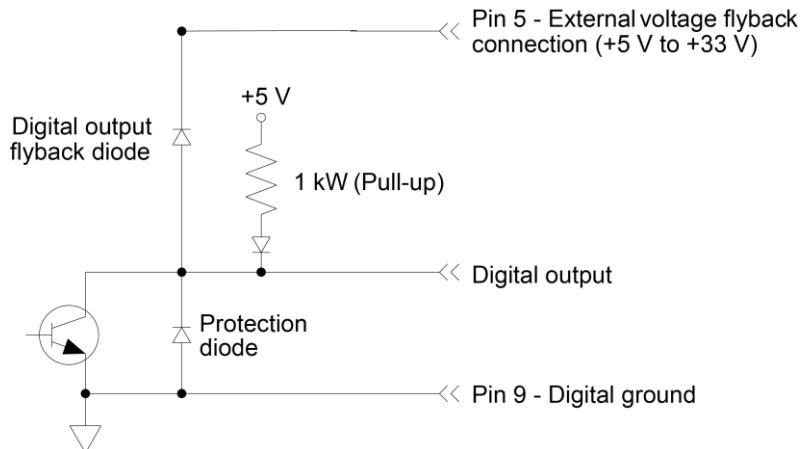


Typical applications for the digital I/O port include the following:

- **Component handler control:** When performing limit tests, a component handler can be used to sort DUT into bins. The digital I/O of the 6487 serves as the interface between the limit tests and the component handler. Using the digital input line (pin 6), the component handler can signal the 6487 when it is ready for the test from the digital input line (pin 6). The 6487 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.
- **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 500 mA. Drive voltage is provided by an external source (+5 V to +33 V).
- **Logic control:** The four digital outputs can be used as inputs to logic devices.

The simplified schematic for the digital outputs is shown in the next figure. This illustration shows the schematic for one digital output. All four digital output circuits are identical.

Figure 47: Digital I/O port simplified schematic



Sink mode — controlling external devices

Each output can be operated from an external supply (voltage range from +5 V to +33 V applied through the external device being driven). The high current sink capacity of the output driver allows direct control of relays, solenoids, and lamps.

Each of the four digital, open-collector outputs includes a built-in pull up resistor to +5 V. The output transistor is capable of sinking 500 mA from voltages up to +33 V. Each output channel contains a fly-back diode for protection when switching inductive loads, such as low power solenoids 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 +5 V and +33 V and the current required by the device does not exceed 500 mA.

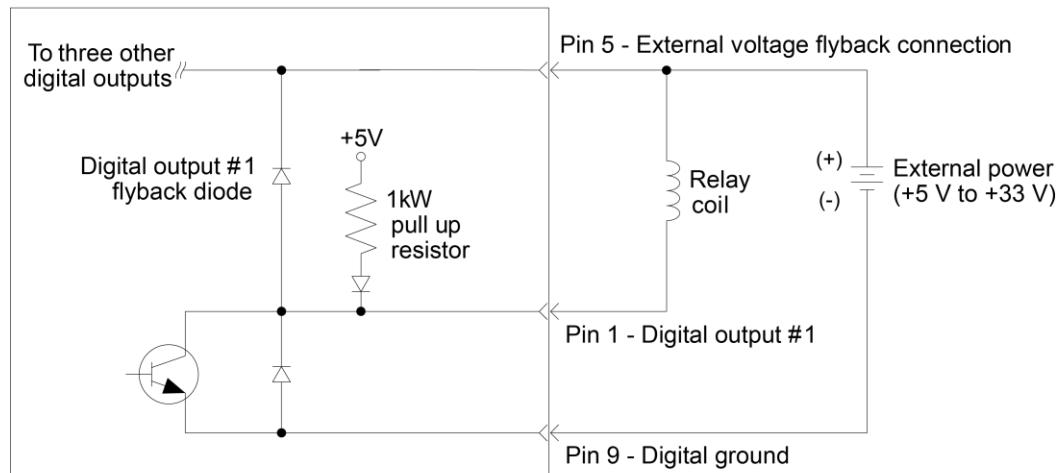
CAUTION

Do not exceed +33 V maximum voltage on pin 5 of the digital I/O port and do not use any output line to sink > 500 mA. Exceeding these limits may cause damage to the instrument that is not covered by the warranty.

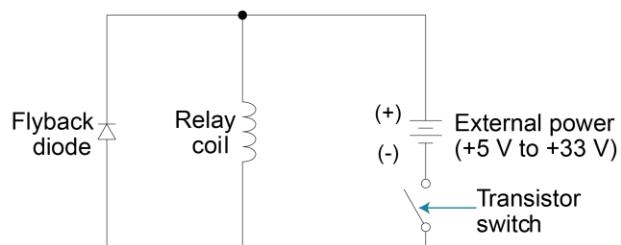
An externally powered relay connected to the digital output port is shown in the next figure. Other externally-powered devices can be connected by replacing the relay with the device. When the output line is set LO (0 V), the output transistor sinks current through the external device. In the HI state, the output transistor is off (transistor switch open). This interrupts current flow through the external device.

Figure 48: Controlling externally-powered relays

Model 6487



Equivalent circuit



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 2 mA.

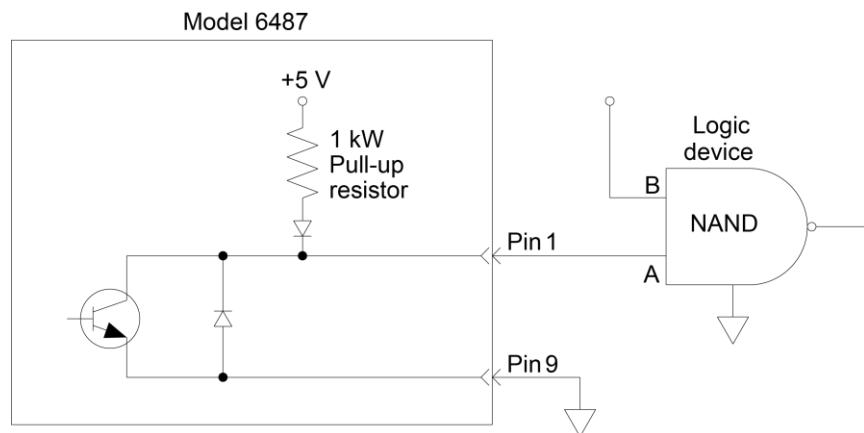
CAUTION

Each output line can source up to 2 mA. Exceeding 2 mA may cause damage to the 6487 that is not covered by the warranty.

The next figure 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 (>3.75 V). 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 (0 V) 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 49: 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).

To set the digital output pattern from the front panel:

1. Press **CONFIG** and then **LIMIT** to access the limits menu.
 2. Press the cursor keys until "LIMIT:PASS" is displayed.
 3. Press **ENTER**. The present digital output pattern value will be displayed.
 4. Use the cursor and **RANGE** 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

Command	Description	Default
<pre>:SOURce2 :TTL <NRf> <NDN> :TTL?</pre>	<p>SOURce2 subsystem: Specify 4-bit digital output pattern. Query the digital output pattern. The value returned is in the decimal format.</p>	15
Parameter Values:		
<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)	

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 SOURc2:TTL #B1010.

Programming example

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

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

Front panel operation — limit tests

Limit test configuration

Most aspects of limit testing are configured from the limit configuration menu. Once in a menu structure, use the cursor keys to display menu items. Use the cursor keys to input values. To change polarity of a value, place the cursor on + or - and press either of the **RANGE** keys. To change the range for the value, place the cursor on the range symbol and scroll using the range keys. Select a menu item or value by pressing **ENTER**.

Digital output bit patterns are set by selecting a decimal value that corresponds to the 4-bit BCD pattern of the output. To determine the output pattern value, add 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).

LIMIT 1 — Configure Limit 1 test:

- **CONTROL:** Enable or disable Limit 1 test.
- **HILIM:** Set the HI limit (-9.999999 T to +9.999999 T).
- **LOLIM:** Set the LO limit (-9.999999 T to +9.999999 T).

LIMIT 2 — Configure Limit 2 test:

- **CONTROL:** Enable or disable Limit 2 test.
- **HILIM:** Set the HI limit (-9.999999 T to +9.999999 T).
- **LOLIM:** Set the LO limit (-9.999999 T to +9.999999 T).

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.
- **DIGOUT:** Set the digital output clear pattern.

LIN4MOD (Line 4 Mode):

- **ENDOFTST (End of Test):** With this mode, 6487 will pulse the EOT line when the test is finished. Use with category register component handlers.
- **/BUSY and BUSY:** Pulls line 4 LO (/Busy) or HI (Busy) while the test is in process. Use with category pulse component handlers.

Arm layer configuration menu

To access this menu, press **CONFIG > TRIG**. Use the **RANGE** keys to scroll to the **ARM** menu.

- **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 low.
- **TEST** — Test starts when the handler pulls the SOT line of the Digital I/O high.
- **BTEST** — Test starts when the handler pulls the SOT line of the Digital I/O either high or low.

NOTE

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

Performing limit tests

Step 1. Configure test system

Configuring the test system can be as simple as connecting a DUT to your instrument.

Step 2. Configure measurement

Configure the 6487 for the desired measurement as covered in the previous sections of this manual.

Step 3. Configure limit tests

Configure the 6487 for the limit tests as explained in [Limit test configuration](#) (on page 8-16).

Step 4. Start testing process

To enable the limit tests, press **LIMIT**. The test begins when **LIMIT** is pressed. You can stop the testing process by again pressing the **LIMIT** key.

SCPI programming — limit tests

Command	Description	Default
:CALCulate2	CALCulate2 Subsystem:	
:FEED <name>	Select input path for limit testing: CALCulate[1] or SENSE[1].	SENS
: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
: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	Enable or disable Limit 1 test.	OFF
: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
:SOURce2 <NDN> or <NRf>	Specify 4-bit output "fail" pattern.	15
: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	Enable or disable Limit 2 test.	OFF
: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 	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
:DATA?	Return CALC2 reading(s) triggered by INITiate.	
:LATEST?	Return last (latest) CALC2 reading.	
:SOURce2	SOURce2 subsystem:	
:TTL <NDN> or <NRf>	Specify 4-bit digital output clear pattern.	15
:CLEar	Clear I/O port (return output to TTL pattern):	
[:IMMEDIATE]	Clear I/O port immediately.	
:AUTO 	Enable or disable auto-clear.	OFF

Command	Description	Default
: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
ARM	Trigger subsystem:	
:SOURce <name>	Arm layer: Select control source: NSTest, PSTest, BSTest, or IMMEDIATE.	IMM
INITiate	Initiate one trigger cycle.	
FORMAT	FORMAT subsystem:	
:SOURce2 <name>	Select data format for reading output patterns: <name> = ASCII (decimal format), HEXAdecimal (hexadecimal format), OCTal (octal format), BINary (binary format)	ASC

:FEED <name>

Name parameters are as follows:

- CALCulate1: Limit tests will be performed on the result of a math calculation ($mX+b$, $m/x+b$, or log).
- 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.

<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, 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 SCPI programming - limit tests](#) (on page 8-18)).

:FAIL?

In the event of a failure, you can read the measurement event register to determine whether the upper or lower limit failed. See [Status structure](#) (on page 10-1) to program and read the measurement event register.

:DATA? and :DATA:LATest?

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 outdated readings or cause an error (-220) if limit is not enabled or there are no readings available.

:ARM:SOURce <name>

Typical test starting 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.
- BSTest: Test starts when component handler pulls the SOT line high or low.

Programming example

The following command sequence will test a DUT using the "Limit tests example" graphic in Limit testing.

Command	Comments
*RST	' Restore RST defaults.
CALC2:LIM:UPP 2e-3	' Set upper limit for Limit 1 ' Return result of Limit 1 test.(2mA).
CALC2:LIM:LOW -2e-3	' Set lower limit for Limit 1 (-2mA).
CALC2:LIM:STAT ON	' Enable Limit 1 test.
CALC2:LIM2:UPP 1e-3	CALC2:LIM2:UPP 1e-3 ' Set upper limit for Limit 2 (1mA).
CALC2:LIM2:LOW -1e-3	CALC2:LIM2:LOW -1e-3 ' Set lower limit for Limit 2 (-1mA).
CALC2:LIM2:STAT ON	CALC2:LIM2:STAT ON ' Enable Limit 2 test.
*	' Connect DUT to input.
SYST:ZCH OFF	' Disable zero check.
INIT	' Perform tests on DUT (one measurement).
CALC2:LIM:FAIL?	' Return result of Limit 1 test.
CALC2:LIM2:FAIL?	' Return result of Limit 2 test.

Section 9

Remote operation

In this section:

Selecting and configuring an interface	9-1
RS-232 interface reference	9-16

Selecting and configuring an interface

Interfaces

The 6487 has a GPIB and an RS-232 interface. You can use only one interface at a time, and you can only select them from the front panel. The GPIB bus interface is the default.

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. The 6487 must be assigned to a unique address. At the factory the address is set to 22, 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. You can only use the SCPI language to program the instrument with the RS-232 interface.

Languages

For the GPIB interface, you can select one of the following programming languages:

- **SCPI (488.2):** Standard Commands for Programmable Instrument (SCPI) is fully supported by the GPIB and RS-232 interfaces. Always calibrate the 6487 using the SCPI language.
- **DDC:** The 6487 implements most DDCs (device-dependent commands) available in the Keithley Model 487 picoammeter. See the 487 Instruction Manual for details on operation.
- **488.1:** See [IEEE-488 and SCPI Conformance Information](#) (on page 21-1) for details.

NOTE

For the RS-232 interface, only the SCPI language can be used to program the instrument.

Interface selection and configuration

NOTE

The unit will reset if the language is changed (SCPI, 488.1, and DDC).

When you select the GPIB interface, the RS-232 interface is disabled. Conversely, selecting the RS-232 interface disables the GPIB interface.

Select the interface from the **COMM** menu structure. Use the **RANGE** keys to change the selected interface (RS-232 or GPIB). Press **ENTER** to save the change.

NOTE

When an interface is enabled (on) or disabled (off), the instrument will exit from the menu structure and reboot.

GPIB interface

Press the **CONFIG** key and then **COMM** to configure the GPIB address and language. From this menu, you can check or change the following settings:

- **Primary address:** 0 to 30
- **Language:** SCPI, 488.1, or DDC

To make changes to a setting, press the cursor right key. Use the **RANGE** keys and the cursor keys to select and modify the value.

Press **ENTER** to save the changes and stay in the menu. You can also press **EXIT** to save the changes but leave the menu.

RS-232 interface

NOTE

Only the SCPI language can be used with the RS-232 interface.

Select the RS-232 interface from the **COMM** menu. Press **CONFIG > COMM** key to configure the RS-232 interface and check or change the following settings:

- **BAUD:** Baud rate (57.6 K, 38.4K, 19.2k, 9600, 4800, 2400, 1200, 600, or 300)
- **BITS:** Data bits (7 or 8)
- **PARITY:** Parity (NONE, ODD, or EVEN)
- **TX TERMINATOR:** Terminator (CR, LF, CRLF, or LFCR)
- **FLOW:** Flow control (NONE or Xon/Xoff)

NOTE

See RS-232 interface reference for information on RS-232 settings and connections to the computer.

To make changes to a setting, press the cursor right key. Use the **RANGE** keys and the cursor keys to select and modify the value.

Press **ENTER** to save the changes and stay in the menu. You can also press **EXIT** to save the changes but leave the menu.

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. The Model 6487 conforms to these standards:

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

These standards define 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.

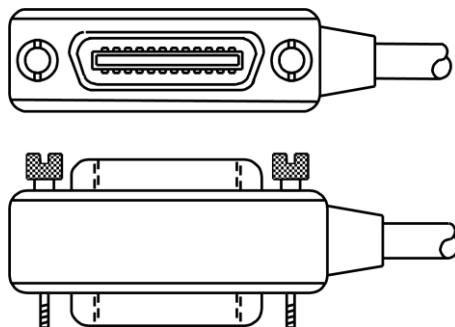
- SCPI 1996.0 (Standard Commands for Programmable Instruments)

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 the 6487 to the GPIB bus, use a cable equipped with standard IEEE-488 connectors.

Figure 50: IEEE-488 connector



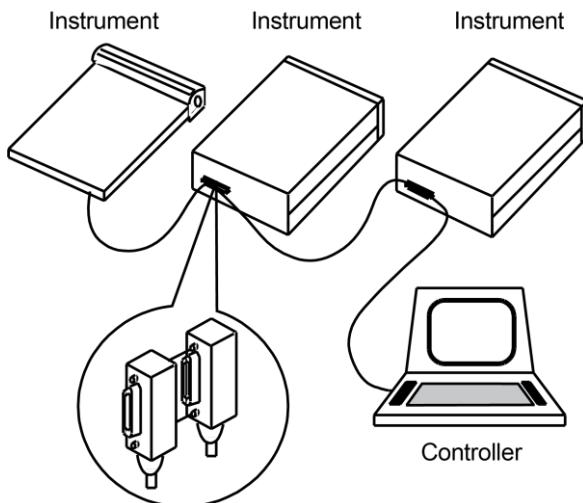
To allow many parallel connections to one instrument, stack the connectors. Two screws are located on each connector to ensure that connections remain secure. Use only shielded IEEE-488 cables to minimize interference caused by electromagnetic radiation.

The next figure shows a typical connection scheme for a multi-unit test system.

CAUTION

To avoid possible mechanical damage, stack no more than three connectors on any one instrument. To minimize interference caused by electromagnetic radiation, use only shielded IEEE-488 cables. Contact Keithley Instruments for shielded cables.

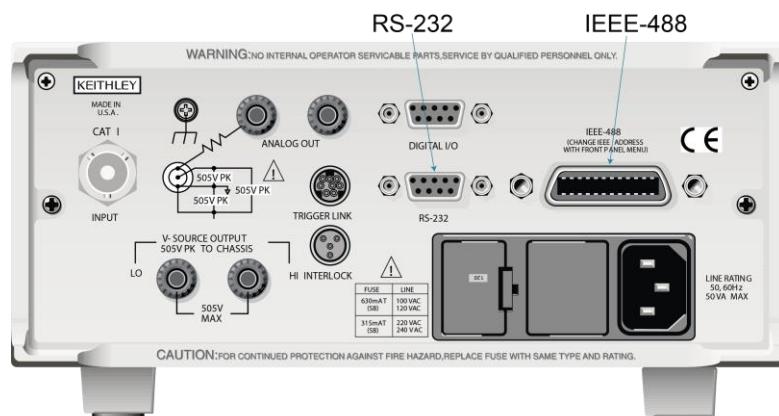
Figure 51: Multi-unit connections



To connect the 6487 to the IEEE-488 bus:

1. Align the cable connector with the connector located on the rear panel. The connector is designed so that it will fit only one way.

Figure 52: IEEE-488 and RS-232 connectors on rear panel



2. Tighten the screws securely. Do not over-tighten.
3. Connect any additional instruments.
4. Make sure that the other end of the cables are properly connected to the controller. Most controllers are equipped with an IEEE-488 style connector, but some may require a different type of connecting cable.

NOTE

You can have up to 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 connected devices, whichever is less. Not observing these limits can cause erratic bus operation.

Primary address

The 6487 is configured with a GPIB address of 22 from the factory. When the instrument powers up, it displays the primary address. You can set the address to a value from 0 to 30. Do not assign the same address to another device or to a controller that is on the same GPIB bus.

Controller addresses are usually assigned address 0 or 21. Make sure the address is the same that is specified in the programming language of the controller. To make sure that the unit interface is properly selected and configured, or to check or change the GPIB address, see Selecting and configuring an interface.

General IEEE-488 bus commands

Commands and associated statements

General commands have the same general meaning regardless of the instrument.

Command	Effect on the 6487
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 and restore front panel operation.
DCL	Returns all devices to known conditions.
SDC	Returns the 6487 to known conditions.
GET	Initiates a trigger.
SPE, SPD	Serial polls the 6487.

REN (remote enable)

The remote enable command is sent to the 6487 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. 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 mode to be a talker.

All front panel controls, except for **LOCAL** and **POWER**, are inoperative while the instrument is in remote mode. You can restore normal front panel operation by pressing the **LOCAL** key.

IFC (interface clear)

The controller sends the **IFC** command to place all instruments on the bus in the local, talker, and listener idle states. The 6487 responds to the command by canceling the 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. The 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 100 µs.

LLO (local lockout)

Use the **LLO** command to prevent local operation of the instrument. After the unit receives the **LLO** command, all front panel controls except **POWER** are inoperative. In this state, pressing **LOCAL** will not restore control to the front panel. See the [GTL](#) (on page 9-7) command for more information.

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. All instruments equipped to implement **DCL** will do so simultaneously.

When the 6487 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. The **DCL** command does not affect instrument settings or 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, as with **DCL**.

GET (group execute trigger)

GET is a GPIB trigger command used as an event to control operation. The 6487 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)

The **SPE**, **SPD** general bus command is used to serial poll the 6487. Serial polling obtains the serial poll byte (status byte). Typically, serial polling is used by the controller to determine which instrument has requested service with the SRQ line.

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.

Status and error messages

The instrument can be programmed to generate an SRQ and command queries can be performed to check for specific error conditions.

See [Status and error messages](#) (on page 18-1) for more information.

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 the 6487 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 unit is in local (not in remote), the LOCAL key acts as a configure key.

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 	Parameter required.
:SYSTem:PRESet	No parameter used.

NOTE

Common commands consist of an asterisk (*) followed by three or four letters. For example, you can reset the instrument by sending *RST.

Insert at least one space character 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
```

Note 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:

 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).

```
*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 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.

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 will generate an error.

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.
- If the fourth letter of the command word is a vowel, delete it and all letters after it.
- If the fourth letter of the command word is a consonant, retain it but drop all the letters after it.
- 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.
- 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.

:STATus	Path (Root)
:OPERation	Path
:ENABLE <NRf>	Command and parameter
:ENABLE?	Query command
:PRESet	Command

Single command messages

The previous 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 these program messages, the path pointer starts at the root command 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 (for example, [: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 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:
 - Do not use optional command words (for example, [:SENSE [1]]).
 - Do not use the colon (:) at the beginning of a program message.
 - Always use the short-form versions of commands and parameters.
 - Minimize the amount of space characters in command strings.
 - Keep numeric parameters simple (for example, 1 instead of 1.000e + 00).
 - Use uppercase letters.

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 the 6487 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, the multiple response messages for all the queries is sent to the computer when the 6487 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
```

See [Multiple command messages](#) (on page 9-13) for more information.

Response Message Terminator (RMT)

Each response is terminated with `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

Always tell the 6487 what to send to the computer. Send the appropriate query commands in a program message, then address the 6487 to talk. The complete response message must be received by the computer before another program message can be sent to the 6487.

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. When using the RS-232 interface, the unit will not respond to DDC or general GPIB commands.

RS-232 settings

Make sure the controller you connect to the 6487 also uses these settings you use for the RS-232 interface.

NOTE

You can break data transmissions by sending a `^C` or `^X` character string to the Model 6487. This clears any pending operation and discards any pending output.

Baud rate

The baud rate is the speed at which the 6487 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 the programming terminal that you are connecting to the 6487 can support the baud rate you have selected. Both the 6487 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

The 6487 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. The 6487 does not support hardware handshaking (flow control).

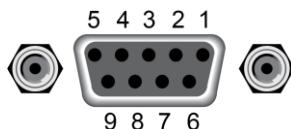
Software flow control is in the form of X_ON and X_OFF characters and is enabled when XonXoff is selected from the RS232 FLOW menu. When the input queue of the 6487 becomes more than three-quarters full, the instrument issues an X_OFF command. The control program should respond to this and stop sending characters until the 6487 issues the X_ON, which it will do once its input buffer has dropped below one-half full. The Model 6487 recognizes X_ON and X_OFF sent from the controller. An X_OFF will cause the Model 6487 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 the Model 6487. 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 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 CTS and RTS hardware handshaking lines.

Figure 53: RS-232 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 9-3 provides pinout identification for the 9-pin (DB-9) or 25-pin (DB-25) serial port connector on the computer (PC).

RS-232 connector pinouts

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, request to send
8	CTS, clear to send
9	No connections

RTS and CTS are tied together.

DCD, DTR, and DSR are tied together.

TXD and RXD are swapped on the 6487 and PC so that null modem cable is not required.

PC serial port pinouts

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

For RS-232 error messages, see [Status and error messages](#) (on page 18-1).

Section 10

Status structure

In this section:

Overview	10-1
Programming and reading registers.....	10-4
Status byte and service request (SRQ).....	10-6
Status register sets	10-10
Queues	10-17

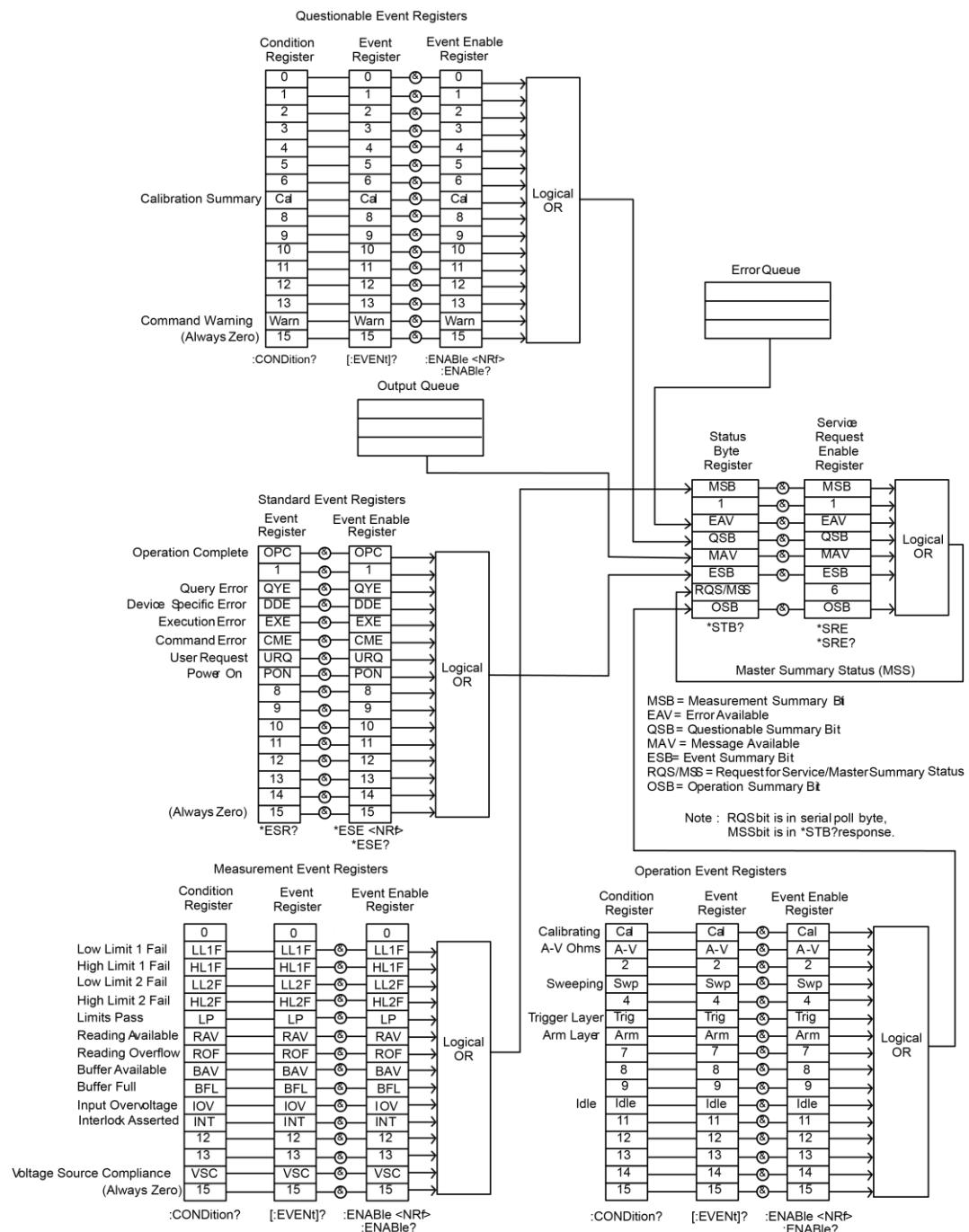
Overview

The 6487 provides a series of status registers and queues allowing the operator to monitor and manipulate the various instrument events. The heart of the status structure is the status byte register. This register can be read by the user's test program to determine if a service request (SRQ) has occurred and what event caused it.

Status byte and SRQ: The status byte register receives the summary bits of four status register sets and two queues. The register sets and queues monitor the various instrument events. When an enabled event occurs, it sets a summary bit in the status byte register. When a summary bit of the status byte is set and its corresponding enable bit is set (as programmed by the user), the RQS/MSS bit will set to indicate that an SRQ has occurred.

Status register sets: A typical status register set is made up of a condition register, an event register, and an event enable register. A condition register is a read-only register that constantly updates to reflect the present operating conditions of the instrument. When an event occurs, the appropriate event register bit sets to 1. The bit remains latched to 1 until the register is reset. When an event register bit is set and its corresponding enable bit is set (as programmed by the user), the output (summary) of the register will set to 1, which in turn sets the summary bit of the status byte register.

Queues: The 6487 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 54: Model 6487 status mode structure

Clearing registers and queues

When the 6487 is powered on, the bits of all registers in the status structure are cleared, and the two queues are empty. Commands to reset the event and event enable registers and the error queue are listed in the following table. 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.

Commands	Description	Note
To reset registers: *CLS STATus :PRESet	Reset all bits of the following event registers to 0: Standard event register Operation event register Measurement event register Questionable event register STATus subsystem: Reset all bits of the following enable registers to 0: Operation event enable register Measurement event enable register Questionable event enable register	*
To clear error queue: *CLS STATus :QUEue :CLEar SYSTem :ERRor :CLEar	Clear all messages from error queue STATus subsystem: Error queue: Clear messages from error queue SYSTem subsystem: Error queue: Clear messages from error queue	** ***

* 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 \(SRQ\)](#) (on page 10-6)".

** STATus:PRESet has no effect on the error queue.

*** 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 determine the parameter values for the various commands used to program enable registers. The actual commands are covered later in this section.

A command to program an event enable register is sent with a parameter value that determines the desired state (0 or 1) of each bit in the appropriate register. An enable register can be programmed using any of the following data formats for the parameter value: binary, decimal, hexadecimal, or octal.

The bit positions of the register indicate the binary parameter value. For example, if you want to set 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

The next figure includes the decimal weight for each register bit. To set bits B4, B3, and B1, the decimal parameter is the sum of the decimal weights for those bits (16+8+2 = 26).

Figure 55: 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)

The <NDN> (non-decimal numeric) parameter type is used to send non-decimal values. These values require a header (#B, #H, or #Q) to identify the data format being sent. The letter in the header can be upper or lower case. The <NRf> (numeric representation format) parameter type is used to send decimal values and does not use a header. The following examples show the proper parameter syntax for setting bits B5, B3, and B2:

```
#b101100 Binary format (<NDN> parameter type)
#h2C     Hexadecimal format (<NDN> parameter type)
#q54     Octal format (<NDN> parameter type)
44       Decimal format (<NRf> parameter type)
```

Valid characters for the non-decimal parameter values are shown as follows:

<NDN> format	Valid characters
Binary	1s and 0s
Hexadecimal	0 through 9 and A through F
Octal	0 through 7

Reading registers

Any register in the status structure can be read by using the appropriate query command. The following explains how to interpret the returned value (response message). The actual query commands are covered later in this section.

The response message will be a value that indicates which bits in the register are set. That value (if not already binary) will have to be converted to its binary equivalent. For example, for a binary value of 100101, bits B5, B2, and B0 are set.

The returned value can be in the binary, decimal, hexadecimal, or octal format. The **FORMAT:SREGister** command is used to select the data format for the returned value.

For non-decimal formats, one of the following headers will accompany the returned value to indicate which format is selected:

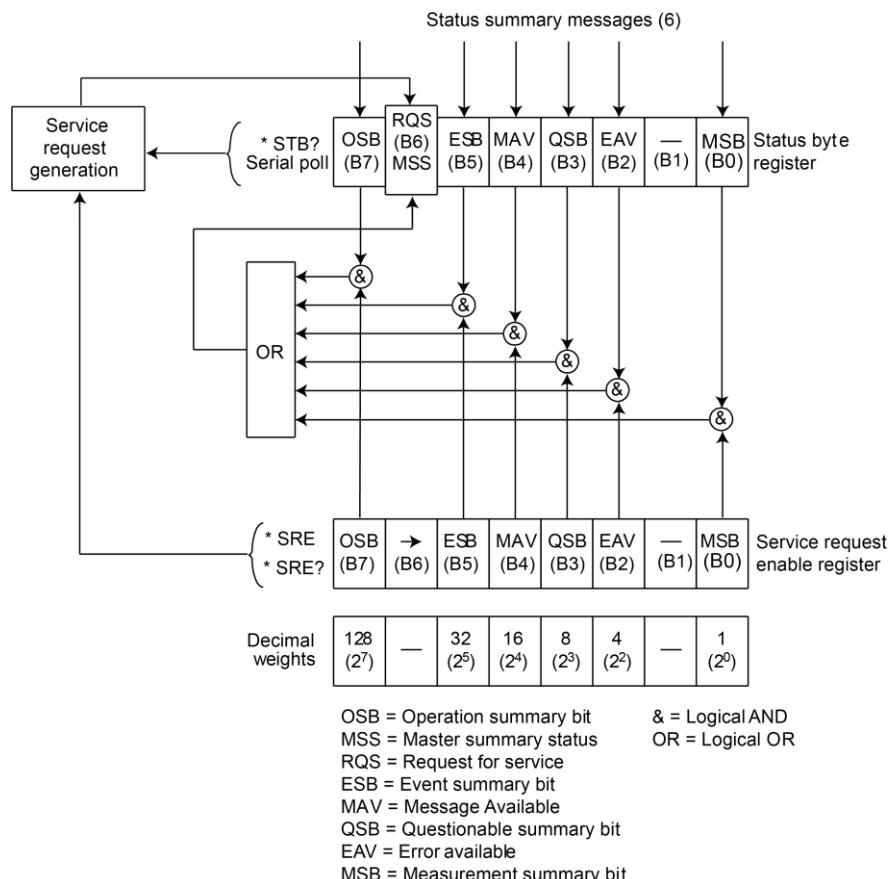
#B = Header for binary values,
 #H = Header for hexadecimal values,
 #Q = Header for octal values.

Command	Description	Default
:FORMAT :SREGISTER <name>	FORMAT subsystem Select data format for reading status registers: <name> = ASCII Decimal format HEXadecimal Hexadecimal format OCTal Octal format BINary Binary format	ASCII

Status byte and service request (SRQ)

A service request is controlled by two 8-bit registers: the status byte register and the service request enable register. The following figure shows the structure of these registers.

Figure 56: 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 the Model 6487 to obtain the status byte (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 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. 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 output is applied to the input of the OR gate and 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 (for example, *SRE 0).

Serial polling and SRQ

Any enabled event summary bit that goes from 0 to 1 will set bit B6 and generate a 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 the 6487. If a 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 a 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 the 6487. 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 the next table. For details on programming and reading registers, see [Programming enable registers](#) (on page 10-4) and [Reading registers](#) (on page 10-5).

To reset the bits of the service request enable register to 0, use 0 as the parameter value for the *SRE command.

Command	Description	Note
*STB?	Read status byte register.	
*SRE <NDN> or <NRF>	Program the service request enable register: <NDN> = #Bxx...x (binary format (each x = 1 or 0)), #Hx (hexadecimal format (x = 0 to FF)), #Qx (octal format (x = 0 to 377)). <NRF> = 0 to 255 Decimal format	*
*SRE?	Read the service request enable register.	

*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. To determine the nature of the error, you will have to read the error queue. See [Queues](#) (on page 10-17) for more information.

Command	Comments
*CLS	' Clear Error Queue.
*SRE 4	' Enable EAV.
FORM:SREG BIN	' Select binary format.
BadCommand	' Generate error.
*STB?	' Read Status Byte Register.

Status register sets

There are four status register sets in the status structure of the 6487:

- Standard event status
- Operation event status
- Measurement event status
- Questionable event status

Register bit descriptions

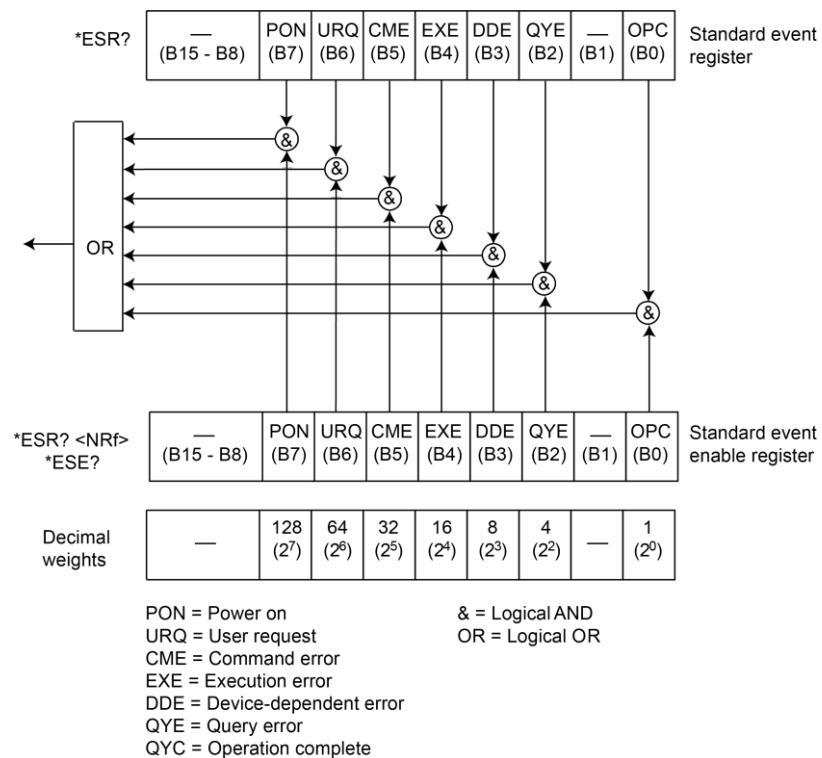
Standard event status

The bits of the standard event register are described as follows:

- Bit B0, operation complete (OPC) — Set bit indicates that all pending selected device operations are completed and the 6487 is ready to accept new commands. This bit only sets in response to the *OPC? query command.
- 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 the 6487 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 — The 6487 received a message that does not follow the defined syntax of the IEEE-488.2 standard.
- Semantic error — The 6487 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.

Figure 57: Standard event status

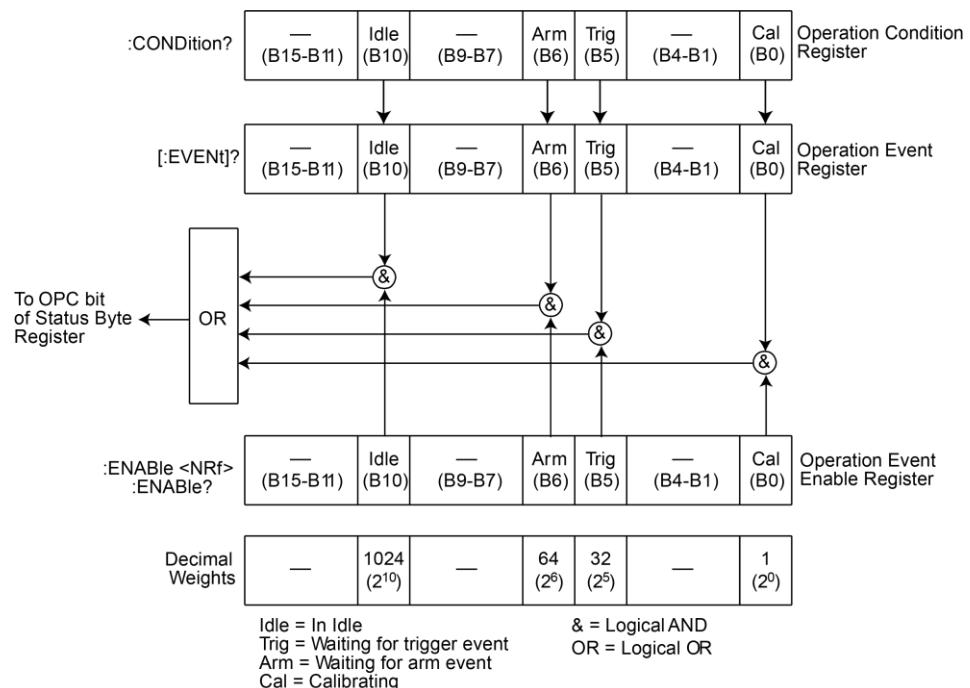
- Bit B6, user request (URQ) — Set bit indicates that the LOCAL key on the 6487 front panel was pressed.
- Bit B7, power ON (PON) — Set bit indicates that 6487 has been turned off and turned back on since the last time this register has been read.

Operation event status

The used bits of the operation event register are described as follows:

- Bit B0, calibrating (CAL) — Set bit indicates that the 6487 is calibrating.
- Bit B1, A-V Ohms — Set bit indicates that alternating voltage ohms is running.
- Bit B3, Sweeping — Set bit indicates that a voltage sweep is running.
- Bit B5, waiting for trigger event (Trig) — Set bit indicates that the 6487 is in the trigger layer waiting for a TLINK trigger event to occur.
- Bit B6, waiting for arm event (Arm) — Set bit indicates that the 6487 is in the arm layer waiting for an arm event to occur.
- Bit B10, idle state (Idle) — Set bit indicates the 6487 is in the idle state.

Figure 58: Operation event status

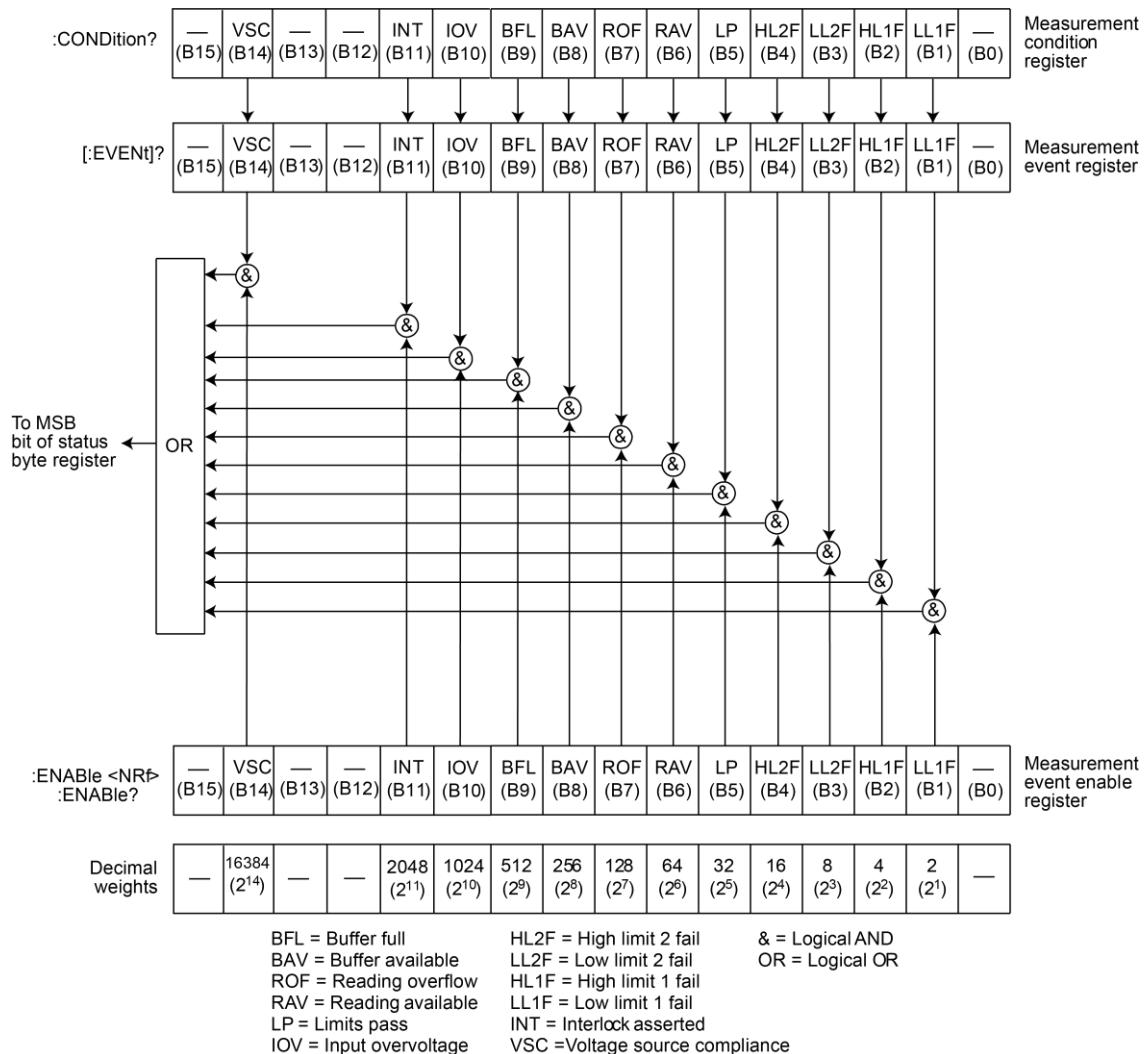


Measurement event status

The bits of the measurement event register 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.

Figure 59: Measurement event status



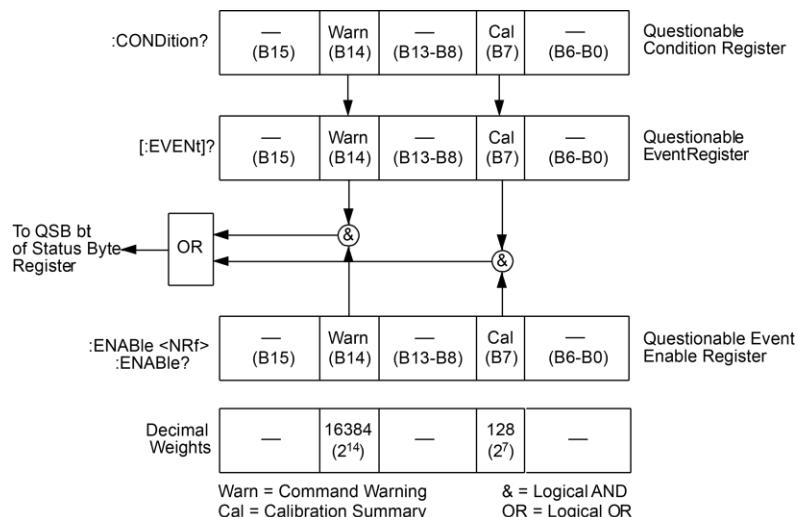
- Bit B3, low-limit 2 fail (LL2F) — Set bit indicates that the low-limit 2 test has failed.
- Bit B4, high-limit 2 fail (HL2F) — Set bit indicates that the high-limit 2 test has failed.
- Bit B5, limits pass (LP) — Set bit indicates that all limit tests passed.
- Bit B6, reading available (RAV) — Set bit indicates that a reading was taken and processed.
- Bit B7, reading overflow (ROF) — Set bit indicates that the reading exceeds the selected measurement range of the 6487.
- 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. This bit will also be set when a voltage sweep has been completed, and if the programmed number of A-V ohms cycles have been taken.
- Bit B10, input overvoltage (IOV) — Set bit indicates there is an input overvoltage condition.
- Bit B11, output interlock asserted (INT) — Set bit indicates that the output interlock is asserted and the voltage source output cannot be turned on.
- Bit B14, voltage source compliance (VSC) — Set bit indicates that the voltage source is in compliance.

Questionable event status

The bits of the questionable event register 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 the 6487.
- Bit B14, command warning (Warn) — Set bit indicates that a signal oriented measurement command parameter has been ignored.

Figure 60: Questionable event status



Condition registers

Each status register set (except the standard event register set) has a condition register. A condition register is a real-time, read-only register that constantly updates to reflect the present operating conditions of the instrument. For example, while the 6487 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 the next table. For details on reading registers, see [Reading registers](#) (on page 10-5).

Command	Description
STATus :OPERation:CONDition? :MEASurement:CONDition? :QUESTIONable:CONDition?	STATus subsystem: Read operation condition register. Read measurement condition register. Read questionable condition register.

Event registers

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 the next table. See [Reading registers](#) (on page 10-5) for additional details.

NOTE

The bits of any enable register can be reset to 0 by sending the 0 parameter value with the appropriate enable command.

Command	Description
*ESR? STATus :OPERation[:EVENT]? :MEASurement[:EVENT]? :QUESTIONable[:EVENT]?	Read standard event status register. STATus subsystem: Read operation event register. Read measurement event register. Read questionable event register.

Power-up and *CLS resets all bits of all event registers to 0. STATus:PRESet has no effect.

Event enable registers

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 the next table. 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.

Command	Description
*ESE <NDN> or <NRf>	Program standard event enable register.
*ESE?	Read standard event enable register.
STATus	STATUS subsystem
:OPERation	Operation event enable register:
:ENABLE <NDN> or <NRf>	Program enable register.
:ENABLE?	Read enable register
MEASurement	Measurement event enable register:
:ENABLE <NDN> or <NRf>	Program enable register
:ENABLE?	Read enable register
QUESTIONable	Questionable event enable register:
:ENABLE <NDN> or <NRf>	Program enable register
: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.

Command	Comments
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

The 6487 uses two queues which are first-in, first-out (FIFO) registers:

- **Output queue:** Used to hold reading and response messages.
- **Error queue:** Used to hold error and status messages.

The 6487 status model 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 the 6487 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 or 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 or 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 and status messages. The commands to read the error queue are listed in the next table. 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 "Status and Error Messages." As shown in the next table, 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 the next table, 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, the messages that are not specified in the list are disabled. When you disable messages, each listed message is removed from the enabled list.

To prevent all messages from entering the error queue, send the enable command along with the null list parameter as follows: STATus:QUEue:ENABLE () .

Command	Description	Default
STATus :QUEue [:NEXT] ? :ENABle <list> :ENABLE? : DISable <list> :DISable? :CLEar	STATus subsystem: Read error queue: Read and clear oldest error/status (code and message). Specify error and status messages for error queue. Read the enabled messages. Specify messages not to be placed in queue. Read the disabled messages. Clear messages from error queue.	*
SYSTem :ERRor [:NEXT] ? :ALL? :COUNT? :CODE [:NEXT] ? :ALL?	SYSTem subsystem: Read error queue: Read and clear oldest error/status (code and message). Read and clear all errors/status (code and message). Read the number of messages in queue. Code numbers only: Read and clear oldest error/status (code only). Read and clear all errors/status (codes only).	**

* Power-up and *CLS empties the error queue. STATus:PRESet has no effect.

** 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.'
```

Section 11

Common commands

In this section:

Common commands 11-1

Common commands

Mnemonic	Name	Description
*CLS	Clear status	Clears all event registers and error queue.
*ESE <NRf>	Event enable command	Program the standard event-enable register.
*ESE?	Event enable query	Read the standard event-enable register.
*ESR?	Event status register query	Read the standard event-enable register and clear it.
*IDN?	Identification query	Returns the manufacturer, model number, serial number, and firmware revision levels of the unit.
*OPC	Operation complete command	Set the operation complete bit in the standard event register after all pending commands have been executed.
*OPC?	Operation complete query	Places an ASCII 1 into the output queue when all pending selected device operations have been completed.
*OPT?	Option query	Returns model number of any installed options.
*RCL <NRf>	Recall command	Returns the 6487 to the user-saved setup.
*RST	Reset command	Returns the 6487 to the *RST default conditions.
*SAV <NRf>	Save command	Saves the present setup as the user-saved setup.
*SRE <NRf>	Service request enable command	Programs the service request enable register.
*SRE?	Service request enable query	Reads the service request enable register.
*STB?	Status byte query	Reads the status byte register.
*TRG	Trigger command	Sends a bus trigger to the 6487.
*TST?	Self-test query	Performs a checksum test on ROM and returns the result.
*WAI	Wait-to-continue command	Wait until all previous commands are executed.

IDN?

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 6487, xxxxxxxx, yyyy/zzzz/w
```

Where: xxxxxxxx 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, and w is the board revision level.

OPC and OPC?

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 *OPC?) are executed. After the last pending command is executed, the OPC bit and/or an ASCII 1 is placed in the output queue.

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 6487 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?.'
```

SAV <NRf> and RCL <NRf>

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.

The 6487 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 6487 to RST defaults.  
*RCL 2      ' Return (recall) 6487 to setup stored in memory location 2.
```

RST

When the *RST command is sent, the 6487 performs the following operations:

- Returns the 6487 to the RST default conditions.
- Cancels all pending commands.
- Cancels response to any previously received *OPC and *OPC? commands.

TST?

Use this query command to perform a checksum test on the instrument's read-only memory (ROM). The command places the coded result (0 or 1) in the output queue. When the 6487 is addressed to talk, the coded result is sent from the output queue to the computer.

A returned value of 0 indicates that the test passed and a value of one indicates that the test failed.

WAI

The *WAI command is a No-Op (no operation) for the 6487 and 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. This command is not needed for sequential commands.

Section 12

SCPI signal-oriented measurement commands

In this section:

SCPI signal-oriented measurement commands	12-1
CONFigure[:<function>]	12-2
FETCh?	12-2
READ?	12-3
MEASure[:<function>]?	12-3

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 the following table.

NOTE

The readings acquired by these commands depend on which data elements are selected.

Command	Description
CONFigure[:<function>]	Places the 6487 in one-shot measurement mode. <function> = CURR[:D]
CONFigure?	Queries the selected function. Returns 'CURR'.
FETCh?	Requests the latest reading(s).
READ?	Performs an INITiate and a :FETCh?.
MEASure[:<function>]? ?	Performs a CONFigure:<function> and a :READ?

CONFigure[:<function>]

This command configures the instrument for [one-shot measurements](#) (on page 3-29). Each subsequent `READ?` command will then trigger a single measurement and acquire the reading.

If the instrument is in the idle state, this command will execute immediately. If the instrument is not in the idle state, the command will execute when the instrument returns to the idle state.

When this command is executed, the 6487 is 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.
- The 6487 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.

The following command sequence selects and configures the 6487 for one-shot measurements. Each subsequent `READ?` triggers a single measurement and requests the reading.

```
CONF:CURR  ' Perform CONFigure operations.  
READ?        ' Trigger measurement and request reading.
```

FETCh?

This command requests the latest post-processed readings. After sending this command and addressing the 6487 to talk, the readings are sent to the computer. This command does not affect the instrument setup.

This command can repeatedly return the same reading. Until there is a new reading, this command continues to return the old reading. If your application requires a new reading, use the `:READ?` command.

This command is automatically executed when the `:READ?` or `:MEASure?` command is sent.

READ?

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 of measurements. The command will execute only when the instrument enters the idle state.

The FETCH? command is executed to acquire the reading(s). The readings are sent to the computer when the 6487 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 stop the measurement, and then use SENSE:DATA[:LAST] ? to return the latest reading.

MEASure[:<function>]?

This command combines all of the other signal oriented measurement commands to perform a [one-shot measurement](#) (on page 3-29) 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.

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?](#) (on page 12-3) for details

DISPlay, FORMat, and SYSTem

In this section:

DISPlay, FORMat, and SYSTem13-1

DISPlay, FORMat, and SYSTem

DISPlay subsystem

The commands in this subsystem are used to control the display over the bus.

Command	Description	Default
:DISPlay		
:DIGits <n>	Set display resolution from 4 to 7.	6
:DIGits?	Query display resolution.	*
:ENABle 	Turn front panel display on or off.	*
:ENABLE?	Query front panel display status.	
[:WINDOW[1]]		
:TEXT		
[:DATA] <a>	Path to control user text messages: Define ASCII message "a" (up to 12 characters).	*
[:DATA] ?	Query-defined ASCII message.	
:STATE 	Enable or disable text message mode.	

DISPlay:ENABLE

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.

DISPlay:TEXT[:DATA] <a>

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.

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)

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.

DISPlay:TEXT:STATe

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 mode. Taking the instrument out of remote or cycling power cancels the message and disables the text message mode.

RS-232 operation. A user-defined message can be canceled 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.

Command	Description	Default
:FORMat		
:DATA <type>[,<length>]	Specify data format: ASCii, REAL, 32 or SREal.	ASCii
:DATA?	Query data format.	
:ELEMEnts <item list>	Specify data elements: READING, UNITS, VSOURCE, TIME, STATUS, DEFault, and ALL.	All except VSO
:BORDer <name>	Specify byte order: NORMAL or SWAPPED.	*
:BORDer?	Query byte order.	
:SREGister <name>	Select data format for reading status registers: ASCii, HEXadecimal, OCTal, or BINary.	ASC
:SREGister?	Query data format for reading status registers.	
:SOURce2 <name>	Select data format for reading output patterns: ASCii, HEXadecimal, OCTal, or BINary.	ASC
:SOURce2?	Query data format for output patterns.	

* *RST default is NORMAL. SYSTEM:PRESet default is SWAPPED.

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 the 6487.

The response to READ?, FETCh?, MEASure?, TRACe:DATA?, CALC1:DATA?, CALC2:DATA?, or CALC3: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. Only the ASCII format is permitted over the RS-232 interface.

NOTE

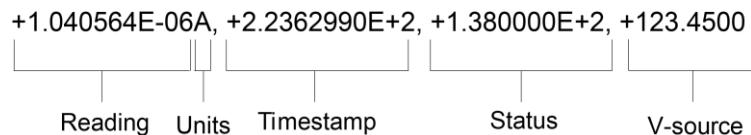
Regardless of which data format for output strings is selected, the instrument will only respond to input commands using the ASCII format.

ASCII data format

The ASCII data format is in a direct readable form for the operator. Most programming languages easily convert ASCII data and exponent to other formats. However, some speed is compromised to accommodate the conversion. The next figure shows an example ASCII string that includes all the data elements. See :ELEMENTs for information on the data elements.

The next figure shows the byte order of the data string. Data elements not specified by the :ELEMENTs command are simply not included in the string. Note that the status value is always an integer, but it is still expressed in scientific notation.

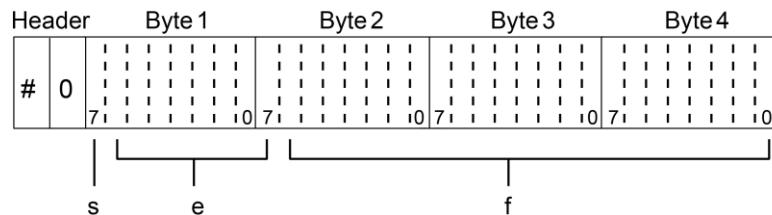
Figure 61: ASCII data format



IEEE-754 single precision format

REAL 32 or SREal will select the binary IEEE-754 single precision data format. The next figure shows the normal byte order format for each data element. For example, if 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. The next figure 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.

Figure 62: 6487 IEEE-754 single precision format



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, do not disable talk on the 6487 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:

$$\text{Bytes} = 2 + (\text{Rdgs} \times 4) + 1$$

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:

$$\text{Bytes} = 2 + (10 \cdot 4) + 1$$

FORMat:ELEMents <item list>

Parameters	READING	= Current or ohms reading
	UNITS	= Units
	TIME	= Timestamp
	STATUS	= Status information
	VSource	= Voltage source value
	ALL	= All data elements
	DEFault	= All except VSource

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 to include the reading with units and the time elements in the data string.

Reading: Returns the current reading for the current function or the ohms readings if ohms is enabled. 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 +9.91E37. -9.9e+36 will be returned for any ohms reading taken when the voltage source was in compliance.

Units: Units reference the returned readings units of measure. For the current function, A will be returned. For the ohms function, OHMS will be returned.

Voltage source: This element returns the programmed voltage source value in volts when the voltage source is in operate. Zero will be returned when the voltage source output is off. -999 will be returned if the voltage source was in compliance.

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 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 6487 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 for 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:

Bit 7 (Overvoltage): Set to 1 if measurement performed with an overvoltage condition on the input.

Bit 9 (Zero Check): Set to 1 when zero check is enabled.

Bit 10 (Zero Correct): Set to 1 when zero correct is enabled.

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 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 a PC.

SYSTem subsystem

Command	Description	Default
:SYSTem		
:ZCHeck	Zero check:	
[:STATE] 	Enable or disable zero check.	ON
[:STATE]?	Query zero check state.	
:ZCORrect	Zero correct:	
[:STATE] 	Enable or disable zero correct.	OFF
[:STATE?]	Query zero correct state.	
:ACQuire	Acquire a new zero correct value *	
:PRESet	Return to SYSTEM:PRESet defaults.	
:LFrequency <freq>	Select power line frequency: 50 or 60 (Hz)	
:LFrequency?	Query power line frequency	
:AUTO	Path to control auto line frequency selection.	
[:STATE] 	Turn automatic line frequency ON or OFF.	
[:STATE]?	Query automatic line frequency state.	
:AZERO	Path to control autozero:	
[:STATE] 	Enable or disable autozero.	ON
[:STATE]?	Query autozero state.	
:TIME	Timestamp:	
:RESet	Reset timestamp to 0 seconds.	
:POSetup <name>	Select power-on setup; RST, PRESet, or SAV0-2	
:POSetup?	Query power-on setup.	
:VERSion?	Query SCPI revision level.	
:ERRor	Read messages in error queue:	
[: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).	

:SYSTem		
:CLEar	Clear messages from error queue.	
:KEY <NRf>	Simulate key-press.	
:KEY?	Query last key pressed.	
:LOCal	RS-232 interface: Take 6487 out of remote (RS-232 only).	
:REMote	Equivalent to GTL . Put Model 6487 in remote (RS-232 only).	
:RWLock	Equivalent to REN . Enable local lockout (RS-232 only).	
:KLOCK 	Equivalent to LLO . When true, functions the same as local lockout and prevents LOCAL key from taking unit out of remote.	OFF
:KLOCK?	Query key lock state.	

* ZCH:STAT must be ON and ZCOR:STAT must be OFF in order to acquire a new zero correct value.

** 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.

SYSTem:PRESet

Returns the instrument to states optimized for front panel operation.

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 the Model 6487 Picoammeter/Voltage Source User's Manual (6487-900-01) for details.

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, or 2)

The *RST and SYSTem:DEFault values are listed in [SCPI reference tables](#) (on page 14-1). A setup is saved in memory using the *SAV command.

SYSTem:VERSion

Reads the version of the SCPI standard being used by the 6487.

SYSTem:KEY <NRf>

Parameters	1 = CONFIG/LOCAL key	17 = MENU key
	2 = I Ω key	18 = COMM key
	3 = MATH key	19 = DISP key
	4 = FILT key	20 = TRIG key
	5 = ZCHK key	21 = LIMIT key
	6 = REL key	22 = DIGITS key
	7 = OPER key	23 = RATE key
	8 = SOURCE up arrow key	24 = Cursor left arrow key
	9 = -----	25 = -----
	10 = -----	26 = SAVE key
	11 = RANGE up arrow key	27 = SETUP key
	12 = AUTO key	28 = STORE key
	13 = RANGE down arrow key	29 = RECALL key
	14 = ENTER key	30 = AZERO key
	15 = Cursor right arrow key	31 = DAMP key
	16 = SOURCE down arrow key	32 = EXIT key

This command is used to simulate front panel key-presses. For example, send the **:SYST:KEY 3** command to simulate pressing the **MATH** key. The queue for the **:SYST:KEY?** query command can only hold one key-press and this query cannot be used to determine keys physically pressed from the front panel.

When **:SYST:KEY?** is sent and the 6487 is addressed to talk, the key-press code number for the last **:SYST:KEY** command is sent to the computer. The value is **-1** if a **:SYST:KEY** command has not been sent since the last time the unit was placed in remote.

Note that sending **:SYST:KEY 1** will simulate a press of the **CONFIG** key. To place the instrument in the local state, send the **GTL** command.

Section 14

SCPI reference tables

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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 () is used to enable or disable an instrument operation. 1 or ON enables the operation and 0 or OFF disables the operation.
- Upper case characters indicate the short-form version for each command word.
- Default Parameter: Listed parameters are both the *RST and :SYSTem:PRESet defaults, unless noted otherwise. Parameter notes are located at the end of each table.
- SCPI: A check mark (✓) indicates that the command and its parameters are SCPI-confirmed. An unmarked command indicates that it is non-SCPI. SCPI-confirmed commands that use one or more non-SCPI parameters are explained by notes.

CALCulate command summary

Command	Description	Default parameter	SCPI
:CALCulate[1] :FORMAT <name>	Subsystem to control CALC1: Select math format (MXB (mX+b), RECiprocal (m/X+b), LOG10)	MXB	✓ ✓
:FORMAT?	Query math format		✓

Command	Description	Default parameter	SCPI
:KMath :MMFactor <NRF>	Path to control math calculations: Set "m" for mX+b and m/X+b (-9.99999e20 to +9.99999e20)	0	
:MMFactor? :MA1Factor <NRF>	Query "m" factor. Set "m" for mX+b and m/X+b (-9.99999e20 to +9.99999e20)	1	
:MA1Factor? :MBFactor <NRF>	Query "m" factor (-9.99999e20 to +9.99999e20) Set "b" for mX+b and m/X+b (-9.99999e20 to +9.99999e20)	0	
:MBFactor? :CALCulate[1]	Query "b" factor		
:KMath :MA0Factor <NRF>	Set "b" for mX+b and m/X+b calculation (same as MBFactor).	1.0	
:MA0Factor? :MUNits <name>	Query "b" factor (same as MBFactor?). Specify units for mX+b or m/X+b result: 1 character: A-Z, '='=^, '\'='=°, '['='=%.	X	
:MUNits? :STATE 	Query units. Enable or disable CALC1 calculation.		
:STATE? :DATA?	Query state of CALC1 calculation. Return all CALC1 results triggered by INITiate.	OFF	✓
:LATest? :CALCulate2	Return last (latest) reading. Path to configure and control limit testing (CALC2):		✓
:FEED <name> :FEED? :LIMIT[1]	Select input path for limit testing: CALCulate[1] or SENSe[1].	SENS	✓
:UPPer [:DATA] <n> [:DATA]? :SOURce2 <NDN> or <NRF>	Configure upper limit: Set limit: -9.99999e20 to 9.99999e20.	1.0	✓
[:DATA]? :SOURce2? :LOWER [:DATA] <n> [:DATA]? :SOURce2 <NDN> or <NRF>	Query upper limit. Specify 4-bit I/O "fail" pattern (0 to 15).	15	✓
[:DATA]? :SOURce2? :STATE 	Query output pattern value. Configure lower limit: Set limit: -9.99999e20 to 9.99999e20.	-1.0	✓
[:DATA]? :SOURce2? :STATE 	Query lower limit. Specify 4-bit I/O "fail" pattern (0 to 15).	15	✓
[:DATA]? :SOURce2? :STATE 	Query output pattern value. Enable or disable limit 1 test.	OFF	✓

Command	Description	Default parameter	SCPI
:STATE?	Query state of limit 1 test.		✓
:FAIL?	Return result of limit 1 test: 0 (pass) or 1 (fail).		✓
:CALCulate2			✓
: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>	Specify 4-bit I/O "fail" pattern (0 to 15).	15	✓
or <NRf>			
: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>	Specify 4-bit I/O "fail" pattern (0 to 15).	15	✓
or <NRf>			
:SOURce2?	Query output pattern value.		✓
:STATE 	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]	Clear I/O port immediately.		
:AUTO 	When enabled, I/O port clears when INITiate is sent.	ON	
:AUTO?	Query auto-clear state.		
:PASS	Define "pass" Digital I/O output pattern:		
[:SOURce2 <NDN>	Set 4-bit "pass" pattern.	15	
or <NRf>			
:SOURce2?	Query output bit pattern.		
:DATA?	Return all CALC2 readings triggered by INITiate.		✓
:LATest?	Return only the last (latest) reading.		
:NULL	Configure and control Rel:		✓
:ACQuire	Use input signal as Rel value.		
:OFFSet <NRf>	Specify Rel value: -9.99999e20 to 9.99999e20.	0.0	✓

:OFFSet?	Query Rel value.		✓
:STATE 	Enable or disable Rel.	OFF	✓
:STATE?	Query state of Rel.		✓
:CALCulate3	Path to configure and control CALC3 calculations on buffer data:		✓
:FORMAT <name>	Select buffer statistic: MEAN, SDEVIation, MAXimum, MINimum or PKPK.	MEAN	✓
:FORMAT?	Query selected statistic.		✓
:DATA?	Read the selected buffer statistic		✓

SOURce2 parameter values:

<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)

DISPlay command summary

Command	Description	Default parameter	SCPI
:DISPLAY			
:DIGits <n>	Set display resolution: 4 to 7.	6	
:DIGits?	Query display resolution.	*	
:ENABLE 	Turn front panel display on or off.		
:ENABLE?	Query display state.		✓
[:WINDOW [1]]	Path to control user text messages:		
:TEXT			✓
[:DATA] <a>	Define ASCII message "a" (up to 12 characters).		✓
[:DATA] ?	Read text message.		✓
:STATE 	Enable or disable text message mode.	***	✓
:STATE?	Query state of text message mode.		✓

* *RST and :SYSTem:PRESet has no effect on a user-defined message.

Cycling power cancels all user-defined messages.

** *RST and :SYSTem:PRESet has no effect on the state of the message mode.

Cycling power disables (OFF) the message mode.

*** *RST and :SYSTem:PRESet has no effect on the display circuitry. Cycling power enables (ON) the display circuitry.

FORMat command summary

Command	Description	Default parameter	SCPI
:FORMAT [:DATA] <type> [,<length>] [:DATA]? :ELEMENTs <item list>	Select data format: (ASCII, REAL, 32, or DREAL) Query data format Specify data elements: (READING, UNITS, VSOURCE, TIME, STATUS, DEFault, and ALL.)	ASC	✓
:ELEMENTs? :BORDer <name>	Query data elements Select binary byte order: (NORMAL or SWAPPED)	All except VSO	✓
:BORDer? :SREGister <name>	Query byte order Select data format for reading status registers; ASCII, HEXAdecimal, OCTal, or BINary.	*	✓
:SREGister? :SOURce2 <name>	Query format for reading event registers. Select data format for reading output patterns: ASCII, HEXAdecimal, OCTal, or BINary.	ASC	
:SOURce2?	Query data format for output patterns.	ASC	

* *RST default is NORMAL. SYSTEM:PRESet default is SWAPPED.

:SENSe command summary

Command	Description	Default parameter	SCPI
[:SENSe[1]] :FUNCTION <name>	Select measurement function: <name> = , 'CURREnt[:DC]'	'CURR'	
:DATA [:LATest]? [:CURREnt[:DC]]	Path to return readings: Return the last instrument reading Path to configure amps function:		✓
:NPLCycles <NRf>	Set integration rate in line cycles (PLC): 0.01 to 60.0 (60 Hz) or 50.0 (50Hz).	6 (60 Hz)	✓
:NPLCycles? [:SENSe[1]]	Query NPLC.	5 (50 Hz)	✓

Command	Description	Default parameter	SCPI
[:CURRent [:DC]]			
:RANGE	Configure measurement range:		✓
[:UPPer] <NRf>	Select range: -0.021 to 0.021 (amps).	2.1e-4	✓
[:UPPer] ?	Query range value.		✓
:AUTO 	Enable or disable autorange	*	✓
:AUTO?	Query state of autorange.		✓
: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-9	
:LLIMit?	Query lower limit for autorange.		
:AVERage	Path to control the Digital Filter:		
:TCONtrol <name>	Select filter control: MOVing or REPeat.	MOV	
:TCONtrol?	Query filter control.		
:COUNT <n>	Specify filter count: 2 to 100.	10	
:COUNT?	Query filter count.		
[:STATe] 	Enable or disable digital filter.	OFF	
[:STATe] ?	Query state of digital filter.		
:MEDian	Path to control median filter:		
:RANK <NRf>	Specify "n" for rank: 1 to 5 (rank = 2n+1).	1	
:RANK?	Query rank.		
[:STATe] 	Enable or disable median filter.	OFF	
[:STATe] ?	Query state of median filter.		
:DAMPing	Path to control analog filter damping:		
[:STATe] 	Enable or disable analog filter damping.	ON	
[:STATe] ?	Query filter damping state.		
[:SENSe[1]]			
[:DAMPing]			
:OHMS	Path to control ohms:		
[:STATe] 	Enable or disable ohms for SENSe1 data.	OFF	
[:STATe] ?	Query ohms SENSe1 data state.		
:AVOLTage	Path to A-V ohms commands:		
[:ARM]	Arm A-V ohms mode.		
[:ARM] ?	Query if A-V ohms is armed. (1 = armed).		
:ABORT	Abort A-V ohms mode.		
:VOLTage <NRf>	Set high voltage value (-505 to 505V).	10 V	

Command	Description	Default parameter	SCPI
:VOLTage?	Query high voltage value.		
:TIME <NRf>	Set time interval for each phase.	15 s **	
:TIME?	Query time interval for each phase.		
:POINTs?	Query number of points.		
:ONESHOT	Enable or disable one-shot mode.	ON	
:ONESHOT?	Query state of one-shot mode.		
:CYCLeS <NRf>	Set number of A-V cycles (1 to 9999).	3	
:CYCLeS?	Query number of A-V cycles.		
:UNITS <name>	Select AMPS or OHMS units.	AMPS	
:UNITS?	Query units.		
:CLEar	Clear A-V ohms buffer.		
:AUTO 	Enable/disable A-V buffer auto clear.	ON	
:AUTO?	Query auto clear state.		
:BCount?	Query number of A-V cycles that have been completed and are averaged to make up present buffer.		

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

** 15 s for 1 PLC or greater, 1 s for 0.1 PLC, and 0.1 s for 0.02 PLC.

:SOURce command summary

Command	Description	Default parameter	SCPI
:SOURce[1] :VOLTage [:LEVEL] [:IMMEDIATE] [:AMPLitude]<NRf> [:AMPLitude]? :RANGE <NRf> :ILIMIT <NRf> :STATE :STATE? :INTERLOCK [:STATe] [:STATe]? :FAIL? :SOURce[1] :VOLTage	SOURce1 subsystem: Path to voltage source commands. Set voltage source amplitude (-500 to 500).* Query voltage source amplitude. Set source range (10, 50, or 500[V]). Set source current limit (2.5e-5 to 2.5e-2[A]).*** Enable or disable source output.**** Query source output state. Path to control interlock: Enable or disable interlock for 10 V range.***** Query interlock state.***** Query interlock status (1 = interlock asserted).*****	0 10 ** 2.5e-2 OFF OFF	

Command	Description	Default parameter	SCPI
<pre>:SWEep :START <NRf> :START? :STOP <NRf> :STOP? :STEP <NRf> :STEP? :CENTER <NRf> :CENTER? :SPAN <NRf> :SPAN? :DELay <NRf> :DELay? :INITiate :ABORT :STATE?</pre> <pre>:SOURce2 :TTL [:LEVel] <NRf> or <NDN> [:LEVel]? :CLEar [:IMMediate] :AUTO :AUTO? :DELay <n> :DELay? :TTL4 :MODE <name> :MODE? :BState :BSTATE?</pre>	<p>Sweep commands:</p> <p>Program start voltage: -505 V to 505 V.</p> <p>Query start voltage.</p> <p>Program stop voltage: -505 V to 505 V.</p> <p>Query stop voltage.</p> <p>Program step voltage: -505 V to 505 V</p> <p>Query step voltage.</p> <p>Program center voltage: -505 V to 505 V.</p> <p>Query center voltage.</p> <p>Program span voltage: -505 V to 505 V.</p> <p>Query span voltage.</p> <p>Set delay: 0 to 999.9999 s.</p> <p>Query delay.</p> <p>Arm sweep, put source in operate.</p> <p>Abort sweep, put source in standby.</p> <p>Query if sweep running: 1 = sweep in progress</p> <p>Path to control Digital I/O port:</p> <p>Set I/O port value directly:</p> <p>Specify 4-bit Digital I/O pattern (0 to 15).</p> <p>Query output value.</p> <p>Clear I/O port (return output to TTL value).</p> <p>Clear I/O port immediately.</p> <p>Enable or disable auto-clear.</p> <p>Query auto-clear state.</p> <p>Specify delay (pulse width) for pass/fail pattern: 0 to 60 (sec).</p> <p>Query delay value.</p> <p>Line 4 mode configuration:</p> <p>Select output line 4 mode: EOTest or BUSY.</p> <p>Query line 4 mode.</p> <p>Select active TTL level for busy: 1 = ON or 0 = OFF.</p> <p>Query active busy TTL level.</p>	0.0001	EOT 0

Command	Description	Default parameter	SCPI
* If voltage source is in operate, value will be updated immediately. Value cannot be set above voltage source range.			
** Default for DDC mode is 50 V.			
*** Limit settings are: 25 mA, 250 mA, 2.5 mA, and 25 mA; current limit will be set to closest programmed value. For the 500 V and the 50 V ranges, the maximum ILIMit is 2.5 mA (0.0025 A). On the 10 V range, any of the four current limit choices can be selected. The default 10 V llimit is 25 mA or 2.5 mA in DDC mode.			
**** STATe ON places source in operate.			
***** Ignored for 50 V and 500 V ranges since interlock is always enabled. Attempting to turn off the interlock state while on the 50 V or 500 V range will generate a "-221 Settings Conflict" error. Upranging from the 10 V range will always cause the interlock to be enabled. When the unit returns to the 10V range, the interlock state will be reset to the state it had when the unit left the 10 V range.			
***** Querying the interlock state while on the 50 V or 500 V range will always return TRUE.			
***** Asserted interlock indicates that voltage source cannot be placed in operate.			
SOURce2 parameter values:			
<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)			

:STATus command summary

Command	Description	Default parameter	SCPI
:STATus		*	✓
:MEASurement			
[:EVENT]?	Path to control measurement event registers: Read the event register	**	
:ENABLE <NRf>	Program the enable register	**	
:ENABLE?	Read the enable register		
:CONDITION?	Read the condition register.		
:STATus			
:OPERation			
[:EVENT]?	Operation event registers: Read the event register.	**	✓
:ENABLE <NDN> or <NRf>	Program the enable register.	***	✓
:ENABLE?	Read the enable register.		✓
:CONDITION?	Read the condition register.		✓
:QUESTIONable	Questionable event registers:		
[:EVENT]?	Read the event register.	**	✓
:ENABLE <NDN> or <NRf>	Program the enable register.	***	✓
: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).	****	✓

:ENABle <list>	Specify error and status messages for error queue.	*****	√
:ENABle?	Read the enabled messages.		
:DISable <list>	Specify messages not to be placed in queue.	*****	√
:DISable?	Read the disabled messages.		
:CLEar	Clear messages from error queue.		

Commands in this subsystem are not affected by *RST and :SYSTem:PRESet. The effects of cycling power, *CLS, and :STATus:PRESet are explained by the following notes.

* Event registers: Power-up and *CLS: Clears all bits of the registers.

:STATus:PRESet: No effect.

** Enable registers: Power-up and :STATus:PRESet: Clears all bits of the registers.

*CLS: No effect.

*** PTR registers: Power-up and :STATus:PRESet Sets all bits of the registers.

*CLS: No effect.

**** NTR registers: Power-up and :STATus:PRESet Clears all bits of the registers.

*CLS: No effect.

***** Error queue: Power-up and *CLS: Clears the error queue.

:STATus:PRESet: No effect.

***** Enable/disable error queue messages: Power-up: Clears list of messages.

*CLS and :STATus:PRESet: No effect.

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

:SYSTem command summary

Command	Description	Default parameter	SCPI
:SYSTem :ZCheck [:STATE] [:STATE]? :ZCORrect [:STATE] [:STATE]? :ACQuire :PRESet :LFRrequency <freq> :LFRrequency? AUTO [:STATE] [:STATE]?	Zero check: Enable or disable zero check. Query state of zero check. Zero correct: Enable or disable zero correct. Query state of zero correct. Acquire a new zero correct value. * Return to SYSTem:PRESet defaults. Select power line frequency: 50 or 60 (Hz). Query frequency setting. Path to control auto frequency. Enable or disable auto frequency. Query state of auto frequency.	ON OFF 6 ON	√

Command	Description	Default parameter	SCPI
:AZERO [:STATe] 	Path to control autozero: Enable or disable autozero.	ON	✓
[:STATe] ?	Query state of autozero.		✓
:TIME :RESet	Timestamp: Reset timestamp to 0 seconds.		✓
:POSetup <name>	Select power-on setup: RST, PRESET, or SAVx (where x = 0 – 2).	PRES	✓
:POSetup?	Query power-on setup.	*	✓
:VERSION?	Query SCPI revision level.		✓
:ERRor [:NEXT] ?	Read error queue: 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 [:NEXT] ?	Code numbers only: Read and clear oldest error/status (code only).		
:ALL?	Read and clear all errors/status (codes only).		
:SYSTem: :CLEar	Clear messages from error queue.		✓
:KEY <NRf>	Simulate key-press.		✓
:KEY?	Query the last pressed key.		
:LOCal	While in LLO, removes the LLO and places the 6487 in local (RS-232 only).		
:REMote	Places the 6487 in remote if not in LLO (RS-232 only).		
:RWLock	Places the 6487 in local lockout (RS-232 only).		
:KLOCK 	When true, functions the same as local lockout and prevents LOCAL key from taking unit out of remote.	OFF	
:KLOCK?	Query key lock state.		

* ZCH:STAT must be ON and ZCOR:STAT must be OFF in order to acquire a new zero correct value.

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.

:TRACe subsystem

Command	Description	Default parameter	SCPI
:TRACe :DATA	Use :TRACe or :DATA as root command.	*	✓
:DATA? [BUFFER]	Read the contents of normal or A-V ohms buffer. ²	BUFFER	✓
:MODE?	Query buffer mode: DC (normal) or AVOLtage (A-V ohms).		
:CLEar	Clear readings from buffer.		
:FREE?	Query bytes available and bytes in use.		✓
:POINTS <n>	Specify size of buffer: 1 to 3000.	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.		

* SYStem:PRESet and *RST have no effect on the commands in this subsystem. The listed defaults are power-on defaults.

** Readings come from A-V ohms buffer if available; normal buffer readings otherwise.

:TRIGger command summary

Command	Description	Default parameter	SCPI
:INITiate [:IMMEDIATE]	Subsystem command path: Initiate one trigger cycle		✓ ✓
:ABORT	Reset trigger system (goes to idle state).		✓
:ARM[:SEQUENCE[1]] [:LAYer[1]]	Path to configure arm layer:		✓
:SOURCE <name>	Select control source: IMMEDIATE, TIMER, BUS, TLINK, MANUAL, PSTEST, NSTEST, or BSTEST.	IMM	✓
:SOURCE?	Query arm control source.		✓
:COUNT <n>	Set measure count: 1 to 2048 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.	ACC	✓
: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	Trigger layer:		
:CLEAR	Clear pending input trigger immediately.		

Command	Description	Default parameter	SCPI
[:SEQUence[1]]	Trigger path.		
:SOURce <name>	Select control source: IMMEDIATE or TLINK.	IMM	✓
:SOURce?	Query trigger control source.		✓
:COUNT <n>	Set measure count: 1 to 2048 or INF (infinite).	1	✓
:COUNT?	Query measure count.		✓
:DELay <n>	Set trigger delay: 0 to 999.9999 (sec).	0.0	✓
:AUTO 	Enable or disable auto delay.	OFF	✓
:AUTO?	Query state of auto delay.		✓
:DELay?	Query delay value.		✓
[:TConfigure]			✓
:DIRection <name>	Enable (SOURce) or disable (ACCeptor) bypass.	ACC	✓
: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.		

* *RST sets the count to 1.

Section 15

Performance verification

In this section:

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Introduction

Use the procedures in this section to verify that the 6487 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 to make sure that it was not damaged during shipment.
- To verify that the unit meets factory specifications.
- To determine if calibration is required.
- Following calibration to 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 Keithley Instruments.

Verification test requirements

Be sure to 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

Be sure to conduct your performance verification procedures in a test environment with:

- An ambient temperature of 18° C to 28° C.
- A relative humidity of less than 70% unless otherwise noted.

Warm-up period

Allow the 6487 to warm up for at least one hour before conducting the verification procedures. If the instrument has been subjected to temperatures outside of the specified ranges, allow additional time for the instrument's internal temperature to stabilize. Typically, allow one extra hour to stabilize a unit that is 10° C outside of the specified temperature range.

Line power

The 6487 requires a line voltage of 100 V to 120 V or 220 V to 240 V at a line frequency of 50 Hz or 60 Hz. Verification tests must be performed within this range. Be sure the line voltage setting agrees with the expected line voltage.

Recommended test equipment

The below table 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 the corresponding 6487 specifications.

Note that the recommended calibrator listed in the following table does not meet this requirement for 20 μ A output. See [Calibration](#) (on page 16-1) for details on uncertainty ratios.

Description	Manufacturer and model	Specifications
Calibrator	Fluke 5700A	DC voltage: 2 V: 7 ppm 20 V: 5 ppm 200 V: 7 ppm DC current: 20 mA: 50 ppm 200 mA: 100 ppm 2 mA: 55 ppm 20 mA: 55 ppm
Electrometer calibration standard	Keithley Model 5156	Nominal Resistance: 100 M Ω : 200 ppm 1 G Ω : 300 ppm
Digital Multimeter	Keithley Model 2001	DC Voltage: 10 V: 32 ppm 50 V: 50 ppm 500 V: 53 ppm
Low-noise triaxial cable Low-noise coaxial cable Triaxial shielding cap Triaxial-to-BNC adapter Dual banana-to-BNC adapter Banana plug test leads	Keithley 7078-TRX-3 Keithley 4801 Keithley CAP-31 Keithley 7078-TRX-BNC Pomona 1269 Keithley 8607	

* 90-day, 23°±5°C full-range accuracy specifications shown. Uncertainty for 20 mA output current does not meet the recommended four-times better uncertainty specification.

** 23°±3°C accuracy of characterization.

*** One-year, DMM accuracy specifications at specified voltage and range.

Verification limits

The verification limits stated in this section have been calculated using only 6487 one-year accuracy specifications and do not include test equipment uncertainty. If a particular measurement falls outside the allowable range, recalculate new limits based on both 6487 specifications and corresponding test equipment specifications.

Example reading limits calculation

As an example of how verification limits are calculated, assume you are testing the 20 mA range using a 20 mA input value. Using the 6487 20 mA range accuracy specification of $\pm(0.1\% \text{ of reading} + 1 \mu\text{A})$, the calculated reading limits are:

$$\begin{aligned}\text{Reading limits} &= 20 \text{ mA} \pm [(20 \text{ mA} \cdot 0.1\%) + 1 \mu\text{A}] \\ &= 20 \text{ mA} \pm (0.02 \text{ mA} + 0.001 \text{ mA}) \\ &= 20 \text{ mA} \pm 0.021 \text{ mA} \\ &= 19.979 \text{ mA to } 20.021 \text{ mA}\end{aligned}$$

Calibrator voltage calculations

When verifying the 2 nA through 2 μ A current ranges, you must calculate the actual calibrator voltages from the desired current values and the characterized Model 5156 Calibration Standard resistor values.

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 testing the 20 nA range using an actual $100.5 \text{ M}\Omega$ standard resistor value. The actual calibrator voltage is: $20 \text{ nA} \cdot 100.5 \text{ M}\Omega = 2.01 \text{ V}$.

Performing the verification test procedures

Test considerations

When performing the verification procedures:

- Be sure to restore the 6487 factory front panel defaults and perform voltage offset calibration as outlined below.
- Make sure that the test equipment is properly warmed up and properly connected to the correct 6487 terminals.
- Be sure the 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 the 6487 through a scanner, multiplexer, or other switching equipment.

WARNING

The maximum safe voltage between the voltage source or ammeter and chassis ground (common mode voltage) is 505 V dc. Exceeding this voltage can create a shock hazard.

CAUTION

Maximum continuous input voltage is 505 V dc. Exceeding this value may cause instrument damage.

Restoring factory defaults

Before performing the verification procedure, you must restore the factory front panel defaults:

To restore the instrument to its factory front panel defaults:

1. Press **SETUP**. The instrument will display RESTORE : FACT.
2. Using either **RANGE** key, select **FACT**.
3. Press **ENTER** to restore the factory default conditions.

NOTE

You can use either **RANGE** key to select among **FACT**, **GPIB**, and **USR0** to **USR2** setups. Be sure you use **FACT** defaults for the verification procedure.

Offset voltage calibration

To perform offset voltage calibration:

1. From the calibration menu, use the up or down **RANGE** key to display CAL: VOFFSET.
2. Press **ENTER**. The instrument displays INPUT CAP.
3. Connect the triaxial shielding cap to the rear panel INPUT jack.
4. Press **ENTER** to complete offset voltage calibration.
5. Press **EXIT** to return to normal display.

Current measurement accuracy

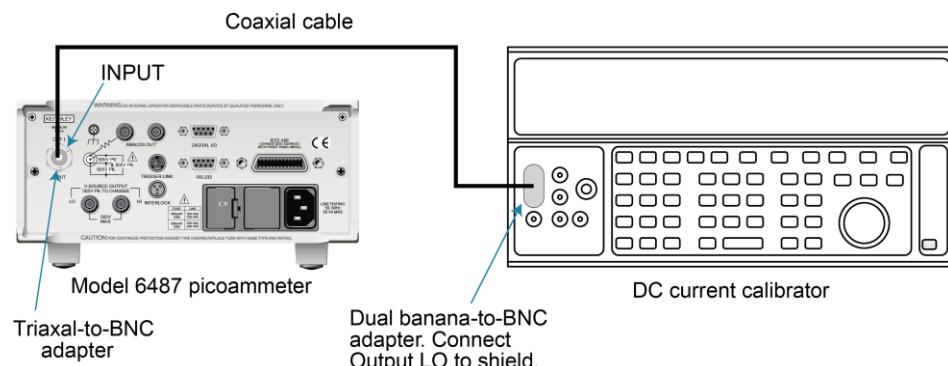
Follow the steps below to verify that 6487 current measurement accuracy is within specified limits. The test involves applying accurate DC currents and then verifying that the 6487 current readings are within required limits.

20 μ A through 20 mA range accuracy

1. With the power off, connect the current calibrator to the 6487 INPUT jack. Use the appropriate coax cable, triaxial-to BNC adapter, and BNC-to-dual banana plug adapter where shown.
2. Turn on the 6487 and the calibrator.
3. Allow the 6487 and calibrator to warm up for one hour.
4. Using either **RANGE** key, set the 6487 to the 20 μ A range.
5. With zero check enabled, zero correct the 6487, then disable zero check.
6. Set the calibrator current to 0.0000 μ A and make sure the output is turned on.
7. Enable REL mode on the 6487. Leave REL enabled for the remainder of the test.
8. Verify current measurement accuracy for each of the currents listed in the next table. For each test point:
 - Select the correct 6487 measurement range.
 - Set the calibrator current to the indicated value.
 - Verify that the 6487 current reading is within the limits given in the table.
9. Repeat the procedure for negative source currents with the same magnitudes as those listed in the following table.

6487 range	Calibrator current	6487 current reading limits (1 Year, 18°C - 28°C)
20 μ A	20.0000 μ A	19.9790 μ A to 20.0210 μ A
200 μ A	200.000 μ A	199.790 μ A to 200.210 μ A
2 mA	2.00000 mA	1.99790 mA to 2.00210 mA
20 mA	20.0000 mA	19.9790 mA to 20.0210 mA

Figure 63: Connections for 20 μ A to 20 mA range verification



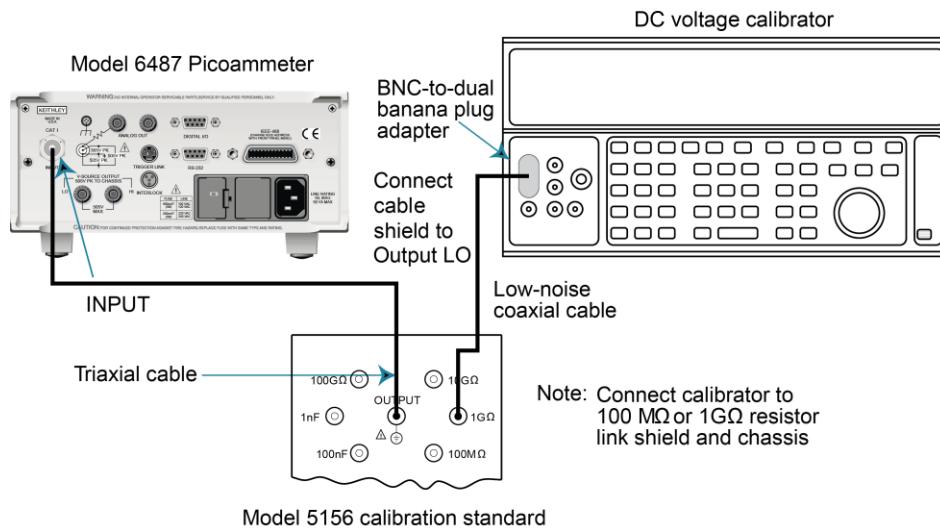
2 nA through 2 µA range accuracy

1. With the power off, connect the voltage calibrator and Model 5156 Electrometer Calibration Standard to the 6487 INPUT jack. Initially, make connections to the 1 GΩ resistor in the calibration standard.
2. Turn on the 6487 and calibrator power. Allow them to warm up for one hour.
3. Set the 6487 to the 2 nA range.
4. With zero check enabled, zero correct the instrument and then disable zero check.
5. Set the calibrator voltage to 0.0000 V and make sure the output is turned on.
6. Enable the 6487 REL mode. Leave REL enabled for the remainder of the test.
7. Verify current measurement accuracy for each of the currents listed in the following table. For each test point:
 - Make connections to the indicated calibration standard resistor.
 - Select the correct 6487 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 the 6487 current reading is within the reading limits listed in the table.
8. Repeat the procedure for negative source currents with the same values as those listed below.

Model 6487 range	Nominal calibrator voltage	Calibration standard resistor*	Nominal applied current	Actual voltage**	Model 6487 current reading limits (1 Year, 18°C to 28°C)
2 nA	2 V	1 GΩ	2.00000 nA	_____ V	1.99360 nA to 2.00640 nA
20 nA	2 V	100 MΩ	20.0000 nA	_____ V	19.9590 nA to 20.0410 nA
200 nA	20 V	100 MΩ	200.000 nA	_____ V	199.690 nA to 200.310 nA
2 µA	200 V	100 MΩ	2.00000 µA	_____ V	1.99690 µA to 2.00310 µA

* Nominal resistance values shown. Use actual characterized value for calculations.

** Calculate actual calibrator voltage as follows: $V = IR$; where I is desired applied current and R is actual standard resistance value.

Figure 64: Connections for 2 nA to 2 μ A range verification

Voltage source output accuracy

Follow the steps below to verify that 6487 voltage source output accuracy is within specified limits. The test involves setting the voltage source output to specific values and then verifying that DMM voltage readings are within required limits.

⚠ WARNING

Hazardous voltages will be present during the following procedure. Use care to avoid a shock hazard. The interlock must be closed to test the 50 V and 500 V ranges.

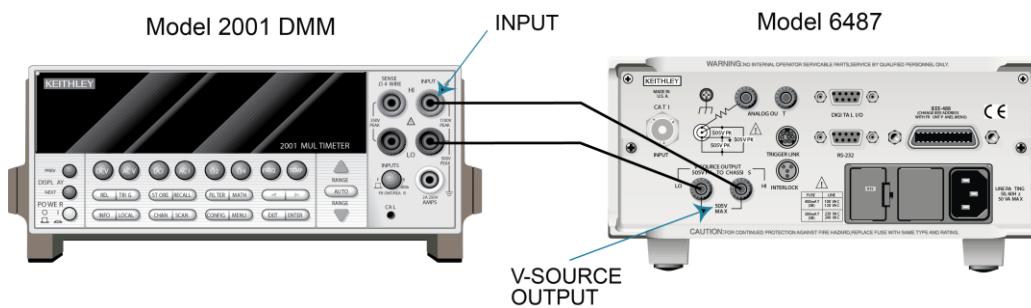
To verify voltage source output accuracy:

1. With the power off, connect the DMM INPUT terminals to the 6487 V-SOURCE OUTPUT jacks. Be sure to observe polarity (HI to HI; LO to LO).
2. Turn on the DMM and the 6487.
3. Allow the 6487 and calibrator to warm up for one hour.
4. Select the **DMM DCV** function and enable autoranging.
5. Temporarily short the ends of the DMM test leads together, then enable the **DMM REL** mode to null offsets. Leave REL enabled for the remainder of the tests.
6. Verify voltage source accuracy for each of the values listed in the following table. For each test point:
 - Select the correct 6487 voltage source range.
 - Set the voltage source output to the indicated value.
 - Make sure the voltage source is in operate (output on).
 - Verify that the DMM voltage reading is within the limits given in the table.

Repeat the procedure for negative source currents with the same values as those listed in the following table.

6487 source range	Output voltage	6487 Output voltage limits (1 Year, 18°C-28°C)
10 V	10.000 V	9.989 V to 10.011 V
50 V	50.000 V	49.946 V to 50.054 V
500 V	500.00 V	499.21 V to 500.79 V

Figure 65: Connections for voltage source output accuracy



Section 16

Calibration

In this section:

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Introduction

Use the procedures in this section to calibrate the 6487 from the front panel. These procedures require accurate test equipment to source precise DC voltages, currents, and resistances.

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.

Environmental conditions

Temperature and relative humidity

Conduct the calibration procedures at an ambient temperature of 22° C to 24° C with relative humidity of less than 70%, unless otherwise noted.

Warm-up period

Allow the 6487 to warm up for at least one hour before conducting the verification procedures. If the instrument has been subjected to temperatures outside of the specified ranges, allow additional time for the instrument's internal temperature to stabilize. Typically, allow one extra hour to stabilize a unit that is 10° C outside of the specified temperature range.

Line power

The 6487 requires a line voltage of 100 V to 120 V or 220 V to 240 V at a line frequency of 50 Hz or 60 Hz. Verification tests must be performed within this range. Be sure the line voltage setting agrees with the expected line voltage.

Calibration considerations

When performing the verification procedures:

- Be sure to restore the 6487 factory front panel defaults and perform voltage offset calibration as outlined below.
- Make sure that the test equipment is properly warmed up and properly connected to the correct 6487 terminals.
- Be sure the 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 the 6487 through a scanner, multiplexer, or other switching equipment.

⚠ WARNING

The maximum safe voltage between the voltage source or ammeter and chassis ground (common mode voltage) is 505 V dc. Exceeding this voltage can create a shock hazard.

CAUTION

Maximum continuous input voltage is 505 V dc. Exceeding this value may cause instrument damage.

Calibration cycle

Perform verification at least once a year to ensure that the unit meets or exceeds its specifications.
Calibrate if necessary.

Recommended calibration equipment

The next table 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 6487 specifications. Note that the recommended calibrator listed in the following table does not meet this requirement for 20 μ A output.

Description	Manufacturer and model	Specifications
Calibrator	Fluke 5700A	DC voltage: 2 V: 7 ppm 20 V: 5 ppm 200 V: 7 ppm DC current: 20 mA: 50 ppm 200 mA: 100 ppm 2 mA: 55 ppm 20 mA: 55 ppm
Electrometer calibration standard	Keithley Model 5156	Nominal Resistance: 100 M Ω : 200 ppm 1 G Ω : 300 ppm
Digital Multimeter	Keithley Model 2001	DC Voltage: 10 V: 32 ppm 50 V: 50 ppm 500 V: 53 ppm
Low-noise triaxial cable Low-noise coaxial cable Triaxial shielding cap Triaxial-to-BNC adapter Dual banana-to-BNC adapter Banana plug test leads	Keithley 7078-TRX-3 Keithley 4801 Keithley CAP-31 Keithley 7078-TRX-BNC Pomona 1269 Keithley 8607	

* 90-day, $23^\circ\pm5^\circ\text{C}$ full-range accuracy specifications shown. Uncertainty for 20 mA output current does not meet the recommended four-times better uncertainty specification.

** $23^\circ\pm3^\circ\text{C}$ accuracy of characterization.

*** One-year, DMM accuracy specifications at specified voltage and range.

Calibration errors

The 6487 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.

Range	5700 + 5156	Test uncertainty ratio
2 nA	7 ppm + 300 ppm	13.0
20 nA	7 ppm + 200 ppm	19.3
200 nA	5 ppm + 200 ppm	9.8
2 µA	7 ppm + 200 ppm	7.2
20 µA	550 ppm	1.8
200 µA	100 ppm	10.0
2 mA	55 ppm	18.2
20 mA	55 ppm	18.2

Range	2001 DMM	Test uncertainty ratio
10 V	32 ppm	31.2
50 V	50 ppm	20.0
500 V	53 ppm	28.3

Calibration menu

You can access the calibration menu by pressing **MENU**, selecting **CAL**, and then pressing **ENTER**. The various selections are summarized in the following table. Use the up and down **RANGE** keys to scroll through these selections.

Menu Item*	Description
VOFFSET	Performs offset voltage calibration.
COUNT	Displays calibration count.
RUN	Calibrates present current range.
VSRC-RUN	Calibrates present voltage source range.
DATES	Displays calibration and due dates.
UNLOCK	Unlocks calibration using code.
LOCK	Locks cal, exits to the main menu.
SAVE	Saves calibration constants.

* Press **MENU**, select **CAL**, then press **ENTER** to access.
Use up or down **RANGE** key to scroll through selections.

Aborting calibration

You can abort the calibration procedure by pressing the **EXIT** key.

Current calculations

When calibrating the 2 nA through 2 μ A current ranges, you must calculate the actual current values from the applied calibrator voltages and the characterized Model 5156 Calibration Standard resistor values. Calibration currents are calculated as follows:

$$I = V/R$$

Where: I = required calibration current

V = calibrator voltage

R = actual standard resistor value

For example, if you are calibrating the 20 nA range using a 2 V calibrator voltage with an actual 100.5 M Ω standard resistor value. The actual calibration current is:

$$2 \text{ V}/100.5 \text{ M}\Omega = 19.9005 \text{ nA.}$$

Calibration procedure

Preparing for calibration

To prepare for calibration:

1. Turn on the 6487 and the calibrator. Allow the instruments to warm up for at least one hour.
2. Press **MENU**, select **CAL**, then press **ENTER**. The instrument will display **CAL: VOFFSET**
3. Use the up or down **RANGE** key to display **CAL: UNLOCK**
4. Press **ENTER**. The instrument will prompt for the calibration code: **CODE? 000000**
5. Enter the present calibration code on the display. (Factory default: 006487).
6. 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.
7. Press **ENTER** to complete the process and the unit will display **CAL UNLOCKED**, followed by **NEW CODE? N**.
8. With **N** displayed, press **ENTER**.

Offset voltage calibration

Before performing the remaining calibration steps, perform offset voltage calibration:

1. From the calibration menu, use the up or down **RANGE** key to display **CAL: VOFFSET**.
2. Press **ENTER**. The instrument displays **INPUT CAP**.
3. Connect the triaxial shielding cap to the rear panel INPUT jack.
4. Press **ENTER** to complete offset voltage calibration.
5. Press **EXIT** to return to normal display.

Current calibration

20 μ A through 20 mA range calibration

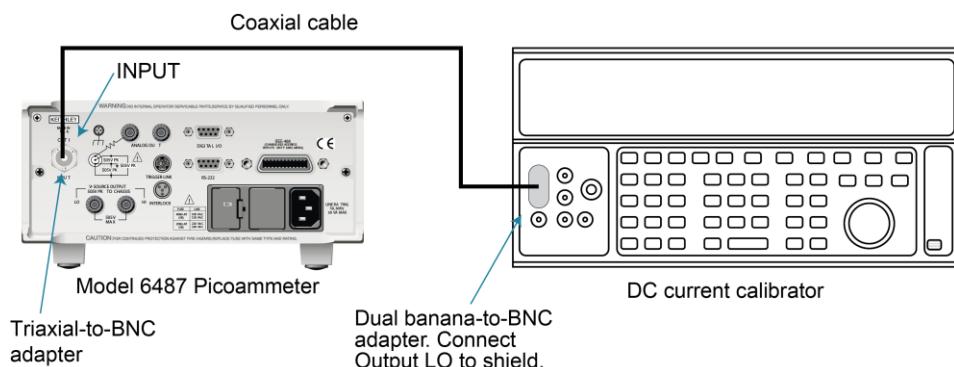
1. Connect the triaxial shielding cap to the 6487 rear panel INPUT jack.
2. Select the 6487 20 mA range.
3. Press **MENU**, select **CAL**, then press **ENTER**. At the **CAL: RUN** prompt, press **ENTER**. The unit will prompt for the zero calibration point: **20mA ZERO**
4. With the triaxial shielding cap connected to the INPUT jack for a 0 mA input current, press **ENTER**.
5. The unit will prompt for the positive full-scale cal point: **+20mA CAL**
6. Connect the current calibrator to the 6487 INPUT jack.
7. Press **ENTER**. The unit will prompt for the positive full-scale current: **+20.00000 mA**
8. Set the calibrator current to +20.00000 mA, then adjust the display to agree with the calibrator current.
9. Press **ENTER**. The unit will prompt for the negative full-scale calibration point: **-20mA CAL**
10. Press **ENTER**. The 6487 will prompt for the negative full-scale calibration current: **-20.00000 mA**
11. Set the calibrator output to -20.00000 mA, then adjust the display to agree with the calibrator value.
12. Press **ENTER** to complete calibration of the present range.

13. Press **EXIT** to return to normal display.
14. Repeat the above steps for the 200 mA through 20 mA ranges using the following table as a guide.

6487 range	Calibrator currents*
20 mA	0 mA +20.00000 mA -20.00000 mA
200 mA	0 mA +200.0000 mA -200.0000 mA
2 mA	0 mA +2.000000 mA -2.000000 mA
20 mA	0 mA +20.00000 mA -20.00000 mA

* Calibrate zero, positive full-scale, and negative full-scale for each range. Triaxial shielding cap used for zero calibration point for all ranges.

Figure 66: Connections for 20 μ A to 20 mA range calibration



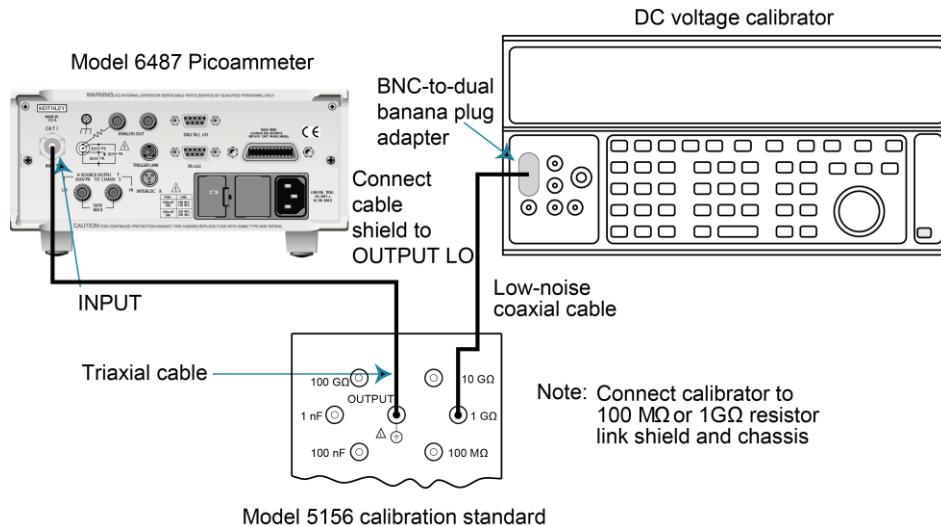
2 nA through 2 µA range calibration

1. Connect the voltage calibrator and the Model 5156 Calibration Standard to the 6487 INPUT jack. Make connections to the 1 GΩ resistance.
2. Set the calibrator to output volts and make sure the calibrator output is turned on.
3. Select the 2 nA range.
4. Press **MENU**, select **CAL**, then press **ENTER**. At the **CAL : RUN** prompt, press **ENTER** again. The unit will prompt for the zero calibration point: **2NA ZERO**
5. Set the calibrator voltage to 0 V then press **ENTER**.
6. The instrument will prompt for the positive full-scale calibration point: **+2NA CAL**
7. Press **ENTER**. The instrument will prompt for the positive full-scale calibration current: **+2.000000 NA**
8. Set the calibrator voltage to +2.000000 V. Calculate the actual calibration current from the calibrator voltage and the actual standard resistor value: $I = V/R$. Adjust the 6487 display to agree with the calculated current, then press **ENTER**.
9. The 6487 will prompt for the negative full-scale calibration point: **-2NA CAL**
10. Press **ENTER**. The instrument will prompt for the negative full-scale current: **-2.000000 NA**
11. Set the calibrator output voltage to -2.000000 V, then calculate the calibration current from the calibrator voltage and standard resistor value: $I = V/R$. Adjust the 6487 display to agree with the calculated current, then press **ENTER** to complete calibration of the present range.
12. Press **EXIT** to return to normal display.
13. Repeat for the 20 nA through 2 mA ranges using the following table as a guide. Be sure to make connections to the correct standard resistor and set the calibrator voltages to the correct values.

6487 range	Calibrator voltages	Standard resistors¹	Calibration currents²
2 nA	0 V +2.000000 V -2.000000 V	1 GΩ 1 GΩ 1 GΩ	0 nA +2 nA -2 nA
20 nA	0 V +2.000000 V -2.000000 V	100 MΩ 100 MΩ 100 MΩ	0 nA +20 nA -20 nA
2 mA	0 V +200.0000 V -200.0000 V	100 MΩ 100 MΩ 100 MΩ	0 mA +2 µA -2 µA

*Nominal resistance values

**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.

Figure 67: Connections for 2nA to 2 μ A range calibration

Voltage source calibration

⚠ WARNING

Hazardous voltages will be present during the following procedure. Use care to avoid a shock hazard. The interlock must be closed to calibrate the 50 V and 500 V ranges. See [Measurement concepts and connections](#) (on page 2-1) for more information.

To calibrate the voltage source:

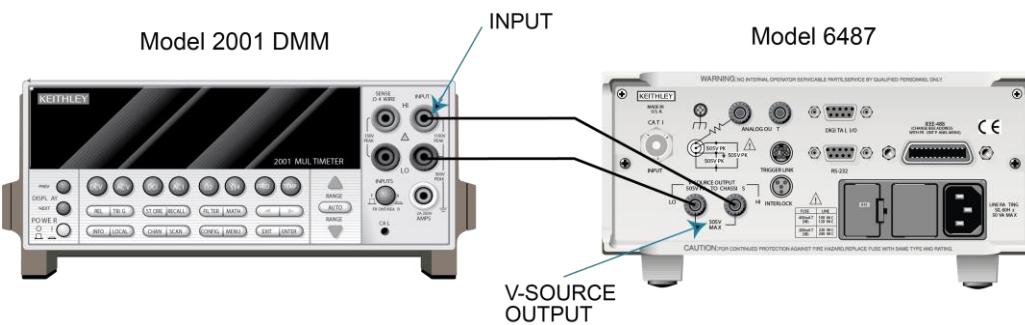
1. Set the DMM to measure DC volts and enable autoranging.
2. Temporarily short the ends of the DMM test leads together, then enable the DMM REL mode. Leave REL enabled for the rest of the calibration procedure.
3. Connect the DMM to the 6487 V-SOURCE OUTPUT jacks.
4. Select the 6487 voltage source 10 V range.
5. Press **MENU**, select **CAL**, then press **ENTER**. At the **CAL: VSRC-RUN** prompt, press **ENTER** again. The unit will prompt for the negative full-range calibration point: **V: -10V CAL**
6. Press **ENTER**. The voltage source will be placed in operate and the instrument will prompt for the negative full-scale calibration voltage: **-10.00000 V**
7. Note the DMM voltage reading. Adjust the 6487 display to agree with that voltage and then press **ENTER**.
8. Operate will turn off and the instrument will prompt for the zero calibration point: **V: 10V ZERO**
9. Press **ENTER**. The voltage source will be placed in operate and the instrument will prompt for the zero calibration voltage: **+0.00000 V**

10. Note the DMM voltage reading. Adjust the 6487 display to agree with that voltage and then press **ENTER**.
11. Operate will turn off and the unit will prompt for the positive full-range calibration point: v: +10V CAL
12. Press **ENTER**. The voltage source will be placed in operate and the instrument will prompt for the positive full-scale calibration voltage: +10.00000 V
13. Note the DMM voltage reading. Adjust the 6487 display to agree with that voltage and then press **ENTER**.
14. Press **EXIT** to return to normal display.
15. Repeat for the 50 V and 500 V ranges using the following table as a guide.

6487 range	Calibration voltages*
10 V	-10.00000 V +0.00000 V +10.0000 V
50 V	-50.00000 V +0.00000 V +50.00000 V
500 V	-500.0000 V +0.00000 V +500.0000 V

* Nominal values. Adjust display to agree with DMM reading.

Figure 68: Connections for voltage source calibration



Entering calibration dates and saving calibration

NOTE

For temporary calibration without saving new calibration constants, see [Locking out calibration](#) (on page 16-11).

1. Press **MENU**, select **CAL**, then press **ENTER** to access the calibration menu.
2. Use either **RANGE** key to display **CAL: SAVE**.
3. Press **ENTER**. The unit will prompt for today's calibration date: **DATE: 11/15/02**
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 11/15/03**
5. Set the calibration due date as desired then press **ENTER**. The unit will prompt you as follows:
SAVE CAL?YES
6. 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

To lock out calibration without saving new calibration constants:

1. Press **MENU**, select **CAL**, then press **ENTER**. Use the up **RANGE** key to display **CAL: LOCK**.
2. Press **ENTER**. The instrument will display the following message: **CAL LOCKED**.

Calibration support

Changing the calibration code

To change the calibration code:

1. Press **MENU**, select **CAL**, then press **ENTER**. The instrument will display the following:
CAL: VOFFSET
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? 000000**
4. Enter the present calibration code on the display. (Factory default: 006487.) 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: **CAL ENABLED** followed by **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 (006487).

Displaying calibration dates

To display calibration dates:

1. From normal display, press **MENU**, select **CAL**, then press **ENTER**. The unit will display the following: **CAL: VOFFSET**
2. Use either **RANGE** key to select **CAL: DATES**, then press **ENTER**. The 6487 will display the last calibration date, for example: **DATE: 11/15/02**
3. Press **ENTER** to view the calibration due date, for example: **NDUE: 11/15/03**
4. Press **EXIT** to return to normal display.

Displaying the calibration count

To display the calibration count:

1. From normal display, press **MENU**, select **CAL**, then press **ENTER**. The unit will display the following: **CAL: VOFFSET**
2. Use either **RANGE** key to select **CAL:COUNT** from the calibration menu, then press **ENTER**. The unit displays the calibration count, for example: **COUNT: 1**
3. Press **EXIT** to return to normal display.

Section 17

Routine maintenance

In this section:

Introduction	17-1
Setting line voltage and replacing line fuse	17-1
Front panel tests	17-2

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, 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 cables and leads connected to the instrument before replacing the line fuse.

The power line fuse is located in the power module next to the AC power receptacle. 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. 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 the following table.

WARNING

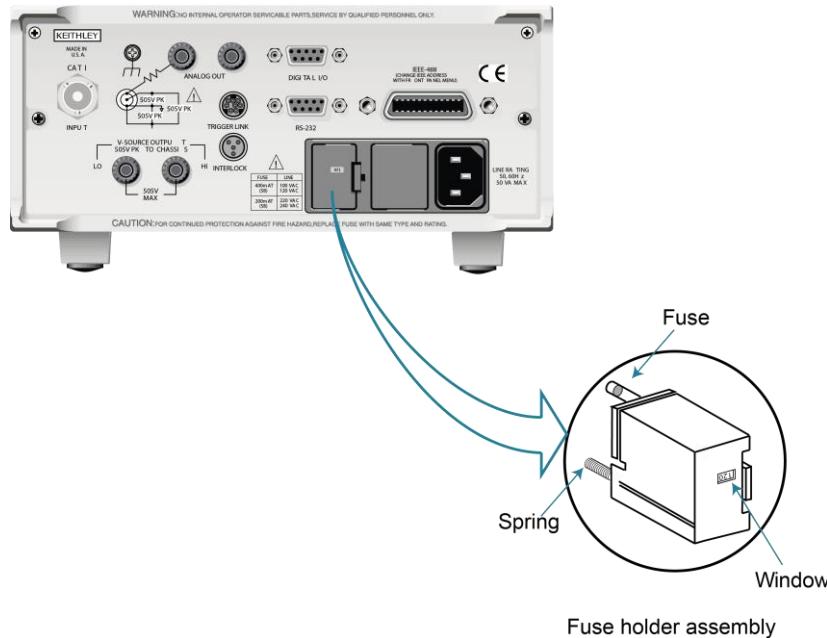
For continued protection against fire or instrument damage, replace the fuse only with the type and rating listed. If the instrument repeatedly blows fuses, it will require servicing.

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.

Line voltage	Rating	Keithley part number
100 V / 120 V	0.4 A, 250 V, 5 ' 20 mm, slow-blow	FU-106-.400
220 V / 240 V	0.2 A, 250 V, 5 ' 20 mm, slow-blow	FU-106-.200

Figure 69: Line fuse location

Model 6487 Picoammeter



Front panel tests

The front panel tests are summarized in the following table. To run a test, press the **MENU** key, select **TEST**, and press **ENTER** to access the test menu. Scroll through the menu choices with the **RANGE** keys and press **ENTER**.

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 **MENU**, select **TEST**, and press **ENTER** 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 **MENU**, select **TEST**, and press **ENTER** 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.

Section 18

Status and error messages

In this section:

Status and error messages	18-1
Eliminating common SCPI errors	18-5

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	Save/recall memory lost	EE
-315	Self-test failed	EE
-314	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

Number	Description	Event
-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
-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
+107	Reading overflow	SE
+108	Buffer available	SE
+109	Buffer full	SE
+110	Input overvoltage	SE

Number	Description	Event
	Operation events:*	
+300	Device calibrating	SE
+301	Device in A-V Ohms	SE
+303	Device sweeping	SE
+305	Waiting in trigger layer	SE
+306	Waiting in arm layer	SE
+310	Re-entering the idle layer	SE
+315	V-source compliance detected	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
+513	10V Positive Vsource Offset	EE
+514	50V Positive Vsource Offset	EE
+515	500V Positive Vsource Offset	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
+607	Vsource calibration data lost	EE
	Communication errors:	
+700	Invalid system communication	EE
+701	ASCII only with RS-232	EE
	Additional (more informative) command execution errors	
+800	Illegal with storage active	EE
+801	Insufficient vector data	EE
+802	OUTPUT blocked by interlock	EE
+804	Expression list full	EE
+805	Undefined expression exists	EE
+806	Expression not found	EE
+807	Definition not allowed	EE

Number	Description	Event
+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
+840	Not allowed with sweep on	EE
+841	Sweep step size too small	EE
+842	Sweep step size too large	EE
+850	Not Allowed with A-V Ohms	EE
+851	Not Allowed with A-V Ohm Buffer	EE
+852	No A-V ohms with Autorange	EE
+853	Too Many A-V Ohms Readings	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
	Keithley 6487 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.

* Measurement events are flagged in Measurement Event Register, standard events are flagged in Standard Event Register, operation events are flagged in Operation Event Register, and questionable events are flagged in Questionable Event Register.

NOTE

For more information on SCPI-confirmed messages, see the [IVI Foundation website](http://ivifoundation.org) (ivifoundation.org).

Eliminating common SCPI errors

The three SCPI errors that occur most often are:

- -113, "Undefined header"
- -410, "Query INTERRUPTED"
- -420, "Query UNTERMINATED"

The following topics discuss the most common causes for these errors and methods for avoiding them.

-113, "Undefined header"

This error indicates that the command you sent to the instrument did not contain a recognizable command name. The most likely causes for this error are:

- **Missing space between the command and its parameter.** There must be one or more spaces between the command and its parameter. For example:

:SOUR1:VOLT10	Incorrect (no space between command and parameter)
:SOUR1:VOLT 10	Correct

- **Improper short or long form.**
- **Blanks (spaces) within the command name.** For example:

:SYST :ERR?	Incorrect (space between :SYST and :ERR?)
:SYST:ERR?	Correct

-410, "Query INTERRUPTED"

This error occurs when you have sent a valid query to the instrument and then send it another command, query, or a group execute trigger (GET) before it has had a chance to send the entire response message (including the line-feed / EOI terminator). The most likely causes are:

- **Sending a query to the instrument and then sending another command or query before reading the response to the first query.** For example, the following sequence of commands will cause an error -410:

```
:SYST:ERR?
```

```
*OPC?
```

This sequence generates an error because you must read the response to :SYST:ERR? before sending the *OPC? query.

- **Incorrectly configured IEEE-488 driver.** The driver must be configured so that when talking on the bus it sends line-feed with EOI as the terminator and when listening on the bus it expects line-feed with EOI as the terminator. See the reference manual for your particular IEEE-488 interface.

- 420, "Query UNTERMINATED"

This error occurs when you address the instrument to talk and there is no response message to send. The most likely causes are:

- **Not sending a query.** You must send a valid query to the instrument before addressing it to talk.
- **Sending an invalid query.** If you have sent a query and still get this error, make sure that the instrument is processing the query without error. For example, sending an ill-formed query that generates an error -113, "Undefined header" and then addressing the instrument to talk will generate an error -420, "Query UNTERMINATED" as well.
- **Valid query following an invalid command.** This situation can occur when you send multiple commands or queries (program message units) within one command string (program message). When the 6487 detects an error in a program message unit, it discards all further program message units until the end of the string; for example:

```
:SENS1:DATE?; :SOUR1:VOLT?
```

In the above program message, the program message unit :SENS1:DATE? will generate error -113, "Undefined header" and the 6487 will discard the second program message unit :SOUR1:VOLT? even though it is a valid query.

Section 19

DDC emulation commands

In this section:

DDC language19-1

DDC language

The 6487 can be configured to accept the device-dependent commands (DDCs) of the Keithley Model 487 picoammeter by enabling the DDC language. To do so, use the LANG/DDC selection in the CONFIG COMM menu, as described in [Selecting and configuring an interface](#) (on page 9-1). The commands for controlling the 6487 with the DDC language are provided in the following table.

Since the architecture of the 6487 differs from that of the 487, 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.

NOTE

When using DDC with the 6487, timing may not match the timing of the 487.

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.

Mode	Command	Description Equivalent SCPI or 488.2 commands	Note	Default
Display Intensity	A0	Normal display DISPlay:ENABLE ON		X
	A1	Dim display	Display Intensity (on page 19-9)	
	A2	Turn display off DISPlay:ENABLE OFF		

Mode	Command	Description Equivalent SCPI or 488.2 commands	Note	Default
Reading Source	B0	Picoammeter readings READ?, FETCh?, MEAS?, or [SENSe[1]] :DATA[:LATest]?		X
	B1	Buffer reading (returns one at a time) TRACe:DATA? (returns entire buffer)		
	B2	All buffer readings TRACe:DATA? (returns entire buffer)		
	B3	Maximum reading from buffer CALCulate3:FORMat MAXimum CALCulate3:DATA?		
	B4	Minimum reading from buffer CALCulate3:FORMat MINimum CALCulate3:DATA?		
Zero Check	C0	Disable Zero Check SYSTem:ZCheck OFF		
	C1	Enable Zero Check SYSTem:ZCheck ON		X
	C2	Enable Zero Check and perform Zero Correct SYSTem:ZCheck ON SYSTem:ZCORrect ON	Zero Check and Zero Correct (on page 19-9)	
Display Text	Da	Display ASCII text message up to 12 characters DISPlay:TEXT <string> DISPlay:TEXT:STATe ON		
	D	Cancel display text mode (return to normal display) DISPlay:TEXT:STATe OFF		X
Ohms	F0	Disable ohms [SENSe[1]] :OHMS OFF		X
	F1	Enable ohms [SENSe[1]] :OHMS ON		
Data Format	G0	ASCII readings with prefix (NDCA-1.23456E-02)	SCPI not available	X
	G1	ASCII readings without prefix (-1.23456E-02)		
	G2	ASCII readings with prefix and buffer suffix (if in B1 or B2, NDCA-1.23456E-02,012)		
	G3	ASCII readings without prefix and buffer suffix (if in B1 or B2, -1.23456E-02,012)		
	G4	Binary readings, IEEE-754 std., single-precision, byte order reversed. FORMAT:DATA SREal FORMAT:BORDer SWAPPED		
	G5	Binary readings, IEEE-754 std., single-precision, normal byte order. FORMAT:DATA SREal FORMAT:BORDer NORMAL		
	G6	Binary readings with exponent, byte order reversed (not supported)		

Mode	Command	Description Equivalent SCPI or 488.2 commands	Note	Default
	G7	Binary readings with exponent, normal byte order (not supported)	Data Format (on page 19-9)	
Hit Key	H1	Hit CONFIG/LOCAL key	Hit Key (on page 19-9)	
	H2	Hit I Ω key		
	H3	Hit MATH key		
	H4	Hit FILT key		
	H5	Hit ZCHK key		
	H6	Hit REL key		
	H7	Hit OPER key		
	H8	Hit V-SOURCE up key		
	H11	Hit RANGE up key		
	H12	Hit AUTO key		
	H13	Hit RANGE down key		
	H14	Hit ENTER key		
	H15	Hit right cursor key		
	H16	Hit V-SOURCE down key		
	H17	Hit MENU key		
	H18	Hit COMM key		
	H19	Hit DISP key		
	H20	Hit TRIG key		
	H21	Hit LIMIT key		
	H22	Hit DIGITS key		
	H23	Hit RATE key		
	H24	Hit cursor left key		
	H26	Hit SAVE key		
	H27	Hit SETUP key		
	H28	Hit STORE key		
	H29	Hit RECALL key		
	H30	Hit AZERO key		
	H31	Hit DAMP key		
	H32	Hit EXIT key		
Self Test	J0	Perform RAM/ROM self-test *TST? (Test ROM only)	Self Test (on page 19-9)	
	J1	Perform RAM/ROM and display self-test *TST? (Test ROM only)		
EOI and Bus Hold-off	K0	Enable both EOI and bus hold-off on X	SCPI not available	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		

Mode	Command	Description Equivalent SCPI or 488.2 commands	Note	Default
Default Conditions and Calibration	L0	Return to factory defaults and save (L1) SYSTem:PRESet *SAV 0	See ARM and TRIGger subsystems in SCPI reference tables (on page 14-1).	
	L1	Save present states as default conditions *SAV 0		
	L2	Return to saved defaults *RCL 0		
	L3-L6	Calibration commands (not supported)		
SRQ	M0	Clears SRQ mask (SRQ disabled) *SRE 0	SRQ (on page 19-10)	X
	M1	Reading Overflow STATus:MEASurement[:EVENT]:ENABLE 128 *SRE 1	Status byte format (on page 19-14)	
	M2	Data Store Full STATus:MEASurement[:EVENT]:ENABLE 512 *SRE 1		
	M4	Data Store Half Full (not SCPI supported)		
	M8	Reading Done STATus:MEASurement[:EVENT]:ENABLE 64 *SRE 1		
	M16	Ready	Status byte format (on page 19-14) and SRQ (on page 19-10)	
	M32	Error	Status byte format (on page 19-14) and SRQ (on page 19-10)	
	M128	Voltage source error	Status byte format (on page 19-14) and SRQ (on page 19-10)	
Data Store	N0	Stop storage, clear buffer	Data Store (on page 19-10)	
	Nn	Arm data store, set buffer size n, where n = 1 through 512	Data Store (on page 19-10)	

Mode	Command	Description Equivalent SCPI or 488.2 commands	Note	Default
Operate	O0	Place voltage source in standby SOURce[1]:VOLTage:STATE OFF		X
	O1	Place voltage source in operate SOURce[1]:VOLTage:STATE ON		
Filters	P0	Both analog and digital filters off		
	P1	Enable digital filter, disable analog filter	Filters (on page 19-10)	
	P2	Disable digital filter, enable analog filter		
	P3	Enable both digital and analog filters	Filters (on page 19-10)	X
Interval	Q0	175 ms TRIGger:DELay 0.175		X
	Q1	Set to "n" seconds, n= 0.01msec to 999.999sec TRIGger:DELay <NRf>	Interval (on page 19-11)	
Range	R0	Enable autorange [SENSe[1]]:RANGE:AUTO ON		X
	R1	2nA range [SENSe[1]]:RANGE 2e-9		
	R2	20nA range [SENSe[1]]:RANGE 20e-9		
	R3	200nA range [SENSe[1]]:RANGE 200e-9		
	R4	2μA range [SENSe[1]]:RANGE 2e-6		
	R5	20μA range [SENSe[1]]:RANGE 20e-6		
	R6	200μA range [SENSe[1]]:RANGE 200e-6		
	R7	2mA range [SENSe[1]]:RANGE 2e-3		
	R8	20mA range [SENSe[1]]:RANGE 20e-3	Range (on page 19-11)	
	R9	20mA range [SENSe[1]]:RANGE 20e-3	Range (on page 19-11)	
	R10	Disable autorange [SENSe[1]]:RANGE:AUTO OFF	Range (on page 19-11)	
Integration Period	S0	Fast integration (1.6msec at 4-1/2 digit resolution) [SENSe[1]]:FUNCTION:NPLCycles 0.1 (at 60Hz)		
	S1	Line cycle (16.67msec, 60Hz; 20msec, 50Hz; 5-1/2d) [SENSe[1]]:FUNCTION:NPLCycles 1.0 (at 60Hz)		

Mode	Command	Description Equivalent SCPI or 488.2 commands	Note	Default
Trigger Mode	T0	Continuous, triggered by talk	SCPI not available	
	T1	One-shot, triggered by talk ARM[:SEQUence[1]]:COUNT 1 TRIGger[:SEQUence[1]]:COUNT 1	Only in 488.1 mode	
	T2	Continuous, triggered by GET ARM[:SEQUence[1]]:SOURCE BUS ARM[:SEQUence[1]]:COUNT 1 TRIGger[:SEQUence[1]]:COUNT INF INIT[:IMMediate]		
	T3	One-shot, triggered by GET ARM[:SEQUence[1]]:SOURCE BUS ARM[:SEQUence[1]]:COUNT INF TRIGger[:SEQUence[1]]:COUNT 1 INIT[:IMMediate]		
	T4	Continuous, triggered by X	SCPI Not Available	
	T5	One-shot, triggered by X	SCPI Not Available	
	T6	Continuous, triggered by External Trigger ARM[:SEQUence[1]]:SOURCE TLINK ARM[:SEQUence[1]]:SOURCE COUNT 1 TRIGger[:SEQUence[1]]:COUNT INF INITiate[:IMMediate]		X
	T7	One-shot, triggered by External Trigger ARM[:SEQUence[1]]:SOURCE TLINK ARM[:SEQUence[1]]:SOURCE COUNT INF TRIGger[:SEQUence[1]]:COUNT 1 INITiate[:IMMediate]		
	T8	Continuous on Operate	SCPI Not Available	
	T9	One-shot on Operate	SCPI Not Available	
Status Word	U0	Return status word. See Figure C-1. Each SCPI parameter must be queried individually. For example: SENSe[1]:CURRent:RANGE?		
	U1	Send error conditions. See Figure C-2.		
	U2	Send model number and firmware revision SYSTem:VERsion?		
	U3	Send calibration value CALibration:PROTected:SENSe:DATA?		
	U4	Send interval ARM:TIMer?		
	U5	Send delay TRIGger:DELay?		
	U6	Send relative value for current CALCulate[1]:NULL:OFFSET?		

Mode	Command	Description Equivalent SCPI or 488.2 commands	Note	Default
	U7	Send relative value for V/I ohms CALCulate[1]:NULL:OFFSET?		
	U8	Send voltage source value SOURce[1]:VOLtage?		
	U9	Send voltage source status word.		
Integration Period	S0	Fast integration (1.6msec at 4-1/2 digit resolution) [SENSe[1]]:FUNCTION:NPLCycles 0.1 (at 60Hz)		
	S1	Line cycle (16.67msec, 60Hz; 20msec, 50Hz; 5-1/2d) [SENSe[1]]:FUNCTION:NPLCycles 1.0 (at 60Hz)		
Trigger Mode	T0	Continuous, triggered by talk	SCPI not available	
	T1	One-shot, triggered by talk ARM[:SEQUence[1]]:COUNT 1 TRIGger[:SEQUence[1]]:COUNT 1	Only in 488.1 mode	
	T2	Continuous, triggered by GET ARM[:SEQUence[1]]:SOURCE BUS ARM[:SEQUence[1]]:COUNT 1 TRIGger[:SEQUence[1]]:COUNT INF INIT[:IMMEDIATE]		
	T3	One-shot, triggered by GET ARM[:SEQUence[1]]:SOURCE BUS ARM[:SEQUence[1]]:COUNT INF TRIGger[:SEQUence[1]]:COUNT 1 INIT[:IMMEDIATE]		
	T4	Continuous, triggered by X	SCPI Not Available	
	T5	One-shot, triggered by X	SCPI Not Available	
	T6	Continuous, triggered by External Trigger ARM[:SEQUence[1]]:SOURCE TLINK ARM[:SEQUence[1]]:SOURCE COUNT 1 TRIGger[:SEQUence[1]]:COUNT INF INITiate[:IMMEDIATE]		X
	T7	One-shot, triggered by External Trigger ARM[:SEQUence[1]]:SOURCE TLINK ARM[:SEQUence[1]]:SOURCE COUNT INF TRIGger[:SEQUence[1]]:COUNT 1 INITiate[:IMMEDIATE]		
	T8	Continuous on Operate	SCPI Not Available	
	T9	One-shot on Operate	SCPI Not Available	
Status Word	U0	Return status word. See Figure C-1. Each SCPI parameter must be queried individually. For example: SENSe[1]:CURRent:RANGE?		
	U1	Send error conditions.		

Mode	Command	Description Equivalent SCPI or 488.2 commands	Note	Default
	U2	Send model number and firmware revision SYSTem:VERsion?		
	U3	Send calibration value CALibration:PROTected:SENSe:DATA?		
	U4	Send interval ARM:TIMer?		
	U5	Send delay TRIGger:DELay?		
	U6	Send relative value for current CALCulate[1]:NULL:OFFSET?		
	U7	Send relative value for V/I ohms CALCulate[1]:NULL:OFFSET?		
	U8	Send voltage source value SOURce[1]:VOLTage?		
	U9	Send voltage source status word.		
Voltage Source	Vn, r, l	Voltage source value, range, current limit n = -505 through 505 SOURce[1]:VOLTage <NRf> r: 0 = 50 V range; 1 = 500 V range SOURce[1]:VOLTage:RANGe <NRf> l: 0 = 25 A limit; 1 = 2.5 A limit SOURce[1]:VOLTage:ILIMit <NRf>		0 V 50 V 2.5 mA
Delay	Wn	Delay trigger for "n" seconds. n = 0 to 999.999 s TRIGger:DELay <NRf>		0
Execute	X	Execute other device-dependent commands. SCPI not applicable (SCPI commands execute as they are received)		
Terminator	Y0	CR LF (carriage return, line feed)		X
	Y1	LF CR (line feed, carriage return)		
	Y2	CR (carriage return)		
	Y3	LF (line feed)	Terminator (on page 19-11)	
	Y4	None		
Relative (REL)	Z0	Disable relative CALCulate[1]:NULL:STATE OFF		X
	Z1	Enable relative using present reading as baseline CALCulate[1]:NULL:ACQuire CALCulate[1]:NULL:STATE ON		
	Z2, V	Enable relative using V as baseline: V = -2e-2 A to 2e-2 A for current. V = 0 Ω to 50.5e16 Ω for V/I ohms. CALCulate2:NULL:OFFSet <NRf> CALCulate2:NULL:STATE ON		
	Z3	Enable relative using previously defined baseline CALCulate[1]:NULL:STATE ON		

Command notes

Display Intensity

Only characters are dimmed. Annunciators are not dimmed.

Zero Check and Zero Correct

- Sending C2X will perform a Zero Correct operation. If the unit is not already in Zero Check, then Zero Check will be turned on, the Zero Correct value is collected, then Zero Check will be turned off.
- You cannot disable Zero Correct on the 487. Once a C2 command has been sent, Zero Correct (and the corresponding MON annunciator) will remain on. To turn off the Zero Correct and MON annunciator, use the front panel to turn off Zero Correct.
- As on the the 487, subsequent C2 commands will cause a new Zero Correct value to be acquired by the 6487
- The 6487 saves only a single Zero Correct value, not one for each range as with the 487. Send a C2 command to acquire new Zero Correct value after selecting the desired range. Unlike the 487, Zero Correct values are not saved across power cycles and must be acquired again after power cycling the unit.

Data Format

G6 and G7 are not supported by the 6487.

Hit Key

As the 487 and 6487 do not share a menu structure or front-panel keys, key mapping is not comparable.

Self-test

J0 and J1 for RAM and ROM self-tests are accepted but take no action. RAM and ROM are tested at power-up. The display may be tested from the front panel.

Default Conditions and Calibration

- Since the 487 DDC mode allows for one saved user setup to be the power-on default, the *SAV 0 location is used for the saved DDC defaults. Changing the instrument language to DDC clears the *SAV 0 location and loads the DDC factory defaults. A setup saved using the DDC mode L1 command will be saved to this location.
- Changing the 6487 language from DDC mode to SCPI will return the SYST:PRESet factory defaults to the *SAV 0 setup location, overwriting the setup stored with the DDC mode L1 command.
- The L3 through L5 calibration commands are not supported. You can only perform 6487 calibration with SCPI commands.

SRQ

You can enable multiple SRQ conditions by adding M command values. For example, M33 enables SRQ both on reading done and on error.

The DDC errors do not map one-to-one with SCPI errors. There are two SCPI errors that cover all of the 6487 Error Events (EE). This will be fairly equivalent to using the M16 DDC command.

After receiving an SRQ on an Error Event, clear the Event by reading the Standard Event Register (*ESR?), then talk to the instrument. There may also be an Error Available event set in the status byte (serial poll).

Data Store

- The 6487 does not support a continuous wrap-around buffer. Therefore, the NO command will stop storage and clear the buffer.
- Nx (x = 1-512) will arm the buffer and storage will begin at the first trigger. Pressing the LOCAL key on a 6487 puts the unit back into continuous trigger mode, so storage will start immediately. On the 487, however, you must press LOCAL followed by a separate press of the TRIGGER key. If all triggering is handled over the GPIB, this difference will not matter in actual practice. Although the 6487 buffer is capable of storing 3000 readings,in DDC mode the limit is the same 512 readings as the 487.

Filters

The digital filter is always a 4-point moving average type and cannot be changed in DDC mode.

Interval

See the [SCPI reference tables](#) (on page 14-1) section of this manual.

Range

The 487 does not allow R8 or R9 since the highest measurement range is R7 (2 mA). The 6487 accepts R8 and R9, both of which select the 20 mA range.

Whether R8 or R9 is sent, 8 will show up in the range position of the U0 response string.

R10 is still used to disable auto range and remain on the present range, as the 487.

Terminator

The SCPI PMT (Program Message Terminator) is LF + EOI.

Sweeps or A-V ohms in DDC mode

Sweeps or A-V ohms are not allowed in the DDC mode. A SCPI ONLY message will be displayed if you attempt to use sweeps or A-V ohms from the front panel.

Status words

The U0, U2, and U9 status words are shown in the next three figures.

Figure 70: U0 machine status word

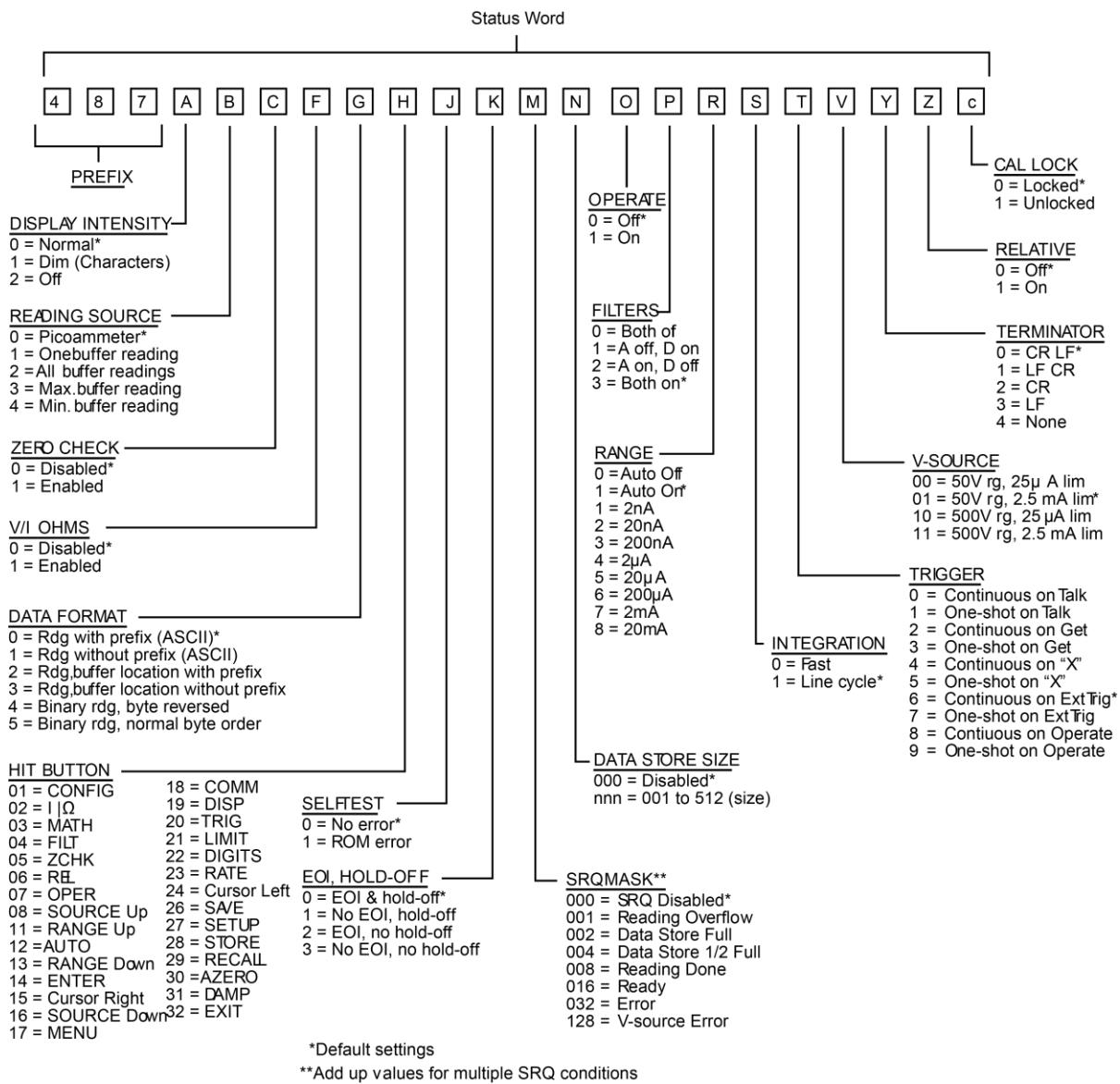
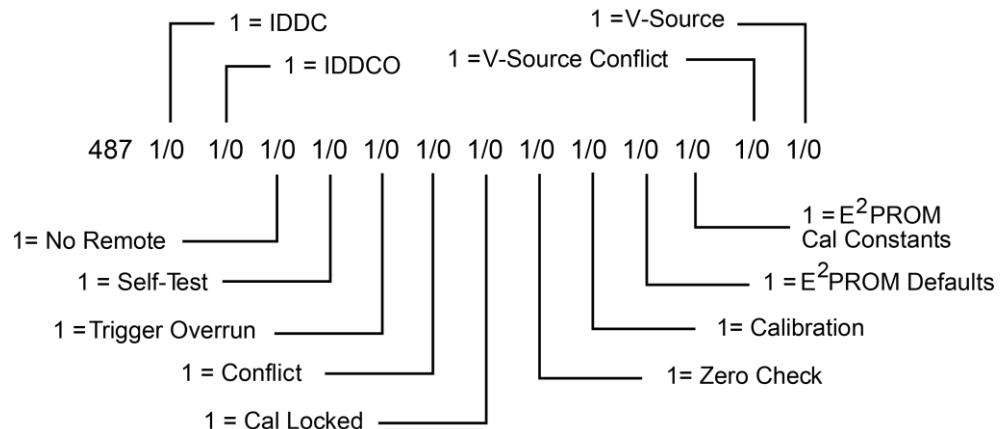
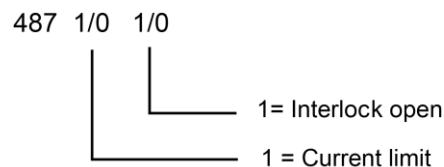


Figure 71: U1 error status word**Figure 72: U9 voltage source status word**

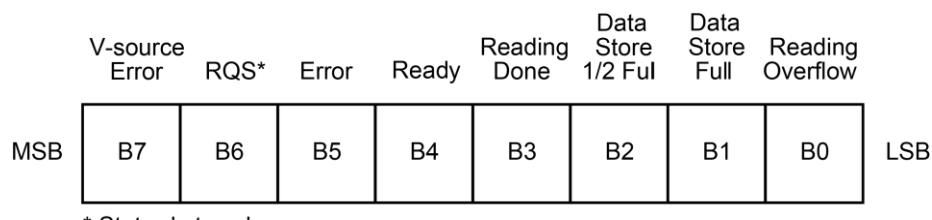
Status byte format

The status byte contains information relating to data and error conditions within the instrument. When a particular bit is set, certain conditions are present. The following table lists the meanings of the various bits and the graphic shows the general format of the status byte, which is obtained by using the SPE, SPD polling sequence.

Bit	Decimal weighting	Description
0 (LSB)	1	Reading Overflow
1	2	Data Store Full
2	4	Data Store 1/2 Full
3	8	Reading done
4	16	Ready
5	32	Error
6	64	RQS (Request for Service)*
7	128	Voltage Source Error

* Status byte only

Figure 73: Status byte format



* Status byte only

If the status byte is read when no SRQ was generated by the 6487 (bit 6 is clear), the current status of the instrument will be read. For example, if a reading was done, bit 3 would be set.

SRQ is enabled by setting the corresponding bit with the SRQ mask using the M command. The 6487 can be programmed to generate an SRQ for more than one condition simultaneously, simply by adding up the command option values.

When an SRQ is generated by the 6487, bit 6 of the status byte is set. After an SRQ, the status byte will remain unchanged until it is read.

The various bits in the status byte are described below:

Reading Overflow (B0): Set when an overrange input is applied to the instrument. Cleared when an on-scale reading has been made.

Data Store Full (B1): Set when the number of readings stored is equal to the buffer size. Cleared by re-arming data store.

Data Store 1/2 Full (B2): Set when the number of readings stored is equal to half the buffer size. Cleared by re-arming data store.

Reading Done (B3): Set when the instrument has completed the present conversion and is ready to take another reading. Cleared when the reading has been sent.

Ready (B4): Set when the instrument has processed all previous commands and is ready to begin processing new commands or triggers. Cleared while instrument is processing commands or triggers.

Error (B5): Set when one of the following errors has occurred:

- IDDC
- IDDCO
- No remote
- Self test
- Trigger overrun
- Conflict
- Cal locked
- Zero check
- Calibration error
- E2PROM defaults error
- E2PROM cal constants error
- V-source conflict
- Interlock

This bit is cleared when the U1 status word is read to determine the nature of the error.

RQS (B6): Set when the 6487 has generated a request for service via the SRQ line. Cleared by reading the status byte.

Voltage Source Error (B7): Set if the voltage source has reached current limit or if the interlock is tripped. Cleared by reading U9 status after correcting the voltage source error.

NOTE

Once the 6487 has generated an SRQ, its status byte must be read to clear the SRQ line. Otherwise, the instrument will continuously assert SRQ.

Section 20

IEEE-488 bus overview

In this section:

Introduction	20-1
Bus description	20-2
Bus lines	20-3
Bus commands	20-6
Interface function codes.....	20-12

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 controller of the communication exchange between all the devices. The controller consists of determining which device will talk and which device will listen. As a talker, a device will output information; 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.

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.

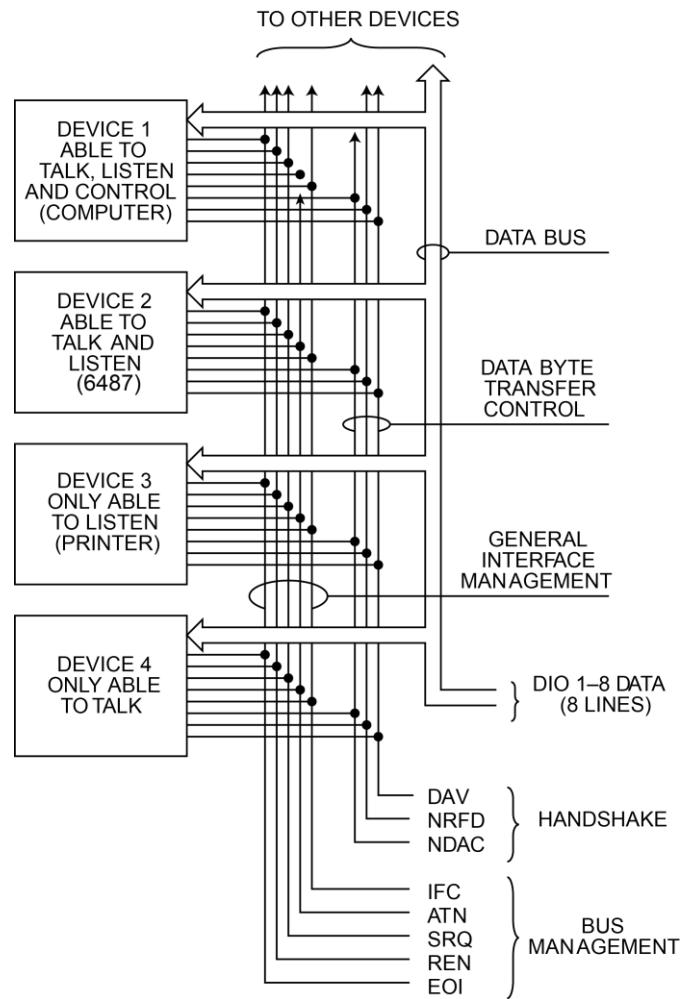
The IEEE-488 bus is limited to 15 devices, including the controller. Any number of talkers and listeners up to that limit may be present on the bus at one time. Although several devices may be commanded to listen simultaneously, the bus can have only one active talker.

A device is placed in the talk or listen state by sending a talk or listen command. 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 assigned from the front panel of the instrument. The actual listen address value sent 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 6487, 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.

A typical setup for controlled operation is shown in the following figure.

Figure 74: IEEE-488 bus configuration

Bus 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.

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:

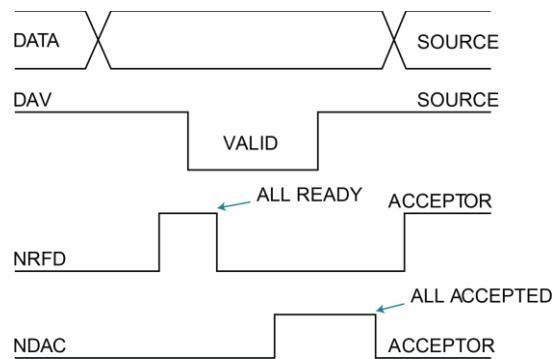
DAV (DATA VALID): The source controls the state of the DAV line to indicate to any listening devices whether or not data bus information is valid.

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 the next figure. 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.

Figure 75: IEEE-488 handshake sequence



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 multi-line commands. The state of the ATN line determines whether the data bus contains data, addresses, or commands as described in the following paragraphs.

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 four categories.

- **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).
- **Multiline commands:** General bus commands which are sent over the data lines with the ATN line true (low).
- **Common commands:** Commands that are common to all devices on the bus; sent with ATN high (false).
- **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 the following table.

Command type	Command	State of ATN line	Comments
Uniline	REN (Remote Enable) EOI IFC (Interface Clear) ATN (Attention) SRQ	X X X Low X	Set up devices for remote operation. Marks end of transmission. Clears interface. Defines data bus contents. Controlled by external device.
Universal Multiline	LLO (Local Lockout) DCL (Device Clear) SPE (Serial Enable) SPD (Serial Poll Disable)	Low Low Low Low	Locks out local operation. Returns device to default conditions. Enables serial polling. Disables serial polling.
Addressed Multiline	SDC (Selective Device Clear) GTL (Go To Local)	Low Low	Returns unit to default conditions. Returns device to local.
Unaddressed	UNL (Unlisten) UNT (Untalk)	Low Low	Removes all listeners from the bus. 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 76: Command codes

*PPC(PARALLEL POLL CONFIGURE) PPU(PARALLEL POLL UNCONFIGURE),

and TCT (TAKE CONTROL) not implemented by Model 6487.

Uniline commands

ATN, IFC, and REN are asserted only by the controller. SRQ is asserted by an external device. EOI may be asserted either by the controller or other devices depending on the direction of data transfer. The following is a description of each command. Each command is sent by setting the corresponding bus line true.

REN (Remote Enable): REN is sent to set up instruments on the bus for remote operation. When REN is true, devices will be removed from the local mode. Depending on device configuration, all front panel controls, except the LOCAL button (if the device is equipped), may be locked out when REN is true. Generally, REN should be sent before attempting to program instruments over the bus.

EOI (End or Identify): EOI is used to positively identify the last byte in a multi-byte transfer sequence, thus allowing data words of various lengths to be transmitted easily.

IFC (Interface Clear): IFC is used to clear the interface and return all devices to the talker and listener idle states.

ATN (Attention): The controller sends ATN while transmitting addresses or multi-line commands.

SRQ (Service Request): SRQ is asserted by a device when it requires service from a controller.

Universal multiline commands

Universal commands are those multi-line commands that require no addressing. All devices equipped to implement such commands will do so simultaneously when the commands are transmitted. As with all multiline commands, these commands are transmitted with ATN true.

LLO (Local Lockout): LLO is sent to the instrument to lock out the LOCAL key and all their front panel controls.

DCL (Device Clear): DCL is used to return instruments to some default state. Instruments usually return to their power-up conditions.

SPE (Serial Poll Enable): SPE is the first step in the serial polling sequence which is used to determine which device has requested service.

SPD (Serial Poll Disable): SPD is used by the controller to remove all devices on the bus from the serial poll mode and is generally the last command in the serial polling sequence.

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 6487) 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 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

Hexadecimal and the decimal values for the various commands are listed in the following table.

Command	Hexidecimal 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 through 3F	32 through 63
TAG	40 through 5F	64 through 95
SCG	60 through 7F	96 through 127
UNL	3F	63
UNT	5F	95

Typical command sequences

For the various multi-line 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. The following table lists a typical bus sequence for sending the addressed multi-line 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.

Step	Command	ATN state	Data bus		
			ASCII	Hex	Decimal
1	UNL	Set low	?	3F	63
2	LAG*	Stays low	.	36	54
3	SDC	Stays low	EOT	04	4
4		Returns high			

*Assumes primary address is 22.

The following table 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.

Step	Command	ATN state	Data bus		
			ASCII	Hex	Decimal
1	UNL	Set low	?	3F	63
2	LAG*	Stays low	.	36	54
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 is 22.

IEEE command groups

Command groups supported by the 6487 are listed in the next table. Common commands and SCPI commands are not included.

HANDSHAKE COMMAND GROUP	
	NDAC = NOT DATA ACCEPTED NRFD = NOT READY FOR DATA DAV = DATA VALID
UNIVERSAL COMMAND GROUP	
	ATN = ATTENTION DCL = DEVICE CLEAR IFC = INTERFACE CLEAR REN = REMOTE ENABLE SPD = SERIAL POLL DISABLE SPE = SERIAL POLL ENABLE
ADDRESS COMMAND GROUP	
LISTEN	LAG = LISTEN ADDRESS GROUP MLA = MY LISTEN ADDRESS UNL = UNLISTEN
TALK	TAG = TALK ADDRESS GROUP MTA = MY TALK ADDRESS UNT = UNTALK OTA = OTHER TALK ADDRESS
ADDRESSED COMMAND GROUP	
	ACG = ADDRESSED COMMAND GROUP GTL = GO TO LOCAL SDC = SELECTIVE DEVICE CLEAR
STATUS COMMAND GROUP	
	RQS = REQUEST SERVICE SRQ = SERIAL POLL REQUEST STB = STATUS BYTE EOI = END OF IDENTIFY

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 6487 are listed in the following table.

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 the 6487 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.

E (Bus-Driver Type): The instrument has open-collector bus drivers (E1).

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).

Section 21

IEEE-488 and SCPI conformance information

In this section:

Introduction	21-1
GPIB 488.1 protocol.....	21-3
Selecting the 488.1 protocol.....	21-3
Protocol differences	21-4

Introduction

The IEEE-488.2 standard requires specific information about how the 6487 implements the standard. Paragraph 4.9 of the IEEE-488.2 standard (Std 488.2-1987) lists the documentation requirements.

The following table provides a summary of the requirements and provides the information or references the manual for that information. The 6487 complies with SCPI version 1996.0.

	Requirements	Description or reference
(1)	IEEE-488 Interface Function Codes.	See IEEE-488 bus overview (on page 20-1).
(2)	Behavior of 6487 when the address is set outside the range 0-30.	Cannot enter an invalid address.
(3)	Behavior of 6487 when valid address is entered.	Address changes and bus resets.
(4)	Power-On Setup Conditions.	Determine by :SYSTem:POSetup. See SCPI reference tables (on page 14-1).
(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 commands).
(d)	Queries that generate a response when read.	None
(e)	Coupled commands.	See the following table
(6)	Functional elements required for SCPI commands.	See SCPI command subsystems tables in SCPI reference tables (on page 14-1).
(7)	Buffer size limitations for block data.	Block display messages: 12 characters max.
(8)	Syntax restrictions.	See Programming Syntax in Remote operation (on page 9-1).

	Requirements	Description or reference
(9)	Response syntax for every query command.	See Programming Syntax in Remote operation (on page 9-1).
(10)	Device-to-device message transfer that does not follow rules of the standard.	None.
(11)	Block data response size.	See DISPlay subsystem.
(12)	Common commands implemented by the 6487.	See Common commands (on page 11-1).
(13)	Calibration query information.	See Applications guide (on page 23-1).
(14)	Trigger macro for *DDT.	Not applicable.
(15)	Macro information.	Not applicable.
(16)	Response to *IDN (identification).	See Common commands (on page 11-1).
(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 (on page 11-1).
(20)	*TST information.	See Common commands (on page 11-1).
(21)	Status register structure.	See Status structure (on page 10-1).
(22)	Sequential or overlapped commands.	All are sequential except :INIT, which is overlapped.
(23)	Operation complete messages.	See Common commands (on page 11-1).

The following table lists coupled commands.

Sending	Changes	To
CALC2:NULL:ACQ	CALC2:NULL:OFFS <n>	Acquired value
TRAC:POIN <n> TRAC:CLE	TRAC:FEED:CONT <name> TRAC:FEED:CONT <name> TRAC:CLE	NEV NEV

GPIB 488.1 protocol

The 6487 supports two GPIB protocols: SCPI (488.2) and 488.1. The 488.1 protocol is included to significantly increase speed over the GPIB.

When using the 488.1 protocol, throughput is enhanced up to 10 times for data sent to the 6487 (command messages) and up to 20 times for data returned by the picoammeter (response messages). The speed of readings sent over the GPIB is also increased.

NOTE

With the 488.1 protocol selected, you will still use SCPI commands to program the 6487. Operational differences between the two protocols are discussed in this chapter.

Selecting the 488.1 protocol

NOTE

The Model 6487 must be set up to be remotely controlled over the GPIB to select the 488.1 protocol. SCPI language is the only language available over the RS-232 bus. To set up the 6487 to use GPIB from the local measurement mode:

1. Press the **COMM** button.
 2. Using the **RANGE** keys, select **GPIB**.
 3. Press **ENTER** to complete the change.
-

To select the 488.1 protocol:

1. Press **CONFIG**. **CONFIGURE** : is displayed).
2. Press **COMM** to access the communications menu. If **BAUD** is displayed flashing, the 6487 is configured to use the RS-232 bus. See the note at the beginning of this topic to use GPIB.
3. Scroll using a **RANGE** key until **LANG** is displayed.
4. Press the right cursor key to place the cursor on the currently selected language (either **DDC**, **SCPI**, or **488.1** will be flashing).
5. Scroll using a **RANGE** key until **488.1** is displayed. To change back to **488.2**, scroll to the **SCPI** menu item.
6. Press **ENTER** to save the change.

When switching between the SCPI protocol, DDC protocol, and 488.1 protocol, the instrument resets. The GPIB protocol setting is saved in EEPROM and the unit will power up with that selected protocol.

The GPIB protocol cannot be changed over the bus. However, there is a query command to determine the presently selected protocol. When the 488.1 protocol is selected, the message exchange protocol (MEP) disables. Therefore, if you use the following query to request the state of MEP, you will know which protocol is enabled:

```
:SYSTem:MEP [:STATe] ?
```

If **1** is returned, MEP is enabled and the SCPI protocol is selected. A **0** indicates that MEP is disabled and the 488.1 protocol is enabled.

Protocol differences

The following information covers the differences between the 488.1 protocol and the SCPI protocol.

Message exchange protocol (MEP)

When the 488.1 protocol is selected, the MEP is disabled to speed up GPIB operation.

The following guidelines/limitations must be followed when using the 488.1 protocol:

- If a query is sent, it must be the only command on the line (this limitation also means no multiple queries can be sent). Otherwise, full SCPI command syntax is still supported including long-form and short form commands, multiple commands, and MIN/MAX/DEF parameter definitions.

For example, the following command strings are invalid:

```
:CURR:RANG .020; *OPC?  
:CURR:RANG?;: READ?  
:READ?;:READ?
```

The following strings are valid:

```
curr:nplc 1.0;:curr:rang min  
:CURR:RANG? MAX  
:READ?
```

- When a query is sent, either the data must be read back or a Device Clear (**DCL**) or Interface Clear (**IFC**) must be performed to reset the query.
- When sending a command or query, do not attempt to read data from the 6487 until the terminator has been sent (usually Line Feed with EOI). Otherwise, a **DCL** or **IFC** must be sent to reset the input parser.
- When receiving data, all data, up to and including the terminator (LF with EOI), must be accepted. Otherwise, a **DCL** or **IFC** must be sent to reset the output task.
- Empty command strings (terminator only) should not be sent.

Using SCPI-based programs

In general, an existing SCPI-based program will run properly and faster in the 488.1 protocol as long as it meets the above guidelines and limitations.

NRFD hold-off

*OPC, *OPC?, and *WAI are still functional but are not needed for the 488.1 protocol. When sending commands, the GPIB is automatically held off when it detects a terminator. The hold-off is released when all the commands have finished executing or if there is some parser or command error. An exception is an initiate command, which releases the hold-off immediately and does not wait for all of the readings to be acquired. This immediate release of bus hold-off is done to support GET, SDC, IFC, *TRG, *RCL, *RST, SYSTem:PRESet, and ABORT during data acquisition.

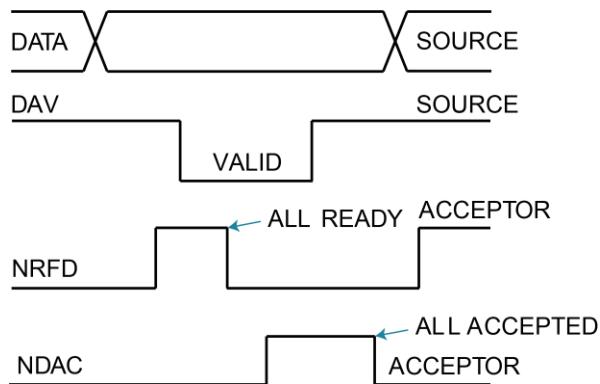
NDAC hold-off

NDAC hold-off is included with the GPIB 488.1 protocol mode to allow a single instrument to hold off all others on the bus until it is finished executing a command. The following command controls NDAC hold-off:

```
SYSTem:MEP:HOLDoff ON | OFF
```

The default is OFF, but NRFD hold-off will still be enabled and will prevent an instrument from accepting further commands. See the following figure for the complete IEEE-488 handshake sequence.

Figure 77: IEEE-488 handshake sequence



Trigger-on-talk

Trigger-on-talk functionality has been added for the 488.1 protocol. If a query has not been received by the instrument, the Model 6487 will automatically assume a READ? command has been sent when it is addressed to talk. This technique increases GPIB speed by decreasing the transmission and parser times for the command.

Trigger-on-talk is extremely useful in the single-shot reading mode (*RST default) and is the main reason for a >2x speed improvement over the SCPI protocol.

The ARM:SOUR BUS and ARM:COUN INF commands are not supported by READ? with the 488.1 protocol selected. If you send one of these commands, a DCL or IFC may be required to reset the GPIB.

Message available

The MAV (message available) bit in the Serial Poll byte will be set when the query is finished being processed, not when there is data available in the output buffer (as with the SCPI protocol). For the 488.1 protocol, output data will not be formatted until the first request for data is received. This delay may cause unexpected time-outs when using SRQ on MAV for queries that take a long time to execute.

General operation notes

The TALK, LSTN, and SRQ annunciators are not functional in the 488.1 protocol. This speeds up data throughput greatly. The REM annunciator still operates since it is critical to fundamental GPIB operation.

If the unit is in REMote, the GTL command may not put the 6487 into the local mode. Only the front panel **LOCAL** key is guaranteed to operate, if not in local lockout (LLO). GTL will still disable LLO.

IEEE-488 bus commands and features (GET, IFC, SDC, DCL, LLO, Serial Poll, and SRQ) are still fully supported.

Multiple TALKs on the same query are supported as in the SCPI protocol. This feature is useful when reading back long ASCII strings.

SRQ when buffer fills with 200 readings

The following QuickBasic program will store 200 readings in the buffer. When the buffer fills to the set amount (200 readings), an SRQ will occur and a message will be displayed on the computer to indicate the event.

```
' $INCLUDE: 'ieeqqb.bi'

CLS      'Clear PC output screen.
CONST addr = 22      'Set instrument address.

'
' Init GPIB
'

CALL initialize(21, 0)
CALL transmit("unt unl listen " + STR$(addr) + " sdc unl", status%)      'Restore *rst
defaults
CALL send(addr, "*rst", status%)          'Send Device Clear.
CALL send(addr, "trac:cle", status%)      'Clear buffer.
CALL send(addr, "trig:coun 200", status%)    '200 trigger count.
CALL send(addr, "trac:poin 200", status%)    'Set buffer size to 200.
CALL send(addr, "trac:feed:cont next", status%)   'Enable buffer.
CALL send(addr, "stat:pres", status%)        'Reset measure enable bits.
CALL send(addr, "*cls", status%)           'Clear all event registers.
CALL send(addr, "stat:meas:enab 512", status%)   'Enable buffer bit B9.
CALL send(addr, "*ese 0", status%)          'Disable standard events.
CALL send(addr, "*sre 1", status%)          'Enable measurement events.
CALL send(addr, "syst:zch off", status%)     'Disable zero check.
CALL send(addr, "init", status%)           'Start measurement/store process.

WAITSRQ:
  WHILE srq = 0:WEND  'Wait for GPIB SRQ line to go true.
  CALL spoll(addr, poll%, status%)  'Clear rqs/mss bit in status bit
  'register.
  CALL send(addr, "*cls", status%)  'Clear all event registers.
  PRINT "BUFFER FULL" 'Display buffer full message.
END
```

Section 22

Remote calibration

In this section:

Introduction	22-1
Calibration commands	22-1
Remote calibration overview	22-2

Introduction

This appendix contains a summary of 6487 remote calibration commands and a basic remote calibration procedure. See [Calibration](#) (on page 16-1) for complete details.

Calibration commands

The following table summarizes the 6487 remote calibration commands.

Command	Description
:CALibration	Calibration subsystem.
:PROTected	Commands protected by code/password.
:CODE '<code>'	Eight character code/password used to enable or unlock calibration. (Default: KI006487.)
:CODE?	Calibration code query.
:LOCK	Lock out further calibration.
:LOCK?	Return 1 if calibration is locked, 0 otherwise.
:SENSe <NRf>	Calibrate active current range.
:DATA?	Query measurement cal constants.
:VSOurce	Voltage source calibration commands:
:NFSCale	Turn on source, set it to negative full scale for present source range.
:NFSValue <NRf>	Calibrate negative full scale using DMM reading.
:ZERO	Set source output to 0 V and turn on output.
:ZVALue <NRf>	Calibrate source zero using DMM reading.
:PFSCale	Turn on source, set it to positive full scale for present source range.
:PFSValue <NRf>	Calibrate positive full scale using DMM reading.
:SOURce	Path to query source calibration constants.
:DATA?	Query constants for present source range. Three values are returned: Vnegative, Vpositive, and Vzero.
:SAVE	Save all calibration data to non-volatile memory.
:DATE <yyyy, mm, dd>	Year, Month, Day when cal was last performed.
:DATE?	Query last cal date.
:NDUE <yyyy, mm, dd>	Year, Month, Day when 6487 is due for re-cal.
:NDUE?	Query cal due date.
:COUNT?	Returns how many times 6487 has been calibrated.
:UNPProtected	Commands not protected by code/password.
:VOFFset	Voltage offset correction.

Remote calibration overview

The steps below outline the general procedure for calibrating the Model 6487 using remote commands. Refer to [Calibration](#) (on page 16-1) for details on calibration steps, calibration points, and test equipment connections.

1. Send the following command to unlock calibration (factory default code shown):

```
:CAL:PROT:CODE 'KI006487'
```

2. Perform voltage offset correction by sending the following command:

```
:CAL:UNPR:VOFF
```

3. Be sure a triaxial shielding cap is connected to the INPUT jack before sending the above command.
4. Send the appropriate command to select the current range to be calibrated. For example, the following command selects the 20 mA range:

```
:SENS:CURR:RANG 2e-2
```

5. 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 20 mA range:

```
:CAL:PROT:SENS 0  
:CAL:PROT:SENS 2e-2  
:CAL:PROT:SENS -2e-2
```

6. Repeat steps 3 and 4 for each range.

WARNING

Hazardous voltages will be present during voltage source calibration steps. Use care to avoid a shock hazard. The interlock must be closed to calibrate the 50 V and 500 V ranges. See [Measurement concepts and connections](#) (on page 2-1) for interlock information.

7. Be sure the DMM is connected to the 6487 voltage source terminals, then send the commands for each calibration point for the selected range. Be sure to include the actual DMM reading for each step.
8. Repeat the previous step for each voltage source range.
9. After all current and voltage source ranges are calibrated, send the commands to program the calibration dates; for example:

```
:CAL:PROT:DATE 2002,12,15  
:CAL:PROT:NDUE 2003,12,15
```

10. Finally, send the following commands to save calibration constants and then lock out calibration:

```
:CAL:PROT:SAVE
:CAL:PROT:LOCK
```

Range	Commands*
2 nA	:SENS:CURR:RANG 2e-9 :CAL:PROT:SENS 0 :CAL:PROT:SENS 2e-9 :CAL:PROT:SENS -2e-9
20 nA	:SENS:CURR:RANG 2e-8 :CAL:PROT:SENS 0 :CAL:PROT:SENS 2e-8 :CAL:PROT:SENS -2e-8
200 nA	:SENS:CURR:RANG 2e-7 :CAL:PROT:SENS 0 :CAL:PROT:SENS 2e-7 :CAL:PROT:SENS -2e-7
2 µA	:SENS:CURR:RANG 2e-6 :CAL:PROT:SENS 0 :CAL:PROT:SENS 2e-6 :CAL:PROT:SENS -2e-6
20 µA	:SENS:CURR:RANG 2e-5 :CAL:PROT:SENS 0 :CAL:PROT:SENS 2e-5 :CAL:PROT:SENS -2e-5
200 µA	:SENS:CURR:RANG 2e-4 :CAL:PROT:SENS 0 :CAL:PROT:SENS 2e-4 :CAL:PROT:SENS -2e-4
2 mA	:SENS:CURR:RANG 2e-3 :CAL:PROT:SENS 0 :CAL:PROT:SENS 2e-3 :CAL:PROT:SENS -2e-3
20 mA	:SENS:CURR:RANG 2e-2 :CAL:PROT:SENS 0 :CAL:PROT:SENS 2e-2 :CAL:PROT:SENS -2e-2

* Full-scale calibration values for 2 nA to 2 µA ranges should be calculated from calibrator voltages and standard resistance values. Values for 20 µA to 20 mA ranges can be used as shown.

Range	Commands*
10 V	:SOUR1:VOLT:RANG 10 :CAL:PROT:VSO:NFSC :CAL:PROT:VSO:NFSV <DMM_Reading> :CAL:PROT:VSO:ZERO :CAL:PROT:VSO:ZVAL <DMM_Reading> :CAL:PROT:VSO:PFSC :CAL:PROT:VSO:PFSV <DMM_Reading>
50 V	:SOUR1:VOLT:RANG 50 :CAL:PROT:VSO:NFSC :CAL:PROT:VSO:NFSV <DMM_Reading> :CAL:PROT:VSO:ZERO :CAL:PROT:VSO:ZVAL <DMM_Reading> :CAL:PROT:VSO:PFSC :CAL:PROT:VSO:PFSV <DMM_Reading>
500 V	:SOUR1:VOLT:RANG 500 :CAL:PROT:VSO:NFSC :CAL:PROT:VSO:NFSV <DMM_Reading> :CAL:PROT:VSO:ZERO :CAL:PROT:VSO:ZVAL <DMM_Reading> :CAL:PROT:VSO:PFSC :CAL:PROT:VSO:PFSV <DMM_Reading>

* Include <DMM_Reading> from output voltage generated by previous step.
 For example, :CAL:PROT:VSO:NFSV <DMM_Reading> value is generated by
 :CAL:PROT:VSO:NFSC command.

Section 23

Applications guide

In this section:

Measurement considerations	23-1
Applications.....	23-16

Measurement considerations

Some considerations for making accurate amps measurements are summarized as follows.

Additional measurement considerations are covered in the Model 6487 Picoammeter/Voltage Source User's Manual. For comprehensive information on precision measurements, refer to the Low Level Measurements handbook, which is available from Keithley Instruments.

It is critical that the picoammeter perform the measurement without interfering with the flow of current in the circuit, possibly affecting operation or inducing additional errors. Voltage burden is the terminal voltage of a picoammeter and ideally this voltage should be zero (no resistive or offset effect). Some meters, such as DMMs, utilize a shunt resistor to measure the voltage drop across a known resistance and a typical burden of 200 mV is not unusual.

The 6487 uses an alternative approach referred to as a feedback picoammeter, where the voltage burden is the input voltage of an operational amplifier. Furthermore, since the input voltage of the operational amplifier is the output voltage divided by the gain (typically 500,000) the voltage burden is in the microvolt range.

Leakage currents and guarding

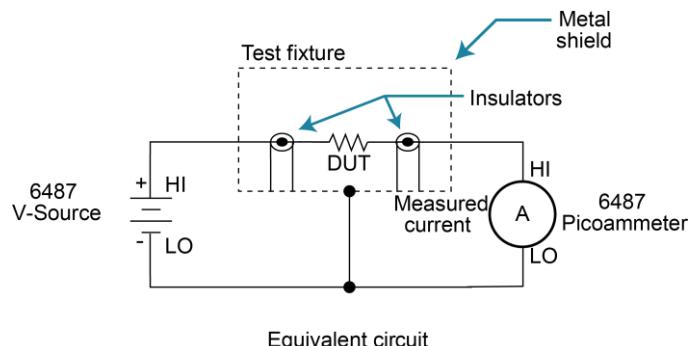
Leakage currents are generated by high resistance paths between the measurements circuit and nearby sources. These currents can considerably degrade the accuracy of low-current measurements. Some ways to reduce leakage currents are to use good quality insulators, maintain cleanliness on the surface of insulators, reduce humidity, and use guarding. Guarding also reduces the effect of shunt capacitance in the measurement circuit.

One way to reduce leakage currents is to use good quality insulators when building the test circuit. The best insulator is air. If possible, use air as the insulator for the sensitive node (the part of the circuit between the source of current and the ammeter HI input). Because this connection must eventually be mechanically supported, good insulators should still be used whenever it is necessary to make physical contact to the sensitive node. Some good quality insulators are Teflon, polyethylene, and sapphire. Avoid materials such as phenolics and nylon. Refer to Keithley's Low Level Handbook, available com the [Keithley Instruments website \(tek.com/keithley\)](http://tek.com/keithley) for additional information on choosing the best insulator.

Humidity may also degrade low-current measurements. The amount of water an insulator absorbs will vary depending upon the insulator. It is best to choose an insulator on which water vapor does not readily form a continuous film. Sometimes this is unavoidable if the material being measured absorbs water easily, so it is best to make the measurements in an environmentally controlled room. In some cases, an insulator may have ionic contaminants and, especially in high humidity, a spurious current may be generated.

Another way to reduce leakage currents is to use guarding. A guard is a conductor connected to a low-impedance point in the circuit that is nearly at the same potential as the high impedance lead (the sensitive node) being guarded. Guarding can isolate the high-impedance input lead of the picoammeter from leakage current due to voltage sources.

Guarding may also be necessary to prevent leakage current due to test fixturing. The next figure shows a high-megohm resistor supported on two insulators mounted in a metal test fixture. This circuit is guarded by connecting the LO of the picoammeter to the metal case. This will put the top of the insulator support post on the right at almost the same potential as the bottom. The voltage difference is equal to the voltage burden of the picoammeter. Since the top and the bottom of the insulator are at nearly the same potential, no significant current will flow through it and nearly all the current from the device under test will flow through the picoammeter.

Figure 78: Guarding to reduce leakage currents

Input bias current

An ideal picoammeter would read 0 A 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. This current emanates from points within the ammeter and flows through the internal ammeter circuitry, but it does not flow through the DUT. The input bias current for the 6487 is included in the offset portion of the accuracy specification.

Voltage burden

The input resistance of the picoammeter 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.

Assume VS is 5 mV and RS is 5 kΩ to configure a 1 μA current source ($5 \text{ mV} / 5 \text{ k}\Omega = 1 \mu\text{A}$). An ideal picoammeter with zero voltage burden would allow 1 μA to flow and measure it accurately.

In practice, however, every picoammeter has a voltage burden. If the voltage burden (VB) is 1 mV, the current that flows will be:

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

The 1 mV voltage burden caused a 20% reduction in actual current. Percent error in a measured reading (IM) due to voltage burden can be calculated as follows:

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

The voltage burden of the 6487 depends on the selected range. Voltage burden may be reduced by performing the voltage offset correction procedure.

Voltage offset correction procedure

NOTE

To maintain specified operation, any time there is a substantial change in the ambient temperature, the voltage offset procedure should be performed and saved.

1. Press the **MENU** key to display the following:

CAL: VOFFSET

2. Press **ENTER**. The instrument will prompt as follows:

INPUT CAP

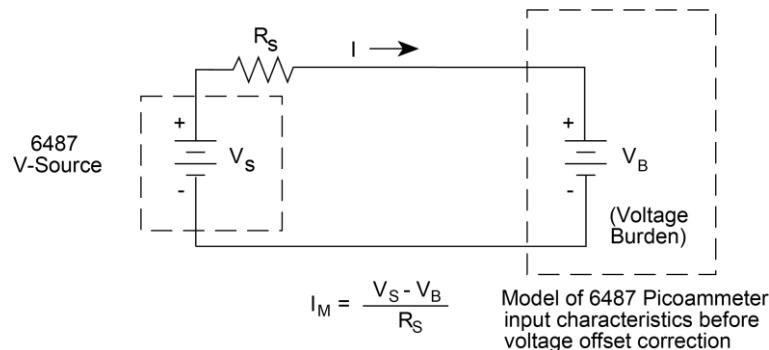
It is not necessary to disconnect signal cables from the 6487, but it is recommended that signal currents be reduced to zero if possible. During the calibration, the input impedance will be $3.5\text{ M}\Omega$, therefore continued signal currents will present a corresponding voltage to the DUT.

3. Press **ENTER** to complete offset voltage calibration.
4. Press **EXIT** to return to normal display.

NOTE

Like the other calibration procedures, this calibration is not permanently stored until **CAL:UNLOCK** and **CAL:SAVE** have been performed. Saving the results of this calibration at a temperature other than that at which the 6487 will be used will adversely affect measurement results.

Figure 79: Voltage burden considerations



Noise and source impedance

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 picoammeter will increase.

The following figure shows a simplified model of the feedback picoammeter. RS and CS represent the source resistance and source capacitance, VS is the source voltage, and VNOISE is the noise voltage. Finally, RF and CF are the feedback resistance and capacitance respectively.

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

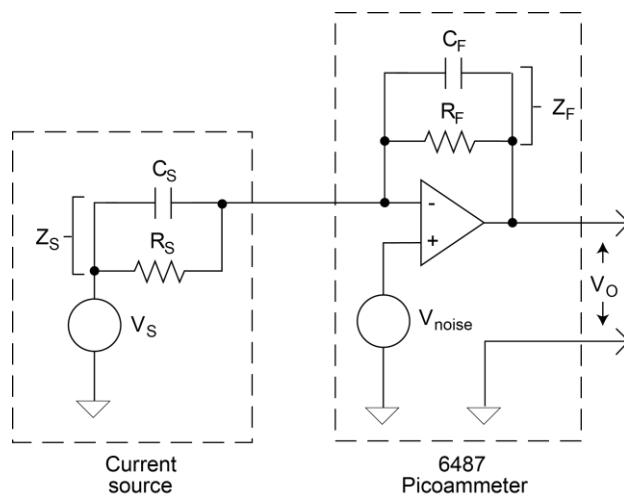
$$\text{Output } V_{\text{NOISE}} = \text{Input } V_{\text{NOISE}} (1 + R_F / R_S)$$

Note that as RS decreases in value, the output noise increases. For example, when RF = RS, 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.

The next table summarizes minimum recommended source resistance values for various measurement ranges. Note that the recommended source resistance varies by measurement range because the RF value also depends on the measurement range.

Range	Minimum recommended source resistance
2 nA, 20 nA	1 MΩ to 1 GΩ
200 nA, 2 μA	10 kΩ to 10 MΩ
20 μA, 200 μA	100 Ω to 100 kΩ
2 mA, 20 mA	10 Ω to 1 kΩ

Figure 80: Simplified model of a feedback picoammeter



Source capacitance

DUT source capacitance will also affect the noise performance of the 6487 picoammeter. 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 picoammeter](#) (on page 23-5) model in the previous topic. The elements of interest for this discussion are the source 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:

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

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 the lower ranges of the 6487 picoammeter is 10,000 pF. You can, however, usually measure at higher source capacitance values by inserting a resistor in series with the picoammeter input, but remember that any series resistance will increase the voltage burden by $I_{\text{IN}} \cdot R_{\text{SERIES}}$. For example, the range of resistance listed in the table in the previous topic will result in voltage burden values in range of 2 mV to 2 V. 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.

Electrostatic interference and shielding

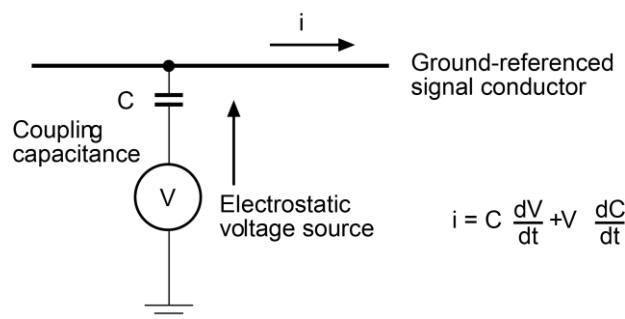
Electrostatic interference is probably the most common source of error when making low-current measurements. Electrostatic coupling or interference occurs when an electrically charged object is brought near an uncharged object. At low impedance levels, the effect of the interference are not noticeable because the charge dissipates rapidly. However, high resistance materials do not allow the charge to decay quickly, which may result in unstable measurements. The erroneous readings may be due to either dc or ac electrostatic fields, so electrostatic shielding will help minimize the effects of these fields.

DC fields can produce noisy readings or undetected errors. These fields can be detected when movement near an experiment (such as the movement of the person operating the instrument or others in the immediate vicinity) causes fluctuations on the picoammeter display. To perform a quick check for interference, place a piece of charged plastic, such as a comb, near the circuit. A large change in the meter reading indicates insufficient shielding.

AC fields can be equally troublesome. These are caused most often by power lines and RF fields. If the ac voltage at the input is large, part of this signal is rectified, producing an error in the dc signal being measured. This can be checked by observing the analog output of the picoammeter with an oscilloscope. A clipped waveform indicates a need to improve electrostatic shielding.

The next figure shows an example of ac electrostatic coupling. An electrostatic voltage source in the vicinity of a conductor, such as a cable or trace on a PC board, generates a current proportional to the rate of change of the voltage and of the coupling capacitance. This current can be calculated with the following equation:

Figure 81: Electrostatic coupling

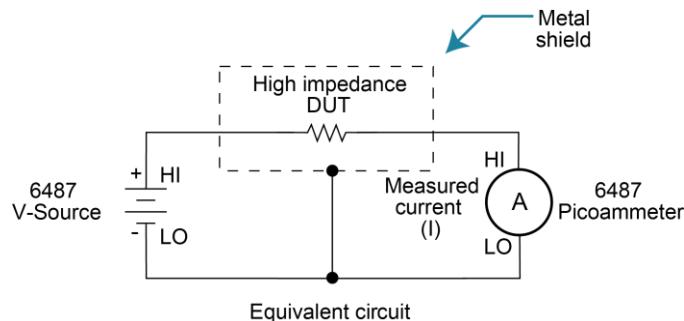


For example, two conductors, each with 1cm^2 area and spaced 1cm apart by air, will have almost 0.1 pF of capacitance. With a voltage difference of 100 V and a vibration causing a change of capacitance of 0.01 pF per second (a 10 % fluctuation), a current of 1 pA will be generated.

To reduce the effects of the fields, a shield can be built to enclose the circuit being measured. The easiest type of shield to make is a simple metal box or meshed screen that encloses the test circuit. Shielded boxes are also available commercially.

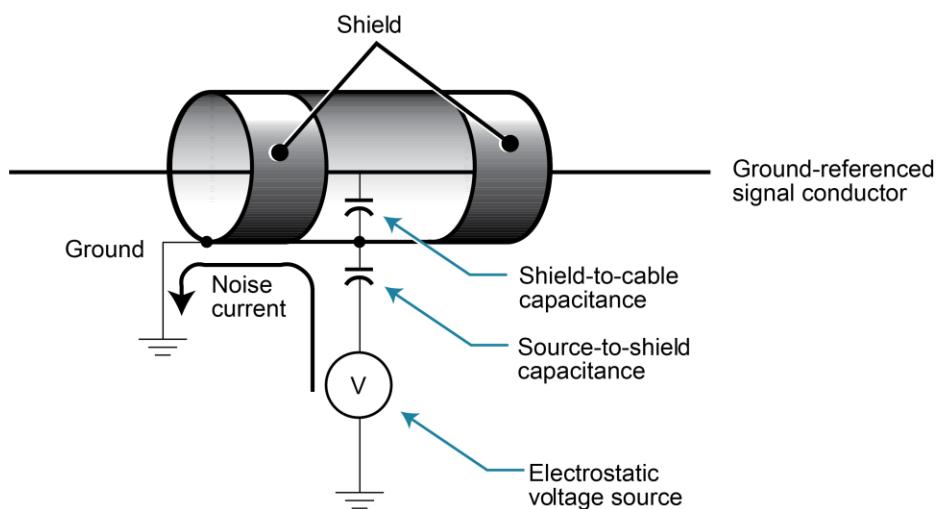
The next figure illustrates an example of shielding. Made from a conductive material, the shield is always connected to the low impedance input of the electrometer or picoammeter. If circuit low is floating above ground, observe special safety precautions to prevent anyone from touching the shield, such as triaxial cable with the outer shield at earth potential.

Figure 82: Shielding a high-impedance device



The cabling in the circuit also requires shielding. Capacitive coupling between an electrostatic noise source and the signal conductors or cables can be greatly reduced by surrounding those conductors with a grounded metal shield. With this shield in place, the noise current generated by the electrostatic voltage source and the coupling capacitance flows through the shield to ground rather than through the signal conductors.

Figure 83: Electrostatic shielding



Shielding vs. guarding

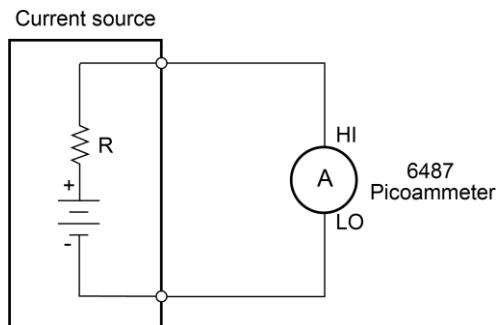
Shielding usually implies the use of a metallic enclosure to prevent electrostatic interference from affecting a high impedance circuit. Guarding implies the use of an added low impedance conductor, maintained at the same potential as the high impedance circuit, which will intercept any interfering voltage or current. A guard does not necessarily provide shielding.

Making connections

To avoid measurement errors, it is critical to make proper connections from the picoammeter to the device under test. To make a proper connection, always connect the high resistance terminal of the meter to the highest resistance point of the circuit under test.

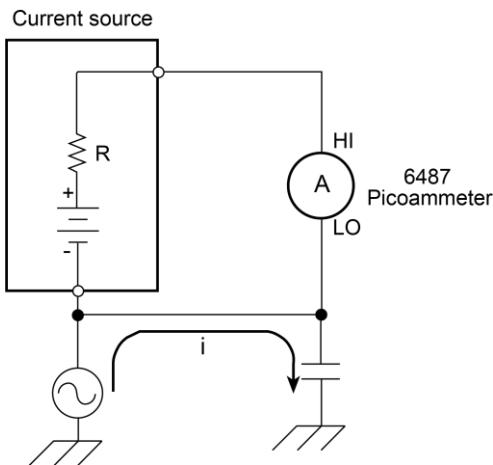
The next figure shows a picoammeter connected to a current source that consists of a voltage source in series with a resistor. An ac-powered voltage source usually has a significant level (often several volts) of line frequency common mode voltage.

Figure 84: Connecting the HI terminal (picoammeter to high resistance)



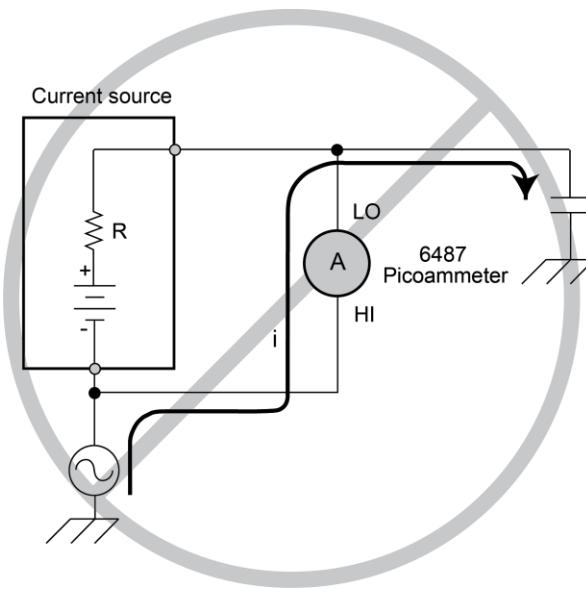
As shown in the next figure, this will cause a current (i) to flow through the low to ground capacitance of the picoammeter (A). Picoammeter HI is connected to the higher resistance side of the circuit being measured, the R side of this current source. This circuit is connected properly, so this current does not flow through the picoammeter and does not cause any measurement errors.

Figure 85: Proper connection



However, when the HI of the picoammeter is connected to the low impedance side of the DUT, this AC current (i) flows through the picoammeter (A) as illustrated in the next figure. This current may affect the measurement accuracy, especially at low signal levels.

Figure 86: Improper connection

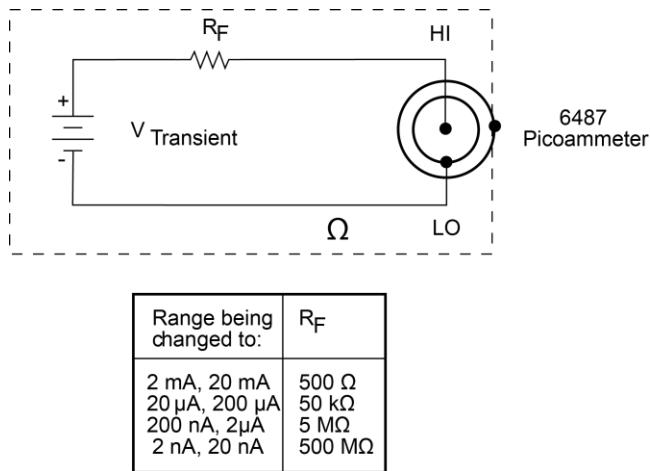


Refer to [Connection fundamentals](#) (on page 2-1) for details on appropriate types of cabling and connectors to use when making picoammeter measurements.

Typical range change transients

During a range change, a picoammeter cannot perfectly maintain its voltage burden specification. When a range change occurs, the picoammeter will momentarily become a current-limited voltage source.

Figure 87: Range change voltage transients



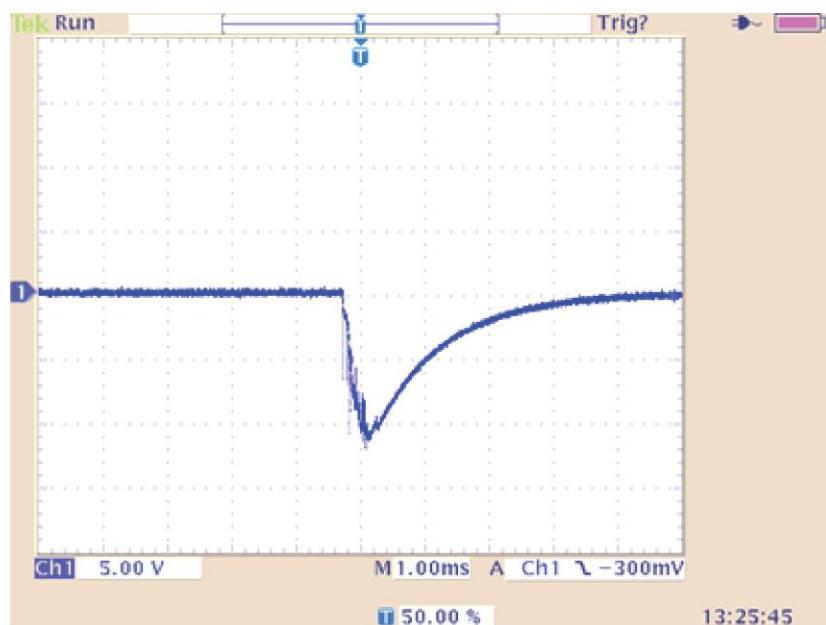
NOTE

The current that can be inadvertently delivered to the DUT is limited by an internal resistance. This internal resistance varies as the range is changed. For example, manually up-ranging from 2 μ A to the 20 μ A range can never deliver more than $10 \text{ V} / 50 \text{ k}\Omega = 200 \text{ }\mu\text{A}$ to the DUT. This current will be further limited by any impedance of the DUT.

Up-range input response

The following figure illustrates the type of transient voltage that can be expected when up-ranging with a full-scale input signal (200 μ A signal on 200 μ A range, up-range to 2 mA range). Both the magnitude and duration of this voltage are reduced for lower current ranges. The current limit imposed by the R_F is also greatly reduced. The polarity depends on the polarity of the input current.

Figure 88: Transient voltage

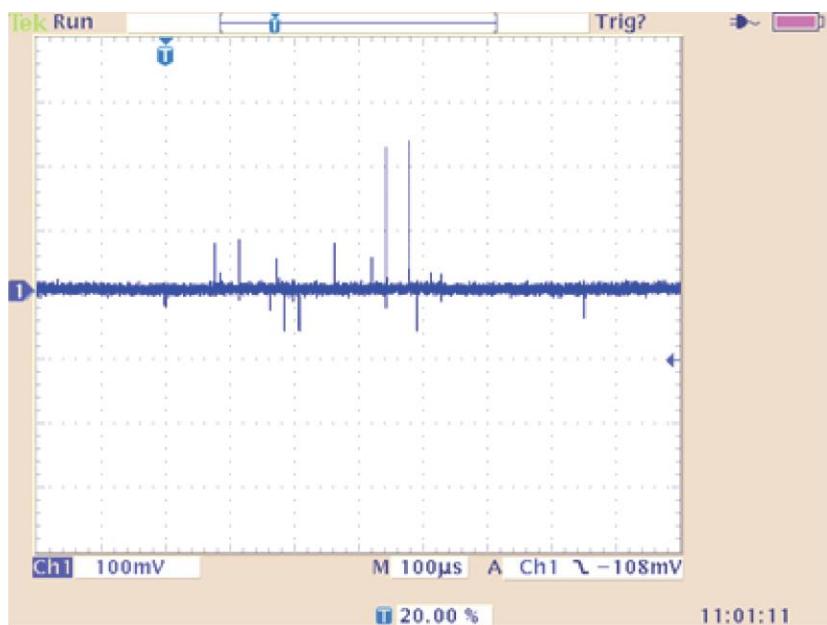


When it is necessary to up-range during auto-ranging operation, multiple ranges may be crossed to find the correct range. The duration of the transient in the above figure can be extended in this case, but the magnitude will not increase significantly.

Down-range voltage transients are smaller

With the exception of the change from the 2 mA range to the 200 μ A range, the down-range voltage transient is significantly smaller than the up-range transients. The next graphic shows the voltage presented at the input, measured during a change from 20 μ A to 2 μ A with a 2 μ A input current. The vast difference from the previous figures in voltage scale and time scale should be noted. Note also that the current limiting resistor will be that of the 2 μ A range, 100 times greater than upranging across the same boundary. The voltage transient of the 2 mA to 200 μ A change with a 200 μ A input signal is similar to the up-range response, with the exception that the current limiting R will be 100 times greater in the case of down-ranging.

Figure 89: Down-range voltage transients



Steps to minimize impact of range change transients

When changing between the following range pairs (up or down), no input transients occur: 2 nA and 20 nA, 200 nA and 2 μ A, 20 μ A and 200 μ A, 2 mA and 20 mA. This is not true when autoranging upwards across these boundaries.

Run test with a fixed range

If possible, run the test within a fixed range. Choose the higher range from any of the range pairs listed above. Alternatively, the autorange upper limit can be set so that the internal limiting resistor (R_F) cannot be reduced to the lower values. Choose the appropriate range to accommodate the maximum current expected during normal measurements.

Down-range by starting at highest current necessary

Make use of down-ranging by starting at the highest current necessary and reducing down to zero, the range change transients can be reduced significantly compared to up-ranging transients.

Using protection circuitry

Using protection circuitry can greatly reduce currents and voltages presented to devices being tested, as well as serving to protect the 6487 from any externally generated transients. If using the scheme from "Noise and safety shields" in the 6487 User's Manual, size the external current limiting resistor such that the sum of the external resistor and the lowest R_F will limit a 10V transient to a current level acceptable to the DUT.

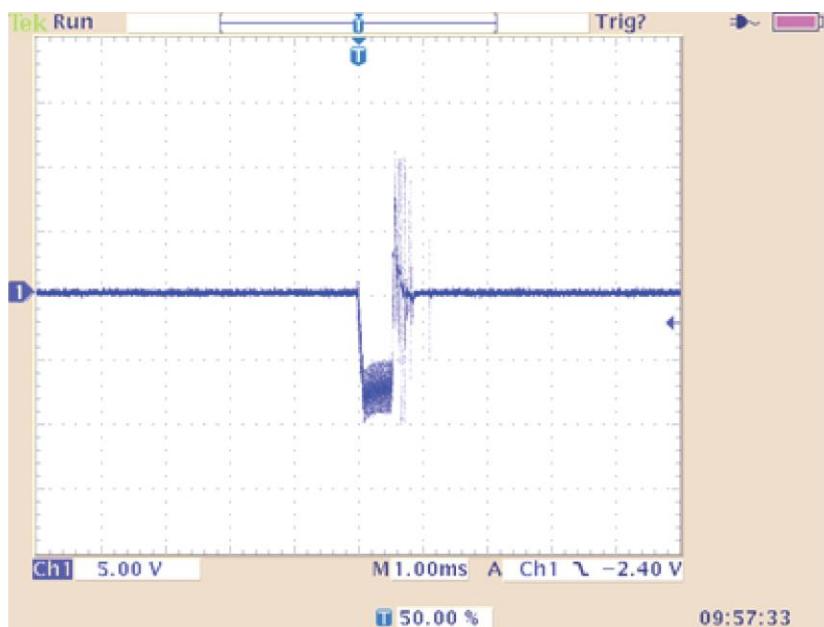
Reduce up-ranging transient

If the application requires that up-ranging be used, and when the transient through the internal limiting resistor R_F would damage the DUT, the up-ranging transient can be reduced greatly by reducing the input current to < 10% of the present range before forcing the range change up (manual or fixed-ranging over the bus). This can be true when running the first I-V curve on devices whose characteristics are not yet known, so that sweeping from low current towards high current is the only way to avoid exceeding a maximum current through the device.

Zero check on and zero check off response

The following figure shows the transient that can be expected from input HI to LO during a change in the zero check mode with no input current. The transition is similar for entering and leaving zero check. For current ranges 2 μ A and below, the magnitude of the response is not as large, but similar in duration. As with range change transients, the zero check transient is presented through an internal impedance which will limit the resulting current through the DUT. If there is an input current while in zero check, the input voltage will depend on the current and the zero check input impedance for the specific range.

Figure 90: Zero check transient



Range Zcheck	Transient impedance
2 mA, 20 mA	500 Ω
20 μ A, 200 μ A	50 k Ω
200 nA, 2 μ A	3.5 M Ω
2 nA, 20 nA	11 M Ω

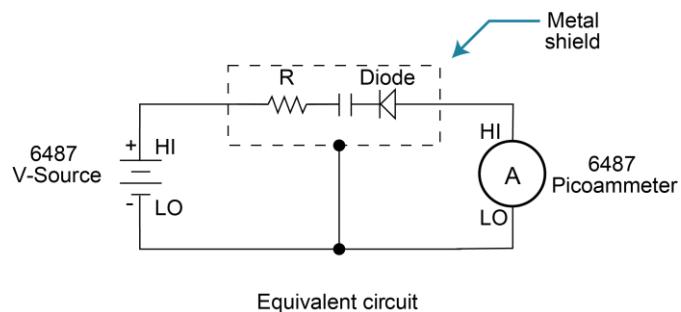
Applications

Diode leakage current

The following figure 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 20 mA or less.

A profile for leakage current can be developed by measuring current at various voltage levels. For example, program the voltage source to sweep voltage from 1 V to 10 V in 1 V steps. The 6487 performs a current measurement on each voltage step. To ensure that the voltage is settled before each current measurement, you can program the 6487 for a delay. For example, if you program the 6487 for a one second delay, each measurement will be performed after the voltage step is allowed to settle for one second. The current measurements are stored in the buffer.

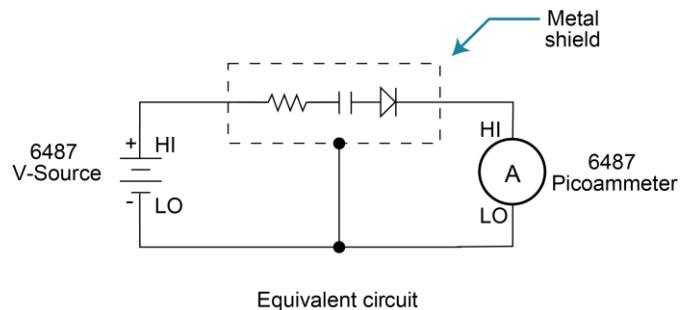
Figure 91: Diode leakage current test connections



Capacitor leakage current

The following figure 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.

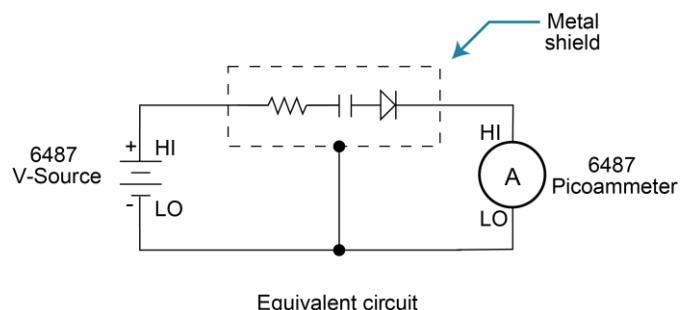
Figure 92: Capacitor leakage current test connections



A resistor and a diode are used to limit noise for the measurement. The resistor limits the current in case the capacitor becomes shorted, and it also offsets the effects of decreasing capacitive reactance with increasing frequency, which affects picoammeter noise performance (see Source capacitance). A good starting point is to choose a resistance value that results in an RC time constant of 0.5 to 2 seconds. The diode acts like a variable resistance, low while the capacitor is charging, and much higher when the capacitor is fully charged. As a result, the resistance value can be significantly smaller. Also damping may help to reduce noise (see Damping).

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 0 V for a specified time to allow the capacitor to discharge. Note that measurements with the voltage source in the high-impedance state (from interlock opening) might have high noise pickup caused by an unshielded voltage source HI terminal.

Figure 93: Capacitor leakage current test connections



Measuring high resistance

The 6487 can be used to make high resistance ($>1\text{ G}\Omega$) measurements using the built-in voltage source. The alternating voltage ohms mode can be used to improve accuracy and repeatability of very high resistance measurements. High resistance measurement applications include insulation resistance testing and resistivity measurements of insulators.

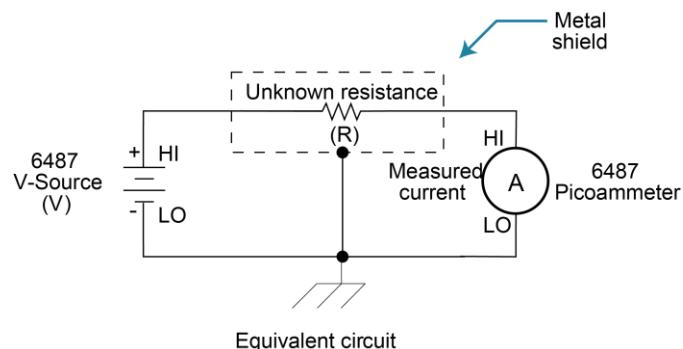
To measure high resistance, the internal voltage source is placed in series with the unknown resistance and the picoammeter. Since the voltage drop across the picoammeter is negligible, essentially all the voltage appears across the unknown resistance. The resulting current is measured by the picoammeter. The resistance is then calculated and displayed using Ohm's Law:

$$R = \frac{V}{I}$$

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

The basic configuration for measuring high resistance using the 6487 Picoammeter is shown in the next figure. The HI terminal of the 6487 picoammeter is connected to one end of the unknown resistance (R) and the HI terminal of the internal voltage source to the other end of the resistance. The LO terminal of the picoammeter is connected to the LO terminal of the voltage source. Both LO terminals are also connected to earth ground. This should be done via the ground link on the rear of the 6487.

Figure 94: Measuring high resistance using the 6487



To prevent generated current due to electrostatic interference, place the unknown resistance in a shielded test fixture. The metal shield is connected to the LO terminal of the 6487.

Alternating voltage ohms measurement

To reduce measurement errors caused by background currents, use the alternating voltage ohms measurement mode. The step voltage and time for each phase should be carefully chosen to assure proper circuit settling, while the averaging a number of reading cycles will improve repeatability. See [Alternating voltage ohms mode](#) (on page 3-24) for details.

Cable insulation resistance

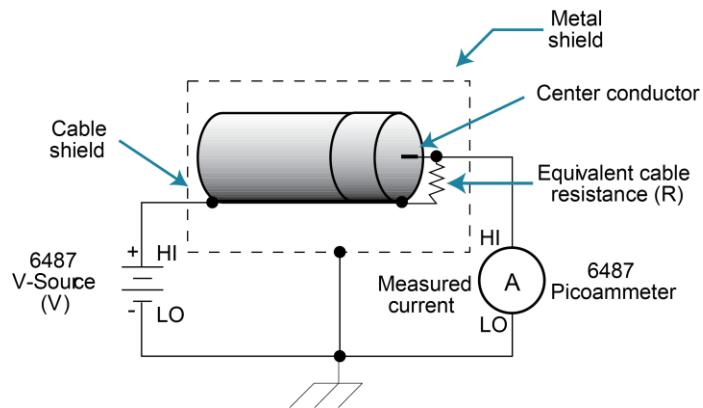
The next figure shows how to measure the insulation resistance of a cable. The resistance of the insulator between the shield and the inner conductor is being measured. The cable sample should be kept as short as possible to minimize input capacitance to the picoammeter.

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:

$$R = \frac{V}{I}$$

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

Figure 95: Cable insulation resistance test connections



Surface insulation resistance (SIR)

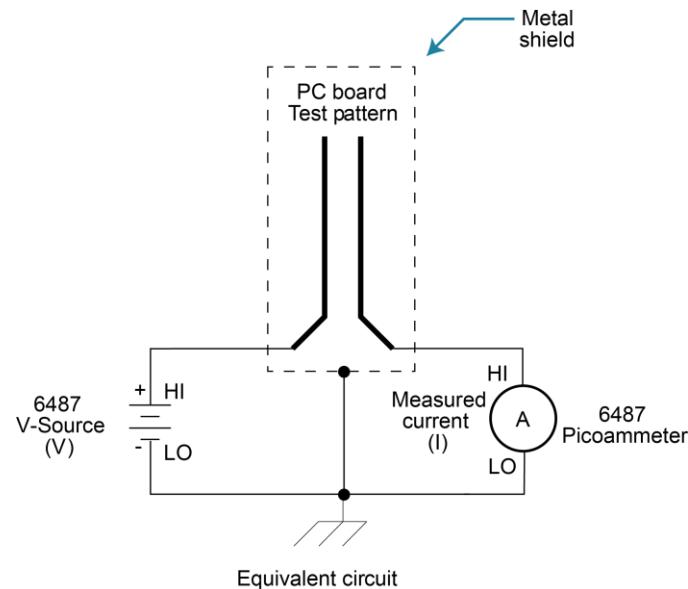
The next figure shows how to measure the insulation resistance between PC board traces. Note that the drawing shows a "Y" test pattern for the measurement. This is a typical test pattern for SIR tests.

A bias voltage (typically 50 V) is applied to the test pattern for a specified time (typically one second) to polarize the test pattern. The test voltage (typically 100 V) is then applied and, after a specified time (typically one second), the 6487 measures the current. Surface insulation resistance (R) can now be calculated as follows:

$$R = \frac{V}{I}$$

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

Figure 96: Surface insulation resistance test connections



Photodiode characterization prior to dicing

The 6487 can be used as part of a cost-effective semiconductor photodiode leakage test system. This test characterizes the photo current under various illumination conditions.

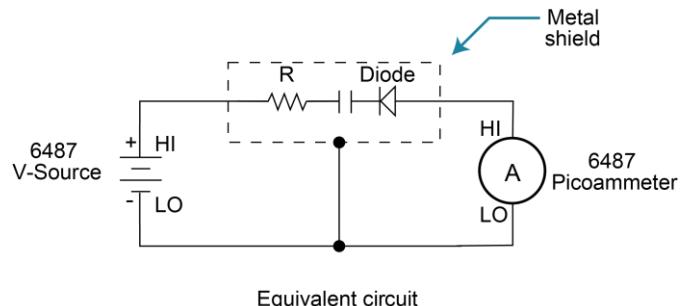
In addition to the 6487, specialized equipment is required. This equipment includes a calibrated optical source in addition to semiconductor equipment (probe card or needle mounts, etc.). Several 6487s can be connected to probe pads to provide leakage current readings forced by the bias voltage source. As an alternative, one or more 6487s can be switched through a switching mainframe and matrix switch card arrangement to take current measurements from multiple pads.

Measuring photodiode leakage can be described in two steps:

1. V_{sweep} , I_{meas} in total darkness.
2. V_{bias} , I_{meas} in calibrated optical flux.

In the first step, voltage sweeps and the resulting current leakage is measured. Then, a bias voltage is applied and resulting current leakage is measured while light is incrementally increased in calibrated steps. The results produce a graph similar to the following.

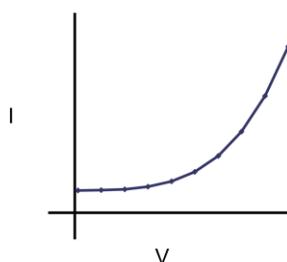
Figure 97: General photodiode leakage



P.I.N. (Positive Intrinsic Negative) diodes respond as shown in the below figure.

Figure 98: PIN photodiode leakage

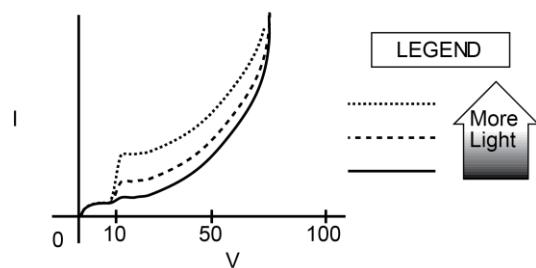
P.I.N. photodiode



In total darkness, Avalanche diodes respond as shown by the solid line in the following figure. Notice the small irregularity of the curve while sweeping around 10 V to 12 V. This irregularity is made larger under additional applied light (dashed lines).

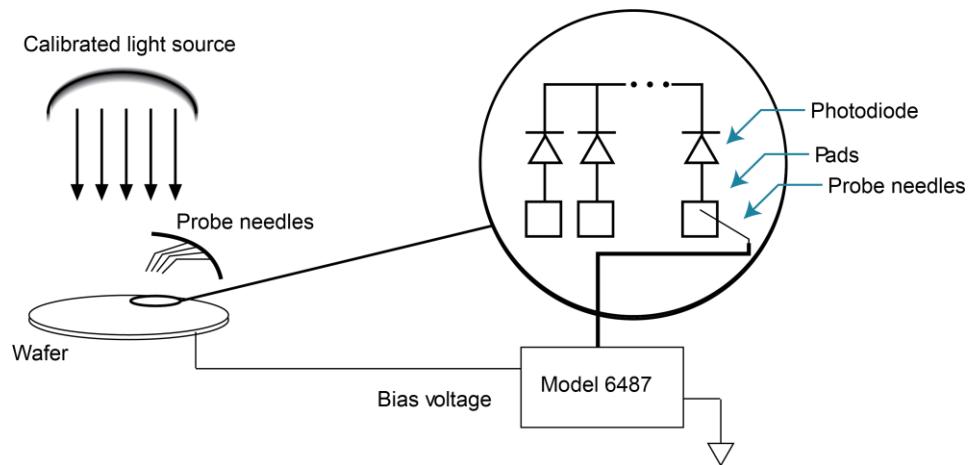
Figure 99: Avalanche photodiode leakage

Avalanche photodiode



Connections are made to the 6487 through the triaxial input connector (located on the rear panel) as well as the voltage source output terminals to provide the necessary bias voltage.

Figure 100: Basic connection scheme



Focused ion beam applications

Focused Ion Beam (FIB) systems have been developed to perform nanometer-scale imaging, micro machining, and mapping in the semiconductor industry. Typical applications include mask repair, circuit modification, defect analysis, and sample preparation of site-specific locations on integrated circuits.

FIB systems use a finely focused ion beam for imaging or for site specific sputtering or milling. The magnitude of the beam current determines what type of operation is performed. A low beam current results in very little material being sputtered and is, therefore, ideal for imaging applications. Utilization of high beam currents resulting in a great deal of material being removed by sputtering, and is subsequently well suited for precision milling operations.

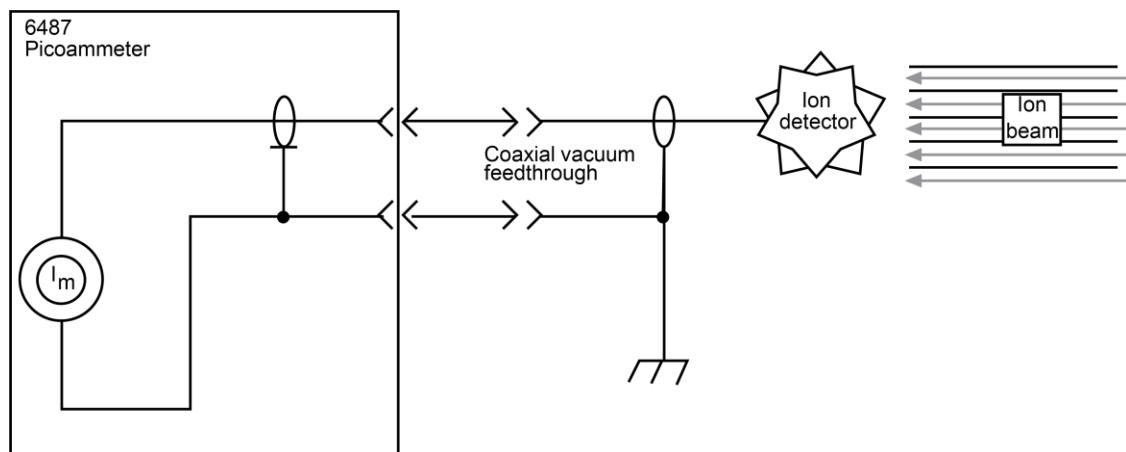
Therefore, whether the application calls for imaging or a complete circuit modification, monitoring and control of the beam current is critical to the success of the process. The ion beam current cannot be measured directly, but requires the use of an ion detector. There are several detectors commonly used throughout the industry including Channeltron®, Daly, Microchannel plate, and the Faraday cup. The Faraday cup can only be used in an analog mode and is, therefore, not as sensitive as newer current pulse devices.

The function of the detector is to develop a secondary current proportional to the current of the primary ion beam, without interfering with the primary beam. The basic operation of most detectors is similar; an ion from the primary beam strikes the detector and a secondary ion is generated, isolated from the primary ion stream. This current is then measured and used to control the intensity of the beam.

The secondary currents generated by the detectors are very low and require a high degree of accuracy and measurement repeatability. Currents as low as 5 or 6 pA are not uncommon; therefore, the measurement device must be capable of achieving resolutions below 1 pA.

The 6487 is ideal for this application because it offers a wide selection of range settings spanning from 20 mA to 2 nA. This will result in 5-1/2 digit resolution ranging from 100 nA to 10 fA. Numerous ranges, and fine measurement granularity, will meet all current requirements for this application, as well as provide additional sensitivity for future development needs.

Signal connections to the picoammeter are made using the triaxial connector mounted on the rear panel. If the source on the ions is biased off ground, then the ion detector will most likely be at ground potential. A simple coaxial vacuum feedthrough can be used to make the connection between the detector and the picoammeter.

Figure 101: Focused ion beam signal connections

Using switching systems to measure multiple current sources

Refer to [External trigger example](#) (on page 7-13).

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