

Model 6487 Picoammeter/Voltage Source

Reference Manual

6487-901-01 Rev. B / March 2011

KEITHLEY

A GREATER MEASURE OF CONFIDENCE

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

This product is intended for use by qualified personnel who recognize shock hazards and are familiar with the safety precautions required to avoid possible injury. Read and follow all installation, operation, and maintenance information carefully before using the product. Refer to the user documentation for complete product specifications. If the product is used in a manner not specified, the protection provided by the product warranty may be impaired.

The types of product users are:

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

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

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

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

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

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

Operators of this product must be protected from electric shock at all times. The responsible body must ensure that operators are prevented access and/or insulated from every connection point. In some cases, connections must be exposed to potential human contact. Product operators in these circumstances must be trained to protect themselves from the risk of electric shock. If the circuit is capable of operating at or above 1000 volts, no conductive part of the circuit may be exposed.

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

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

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

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

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

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

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

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

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

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

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

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

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

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

The  symbol indicates a connection terminal to the equipment frame.

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

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

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

Instrumentation and accessories shall not be connected to humans.

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

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

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

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1 Getting Started

- [Introduction](#) — Description of the Model 6487 Picoammeter.
- [Overview of this manual](#) — Provides content of this manual.
- [General information](#) — Covers general information that includes warranty information, contact information, safety symbols and terms, and inspection.
- [Power-up](#) — Covers line power connection, line voltage setting, fuse replacement, power line frequency, and the power-up sequence.
- [Front panel operation](#) — Shows the location of front panel controls, displays, and indicators.
- [Status and error messages](#) — Status and error messages.
- [Default settings](#) — Covers the five instrument setup configurations available to the user: three user defined, GPIB defaults, or factory defaults.
- [Menus](#) — Listing of the main and configuration menu items.
- [SCPI programming](#) — Explains how SCPI commands are presented in this manual.

Introduction

The Model 6487 is a high resolution bus-programmable (RS-232 and IEEE-488) picoammeter. The Model 6487 has the following current measurement ranges: 8 ranges, from 20mA down to the 2nA range. The Model 6487 also has a built-in $\pm 500\text{V}$ DC voltage source and an ohms function that includes an alternating voltage mode for enhanced high resistance measurement accuracy.

Overview of this manual

This manual describes how to connect, program, and maintain the Model 6487 Picoammeter. The sections of the manual are organized as follows:

- [Section 1](#): Getting Started
- [Section 2](#): Measurement Concepts and Connections
- [Section 3](#): Measurements and Sourcing Voltage
- [Section 4](#): Range, Units, Digits, Rate, and Filters
- [Section 5](#): Relative, $mX+b$, $m/X+b$, and log
- [Section 6](#): Buffer and Sweeps
- [Section 7](#): Triggering
- [Section 8](#): Limit Tests and Digital I/O
- [Section 9](#): Remote Operation
- [Section 10](#): Status Structure
- [Section 11](#): Common Commands
- [Section 12](#): SCPI Signal Oriented Measurement Commands
- [Section 13](#): DISPlay, FORMat, and SYSTem
- [Section 14](#): SCPI Reference Tables
- [Section 15](#): Performance Verification
- [Section 16](#): Calibration
- [Section 17](#): Routine Maintenance

Appendices to this manual contain specifications and also provide additional information on specific topics. The appendices are organized as follows:

- [Appendix A](#): Specifications
- [Appendix B](#): Status and Error Messages
- [Appendix C](#): DDC Emulation Commands
- [Appendix D](#): IEEE-488 Bus Overview
- [Appendix E](#): IEEE-488 and SCPI Conformance Information
- [Appendix F](#): Remote Calibration
- [Appendix G](#): Applications Guide

General information

Warranty information

Warranty information is located at the front of this manual. Should your Model 6487 require warranty service, contact the Keithley representative or authorized repair facility in your area for further information. When returning the instrument for repair, be sure to fill out and include the service form at the back of this manual to provide the repair facility with the necessary information.

Contact information

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

Safety symbols and terms

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

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

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

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

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

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

Unpacking and Inspection

Inspection for damage

The Model 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 Model 6487 from the bag, observe the following handling precautions.

Handling precautions

- Always grasp the Model 6487 by the covers.
- After removing the Model 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 Model 6487 is not installed and connected, keep the unit in its anti-static bag and store it in the original packing carton.

Package content

The following items are included with every Model 6487 order:

- Model 6487 Picoammeter with line cord
- Protective triax Shield/Cap (CAP-31)
- 7078-TRX-3 Triax cable
- Model 8607 1kV Source banana cable set
- CS-459 4-Pin Female interlock connector
- Accessories as ordered
- Certificate of calibration
- Model 6487 User's Manual (P/N 6487-900-00)
- Product information CD-ROM that contains PDFs of the User's and Reference Manuals

Reference manual

If a printed copy of the Model 6487 Reference Manual is required, order the manual package. The Keithley part number for the reference manual package is 6487-901-00. The manual package includes an instruction manual and any pertinent addenda.

Additional references

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

Model 6487 User's Manual — Supplied in printed form and as a PDF on the Product Information CD-ROM included with your shipment, this manual contains basic operating information for the user.

Low Level Measurements handbook — Keithley's guide for effective low current, low voltage, and high impedance measurements. Refer to www.keithley.com for more details.

Power-up

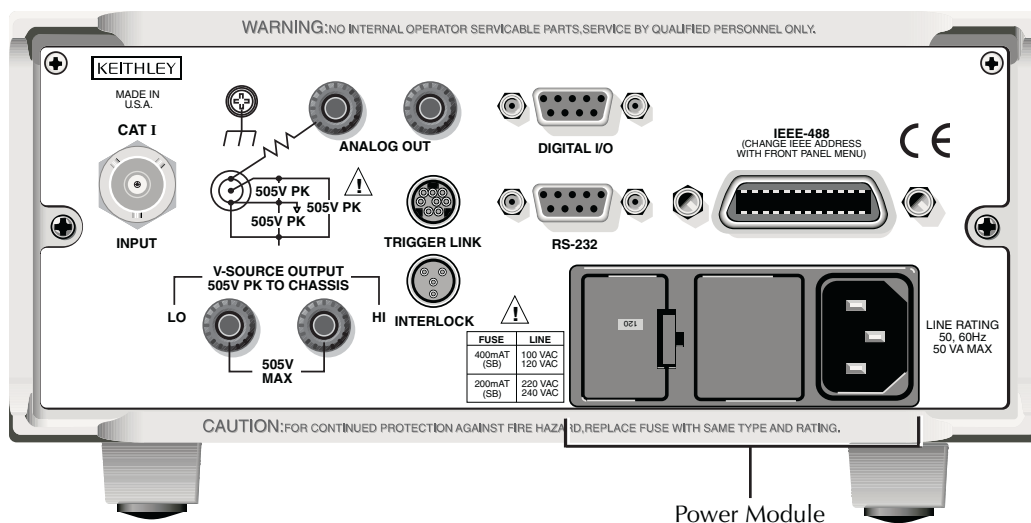
Line power connection

Follow the procedure below 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 (Figure 1-1) is correct for the operating voltage in your area. If not, refer to the procedure in Section 17 for setting line voltage and fuse replacement.

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

Figure 1-1
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 Model 6487 contains a separate ground wire for use with grounded outlets. When proper connections are made, instrument chassis is connected to power line ground through the ground wire in the power cord. Failure to use a grounded outlet may result in personal injury or death due to electric shock.

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

Line frequency

The Model 6487 operates at line frequencies of 50 or 60Hz. 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 (see the following procedure) or over the bus. Refer to [Table 1-1](#) for commands.

Front panel procedure

1. Press MENU.
2. Scroll to the LFREQ: menu item using the and RANGE keys. The present setting is displayed.
3. Press the ► cursor key.
4. Use the and RANGE keys to scroll to the desired menu item: AUTOXX, 50, or 60
5. Press ENTER.

NOTE In the setting of AUTOXX, XX is the currently detected frequency.

SCPI programming — line frequency

Table 1-1

SCPI commands — line frequency

Command	Description
SYSTem :LFRequency <freq> :AUTO :AUTO? [:STATE] [:STATE]? :LFRequency?	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.

Power-up sequence

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

1. The Model 6487 performs self-tests on its EPROM and RAM with all digits and annunciators turned on. If a failure is detected, the instrument momentarily displays an error message and the ERR annunciator turns on. Error messages are listed in [Appendix B](#).

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

2. If the instrument passes the self-tests, the firmware revision levels are displayed.
For example:
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. **GPIB** — If the GPIB is the selected interface, the instrument will display the selected language (SCPI, 488.1, or DDC) and primary address.
Examples:
SCPI ADDR: 22
DDC ADDR: 22
 - b. **RS-232** — If RS-232 is the selected interface, the instrument will display the baud rate setting. For example:
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

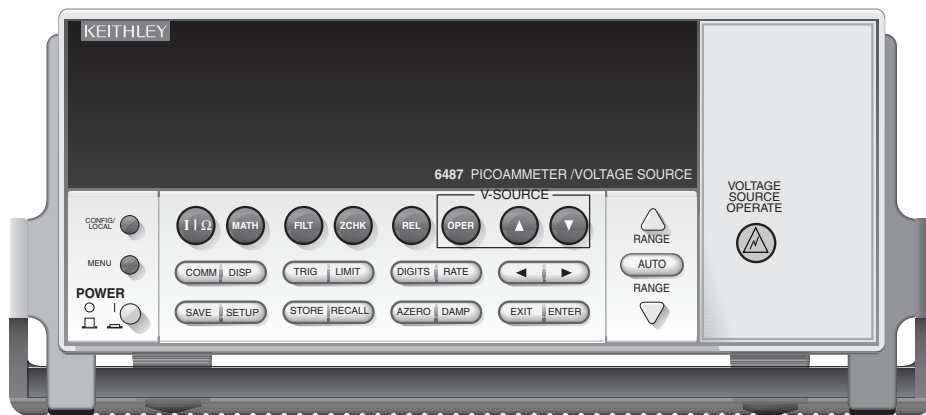
NOTE *To configure power-on set up:*

1. *Display PWR-ON: menu, press CONFIG and then SETUP.*
2. *Use and 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

Figure 1-2 shows the front panel of the Model 6487. For a detailed description of the various controls, displays, and indicators, see Section 1 of the Model 6487 User's Manual.

Figure 1-2
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 either of status or error variety, as listed in [Appendix B](#).

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

Default settings

The Model 6487 can be restored to one of five setup configurations: factory default (FACT), three user-saved (USR0, USR1, and USR2), and bus default (GPIB). As shipped from the factory, the Model 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. Factory and GPIB default settings are listed in [Table 1-2](#).

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 Model 6487 for the desired measurement application.
2. Press SAVE to access the save setup menu.
3. Use the **or** 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 **or** 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 **or** 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 [Section 11](#).

Restoring factory or GPIB default setups

The SYSTem:PRESet command returns Model 6487 to the factory defaults and the *RST command returns it to the GPIB defaults. The *RST command is documented in [Section 11](#) and SYSTem:PRESet is covered in [Section 13](#).

Selecting power-on setup

The SYSTem:POSetup command is used to select which setup to return to on power-up. The SYSTem:POSetup command is documented in [Section 13](#).

Table 1-2
Default settings

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

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

Table 1-2 (cont.)

Default settings

Setting	Factory (:SYStem:PRESet)	GPiB (*RST)
Rate: NPLC	Slow 6.0 (60Hz) or 5.0 (50Hz)	* *
Rel: Rel Value (VAL)	Off 0.0	* *
RS-232: All Settings	No effect (Off at factory) No effect	* *
Trigger Layer (CONFIG TRIG): Trig-In Source Event Trigger Count Trigger Delay Input Trigger Link Line Source Bypass Output Trigger Link Line	IMM 1 0 1 NEVER 2	* * * * * *
Units	No effect	*
Voltage Source: Operate Amplitude Range Current Limit 10V Range Interlock Sweeps: Start Voltage Stop Voltage Step Voltage Center Voltage Span Voltage Delay	Off 0V 10V 25mA Off 0V 10V 1V 5V 10V 1s	* * * * * * * * * * *
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 [Table 1-3](#). Refer to the section listed in the table for in-depth information. To access the main menus, press the MENU key. Use the $\leftarrow$ and RANGE keys to scroll through the menu items and the $\leftarrow$ and $\rightarrow$ cursor 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.*

Table 1-3

Main MENU structure

Menu item	Description	Reference
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.	Section 15 , Section 16
TSTAMP	Timestamp format can be ABSolute or DELTa.	Section 6
UNITS	Readings can be displayed in ENGINEERING units or SCIENTIFIC notation.	Section 6
TEST	Run display or key tests.	Section 17
SNUM	Displays the units serial number.	Section 11
LFREQ	Line frequency can be manually set to 50 or 60 Hz, or AUTOMATICALLY set. The number after AUTO indicates present detected frequency value.	“Line frequency,” page 1-6

Configuration menus

Many keys have configuration menus that allow you to configure various Model 6487 operating modes. [Table 1-4](#) summarizes the various configuration menus available. To access a configuration menu, press CONFIG and then the corresponding front panel key.

Table 1-4

Configuration menus

Key*	Description	Reference
I Ω	Configure normal or alternating voltage ohms modes.	Section 3
MATH	Set up MX + B, M/X + B, and LOG math functions.	Section 5
FILT	Configure median and average filters.	Section 4
REL	Enter relative value.	Section 4
OPER	Select DC or SWEEP mode, set source amplitude and current limit.	Section 3
COMM	Configure GPIB or RS-232 interface.	Section 9
TRIG	Configure trigger parameters.	Section 7
LIMIT	Set up and enable limit tests.	Section 8
RATE	Set integration rate in number of power line cycles (NPLCs).	Section 4
SETUP	Select power-on setup.	page 9
STORE	Select number of readings to store in buffer.	Section 6
RANGE	Set upper auto range limit.	Section 4
RANGE	Set lower auto range limit.	Section 4

* Press CONFIG followed by indicated key to access configuration menu.

SCPI programming

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

NOTE *Except for [Section 14](#), most SCPI tables in this manual are abridged. That is, they do NOT include most optional command words and query commands. Optional command words and query commands are summarized as follows.*

Optional command words

In order to be in conformance with the IEEE-488.2 and SCPI standards, the Model 6487 accepts optional command words. Any command word that is enclosed in brackets ([]) is optional and need not be included in the program message.

Query commands

Most command words have a query form. A query command is identified by the question mark (?) that follows the command word. A query command requests (queries) the programmed status of that command. When a query command is sent and the Model 6487 is addressed to talk, the response message is sent to the computer.

2

Measurement Concepts and Connections

- **Connection fundamentals** — Covers fundamental information about connecting test circuits to the picoammeter.
- **Basic connections to DUT** — Details connecting test circuits to the picoammeter for both current and ohms measurements.
- **Using a test fixture** — Discusses using general test fixtures as well as the Model 8009 test fixture.
- **Interlock** — Covers interlock connections and operation.
- **Analog output** — Covers analog output connections and discusses considerations when using the analog output.
- **Measurement considerations** — Summarizes considerations that could affect overall measurement accuracy.

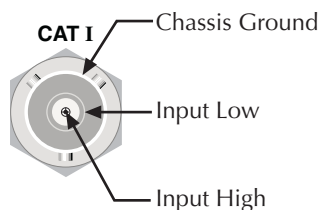
Connection fundamentals

The following provides important fundamental information on input connections to the Model 6487. Typical connection drawings are provided in [“Basic connections to DUT,”](#) [page 2-4](#). More detailed connections for specific measurements are in [Section 3](#).

Input connector

The rear panel INPUT connector is a 3-lug female triax connector ([Figure 2-1](#)). Make connections using a male terminated triax cable ([“Low-noise input cables,”](#) [page 2-3](#).)

Figure 2-1
Triax input connector



Voltage source output connectors

The rear panel V-SOURCE OUTPUT HI and LO connectors (see [Figure 1-1](#) in [Section 1](#)) 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 stand-alone source operation. See [“Ohms measurement connections,”](#) [page 2-5](#) and [“Voltage source connections,”](#) [page 2-6](#) for details.

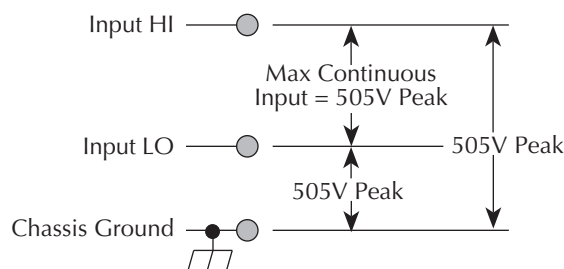
Maximum input levels

The maximum input levels to the Model 6487 are summarized in [Figure 2-2](#).

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

CAUTION Maximum continuous input voltage is 505V peak.

Figure 2-2
Maximum input levels



Low-noise input cables

When making precision measurements, you should always use low-noise cables for INPUT connections. The following low-noise cables are recommended for use with the Model 6487:

Model 237-ALG-2 Triax Cable — This 2m (6.6 ft) low-noise triax cable terminated with a 3-slot male triax connector on one end and 3 alligator clips on the other end.

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

NOTE As a general rule, always use the shortest possible cable for measurements.

Voltage source test leads

When using the voltage source, the test leads must be rated for 505V minimum and should include safety sheaths. These test leads are recommended for use with the Model 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 30V RMS, 42.4V peak; the test probes are rated at 1000V.) 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 (1000V) banana cables. The cables are terminated with banana plugs that have retractable sheaths.

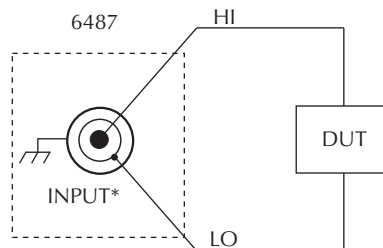
WARNING Use only test leads with a minimum rating of 505V peak for connections to the voltage source to avoid a possible shock hazard.

Basic connections to DUT

Current measurement connections

Basic connections for current measurements are shown in [Figure 2-3](#); 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 the connector's input LO (inner shield).

Figure 2-3
Basic current measurement connections



* Maximum Continuous Input: 505V Peak

WARNING If it is possible for the DUT or external supply to present more than 505V 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 505V.

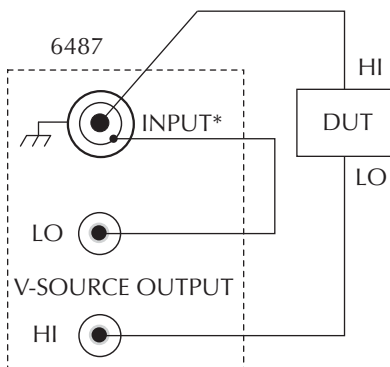
CAUTION Current limiting resistors are required for DUTs capable of forcing voltages 505V or greater. Damage to the instrument may result if voltages greater than 505V are forced on the Model 6487 INPUT HI.

Ohms measurement connections

Basic connections for ohms measurements are shown in [Figure 2-4](#); 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 2-4

Basic ohms connections



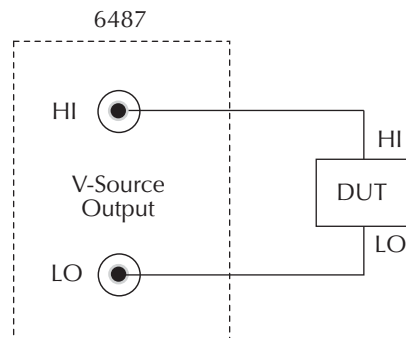
* Maximum Continuous Input: 505V Peak.

Voltage source connections

Basic connections for using the voltage source independently are shown in [Figure 2-5](#); 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 2-5
Basic voltage source connections



Voltages greater than 505V

Occasionally, 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 505V. 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 Model 6487. To prevent this damage, the following steps should be taken as a protection 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 specs, the applied voltage, and largest resistance desired to measure. If using auto range, program the Model 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 and 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.

To set the auto range lower limit over the bus, use [CURRENT]:RANGe:AUTO:LLIMit (Section 4).

Use the following formula to determine the minimum resistance for proper current limiting resistors:

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

Lowest range to be used	R _{in}
2nA or 20nA	11MΩ
200nA or 2μA	3.5MΩ
20μA or 200μA	50kΩ
2mA or 20mA	510Ω

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

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

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

$$\text{minimum R}_{\text{series}} = (750\text{V} - 505\text{V}) / 505\text{V} \times 11\text{ M}\Omega = 12.25\text{M}\Omega$$

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

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

The Model 6487 can be programmed to calculate the resistance and subtract the series resistance. Using the M/X+B function, in the example above, one would set M to 500, B to -14e6, and the units character to “omega”. For more details on the M/X+B function, see Section 5.

Noise and safety shields

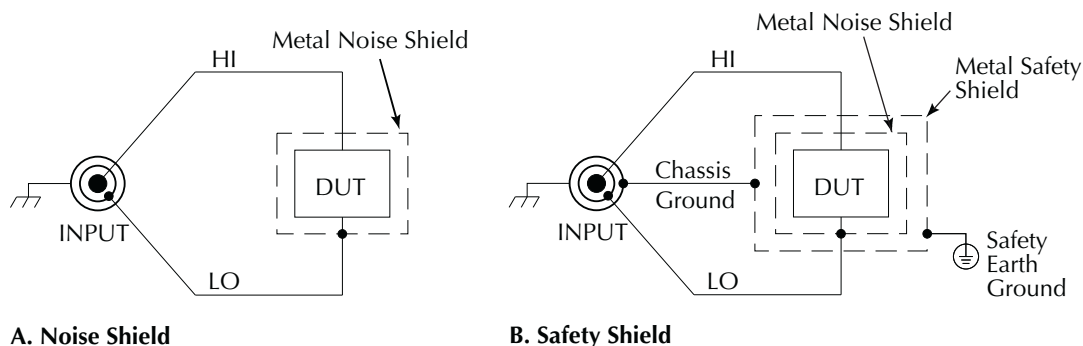
Figure 2-6 shows typical measurement shielding. In Figure 2-6(A), a noise shield is used to prevent unwanted signals from being induced on the picoammeter input. Amps measurements below $1\mu\text{A}$ may benefit from effective shielding. Typically, the noise shield is connected to picoammeter input LO. Additionally, Figure 2-6(B) shows an added safety shield connected to earth ground and Model 6487 chassis. This type of shielding should be used whenever hazardous voltages will be present in the test circuit.

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

If it is possible for the DUT or external supply to present more than 505V 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 505V.

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

Figure 2-6
Shielding for measurements (unguarded)



Using a test fixture

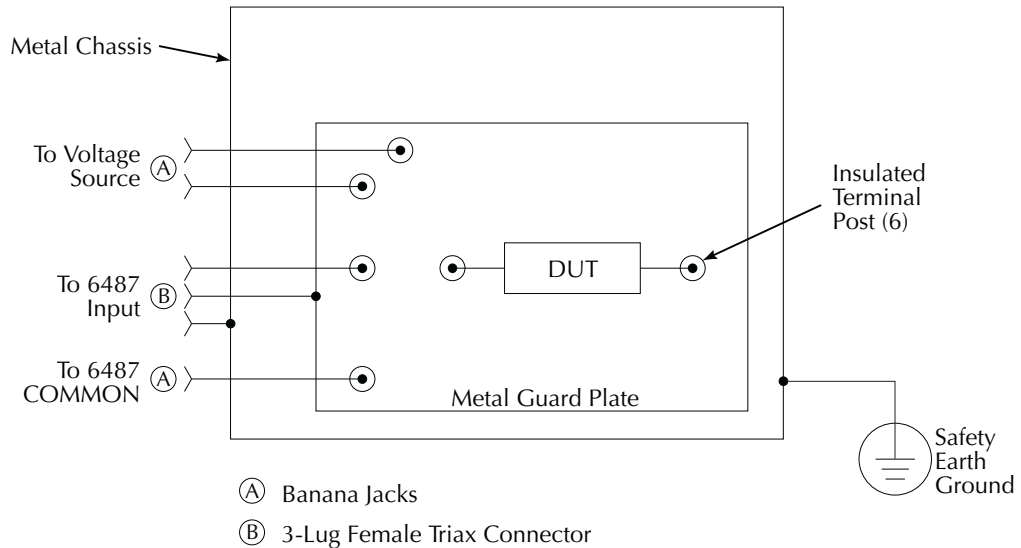
Whenever possible, use a shielded low-leakage test fixture to make precision measurements and for safety when high voltages ($>30\text{V}$) are used.

General purpose test fixture

A general purpose test fixture is shown in [Figure 2-7](#). This test fixture will accommodate a variety of connection requirements.

Figure 2-7

General purpose test fixture connections



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 triax 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 triax 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 bodies of DUT or test circuit components. 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. Clean the areas as explained in the next tip.
- To clean contaminated areas, use methanol and clean foam-tipped swabs. After cleaning a large area, you may want to flush the area with methanol. Blow dry with dry nitrogen gas.
- After cleaning, the test fixture (and any other cleaned devices or test circuits) should be allowed to dry in a 122° F (50° C) low-humidity environment for several hours.

Model 8009 resistivity test fixture

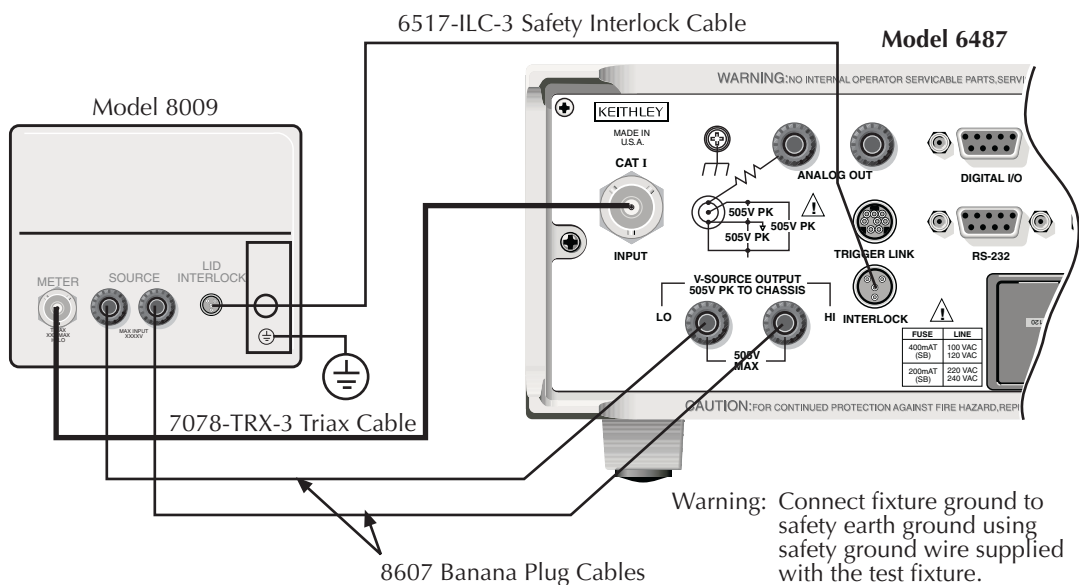
This test fixture allows volume resistivity in the range from 10^3 to $10^{18\frac{3}{4}}$ -cm and surface resistivity in the range from 10^3 to $10^{17\frac{3}{4}}$ /sq. Features include:

- A 3-lug triax connector and dual binding posts make connections to the Model 6487 simple.
- Guarded electrodes that can accommodate samples up to 1/8" thick and 4" x 4".
- Safety Interlock: When properly connected to the Model 6487, the V-source goes into a high impedance state when the test fixture's lid is opened. Note that this could leave a charged device in the fixture.
- Screw terminal on the test fixture for safety earth ground.

For typical connections to the Model 6487, refer to [Figure 2-8](#).

Figure 2-8

Typical connections for measurements using the Model 8009 test fixture



Floating measurements

Figure 2-9 shows an example where the Model 6487 floats.

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](#),” page 2-2. Death or injury due to electrical shock can result if adequate safety measures are not taken.

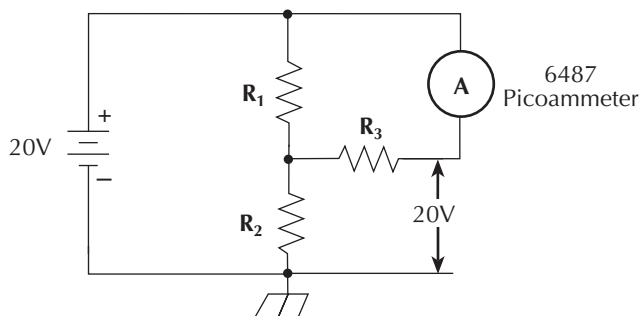
The maximum safe voltage between picoammeter LO and chassis ground (common mode voltage) is 505V. The Model 6487 does not internally limit the LO-to-chassis voltage. Exceeding 505V can create a shock hazard.

If it is possible for the DUT or external supply to present more than 505V 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 505V.

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

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

Figure 2-9
Floating measurements



Interlock

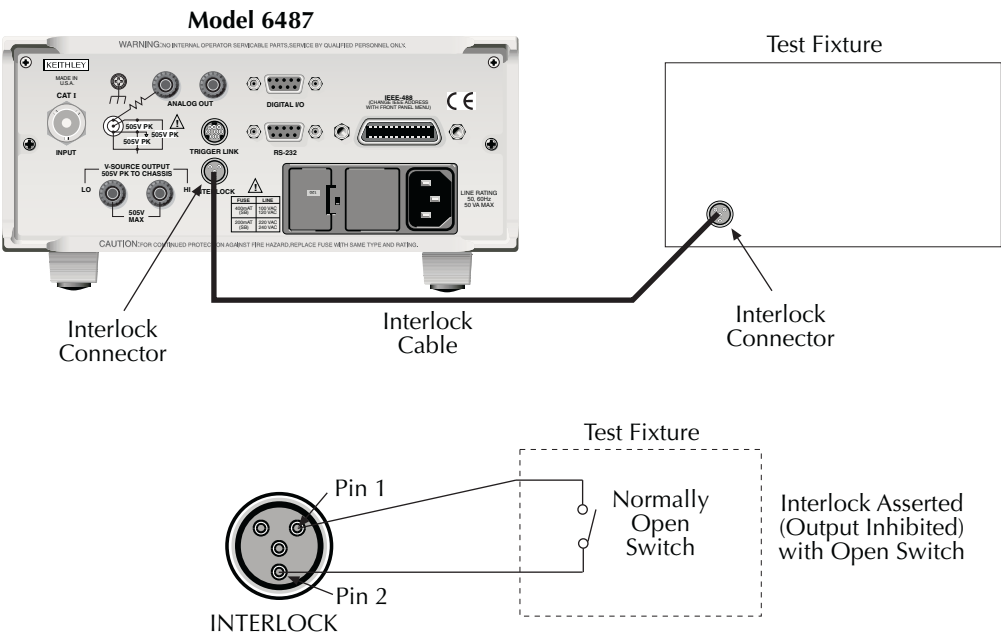
The Model 6487 has a built-in interlock that works in conjunction with the voltage source. The interlock prevents the voltage source from being operated on the 50V and 500V ranges, and optionally on the 10V range, to assure safe operation.

Interlock connections

Figure 2-10 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 50V or 500V voltage source ranges, and optionally for the 10V 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 2-10
Interlock connections



Interlock operation

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

Interlock programming

[Table 2-1](#) summarizes the commands associated with controlling the 10V range interlock and determining if the interlock is asserted. For example, to enable the 10V range interlock, send SOURce[1]:VOLTage:INTerlock[:STATe] ON. See [Section 3](#) and [Section 14](#) for information on additional voltage source commands.

Table 2-1
Interlock commands

Command	Description	Default
SOURce[1] :VOLTage :INTerlock [:STATe] :FAIL?	SOURce1 Subsystem: Interlock control: Enable or disable 10V range interlock. ¹ Query if interlock is asserted: ² 1 = asserted; source cannot be turned on.	OFF

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

Analog output

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

WARNING The maximum safe voltage between the voltage source or ammeter and chassis ground (common mode voltage) is 505V 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 triax shell.

Connections for using this output are shown in [Figure 2-11](#). For a full-scale input (i.e. 2mA on the 2mA range), the output will be -2V. Example analog outputs are listed in [Table 2-2](#).

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

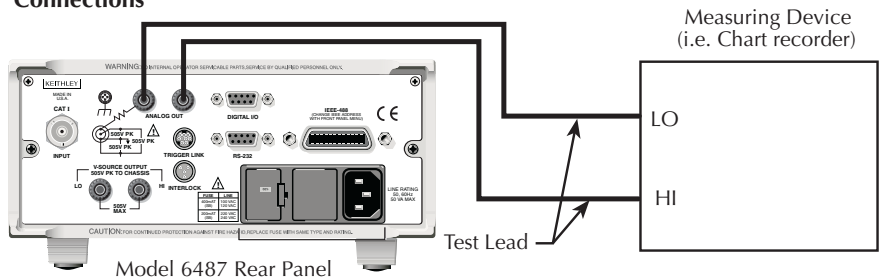
The output impedance is $<100\Omega$. To minimize the effects of loading, the input impedance of the device connected to the ANALOG OUT should be as high as possible. For example, for a device that has an input impedance of $1M\Omega$, the error due to loading will be approximately 0.01%. High capacitance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

An internal $1k\Omega$ 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 2V analog output is scaled only to the actual input.

Figure 2-11
Typical analog output connections

A. Connections



B. Equivalent Circuit

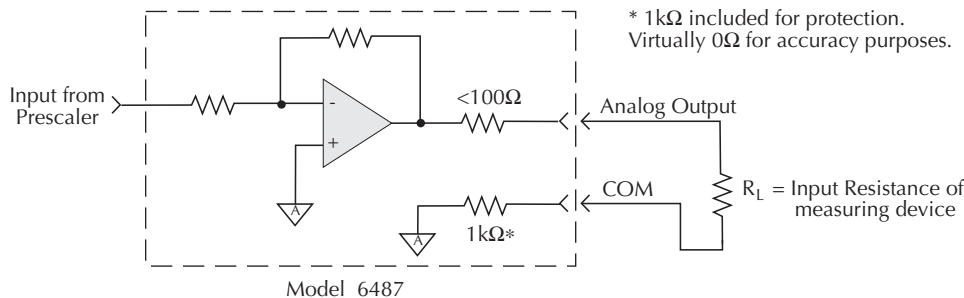


Table 2-2
Example 2V analog output values

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

* 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 [Table 2-3](#) and are detailed in [Appendix G](#) of this manual and Appendix B of the Model 6487 User's Manual. For comprehensive information on all measurement considerations, refer to the Low Level Measurements handbook, which is available from Keithley Instruments. Check www.keithley.com for more details on the handbook.

Table 2-3
Summary of measurement considerations

Considerations	Description
	See Appendix G for details
Input bias current	Offset current of Model 6487 could affect low current measurements.
Voltage burden	Offset voltage of Model 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.
	See Model 6487 User's Manual Appendix B for details
Ground loops	Multiple ground points can create error signals.
Triboelectric effects	Charge currents generated in a cable by friction between a conductor and the surrounding insulator (i.e. bending a triax cable).
Piezoelectric and stored charge effects	Currents generated by mechanical stress on certain insulating materials.
Electrochemical effects	Currents generated by the formation of chemical batteries on a circuit board caused by ionic contamination.
Humidity	Reduces insulation resistance on PC boards and test connection insulators.
Light	Light sensitive components must be tested in a light-free environment.
Electrostatic interference	Charge induced by bringing a charged object near your test circuit.
Magnetic fields	The presence of magnetic fields can generate EMF (voltage).
Electromagnetic interference (EMI)	EMI from external sources (i.e. radio and TV transmitters) can affect sensitive measurements.

3 Measurements and Sourcing Voltage

- **Measurement overview** — Explains the basic measurement and voltage source capabilities of Model 6487.
- **Performance considerations** — Covers warm-up period, voltage offset correction, autozero, zero check, and zero correct.
- **Current measurements** — Provides a basic procedure to measure current.
- **Ohms measurements** — Covers methods to set up and use the ohms measurement function.
- **Voltage source operation** — Discusses configuring and using the voltage source.
- **Alternating voltage ohms mode** — Discusses the alternating voltage mode that can be used to improve accuracy and repeatability of very high resistance measurements.

Measurement overview

Current measurements

The basic current measurement capabilities of the Model 6487 are summarized in [Table 3-1](#). Accuracy for each measurement function and range is listed in the specifications ([Appendix A](#)).

Table 3-1
Basic current measurement capabilities

Range	Maximum Reading	5 -Digit Resolution
2nA	±2.1nA	10fA
20nA	±21nA	100fA
200nA	±210nA	1pA
2uA	±2.1μA	10pA
20uA	±21μA	100pA
200uA	±210μA	1nA
2mA	±2.1mA	10nA
20mA	±21mA	100nA

Voltage source

The basic voltage source output capabilities of the Model 6487 are summarized in [Table 3-2](#). Accuracy specifications are shown in [Appendix A](#).

Table 3-2
Basic voltage source output capabilities

Range	Maximum Output	Step Size
10V	±10.1V	200μV
50V	±50.5V	1mV
500V	±505V	10mV

Performance considerations

Warm-up period

Model 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 correction:

1. Press the MENU key, select CAL, then press ENTER.
2. The unit will display the following:
CAL: VOFFSET
3. Press ENTER. The instrument will prompt as follows:
INPUT CAP
4. Connect the triax shielding cap to the INPUT jack.
5. Press ENTER to complete voltage offset correction.
6. Press EXIT to return to normal display.

To perform correction via remote, connect the triax shielding cap to the INPUT, then send CALibration:UNPRotected:VOFFset.

Autozero

To help maintain stability and accuracy over time and changes in temperature, the Model 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 button. 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

Table 3-3
SCPI commands — autozero

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.

Programming example

The following examples enable or disable the autozero feature:

SYST:AZER ON

SYST:AZER OFF

SYST:AZER?

' Enable autozero.

' Disable autozero.

' Query autozero. 1=on, 0=off

Zero check and zero correct

Zero check

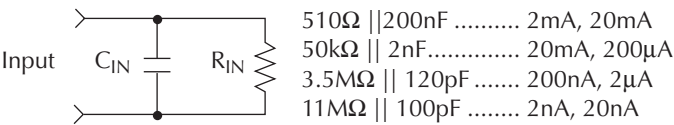
When zero check is enabled (on), the input amplifier is reconfigured to shunt the input signal to low with the input impedance (Figure 3-1).

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

From the front panel, enable/disable zero check by pressing the ZCHK key (ZEROCHK message displayed). Refer to Table 3-4 for bus commands.

NOTE Leave zero check enabled when connecting or disconnecting input signals.

Figure 3-1
Equivalent input impedance with zero check enabled



Zero correct

NOTE The Model 6487 saves a single Zero Correct value (not one for each range). For best results, acquire a new Zero Correct value after changing to the desired range.

The Model 6487 has a zero correct feature to algebraically subtract the voltage offset term from the measurement (to actually reduce the voltage at the input terminals, see [“Voltage offset correction,” page 3-3](#)). Perform the following steps to algebraically zero correct the measurement:

NOTE The REL key toggles zero correct on and off if zero check is enabled (“ZEROCCHK” message displayed). The MON annunciator turns on when zero correct is enabled.

1. Enable zero check (“ZEROCHK” message 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” message 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 With regard to the zero correct feature:

- The Model 6487 will remain zero corrected even if it is upranged. If downranged, re-zero the instrument.
- The Model 6487 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 Model 6487 is operating at or near T_{CAL} , zero correction will have very little effect. T_{CAL} is the internal temperature of the Model 6487 when it was last calibrated.

SCPI programming — zero check and zero correct

Table 3-4

SCPI commands — zero check and zero correct

Commands	Description	Default	Ref
SYSTem :ZCheck [:STATe] 	SYSTem Subsystem: Zero check: Enable or disable zero check. When Zero check is on, the reading on the display is replaced with ZEROCHK.	ON	
:ZCORrect [:STATe] :ACQuire	Zero correct: Enable or disable zero correct. Acquire a new zero correct value.	OFF	A B
INITiate	Trigger a reading.		

A) 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.

B) 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 200uA 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 [Section 7](#) 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 505V. The Model 6487 does not internally limit the LO to chassis voltage. Exceeding 505V can create a shock hazard.

If it is possible for the DUT or external supply to present more than 505V 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 505V.

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

The maximum input voltage and current to Model 6487 is 505V peak and 21mA. 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. Information about these offsets are provided in [“Measurement considerations” on page -2](#).

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 2nA range and zero check disabled, allow the reading to settle until the input bias current is within specifications. The specifications for input bias current are included in the offset portion of the accuracy specification listed in [Appendix A](#).

Perform the following steps to measure current:

Step 1. Select current function

Press the $I \frac{3}{4}$ 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. When on, the “ZEROCHK” message is displayed.

Step 3. Perform zero correction

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

- Select the 2nA range (which is the lowest range).
- 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 and keys to select a manual measurement range or press AUTO to enable auto range. With auto range enabled, the instrument will automatically go to the most sensitive range to make the measurement. See [Section 4](#) for details on range.

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

Basic connections for measurements are shown in [Figure 3-2](#).

WARNING A safety shield is advisable whenever floating measurements are being made (see “[Floating measurements](#),” page 2-12). Connections for the safety shield are shown in [Figure 3-2](#). 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 Model 6487.

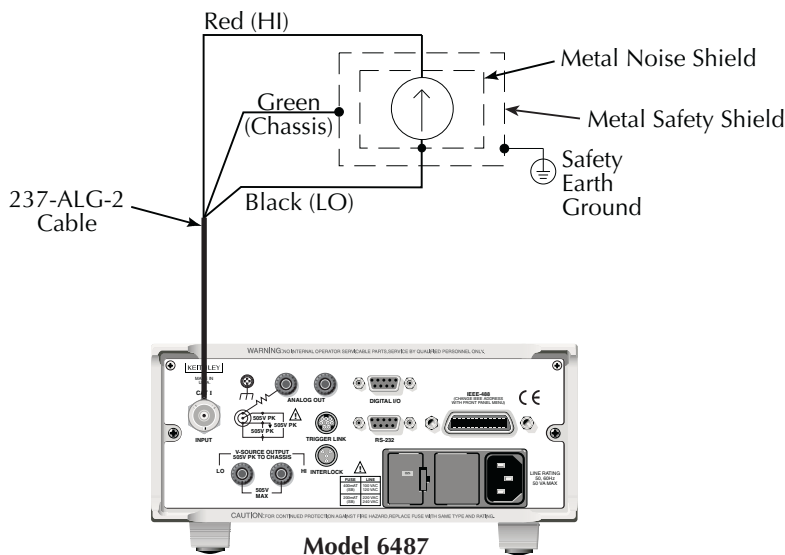
Fundamental information on making connections to the picoammeter input is provided in [Section 2](#).

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 [Section 4](#).

Figure 3-2

Connections for amps



SCPI programming

Table 3-5

SCPI commands — amps function

Commands	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 reading(s).	CURR	A B C D

A) SENSE:DATA?

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

While Model 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 [Section 13](#).

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

B) FUNCTION 'CURRent'

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

C) 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 [Section 7](#).

D) READ?

The READ? command can be used to return “fresh” readings. This command triggers and returns the readings. See [Section 12](#) for details.

Programming example

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

*RST	' Return 6487 to RST defaults.
FUNC 'CURR'	' Select current function.
SYST:ZCH ON	' Enable zero check.
CURR:RANG 2e-9	' Select the 2nA 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 Model 6487, you must set up the voltage source to the desired range, value, and current limit (see [“Voltage source operation,” page 3-15](#)), choose an appropriate current measurement range (or use auto range), and enable the ohms function. With the ohms function enabled, the Model 6487 calculates the measured resistance from the voltage source value and the measured current: $R = V/I$. When setting up the voltage source, choose as high a 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,” page 3-21](#) for information on the alternating voltage mode.*

Procedure

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

Perform the following steps to measure resistance:

Step 1. Set up voltage source

Press either of the V-SOURCE adjustment keys, then use a manual RANGE key to set the voltage source range. 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, it is recommended that you zero correct the picoammeter before enabling the ohms function. To do so, make sure that zero check and the 2nA range are selected, then press the REL key to perform zero correction. The MON annunciator will be on 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: $I = V/R$.

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

Basic connections for ohms measurements are shown in [Figure 3-3](#). 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 30V DC. Connections for the safety shield are shown in [Figure 3-3](#). 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.

Step 5. Select ohms function

Press the $I\frac{3}{4}$ 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. The VOLTAGE SOURCE OPERATE indicator will turn on.

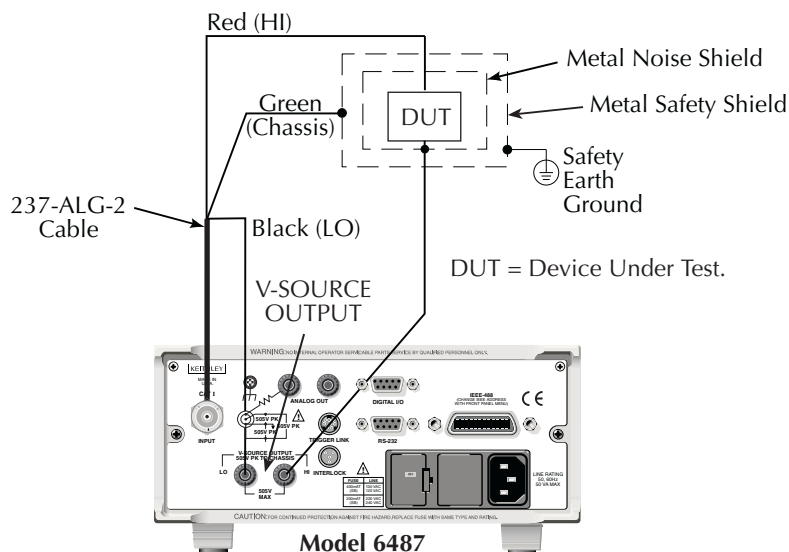
Step 7. Disable zero check and take a reading from the display

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 3-3

Connections for ohms measurements



SCPI programming — ohms measurements

Table 3-6

SCPI commands — basic ohms measurements

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

* Zero correct and zero check commands not included. See [Table 3-4](#).

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

Use this command to turn the ohms function on or off. When the ohms function is enabled, the Model 6487 calculates the reading from the measured current and the voltage source setting: $R = V/I$. Additional OHMS commands control the alternate voltage ohms mode as described in “[Alternating voltage ohms mode](#),” [page 3-21](#).

B) 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 [Section 6](#)).

Programming example — ohms measurements

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

*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 and keys will operate in the same manner as the RANGE and 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 0V.

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 (see [Section 6](#) for details on 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 and arrows to change the voltage source range and indicate the range selected (10V, 50V, or 500V).

5. Enter the desired voltage source value, then press ENTER. Voltage values are changed immediately from this configuration by pressing the arrow keys. The **←** and **→** arrows are used to select the digit being edited and the **V-SOURCE** and **ENTER** 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** and **ENTER** keys will operate in the same manner as the **RANGE** and **ENTER** 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 range (Table 3-7). Pressing ENTER or EXIT from this display returns you to the normal readings display.

Table 3-7

Voltage source current limits

Source Range:	Selectable Current Limit			
10.0000V Range	25μA	250μA	2.5mA	25mA
50.000V Range	25μA	250μA	2.5mA	
500.00V Range	25μA	250μA	2.5mA	

Sourcing voltage

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

Perform the following steps to source voltage:

Step 1. Set up voltage source

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

Step 2. Connect the load to the source output

Basic connections for sourcing voltage are shown in [Figure 3-4](#).

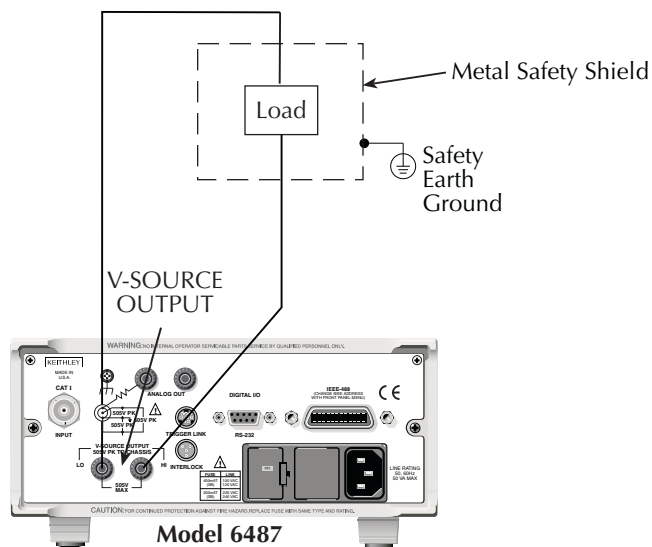
WARNING A safety shield is advisable whenever measurements are being made with voltages over 30V DC. Connections for the safety shield are shown in [Figure 3-4](#). The metal safety shield must completely surround the noise shield or floating test circuit and it must be connected to safety earth ground using #18 AWG or larger wire.

Step 3. Turn on 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 3-4
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 Model 6487 must be in local (see [Section 9](#)).

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 0V on the selected range. It will enter this state on power-up after the VOLTAGE SOURCE OPERATE light blinks. In contrast, the safety interlock *will* cause the voltage source to go into a high-impedance state instead of 0V output and the source will stay in the high-impedance state until the operate state is changed to on. The exception is the 10V range where the interlock is optional. The OPERATE light and front panel display do not indicate the difference between 0V output and high-impedance output caused by an open interlock. The interlock status is available by query via remote (see [Table 3-8](#)).

Compliance indication

At any time, it is possible that the voltage source will go into compliance (current limit reached). Should this situation occur, the OCOMP annunciator (Output Compliance) will flash and the displayed voltage value for readings of less than 6 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 or 500V 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 ([Section 10](#)). The open interlock takes precedence.

SCPI commands — voltage source

Table 3-8
SCPI commands — voltage source

Commands	Description	Default	Ref
SOURce[1] :VOLTage [:LEVel] [:IMMediate] [:AMPLitude] <NRf> :RANGe <NRf> :ILIMit <NRf> :STATe :INTerlock :FAIL?	SOURce[1] subsystem: Voltage source commands: Set output voltage level (-505V to +505V). Set voltage source range (10, 50, or 500V). Set current limit (25μA, 250μA, 2.5mA, or 25mA). ¹ Turn voltage source output on or off. Enable or disable interlock for 10V range. ² Query interlock state (1 = asserted, and source output cannot be turned on).	 0V 10V 25mA OFF OFF	 A B C D E

- 1. 25mA not available for 50V and 500V ranges.
- 2. See [Section 2](#) for interlock operation.

A) [:LEVel] [:IMMediate] [:AMPLitude] <NRf>

Use this command to set the voltage source output level from -505V to 505V. 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, you must first change the source range.

B) RANGe <NRf>

This command selects the range: 10V, 50V, or 500V. If you choose a range lower than the present 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 50V range.

C) ILIMit <NRf>

Use this command to set the voltage source current limit to 25μA, 250μA, 2.5mA, or 25mA. Note, however, that the maximum current limit for the 50V and 500V ranges is 2.5mA.

D) 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 0V source (limited to approximately 1mA) and will discharge small capacitances (DUT, cables, etc.).

E) INTERlock

These commands control the interlock for the 10V range and query whether or not the interlock is asserted. Note that for the 50 and 500V 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 10V range. Attempting to turn off the interlock state while on the 50 or 500V ranges will generate a -221 “Settings Conflict” error. Up-ranging from the 10V range will always cause the interlock to be enabled. When you range back down to the 10V range, the interlock state will be reset to what it was when you left the 10V range. See [Section 2](#) for more interlock information.

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 5V on the 10V range with a 2.5mA limit:

*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 one of two ways: 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 0V and a user-selected value (Figure 3-5). 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 via remote, A-V ohms readings always come from the V-Delta buffer.

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 0V, 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 0V (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.

Figure 3-5

Alternating voltage ohms

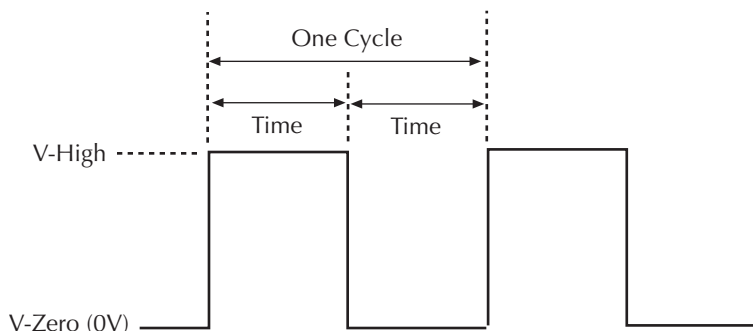


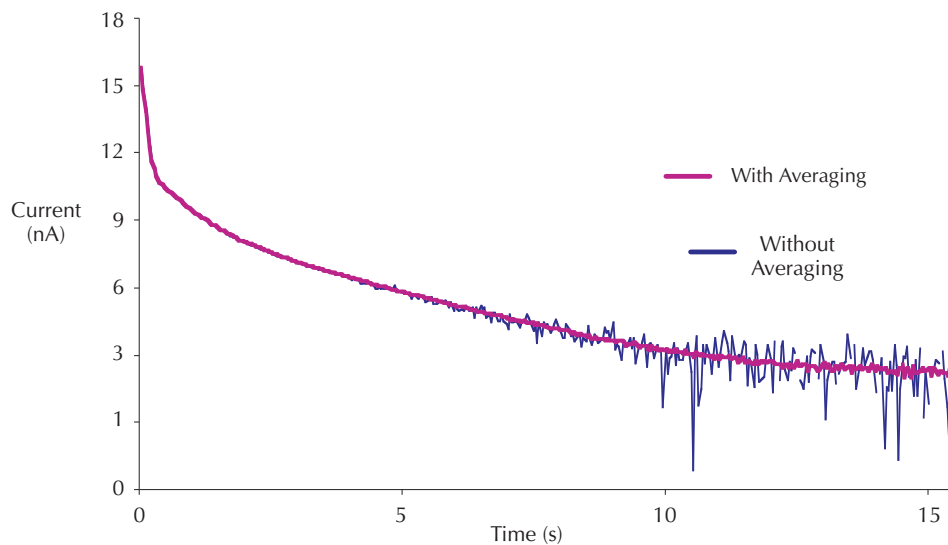
Figure 3-6 shows a comparison of the A-V voltage and the resulting current. When the voltage first makes a transition from low to high or high to low, the current initially increases to maximum and then decays to its quiescent value. The decay period, of course, depends on the RC time constant (τ) of the circuit being tested.

Figure 3-7 demonstrates the clear advantages of A-V ohms. The decaying curve shows how current decays time without averaging, while the steady-steady current plot at the bottom shows substantially improved results due to averaging of the A-V readings.

Figure 3-6
A-V voltage and current



Figure 3-7
Averaged A-V current



Storing A-V ohms readings

Follow the steps below to setup and use the A-V ohms mode. Refer to [Table 3-9](#) for A-V ohms configuration menu items.

NOTE The following procedure assumes the Model 6487 is connected to the DUT. See [Figure 3-3](#) and [Section 2](#) for details on ohms connections.

NOTE 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.

Table 3-9

A-V ohms menu selections

Menu Item	Description	Default
V-HI	High source voltage value (-505 to 505V).	10V
TIME	Time for each A-V phase.	15s*
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: 15s for 1 PLC or greater, 1s for 0.1 PLC, and 0.1s for 0.02 PLC.

1. Press CONFIG then I | $\frac{3}{4}$ 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
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 Model 6487 will prompt for the one-shot mode:
ONE-SHOT: YES
5. Select either YES to enable the one-shot mode (taking only one current measurement at the end of each phase) or NO to disable the one-shot mode (taking current measurements continuously during each phase, which will result in a difference buffer of many points, detailing the step response of the DUT), then press ENTER. The unit will prompt for the number of A-V cycles:
CYCLES: 0003

6. 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
7. Select Y or N as desired, then press ENTER.
8. At this point, the voltage source is in operate at 0V and the unit displays the message TRIG TO STRT.
9. 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 the 1 3/4 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 the 1 3/4 once and the A-V ohms sequence will again be armed.*

Alternatively from this reading display, press CONFIG → 1 3/4 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 1 3/4 TO REARM to appear.

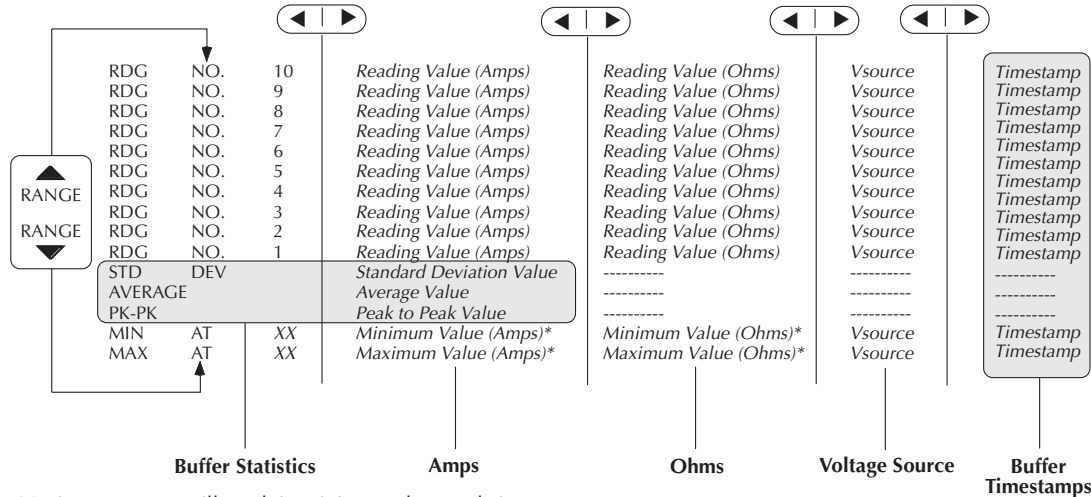
Recalling A-V ohms readings

Over 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 $\leftarrow$ and $\rightarrow$ cursor keys to cycle among amps, ohms, voltage source, and time values for each reading. Use the RANGE $\leftarrow$ and $\rightarrow$ keys to cycle through individual readings or buffer statistics, which are calculated on the basis of the amps readings (see [Figure 3-8](#) for recall sequence).

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 Pk-Pk display. Average will be converted to ohms.

Figure 3-8
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.

Operating considerations

Range

Auto range cannot be used with A-V ohms. Auto range will be automatically disabled when arming A-V ohms from the front panel. Over the GPIB, however, sending the CURR:OHMS:AVOL:ARM command with auto range on will result in error +852 “No A-V ohms with Autorange”. Also, only the following ranges can be used: 20nA, 2μA, 200μA, and 20mA. If on any other range, the unit will uprange to the closest allowed range.

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 msec, so sending the OHM:AVOL:ARM command will set the ARM-IN timer interval to 18 msec. (The detailed table is below.) 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 [Section 7](#) for additional triggering information.

PLC	50Hz measurement interval (milliseconds)	60Hz measurement interval (milliseconds)
0.02	2	2
0.1	4	4
1	22	18
5 (50Hz) 6 (60Hz)	102	102
50 (50Hz) 60 (60Hz)	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 ¼ TO REARM” message will obscure these readings until you press EXIT). Send an INIT:IMM command to resume taking readings. See [Section 7](#) for more triggering 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 ¼ 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.

The converse also applies if you have collected some A-V ohms readings and then press the STORE key. 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 (easy to do, since STORE is located right next to RECALL). 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

When A-V ohms is running, the following commands are locked out. Attempting any of them returns error +850 “Not Allowed with A-V Ohms.”

SENS:CURR:DC:MED:STAT
SENS:CURR:DC:MED:RANK
SENS:CURR:DC:AVER:TCON
SENS:CURR:OHMS:STAT
SENS:CURR:DC:NPLC
SENS:CURR:DC:RANG
SENS:CURR:DC:RANG:AUTO
SOUR:VOLT[:LEV][:IMM][:AMPL]
SOUR:VOLT:STATe
SOUR:VOLT:RANGe
TRAC:FEED
TRAC:FEED:CONT
TRAC:POIN
TRAC:TST:FORM
TRAC:DATA?
SYST:AZER:STAT
DISP:ENAB

Tight timing is crucial to getting reliable results with A-V ohms. Anything that changes the timing between readings would make it impossible to continue averaging in with any previously collected readings. Therefore, the following command is locked out from the GPIB while A-V ohms readings are present in the buffer. You must first clear the buffer with TRAC:CLEAr, otherwise an error +851 “Not allowed with A-V Ohms buffer” will be generated.

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

Table 3-10

SCPI commands — A-V ohms

Commands	Description	Default	Ref
<i>To make measurements:</i>			
[SENSe[1]]	SENSe[1] subsystem:		
[:CURRent[:DC]]	Current measurement commands:		
:OHMS	Ohms mode commands:		
:AVOLtage	Path to A-V ohms commands:		
[:ARM]	Arm A-V ohms mode.		A
[:ARM]?	Query if A-V ohms is armed. (1 = armed).		A
:ABORt	Abort A-V ohms mode.		B
:VOLtage <NRf>	Set high voltage value (-505 to 505V).	10V	C
:TIME <NRf>	Set time interval for each phase.	15s*	D
:POINts?	Query number of points.		E
:ONEShot 	Enable or disable one-shot mode.	ON	F
:CYCLes <NRf>	Set number of A-V cycles (1 to 9999).	3	G
:UNITs <name>	Select AMPS or OHMS units.	AMPS	H
:CLEar	Clear A-V ohms buffer.		I
:AUTO 	Enable/disable A-V buffer auto clear.	ON	I
:BCOunt?	Query number of A-V points.		J
<i>To access A/V readings:</i>			
TRACe	TRACe subsystem:		
:DATA? [BUFFER]	Request data from BUFFER.	BUFFER	K
:MODE?	Query buffer mode: DC or AVOLtage.		L
CALCulate3	CALCulate3 Subsystem:		
:FORMat <name>	Select buffer statistic; MINimum, MAXimum, MEAN, SDEViation, or PKPK.	MEAN	Section 6
:DATA?	Read the selected buffer statistic.		

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

A) 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 a “1” if A-V ohms has been armed even if the unit is still in the idle state (See [Section 7](#)).

NOTE We strongly recommend that no commands except for the INIT be sent after sending the OHMS:AVOL:ARM command.

B) OHMS:AVOLtage:ABORT

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

C) OHMS:AVOLtage:VOLtage <NRf>

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

D) 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.

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

E) 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 not yet 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.

**F) 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.

G) 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.

H) OHMS:AVOLTage:UNITs <name>

This command sets the units that the A-V ohms readings will be stored and returned in, amps or ohms.

I) OHMS:AVOLTage:CLEar

CLE 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.

J) OHMS:AVOLTage:BCOunt?

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

K) 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.

L) 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 5V high value, 10s 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.

4

Range, Units, Digits, Rate, and Filters

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

Range, units, and digits

Range

The ranges for current measurements are listed in [Table 4-1](#).

Table 4-1
Measurement ranges

nA	μ A	mA
2nA	2 μ A	2mA
20nA	20 μ A	20mA
200nA	200 μ A	

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.

Manual ranging

To select a range, press the RANGE or key. The instrument changes one range per key-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 μ A range, the instrument will go up to the 200 μ A range when the input signal exceeds 21 μ A. While on the 200 μ A range, the instrument will go down to the 20 μ A range when the input level goes below 20 μ A.

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

Every time an autorange occurs, a search for every available range of the selected function is performed. The time it takes to perform the search could slow down range change speed significantly. 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 $1\mu\text{A}$, set the upper current range limit to $2\mu\text{A}$. This eliminates the $20\mu\text{A}$, $200\mu\text{A}$, 2mA , and 20mA ranges from the search, thereby increasing the range change speed. Should the input exceed $2.1\mu\text{A}$, the OVRFLOW message will be displayed.

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

1. Press CONFIG key (CONFIGURE: will be displayed).
2. Display the desired limit (UPPER or LOWER):
 - a. Press the RANGE key to display the present UPPER range limit.
 - b. Press the RANGE key to display the present LOWER range limit.
3. Scroll through the available range limits using the or 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 $20\mu\text{A}$, trying to set the upper limit to $2\mu\text{A}$ will result in 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) units (i.e. 1.236 mA) or scientific (SCI) notation (i.e. 1.236E-03A). Perform the following steps to change the units setting:

1. Press MENU key.
2. Scroll down to the UNITS item using the or RANGE key (UNITS: will be flashing).
3. Press ENTER to select setting (ENG or SCI will be flashing).
4. Use the or key to display the desired units setting.
5. Press ENTER.
6. Press EXIT to return to normal display.

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

Digits

The DIGITS key sets display resolution for the Model 6487. Display resolution can be set from 3 to 6 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. Also changing display resolution does not change the rate setting.

The voltage source value will not be displayed with the 6 digit setting.

SCPI programming — range and digits

Table 4-2

SCPI commands — digits

Commands	Description	Default
[[:CURRent] :RANGe [:UPPer] <n> : AUTO :ULIMit <n> :LLIMit <n>	Measure current: Range selection: Specify expected reading: -0.021 to 0.021 (A). See Table 4-3 . Enable or disable autorange. Specify upper range limit for autorange: -0.021 to 0.021 (A). Specify lower range limit for autorange: -0.021 to 0.021 (A).	200μA ON 20mA 2nA
<i>For Digits:</i> DISPlay :DIGits <n>	DISPlay Subsystem: Set display resolution: 4 to 7, where <n> of: 4 = 3 digit resolution 5 = 4 digit resolution 6 = 5 digit resolution 7 = 6 digit resolution Note: Rational numbers can be used. For example, to set 5 resolution send a value of 4.5 (the 6487 rounds it to 5).	6

Programming example — range and digits

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

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

Table 4-3
Ranges and values

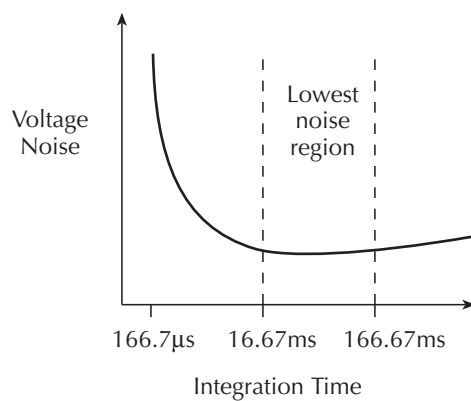
Range	<n> value	Display (5 digit resolution)
20mA	2E-2 or 0.02	00.0000mA
2mA	2E-3 or 0.002	0.00000mA
200μA	2E-4 or 0.0002	000.000μA
20μA	2E-5 or 0.00002	00.0000μA
2μA	2E-6 or 0.000002	0.00000μA
200nA	2E-7 or 0.0000002	000.000nA
20nA	2E-8 or 0.00000002	00.0000nA
2nA	2E-9 or 0.000000002	0.00000nA

Rate

The RATE key selects the integration time of the A/D converter. This is the period of time the input signal is measured. The integration time affects the amount of reading noise, as well as the ultimate reading rate of the instrument. The integration time is specified in parameters based on a number of power line cycles (NPLCs), where 1 PLC for 60Hz is 16.67msec (1/60) and 1 PLC for 50Hz (and 400Hz) is 20msec (1/50).

In general, the Model 6487 has a parabola-like shape for its speed vs. noise characteristics and is shown in Figure 4-1. The Model 6487 is optimized for the 1 PLC to 10 PLC reading rate. At these speeds (lowest noise region in the graph), The Model 6487 will make corrections for its own internal drift and still be fast enough to settle a step response <100ms.

Figure 4-1
Speed vs. noise characteristics



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

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

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

- **SLOW** — Selects the slowest preset integration time (6 PLC for 60Hz or 5 PLC for 50Hz). 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).

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

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

1. Press **CONFIG / LOCAL** and then **RATE** to display the present PLC value.
2. Use the **,** **.**, **←**, and **→** keys to adjust to the desired PLC value. Valid values are:
 60Hz operation: 0.01 to 60
 50Hz 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 60Hz), medium (1 PLC), or fast (0.1 PLC) integration rate. For example, with the integration rate set to 2 PLC, none of the rate annunciators will turn on.

SCPI programming — rate

Table 4-4 contains the path and the command to set rate.

Table 4-4

SCPI commands – rate

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

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 seen at the input will increase reading noise. This capacitance can be attributed to a long input cable or to the capacitance of the source or a combination of both. Enabling damping (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 simply press the DAMP key. DAMP ON or DAMP OFF will be displayed briefly 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.

Table 4-5

SCPI commands — Damping

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 noisy measurements caused by noisy input signals. The Model 6487 uses two types of filters: median and digital. The displayed, stored, or transmitted reading is simply the result of the filtering processes. Note that both the median and digital filters can be in effect at the same time.

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

The settings for the filter are global. 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 "middle-most" reading from a group of readings that are arranged according to size. For example, assume the following readings:

20mA, 1mA, 3mA

The readings are rearranged in an ascending order as follows:

1mA, 3mA, 20mA

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

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

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

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

Median filter operation — The median filter operates as a moving type filter. For example, if the median filter is configured to sample 11 readings (Rank 5), the first filtered reading will be calculated (and displayed) after 11 readings are acquired and placed in its filter stack. Each subsequent reading will then be added to the stack (oldest reading discarded) and another median filter reading will be calculated and displayed. The median filter operation will reset (start over) whenever the Zero Check operation is performed or the 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 (flashing).
6. Use the RANGE (or) keys to display the desired rank (1 to 5).
7. Press ENTER to set. To return to the previously set value, press EXIT instead of ENTER.

Digital filter

Digital filter types

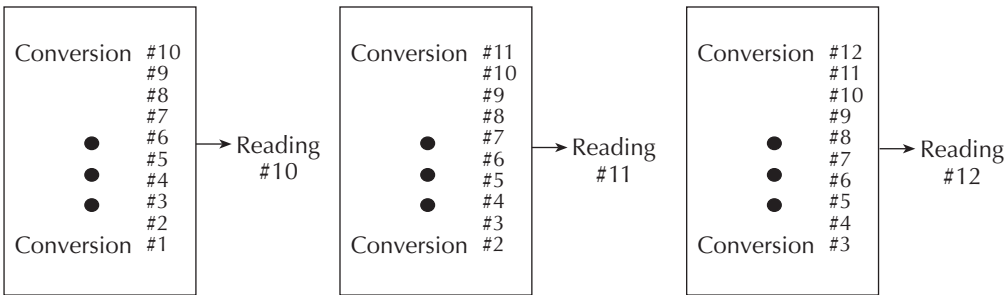
An additional filter parameter is type (type is either moving or repeating). Filter types are compared in [Figure 4-2](#).

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

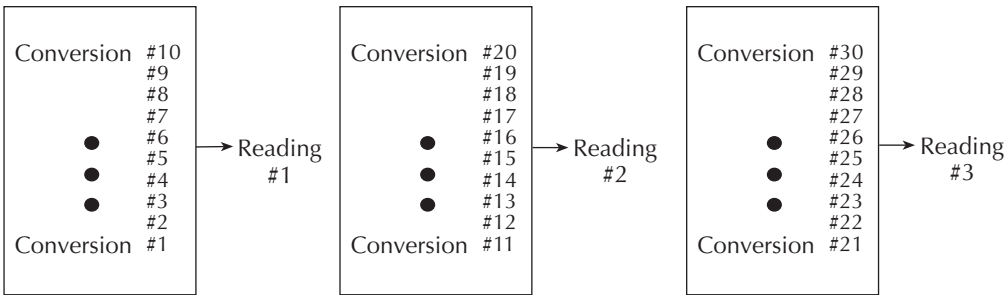
Repeating Filter — Takes a selected number of reading conversions, averages them, and yields a reading. It then flushes its stack and starts over.

Figure 4-2
Digital filter types; moving and repeating

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:

- **Number of reading conversions** — Speed and noise are tradeoffs.

Operation consideration

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

Digital filter control

To configure the average filter:

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

SCPI programming — filters

Table 4-6
SCPI commands — filters

Commands	Description	Default
<i>For median filter:</i> [:SENSe[1]] :MEDian :RANK <n> [:STATe] 	SENSe Subsystem: Median Filter: Specify filter rank: 1 to 5. Enable or disable median filter.	1 OFF
<i>For digital filter:</i> [: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

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.
```

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

- **Relative** — Explains how to null an offset or establish a baseline value. Includes the SCPI commands for remote operation.
- **$mX+b$, $m/X+b$ (reciprocal), and logarithmic** — Covers these three basic math operations and includes the SCPI commands for remote operation.

Relative

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

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

A Rel value is the same for all measurement ranges. For example, a Rel value of $1\text{E-}6$ is $1\mu\text{A}$ on the $2\mu\text{A}$ range. It is also $1\mu\text{A}$ on the $20\mu\text{A}$ range and the $200\mu\text{A}$ 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 Rel'ed reading. However, this does not increase the maximum allowable input for that range. An over-range input signal will still cause the display to overflow. For example, on the $20\mu\text{A}$ range, the Model 6487 still overflows for a $21\mu\text{A}$ input.

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

Setting and controlling relative

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

REL key

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

1. 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. The REL annunciator turns off.

NOTE *When Rel is disabled, the Rel value is remembered. To reinstate the previous Rel value, press CONFIG then press REL and finally press 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 keying in REL

Pressing CONFIG and then REL displays the present Rel value. This displayed Rel value can be enabled (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 (Table 5-1).
3. With the desired Rel value displayed, press ENTER to enable Rel.

Table 5-1
Range symbols for rel values

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

SCPI programming — relative

Table 5-2

SCPI commands — relative (null)

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

A) :FEED <name>

With SENSE[1] selected, the Rel operation will be performed on the input signal. With CALCulate[1] selected, the Rel operation will be performed on the result of the $mX+b$ or $m/X+b$ calculation.

B) :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) — 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 will be used.

C) :DATA? and :DATA:LATest?

With Rel enabled, these commands will return one or more Rel'ed readings. They will not trigger fresh (new) readings. Use the INITiate command to trigger new readings (see [Section 7](#) for details on INITiate).

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

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

Programming example — relative

This program fragment establishes a $1\mu\text{A}$ baseline for measurements:

```

CALC2:NULL:OFFS 1e-6           ' Set Rel value of 1μA.
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) mathematically 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 $m/X+b$

To configure and control either of these math calculations, perform the following steps:

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

1. Press CONFIG then 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: $+1.000000 \wedge$ (factory default)

3. Key in a scale factor value. The $\leftarrow$ and $\rightarrow$ keys control cursor position and the $\uparrow$ and $\downarrow$ RANGE keys increment and decrement the digit value. To change range, place the cursor on the range symbol and use the $\leftarrow$ and $\rightarrow$ keys. With the cursor on the polarity sign, the $\uparrow$ and $\downarrow$ keys toggle polarity.

NOTE Range symbols are defined in [Table 5-1](#).

4. Press ENTER to enter the M value and display the offset (B) value:
B: +0.000000 P (factory default)
5. Key in 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 (default is "X"), press the $\rightarrow$ cursor key and use the manual RANGE keys. The character can be any letter in the alphabet (A through Z).
8. Press ENTER.
9. To enable math, press the MATH key from normal display. 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 1mA is being measured by the Model 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 log, perform the following steps:

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

1. Press CONFIG then 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

Table 5-3

SCPI commands — $mX+b$, $m/X+b$, and log

Commands	Description	Default	Ref
CALCulate[1]	CALCulate1 Subsystem:		
:FORMat <name>	Select calculation: MXB, RECiprocal, or LOG10.	MXB	A
:KMATH	Path to configure $mX+b$ and $m/X+b$:		B
:MMFactor <n>	Specify scale factor (M) for $mX+b$ and $m/X+b$: -9.99999e20 to 9.99999e20.	1.0	
:MBFactor <n>	Specify offset (B) for $mX+b$ and $m/X+b$: -9.99999e20 to 9.99999e20.	0.0	
:MUNits <name>	Specify units for $mX+b$ or $m/x+b$ result: 1 character: A–Z, ‘[’=¾, ‘\’=°, ‘]’=%.	“X”	
:STATe 	Enable or disable the selected calculation.	OFF	
:DATA?	Returns all CALC1 results triggered by the INITiate.		C
:DATA:LATest?	Returns only the latest CALC1 reading.		C

A) :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.

B) :KMATH

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

C) :DATA? and :DATA:LATest?

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

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

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

Programming example — $mX+b$

This command sequence performs a single $mX+b$ calculation, using “X” as the units designator, and displays the result on the computer CRT:

*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.

6

Buffer and Sweeps

- **Buffer operations** — Explains how to store and recall readings including buffer statistics.
- **Voltage sweeps** — Discusses how to generate sweeps using the voltage source.

Buffer operations

The Model 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. In addition, recalled data includes statistical information (maximum, minimum, peak-to-peak, average, and standard deviation).

The buffer fills with the specified number of readings and stops. Readings are placed in the buffer after any 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 — it is not saved through a power cycle.

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

Store

Perform the following steps to store readings:

1. Set up the instrument for the desired configuration.
2. Press CONFIG (CONFIGURE: will be displayed).
3. Press STORE. The present buffer size (in readings) is displayed.
4. Use the cursor and ► keys and the RANGE and keys to set the number of readings to store (1 to 3000).
5. Press ENTER to save the buffer size. 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. See [Section 7](#) for information on triggering.

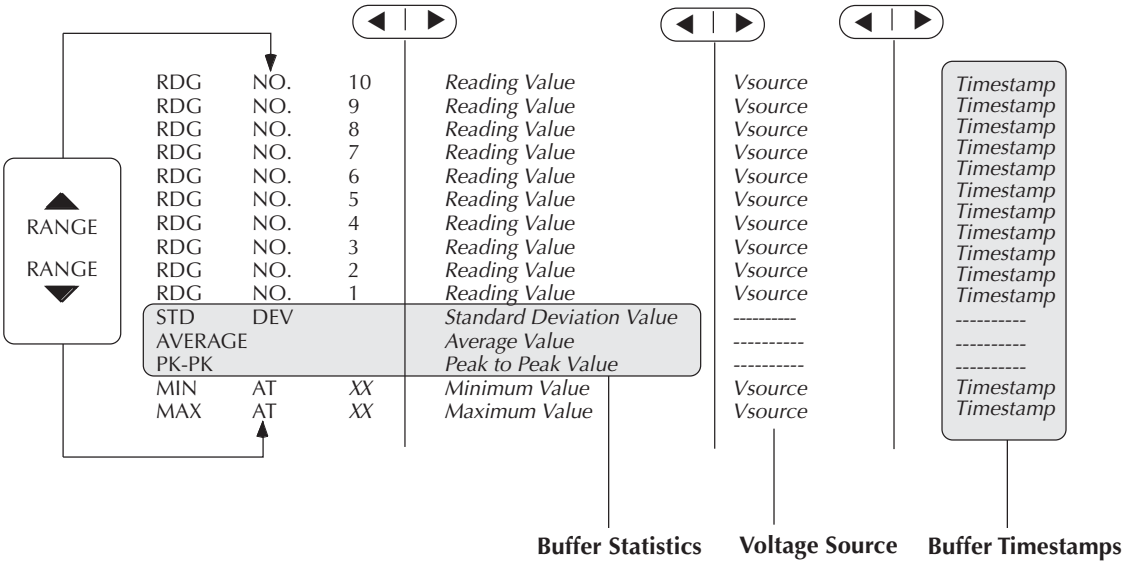
NOTE The asterisk (*) annunciator turns on to indicate that the data storage operation is enabled. It will turn off when the storage process is finished (buffer full).

Recall

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

1. Press 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 and keys and the cursor and ► keys to navigate through the reading numbers and buffer statistics, reading values, voltage source values, and timestamps ([Figure 6-1](#)). For information on how to set buffer timestamps, see [“Buffer timestamps,” page 6-3](#).
3. Press EXIT to return to the normal display.

Figure 6-1
Buffer locations



Buffer timestamps

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 RANGE and keys.
3. Press ENTER.
4. Using RANGE and keys, select desired setting. Available options are ABS (absolute) or DELT (delta).
5. ABS: each timestamp is referenced to the first reading stored in the buffer. The first reading always has a timestamp of 0000000.0000.
6. DELT: each timestamp provides the time between the readings.

Buffer statistics

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

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

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

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 [Table 6-1](#). The TRACe commands are used to store and recall readings in the buffer. The FORMat:ELEMents command is used to specify which data elements to include in the response message for TRACe:DATA? (which is the command to read the buffer). The CALCulate3 commands are used to obtain statistics from the buffer data.

NOTE The Model 6487 uses 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. See [Section 7](#) for details on triggering.

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 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.

Table 6-1

SCPI commands – buffer

Commands	Description	Default	Ref
:TRACe	TRACe Subsystem:	See Note	
:CLEAr	Clear readings from buffer.		A
: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	B
:CONTRol <name>	Select buffer control mode: NEVER or NEXT.	NEV	C
:TSTamp	Timestamp:		
:FORMat <name>	Select timestamp format: ABSolute or DELTa.	ABS	D
:DATA?	Read all readings in buffer.		E
:MODE?	Query the type of data (DC or AVOL) stored in the buffer.		
:FORMat	FORMat Subsystem:		Section 13
: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	F
:CALCulate3	CALCulate3 Subsystem:		
:FORMat <name>	Select buffer statistic: MINimum, MAXimum, MEAN, SDEVIation, or PKPK.	MEAN	G
:DATA?	Read the selected buffer statistic.		H

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

A) :TRACe:FREE?

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

B) :TRACe:FEED <name>

Name parameters:

- SENSE — Raw input readings are stored in the buffer.
- CALCulate1 — The results of the $mX+b$, $m/X+b$, or log calculation are stored in the buffer. See [Section 5](#) for information on $mX+b$, $m/X+b$, or log.
- CALCulate2 — Test limit or Rel readings are stored in the buffer. See [Section 8](#) for information on limit tests.

C) :TRACe:FEED:CONTrol <name>

Name parameters:

- NEXT — Enables the buffer and turns on the asterisk (*) annunciator. After the buffer stores the specified number of readings, the asterisk annunciator turns off.
- NEVER — Disables the buffer.

D) :TRACe:TSTamp:FORMat <name>

Name parameters:

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

E) :TRACe:DATA?

1. The response message will include one to four data elements for each stored reading. Use the FORMat:ELEMents command (see Ref F) to specify the elements.
2. Reading an empty buffer will result in the “ERROR: -230” display message.
3. Buffer data can be sent in the binary format. (See “[FORMat subsystem](#),” page 13-4 for details).

F) :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 (see Ref D).
- STATus — Includes a status word for each reading. It provides status information on instrument operation. (See “FORMat subsystem,” page 13-4.)
- 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 (i.e. FORMat:ELEMents, READing, TIME). 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.

G) :CALCulate3:FORMat <name>

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

Name parameters:

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

H) :CALCulate3:DATA?

1. If the number of data points in the buffer is one or none, CALCulate3:DATA? will result in an error (-230).
2. If there is a lot of data in the buffer, some statistic operations may take too long and cause a bus time-out error. To avoid this, send CALC3:DATA? and then wait for the MAV (message available) bit in the Status Byte Register to set before addressing the Model 6487 talk ([Section 10](#)).

Programming example

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

```
' Select data elements:
*RST                                ' Return 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 Model 6487 voltage source can be used to generate voltage sweeps from a start voltage to a stop voltage at discrete step voltages. The Model 6487 stores readings in the buffer for later recall, one set of readings per voltage step.

Overview

As shown in [Figure 6-2](#), a voltage sweep is performed from a start voltage to a step 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.

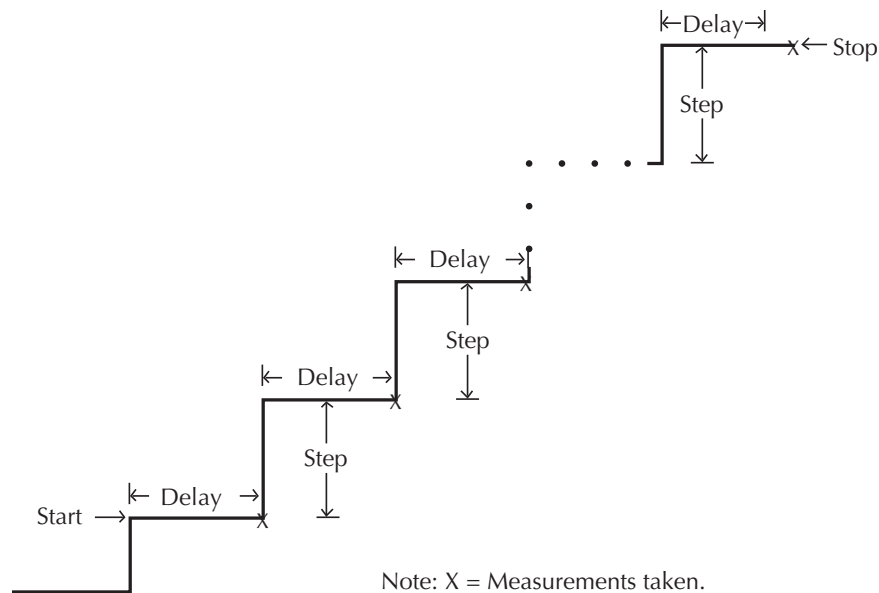
Note that sweeps can be positive-going or negative-going by programming the start and stop voltages accordingly, but the programmed step voltage is always positive.

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” briefly 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 6-2

Voltage sweeps



Sweep operation

Using [Table 6-2](#) as a guide, follow these steps 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. The unit will then prompt for the STOP voltage.
4. Enter the stop voltage, then press ENTER. The unit will prompt for the step voltage.
5. Enter the step voltage, then press ENTER. The unit will prompt for the delay.
6. Enter the delay period, then press ENTER. The unit will prompt you to press TRIG to start the sweep. The SCAN annunciator will be on to show the sweep is armed.
7. To start a sweep, press the TRIG key. 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.

Table 6-2

Sweep parameter menu selections

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

Recalling sweep data

To recall sweep data, press the RECALL key then use the manual RANGE and cursor keys to display readings. See [“Recall,” 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 +2V to +11 V in 1V steps will start on the 50V range and remain on the 50V 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 -25V to +25V in 5 V steps, 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 7V 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 (Section 7), 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, the INIT:IMM will take only a single reading in the sweep. To collect all 11 readings, you would need to send eleven INIT:IMM commands. After each INIT:IMM command arrives, the source will jump immediately to the new voltage, there will be a two-second delay, then the reading will be 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 0V 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 2-second sweep delay, but instead will be collected at the normal (Slow, 6 PLC) rate.

Status model

Bit 3 of the Operation Condition Register (Section 10) 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.

Table 6-3

SCPI commands — sweeps

Commands	Description	Default	Ref.
SOURce[1]	SOURce1 subsystem:		
:VOLTage	Voltage source commands:		
:SWEep	Sweep commands		
:START <NRf>	Set start voltage: -505V to 505V.	0V	A
:STOP <NRf>	Program stop voltage: -505V to 505V.	10V	B
:STEP <NRf>	Program step voltage: -505V to 505V.	1V	C
:CENTer <NRf>	Program center voltage: -505V to 505V.	5V	D
:SPAN <NRf>	Program span voltage: -505V to 505V.	10V	E
:DELay <NRf>	Set delay: 0 to 999.9999s.	1s	F
:INITiate	Arm sweep, put source in operate.		G
:ABORt	Abort sweep, put source in standby.		H
:STATe?	Query if sweep running: 1 = sweep in progress.		I
INITiate	Trigger sweep.		

A) :VOLTage:SWEep:START <NRf>

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

B) :VOLTage:SWEep:STOP <NRf>

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

C) :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.

D) :VOLTage:SWEEp:CENTer <NRf>

This command enters the mid-point of the sweep. Note that CENTER and SPAN are intimately coupled with START and STOP and simply offer another way to specify the sweep.

E) :VOLTage:SWEEp:SPAN <NRf>

This command enters the total span of the sweep. CENTER and SPAN are coupled with START and STOP and are another way to specify the sweep.

F) :VOLTage:SWEEp:DELay <NRf>

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

G) :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), then you get Error +842 "Sweep step size too large".

H) :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 was started.

I) :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 1V to 10V in 1V increments and recalls all readings:

*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.

7

Triggering

- [Trigger models](#) — Explains the various components of the trigger models which control the triggering operations of the instrument. Also, explains how to configure the trigger model from the front panel.
- [SCPI programming](#) — Includes the commands used to configure the trigger model and the commands to control the measurement process.
- [External triggering](#) — Explains external triggering which allows the Model 6487 to trigger other instruments and to be triggered by other instruments.

Trigger models

The flowcharts in [Figure 7-1](#) and [Figure 7-2](#) summarize triggering for the Model 6487. They are called trigger models because they are modeled after the SCPI commands to control triggering (operation).

Figure 7-1

Trigger model — front panel operation

Turn 6487 ON

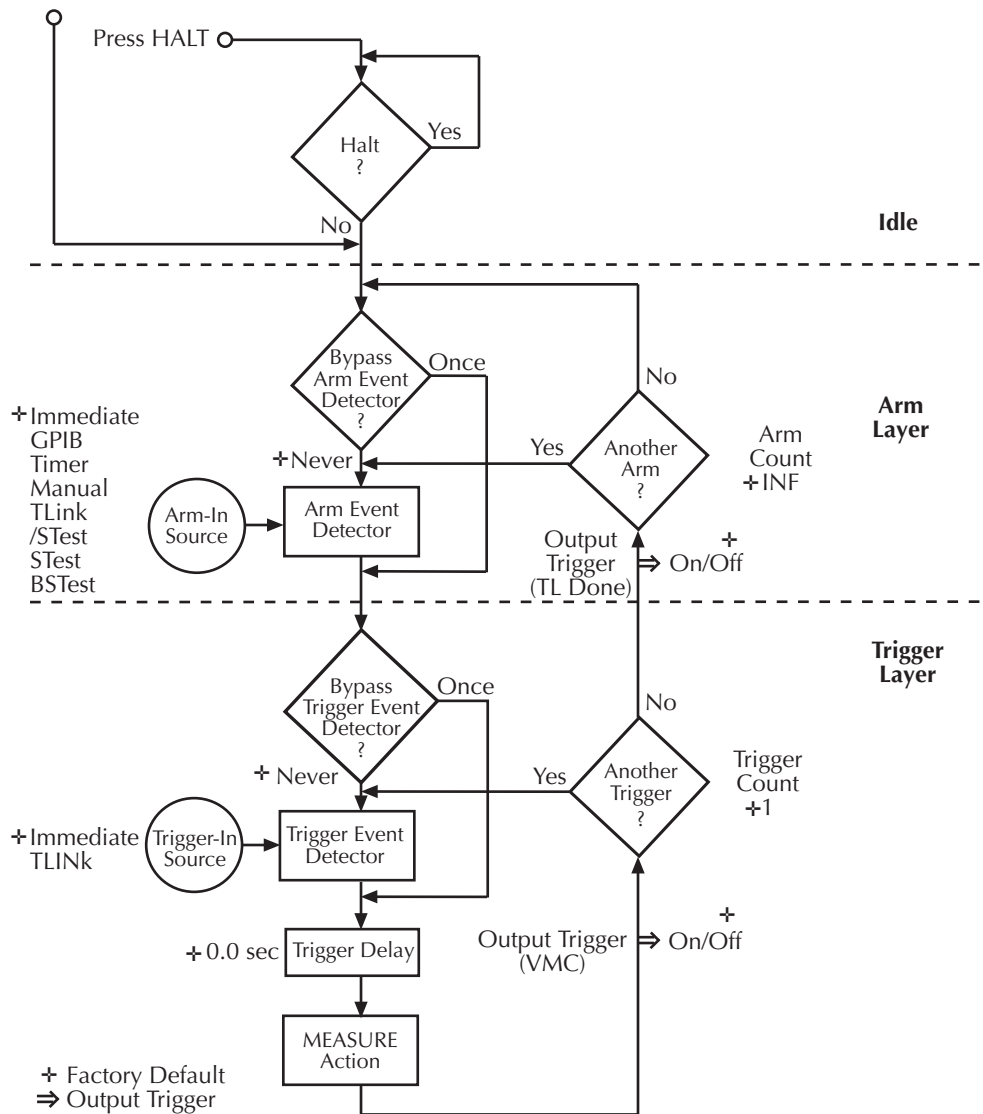
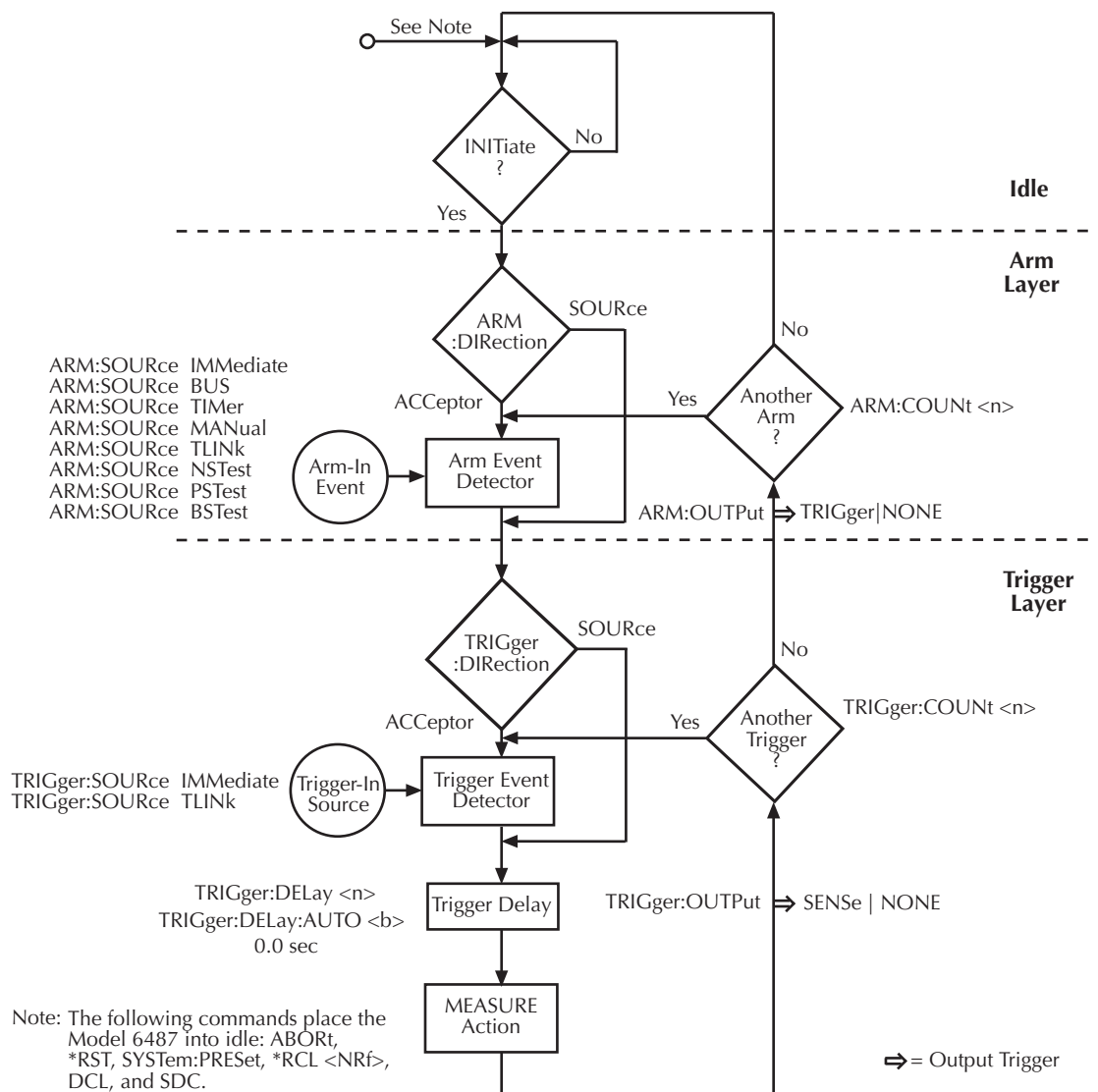


Figure 7-2

Trigger model – remote operation



Idle and initiate

While in the idle state, the instrument cannot perform measurements. While in idle, the reading remains frozen or dashes replace the reading (i.e. -.-.-.-.- A). Once the Model 6487 is taken out of idle, operation proceeds through the trigger model.

Front panel operation — As shown in [Figure 7-1](#), the Model 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 Model 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. Other front panel keys can be pressed instead, but they may change the setup.

Remote operation — As shown in [Figure 7-2](#), an initiate command is required to take the instrument out of idle. The following commands perform an initiate operation:

- INITiate
- READ?
- MEASure?

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

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

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

NOTE For fastest response, use SDC or DCL to return to idle (see [Section 9](#) for details on general bus commands).

Trigger model operation

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

NOTE *The following discussion focuses on the front panel trigger model (Figure 7-1). However, equivalent SCPI commands are included where appropriate.*

Event detectors and control sources

A control source holds up operation until the programmed event occurs and is detected. Note that there are two detector bypasses. A bypass around a detector is only enabled if the appropriate TLink control source is selected. See TLink control source (Arm-In and Trigger-In) as follows for details.

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

- **Immediate** (ARM:SOURce IMMEDIATE) — Event detection for the arm layer is satisfied immediately allowing operation to continue 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 Model 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 Model 6487 in local.
- **TLink** (ARM:SOURce TLINK) — Event detection for the arm layer is satisfied when an input trigger via the TRIGGER LINK connector is received by the Model 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 (see [Limit Tests and Digital I/O](#) in [Section 8](#)).
- **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 (see [Limit Tests and Digital I/O](#) in [Section 8](#)).
- **BSTest** (ARM:SOURce BSTest) — Event detection for the arm layer is satisfied when either a positive-going or a negative-going pulse (via the SOT line of the Digital I/O) is received from a component handler (see [Limit Tests and Digital I/O](#) in [Section 8](#)).

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

- **Immediate** (TRIGger:SOURce IMMEDIATE) — Event detection for the trigger layer is satisfied immediately allowing operation to continue 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 Model 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 Model 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 Model 6487 automatically sets delay according to range. The auto delay settings are listed in [Table 7-1](#).

Table 7-1
Auto delay settings

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

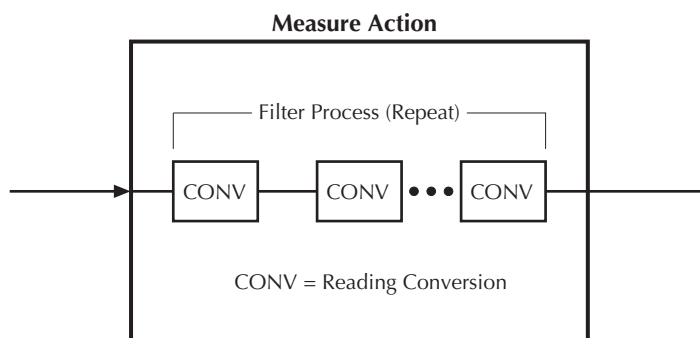
Measure action

The measure action block of the trigger model is where a measurement is performed. However, if the repeating filter is enabled (Figure 7-3), the instrument samples the specified number of reading conversions to yield single filtered reading. Only one reading conversion is performed if the digital filter is disabled or after the specified number of reading conversions for a moving average filter is reached.

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

Figure 7-3

Measure action block of trigger model



Output triggers

The Model 6487 can send out an output trigger (via the rear panel TRIGGER LINK connector) right after the measure action and/or when operation leaves the trigger layer. An output trigger can be used to trigger another instrument to perform an operation (e.g., select the next output step for a source).

Counters

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

Trigger model configuration — front panel

NOTE See “SCPI Programming” (Table 7-3) for the SCPI commands to configure the trigger model over the bus.

Press CONFIG and then TRIG to configure both the TRIG and ARM layers of the trigger model.

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. A menu item or value is selected by pressing ENTER. Use the EXIT key to exit from the menu (saving all changes made).

Table 7-2
Trigger model menu structure

Menu	Description
CONFIG	Path to TRIG and ARM menus. Access by pressing CONFIG and then TRIG.
- TRIG	Path to TRIG layer sub-menus.
- - COUNT	Set TRIG measure count.
- - - INF	Specify an INFinite measure count.
- - - FIN	Specify a FINite measure count: 1–2048.
- - DELAY	Set trigger delay.
- - - MAN	Specify trigger delay: 0–999.9998 sec.
- - - AUTO	Enable auto delay.
- - TRIG-OUT	Configure output triggers.
- - - LINE	Select the output trigger link line.
- - - - TLINK	Set trigger link value: 1–6.
- - - EVENTS	Select VMC (voltmeter complete) output trigger.
- - - - VMC	Enable/disable VMC (on or off).
- - TRIG-IN	Path to control source.
- - - SOURCE	Set the TRIG-IN control source.
- - - - IMM	Set control source to IMMEDIATE.
- - - - TLINK	Set control source to TLINK.
- - - - - TLINK	Set TLINK value: 1–6.
- - - - - EVENT	Enable (set to ONCE) or disable (set to NEVER).

Table 7-2 (cont.)
Trigger model menu structure

Menu	Description
- HALT	Stops triggering. Press TRIG to resume.
- ARM	Path to ARM layer submenus.
- - ARM-IN	Path to ARM-IN control source.
- - - IMM	Set control source to IMMEDIATE.
- - - GPIB	Set control source to GPIB.
- - - TIMER	Set control source to TIMER. Set timer from 0.001S to 27H, 46M, and 39.992S.
- - - MAN	Set control source to MANUAL.
- - - TLINK	Set control source to TLINK.
- - - - TLINK	Set TLINK value: 1–6.
- - - - EVENT	Enable (set to ONCE) or disable (set to NEVER).
- - - /STEST	Set control to negative pulse on SOT line (Section 8).
- - - STEST	Set control to positive pulse on SOT line (Section 8).
- - - BSTEST	Set control to positive or negative pulse on SOT line (Section 8).
- - ARM-OUT	Path to ARM-OUT trigger.
- - - LINE	Set the output trigger link line.
- - - - TLINK	Set trigger link value: 1–6.
- - - EVENT	Set Trigger Layer Done event.
- - - - T - L - DONE	Enable/disable Trigger Layer Done (on / off).
- - COUNT	Set ARM measure count.
- - - INF	Specify an INFinite measure count.
- - - FIN	Specify a FINite measure count: 1–2048.

NOTE 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

Table 7-3

SCPI commands — triggering

Command	Description	Default	Ref
ABORt	Reset trigger system (goes to idle state).		A
INITiate	Initiate one trigger cycle.		B
FEtCh?	Request latest reading.		B
READ?	Trigger and request a “fresh” reading.		B
ARM[:SEQuence[1]]	Arm Layer:		
[:LAYer[1]]			
:SOURce <name>	Select control source: IMMEDIATE, TIMer, BUS, MANual, TLink, PSTest, NSTest, or BSTest.	IMM	C
:COUNT <n>	Set measure count: 1 to 2048, or INF (infinite).	1	
:TIMer <n>	Set timer interval: 0.001 to 99999.999 (sec).	0.1	
[:TCONfigure]			
:DIREction <name>	Enable (SOURce) or disable (ACCEptor) bypass.	ACC	D
[:ASYNchronous]	Configure input/output triggers:		
:ILINe <NRf>	Select input trigger line: 1, 2, 3, 4, 5, or 6.	1	E
:OLINe <NRf>	Select output trigger line: 1, 2, 3, 4, 5, or 6.	2	E
:OUTPut <name>	Output trigger (TRIGger) or not at all (NONE).	NONE	
TRIGger	Trigger Layer:		
:CLEar	Clear pending input trigger immediately.		F
[: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 (sec).	0.0	
:AUTO 	Enable or disable auto delay.	OFF	
[:TCONfigure]			
:DIREction <name>	Enable (SOURce) or disable (ACCEptor) bypass.	ACC	D
[:ASYNchronous]	Configure input/output triggers:		
:ILINe <NRf>	Select input trigger line: 1, 2, 3, 4, 5, or 6.	1	E
:OLINe <NRf>	Select output trigger line: 1, 2, 3, 4, 5, or 6.	2	E
:OUTPut <name>	Output trigger after measurement (SENSe) or not at all (NONE).	NONE	

A) 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.

B) INITiate, FETCh, and READ?

1. 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.
2. If INITiate is sent while the instrument is operating within the trigger model, it will not execute until the operation returns to the idle state.
3. One alternative to using INITiate is to use the READ? command. When READ? is sent, the instrument is taken out of idle and all readings that are taken are returned (See [Section 12](#) for details on READ?).

C) ARM:SOURce <name>

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

D) ARM:DIRection <name>

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

E) 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.

F) 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 a initiate command. (See “INITiate” command.)

Programming example

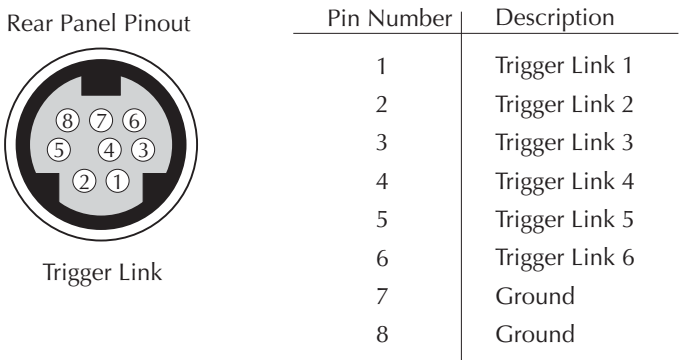
The following command sequence will trigger and return 10 readings.

*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

Input and output triggers are received and sent via the rear panel TRIGGER LINK connector. The trigger link has six lines. At the factory line #2 is selected for output triggers and line #1 is selected for input triggers. These input/output assignments can be changed as previously explained in this section. The connector pinout is shown in [Figure 7-4](#).

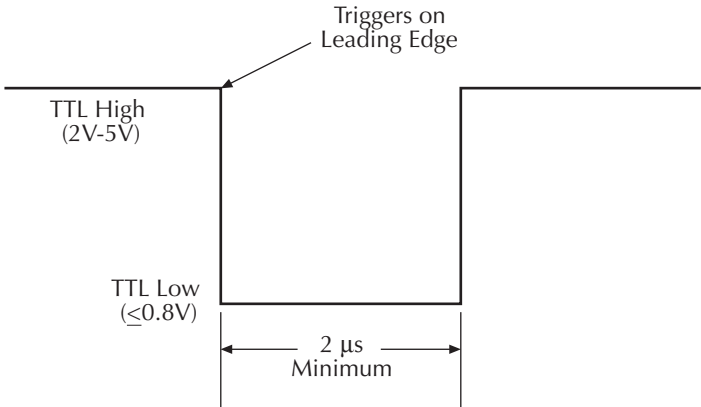
Figure 7-4
Trigger link connection operation



Input trigger requirements

An input trigger is used to satisfy event detection for a trigger model layer that is using the TLINK control source. The input requires a falling-edge, TTL-compatible pulse with the specifications shown in [Figure 7-5](#).

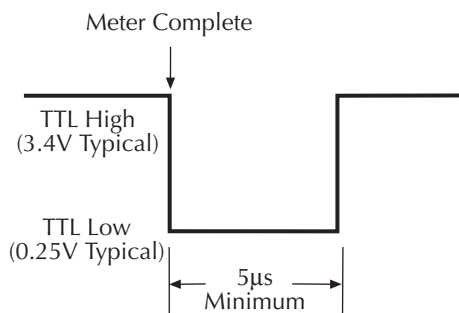
Figure 7-5
Trigger link input pulse specifications



Output trigger specifications

The Model 6487 can be programmed to output a trigger immediately after a measurement and/or when operation leaves the trigger layer of the trigger model. The output trigger provides a TTL-compatible output pulse that can be used to trigger other instruments. The specifications for this trigger pulse are shown in [Figure 7-6](#). A trigger link line can source 1mA and sink up to 50mA.

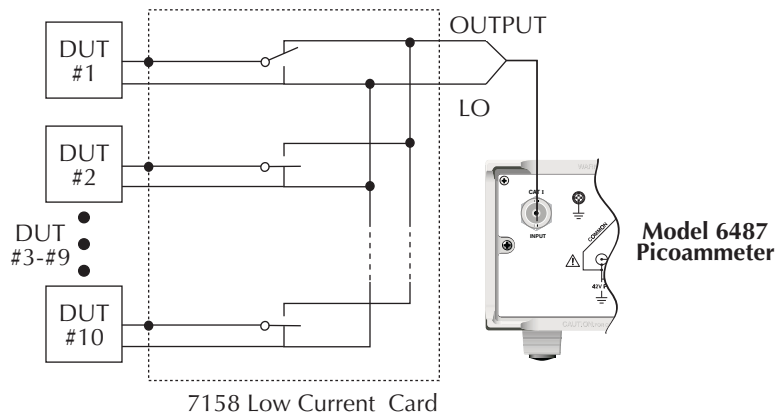
Figure 7-6
Trigger link output pulse specifications



External trigger example

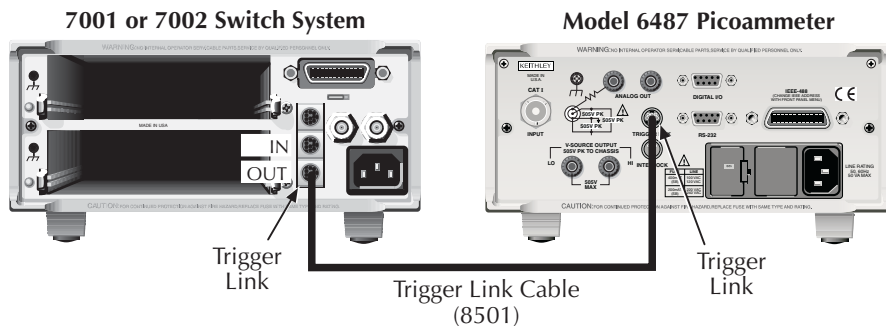
In a simple test system, you may want to close a switching channel and measure the current from a DUT connected to that channel. Such a test system is shown in [Figure 7-7](#). This example uses a Model 6487 to measure 10 DUTs switched by a Model 7158 low current card in a Model 7001 or 7002 switch system.

Figure 7-7
DUT test system



The trigger link connections for this test system are shown in [Figure 7-8](#). The trigger link of the Model 6487 is connected to the trigger link (IN or OUT) of the switching mainframe. Note that with the default trigger settings of the switching mainframe, line #1 is an input and line #2 is an output.

Figure 7-8
Trigger link connections



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

Model 6487

Factory Defaults Restored
 Trig-In Event = TLink
 Trigger Input Line = #2
 Trigger Output Line = #1
 Trigger Output Event = ON
 Trigger Count = 10
 Trigger Delay = Auto

Switching Mainframe

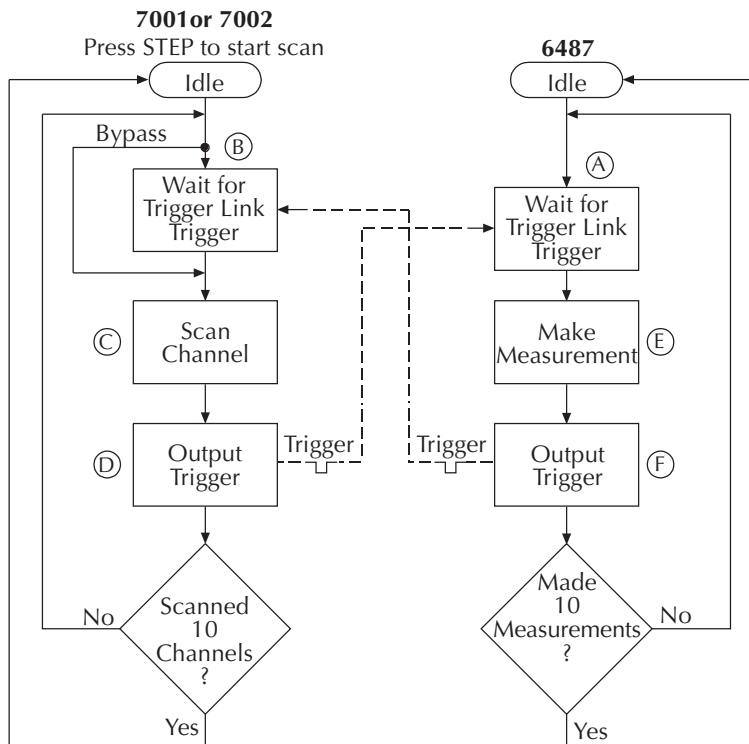
Factory Defaults Restored
 Scan List = 1!1-1!10
 Number of Scans = 1
 Channel Spacing = TrigLink

To store readings in the Model 6487 buffer, first set the number of points to store in the buffer:

1. Press CONFIG and then STORE.
2. Set the buffer size to 10 using the RANGE and cursor keys.
3. Press ENTER.
4. The next time STORE is pressed, the asterisk (*) annunciator turns on to indicate the buffer is enabled. (See the Model 6487 User's Manual 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 Model 6487 to take a reading and store it. the Model 6487 then sends an output trigger pulse to the switching mainframe to close the next channel. This process continues until all 10 channels are scanned, measured, and stored.

Figure 7-9
Operation model for triggering example



Details of this testing process are explained in the following paragraphs and are referenced to the operation model shown in [Figure 7-9](#).

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

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

8 Limit Tests and Digital I/O

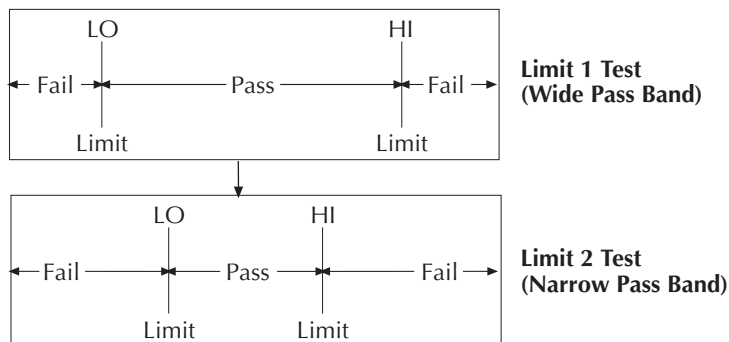
- **Limit testing** — Explains the basic Limit 1 and Limit 2 testing operations.
- **Binning** — Explains how to use a component handler to perform binning operations.
- **Digital I/O port** — Explains how to use the digital I/O port to control external circuitry.
- **Front panel operation — limit tests** — Explains how to configure and run limit tests from the front panel.
- **SCPI programming — limit tests** — Covers the SCPI commands for remote limit test operation.

Limit testing

As shown in [Figure 8-1](#), there are two limit tests that can be performed on a DUT. Limit 1 is used as the wide pass band and Limit 2 is used as the narrow pass band. It is up to the user to specify limits that conform to this pass band relationship.

Figure 8-1

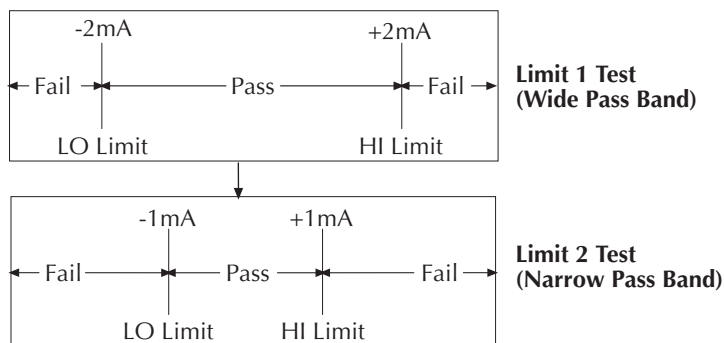
Limit tests



[Figure 8-2](#) shows an example where the HI and LO limits for Limit 1 are $\pm 2\text{mA}$ and the HI and LO limits for Limit 2 are $\pm 1\text{mA}$. A 0mA reading passes both Limit 1 and Limit 2 tests. A $+1.5\text{mA}$ reading passes Limit 1 but fails Limit 2. A $+2.5\text{mA}$ reading fails both Limit 1 and Limit 2.

Figure 8-2

Limit tests example



The 2-stage limit testing process is shown in . 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. The display messages for limit tests are summarized in [Table 8-1](#).

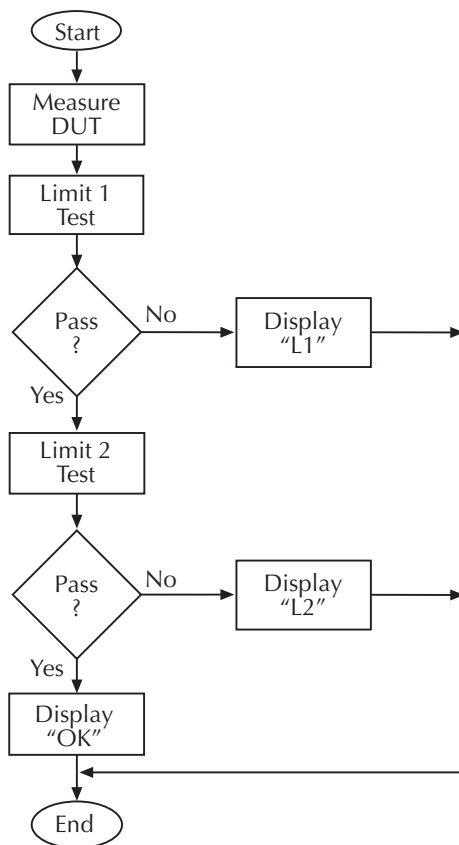
NOTE When limit tests are enabled, the voltage source value display is not visible, but it can still be viewed by using the *CONFIG V-SOURCE* menu or by pressing the *V-SOURCE* up or down arrow keys.

Table 8-1
Test limit display messages

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

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

Figure 8-3
Operation model for limit test



NOTE Display messages indicate which test or tests have failed, but they do not indicate which limit (HI or LO) has failed. When using remote operation, you can determine which limit failed by reading the measurement event register. See Ref C for the FAIL? commands in [Table 8-3 on page 8-18](#).

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). These math operations are covered in [Section 5](#).

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

Figure 8-4 shows a basic binning system. After all programmed testing on the DUT is completed, the appropriate digital output pattern is sent to the component handler, which then places the DUT in the appropriate bin. The component handler selects the next DUT and the testing process is repeated.

Figure 8-4
Binning system

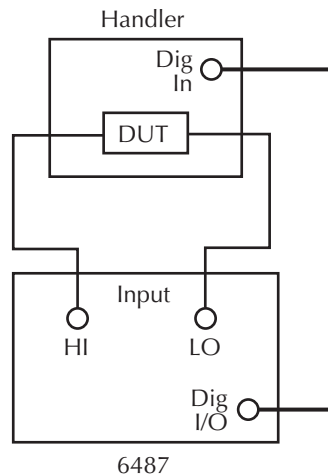
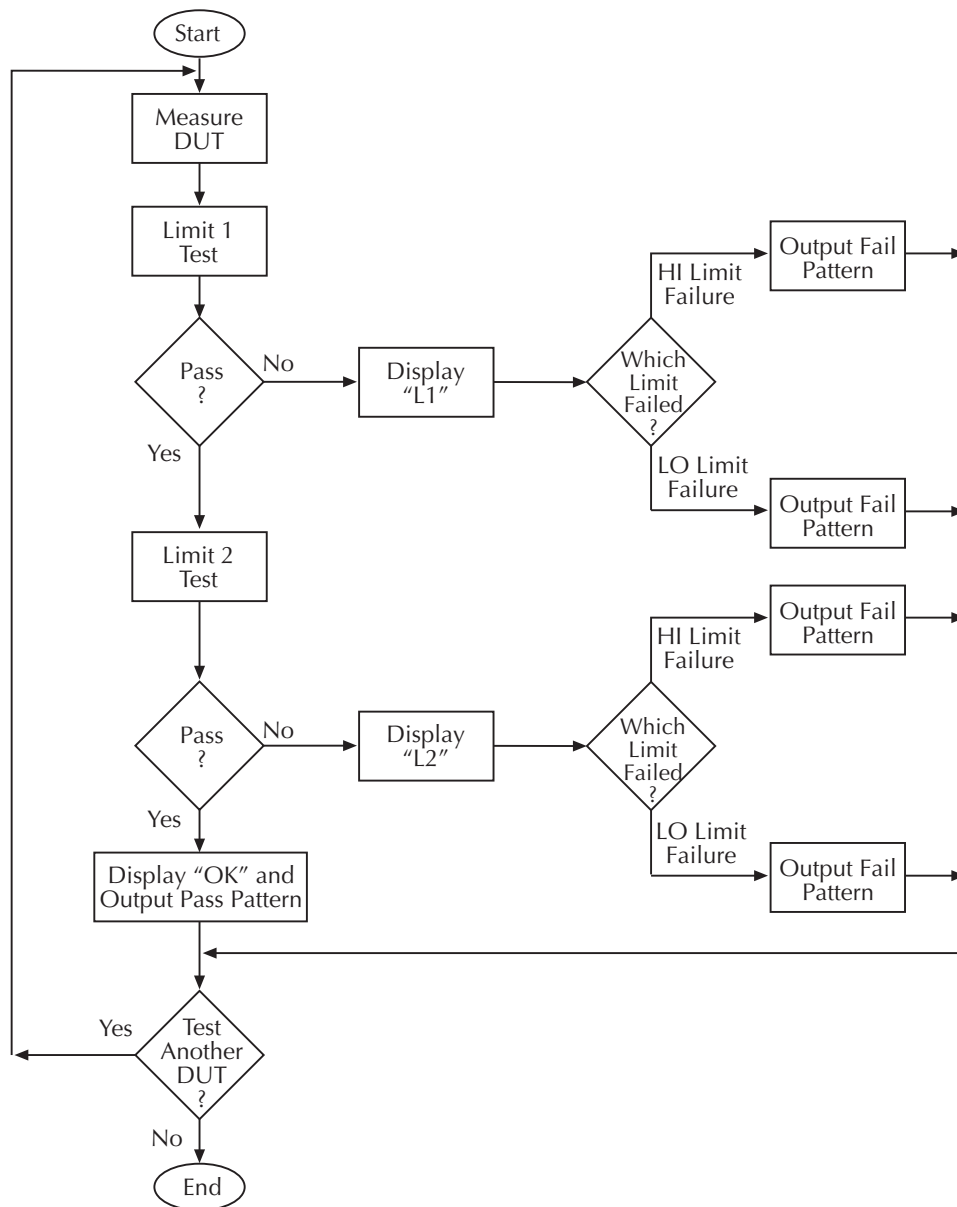


Figure 8-5 shows the basic limit testing flowchart expanded to include binning. Notice that there are five possible output patterns (one pass pattern and four fail patterns), but only one will be sent to the component handler for each DUT that is tested.

Figure 8-5

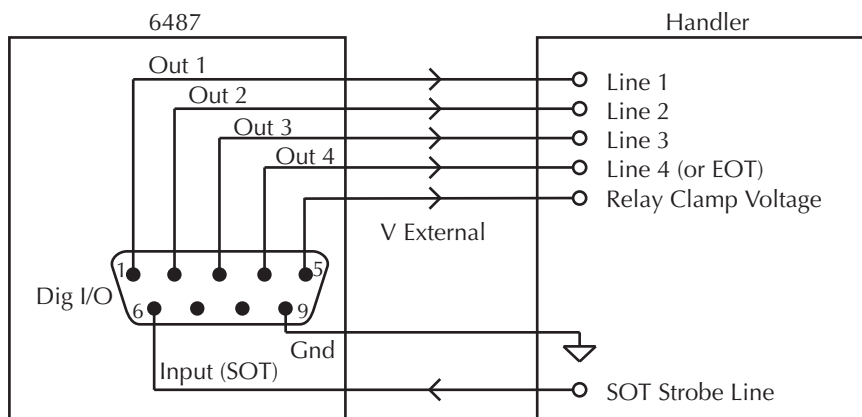
Operation model for limit testing with binning

Component handler interface

The Model 6487 is interfaced to a component handler via the Digital I/O port as shown in Figure 8-6. (See “Digital I/O port,” page 8-11 for more information.) The I/O port has four lines for output signals and one line for input signals. The input line is used to start the test and the output lines are used to send the test pass/fail signal(s) to the component handler to perform the binning operation.

Figure 8-6

Handler interface connections



The digital I/O lines are available at the DB-9 connector on the rear panel of the Model 6487. A custom cable using a standard female DB-9 connector is required for connection to the Model 6487.

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 STTest is the selected arm-in event, the test will start when the SOT line is pulled high. When BSTTest is the selected arm-in event, the test will start when the SOT line is pulled either high or low. Section 7 provides details on trigger model configuration.

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

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

Digital output patterns

The Model 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 Model 6487 can be used with either of the two basic types of handlers. When used with a category pulse handler, the Model 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 Model 6487 outputs a bit pattern to three handler lines. After the Model 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 Model 6487 can accommodate two different types of component handlers: category pulse and category register.

Category pulse component handler

When using this type of handler, the Model 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 Model 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 Model 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 Model 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 Model 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 Model 6487 must be set for the End of Test mode. In this mode, the Model 6487 sends the EOT pulse to the component handler as previously explained.

Digital output clear pattern

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

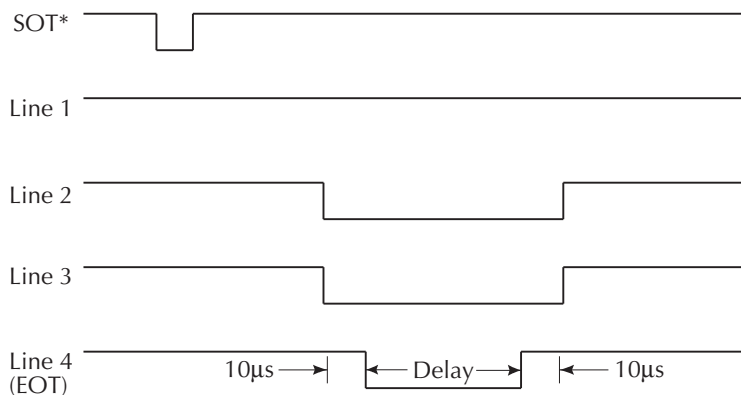
The Model 6487 can be programmed to automatically clear the digital output after the pass or fail pattern is sent. With auto-clear, you must specify the required pulse width (delay) for the pass or fail pattern. When not using auto-clear, you must return the digital output to its clear pattern.

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*.

Auto-Clear timing — The following example timing diagram (Figure 8-7) and discussion explain the relationship between the digital output lines for auto-clear.

Figure 8-7

Digital output auto-clear timing example



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

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

The pulse width (delay) of the pass/fail pattern can be set from 0 to 60 sec (10µsec resolution) as required by the component handler. Note that the delay specifies the pulse width of line 4. The pulse width of lines 1, 2, and 3 is actually 20µsec longer. Line 4 is skewed because it is used as the End-Of-Test (EOT) strobe by category register component han-

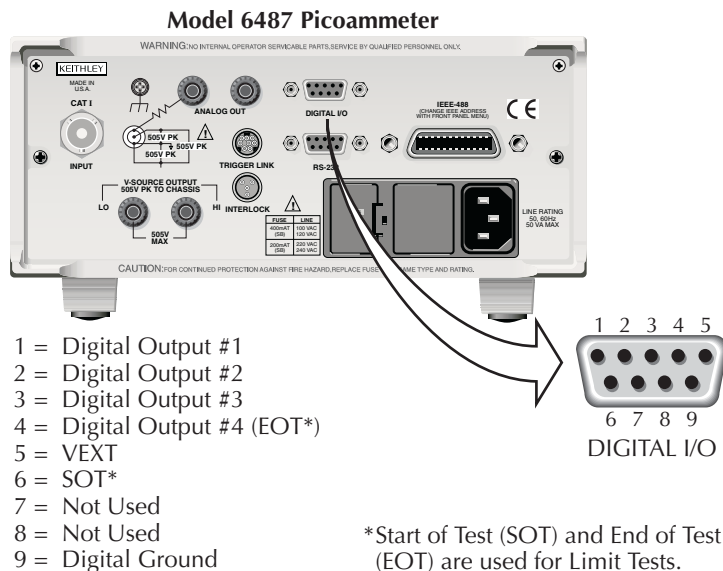
dlers. Lines 1, 2, and 3 establish the bit pattern and then 10 μ sec later the SOT strobe “tells” the handler to read the bit pattern and perform the binning operation. This 10 μ sec offset is used to make sure the correct bit pattern is read by the handler.

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

Digital I/O port

The Model 6487's Digital I/O port is a male DB-9 connector located on the rear panel. The port location and pin designations are shown in [Figure 8-8](#). The four active-low, digital output lines and one input line are used to control external circuitry.

Figure 8-8
Digital I/O port



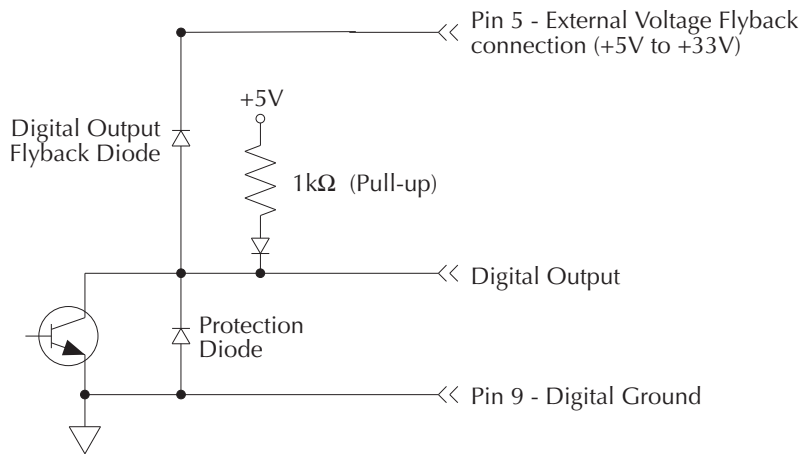
Typical applications for the digital I/O port include the following:

- Component handler control** — When performing limit tests, a component handler can be used to sort DUT into bins. (See [“Binning,”](#) page 8-5 for details.) The digital I/O of the Model 6487 serves as the interface between the limit tests and the component handler. Via the digital input line (pin 6), the component handler can tell the Model 6487 when it is ready for the test. Via the digital output lines, The Model 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 500mA. Drive voltage is provided by an external source (+5V to +33V).
- **Logic Control** — The four digital outputs can be used as inputs to logic devices.

The simplified schematic for the digital outputs is shown in [Figure 8-9](#). Note that this illustration shows the schematic for one digital output. All four digital output circuits are identical.

Figure 8-9
Digital I/O port simplified schematic



Sink mode — controlling external devices

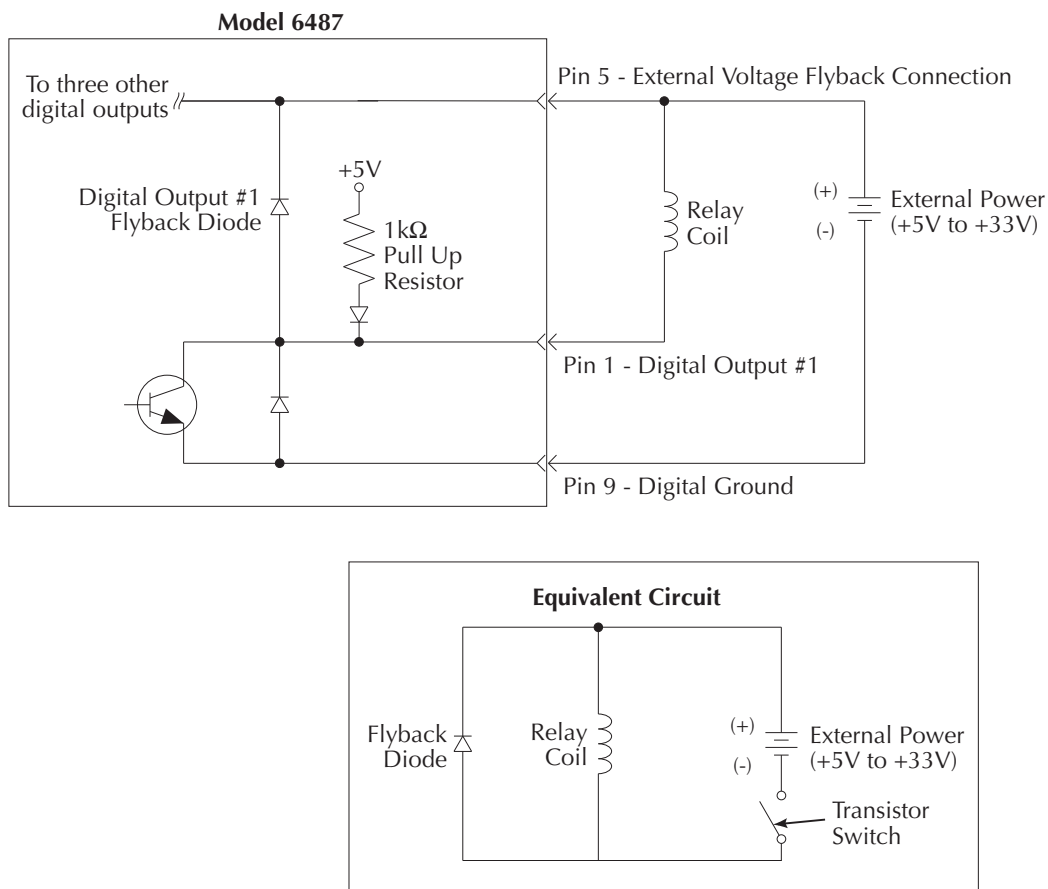
Each output can be operated from an external supply (voltage range from +5V to +33V applied through the external device being driven). The high current sink capacity of the output driver allows direct control of relays, solenoids, and lamps (no additional circuitry needed).

As shown in [Figure 8-9](#), each of the four digital, open-collector outputs includes a built-in pull up resistor to +5V. The output transistor is capable of sinking 500mA from voltages up to +33V. Each output channel contains a fly-back diode for protection when switching inductive loads (such as a low power solenoid or relay coils). To use these fly-back diodes, connect the external supply voltage to pin 5 of the digital I/O port. Make sure the external supply voltage is between +5V and +33V and the current required by the device does not exceed 500mA.

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

An externally powered relay connected to the digital output port is shown in Figure 8-10. Other externally powered devices can be similarly connected by replacing the relay with the device. When the output line is set LO (0V), the output transistor sinks current through the external device. In the HI state, the output transistor is off (transistor switch open). This interrupts current flow through the external device.

Figure 8-10

Controlling externally powered relays

Source mode — logic control

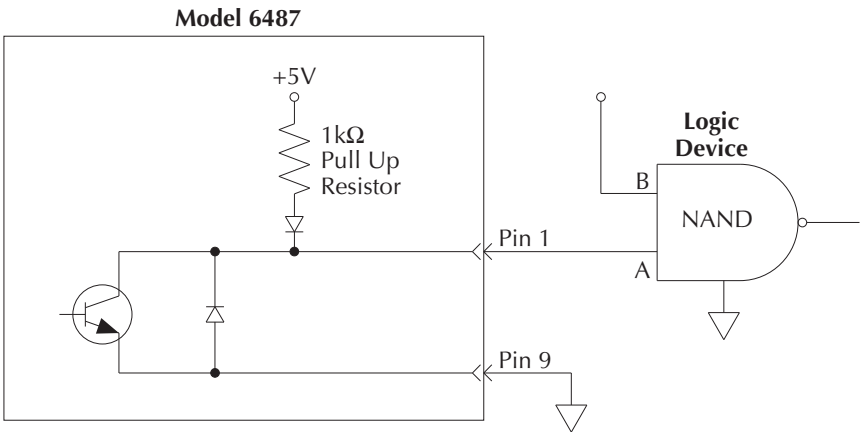
The digital outputs can be used as logic inputs to active TTL, low-power TTL, or CMOS inputs. For this mode of operation, the output lines can source up to 2mA.

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

Figure 8-11 shows how to connect a logic device to one of the output lines. When the output line is set HI, the transistor will turn off (transistor switch open) to provide a reliable logic high output (>3.75V). When the output line is set LO, the transistor turns on (transistor switch closed) to route current to digital ground. As a result, a low logic output (0V) is provided at the output.

If the second input (B) of the NAND gate is connected to another output line of the port, the output of the NAND gate will go to logic 0 when both digital outputs are set HI.

Figure 8-11
NAND gate control



Setting digital output lines

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

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

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

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

- 1. Press 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

Table 8-2
SCPI commands — digital outputs

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

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

Programming example

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

SOUR2:TTL 10
SOUR2:TTL?

' Set output lines 4 and 2 HI.
' 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 key in values. To change polarity of a value, place the cursor on “+” or “-” and press either of the RANGE keys. To change range for the value, place the cursor on the range symbol and scroll using the range keys (P = pico, N = nano, μ = micro, m = milli, $\wedge$ = $\times 1$, K = kilo, M = mega, G = giga, T = tera). A menu item or value is selected by pressing ENTER.

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

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

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

Limits configuration menu

The configuration menu for limits is structured as follows. Bullets denote the main items of the menu. To access the menu, press CONFIG and then LIMIT.

LIMIT 1 — Configure Limit 1 test:

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

LIMIT 2 — Configure Limit 2 test:

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

PASS — Set the digital output bit pattern for the “all tests pass” condition (0 to 15).

DIG CLR (Digital Clear):

- **AUTO CLR** — Enable or disable auto-clear for the digital output.
- **DEL (Delay)** — Set the pass/fail pattern pulse width (0 to 60 sec with 10 μ sec resolution).
- **DIGOUT** — Set the digital output clear pattern (0 to 15).

LIN4MOD (Line 4 Mode):

- **ENDOFTST** (End of Test) — With this mode, Model 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 the menu, press CONFIG and then 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.
 - **/STEST** — Test starts when the handler pulls the SOT line of the Digital I/O low.
 - **STEST** — Test starts when the handler pulls the SOT line of the Digital I/O high.
 - **BSTEST** — 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**

As previously explained, testing the system could be as simple as connecting a DUT to the Model 6487.

Step 2. Configure measurement

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

Step 3. Configure limit tests

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

Step 4. Start testing process

To enable the limit tests, press the LIMIT key—the testing process will start when LIMIT is pressed. The testing process can be terminated at any time by again pressing the LIMIT key.

SCPI programming — limit tests

Table 8-3

Limit test commands

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

Table 8-3 (cont.)

Limit test commands

Command	Description	Default	Ref
.SOURce2	SOURce2 Subsystem:		
:TTL <NDN> or <NRf>	Specify 4-bit digital output clear pattern.	15	B
:CLEar	Clear I/O port (return output to TTL pattern):		
[:IMMediate]	Clear I/O port immediately.		
:AUTO 	Enable or disable auto-clear.	OFF	
:DElay <n>	Specify delay (pulse-width) for pass/fail pattern: 0 to 60 (sec).	0.0001	
:TTL4	Line 4 Mode configuration:		
:MODE <name>	Select output line 4 mode: EOTest or BUSY.	EOT	
:BSTate <ttl>	Select active TTL level for busy: 1 (HI) or 0 (LO).	0	
	Trigger Subsystem:		Sec 7
ARM	Arm Layer:		
:SOURce <name>	Select control source: NSTest, PSTest, BSTest, or IMMEDIATE.	IMM	E
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	

A) :FEED <name>

Name parameters:

- 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 (see CALCulate1:NULL). Details on relative, $mX+b$, $m/X+b$, and $\log$ are provided in [Section 5](#).

B) <NDN> and <NRf> parameters

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

 <NRf> = 0 to 15 Decimal format

An output pattern is set by sending a parameter value that corresponds to the 4-bit BCD pattern of the output. The parameter value can be sent in the binary, decimal, hexadecimal, or octal format. For example, if you wish to set lines 4, 2, and 1 HI, the binary parameter value would be 1011. To use one of the other formats, convert the binary number to its decimal, hexadecimal, or octal equivalent:

Binary 1011 = Decimal 11 = Hexadecimal B = Octal 13

The <NDN> (non-decimal numeric) parameter type is used to send non-decimal values. These values require a header (#B, #H, or #Q) to identify the data format being sent. The letter in the header can be upper or lower case. The <NRf> (numeric representation format) parameter type is used to send decimal values and does not use a header.

The following examples show the proper parameter syntax to set an output pattern to 1101 (lines 4, 3, and 1 set HI):

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

NOTE *When a query command to read a programmed output pattern (i.e., CALC2:LIM:UPP:SOUR2?) is sent, the format for the returned value is determined by the presently selected response message format for output patterns (see FORMAT:SOURce2 command in [Table 8-3](#)).*

C) :FAIL?

In the event of a failure, you can read the measurement event register to determine which limit (upper or lower) failed. See [Section 10](#) to program and read the measurement event register.

D) :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 “old” readings or cause an error (-220) if limit is not enabled or there are no readings available.

E) :ARM:SOURce <name>

Typical “start of test” options:

- IMMEDIATE — Test starts when LIMIT key is pressed.
- NSTEST — Test starts when component handler pulls the SOT line low.
- PSTEST — Test starts when component handler pulls the SOT line high.
- BSTEST — Test starts when component handler pulls the SOT line high or low.

Programming example

The following command sequence will test DUT using the limit tests example shown in [Figure 8-2](#).

```

*RST                                ' Restore RST defaults.
CALC2:LIM:UPP 2e-3                 ' Set upper limit for Limit 1 (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                 ' Set upper limit for Limit 2 (1mA).
CALC2:LIM2:LOW -1e-3                ' Set lower limit for Limit 2 (-1mA).
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.

```

9

Remote Operation

- [Selecting and configuring an interface](#) — Explains how to select and configure an interface: GPIB or RS-232.
- [GPIB operation and reference](#) — Covers the following GPIB topics:
 - GPIB bus standards
 - GPIB bus connections
 - Primary address
 - General IEEE-488 bus commands
 - Front panel GPIB operation
 - Programming syntax
- [RS-232 interface reference](#) — Provides basic reference information for the RS-232 interface and explains how to make connections to the computer.

Selecting and configuring an interface

Interfaces

The Model 6487 supports two built-in remote interfaces:

- GPIB interface
- RS-232 interface

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

GPIB interface — The GPIB is the IEEE-488 interface. The Model 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. For the RS-232 interface, you can only use the SCPI language to program the instrument.

Languages

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

- SCPI language (488.2)
- DDC language
- 488.1 language

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

SCPI language — Standard Commands for Programmable Instrument (SCPI) is fully supported by the GPIB and RS-232 interfaces. Always calibrate the Model 6487 using the SCPI language.

DDC language — The Model 6487 implements most DDCs (device-dependent commands) available in the Keithley Model 487 picoammeter. The available commands are provided in [Appendix C](#). See the Model 487 Instruction Manual for details on operation. The PDF of this manual is on the CD-ROM that was included with your shipment.

488.1 language — See [Appendix E](#) for details.

Interface selection and configuration procedures

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

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

Select the interface from the COMM menu structure (access by pressing the COMM key while in local). 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 perform the power-on sequence.*

Configuring the GPIB interface

Select the GPIB interface from the COMM menu structure (access by pressing the COMM key while in local). After selecting the GPIB interface, press the CONFIG key and then the COMM key to configure the GPIB address and language. From this menu you can check or change the following settings:

- Primary address: 0–30
- Language: SCPI (SCPI 1996.0 which includes 488.2), 488.1, or DDC

Press the RANGE keys to scroll through ADDRESS and LANGUAGE available. To make changes to a setting, press the cursor right key. Then use the RANGE keys and the cursor keys to select and modify the value as desired. Press ENTER to save the changes and stay in the menu (pressing EXIT also saves the changes but leaves the menu).

RS-232 interface

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

Select the RS-232 interface from the COMM menu structure (access by pressing the COMM key while in local). After selecting the RS-232 interface, press the CONFIG key and then the COMM key to configure the RS-232 interface and check or change the following settings:

- BAUD: Baud rate (57.6K, 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,” on page 9-16 for information on RS-232 settings and connections to the computer.*

Press the RANGE keys to scroll through the available RS-232 settings. To make changes to a setting, press the right cursor key and then use the RANGE keys to select and modify the value as desired. Press ENTER to save the changes and move to the next menu item (pressing EXIT also saves the changes but leaves the menu). At the last menu item, ENTER will save and exit 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.

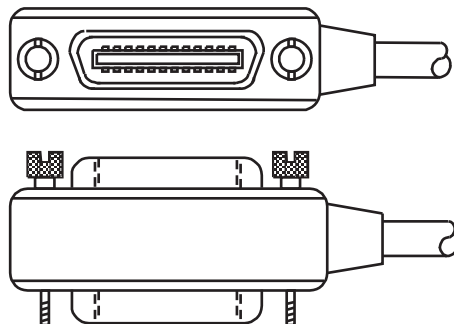
- SCPI 1996.0 (Standard Commands for Programmable Instruments)

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 Model 6487 to the GPIB bus, use a cable equipped with standard IEEE-488 connectors as shown in [Figure 9-1](#).

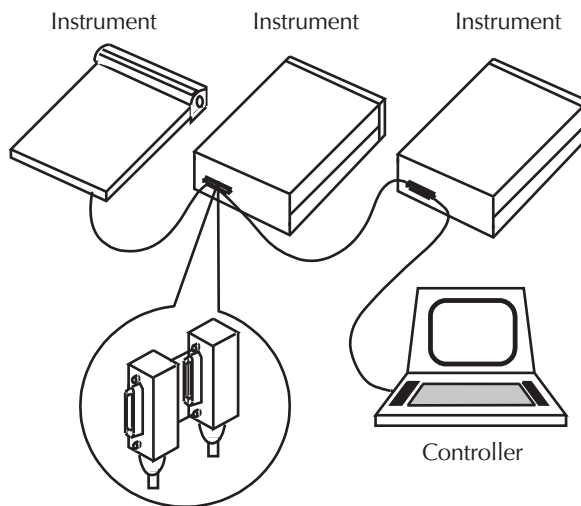
Figure 9-1
IEEE-488 connector



To allow many parallel connections to one instrument, stack the connector. Two screws are located on each connector to ensure that connections remain secure. Current standards call for metric threads, which are identified with dark-colored screws. Earlier versions had different screws, which were silver-colored. Do not use these types of connectors on the Model 6487, because it is designed for metric threads.

Figure 9-2 shows a typical connecting scheme for a multi-unit test system.

Figure 9-2
Multi-unit connections



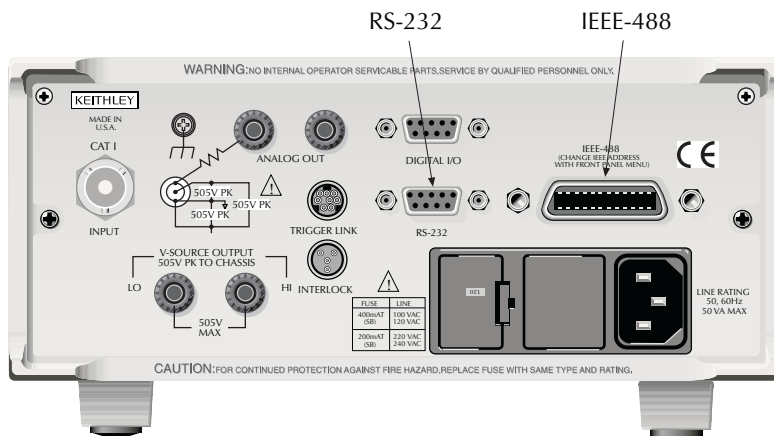
To avoid possible mechanical damage, stack no more than three connectors on any one unit.

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

To connect the Model 6487 to the IEEE-488 bus, follow these steps:

1. Line up the cable connector with the connector located on the rear panel. The connector is designed so that it will fit only one way. [Figure 9-3](#) shows the location of the IEEE-488 connector.

Figure 9-3
IEEE-488 and RS-232 connector locations



2. Tighten the screws securely, making sure not to over tighten them.
3. Connect any additional connectors from other instruments as required for your application.
4. Make sure that the other end of the cable is properly connected to the controller. Most controllers are equipped with an IEEE-488 style connector, but a few may require a different type of connecting cable. See your controllers instruction manual for information about properly connecting to the IEEE-488 bus.

NOTE You can only have 15 devices connected to an IEEE-488 bus, including the controller. The maximum cable length is either 20 meters or two meters times the number of devices, whichever is less. Not observing these limits may cause erratic bus operation.

Primary address

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

Usually controller addresses are 0 or 21, but see the controllers instruction manual for details. Make sure the address of the controller is the same as that specified in the controllers programming language. To make sure the unit's interface is properly selected and configured or to check or change the GPIB address, refer to [“Selecting and configuring an interface,” page 9-2.](#)

General IEEE-488 bus commands

Commands and associated statements

General commands are those commands, such as DCL, that have the same general meaning regardless of the instrument. [Table 9-1](#) lists the general bus commands.

Table 9-1

General bus commands

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

REN (remote enable)

The remote enable command is sent to the Model 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. Simply setting REN true does not actually place the instrument in the remote state. You must address the instrument to listen after setting REN true before it goes into remote.

Note that the instrument does not have to be in remote to be a talker.

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

IFC (interface clear)

The IFC command is sent by the controller to place all instruments on the bus in the local, talker, listener idle states. The Model 6487 responds to the IFC command by canceling front panel TALK or LSTN lights, if the instrument was previously placed in one of those states. Note that this command does not affect the status of the instrument; settings, data, and event registers are not changed.

To send the IFC command, the controller must set the IFC line true for a minimum of 100 μ s.

LLO (local lockout)

Use the LLO command to prevent local operation of the instrument. After the unit receives LLO, all its front panel controls except the POWER are inoperative. In this state, pressing LOCAL will not restore control to the front panel. The GTL command restores control to the front panel.

GTL (go to local)

Use the GTL command to put a remote mode instrument into local mode. The GTL command also restores front panel key operation.

DCL (device clear)

Use the DCL command to clear the GPIB interface and return it to a known state. Note that the DCL command is not an addressed command, so all instruments equipped to implement DCL will do so simultaneously.

When the Model 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. A DCL does not affect instrument settings and stored data.

SDC (selective device clear)

The SDC command is an addressed command that performs essentially the same function as the DCL command. However, since each device must be individually addressed, the SDC command provides a method to clear only selected instruments instead of clearing all instruments simultaneously, as is the case with DCL.

GET (group execute trigger)

GET is a GPIB trigger that is used as an event to control operation. The Model 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)

Use the serial polling sequence to obtain the Model 6487 serial poll byte. The serial poll byte contains important information about internal functions. Generally, the serial polling sequence is used by the controller to determine which of several instruments has requested service with the SRQ line. However, the serial polling sequence may be performed at any time to obtain the status byte from the Model 6487.

Front panel GPIB operation

The following paragraphs describe aspects of the front panel that are part of GPIB operation, including messages, status indicators, and the LOCAL key.

Error and status messages

See [Appendix B](#) for a list of error and status messages associated with IEEE-488 programming. The instrument can be programmed to generate an SRQ and command queries can be performed to check for specific error conditions.

GPIB status indicators

The REM (remote), TALK (talk), LSTN (listen), and SRQ (service request) annunciators show the GPIB bus status. Each of these indicators is described below.

- **REM** — This indicator shows when the instrument is in the remote state. REM does not necessarily indicate the state of the REM line, as the instrument must be addressed to listen with REM true before the REM indicator turns on. When the instrument is in remote, all front panel keys, except for the LOCAL key, are locked out. When REM is turned off, the instrument is in the local state and front panel operation is restored.
- **TALK** — This indicator is on when the instrument is in the talker active state. Place the unit in the talk state by addressing it to talk with the correct MTA (My Talk Address) command. TALK is off when the unit is in the talker idle state. Place the unit in the talker idle state by sending a UNT (Untalk) command, addressing it to listen, or sending the IFC (Interface Clear) command.
- **LSTN** — This indicator is on when the Model 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 (see “Front panel operation,” page 4-8.)

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.

Put at least one space between the command word and the parameter.

- **Brackets []** — Some command words are enclosed in brackets ([]). These brackets are used to denote an optional command word that does not need to be included in the program message. For example:

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

These brackets indicate that :IMMediate is implied (optional) and does not have to be used. Thus, the above command can be sent in one of two ways:

```
:INITiate or :INITiate:IMMediate
```

Notice that the optional command is used without the brackets. When using optional command words in your program, do not include the brackets.

- **Parameter types** — The following are some of the common parameter types:

	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

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, MINi-
mum, and MAXimum parameters for the query form. These query forms are used to deter-
mine the *RST default value and the upper and lower limits for the fundamental
command.

:ARM:TiMer? DEFault	Queries the *RST default value
:ARM:TiMer? MINimum	Queries the lowest allowable value
:ARM:TiMer? MAXimum	Queries the largest allowable value

Case sensitivity

Common commands and SCPI commands are not case sensitive. You can use upper or lower case and any case combination. Examples:

*RST	= *rst
:DATA?	= :data?
:SYSTem:PRESet	= :system:preset

Long-form and short-form versions

A SCPI command word can be sent in its long-form or short-form version. The command tables in this manual use the long-form version. However, the short-form version is indicated by upper case characters.

:SYSTem:PRESet	long-form
:SYST:PRES	short form
:SYSTem:PRES	long-form and short-form combination

Note that each command word must be in either long-form or short-form. For example, :SYSTe:PRESe is illegal and will generate an error. The command will not be executed.

Short-form rules

Use the following rules to determine the short-form version of any SCPI command:

- If the length of the command word is four letters or less, no short form version exists.

:auto = :auto

These rules apply to command words that exceed four letters:

- If the fourth letter of the command word is a vowel, delete it and all letters after it.
immediate = :imm
- If the fourth letter of the command word is a consonant, retain it but drop all the letters after it.
:format = :form
- If the command contains a question mark (?) or a non-optional number included in the command word, you must include it in the short-form version.
:delay? = :del?
- Command words or characters that are enclosed in brackets ([]) are optional and need not be included in the program message.

Program messages

A program message is made up of one or more command words sent by the computer to the instrument. Each common command is simply a three letter acronym preceded by an asterisk (*). The following SCPI commands from the STATUS subsystem are used to help explain how command words are structured to formulate program messages.

Command structure

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

Single command messages

The above command structure has three levels. The first level is made up of the root command (:STATus) and serves as a path. The second level is made up of another path (:OPERation) and a command (:PRESet). The third path is made up of one command for the :OPERation path. The three commands in this structure can be executed by sending three separate program messages as follows:

```
:stat:oper:enab <NRf>
:stat:oper:enab?
:stat:pres
```

In each of the above program messages, the path pointer starts at the root command (:stat) and moves down the command levels until the command is executed.

Multiple command messages

You can send multiple command messages in the same program message as long as they are separated by semicolons (;). The following is an example showing two commands in one program message:

```
:stat:oper; :stat:oper:enab <NRf>
```

When the above is sent, the first command word is recognized as the root command (:stat). When the next colon is detected, the path pointer moves down to the next command level and executes the command. When the path pointer sees the colon after the semicolon (;), it resets back to the root level and starts over.

Commands that are on the same command level can be executed without having to retype the entire command path. Example:

```
:stat:oper:enab <NRf>; enab?
```

After the first command (:enab) is executed, the path pointer is at the third command level in the structure. Since :enab? is also on the third level, it can be entered without repeating the entire path name. Notice that the leading colon for :enab? is not included in the program message. If a colon were included, the path pointer would reset to the root level and expect a root command. Since :enab? is not a root command, an error would occur.

Command path rules

- Each new program message must begin with the root command, unless it is optional (e.g., [:SENSe]). If the root is optional, simply treat a command word on the next level as the root.
- The colon (:) at the beginning of a program message is optional and need not be used.

```
:stat:pres = stat:pres
```

- When the path pointer detects a colon (:), it moves down to the next command level. An exception is when the path pointer detects a semicolon (;), which is used to separate commands within the program message.
- When the path pointer detects a colon (:) that immediately follows a semicolon (;), it resets to the root level.
- The path pointer can only move down. It cannot be moved up a level. Executing a command at a higher level requires that you start over at the root command.

Using common commands and SCPI commands in the same message

Both common commands and SCPI commands can be used in the same message as long as they are separated by semicolons (;). A common command can be executed at any command level and will not affect the path pointer.

```
:stat:oper:enab <NRf>; *ESE <NRf>
```

Program Message Terminator (PMT)

Each program message must be terminated with an LF (line feed), EOI (end or identify), or an LF+EOI. The bus will hang if your computer does not provide this termination. The following example shows how a program message must be terminated:

```
:trac:poin 10 <PMT>
```

Command execution rules

- Commands execute in the order that they are presented in the program message.
- An invalid command generates an error and, of course, is not executed.
- Valid commands that precede an invalid command in a multiple command program message are executed.
- Valid commands that follow an invalid command in a multiple command program message are ignored.
- For fastest command execution:
 1. Do not use optional command words (i.e., [:SENSE [1]]).
 2. Do not use the colon (:) at the beginning of a program message.
 3. Always use the short-form versions of commands and parameters.
 4. Minimize the amount of “white” space in command strings.
 5. Keep numeric parameters simple (i.e., 1 vs. 1.000e + 00).
 6. Use all uppercase.

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 Model 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 (see [“Multiple command messages,” on page 9-14](#)), the multiple response messages for all the queries is sent to the computer when the Model 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
```

Response Message Terminator (RMT)

Each response is terminated with an LF (line feed) and EOI (end or identify). The following example shows how a multiple response message is terminated:

0; 1; 1; 0; <RMT>

Message exchange protocol

Two rules summarize the message exchange protocol:

- Rule 1.** Always tell the Model 6487 what to send to the computer. The following two steps must always be performed to send information from the instrument to the computer:
1. Send the appropriate query command(s) in a program message.
 2. Address the Model 6487 to talk.
- Rule 2.** The complete response message must be received by the computer before another program message can be sent to the Model 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

The procedure to select and configure the RS-232 interface is provided in [“Selecting and configuring an interface,” page 9-2](#). Make sure the controller you connect to the Model 6487 also uses these settings.

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 rate at which the Model 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 that the programming terminal that you are connecting to the Model 6487 can support the baud rate you selected. Both the Model 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 Model 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 Model 6487 does not support hardware handshaking (flow control).

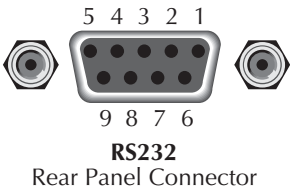
Software flow control is in the form of X_ON and X_OFF characters and is enabled when XonXoFF is selected from the RS232 FLOW menu. When the input queue of the Model 6487 becomes more than ⁱ full, the instrument issues an X_OFF command. The control program should respond to this and stop sending characters until the Model 6487 issues the X_ON, which it will do once its input buffer has dropped below 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 (i.e., personal computer) using a straight through RS-232 cable terminated with DB-9 connectors. **Do not use a null modem cable.** The serial port uses the transmit (TXD), receive (RXD), and signal ground (GND) lines of the RS-232 standard. It does not use the hardware handshaking lines CTS and RTS. [Figure 9-4](#) shows the rear panel connector for the RS-232 interface and [Table 9-2](#) shows the pinout for the connector. The connector location on the rear panel is shown in [Figure 9-3](#).

Figure 9-4
RS-232 interface 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).

Table 9-2
RS-232 connector pinout

Pin number	Description
1	DCD, data carrier detect
2	TXD, transmit data
3	RXD, receive data
4	DTR, data terminal ready
5	GND, signal ground
6	DSR, data set ready
7	RTS, 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 Model 6487 and PC so
that null modem cable is not required.

Table 9-3
PC serial port pinout

Signal	DB-9 pin number	DB-25 pin number
DCD, data carrier detect	1	8
RXD, receive data	2	3
TXD, transmit data	3	2
DTR, data terminal ready	4	20
GND, signal ground	5	7
DSR, data set ready	6	6
RTS, request to send	7	4
CTS, clear to send	8	5
RI, ring indicator	9	22

Error messages

See [Appendix B](#) for RS-232 error messages.

10

Status Structure

- **Overview** — Provides an operational overview of the status structure for the Model 6487.
- **Clearing registers and queues** — Covers the actions that clear (reset) registers and queues.
- **Programming and reading registers** — Explains how to program enable registers and read any register in the status structure.
- **Status byte and service request (SRQ)** — Explains how to program the status byte to generate service requests (SRQs). Shows how to use the serial poll sequence to detect SRQs.
- **Status register sets** — Provides bit identification and command information for the four status register sets: standard event status, operation event status, measurement event status, and questionable event status.
- **Queues** — Provides details and command information on the output queue and error queue.

Overview

The Model 6487 provides a series of status registers and queues allowing the operator to monitor and manipulate the various instrument events. The status structure is shown in [Figure 10-1](#). The heart of the status structure is the status byte register. This register can be read by the user's test program to determine if a service request (SRQ) has occurred and what event caused it.

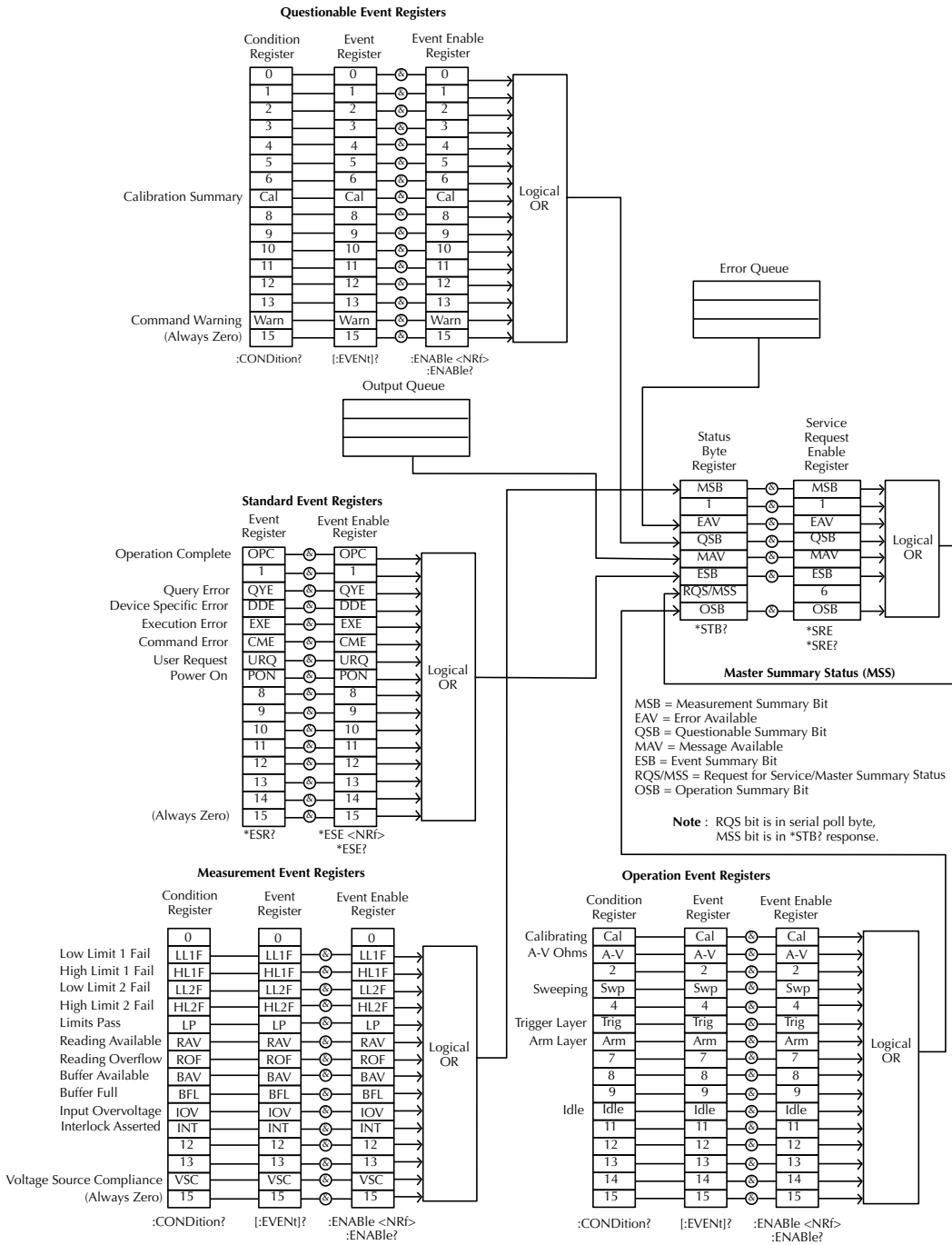
Status byte and SRQ — The status byte register receives the summary bits of four status register sets and two queues. The register sets and queues monitor the various instrument events. When an enabled event occurs, it sets a summary bit in the status byte register. When a summary bit of the status byte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

Status register sets — A typical status register set is made up of a condition register, an event register, and an event enable register. A condition register is a read-only register that constantly updates to reflect the present operating conditions of the instrument.

When an event occurs, the appropriate event register bit sets to 1. The bit remains latched to 1 until the register is reset. When an event register bit is set and its corresponding enable bit is set (as programmed by the user), the output (summary) of the register will set to 1, which in turn sets the summary bit of the status byte register.

Queues — The Model 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 10-1
Model 6487 status mode structure



Clearing registers and queues

When the Model 6487 is turned on, the bits of all registers in the status structure are clear (reset to 0) and the two queues are empty. Commands to reset the event and event enable registers and the error queue are listed in [Table 10-1](#). In addition to these commands, any enable register can be reset by sending the 0 parameter value with the individual command to program the register.

NOTE *SYSTEM:PRESet and *RST have no effect on status structure registers and queues.*

Table 10-1

Common and SCPI commands – reset registers and clear queues

Commands	Description	Ref
<i>To reset registers:</i> *CLS	Reset all bits of the following event registers to 0: Standard event register Operation event register Measurement event register Questionable event register	Note 1
STATus :PRESet	STATus subsystem: Reset all bits of the following enable registers to 0: Operation event enable register Measurement event enable register Questionable event enable register	Note 1
<i>To clear error queue:</i> *CLS	Clear all messages from error queue	Note 2
STATus :QUEue :CLEar	STATus subsystem: Error queue: Clear messages from error queue	Note 3
SYSTem :ERRor :CLEar	SYSTem subsystem: Error queue: Clear messages from error queue	Note 3

Notes:

1. The standard event enable register is not reset by STATUS:PRESet or *CLS. Send the 0 parameter value with *ESE to reset all bits of that enable register to 0 (see “Status byte and service request (SRQ),” page 10-7).
2. STATUS:PRESet has no effect on the error queue.
3. Use either of the two clear commands to clear the error queue.

Programming and reading registers

Programming enable registers

The only registers that can be programmed by the user are the enable registers. All other registers in the status structure are read-only registers. The following explains how to ascertain the parameter values for the various commands used to program enable registers. The actual commands are covered later in this section (Table 10-3 through Table 10-6).

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

The bit positions of the register (Figure 10-1) indicate the binary parameter value. For example, if you wish 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

Note that Figure 10-2 includes the decimal weight for each register bit. To set bits B4, B3, and B1, the decimal parameter value would be the sum of the decimal weights for those bits (16+8+2 = 26).

Figure 10-2
16-bit status register

A. Bits 0 through 7

Bit Position	B7	B6	B5	B4	B3	B2	B1	B0
Binary Value	0/1	0/1	0/1	0/1	0/1	0/1	0/1	0/1
Decimal Weights	128 (2 ⁷)	64 (2 ⁶)	32 (2 ⁵)	16 (2 ⁴)	8 (2 ³)	4 (2 ²)	2 (2 ¹)	1 (2 ⁰)

B. Bits 8 through 15

Bit Position	B15	B14	B13	B12	B11	B10	B9	B8
Binary Value	0/1	0/1	0/1	0/1	0/1	0/1	0/1	0/1
Decimal Weights	32768 (2 ¹⁵)	16384 (2 ¹⁴)	8192 (2 ¹³)	4096 (2 ¹²)	2048 (2 ¹¹)	1024 (2 ¹⁰)	512 (2 ⁹)	256 (2 ⁸)

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 for-

mat) parameter type is used to send decimal values and does not use a header. The following examples show the proper parameter syntax for setting bits B5, B3, and B2:

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

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

<NDN> Format	Valid Characters
Binary	1's and 0's
Hexadecimal	0 through 9 and A through F
Octal	0 through 7

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 (Table 10-3 through Table 10-6).

The response message will be a value that indicates which bits in the register are set. That value (if not already binary) will have to be converted to its binary equivalent. For example, for a binary value of 100101, bits B5, 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 (Table 10-2).

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

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

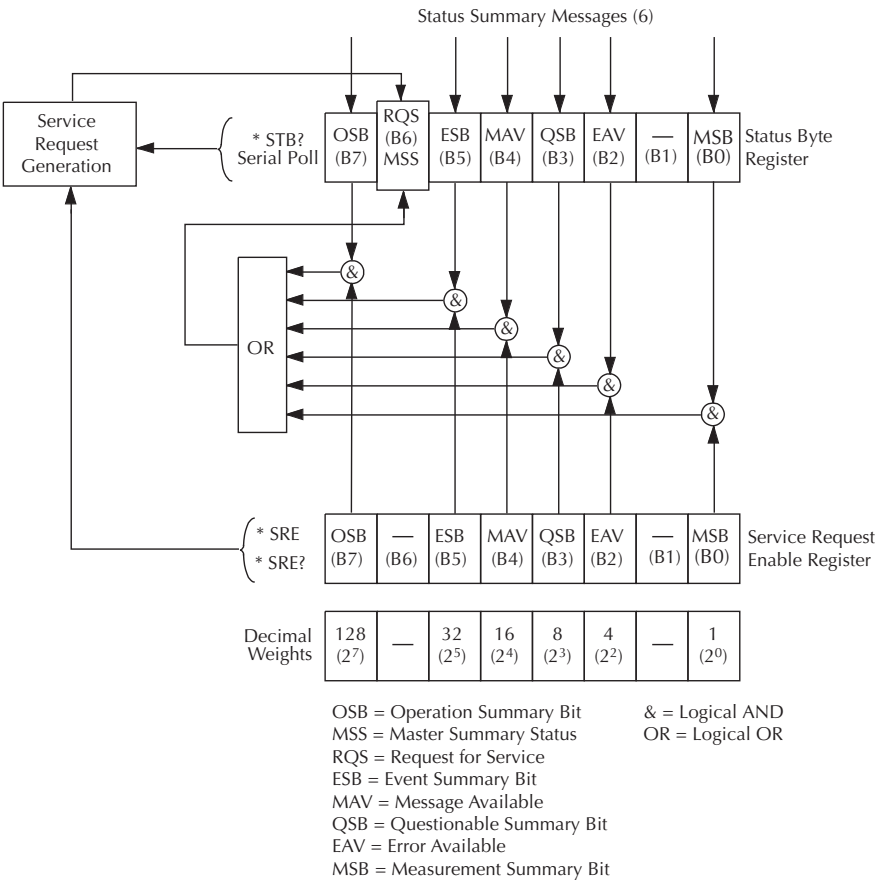
Table 10-2
SCPI command — data formats for reading status registers

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)

Service request is controlled by two 8-bit registers: the status byte register and the service request enable register. Figure 10-3 shows the structure of these registers.

Figure 10-3
Status byte and service request



Status byte register

The summary messages from the status registers and queues are used to set or clear the appropriate bits (B0, B2, B3, B4, B5, and B7) of the status byte register. These summary bits do not latch and their states (0 or 1) are solely dependent on the summary messages (0 or 1). For example, if the standard event register is read, its register will clear. As a result, its summary message will reset to 0, which in turn will reset the ESB bit in the status byte register.

The bits of the status byte register are described as follows:

- **Bit B0, measurement status (MSB)** — Set summary bit indicates that an enabled measurement event has occurred.
- **Bit B1** — Not used.
- **Bit B2, error available (EAV)** — Set summary bit indicates that an error or status message is present in the error queue.
- **Bit B3, questionable summary bit (QSB)** — Set summary bit indicates that an enabled questionable event has occurred.
- **Bit B4, message available (MAV)** — Set summary bit indicates that a response message is present in the output queue.
- **Bit B5, event summary bit (ESB)** — Set summary bit indicates that an enabled standard event has occurred.
- **Bit B6, request service (RQS)/master summary status (MSS)** — Set bit indicates that an enabled summary bit of the status byte register is set.
- **Bit B7, operation summary (OSB)** — Set summary bit indicates that an enabled operation event has occurred.

Depending on how it is used, bit B6 of the status byte register is either the request for service (RQS) bit or the master summary status (MSS) bit:

- When using the serial poll sequence of the Model 6487 to obtain the status byte (a.k.a. serial poll byte), B6 is the RQS bit. See [“Serial polling and SRQ,” page 10-9](#) for details on using the serial poll sequence.
- When using the *STB? command ([Table 10-3](#)) to read the status byte, B6 is the MSS bit.

Service request enable register

The generation of a service request is controlled by the service request enable register. This register is programmed by you and is used to enable or disable the setting of bit B6 (RQS/MSS) by the status summary message bits (B0, B2, B3, B4, B5, and B7) of the status byte register. As shown in [Figure 10-3](#), the summary bits are logically ANDed (&) with the corresponding enable bits of the service request enable register. When a set (1) summary bit is ANDed with an enabled (1) bit of the enable register, the logic “1” output is applied to the input of the OR gate and, therefore, sets the MSS/RQS bit in the status byte register.

The individual bits of the service request enable register can be set or cleared by using the *SRE common command. To read the service request enable register, use the *SRE? query command. The service request enable register clears when power is cycled or a parameter value of 0 is sent with the *SRE command (i.e. *SRE 0). The commands to program and read the SRQ enable register are listed in [Table 10-3](#).

Serial polling and SRQ

Any enabled event summary bit that goes from 0 to 1 will set bit B6 and generate an SRQ (service request). In your test program, you can periodically read the status byte to check if an SRQ has occurred and what caused it. If an SRQ occurs, the program can, for example, branch to an appropriate subroutine that will service the request.

Typically, SRQs are managed by the serial poll sequence of the Model 6487. If an SRQ does not occur, bit B6 (RQS) of the status byte register will remain cleared and the program will simply proceed normally after the serial poll is performed. If an SRQ does occur, bit B6 of the status byte register will set and the program can branch to a service subroutine when the SRQ is detected by the serial poll.

The serial poll automatically resets RQS of the status byte register. This allows subsequent serial polls to monitor bit B6 for an SRQ occurrence generated by other event types. After a serial poll, the same event can cause another SRQ, even if the event register that caused the first SRQ has not been cleared.

The serial poll does not clear MSS. The MSS bit stays set until all status byte summary bits are reset.

SPE, SPD (serial polling)

The SPE, SPD general bus command is used to serial poll the Model 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 [Table 10-3](#). For details on programming and reading registers, see [“Programming enable registers,” page 10-5](#) and [“Reading registers,” page 10-6](#).

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

Table 10-3
Common commands — status byte and service request enable registers

Command	Description	Default
*STB?	Read status byte register.	(Note)
*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.	

Note: *CLS and STATUS:PRESet have no effect on the service request enable register.

Programming example — set MSS (B6) when error occurs

The first command of the following sequence enables EAV (error available). When an invalid command is sent (line 4), bits B2 (EAV) and B6 (MSS) of the status byte register set to 1. The last command reads the status byte register using the binary format (which directly indicates which bits are set). The command to select format (FORMat:SREGister) is documented in [Table 10-2](#). To determine the exact nature of the error, you will have to read the error queue (see “[Queues](#),” [page 10-17](#)).

```
*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

As shown in [Figure 10-1](#), there are four status register sets in the status structure of the Model 6487: standard event status, operation event status, measurement event status, and questionable event status.

Register bit descriptions

Standard event status

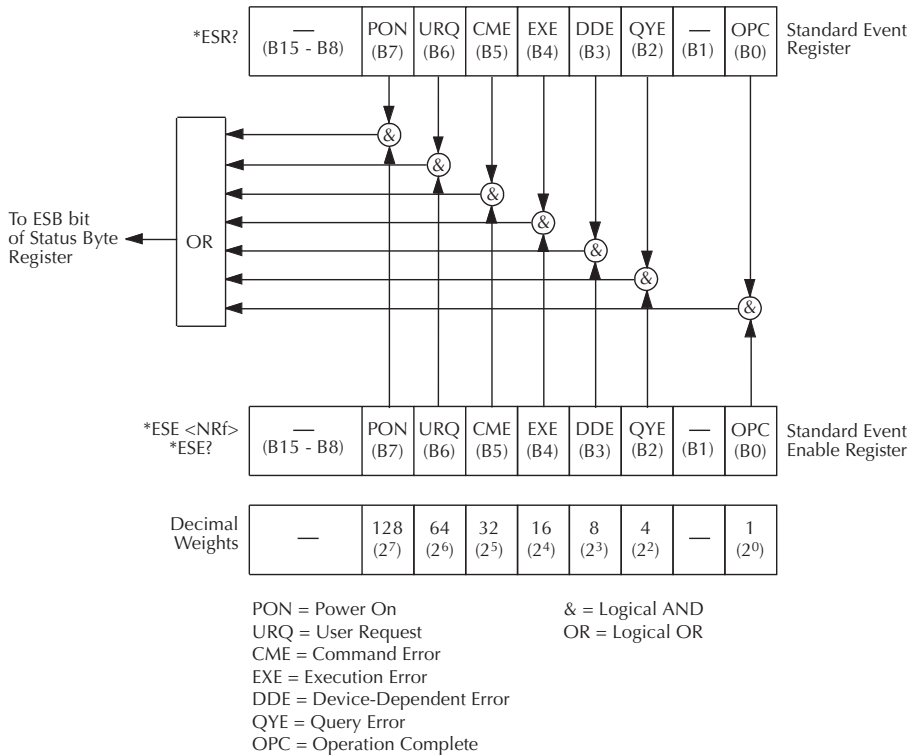
The used bits of the standard event register ([Figure 10-4](#)) are described as follows:

- **Bit B0, operation complete (OPC)** — Set bit indicates that all pending selected device operations are completed and the Model 6487 is ready to accept new commands. This bit only sets in response to the *OPC? query command. See [Section 11](#) for details on *OPC and *OPC?.
- **Bit B2, query error (QYE)** — Set bit indicates that you attempted to read data from an empty output queue.
- **Bit B3, device-dependent error (DDE)** — Set bit indicates that an instrument operation did not execute properly due to some internal condition.
- **Bit B4, execution error (EXE)** — Set bit indicates that the Model 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 Model 6487 received a message that does not follow the defined syntax of the IEEE-488.2 standard.
- Semantic error — The Model 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 10-4
Standard event status



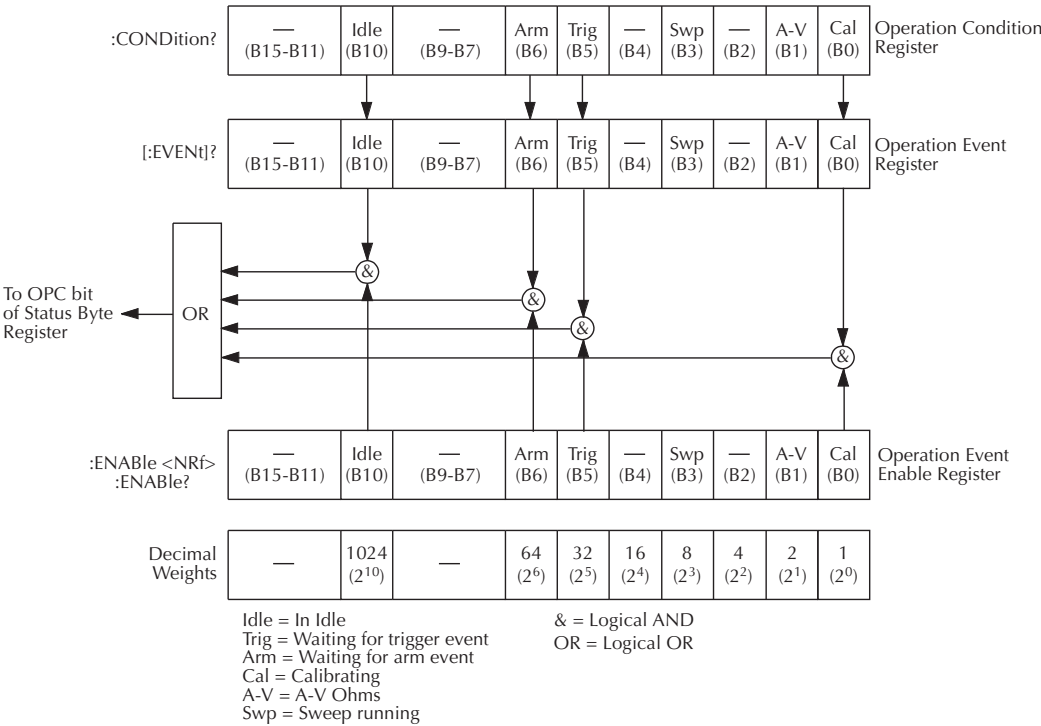
- **Bit B6, user request (URQ)** — Set bit indicates that the LOCAL key on the Model 6487 front panel was pressed.
- **Bit B7, power ON (PON)** — Set bit indicates that Model 6487 has been turned off and turned back on since the last time this register has been read.

Operation event status

The used bits of the operation event register (Figure 10-5) are described as follows:

- **Bit B0, calibrating (CAL)** — Set bit indicates that the Model 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 Model 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 Model 6487 is in the arm layer waiting for an arm event to occur.
- **Bit B10, idle state (Idle)** — Set bit indicates the Model 6487 is in the idle state.

Figure 10-5
Operation event status

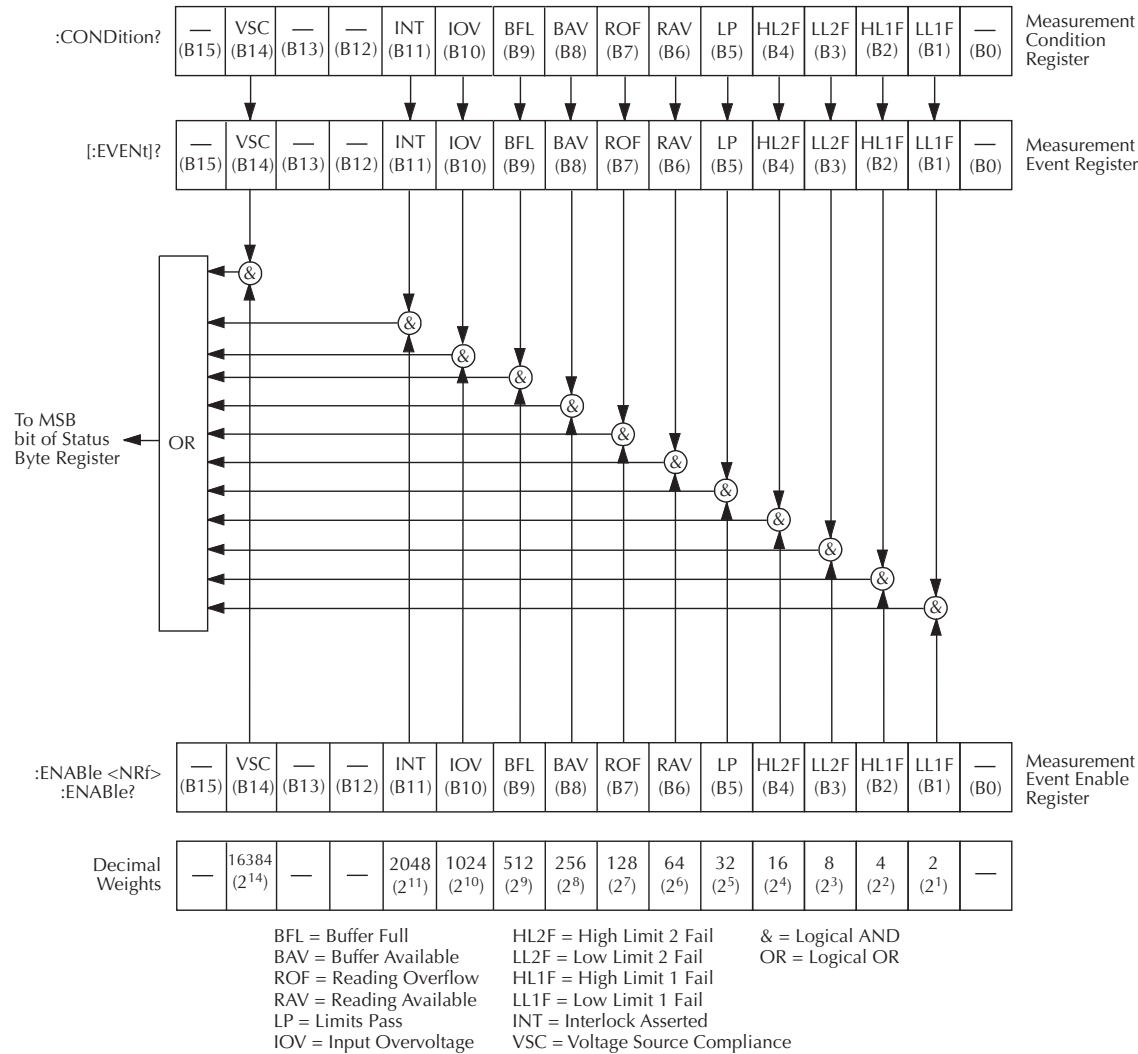


Measurement event status

The used bits of the measurement event register (Figure 10-6) are described as follows:

- **Bit B1, low limit 1 fail (LL1F)** — Set bit indicates that the low limit 1 test has failed.
- **Bit B2, high limit 1 fail (HL1F)** — Set bit indicates that the high limit 1 test has failed.

Figure 10-6
Measurement event status



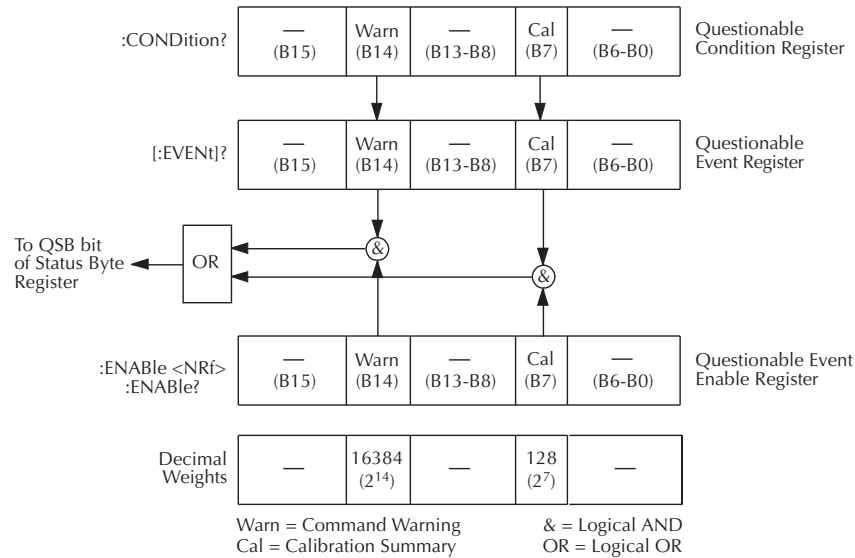
- **Bit B3, low limit 2 fail (LL2F)** — Set bit indicates that the low limit 2 test has failed.
- **Bit B4, high limit 2 fail (HL2F)** — Set bit indicates that the high limit 2 test has failed.
- **Bit B5, limits pass (LP)** — Set bit indicates that all limit tests passed.
- **Bit B6, reading available (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 Model 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 ([Section 6](#)), and if the programmed number of A-V ohms cycles have been taken ([Section 3](#)).
- **Bit B10, input overvoltage (IOV)** — Set bit indicates there is an input over voltage 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 used bits of the questionable event register ([Figure 10-7](#)) are described as follows:

- **Bit B7, calibration summary (Cal)** — Set bit indicates that an invalid calibration constant was detected during the power-up sequence. This error will clear after successful calibration of the Model 6487.
- **Bit B14, command warning (Warn)** — Set bit indicates that a signal oriented measurement command parameter has been ignored.

Figure 10-7
Questionable event status



Condition registers

As [Figure 10-1](#) shows, each status register set (except the standard event register set) has a condition register. A condition register is a real-time, read-only register that constantly updates to reflect the present operating conditions of the instrument. For example, while the Model 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 [Table 10-4](#). For details on reading registers, see [“Reading registers,” page 10-6](#).

Table 10-4

Common and SCPI commands — condition registers

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

As [Figure 10-1](#) shows, each status register set has an event register. When an event occurs, the appropriate event register bit sets to 1. The bit remains latched to 1 until the register is reset. Reading an event register clears the bits of that register. *CLS resets all four event registers.

The commands to read the event registers are listed in [Table 10-5](#). For details on reading registers, see “[Reading registers](#),” [page 10-6](#).

Table 10-5
Common and SCPI commands — event registers

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

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

Event enable registers

As [Figure 10-1](#) shows, each status register set has an enable register. Each event register bit is logically ANDed (&) to a corresponding enable bit of an enable register. Therefore, when an event bit is set and the corresponding enable bit is set (as programmed by the user), the output (summary) of the register will set to 1, which in turn sets the summary bit of the status byte register.

The commands to program and read the event enable registers are listed in [Table 10-6](#). For details on programming and reading registers, see “[Programming enable registers](#),” [page 10-5](#) and “[Reading registers](#),” [page 10-6](#).

NOTE *The bits of any enable register can be reset to 0 by sending the 0 parameter value with the appropriate enable command (i.e. STATus:OPERation:ENABle 0).*

Table 10-6
Common and SCPI commands — event enable registers

Command	Description
*ESE <NDN> or <NRf> *ESE?	Program standard event enable register (see “Parameters”). Read standard event enable register.
STATus :OPERation :ENABLE <NDN> or <NRf> :ENABLE? :MEASurement :ENABLE <NDN> or <NRf> :ENABLE? :QUESTionable :ENABLE <NDN> or <NRf> :ENABLE?	STATus subsystem: Operation event enable register: Program enable register (see “Parameters”). Read enable register. Measurement event enable register: Program enable register (see “Parameters”). Read enable register. Questionable event enable register: Program enable register (see “Parameters”). Read measurement event enable register.
Parameters: <NDN> = #Bxx...x Binary format (each x = 1 or 0) = #Hx Hexadecimal format (x = 0 to FFFF) = #Qx Octal format (x = 0 to 177777) <NRf> = 0 to 65535 Decimal format	

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

Programming example — program and read registers

This command sequence programs and reads the measurement registers. Registers are read using the binary format (which directly indicates which bits are set). The command to select format (FORMat:SREGister) is documented in [Table 10-2](#).

```
FORM:SREG BIN           ' Select binary format to read registers.
STAT:MEAS:ENAB 512      ' Enable BFL (buffer full).
STAT:MEAS:COND?         ' Read Measurement Condition Register.
STAT:MEAS?              ' Read Measurement Event Register.
```

Queues

The Model 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 Model 6487 status model ([Figure 10-1](#)) shows how the two queues are structured with the other registers.

Output queue

The output queue holds data that pertains to the normal operation of the instrument. For example, when a query command is sent, the response message is placed in the output queue.

When data is placed in the output queue, the message available (MAV) bit in the status byte register sets. A data message is cleared from the output queue when it is read. The output queue is considered cleared when it is empty. An empty output queue clears the MAV bit in the status byte register.

A message is read from the output queue by addressing the Model 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/status is placed in the error queue.

When a message is placed in the error queue, the error available (EAV) bit in the status byte register is set. An error/status message is cleared from the error queue when it is read. The error queue is considered cleared when it is empty. An empty error queue clears the EAV bit in the status byte register.

The error queue holds up to 10 error/status messages. The commands to read the error queue are listed in [Table 10-7](#). When you read a single message in the error queue, the “oldest” message is read and then removed from the queue. If the queue becomes full, the message “350, ‘queue overflow’” will occupy the last memory location. On power-up, the error queue is empty. When empty, the message “0, No Error” is placed in the queue.

Messages in the error queue are preceded by a code number. Negative (-) numbers are used for SCPI defined messages and positive (+) numbers are used for Keithley defined messages. The messages are listed in [Appendix B](#). As shown in [Table 10-7](#), there are commands to read the entire message (code and message) or the code only.

On power-up, all error messages are enabled and will go into the error queue as they occur. Status messages are not enabled and will not go into the queue. As listed in [Table 10-7](#), there are commands to enable and/or disable messages. For these commands, the <list> parameter is used to specify which messages to enable or disable. The messages are specified by their codes. The following examples show various forms for using the <list> parameter.

<list>	= (-110)	Single message
	= (-110:-222)	Range of messages (-110 through -222)
	= (-110:-222, -220)	Range entry and single entry (separated by a comma)

When you enable messages, messages not specified in the list are disabled. When you disable messages, each listed message is removed from the enabled list.

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

Table 10-7
SCPI commands — error queue

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.	(Note 1) (Note 2) (Note 2)
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).	(Note 1)

- Notes:
1. Power-up and *CLS empties the error queue. STATus:PRESet has no effect.
 2. Power-up enables error messages and disables status messages. *CLS and STATus:PRESet have no effect.

Programming example — read error queue

The following command reads the error queue:

```
STAT:QUE?           ' Read Error Queue.
```

11

Common Commands

- [Common commands](#) — This section lists and describes the common commands.

Common commands

Common commands (summarized in [Table 11-1](#)) are device commands that are common to all devices on the bus. These commands are designated and defined by the IEEE-488.2 standard.

Table 11-1

IEEE-488.2 common commands and queries

Mnemonic	Name	Description	Ref
*CLS	Clear status	Clears all event registers and error queue.	Section 10
*ESE <NRf>	Event enable command	Program the standard event enable register.	Section 10
*ESE?	Event enable query	Read the standard event enable register.	Section 10
*ESR?	Event status register query	Read the standard event enable register and clear it.	Section 10
*IDN?	Identification query	Returns the manufacturer, model number, serial number, and firmware revision levels of the unit.	A
*OPC	Operation complete command	Set the operation complete bit in the standard event register after all pending commands have been executed.	B
*OPC?	Operation complete query	Places an ASCII “1” into the output queue when all pending selected device operations have been completed.	B
*OPT?	Option query	Returns model number of any installed options.	
*RCL <NRf>	Recall command	Returns Model 6487 to the user-saved setup.	C
*RST	Reset command	Returns Model 6487 to the *RST default conditions.	D
*SAV <NRf>	Save command	Saves the present setup as the user-saved setup.	C
*SRE <NRf>	Service request enable command	Programs the service request enable register.	Section 10
*SRE?	Service request enable query	Reads the service request enable register.	Section 10
*STB?	Status byte query	Reads the status byte register.	Section 10
*TRG	Trigger command	Sends a bus trigger to Model 6487.	E
*TST?	Self-test query	Performs a checksum test on ROM and returns the result.	F
*WAI	Wait-to-continue command	Wait until all previous commands are executed.	G

A) IDN? — identification query

Reads identification code

The identification code includes the manufacturer, model number, serial number, and firmware revision levels and is sent in the following format:

KEITHLEY INSTRUMENTS INC., MODEL 6487, xxxxxxx, yyyy/zzzz/w

Where: xxxxxxx is the serial number.

yyyy/zzzz is the firmware revision levels of the digital board ROM and display board ROM. Note that yyyy also provides build date and time information. w is the board revision level.

B) OPC — operation complete

Sets OPC bit

OPC? — operation complete query

Places a “1” in output queue

When *OPC is sent, the OPC bit in the standard event register will set after all pending command operations are complete. When *OPC? is sent, an ASCII “1” is placed in the output queue after all pending command operations are complete.

Typically, either one of these commands is sent after the INITiate command. The INITiate command is used to take the instrument out of idle in order to perform measurements.

While operating within the trigger model layers, all sent commands (except DCL, SDC, IFC, SYSTem:PRESet, *RST, GET, and ABORt) will not execute.

After all programmed operations are completed, the instrument returns to the idle state at which time all pending commands (including *OPC and/or *OPC?) are executed. After the last pending command is executed, the OPC bit and/or an ASCII “1” is placed in the output queue.

Programming example — The following command sequence will perform 10 measurements. After the measurements are completed (in approximately 10 seconds), an ASCII “1” will be placed in the output queue.

*RST	' Return 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?.

C) SAV <NRf> — save	Save present setup in memory
RCL <NRf> — recall	Return to setup stored in memory

Parameters 0 = Memory location 0
 1 = Memory location 1
 2 = Memory location 2

Use the *SAV command to save the present instrument setup configuration in memory for later recall. Any control affected by *RST can be saved by the *SAV command. The *RCL command is used to restore the instrument to the saved setup configuration. Three setup configurations can be saved and recalled.

The Model 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.
```

D) RST — reset	Return Model 6487 to RST defaults
-----------------------	-----------------------------------

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

1. Returns Model 6487 to the RST default conditions (see “Default” column of SCPI tables).
2. Cancels all pending commands.
3. Cancels response to any previously received *OPC and *OPC? commands.

E) TRG — trigger	Send bus trigger to Model 6487
-------------------------	--------------------------------

Use the *TRG command to issue a GPIB trigger to the Model 6487. It has the same effect as a group execute trigger (GET).

Use the *TRG command as an event to control operation. The Model 6487 reacts to this trigger if BUS is the programmed arm control source. The control source is programmed from the TRIGger subsystem.

NOTE Details on triggering are covered in [Section 7](#).

Programming example — The following command sequence configures the Model 6487 to be controlled by bus triggers. The last line, which sends a bus trigger, triggers one measurement. Each subsequent bus trigger will also trigger a single measurement.

```
*RST          ' Restore RST defaults.
ARM:SOUR BUS  ' Select BUS control source.
ARM:COUN INF  ' Set arm layer count to infinite.
INIT          ' Take 6487 out of idle.
*TRG          ' Trigger one measurement.
```

F) TST? — self-test query Run self-test and read result

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

A returned value of zero (0) indicates that the test passed and a value of one (1) indicates that the test failed.

G) WAI — wait-to-continue Wait until previous commands are completed

Effectively, the *WAI command is a No-Op (no operation) for the Model 6487 and thus, does not need to be used.

Two types of device commands exist:

- Sequential commands — A command whose operations are allowed to finish before the next command is executed.
- Overlapped commands — A command that allows the execution of subsequent commands while device operations of the overlapped command are still in progress.

The *WAI command is used to suspend the execution of subsequent commands until the device operations of all previous overlapped commands are finished. The *WAI command is not needed for sequential commands.

SCPI Signal Oriented Measurement Commands

The signal oriented measurement commands are used to acquire readings. You can use these high level instructions to control the measurement process. These commands are summarized in [Table 12-1](#).

NOTE The readings acquired by these commands depend on which data elements are selected. (See Table 13-3 for details.)

Table 12-1

Signal oriented measurement command summary

Command	Description	Ref
CONFigure[:<function>]	Places Model 6487 in a “one-shot” measurement mode. <function> = CURR[:DC]	A
CONFigure?	Queries the selected function. Returns ‘CURR’.	
FETCh?	Requests the latest reading(s).	B
READ?	Performs an INITiate and a :FETCh?.	C
MEASure[:<function>]?	Performs a CONFigure:<function> and a :READ?.	D

A) CONFigure[:<function>] Configure Model 6487 for “one-shot” measurements
 <function> = CURRent[:DC] Configure current

This command configures the instrument for “one-shot” measurements. Each subsequent READ? command will then trigger a single measurement and acquire the reading (see READ? for details).

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

When this command is executed, the Model 6487 will be configured as follows:

- The specified function is selected.
- All controls related to the selected function are defaulted to the *RST values.
- The event control sources of the trigger model are set to immediate.
- The arm and trigger count values of the trigger model are set to one.
- The delay of the trigger model is set to zero.
- The Model 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.

Programming example — The following command sequence selects and configures the Model 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.
```

B) FETCh?

Request latest reading

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

This command does not trigger a measurement. The command simply requests the last group of readings. Note that this command can repeatedly return the same readings. Until there is a new reading(s), this command continues to return the old reading(s). If your application requires a “fresh” reading, use the :READ? command.

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

C) READ?

Trigger measurement(s) and request reading(s)

This command is used to trigger and acquire readings. The number of readings depends on how the trigger model is configured. For example, if configured for 20 measurements (arm count 1, trigger count 20), 20 sets of readings will be acquired.

When this command is sent, the following commands execute in the order they are presented:

- INITiate
- FETCh?

If the instrument is in the idle state, INITiate takes the instrument out of idle to perform the programmed number of measurements. If the instrument is not in the idle state, execution of this command will wait until it goes back into idle.

The FETCh? command is executed to acquire the reading(s). The readings are sent to the computer when the Model 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 abort the measurement process, and then use SENSE:DATA[:LATest]? to return the last (latest) reading.*

D) MEASure[:<function>]? Configure and perform “one-shot” measurement

<function> = CURRent[:DC] Measure current

This command combines all of the other signal oriented measurement commands to perform a “one-shot” measurement and acquire the reading.

When this command is sent, the following commands execute in the order that they are presented.

- CONFigure:<function>
- READ?

When :CONFigure is executed, the instrument goes into a “one-shot” measurement mode. See CONFigure for details.

When READ? is executed, its operations will then be performed. In general, an INITiate is executed to perform the measurement and a FETCh? is executed to acquire the reading. See :READ? for details.

13

DISPlay, FORMat, and SYSTem

- **DISPlay subsystem** — Covers the SCPI commands that are used to control the display.
- **FORMat subsystem** — Covers the SCPI commands to configure the format that readings are sent over the bus.
- **SYSTem subsystem** — Covers miscellaneous SCPI commands.

DISPlay subsystem

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

Table 13-1

SCPI commands — *display*

Command	Description	Default	Ref
:DISPlay :DIGits <n>	Set display resolution: 4 to 7.	6	Section 4
:DIGits?	Query display resolution.		
:ENABle 	Turn front panel display on or off.	(see Note)	A
:ENABle?	Query front panel display status.		
[:WINDow[1]] :TEXT	Path to control user text messages:	(see Note)	
[:DATA] <a>	Define ASCII message “a” (up to 12 characters).		B
[:DATA]?	Query defined ASCII message.		
:STATe 	Enable or disable text message mode.		C

Note: *RST and SYSTem:PRESet have no effect on the display circuitry and user-defined text messages.

A) DISPlay:ENABle

With front panel circuitry turned off, the instrument operates at a higher speed. While disabled, the display is frozen and all front panel controls (except LOCAL) are disabled. Normal display operations can be resumed by using :ENABle to enable the display, pressing the LOCAL key, or cycling power.

B) DISPlay:TEXT[:DATA] <a>

Message Types:	String	'aa...a' or "aa...a"
	Indefinite Block	#0aa...a
	Definite Block	#XYaa...a

where: Y = number of characters in message (up to 12)

X = number of digits that make up Y (1 or 2)

The display message can be up to 12 characters (ASCII) long. A space is counted as a character. Excess message characters result in an error. Note that for the string type, the message must be enclosed by single or double quotes.

An indefinite block message must be the only command in the program message or the last command in the program message. If you include a command after an indefinite block message (on the same line), it will be treated as part of the message and is displayed instead of executed.

**C) DISPlay:TEXT:STATe **

When the text message mode is enabled, a defined message is displayed. When disabled, the message is removed from the display.

GPIB operation — A user-defined message remains displayed only as long as the instrument is in remote. Taking the instrument out of remote (by pressing LOCAL or sending the GTL (go to local) command) or cycling power cancels the message and disables the text message mode.

RS-232 operation — A user-defined message can be cancelled by sending SYSTem:LOCal, pressing LOCAL, or cycling power.

FORMat subsystem

The commands in this subsystem are used to select the format for transferring data over the bus.

Table 13-2
SCPI commands — data format

Command	Description	Default	Ref
:FORMat			
:DATA <type>[,<length>]	Specify data format: ASCii, REAL, 32 or SREal.	ASCii	A
:DATA?	Query data format.		
:ELEMents <item list>	Specify data elements: READing, UNITS, VSource, TIME, STATus, DEFault, and ALL.	All except VSO	B
:BORDER <name>	Specify byte order: NORMal or SWAPped.	(see Note)	C
:BORDER?	Query byte order.		
:SREGister <name>	Select data format for reading status registers: ASCii, HEXadecimal, OCTal, or BINary.	ASC	Section 10
:SREGister?	Query data format for reading status registers.		
:SOURce2 <name>	Select data format for reading output patterns: ASCii, HEXadecimal, OCTal, or BINary.	ASC	Section 8
:SOURce2?	Query data format for output patterns.		

Note: *RST default is NORMal. SYSTem:PRESet default is SWAPped.

A) FORMat:DATA <type>[,<length>]

Parameters ASCii = ASCII format
 REAL, 32 = Binary IEEE-754 single precision format
 SREal = Binary IEEE-754 single precision format

NOTE <length> is not used for the ASCii or SREal parameters. It is optional for the REAL parameter. If you do not use <length> with REAL, <length> defaults to 32 (single precision format). The double precision format (<length> = 64) is not supported by Model 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.

Over the RS-232 interface, only the ASCII format is allowed.

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

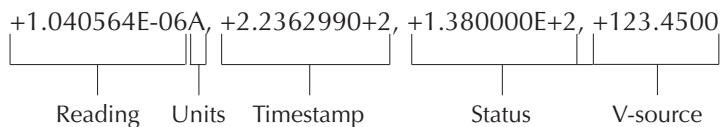
ASCII data format

The ASCII data format is in a direct readable form for the operator. Most programming languages easily convert ASCII mantissa and exponent to other formats. However, some speed is compromised to accommodate the conversion. [Figure 13-1](#) shows an example ASCII string that includes all the data elements. See :ELEMents for information on the data elements.

[Figure 13-1](#) also shows the byte order of the data string. Data elements not specified by the :ELEMents command are simply not included in the string. Note that the status value is always an integer, but it is still expressed in scientific notation.

Figure 13-1

ASCII data format



B) 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 (i.e. send “:ELEMents READing, UNITs, TIME”) to include the reading with units and the time elements in the data string. The elements for the ASCii, ALL format in the order sent are shown in [Figure 13-1](#). Note that elements are delimited with commas.

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 Model 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 (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.

Example — The ASCII data string on [page 13-5](#) contains all four data elements. The status value of 138 has a binary equivalent of 01001010, which indicates that bits B1, B3, and B7 are set. Therefore, the reading is 1.04056 μ A with null (REL) and the AVG filter enabled. The reading was taken 223.6299 seconds after the instrument was turned on. The voltage source was on and set to +123.45V.

C) FORMat:BORDER <name>

Parameters NORMAL = Normal byte order for IEEE-754 binary format
 SWAPped = Reverse byte order for IEEE-754 binary format

For normal byte order, the data format for each element is sent as follows:

Byte 1	Byte 2	Byte 3	Byte 4
--------	--------	--------	--------

For reverse byte order, data is sent as follows:

Byte 4	Byte 3	Byte 2	Byte 1
--------	--------	--------	--------

The “#0” header is not affected by this command. The header is always sent at the beginning of the data string for each measurement conversion.

The ASCII data format can only be sent in the normal byte order. The SWAPped selection is ignored when the ASCII format is selected.

NOTE *The SWAPped byte order must be used when transmitting binary data to any IBM PC.*

SYSTem subsystem

Table 13-3

SCPI commands — system

Command	Description	Default	Ref
:SYSTem			
:ZCheck [:STATe] [:STATe]?	Zero check: Enable or disable zero check. Query zero check state.	ON	Section 3
:ZCORrect [:STATe] [:STATe]?	Zero correct: Enable or disable zero correct. Query zero correct state.	OFF	Section 3
:ACQuire	Acquire a new zero correct value. ¹		
:PRESet	Return to SYSTem:PRESet defaults.		A
:LFRequency <freq> :LFRequency?	Select power line frequency: 50 or 60 (Hz). Query power line frequency		Section 1
:AUTO [:STATe] [:STATe]?	Path to control auto line frequency selection. Turn automatic line frequency ON or OFF. Query automatic line frequency state.		
:AZERo [:STATe] [:STATe]?	Path to control autozero: Enable or disable autozero. Query autozero state.	ON	Section 3
:TIME :RESet	Timestamp: Reset timestamp to 0 seconds.		B
:POSetup <name> :POSetup?	Select power-on setup; RST, PRESet, or SAV0-2 Query power-on setup.		C
:VERSIon?	Query SCPI revision level.		D
:ERRor [:NEXT]?	Read messages in error queue: Return and clear oldest error (code and message).	Note ²	Section 10
:ALL?	Return and clear all errors (code and message).		
:COUNt?	Return the number of errors.		
:CODE [:NEXT]?	Error code numbers only: Return and clear oldest error (code only).		
:ALL?	Return and clear all errors (codes only).		

Table 13-3 (cont.)

SCPI commands — system

Command	Description	Default	Ref
:SYSTem			
:CLEar	Clear messages from error queue.		Section 10 E
:KEY <NRf>	Simulate key-press.		
:KEY?	Query last key pressed.		
	<i>RS-232 interface:</i>		Section 9
:LOCal	Take Model 6487 out of remote (RS-232 only). Equivalent to GTL.		
:REMote	Put Model 6487 in remote (RS-232 only). Equivalent to REN.		
:RWLock	Enable local lockout (RS-232 only). Equivalent to LLO.		Section 9
: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.		

1. ZCH:STAT must be ON and ZCOR:STAT must be OFF in order to acquire a new zero correct value.
2. Clearing the error queue - power-up and *CLS clears the error queue. *RST, SYSTem:PRESet, and STATus:PRESet have no effect on the error queue.

A) SYSTem:PRESet

Returns the instrument to states optimized for front panel operation. SYSTem:PRESet defaults are listed in the SCPI tables in [Section 14](#).

B) SYSTem:TIME:RESet

Resets the absolute timestamp to 0 seconds. The timestamp also resets when power is cycled or after the instrument is on for 99,999.99 seconds. The TRACe:TSTamp:FORMat command is used to select the absolute timestamp. See the Model 6487 User's Manual for details.

C) SYSTem:POSetup <name>

Parameters	RST	Power-up to *RST defaults
	PRESet	Power-up to SYSTem:PRESet defaults
	SAVx	Power-up to setup stored in memory (x = memory location 0, 1, or 2)

The *RST and SYSTem:DEFaults are listed in the SCPI tables in the [Section 14](#). A setup is saved in memory using the *SAV command. See [Section 11](#) (Common Commands) for details.

D) SYSTem:VERSion

Read the version of the SCPI standard being used by Model 6487. Example response message: 1996.0.

E) 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 following command to simulate pressing the “MATH” key: SYSTem:KEY 3. 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 Model 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, not LOCAL. To place the instrument in the local state, send the GTL command as described in [Section 9](#).

14

SCPI Reference Tables

- [Table 14-1](#) — CALCulate command summary
- [Table 14-2](#) — DISPlay command summary
- [Table 14-3](#) — FORMat command summary
- [Table 14-4](#) — SENSE command summary
- [Table 14-5](#) — SOURce command summary
- [Table 14-6](#) — STATus command summary
- [Table 14-7](#) — SYSTem command summary
- [Table 14-8](#) — TRACe command summary
- [Table 14-9](#) — TRIGger command summary
- “Calibration commands” — See [Appendix F, Table F-1 on page F-2](#).

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.
- Uppercase characters indicated the short-form version for each command word.
- Default parameter — Listed parameters are both the *RST and SYSTem:PRESet defaults, unless noted otherwise. Parameter notes are located at the end of each table.
- Ref — Refers you to the section (Sec) that provides operation information for that command or command subsystem.
- SCPI — A checkmark (✓) indicates that the command and its parameters are SCPI confirmed. An unmarked command indicates that it is a SCPI command, but does not conform to the SCPI standard set of commands. It is not a recognized command by the SCPI consortium. SCPI confirmed commands that use one or more non-SCPI parameters are explained by notes.

Table 14-1

CALCulate command summary

Command	Description	Default parameter	Ref Section	SCPI
:CALCulate[1]	Path to configure and control CALC1 calculations.		5	✓
:FORMat <name>	Select math format; MXB (mX+b), RECiprocal (m/X+b), or LOG10.	MXB		✓
:FORMat?	Query math format.			✓
:KMATH	Configure math calculations:			
:MMFactor <NRf>	Set “m” for mX+b and m/X+b calculation: -9.99999e20 to 9.99999e20.	1.0		
:MMFactor?	Query “m” factor.			
:MA1Factor <NRf>	Set “m” for mX+b and m/X+b calculation (same as MMFactor).	1.0		
:MA1Factor?	Query “m” factor (same as MMFactor?).			
:MBFactor <NRf>	Set “b” for mX+b and m/X+b calculation: -9.99999e20 to 9.99999e20.	0.0		
:MBFactor?	Query “b” factor.			

Table 14-1 (cont.)

CALCulate command summary

Command	Description	Default parameter	Ref Section	SCPI
:CALCulate[1]			5	
:KMAth				
:MA0Factor <NRf>	Set “b” for $mX+b$ and $m/X+b$ calculation (same as MBFactor).	1.0		
:MA0Factor?	Query “b” factor (same as MBFactor?).			
:MUNits <name>	Specify units for $mX+b$ or $m/X+b$ result: 1 character: A–Z, [‘=Ω, ‘\’=°, ‘]’=%.	“X”		
:MUNits?	Query units.			
:STATe 	Enable or disable CALC1 calculation.	OFF		√
:STATe?	Query state of CALC1 calculation.			√
:DATA?	Return all CALC1 results triggered by INITiate.			√
:LATest?	Return last (latest) reading.			
:CALCulate2	Path to configure and control limit testing (CALC2):		8	√
:FEED <name>	Select input path for limit testing: CALCulate[1] or SENSE[1].	SENS		√
:FEED?	Query input path for limit tests.			√
:LIMit[1]	Limit 1 Testing:			√
:UPPer	Configure upper limit:			√
[:DATA] <n>	Set limit: -9.99999e20 to 9.99999e20.	1.0		√
[:DATA]?	Query upper limit.			√
:SOURce2 <NDN> or <NRf>	Specify 4-bit I/O “fail” pattern (0 to 15).	15	(see note)	√
:SOURce2?	Query output pattern value.			√
:LOWer	Configure lower limit:			√
[:DATA] <n>	Set limit: -9.99999e20 to 9.99999e20.	-1.0		√
[:DATA]?	Query lower limit.			√
:SOURce2 <NDN> or <NRf>	Specify 4-bit I/O “fail” pattern (0 to 15).	15	(see note)	√

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)

Table 14-1 (cont.)

CALCulate command summary

Command	Description	Default parameter	Ref Section	SCPI
:SOURce2?	Query output pattern value.			√
:STATe 	Enable or disable limit 1 test.	OFF		√
:STATe?	Query state of limit 1 test.			√
:FAIL?	Return result of limit 1 test: 0 (pass) or 1 (fail).			√
:CALCulate2			8	
:LIMit2	Limit 2 Testing:			√
:UPPer	Configure upper limit:			√
[:DATA] <n>	Set limit: -9.99999e20 to 9.99999e20.	1.0		√
[:DATA]?	Query upper limit.			√
:SOURce2 <NDN> or <NRf>	Specify 4-bit I/O “fail” pattern (0 to 15).	15	(see note)	√
:SOURce2?	Query output pattern value.			√
:LOWer	Configure lower limit:			√
[:DATA] <n>	Set limit; -9.99999e20 to 9.99999e20.	-1.0		√
[:DATA]?	Query lower limit.			√
:SOURce2 <NDN> or <NRf>	Specify 4-bit I/O “fail” pattern (0 to 15).	15	(see note)	√
: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 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)

Table 14-1 (cont.)
CALCulate command summary

Command	Description	Default parameter	Ref Section	SCPI
:SOURce2 <NDN> or <NRf>	Set 4-bit “pass” pattern.	15	(see note)	
:SOURce2?	Query output bit pattern.			
:DATA?	Return all CALC2 readings triggered by INI-Tiate.			√
:LATest?	Return only the last (latest) reading.			
:NULL	Configure and control Rel:		5	√
:ACQuire	Use input signal as Rel value.			
:OFFSet <NRf>	Specify Rel value: -9.999999e20 to 9.999999e20.	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:		6	√
: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>= #Bxxx Binary format (each x = 1 or 0)
= #Hx Hexadecimal format (x = 0 to F)
= #Qxx Octal format (x = 0 to 17)

Table 14-2

DISPlay command summary

Command	Description	Default parameter	Ref Section	SCPI
:DISPlay			13	
:DIGits <n>	Set display resolution: 4 to 7.	6	4	
:DIGits?	Query display resolution.			
:ENABLE 	Turn front panel display on or off.	(Note 1)		√
:ENABLE?	Query display state.			√
[:WINDow[1]]	Path to control user text messages:			√
:TEXT		(Note 2)		√
[:DATA] <a>	Define ASCII message “a” (up to 12 characters).			√
[:DATA]?	Read text message.			√
:STATe 	Enable or disable text message mode.	(Note 3)		√
:STATe?	Query state of text message mode.			√

Notes:

1. *RST and SYSTem:PRESet have no effect on the display circuitry. Pressing LOCAL or cycling power enables (ON) the display circuit.
2. *RST and SYSTem:PRESet have no effect on a user-defined message. Pressing LOCAL or cycling power cancels all user-defined messages.
3. *RST and SYSTem:PRESet have no effect on the state of the message mode. Pressing LOCAL or cycling power disables (OFF) the message mode.

Table 14-3

FORMat command summary

Command	Description	Default parameter	Ref Section	SCPI
:FORMat			13	
[[:DATA] <type>[,<length>]	Specify data format; ASCii, REAL, 32, or SREal.	ASC		√
[[:DATA]?]	Query data format.			√
:ELEMents <item list>	Specify data elements; READING, UNITS, VSource, TIME, STATUS, DEFault, and ALL.	All except VSO		
:ELEMents?	Query data format elements.			
:BORDER <name>	Specify byte order; NORMAl or SWAPped.	(see Note)		√
:BORDER?	Query byte order.			√
:SREGister <name>	Select data format for reading status registers; ASCii, HEXadecimal, OCTal, or BINary.	ASC		
:SREGister?	Query format for reading event registers.			
:SOURce2 <name>	Select data format for reading output patterns: ASCii, HEXadecimal, OCTal, or BINary.	ASC		
:SOURce2?	Query data format for output patterns.			

Note: *RST default is NORMAl. SYSTem:PRESet default is SWAPped.

Table 14-4

SENSe command summary

Command	Description	Default parameter	Ref. Section	SCPI
[[:SENSe[1]] [:FUNCTION][:<name>]	Select measure function: <name> = 'CURRENT[:DC]'	'CURR'		
:DATA	Path to return instrument readings:		3	√
[:LATest]?]	Return the last instrument reading.			√
[[:CURRENT[:DC]] :NPLCycles <NRf>	Path to configure amps function: Set integration rate in line cycles (PLC): 0.01 to 60.0 (60 Hz) or 50.0 (50Hz).	6 (60Hz) 5 (50Hz)	4	√ √
:NPLCycles?	Query NPLC.			√

Table 14-4 (cont.)

SENSe command summary

Command	Description	Default parameter	Ref. Section	SCPI
<i>[[:DAMPing]</i>				
:OHMS	Path to control ohms:		3	
[:STATe] 	Enable or disable ohms for SENSe1 data.	OFF		
[:STATe]?	Query ohms SENSe1 data state.			
:AVOLtage	Path to A-V ohms commands:		3	
[: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).	10V		
:VOLTage?	Query high voltage value.			
:TIME <NRf>	Set time interval for each phase.	15s*		
: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.			

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

Table 14-5

SOURCE command summary

Command	Description	Default parameter	Ref. Section	SCPI
:SOURCE[1] :VOLTage [:LEVel] [:IMMediate] [:AMPLitude] <NRf> [:AMPLitude]? :RANGe <NRf> :ILIMit <NRf> :STATe :STATe? :INTERlock [:STATe] [:STATe]? :FAIL?	SOURCE1 subsystem: Path to voltage source commands. Set voltage source amplitude (-500 to 500). ¹ Query voltage source amplitude. Set source range (10, 50, or 500[V]). Set source current limit (2.5e-5 to 2.5e-2[A]). ³ Enable or disable source output. ⁴ Query source output state. Path to control interlock: Enable or disable interlock for 10V range. ⁵ Query interlock state. ⁶ Query interlock status (1 = interlock asserted). ⁷	0 10 ² 2.5e-2 OFF OFF	3	

¹. If voltage source is in operate, value will be updated immediately. Value cannot be set above voltage source range.

². Default for DDC mode (see [Appendix C](#)) is 50V.

³. Limit settings are: 25μA, 250μA, 2.5mA, and 25mA; current limit will be set to closest programmed value. For the 500V and the 50V ranges, the maximum ILIMit is 2.5mA (0.0025A). On the 10V range, any of the four current limit choices can be selected. The default 10V ILimit is 25mA or 2.5mA in DDC mode (see [Appendix C](#)).

⁴. STATe ON places source in operate.

⁵. Ignored for 50V and 500V ranges since interlock is always enabled. Attempting to turn off the interlock state while on the 50 or 500V range will generate a “-221 Settings Conflict” error. Upranging from the 10V 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 10V range.

⁶. Querying the interlock state while on the 50V or 500V range will always return TRUE.

⁷. Asserted interlock indicates that voltage source cannot be placed in operate.

Table 14-5 (cont.)

SOURce command summary

Command	Description	Default parameter	Ref. Section	SCPI
:SOURce[1] :VOLTage				
:SWEep	Sweep commands:		6	
:START <NRf>	Program start voltage: -505V to 505V.	0V		
:START?	Query start voltage.			
:STOP <NRf>	Program stop voltage: -505V to 505V.	10V		
:STOP?	Query stop voltage.			
:STEP <NRf>	Program step voltage: -505V to 505V.	1V		
:STEP?	Query step voltage.			
:CENTer <NRf>	Program center voltage: -505V to 505V.	5V		
:CENTer?	Query center voltage.			
:SPAN <NRf>	Program span voltage: -505V to 505V.	10V		
:SPAN?	Query span voltage.			
:DELay <NRf>	Set delay: 0 to 999.9999s.	1s		
:DELay?	Query delay.			
:INITiate	Arm sweep, put source in operate.			
:ABORT	Abort sweep, put source in standby.			
:STATe?	Query if sweep running: 1 = sweep in progress.			
:SOURce2	Path to control Digital I/O port:		8	
:TTL	Set I/O port value directly:			
[:LEVel] <NRf> or <NDN>	Specify 4-bit Digital I/O pattern (0 to 15).	15	(see note)	
[:LEVel]?	Query output value.			
:CLEar	Clear I/O port (return output to TTL value).			
[:IMMediate]	Clear I/O port immediately.			
:AUTO 	Enable or disable auto-clear.	OFF		

SOURce2 parameter values:

<NRf> = 0 to 15 Decimal format

<NDN> = #Bxxx Binary format (each x = 1 or 0)

= #Hx Hexadecimal format (x = 0 to F)

= #Qxx Octal format (x = 0 to 17)

Table 14-5 (cont.)

SOURce command summary

Command	Description	Default parameter	Ref. Section	SCPI
:AUTO?	Query auto-clear state.			
:DELaY <n>	Specify delay (pulse width) for pass/fail pattern: 0 to 60 (sec).	0.0001		
:DELaY?	Query delay value.			
:TTL4	Line 4 mode configuration:			
:MODE <name>	Select output line 4 mode: EOTest or BUSY.	EOT		
:MODE?	Query line 4 mode.			
:BSTate 	Select active TTL level for busy: 1 = ON or 0 = OFF.	0		
:BSTATe?	Query active busy TTL level.			

Table 14-6

STATus command summary

Command	Description	Default parameter	Ref Section	SCPI
:STATus		(Note 1)	10	√
:MEASurement	Measurement event registers:			
[:EVENTt]?	Read the event register.	(Note 2)		
:ENABle <NDN> or <NRf>	Program the enable register.	(Note 3)		
:ENABle?	Read the enable register.			
:CONDition?	Read the condition register.			
:STATus				
:OPERation	Operation event registers:			√
[:EVENTt]?	Read the event register.	(Note 2)		√
:ENABle <NDN> or <NRf>	Program the enable register.	(Note 3)		√
:ENABle?	Read the enable register.			√
:CONDition?	Read the condition register.			√
:QUESTionable	Questionable event registers:			√
[:EVENTt]?	Read the event register.	(Note 2)		√
:ENABle <NDN> or <NRf>	Program the enable register.	(Note 3)		√
:ENABle?	Read the enable register.			√
:CONDition?	Read the condition register.			√
:PRESet	Return status registers to default states.			√
:QUEue	Read error queue:			√
[:NEXT]?	Read and clear oldest error/status (code and message).	(Note 4)		√
:ENABle <list>	Specify error and status messages for error queue.	(Note 5)		√
:ENABle?	Read the enabled messages.			√

Notes:

1. Commands in this subsystem are not affected by *RST or SYSTem:PRESet. The effects of cycling power, *CLS and STATus:PRESet are explained by the following notes.
2. Event registers — Power-up and *CLS clears all bits. STATus:PRESet has no effect.
3. Enable registers — Power-up and STATus:PRESet clears all bits. *CLS has no effect.
4. Error queue — Power-up and *CLS empties the error queue. STATus:PRESet has no effect.
5. Error queue messages — Power-up enables error messages and disables status messages. *CLS and STATus:PRESet have no effect.

Table 14-6 (cont.)
STATus command summary

Command	Description	Default parameter	Ref Section	SCPI
:DISable <list>	Specify messages not to be placed in queue.	(Note 5)		
:DISable?	Read the disabled messages.			
:CLEar	Clear messages from error queue.			
<i>Parameters:</i>				
<NDN> = #Bxx...x	Binary format (each x = 1 or 0)			
= #Hx	Hexadecimal format (x = 0 to FFFF)			
= #Qx	Octal format (x = 0 to 177777)			
<NRf> = 0 to 65535	Decimal format			
<list> = (100:200, -224)	Example of a range and single entry (+100 through +200 and -224).			

- Notes:
1. Commands in this subsystem are not affected by *RST or SYSTem:PRESet. The effects of cycling power, *CLS, and STATus:PRESet are explained by the following notes.
 2. Event registers — Power-up and *CLS clears all bits. STATus:PRESet has no effect.
 3. Enable registers — Power-up and STATus:PRESet clears all bits. *CLS has no effect.
 4. Error queue — Power-up and *CLS empties the error queue. STATus:PRESet has no effect.
 5. Error queue messages — Power-up enables error messages and disables status messages. *CLS and STATus:PRESet have no effect.

Table 14-7

SYSTem command summary (see [Section 13](#) for detailed information)

Command	Description	Default parameter	Ref Section	SCPI
:SYSTem			13	
:ZCheck	Zero check:		3	
[:STATe] 	Enable or disable zero check.	ON		
[:STATe]?	Query state of zero check.			
:ZCORrect	Zero correct:		3	
[:STATe] 	Enable or disable zero correct.	OFF		
[:STATe]?	Query state of zero correct.			
:ACQuire	Acquire a new zero correct value. *			
:PRESet	Return to SYSTem:PRESet defaults.			√
:LFRequency <freq>	Select power line frequency: 50 or 60 (Hz).	60	1	
:LFRequency?	Query frequency setting.			
:AUTO	Path to control auto frequency.			
[:STATe] 	Enable or disable auto frequency.	ON		
[:STATe]?	Query state of auto frequency.			
:AZERo	Path to control autozero:		3	√
[:STATe] 	Enable or disable autozero.	ON		√
[:STATe]?	Query state of autozero.			√
:TIME	Timestamp:			
:RESet	Reset timestamp to 0 seconds.			
:POSetup <name>	Select power-on setup: RST, PRESet, or SAV _x (where x = 0 – 2).	PRES		
:POSetup?	Query power-on setup.			
:VERSion?	Query SCPI revision level.			√
:ERRor	Read error queue:	(see note)	10	√
[:NEXT]?	Read and clear oldest error/status (code and message).			
:ALL?	Read and clear all errors/status (code and message).			

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

Note: Clearing the error queue – Power-up and *CLS clears the error queue. *RST, SYSTem:PRESet, and STATus:PRESet have no effect on the error queue.

Table 14-7 (cont.)

SYSTEM command summary (see [Section 13](#) for detailed information)

Command	Description	Default parameter	Ref Section	SCPI
:COUNT?	Read the number of messages in queue.			
:CODE	Code numbers only:			
[:NEXT]?	Read and clear oldest error/status (code only).			
:ALL?	Read and clear all errors/status (codes only).			
:SYSTEM:				
:CLEAR	Clear messages from error queue.		10	
:KEY <Nrf>	Simulate key-press.			√
:KEY?	Query the last “pressed” key.			√
	<i>RS-232 interface:</i>		9	
:LOCAL	While in LLO, removes the LLO and places the Model 6487 in local (RS-232 only).			
:REMOTE	Places the Model 6487 in remote if not in LLO (RS-232 only).			
:RWLOCK	Places the Model 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	9	
:KLOCK?	Query key lock state.			

Table 14-8

TRACe command summary

Command	Description	Default parameter	Ref Section	SCPI
:TRACel:DATA	Use :TRACe or :DATA as root command.	Note ¹	6	√
: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.			

¹. SYSTem:PRESet and *RST have no effect on the commands in this subsystem. The listed defaults are power-on defaults.

². Readings come from A-V ohms buffer if available; normal buffer readings otherwise.

Table 14-9

TRIGger command summary

Command	Description	Default parameter	Ref Section	SCPI
:INITiate	Path to initiate measurement cycle(s):		7	√
[:IMMediate]	Initiate one trigger cycle.			√
:ABORt	Reset trigger system (goes to idle state).			√
:ARM[:SEquence[1]]	Path to configure arm layer:			√
[:LAYer[1]]				
:SOURce <name>	Select control source: IMMediate, TIMer, BUS, TLINk, MANual, PSTest, NSTest, or BSTest.	IMM		√
:SOURce?	Query arm control source.			√
:COUNT <n>	Set measure count: 1 to 2048 or INF (infinite).	1 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.			

¹. *RST default is 1. SYST:PRES default is INF.

Table 14-9 (cont.)

TRIGger command summary

Command	Description	Default parameter	Ref Section	SCPI
:TRIGger	Trigger layer:		7	√
:CLEar	Clear pending input trigger immediately.			
[: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.			

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Performance Verification

- **Verification test requirements** — Summarizes environmental conditions, warm-up period, and line power requirements.
- **Recommended test equipment** — Lists all equipment necessary for verification and gives pertinent specifications.
- **Verification limits** — Describes how reading limits are calculated and gives an example.
- **Calibrator voltage calculations** — Details the method for calculating calibrator voltages when testing the 2nA to 2 μ A ranges.
- **Performing the verification test procedures** — Summarizes test considerations and describes how to restore factory defaults.
- **Offset voltage calibration** — Lists steps necessary to null voltage offset before performing verification.
- **Current measurement accuracy** — Lists detailed steps for verifying measurement accuracy of all current ranges. The 2nA to 2 μ A and 20 μ A to 20mA ranges are covered separately because of the different test equipment required.
- **Voltage source output accuracy** — Summarizes the method to test voltage source output accuracy.

Introduction

Use the procedures in this section to verify that Model 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 your Keithley representative or the factory to determine the correct course of action. Refer to [Section 16](#) for calibration procedures.*

Verification test requirements

Be sure that you perform the verification tests:

- Under the proper environmental conditions.
- After the specified warm-up period.
- Using the correct line voltage.
- Using the proper test equipment.
- Using the specified test signals and reading limits.

Environmental conditions

Conduct your performance verification procedures in a test environment with:

- An ambient temperature of 65° to 82°F (18° to 28°C).
- A relative humidity of less than 70% unless otherwise noted.

Warm-up period

Allow the Model 6487 to warm up for at least one hour before conducting the verification procedures. If the instrument has been subjected to temperature extremes (those outside the ranges stated above), allow additional time for the instrument's internal temperature to stabilize. Typically, allow one extra hour to stabilize a unit that is 18°F (10°C) outside the specified temperature range.

Allow the test equipment to warm up for the minimum time specified by the manufacturer.

Line power

The Model 6487 requires a line voltage of 100 to 120V or 220 to 240V at a line frequency of 50 to 60Hz. Verification tests must be performed within this range. Be sure the line voltage setting agrees with the expected line voltage ([Section 17](#)).

Recommended test equipment

[Table 15-1](#) summarizes recommended verification equipment. You can use alternate equipment, but keep in mind that test equipment accuracy will add to the uncertainty of each measurement. Generally, the test equipment should have accuracy or uncertainty at least four times better than corresponding Model 6487 specifications. Note, however, that the recommended calibrator listed in [Table 15-1](#) does not meet this requirement for 20μA output. See [Table 16-2](#) and [Table 16-3](#) in [Section 16](#) for details on uncertainty ratios.

Table 15-1

Recommended performance verification equipment

Description	Manufacturer/Model	Specifications
Calibrator	Fluke 5700A	DC Voltage: ¹ 2V: 7ppm 20V: 5ppm 200V: 7ppm DC Current: ¹ 20μA: 550ppm 200μA: 100ppm 2mA: 55ppm 20mA: 55ppm
Electrometer Calibration Standard	Keithley Model 5156	Nominal Resistance: ² 100MΩ: 200ppm 1GΩ: 300ppm
Digital Multimeter	Keithley Model 2001	DC Voltage: ³ 10V: 32ppm 50V: 50ppm 500V: 53ppm
Low-noise triax cable Low-noise coax cable Triax shielding cap Triax-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	

¹. 90-day, 23°±5°C full-range accuracy specifications shown. Uncertainty for 20μA output current does not meet the recommended four-times better uncertainty specification.

². 23°±3°C accuracy of characterization.

³. One-year, DMM accuracy specifications at specified voltage and range.

Verification limits

The verification limits stated in this section have been calculated using only Model 6487 one-year accuracy specifications and *they do **not** include test equipment uncertainty*. If a particular measurement falls outside the allowable range, recalculate new limits based on both Model 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 20mA range using a 20mA input value. Using the Model 6487 20mA range accuracy specification of $\pm(0.1\% \text{ of reading} + 1\mu\text{A})$, the calculated reading limits are:

$$\begin{aligned}\text{Reading limits} &= 20\text{mA} \pm [(20\text{mA} \times 0.1\%) + 1\mu\text{A}] \\ &= 20\text{mA} \pm (0.02\text{mA} + 0.001\text{mA}) \\ &= 20\text{mA} \pm 0.021\text{mA} \\ &= 19.979\text{mA to } 20.021\text{mA}\end{aligned}$$

Calibrator voltage calculations

When verifying the 2nA-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 20nA range using an actual 100.5M Ω standard resistor value. The actual calibrator voltage is: $20\text{nA} \times 100.5\text{M}\Omega = 2.01\text{V}$.

Performing the verification test procedures

Test considerations

When performing the verification procedures:

- Be sure to restore Model 6487 factory front panel defaults and perform voltage off-set calibration as outlined below.
- Make sure that the test equipment is properly warmed up and properly connected to the correct Model 6487 terminal(s).
- 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 Model 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 505V DC. Exceeding this voltage can create a shock hazard.

CAUTION Maximum continuous input voltage is 505V DC. Exceeding this value may cause instrument damage.

Restoring factory defaults

Before performing the verification procedure, restore the instrument to its factory front panel defaults as follows:

1. Press **SETUP**. The instrument will display the following prompt:
RESTORE: FACT
2. Using either **RANGE** key, select **FACT** then restore the factory default conditions by pressing **ENTER**.

NOTE You can use either **RANGE** key to select among **FACT**, **GPIB**, and **USR0** to **USR2** setups. Be sure you use **FACT** defaults for the verification procedure.

Offset voltage calibration

Before performing the current performance verification procedure, perform offset voltage calibration as outlined below.

1. Press the MENU key, select CAL, then press ENTER.
2. The unit will display the following:
CAL: VOFFSET
3. Press ENTER. The instrument will prompt as follows:
INPUT CAP
4. Connect the triax shielding cap to the INPUT jack.
5. Press ENTER to complete offset voltage calibration.
6. Press EXIT to return to normal display.

Current measurement accuracy

Follow the steps below to verify that Model 6487 current measurement accuracy is within specified limits. The test involves applying accurate DC currents and then verifying that the Model 6487 current readings are within required limits.

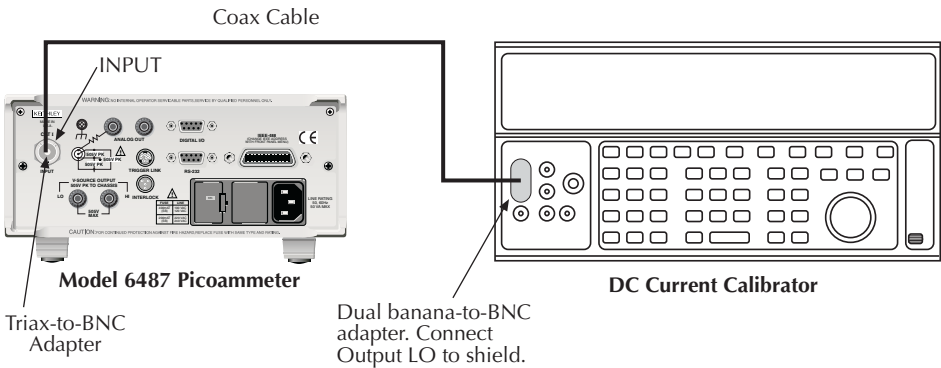
20 μ A-20mA range accuracy

1. With the power off, connect the current calibrator to the Model 6487 INPUT jack ([Figure 15-1](#)). Use the appropriate coax cable, triax-to BNC adapter, and BNC-to-dual banana plug adapter where shown.
2. Turn on the Model 6487 and calibrator. Allow them to warm up for one hour.
3. Set the Model 6487 to the 20 μ A range using the up or down RANGE key.
4. With zero check enabled, zero correct the Model 6487 and then disable zero check.
5. Set the calibrator current to 0.0000 μ A and make sure the output is turned on.
6. Enable the Model 6487 REL mode. Leave REL enabled for the remainder of the test.
7. Verify current measurement accuracy for each of the currents listed in [Table 15-2](#).
For each test point:
 - Select the correct Model 6487 measurement range.
 - Set the calibrator current to the indicated value.
 - Verify that the Model 6487 current reading is within the limits given in the table.
8. Repeat the procedure for negative source currents with the same magnitudes as those listed in [Table 15-2](#).

Table 15-2
Reading limits for 20μA to 20mA ranges

Model 6487 Range	Calibrator Current	Model 6487 Current Reading Limits (1 Year, 18°C-28°C)
20μA	20.0000μA	19.9790 to 20.0210μA
200μA	200.000μA	199.790 to 200.210μA
2mA	2.00000mA	1.99790 to 2.00210mA
20mA	20.0000mA	19.9790 to 20.0210mA

Figure 15-1
Connections for 20μA to 20mA range verification



2nA-2μA range accuracy

1. With the power off, connect the voltage calibrator and Model 5156 Electrometer Calibration Standard to the Model 6487 INPUT jack (Figure 15-2). Initially, make connections to the 1GΩ resistor in the calibration standard.
2. Turn on the Model 6487 and calibrator power. Allow them to warm up for one hour.
3. Set the Model 6487 to the 2nA range.
4. With zero check enabled, zero correct the instrument and then disable zero check.
5. Set the calibrator voltage to 0.0000V and make sure the output is turned on.
6. Enable the Model 6487 REL mode. Leave REL enabled for the remainder of the test.

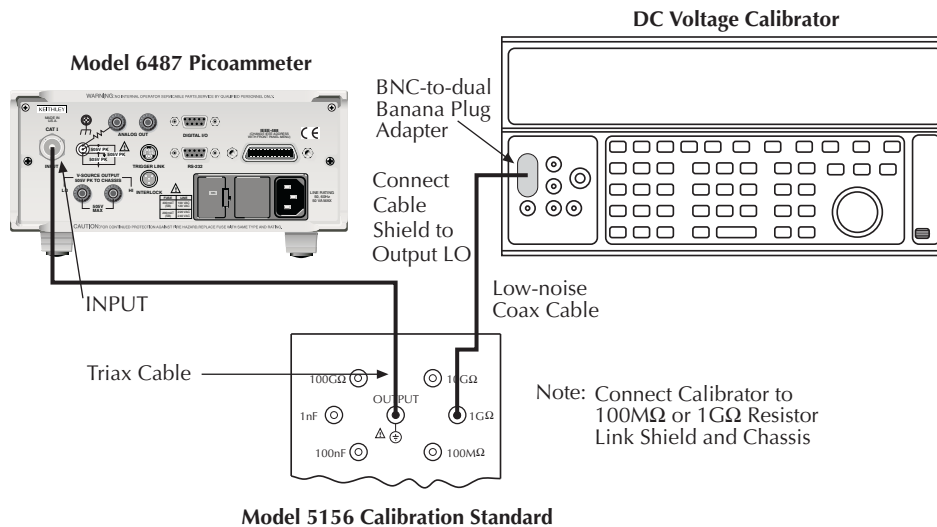
7. Verify current measurement accuracy for each of the currents listed in [Table 15-3](#).
For each test point:
- Make connections to the indicated calibration standard resistor.
 - Select the correct Model 6487 measurement range.
 - Calculate the actual required calibrator voltage: $V = IR$; where I is the desired applied current and R is the actual standard resistor value.
 - Set the calibrator to the calculated voltage.
 - Verify that the Model 6487 current reading is within the reading limits listed in the table.
8. Repeat the procedure for negative source currents with the same magnitudes as those listed in [Table 15-3](#).

Table 15-3
Reading limits for 2nA to 2μA ranges

Model 6487 range	Nominal calibrator voltage	Calibration standard resistor ¹	Nominal applied current	Actual voltage ²	Model 6487 current reading limits (1 Year, 18°C-28°C)
2nA	2V	1GΩ	2.00000nA	_____ V	1.99160 to 2.00840nA
20nA	2V	100MΩ	20.0000nA	_____ V	19.9190 to 20.0810nA
200nA	20V	100MΩ	200.000nA	_____ V	199.590 to 200.410nA
2μA	200V	100MΩ	2.00000μA	_____ V	1.99690 to 2.00310μA

¹. Nominal resistance values shown. Use actual characterized value for calculations.
². Calculate actual calibrator voltage as follows: $V = IR$; where I is desired applied current and R is actual standard resistance value.

Figure 15-2
Connections for 2nA to 2 μ A range verification



Voltage source output accuracy

Follow the steps below to verify that Model 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 50V and 500V ranges. See [Section 2](#) for interlock information.

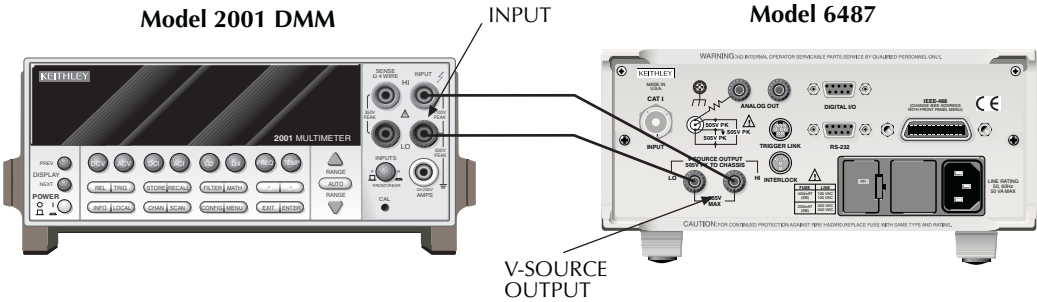
1. With the power off, connect the DMM INPUT terminals to the Model 6487 V-SOURCE OUTPUT jacks ([Figure 15-3](#)). Be sure to observe polarity (HI to HI; LO to LO).
2. Turn on the DMM and Model 6487; allow them to warm up for one hour.
3. Select the DMM DCV function and enable autoranging.
4. Temporarily 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.

5. Verify voltage source accuracy for each of the values listed in [Table 15-4](#). For each test point:
- Select the correct Model 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.
6. Repeat the procedure for negative source currents with the same magnitudes as those listed in [Table 15-4](#).

Table 15-4
Reading limits for voltage source accuracy

Model 6487 Source Range	Output Voltage	Model 6487 Output Voltage Limits (1 Year, 18°C-28°C)
10V	10.000V	9.989 to 10.011V
50V	50.000V	49.946 to 50.054V
500V	500.00V	499.21 to 500.79V

Figure 15-3
Connections for voltage source output accuracy



16

Calibration

- **Environmental conditions** — Summarizes temperature and relative humidity, warm-up period, and line power requirements.
- **Calibration considerations** — Lists considerations to take into account when calibrating the unit.
- **Calibration cycle** — States how often the Model 6487 should be calibrated.
- **Recommended calibration equipment** — Lists all equipment necessary for calibration and gives pertinent specifications.
- **Calibration errors** — Discusses error messages that might occur during calibration.
- **Calibration menu** — Discusses calibration menu items.
- **Aborting calibration** — Describes how to halt the calibration procedure at any time.
- **Current calculations** — Details how to calculate currents from calibrator voltages and standard resistor values when calibrating the 2nA to 2 μ A ranges.
- **Calibration procedure** — Provides step-by-step procedures for calibrating all current ranges, as well as all three ranges of the voltage source. The 2nA to 2 μ A and 20 μ A to 20mA ranges require separate procedures because of the different calibration equipment involved.
- **Calibration support** — Describes how to change the calibration code, reset the calibration code, and view calibration dates and count.

Introduction

Use the procedures in this section to calibrate the Model 6487 from the front panel. (See [Appendix F](#) for information on remote calibration.) 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° to 24°C with relative humidity of less than 70% unless otherwise noted.

Warm-up period

Allow the Model 6487 to warm up for at least one hour before performing calibration.

If the instrument has been subjected to temperature extremes (those outside the ranges stated above), allow additional time for the instrument's internal temperature to stabilize. Typically, allow one extra hour to stabilize a unit that is 10°C outside the specified temperature range.

Allow the test equipment to warm up for the minimum time specified by the manufacturer.

Line power

The Model 6487 requires a line voltage of 100 to 120V or 220 to 240V at a line frequency of 50 to 60Hz. The instrument must be calibrated while operating from a line voltage within this range. Be sure the line voltage setting agrees with the expected line voltage ([Section 17](#)).

Calibration considerations

When performing the calibration procedures:

- Make sure that the test equipment is properly warmed up and connected to the correct Model 6487 terminal(s).
- Always allow the source signal to settle before calibrating each point.
- Do not connect test equipment to the Model 6487 through a scanner or other switching equipment.
- If an error occurs during calibration, the Model 6487 will generate an appropriate error message.

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

CAUTION Maximum continuous input voltage is 505V DC. Exceeding this value may cause instrument damage.

Calibration cycle

Perform verification at least once a year to ensure the unit meets or exceeds its specifications (see [Section 15](#)). Calibrate if necessary.

Recommended calibration equipment

[Table 16-1](#) lists the recommended equipment for the calibration procedures. You can use alternate equipment, but keep in mind that test equipment uncertainty will affect calibration accuracy. Calibration equipment should have accuracy specifications at least four times better than corresponding Model 6487 specifications. Note, however, that the recommended calibrator listed in [Table 16-1](#) does not meet this requirement for 20 μ A output. [Table 16-2](#) lists uncertainty ratios for current calibration equipment, while [Table 16-3](#) lists uncertainty ratios for voltage source calibration equipment.

Table 16-1

Recommended calibration equipment

Description	Manufacturer/Model	Specifications
Calibrator	Fluke 5700A	DC Voltage: ¹ 2V: 7ppm 20V: 5ppm 200V: 7ppm DC Current: ¹ 20μA: 550ppm 200μA: 100ppm 2mA: 55ppm 20mA: 55ppm
Electrometer Calibration Standard	Keithley Model 5156	Nominal Resistance: ² 100MΩ: 200ppm 1GΩ: 300ppm
Digital Multimeter	Keithley Model 2001	DC Voltage: ³ 10V: 32ppm 50V: 50ppm 500V: 53ppm
Low-noise triax cable Low-noise coax cable Triax shielding cap Triax-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	

¹. 90-day, 23°±5°C full-range accuracy specifications shown. Includes ppm of range and offset. Uncertainty for 20μA output current does not meet the recommended four-times better uncertainty specification.

². 23°±3°C accuracy of characterization.

³. One-year, DMM accuracy specifications at specified voltage and range.

Calibration errors

The Model 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.

Table 16-2

Current test uncertainty ratios with recommended equipment

Range	5700 + 5156	Test uncertainty ratio
2nA	7ppm + 300ppm	13.0
20nA	7ppm + 200ppm	19.3
200nA	5ppm + 200ppm	9.8
2μA	7ppm + 200ppm	7.2
20μA	550ppm	1.8
200μA	100ppm	10.0
2mA	55ppm	18.2
20mA	55ppm	18.2

Table 16-3

Voltage source test uncertainty ratios with recommended equipment

Range	2001 DMM	Test uncertainty ratio
10V	32ppm	31.2
50V	50ppm	20.0
500V	53ppm	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 [Table 16-4](#). Use the up and down RANGE keys to scroll through these selections.

Table 16-4
Calibration menu

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 at any time by pressing the EXIT key.

Current calculations

When calibrating the 2nA-2μA 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, assume you are calibrating the 20nA range using a 2V calibrator voltage with an actual 100.5MΩ standard resistor value. The actual calibration current is:
 $2V/100.5M\Omega = 19.9005nA$.

Calibration procedure

The calibration procedure should be performed in the following order:

- Preparing for calibration
- Offset voltage calibration
- Current calibration
- Voltage source calibration
- Entering calibration dates and saving calibration
- Locking out calibration

Preparing for calibration

1. Turn on the Model 6487 and the calibrator; allow them to warm up for at least one hour before performing calibration.
2. Press MENU, select CAL, then press ENTER. The instrument will display the following:
CAL: VOFFSET
3. Use the up or down RANGE key to display the following:
CAL: UNLOCK
4. Press ENTER. The instrument will prompt for the calibration code:
CODE? 000000
5. 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 UNLOCKED
Followed by:
NEW CODE? N
6. With N displayed, press ENTER.

Offset voltage calibration

Before performing the remaining calibration steps, perform offset voltage calibration as outlined below.

1. From the calibration menu, use the up or down RANGE key to display the following:
CAL: VOFFSET
2. Press ENTER. The instrument will prompt as follows:
INPUT CAP
3. Connect the triax 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-20mA range calibration

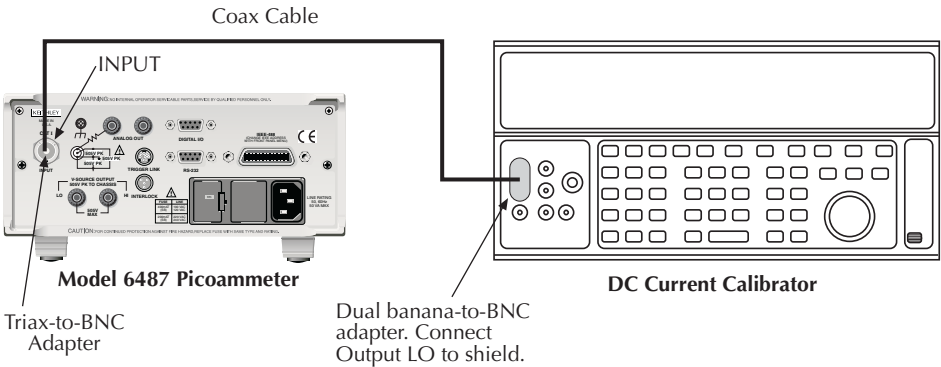
1. Connect the triax shielding cap to the Model 6487 rear panel INPUT jack.
2. Select the Model 6487 20 μ A range.
3. Press MENU, select CAL, then press ENTER. At the CAL: RUN prompt, press ENTER. The unit will prompt for the zero calibration point:
20 μ A ZERO
4. With the triax shielding cap connected to the INPUT jack for a 0 μ A input current, press ENTER.
5. The unit will prompt for the positive full-scale cal point:
+20 μ A CAL
6. Connect the current calibrator to the Model 6487 INPUT jack ([Figure 16-1](#)). Use the coax cable and two adapters where shown.
7. Press ENTER. The unit will prompt for the positive full-scale current:
+20.00000 μ A
8. Set the calibrator current to +20.00000 μ A then adjust the display to agree with the calibrator current.
9. Press ENTER. The unit will prompt for the negative full-scale calibration point:
-20 μ A CAL
10. Press ENTER. The Model 6487 will prompt for the negative full-scale calibration current:
-20.00000 μ A
11. Set the calibrator output to -20.00000 μ A, then adjust the display to agree with the calibrator value. Press ENTER to complete calibration of the present range.
12. Press EXIT to return to normal display.
13. Repeat steps 1 through 12 for the 200 μ A through 20mA ranges using [Table 16-5](#) as a guide.

Table 16-5
20μA to 20mA range calibration summary

Model 6487 Range	Calibrator Currents*
20μA	0μA +20.00000μA -20.00000μA
200μA	0μA +200.0000μA -200.0000μA
2mA	0mA +2.000000mA -2.000000mA
20mA	0mA +20.00000mA -20.00000mA

* Calibrate zero, positive full-scale, and negative full-scale for each range. Triax shielding cap used for zero calibration point for all ranges. See procedure.

Figure 16-1
Connections for 20μA to 20mA range calibration



2nA-2μA range calibration

1. Connect the voltage calibrator and the Model 5156 Electrometer Calibration Standard to the Model 6487 INPUT jack (Figure 16-2). Initially, make connections to the 1GΩ resistance.
2. Set the calibrator to output volts and make sure the calibrator output is turned on.
3. Select the Model 6487 2nA range.

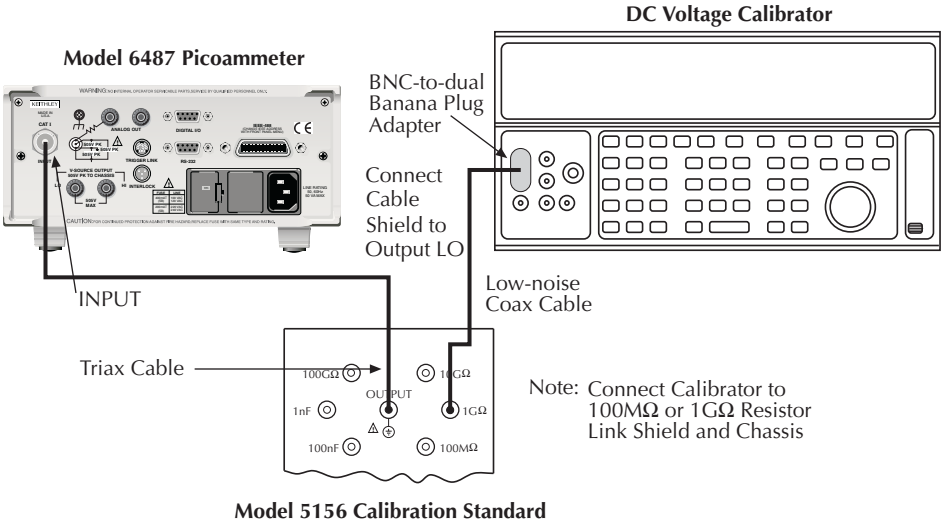
4. Press MENU, select CAL, then press ENTER. At the CAL: RUN prompt, press ENTER again. The unit will prompt for the zero calibration point:
2NA ZERO
5. Set the calibrator voltage to 0V then press ENTER.
6. The instrument will prompt for the positive full-scale calibration point:
+2NA CAL
7. Press ENTER. The instrument will prompt for the positive full-scale calibration current:
+2.000000 NA
8. Set the calibrator voltage to +2.000000V. Calculate the actual calibration current from the calibrator voltage and the actual standard resistor value: $I = V/R$. Adjust the Model 6487 display to agree with the calculated current, then press ENTER.
9. The Model 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 -2.000000V, then calculate the calibration current from the calibrator voltage and standard resistor value: $I = V/R$. Adjust the Model 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 steps 3 through 12 for the 20nA through 2μA ranges using [Table 16-6](#) as a guide. Be sure to make connections to the correct standard resistor and set the calibrator voltages to the correct values.

Table 16-6
2nA to 2μA range calibration summary

Model 6487 range	Calibrator voltages	Standard resistors ¹	Calibration currents ²
2nA	0V	1GΩ	0nA
	+2.000000V	1GΩ	+2nA
	-2.000000V	1GΩ	-2nA
20nA	0V	100MΩ	0nA
	+2.000000V	100MΩ	+20nA
	-2.000000V	100MΩ	-20nA
2μA	0V	100MΩ	0μA
	+200.0000V	100MΩ	+2μA
	-200.0000V	100MΩ	-2μA

1. ¹Nominal resistance values.
2. ²Nominal 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 16-2
Connections for 2nA to 2μA 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 50V and 500V ranges. See [Section 2](#) for interlock information.

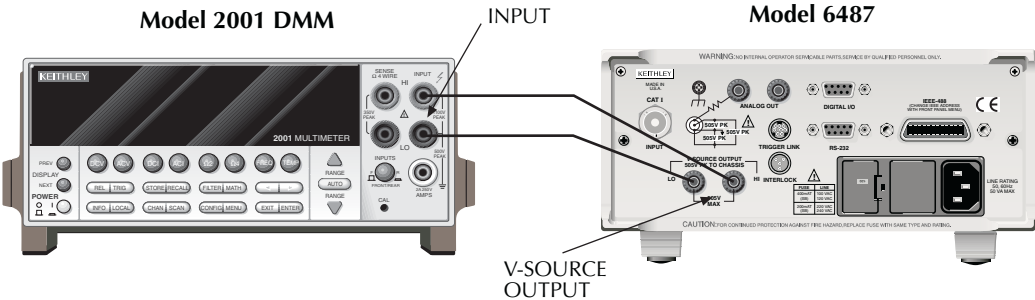
1. Set the DMM to measure DC volts and enable autoranging.
2. Temporarily short the ends of the DMM test leads together, then enable the DMM REL mode. Leave REL enabled for the rest of the calibration procedure.
3. Connect the DMM to the Model 6487 V-SOURCE OUTPUT jacks ([Figure 16-3](#)).
4. Select the Model 6487 voltage source 10V 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 Model 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 Model 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 Model 6487 display to agree with that voltage and then press ENTER.
14. Press EXIT to return to normal display.
15. Repeat steps 4 through 14 for the 50V and 500V ranges using [Table 16-7](#) as a guide.

Table 16-7
Voltage source calibration summary

Model 6487 Range	Calibration Voltages*
10V	-10.00000V +0.00000V +10.0000V
50V	-50.00000V +0.00000V +50.00000V
500V	-500.0000V +0.00000V +500.0000V

* Nominal values. Adjust display to agree with DMM reading.

Figure 16-3
Connections for voltage source calibration



Entering calibration dates and saving calibration

NOTE For temporary calibration without saving new calibration constants, proceed to “Locking out calibration”.

1. Press MENU, select CAL, then press ENTER to access the calibration menu.
2. Use either RANGE key to display the following:
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

Use the following procedure to lock out calibration without saving new calibration constants:

1. Press MENU, select CAL, then press ENTER. Use the up RANGE key to display the following:
CAL: LOCK
2. Press ENTER. The instrument will display the following message:
CAL LOCKED.

Calibration support

Changing the calibration code

Follow the steps below 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 at any time:

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 Model 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 at any time:

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.

17

Routine Maintenance

- **Setting line voltage and replacing line fuse** — Describes how to set the line voltage properly and replace the line fuse with the correct rating.
- **Front panel tests** — Covers testing the front panel keys and the display.

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 (Figure 17-1). If the line voltage must be changed or if the line fuse requires replacement, perform the following steps:

1. Place the tip of a flat-blade screwdriver into the power module by the fuse holder assembly (Figure 17-1). Gently push in and to the left. Release pressure on the assembly and its internal spring will push it out of the power module.
2. Remove the fuse and replace it with the type listed in Table 17-1.

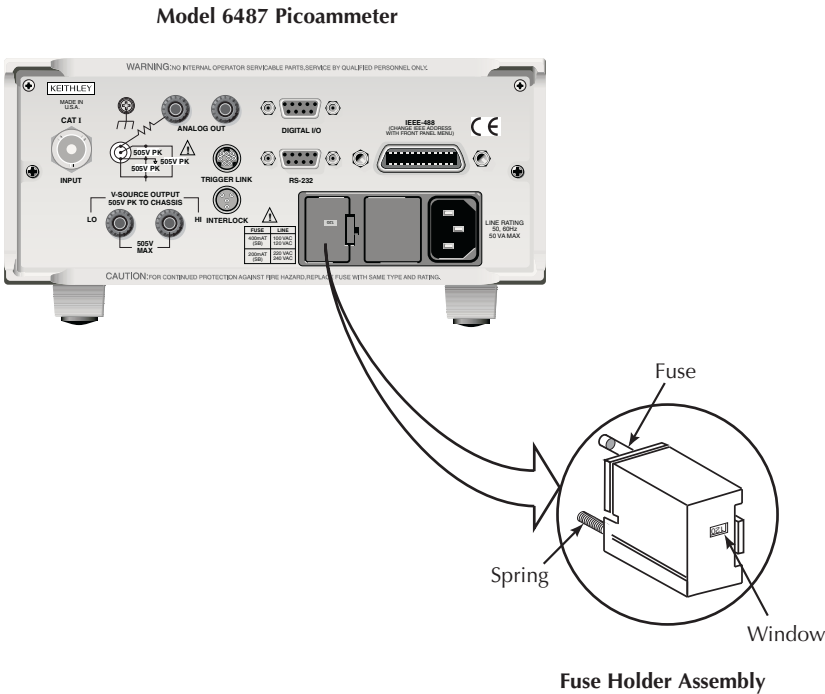
WARNING For continued protection against fire or instrument damage, replace the fuse only with the type and rating listed. If the instrument repeatedly blows fuses, it will require servicing.

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.

Table 17-1
Line fuse ratings

Line Voltage	Rating	Keithley Part No.
100/120V	0.4A, 250V, 5 × 20mm, slow blow	FU-106-.400
220/240V	0.2A, 250V, 5 × 20mm, slow-blow	FU-106-.200

Figure 17-1
Line fuse location



Front panel tests

The front panel tests are summarized in [Table 17-2](#). To run a test, simply 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.

Table 17-2
Front panel tests

Test	Description
DISP	Test display
KEY	Test front panel keys

DISP test

The display test allows you to verify that each segment and annunciator in the vacuum fluorescent display is working properly. Perform the following steps to run the display test:

1. Press 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.

A Specifications

6487 Picoammeter Specifications

RANGE	5½ DIGIT DEFAULT RESOLUTION	ACCURACY (1YR) ¹ ±(% RDG. + OFFSET) 18°–28°C, 0–70% RH	TYPICAL RMS NOISE ²	TYPICAL ANALOG RISE TIME (10% TO 90%) ³ DAMPING ⁴	
				OFF	ON
2 nA	10 fA	0.3 % + 400 fA	20 fA	4 ms	80 ms
20 nA	100 fA	0.2 % + 1 pA	20 fA	4 ms	80 ms
200 nA	1 pA	0.15 % + 10 pA	1 pA	300 µs	1 ms
2 µA	10 pA	0.15% + 100 pA	1 pA	300 µs	1 ms
20 µA	100 pA	0.1 % + 1 nA	100 pA	110 µs	110 µs
200 µA	1 nA	0.1 % + 10 nA	100 pA	110 µs	110 µs
2 mA	10 nA	0.1 % + 100 nA	10 nA	110 µs	110 µs
20 mA	100 nA	0.1 % + 1 µA	10 nA	110 µs	110 µs

TEMPERATURE COEFFICIENT: 0°–18°C & 28°–50°C. For each °C, add 0.1 × (% rdg + offset) to accuracy spec.

INPUT VOLTAGE BURDEN: <200µV on all ranges except <1mV on 20mA range.

MAXIMUM INPUT CAPACITANCE: Stable to 10nF on all nA ranges and 2µA range; 1µF on 20µA and 200µA ranges, and on mA ranges.

MAXIMUM CONTINUOUS INPUT VOLTAGE: 505 VDC

NMRR¹: (50 or 60Hz) :60dB

ISOLATION (Ammeter Common or Voltage Source to chassis): Typically >1×10¹¹Ω in parallel with <1nF.

MAXIMUM COMMON MODE VOLTAGE (Between Chassis and Voltage Source or Ammeter): 505 VDC.

MAXIMUM VOLTAGE BETWEEN VOLTAGE SOURCE AND AMMETER: 505 VDC

ANALOG OUTPUT: Scaled voltage output (inverting 2V full scale on all ranges) 2.5% ±2mV

ANALOG OUTPUT IMPEDANCE³: <100Ω, DC–2kHz.

VOLTAGE SOURCE

Range (Max)	Step Size (typical)	Accuracy ⁵ ±(% PROG. + OFFSET) 18°C - 28°C, 0 - 70% R.H.	Noise (p-p) 0.1 - 10 Hz	Temperature Coefficient	Typical Rise Time ^{6,8} (10%-90%)	Typical Fall Time ^{7,8} (90%-10%)
±10.100	200µV	0.1% + 1mV	<50µV	(0.005% + 20µV) / °C	250 µs	150 µs
±50.500	1mV	0.1% + 4mV	<150µV	(0.005% + 200µV) / °C	250 µs	300 µs
±505.00	10mV	0.15% + 40mV	<1.5mV	(0.008% + 2mV) / °C	4.5 ms	1 ms

SELECTABLE CURRENT LIMIT: 2.5mA, 250µA, 25µA for 50V and 500V ranges, 25mA additional limit for 10V range. All current limits are -20%/+35% of nominal.

WIDEBAND NOISE⁹: <30mVp-p 0.1Hz - 20MHz.

TYPICAL TIME STABILITY: ±(0.003% + 1mV) over 24 hours at constant temperature (within 1°C, between 18°C - 28°C, after 5 minute settling).

OUTPUT RESISTANCE: <2.5Ω.

VOLTAGE SWEEPS: Supports linear voltage sweeps on fixed source range, one current or resistance measurement per step. Maximum sweep rate: 200 steps per second. Maximum step count 3000. Optional delay between step and measure.

RESISTANCE MEASUREMENT (V/I): Used with voltage source; resistance calculated from voltage setting and measured current. Accuracy is based on voltage source accuracy plus ammeter accuracy. Typical accuracy better than 0.6% for readings between 1kΩ and 1TΩ.

ALTERNATING VOLTAGE RESISTANCE MEASUREMENT: Offers alternating voltage resistance measurements for resistances from 10³Ω to 10¹⁴Ω. Alternates between 0V and user-selectable voltage up to ±505V.

¹ At 1 PLC – limited to 60 rdgs/sec under this condition.

² At 6 PLC, 1 standard deviation, 100 readings, filter off, capped input – limited to 10 rdgs/sec under this condition.

³ Measured at analog output with resistive load >2kΩ.

⁴ Maximum rise time can be up to 25% greater.

⁵ Accuracy does not include output resistance/load regulation.

⁶ Rise Time is from 0V to ± full-scale voltage (increasing magnitude).

⁷ Fall Time is from ± full-scale voltage to 0V (decreasing magnitude).

⁸ For capacitive loads, add C*ΔV/I_{limit} to Rise Time, and C*ΔV/1mA to Fall Time.

⁹ Measured with LO connected to chassis ground.

REMOTE OPERATION

IEEE-488 BUS IMPLEMENTATION: SCPI (IEEE-488.2, SCPI-1996.0);

DDC (IEEE-488.1).

LANGUAGE EMULATION: Keithley Model 486/487 emulation via DDC mode.

RS-232 IMPLEMENTATION:

Supports: SCPI 1996.0.

Baud Rates: 300, 600, 1200, 2400, 4800, 9600, 19.2k, 38.4k, 57.6k.

Protocols: Xon/Xoff, 7 or 8 bit ASCII, parity-odd/even/none.

Connector: DB-9 TXD/RXD/GND.

GENERAL

AMMETER INPUT CONNECTOR: Three lug triaxial on rear panel.

ANALOG OUTPUT CONNECTOR: Two banana jacks on rear panel.

VOLTAGE SOURCE OUTPUT CONNECTOR: Two banana jacks on rear panel.

INTERLOCK CONNECTOR: 4 pin DIN.

TRIGGER LINE: Available, see manual for usage.

DISPLAY: 12 character vacuum fluorescent.

DIGITAL FILTER: Median and averaging (selectable from 2 to 100 readings).

RANGING: Automatic or manual.

AUTORANGING TIME³: <250ms (analog filter off, 1PLC)

OVERRANGE INDICATION: Display reads "OVRFLOW".

CONVERSION TIME: Selectable 0.01 PLC to 60 PLC (50PLC under 50Hz operation). (Adjustable from 200µs to 1s)

READING RATE:

To internal buffer 1000 readings/second¹

To IEEE-488 bus 900 readings/second^{1,2}

BUFFER: Stores up to 3000 readings.

PROGRAMS: Provide front panel access to IEEE address, choice of engineering units or scientific notation, and digital calibration.

EMC: Conforms with European Union Directive 89/336/EEC, EN61326-1.

SAFETY: Conforms with European Union Directive 73/23/EEC, EN61010-1, CAT I.

ENVIRONMENT:

Operating: 0°–50°C; relative humidity 70% non-condensing, up to 35°C. Above 35°C, derate humidity by 3% for each °C.

Storage: –10°C to +65°C.

WARM-UP: 1 hour to rated accuracy (see manual for recommended procedure).

POWER: 100–120V or 220–240V, 50–60Hz, (50VA).

PHYSICAL:

Case Dimensions: 90mm high × 214mm wide × 369mm deep (3½ in. × 8½ in. × 14½ in.).

Working Dimensions: From front of case to rear including power cord and IEEE-488 connector: 394mm (15.5 inches).

NET WEIGHT: <4.7 kg (<10.3 lbs).

Notes:

¹ 0.01 PLC, digital filters off, front panel off, auto zero off.

² Binary transfer mode. IEEE-488.1.

³ Measured from trigger in to meter complete.

Specifications are subject to change without notice.

B

Status and Error Messages

Table B-1
Status and error messages

Number	Description	Event
-440	Query unterminated after indefinite response	EE
-430	Query deadlocked	EE
-420	Query unterminated	EE
-410	Query interrupted	EE
-363	Input buffer overrun	EE
-362	Framing error in program message	EE
-361	Parity error in program message	EE
-360	Communications error	EE
-350	Queue overflow	SYS
-330	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
-202	Settings lost due to rtl	EE
-201	Invalid while in local	EE
-200	Execution error	EE
-178	Expression data not allowed	EE
-171	Invalid expression	EE
-170	Expression error	EE
-168	Block data not allowed	EE
-161	Invalid block data	EE
-160	Block data error	EE

Table B-1 (cont.)

Status and error messages

Number	Description	Event
-158	String data not allowed	EE
-154	String too long	EE
-151	Invalid string data	EE
-150	String data error	EE
-148	Character data not allowed	EE
-144	Character data too long	EE
-141	Invalid character data	EE
-140	Character data error	EE
-128	Numeric data not allowed	EE
-124	Too many digits	EE
-123	Exponent too large	EE
-121	Invalid character in number	EE
-120	Numeric data error	EE
-114	Header suffix out of range	EE
-113	Undefined header	EE
-112	Program mnemonic too long	EE
-111	Header separator error	EE
-110	Command header error	EE
-109	Missing parameter	EE
-108	Parameter not allowed	EE
-105	GET not allowed	EE
-104	Data type error	EE
-103	Invalid separator	EE
-102	Syntax error	EE
-101	Invalid character	EE
-100	Command error	EE
+000	No error	SE
	Measurement events:*	
+101	Low limit 1 failed	SE
+102	High limit 1 failed	SE
+103	Low limit 2 failed	SE
+104	High limit 2 failed	SE
+105	Active limit tests passed	SE
+106	Reading available	SE

Table B-1 (cont.)

Status and error messages

Number	Description	Event
+107	Reading overflow	SE
+108	Buffer available	SE
+109	Buffer full	SE
+110	Input overvoltage	SE
+111	OUTPUT interlock asserted	SE
Standard events:*		
+200	Operation complete	SE
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

Table B-1 (cont.)

Status and error messages

Number	Description	Event
+700	Communication errors:	EE
+701	Invalid system communication 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
+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

Table B-1 (cont.)

Status and error messages

Number	Description	Event
	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. See Section 10 for details.		

NOTE SCPI-confirmed messages are described in Volume 2: Command Reference of the Standard Commands for Programmable Instruments. Refer to the :SYSTem:ERRor? command.

Eliminating common SCPI errors

There are three SCPI errors that occur more often than any others:

- -113, "Undefined header"
- -410, "Query INTERRUPTED"
- -420, "Query UNTERMINATED"

The following paragraphs 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 (blanks) 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.* Check the command list in [Section 14](#) for the correct command name.
- *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 Model 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 Model 6487 will discard the second program message unit :SOUR1:VOLT? even though it is a valid query.

C DDC Emulation Commands

DDC language

The Model 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,” page 9-2 in Section 9](#). The commands for controlling the Model 6487 with the DDC language are provided in [Table C-1](#). For details on Model 487 operation, refer to the appropriate instruction manual PDF on the product information CD-ROM included with your shipment.

Since the architecture of the Model 6487 differs from that of the Model 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.

CAUTION The DDC language is intended to be used only over the IEEE-488 bus. Using front panel controls in conjunction with this language may cause erratic operation. In this case, results cannot be guaranteed.

Table C-1
Device dependent command summary

Mode	Command	Description Equivalent SCPI or 488.2 commands	Note	Default
Display Intensity	A0	Normal display DISPlay:ENABle ON		X
	A1	Dim display	A	
	A2	Turn display off DISPlay:ENABle OFF		
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?		

Table C-1 (cont.)

Device dependent command summary

Mode	Command	Description Equivalent SCPI or 488.2 commands	Note	Default
Zero Check	C0	Disable Zero Check SYSTem:ZCheck OFF		X
	C1	Enable Zero Check SYSTem:ZCheck ON		
	C2	Enable Zero Check and perform Zero Correct SYSTem:ZCheck ON SYSTem:ZCORrect ON	B	
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 See FORMat subsystem.	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 NORMa1		
	G6	Binary readings with exponent, byte order reversed (not supported)	C	
	G7	Binary readings with exponent, normal byte order (not supported)	C	

Table C-1 (cont.)

Device dependent command summary

Mode	Command	Description Equivalent SCPI or 488.2 commands	Note	Default
Hit Key	H1	Hit CONFIG/LOCAL key	D	
	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)	E	
	J1	Perform RAM/ROM and display self-test *TST? (Test ROM only)		

Table C-1 (cont.)

Device dependent command summary

Mode	Command	Description Equivalent SCPI or 488.2 commands	Note	Default
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	SCPI not available	
	K2	Enable EOI, disable bus hold-off on X	SCPI not available	
	K3	Disable both EOI and bus hold-off on X	SCPI not available	
Default Conditions and Calibration	L0	Return to factory defaults and save (L1) SYSTem:PRESet *SAV 0	F	
	L1	Save present states as default conditions *SAV 0		
	L2	Return to saved defaults *RCL 0		
	L3-L6	Calibration commands (not supported)	G	
SRQ	M0	Clears SRQ mask (SRQ disabled) *SRE 0	SRQ Mask Bits: (H) (None)	X
	M1	Reading Overflow STATus:MEASurement[:EVENT]:ENABLE 128 *SRE 1	(B0) page C-14	
	M2	Data Store Full STATus:MEASurement[:EVENT]:ENABLE 512 *SRE 1	(B1) page C-14	
	M4	Data Store Half Full (not SCPI supported)	(B2) page C-14	
	M8	Reading Done STATus:MEASurement[:EVENT]:ENABLE 64 *SRE 1	(B3) page C-14	
	M16	Ready	(B4) page C-14 , I	
	M32	Error	(B5) page C-14 , I	
	M128	Voltage source error	(B7) page C-15 , I	

Table C-1 (cont.)

Device dependent command summary

Mode	Command	Description Equivalent SCPI or 488.2 commands	Note	Default
Data Store	N0	Stop storage, clear buffer	J	
	Nn	Arm data store, set buffer size “n” where n =1 to 512	J	
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	K	
	P2	Disable digital filter, enable analog filter		
	P3	Enable both digital and analog filters	K	X
Interval	Q0	175msec TRIGger:DElay 0.175		X
	Q1	Set to “n” seconds, n= 0.01msec to 999.999sec TRIGger:DElay <NRf>	L	
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	M	
	R9	20mA range [SENSe[1]]:RANGe 20e-3	M	
	R10	Disable autorange [SENSe[1]]:RANGe:AUTO OFF	M	

Table C-1 (cont.)

Device dependent command summary

Mode	Command	Description Equivalent SCPI or 488.2 commands	Note	Default
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	

Table C-1 (cont.)

Device dependent command summary

Mode	Command	Description Equivalent SCPI or 488.2 commands	Note	Default
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?		
	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. See Figure C-3 .		
Voltage Source	Vn,r,l	Voltage source value, range, current limit n = -505 to 505 SOURce[1]:VOLtage <NRf> r: 0 = 50V range; 1 = 500V range SOURce[1]:VOLtage:RANGe <NRf> l: 0 = 25 μ A limit; 1 = 2.5mA limit SOURce[1]:VOLtage:ILIMit <NRf>		0V 50V 2.5mA
Delay	Wn	Delay trigger for “n” seconds. n = 0 to 999.999sec 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)	N	
	Y4	None		

Table C-1 (cont.)

Device dependent command summary

Mode	Command	Description Equivalent SCPI or 488.2 commands	Note	Default
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: $V = -2e-2$ to $2e-2A$ for current. $V = 0\Omega$ to $50.5e16\Omega$ for V/I ohms. CALCulate2:NULL:OFFSet <NRf> CALCulate2:NULL:STATe ON		
	Z3	Enable relative using previously defined baseline CALCulate[1]:NULL:STATe ON		

- A) Only characters will be dimmed. Annunciators will not be dimmed.
- B) Zero Correct and Zero Correct notes:
 - a. Sending C2X will perform a Zero Correct operation. If the unit is not already in Zero Check, then Zero Check will be turned on first, then the Zero Correct value collected, then Zero Check will be turned off.
 - b. The 487 offers no way to "turn off" Zero Correct. 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.
 - c. Like the 487, subsequent C2 commands will cause a new Zero Correct value to be acquired.
 - d. The 6487 saves only a single Zero Correct value, not one for each range as with the 487. For best results, send a C2 command to acquire new Zero Correct value after going to the desired range. Also, unlike the 487, Zero Correct values are not saved across power cycles and must be re-acquired after power cycling the unit.
- C) G6 and G7 are not supported by the Model 6487 since they are seldom used.
- D) The Model 487 uses different keys and menu structure than the Model 6487, so key mapping is not comparable.
- E) The J commands (J0, J1) for RAM and ROM self-tests will be accepted but take no action. RAM and ROM are tested at power-up. The display may be tested from the front panel.

- F) Since the Model 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. Therefore, changing the instrument language to DDC will clear out the *SAV 0 location and load it with the DDC factory defaults. A setup saved using the DDC mode L1 command will be saved into this location. Likewise, changing the Model 6487 language from DDC mode to SCPI will return the SYST:PRESet factory defaults into the *SAV 0 setup location, overwriting the setup that had been stored with the DDC mode L1 command.
- G) Calibration can be performed only with SCPI calibration commands. See [Appendix F](#).
- H) Multiple SRQ conditions can be enabled by adding up M command values. For example, M33 enables SRQ both on reading done and on error.
- I) 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 getting an SRQ on an Error Event, to clear the event, read the Standard Event Register (*ESR?, then talk the instrument). There may also be an Error Available event set in the status byte (serial poll).
- J) Buffer operating notes:
 - a. The 6487 does not support a continuous wrap-around buffer. Therefore, the N0 command will simply stop storage and clear the buffer.
 - b. Nx (x=1-512) will arm the buffer and storage will commence at the first trigger. A key difference between the 487 and the 6487 is that 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.
- K) The digital filter is always a 4-point moving average type and cannot be changed in DDC mode.
- L) See ARM and TRIGger subsystems in [Section 14](#).
- M) The 487 does not allow R8 or R9, since its highest measurement range is R7, which is the 2mA range. The 6487 accepts R8 and R9, both of which select the 20mA range. Whether R8 or R9 is sent, an '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 in the 487.
- N) SCPI PMT (Program Message Terminator) is always LF + EOI.

NOTE DDC timing is not guaranteed to match the timing of the original instrument (487) being emulated.

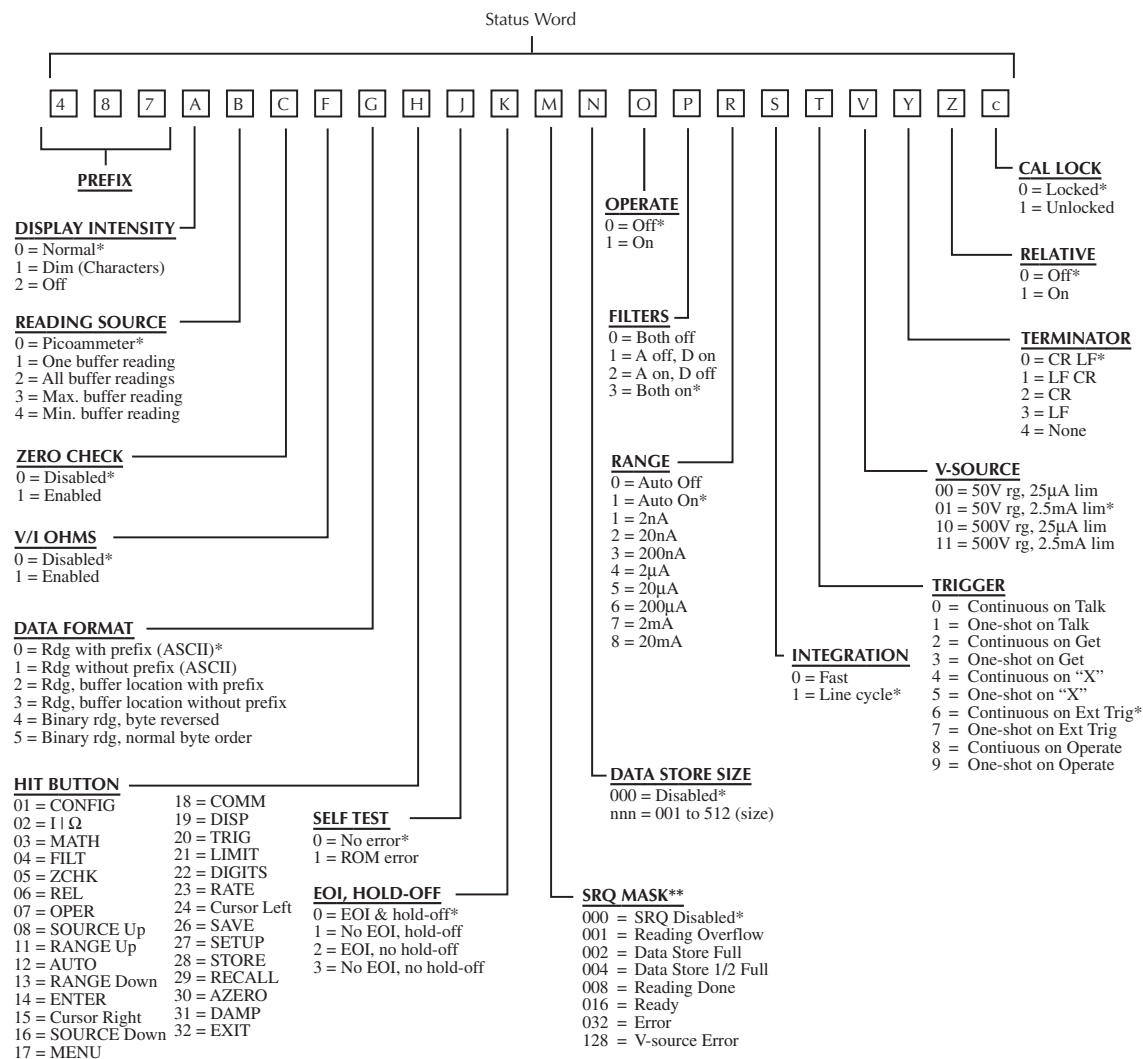
Sweeps or A-V ohms in DDC mode

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 [Figure C-1](#), [Figure C-2](#), and [Figure C-3](#).

Figure C-1

U0 machine status word

*Default settings

**Add up values for multiple SRQ conditions

Figure C-2
U1 error status word

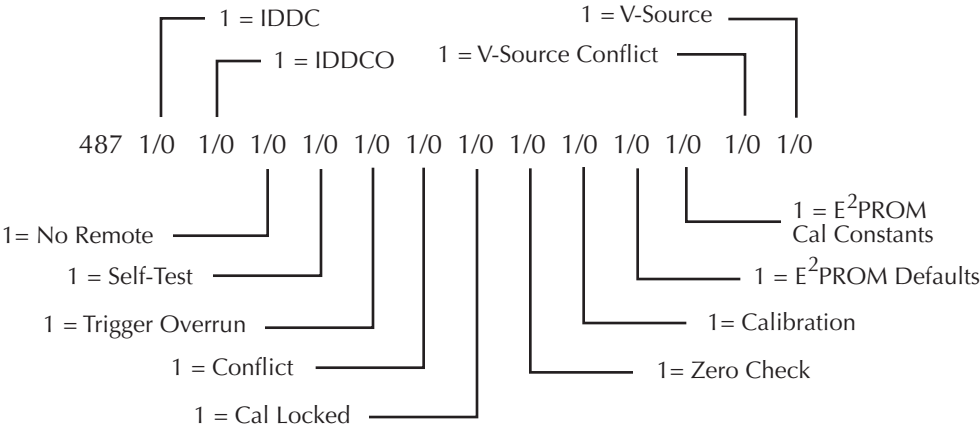
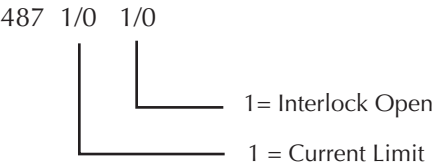


Figure C-3
U9 voltage source status word



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. [Table C-2](#) lists the meanings of the various bits and [Figure C-4](#) shows the general format of the status byte, which is obtained by using the SPE, SPD polling sequence.

If the status byte is read when no SRQ was generated by the Model 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 (see [Table C-1](#)). The Model 6487 may 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 Model 6487, bit 6 of the status byte will be 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 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 (see [Figure C-2](#).)

RQS (B6) — Set when the Model 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 (see [Figure C-3](#)).

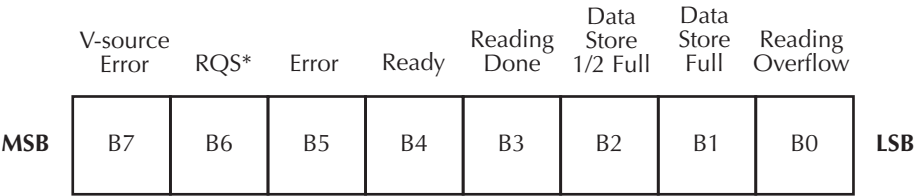
***NOTE** Once the Model 6487 has generated an SRQ, its status byte must be read to clear the SRQ line. Otherwise, the instrument will continuously assert SRQ.*

Table C-2
Status byte and SRQ mask interpretation

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 C-4
Status byte format



* Status bye only

D IEEE-488 Bus Overview

- **Bus description** – This section gives a detailed description of the bus. Introduces and defines the controller, talker, and listener.
- **Bus lines** – This section describes the operation of data lines, bus management lines, and handshake lines.
- **Bus commands** – This section describes the purpose of bus commands, lists the three categories of bus commands, and defines the three categories.
- **Interface function codes** – This section lists and defines the interface function codes for the Model 6487.

Introduction

The IEEE-488 bus is a communication system between two or more electronic devices. A device can be either an instrument or a computer. When a computer is used on the bus, it serves as a supervisor of the communication exchange between all the devices and is known as the controller. Supervision by the controller consists of determining which device will talk and which device will listen. As a talker, a device will output information; as a listener, a device will receive information. To simplify the task of keeping track of the devices, a unique address number is assigned to each.

On the bus, only one device can talk at a time and is addressed to talk by the controller. The device that is talking is known as the active talker. The devices that need to listen to the talker are addressed to listen by the controller. Each listener is then referred to as an active listener. Devices that do not need to listen are instructed to unlisten. The reason for the unlisten instruction is to optimize the speed of bus information transfer since the task of listening takes up bus time.

Through the use of control lines, a handshake sequence takes place in the transfer process of information from a talker to a listener. This handshake sequence helps ensure the credibility of the information transfer. The basic handshake sequence between an active controller (talker) and a listener is as follows:

1. The listener indicates that it is ready to listen.
2. The talker places the byte of data on the bus and indicates that the data is available to the listener.
3. The listener, aware that the data is available, accepts the data and then indicates that the data has been accepted.
4. The talker, aware that the data has been accepted, stops sending data and indicates that data is not being sent.
5. The listener, aware that there is no data on the bus, indicates that it is ready for the next byte of data.

Bus description

The IEEE-488 bus, which is also referred to as the GPIB (General Purpose Interface Bus), was designed as a parallel transfer medium to optimize data transfer without using an excessive number of bus lines. In keeping with this goal, the bus has only eight data lines that are used for both data and with most commands. Five bus management lines and three handshake lines round out the complement of bus signal lines.

A typical setup for controlled operation is shown in [Figure D-1](#). Generally, a system will contain one controller and a number of other instruments to which the commands are given. Device operation is categorized into three operators: controller, talker, and listener. The controller controls the instruments on the bus. The talker sends data while a listener receives data. Depending on the type of instrument, any particular device can be a talker only, a listener only, or both a talker and listener.

There are two categories of controllers: system controller and basic controller. Both are able to control other instruments, but only the system controller has the absolute authority in the system. In a system with more than one controller, only one controller may be active at any given time. Certain protocol is used to pass control from one controller to another.

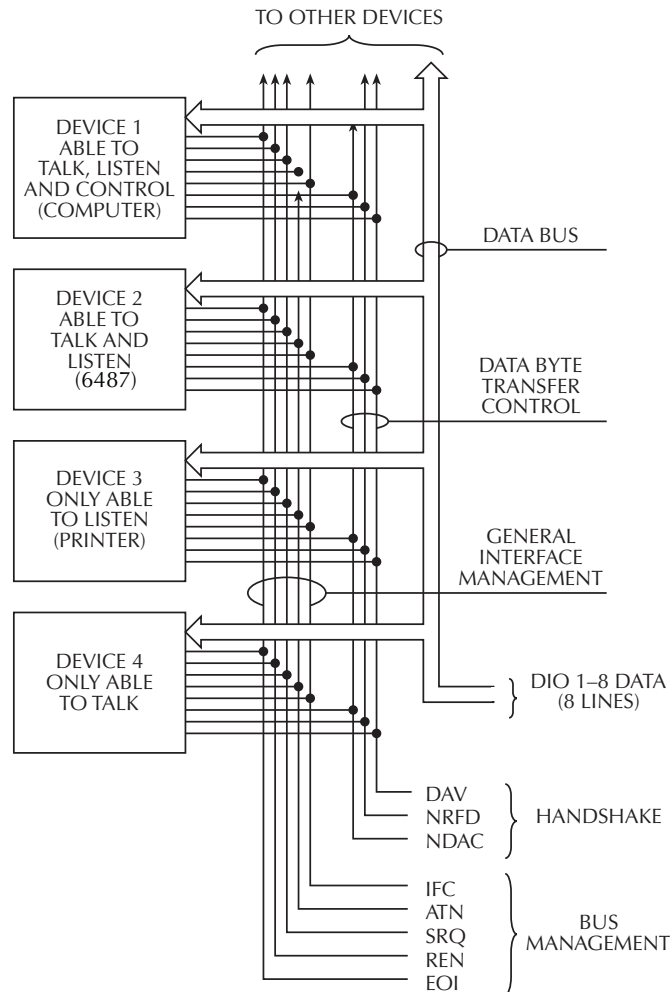
The IEEE-488 bus is limited to 15 devices, including the controller. Thus, any number of talkers and listeners up to that limit may be present on the bus at one time. Although several devices may be commanded to listen simultaneously, the bus can have only one active talker or communications would be scrambled.

A device is placed in the talk or listen state by sending an appropriate talk or listen command. These talk and listen commands are derived from an instrument's primary address. The primary address may have any value between 0 and 31, and is generally set by rear panel DIP switches or programmed in from the front panel of the instrument. The actual listen address value sent out over the bus is obtained by ORing the primary address with \$20. For example, if the primary address is \$14, the actual listen address is \$34 ($\$34 = \$14 + \20). In a similar manner, the talk address is obtained by ORing the primary address with \$40. With the present example, the talk address derived from a primary address of \$14 would be \$54 ($\$54 = \$14 + \$40$).

The IEEE-488 standards also include another addressing mode called secondary addressing. Secondary addresses lie in the range of \$60-\$7F. Note, however, that many devices, including the Model 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.

Figure D-1
IEEE-488 bus configuration



Bus lines

The signal lines on the IEEE-488 bus are grouped into three different categories: data lines, management lines, and handshake lines. The data lines handle bus data and commands, while the management and handshake lines ensure that proper data transfer and operation takes place. Each bus line is active low, with approximately zero volts representing a logic 1 (true). The following paragraphs describe the operation of these lines.

Data lines

The IEEE-488 bus uses eight data lines that transfer data one byte at a time. DIO1 (Data Input/Output) through DIO8 (Data Input/Output) are the eight data lines used to transmit both data and multiline commands and are bi-directional. The data lines operate with low true logic.

Bus management lines

The five bus management lines help to ensure proper interface control and management. These lines are used to send the uniline commands.

ATN (Attention) — The ATN state determines how information on the data bus is to be interpreted.

IFC (Interface Clear) — The IFC line controls clearing of instruments from the bus.

REN (Remote Enable) — The REN line is used to place the instrument on the bus in the remote mode.

EOI (End or Identify) — The EOI line is used to mark the end of a multi-byte data transfer sequence.

SRQ (Service Request) — The SRQ line is used by devices when they require service from the controller.

Handshake lines

The bus handshake lines operate in an interlocked sequence. This method ensures reliable data transmission regardless of the transfer rate. Generally, data transfer will occur at a rate determined by the slowest active device on the bus.

One of the three handshake lines is controlled by the source (the talker sending information), while the remaining two lines are controlled by accepting devices (the listener or listeners receiving the information). The three handshake lines are:

DAV (DATA VALID) — The source controls the state of the DAV line to indicate to any listening devices whether or not data bus information is valid.

NRFD (Not Ready For Data) — The acceptor controls the state of NRFD. It is used to signal to the transmitting device to hold off the byte transfer sequence until the accepting device is ready.

NDAC (Not Data Accepted) — NDAC is also controlled by the accepting device. The state of NDAC tells the source whether or not the device has accepted the data byte.

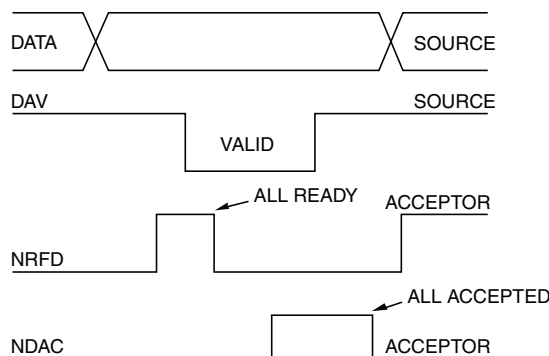
The complete handshake sequence for one data byte is shown in [Figure D-2](#). Once data is placed on the data lines, the source checks to see that NRFD is high, indicating that all active devices are ready. At the same time, NDAC should be low from the previous byte transfer. If these conditions are not met, the source must wait until NDAC and NRFD have

the correct status. If the source is a controller, NRFD and NDAC must be stable for at least 100ns after ATN is set true. Because of the possibility of a bus hang up, many controllers have time-out routines that display messages in case the transfer sequence stops for any reason.

Once all NDAC and NRFD are properly set, the source sets DAV low, indicating to accepting devices that the byte on the data lines is now valid. NRFD will then go low, and NDAC will go high once all devices have accepted the data. Each device will release NDAC at its own rate, but NDAC will not be released to go high until all devices have accepted the data byte.

The previous sequence is used to transfer both data, talk, and listen addresses, as well as multiline commands. The state of the ATN line determines whether the data bus contains data, addresses, or commands as described in the following paragraphs.

Figure D-2
IEEE-488 handshake sequence



Bus commands

The instrument may be given a number of special bus commands through the IEEE-488 interface. The following paragraphs briefly describe the purpose of the bus commands which are grouped into the following three categories.

1. **Uniline commands** — Sent by setting the associated bus lines true. For example, to assert REN (Remote Enable), the REN line would be set low (true).
2. **Multiline commands** — General bus commands which are sent over the data lines with the ATN line true (low).
3. **Common commands** — Commands that are common to all devices on the bus; sent with ATN high (false).
4. **SCPI commands** — Commands that are particular to each device on the bus; sent with ATN (false).

These bus commands and their general purpose are summarized in [Table D-1](#).

Table D-1

IEEE-488 bus command summary

Command type	Command	State of ATN line	Comments
Uniline	REN (Remote Enable)	X	Set up devices for remote operation.
	EOI	X	Marks end of transmission.
	IFC (Interface Clear)	X	Clears interface.
	ATN (Attention)	Low	Defines data bus contents.
	SRQ	X	Controlled by external device.
Multiline Universal	LLO (Local Lockout)	Low	Locks out local operation.
	DCL (Device Clear)	Low	Returns device to default conditions.
	SPE (Serial Enable)	Low	Enables serial polling.
	SPD (Serial Poll Disable)	Low	Disables serial polling.
Addressed	SDC (Selective Device Clear)	Low	Returns unit to default conditions.
	GTL (Go To Local)	Low	Returns device to local.
Unad- dressed	UNL (Unlisten)	Low	Removes all listeners from the bus.
	UNT (Untalk)	Low	Removes any talkers from the bus.
Common	—	High	Programs IEEE-488.2 compatible instruments for common operations.
SCPI	—	High	Programs SCPI compatible instruments for particular operations.

Table D-2
Command codes

D ₇ D ₆ D ₅ D ₄	D ₃ D ₂ D ₁ D ₀ Column Row				Command	1 (A)	1 (B)	2 (A)	2 (B)	3 (A)	3 (B)	4 (A)	Primary Address	4 (B)	5 (A)	5 (B)	6 (A)	6 (B)	7 (A)	7 (B)		
Bits	D ₃	D ₂	D ₁	D ₀	Command	X	X	X	Primary Address	X	Primary Address	X	Primary Address	X	Primary Address	X	X	X	X	X		
	0	0	0	0	0 (A)	0 (B)	1 (A)	1 (B)	2 (A)	2 (B)	3 (A)	3 (B)	4 (A)	Primary Address	5 (A)	5 (B)	6 (A)	6 (B)	7 (A)	7 (B)		
	0	0	0	0	NUL	DLE	0	0	SP	0	0	16	@	0	P	16			p			
	0	0	0	1	SOH	DC1	1	1	!	1	1	17	A	1	Q	17	a		q			
	0	0	1	0	STX	DC2	2	2	"	2	2	18	B	2	R	18	b		r			
	0	0	1	1	ETX	DC3	3	3	#	3	3	19	C	3	S	19	c		s			
	0	1	0	0	EOT	DC4	4	4	\$	4	4	20	D	4	T	20	d		t			
	0	1	0	1	ENQ	PPC*	5	5	%	5	5	21	E	5	U	21	e		u			
	0	1	1	0	ACK	SYN	6	6	&	6	6	22	F	6	V	22	f		v			
	0	1	1	1	BEL	ETB	7	7	'	7	7	23	G	7	W	23	g		w			
	1	0	0	0	BS	CAN	8	8	(	8	8	24	H	8	X	24	h		x			
	1	0	0	1	HT	TCT*	9	9	)	9	9	25	I	9	Y	25	i		y			
	1	0	1	0	LF	SUB	10	:	•	10	:	26	J	10	Z	26	j		z			
	1	0	1	1	VT	ESC	11	;	+	11	;	27	K	11	[	27	k		{			
	1	1	0	0	FF	FS	12	<	,	12	<	28	L	12	\	28	l		:			
	1	1	0	1	CR	GS	13	=	-	13	=	29	M	13	]	29	m		}			
	1	1	1	0	SO	RS	14	>	.	14	>	30	N	14	^	30	n		≡			
	1	1	1	1	SI	US	15	?	/	15	?	UNL	O	15	∞	UNT	o		DEL			
					ADDRESSED COMMAND GROUP (ACG)	UNIVERSAL COMMAND GROUP (UCCG)				LISTEN ADDRESS GROUP (LAG)				TALK ADDRESS GROUP (TAG)								
					PRIMARY COMMAND GROUP (PCG)										SECONDARY COMMAND GROUP (SDC)							

*PPC (PARALLEL POLL CONFIGURE) PPU (PARALLEL POLL UNCONFIGURE),
and TCT (TAKE CONTROL) not implemented by Model 6514.
Note: D₀ = DIO1 ... D₇ = DIO8; X = Don't Care.

*PPC (PARALLEL POLL CONFIGURE) PPU (PARALLEL POLL UNCONFIGURE),
and TCT (TAKE CONTROL) not implemented by Model 6514.
Note: D₀ = DIO1 ... D₇ = DIO8; X = Don't Care.

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 so 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 multiline commands.

SRQ (Service Request) — SRQ is asserted by a device when it requires service from a controller.

Universal multiline commands

Universal commands are those multiline 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 Model 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's SCPI standard.

Generally, these commands are sent as one or more ASCII characters that tell the device to perform a particular operation, such as setting a range or closing a relay. The IEEE-488 bus treats these commands as data in that ATN is false when the commands are transmitted.

Command codes

Command codes for the various commands that use the data lines are summarized in [Table D-2](#). Hexadecimal and the decimal values for the various commands are listed in [Table D-3](#).

Table D-3
Hexadecimal and decimal command codes

Command	Hex value	Decimal value
GTL	01	1
SDC	04	4
GET	08	8
LLO	11	17
DCL	14	20
SPE	18	24
SPD	19	25
LAG	20-3F	32-63
TAG	40-5F	64-95
SCG	60-7F	96-127
UNL	3F	63
UNT	5F	95

Typical command sequences

For the various multiline commands, a specific bus sequence must take place to properly send the command. In particular, the correct listen address must be sent to the instrument before it will respond to addressed commands. [Table D-4](#) lists a typical bus sequence for sending the addressed multiline commands. In this instance, the SDC command is being sent to the instrument. UNL is generally sent as part of the sequence to ensure that no other active listeners are present. Note that ATN is true for both the listen command and the SDC command byte itself.

Table D-4

Typical bus sequence

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 = 22.

[Table D-5](#) gives a typical common command sequence. In this instance, ATN is true while the instrument is being addressed, but it is set high while sending the common command string.

Table D-5

Typical addressed command sequence

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 = 22.

IEEE command groups

Command groups supported by the Model 6487 are listed in [Table D-6](#). Common commands and SCPI commands are not included in this list.

Table D-6
IEEE command groups

	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 Model 6487 are listed in [Table D-7](#).

Table D-7

Model 6487 interface function codes

Code	Interface function
SH1	Source Handshake capability
AH1	Acceptor Handshake capability
T5	Talker (basic talker, talk-only, serial poll, unaddressed to talk on LAG)
L4	Listener (basic listener, unaddressed to listen on TAG)
SR1	Service Request capability
RL1	Remote/Local capability
PP0	No Parallel Poll capability
DC1	Device Clear capability
DT1	Device Trigger capability
C0	No Controller capability
E1	Open collector bus drivers
TE0	No Extended Talker capability
LE0	No Extended Listener capability

The codes define Model 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).

E IEEE-488 and SCPI Conformance Information

- [GPIB 488.1 Protocol](#) – This section introduces the GPIB 488.1 protocol.
- [Selecting the 488.1 protocol](#) – This section describes how to select the 488.1 protocol.
- [Protocol differences](#) – This section covers the differences between the 488.1 protocol and the SCPI protocol.

Introduction

The IEEE-488.2 standard requires specific information about how the Model 6487 implements the standard. Paragraph 4.9 of the IEEE-488.2 standard (Std 488.2-1987) lists the documentation requirements. [Table E-1](#) provides a summary of the requirements and provides the information or references the manual for that information. [Table E-2](#) lists the coupled commands used by the Model 6487.

The Model 6487 complies with SCPI version 1996.0. [Table 14-1](#) through [Table 14-9](#) list the SCPI confirmed commands and the non-SCPI commands implemented by the Model 6487.

Table E-1

IEEE-488 documentation requirements

	Requirements	Description or Reference
(1)	IEEE-488 Interface Function Codes.	See Appendix D .
(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 (Section 14).
(5)	Message Exchange Options:	
(a)	Input buffer size.	2048 bytes.
(b)	Queries that return more than one response message unit.	None.
(c)	Queries that generate a response when parsed.	All queries (Common Commands and SCPI).
(d)		None.
(e)	Queries that generate a response when read.	See Table E-2 .
(6)	Coupled commands.	Contained in SCPI command subsystems tables (see Table 14-1 through Table 14-9).
(7)	Functional elements required for SCPI commands.	Block display messages: 12 characters max.
(8)	Buffer size limitations for block data.	See Programming Syntax in Section 9 .
(9)	Syntax restrictions.	See Programming Syntax in Section 9 .
(10)	Response syntax for every query command.	None.
(11)	Device-to-device message transfer that does not follow rules of the standard.	See Display Subsystem in Section 13 .
(12)	Block data response size.	See Common Commands in Section 11 .
(13)	Common Commands implemented by 6487.	Appendix F .
(14)	Calibration query information.	Not applicable.
	Trigger macro for *DDT.	

Table E-1 (cont.)
IEEE-488 documentation requirements

	Requirements	Description or Reference
(15)	Macro information.	Not applicable.
(16)	Response to *IDN (identification).	See Common Commands in Section 11 .
(17)	Storage area for *PUD and *PUD?	Not applicable.
(18)	Resource description for *RDT and *RDT?	Not applicable.
(19)	Effects of *RST, *RCL, and *SAV.	See Common Commands in Section 11 .
(20)	*TST information.	See Common Commands in Section 11 .
(21)	Status register structure.	See Status Structure in Section 10 .
(22)	Sequential or overlapped commands.	All are sequential except :INIT which is overlapped.
(23)	Operation complete messages.	*OPC, *OPC?, and *WAI; see Common Commands in Section 11 .

Table E-2
Coupled commands

Sending	Changes	To
CALC2:NULL:ACQ	CALC2:NULL:OFFS <n>	Acquired value
TRAC:POIN <n>	TRAC:FEED:CONT <name>	NEV
TRAC:CLE	TRAC:FEED:CONT <name> TRAC:CLE	NEV

GPIB 488.1 Protocol

The Model 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 Model 6487. Operation differences between the two protocols are discussed in this appendix.*

Selecting the 488.1 protocol

Perform the following steps to select 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 setup the Model 6487 to use GPIB from the local measurement mode:*

- *Press the COMM button.*
 - *Using the RANGE keys, select GPIB.*
 - *Press Enter to complete the change.*
1. Press CONFIG (CONFIGURE: will be displayed).
 2. Press COMM to access the communications menu. If a BAUD is displayed flashing, the 6487 is configured to use the RS-232 bus. See the Note above and change to control over the 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 a “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. To summarize:

1 = SCPI protocol
0 = 488.1 protocol

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 Model 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

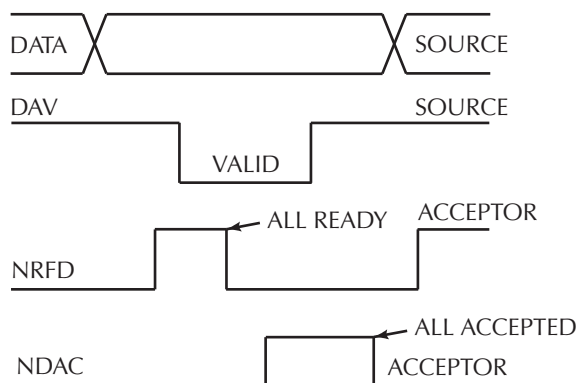
NDAC hold-off is included with the GPIB 488.1 protocol mode to allow a single instrument to hold off all others on the bus until it is finished executing a command. The following command controls NDAC hold-off:

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 [Figure E-1](#) for the complete IEEE-488 handshake sequence.

Figure E-1

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 Model 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.

F Remote Calibration

- [Calibration commands](#) — Summarizes those commands necessary to calibrate the Model 6487 by remote.
- [Remote calibration overview](#) — Gives an overview of the basic procedure for calibrating the Model 6487 via remote.

Introduction

This appendix contains a summary of Model 6487 remote calibration commands and a basic remote calibration procedure. See [Section 16](#) for complete calibration information.

Calibration commands

[Table F-1](#) summarizes Model 6487 remote calibration commands.

Table F-1

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 0V 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.
:UNPRotected	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 [Section 16](#) for details on calibration steps, calibration points, and test equipment connections.

1. Send the following command to unlock calibration:
:CAL:PROT:CODE 'KI006487'
Note that the above command uses the factory default code.
2. Perform voltage offset correction by sending the following command:
:CAL:UNPR:VOFF
Be sure a triax shielding cap is connected to the INPUT jack before sending the above command.
3. Send the appropriate command to select the current range to be calibrated. For example, the following command selects the 20mA range:
:SENS:CURR:RANG 2e-2
4. Make appropriate connections (see [Figure 16-1](#) and [Figure 16-2](#)), then send the commands for each calibration point for the selected function and range. For example, send the following commands for the 20mA range:
:CAL:PROT:SENS 0
:CAL:PROT:SENS 2e-2
:CAL:PROT:SENS -2e-2
5. Repeat steps 3 and 4 for each range ([Table F-2](#)).

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 50V and 500V ranges. See [Section 2](#) for interlock information.

6. Be sure the DMM is connected to the Model 6487 voltage source terminals (see [Figure 16-3](#)), then send the commands for each calibration point for the selected range, as summarized in [Table F-3](#). Be sure to include the actual DMM reading for each step where shown.
7. Repeat step 6 for each voltage source range.
8. 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
9. Finally, send the following commands to save calibration constants and then lock out calibration:
:CAL:PROT:SAVE
:CAL:PROT:LOCK

Table F-2
Current calibration commands by range

Range	Commands*
2nA	:SENS:CURRE:RANG 2e-9 :CAL:PROT:SENS 0 :CAL:PROT:SENS 2e-9 :CAL:PROT:SENS -2e-9
20nA	:SENS:CURRE:RANG 2e-8 :CAL:PROT:SENS 0 :CAL:PROT:SENS 2e-8 :CAL:PROT:SENS -2e-8
200nA	:SENS:CURRE:RANG 2e-7 :CAL:PROT:SENS 0 :CAL:PROT:SENS 2e-7 :CAL:PROT:SENS -2e-7
2μA	:SENS:CURRE:RANG 2e-6 :CAL:PROT:SENS 0 :CAL:PROT:SENS 2e-6 :CAL:PROT:SENS -2e-6
20μA	:SENS:CURRE:RANG 2e-5 :CAL:PROT:SENS 0 :CAL:PROT:SENS 2e-5 :CAL:PROT:SENS -2e-5
200μA	:SENS:CURRE:RANG 2e-4 :CAL:PROT:SENS 0 :CAL:PROT:SENS 2e-4 :CAL:PROT:SENS -2e-4
2mA	:SENS:CURRE:RANG 2e-3 :CAL:PROT:SENS 0 :CAL:PROT:SENS 2e-3 :CAL:PROT:SENS -2e-3
20mA	:SENS:CURRE:RANG 2e-2 :CAL:PROT:SENS 0 :CAL:PROT:SENS 2e-2 :CAL:PROT:SENS -2e-2

* Full-scale calibration values for 2nA to 2μA ranges should be calculated from calibrator voltages and standard resistance values. (See [Section 16](#).) Values for 20μA to 20mA ranges can be used as shown.

Table F-3

Voltage source calibration commands by range

Range	Commands*
10V	: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>
50V	: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>
500V	: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.

G Applications Guide

- **Measurement considerations** — Covers measurement considerations for low current measurements including [Leakage currents and guarding](#), [Input bias current](#), [Voltage burden](#), [Noise and source impedance](#), [Electrostatic interference and shielding](#), and [Making connections](#).
- **Applications** — Covers applications to measure [Diode leakage current](#), [Capacitor leakage current](#), [Measuring high resistance](#), [Cable insulation resistance](#), [Surface insulation resistance \(SIR\)](#), [Photodiode characterization prior to dicing](#), [Focused ion beam applications](#) and [Using switching systems to measure multiple current sources](#).

Measurement considerations

Some considerations for making accurate amps measurements are summarized as follows. Additional measurement considerations are covered in Appendix C of the Model 6487 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 200mV is not unusual.

The Keithley Model 6487 uses an alternative approach referred to as a feedback picoammeter, where the voltage burden is simply 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 for additional information on choosing the best insulator.

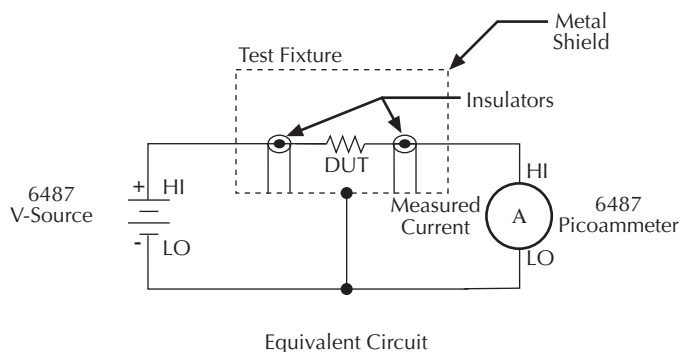
Humidity may also degrade low current measurements. The amount of water an insulator absorbs will vary depending upon the insulator. It is best to choose an insulator on which water vapor does not readily form a continuous film. Sometimes this is unavoidable if the material being measured absorbs water 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.

Figure G-1 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 G-1
Guarding to reduce leakage currents



Input bias current

An ideal picoammeter would read 0A with an open input. In practice, however, ammeters do have some current that flows when the input is open. This current is known as the input bias (offset) current. It should be noted that 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 Model 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.

Refer to [Figure G-2](#) to see how voltage burden affects current measurements. Assume V_S is 5mV and R_S is 5k Ω to configure a 1 μ A current source (5mV/5k Ω = 1 μ A). An ideal picoammeter with zero voltage burden would allow 1 μ A to flow and measure it accurately.

In practice, however, every picoammeter has a voltage burden. If the voltage burden (V_B) is 1mV, 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 1mV voltage burden caused a 20% reduction in actual current. Percent error in a measured reading (I_M) due to voltage burden can be calculated as follows:

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

The voltage burden of the Model 6487 depends on the selected range (see specifications). Voltage burden may be reduced by performing the voltage offset correction procedure.

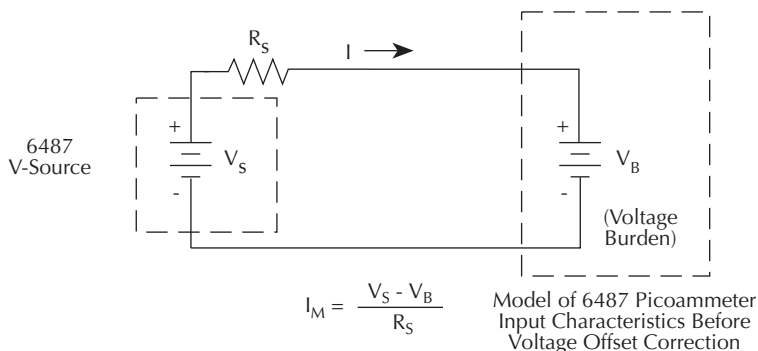
Voltage offset correction procedure

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
3. It is not necessary to disconnect signal cables from the Model 6487, but it is recommended that signal currents be reduced to zero if possible. During the calibration, the input impedance will be 3.5M Ω , therefore continued signal currents will present a corresponding voltage to the DUT.
4. Press ENTER to complete offset voltage calibration.
5. 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 Model 6487 will be used will adversely affect measurement results.*

Figure G-2

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, as we will now discuss.

Figure G-3 shows a simplified model of the feedback picoammeter. R_S and C_S represent the source resistance and source capacitance, V_S is the source voltage, and V_{NOISE} is the noise voltage. Finally, R_F and C_F are the feedback resistance and capacitance respectively.

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

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

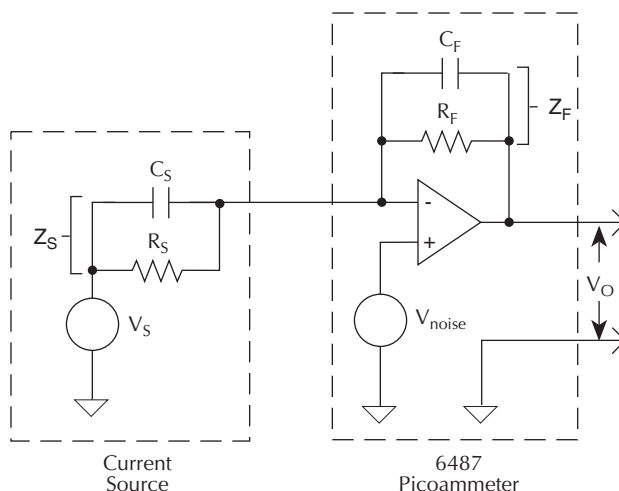
Note that as R_S decreases in value, the output noise increases. For example, when $R_F = R_S$, the input noise is multiplied by a factor of two. Since decreasing the source resistance can have a detrimental effect on noise performance, there are usually minimum recommended source resistance values based on measurement range. Table G-1 summarizes minimum recommended source resistance values for various measurement ranges. Note that the recommended source resistance varies by measurement range because the R_F value also depends on the measurement range.

Table G-1

Minimum recommended source resistance values

Range	Minimum recommended source resistance
2nA, 20nA	1 M Ω to 1 G Ω
200nA, 2 μ A	10 k Ω to 10 M Ω
20 μ A, 200 μ A	100 Ω to 100 k Ω
2mA, 20mA	10 Ω to 1k Ω

Figure G-3

Simplified model of a feedback picoammeter

Source capacitance

DUT source capacitance will also affect the noise performance of the Model 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 model in [Figure G-3](#). 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:

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

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

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

and,

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

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

The maximum value of source capacitance (C_S) for the lower ranges of the Model 6487 picoammeter is 10,000pF. 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 $I_{IN} \cdot R_{SERIES}$. For example, the range of resistance listed in [Table G-1](#) will result in voltage burden values in range of 2mV to 2V. 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.

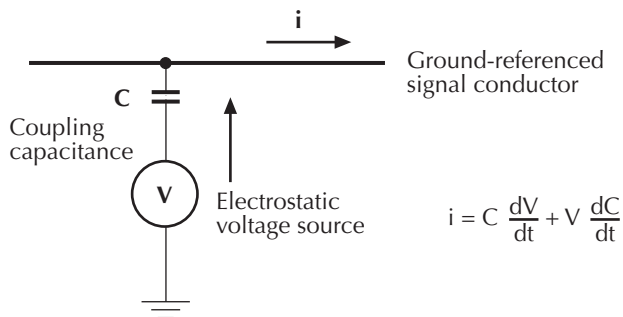
DC fields can produce noisy readings or undetected errors. These fields can be detected when movement near an experiment (such as the movement of the person operating the instrument or others in the immediate vicinity) causes fluctuations on the picoammeter's display. To perform a quick check for interference, 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.

Figure G-4 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:

$$i = C \frac{dV}{dt} + V \frac{dC}{dt}$$

Figure G-4
Electrostatic coupling

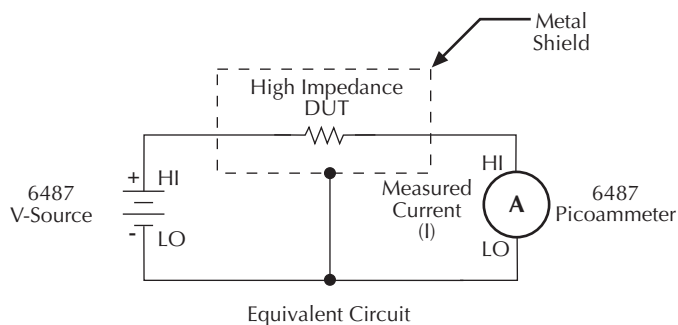


For example, two conductors, each with 1cm^2 area and spaced 1cm apart by air, will have almost 0.1pF of capacitance. With a voltage difference of 100V and a vibration causing a change of capacitance of 0.01pF/second (a 10% fluctuation), a current of 1pA will be generated.

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.

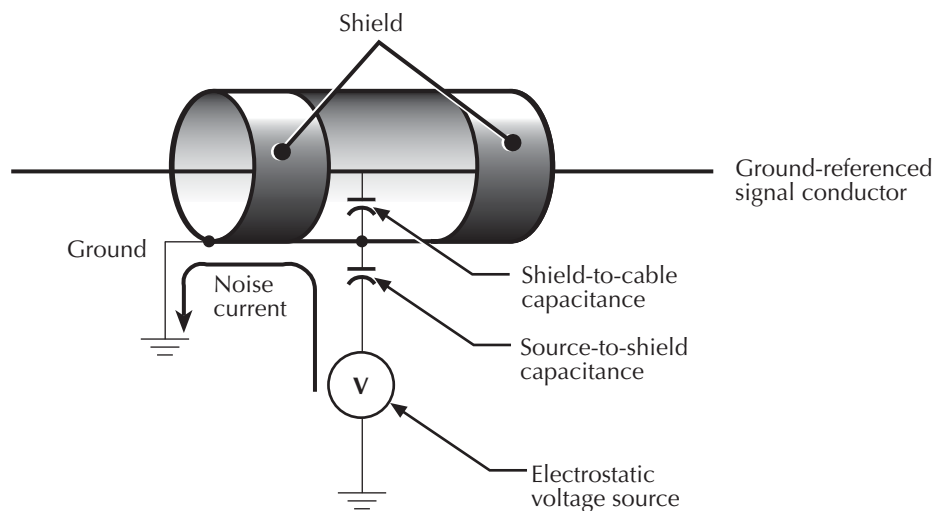
Figure G-5 illustrates an example of shielding. Made from a conductive material, the shield is always connected to the low impedance input of the electrometer or picoammeter. If circuit low is floating above ground, observe special safety precautions to prevent anyone from touching the shield, such as triaxial cable with the outer shield at earth potential.

Figure G-5
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 (Figure G-6). 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 G-6
Electrostatic shielding



To summarize, error currents due to electrostatic coupling can be minimized by following these guidelines:

- Keep all charged objects (including people) and conductors away from sensitive areas of the test circuit.
- Avoid movement and vibration near the test area.
- When measuring currents $< 10\text{nA}$, shield the device under test by surrounding it with a metal enclosure and connect the enclosure electrically to the test circuit common terminal.

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. (“[Leakage currents and guarding](#),” page G-2.)

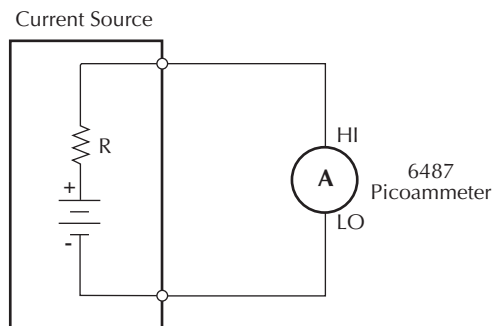
Making connections

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.**

[Figure G-7](#) 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.

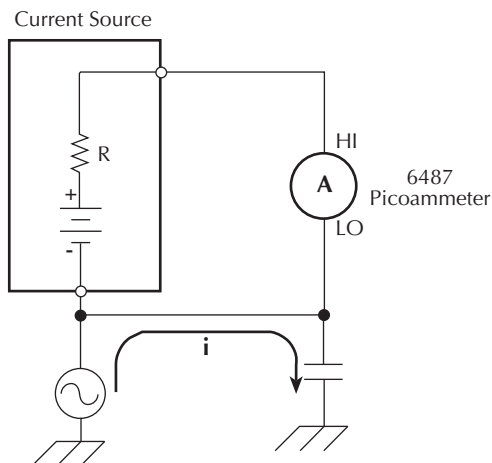
Figure G-7

Connecting the HI terminal (picoammeter) to high resistance



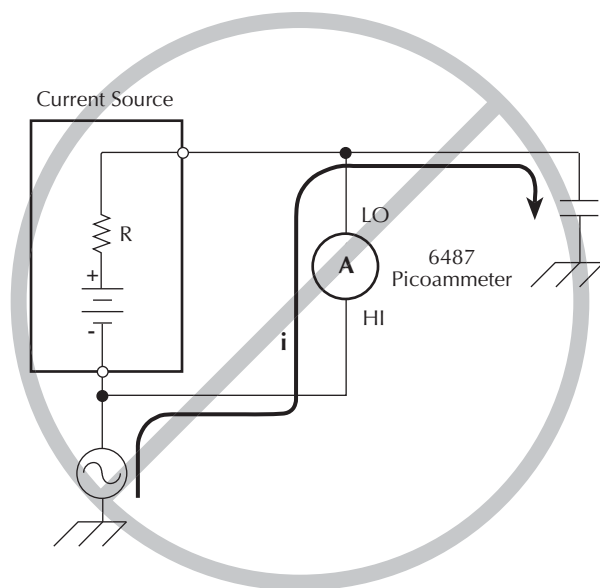
As shown in [Figure G-8](#), this will cause a current (i) to flow through the low to ground capacitance of the picoammeter (A). Picoammeter HI is connected to the higher resistance side of the circuit being measured, the “R” side of this current source. This circuit is connected properly, so this current does not flow through the picoammeter and, therefore, does not cause any measurement errors.

Figure G-8
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 [Figure G-9](#). This current may affect the measurement accuracy, especially at low signal levels.

Figure G-9
Improper connection

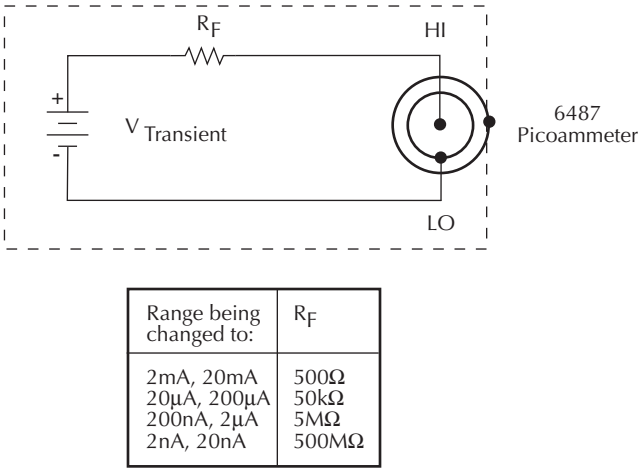


Refer to [“Connection fundamentals,” page 2-2](#) for details on appropriate types of cabling and connectors to use when making picoammeter measurements.

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 G-10](#)).

Figure G-10
Range change voltage transients

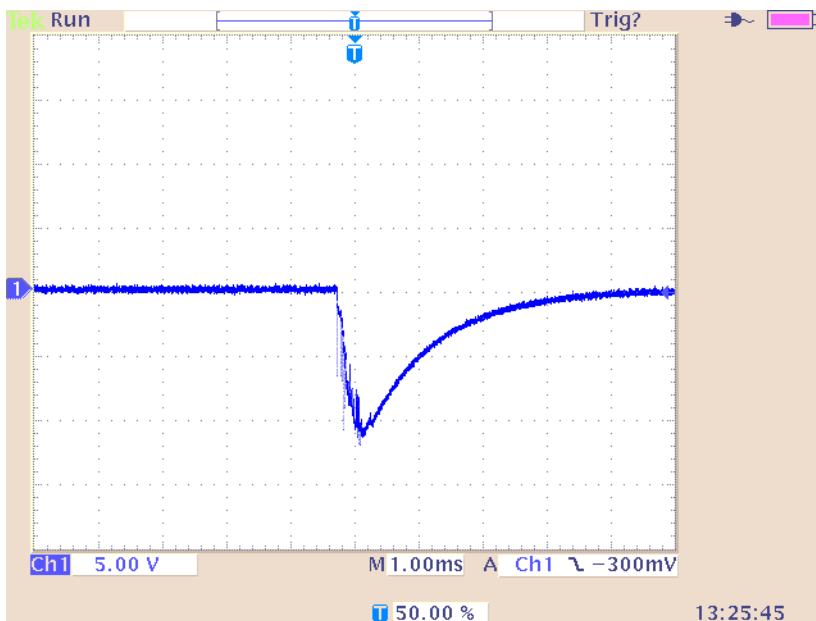


NOTE *The current that can be inadvertently delivered to the DUT is limited by an internal resistance. This internal resistance varies as the range is changed. For example, manually up-ranging from 2 μ A to the 20 μ A range can never deliver more than $10V/50k\Omega = 200\mu A$ to the DUT. This current will be further limited by any impedance of the DUT.*

Up-range input response

Figure G-11 illustrates the type of transient voltage that can be expected when up-ranging with a full-scale input signal ($200\mu\text{A}$ signal on $200\mu\text{A}$ range, up-range to 2mA 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 G-11 was measured with a positive input current.

Figure G-11
Transient Voltage



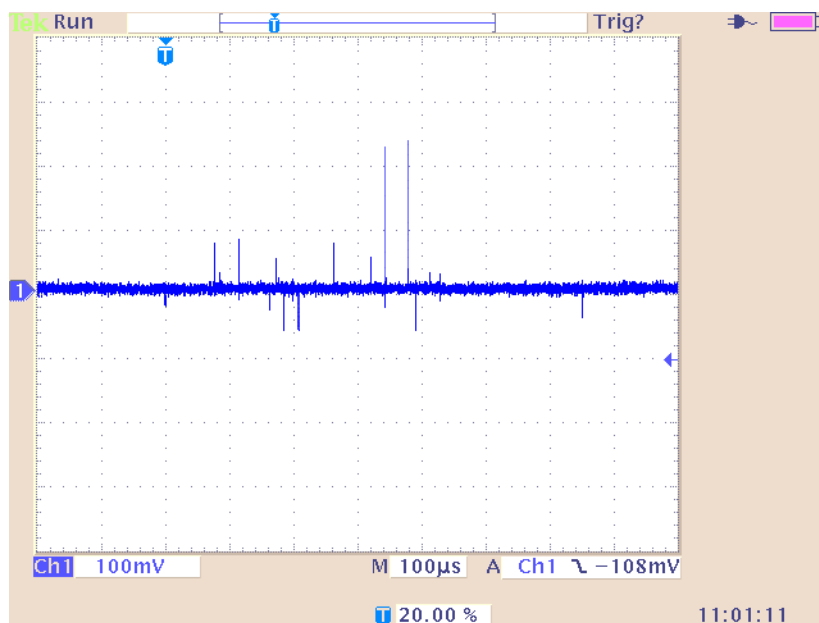
When it is necessary to up-range during auto-ranging operation, multiple ranges may be crossed to find the correct range. The duration of the transient in Figure G-11 can be extended in this case, but the magnitude will not increase significantly.

Down-range voltage transients are smaller

With the exception of the change from the 2mA range to the 200 μ A range, the down-range voltage transient is significantly smaller than the up-range transients. Figure G-12 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 2mA 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 G-12

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: 2nA and 20nA, 200nA and 2 μ A, 20 μ A and 200 μ A, 2mA and 20mA. This is not true when auto-ranging 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 (:RANGe:AUTO:ULIMit, see “Noise and safety shields” or “Autorange limits” in the 6487 User’s Manual) 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 Model 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 / off response

Figure G-13 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 $2\mu\text{A}$ 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 (Table G-2). 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 G-13
Zero check transient

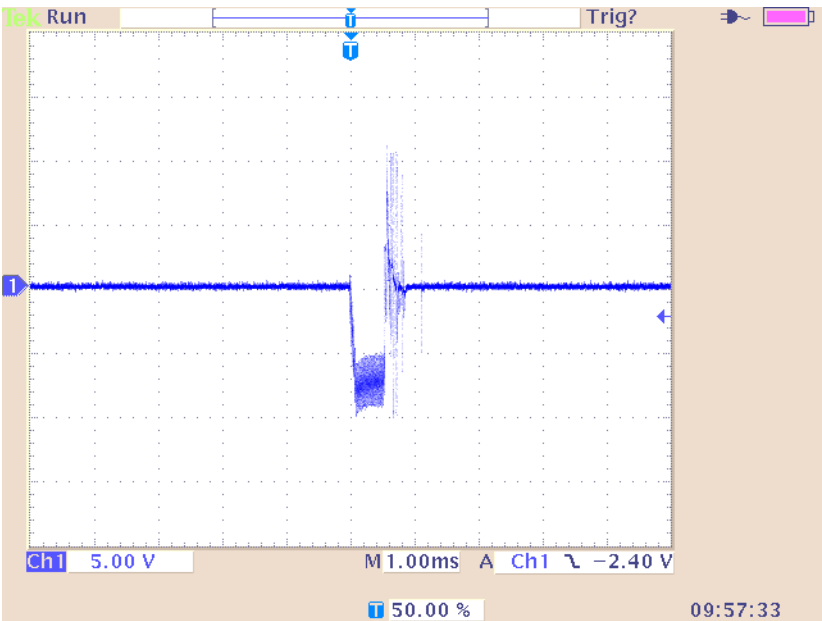


Table G-2
Internal impedance for zero check transient

Range Zcheck	Transient impedance
2mA,20mA	500Ω
20μA,200μA	50kΩ
200nA,2μA	3.5MΩ
2nA,20nA	11MΩ

Applications

Diode leakage current

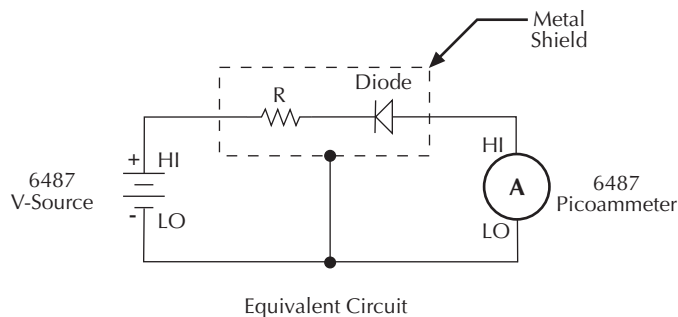
Figure G-14 shows how to measure the leakage current for a diode. By sourcing a positive voltage, the leakage current through the diode will be measured. Note that if you source a negative voltage, you will forward bias the diode. Resistor R is used to limit current in the event that the diode shorts out or it becomes forward biased. Select a value of R that will limit current to 20mA or less.

A profile for leakage current can be developed by measuring current at various voltage levels. For example, program the voltage source to sweep voltage from 1 to 10V in 1V steps. The Model 6487 performs a current measurement on each voltage step. To ensure that the voltage is settled before each current measurement, you can program the Model 6487 for a delay. For example, if you program the Model 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.

NOTE Buffer and voltage sweep operation are covered in [Section 6](#).

Figure G-14

Connections; diode leakage current test



NOTE The details on “Typical range change transients,” page G-12 may be particularly relevant to this application

Capacitor leakage current

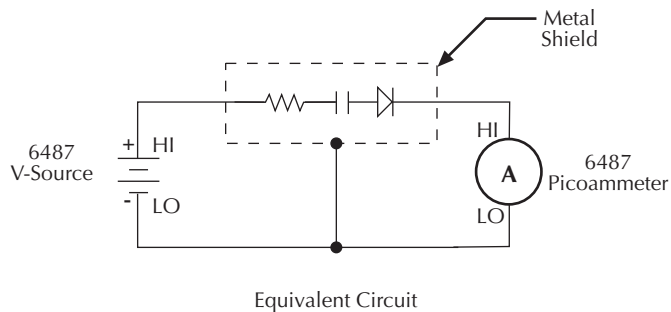
Figure G-15 shows how to measure the leakage current for a capacitor. The magnitude of the leakage is dependent on the type of dielectric and the applied voltage.

A resistor and a diode are used to limit noise for the measurement. 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,” page G-6). A good starting point is to choose a resistance value that results in an RC time constant of 0.5 to 2 seconds. (See Table G-1 for minimum recommended resistance values based on measurement range.) 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,” page 4-8).

For this test, a fixed bias voltage is to be applied to the capacitor for a specified time to allow the capacitor to fully charge (current decays exponentially with time). The leakage current is then measured. After the measurement, the voltage source is set to output 0V for a specified time to allow the capacitor to discharge. 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 G-15

Connections; capacitor leakage current test



Measuring high resistance

The Model 6487 can be used to make high resistance ($>1\text{G}\Omega$) measurements using the built-in voltage source. The alternating voltage ohms mode (Section 3) 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.

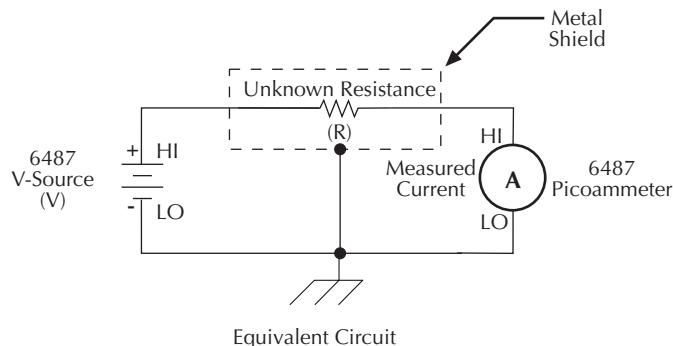
To measure high resistance, the internal voltage source is placed in series with the unknown resistance and the picoammeter. Since the voltage drop across the picoammeter is negligible, essentially all the voltage appears across the unknown resistance. The resulting current is measured by the picoammeter. 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 Model 6487 Picoammeter is shown in [Figure G-16](#). The HI terminal of the Model 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 Model 6487.

Figure G-16
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,”](#) page 3-21 in [Section 3](#) for details.

Cable insulation resistance

Figure G-17 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.

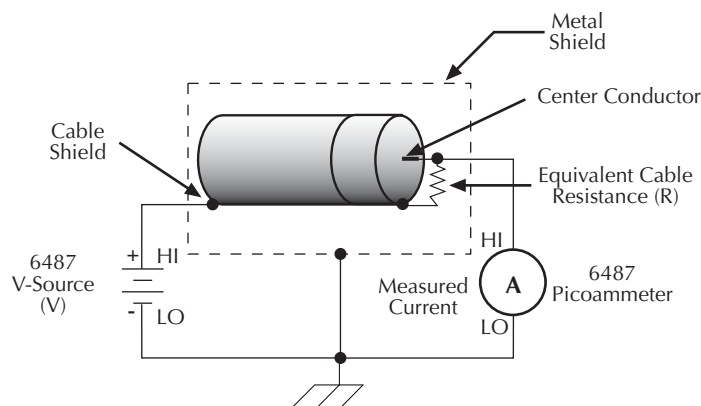
For this test, a fixed bias voltage is applied across the insulator for a specified time to allow the charging effects of cable capacitance to stabilize. The current is then measured. Cable resistance (R) can then be calculated as follows:

$$R = \frac{V}{I}$$

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

Figure G-17

Connections; cable insulation resistance test



Surface insulation resistance (SIR)

Figure G-18 shows how to measure the insulation resistance between PC board traces. Note that the drawing shows a “Y” test pattern for the measurement. This is a typical test pattern for SIR tests.

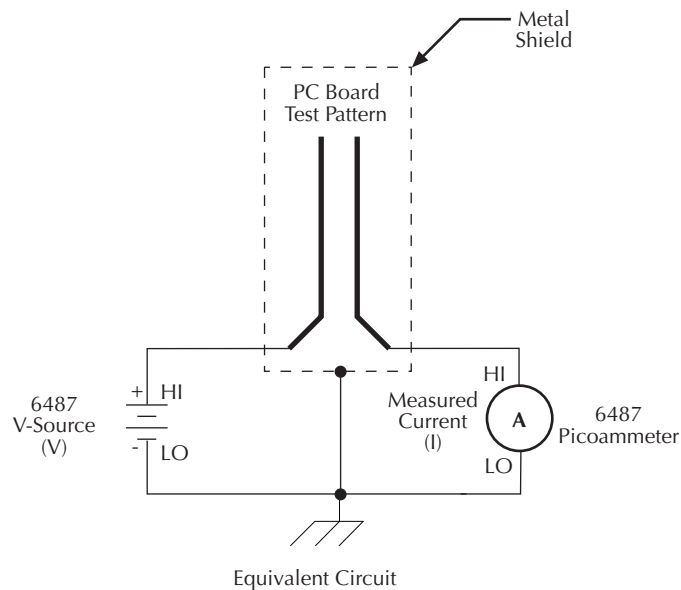
A bias voltage (typically 50V) is applied to the test pattern for a specified time (typically one second) to polarize the test pattern. The test voltage (typically 100V) is then applied and, after a specified time (typically one second), the Model 6487 measures the current. Surface insulation resistance can now be calculated as follows:

$$\text{SIR} = \frac{V}{I}$$

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

Figure G-18

Connections; surface insulation resistance test



Photodiode characterization prior to dicing

The Model 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 Model 6487, specialized equipment is required. This equipment includes a calibrated optical source in addition to semiconductor equipment (probe card or needle mounts, etc.). Several Model 6487s can be connected to probe pads to provide leakage current readings forced by the bias voltage source. As an alternative, one or more Model 6487s could be switched through a switching mainframe and matrix switch card arrangement to take current measurements from multiple pads.

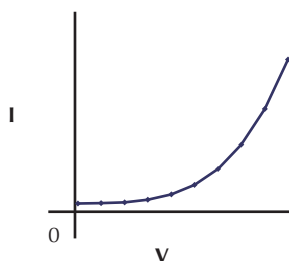
Measuring photodiode leakage can be described in two steps:

1. $V_{\text{sweep}}, I_{\text{meas}}$ in total darkness.
2. $V_{\text{bias}}, I_{\text{meas}}$ in calibrated optical flux.

In the 1st step, voltage sweeps and the resulting current leakage is measured (see “[Voltage sweeps](#),” page 6-8). 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 [Figure G-19](#).

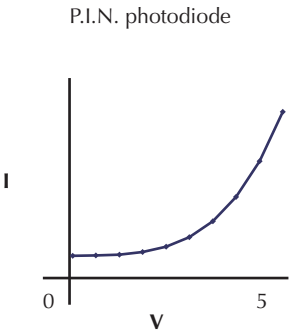
Figure G-19
General photodiode leakage

General photodiode



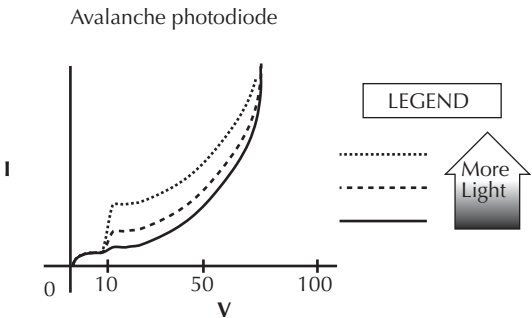
P.I.N. (Positive Intrinsic Negative) diodes respond as shown in [Figure G-20](#).

Figure G-20
PIN photodiode leakage



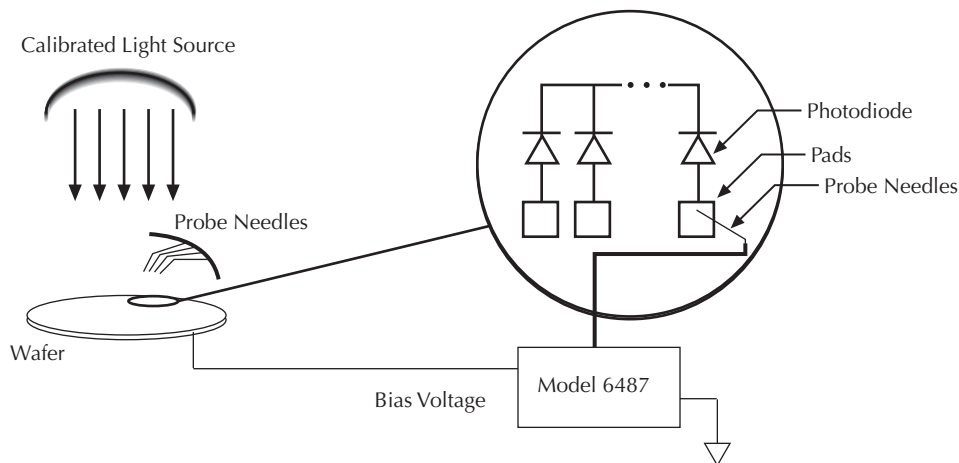
In total darkness, Avalanche diodes respond as shown by the solid line in [Figure G-21](#). Notice the small irregularity of the curve while sweeping around 10-12V. This irregularity is made larger under additional applied light (see dashed lines of [Figure G-21](#)).

Figure G-21
Avalanche photodiode leakage



Connections are made to the Model 6487 through the triax input connector (located on the rear panel) (Figure G-22) as well as the voltage source output terminals to provide the necessary bias voltage.

Figure G-22
Basic connection scheme



NOTE The details on “Typical range change transients,” page G-12 may be particularly relevant to this application

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.

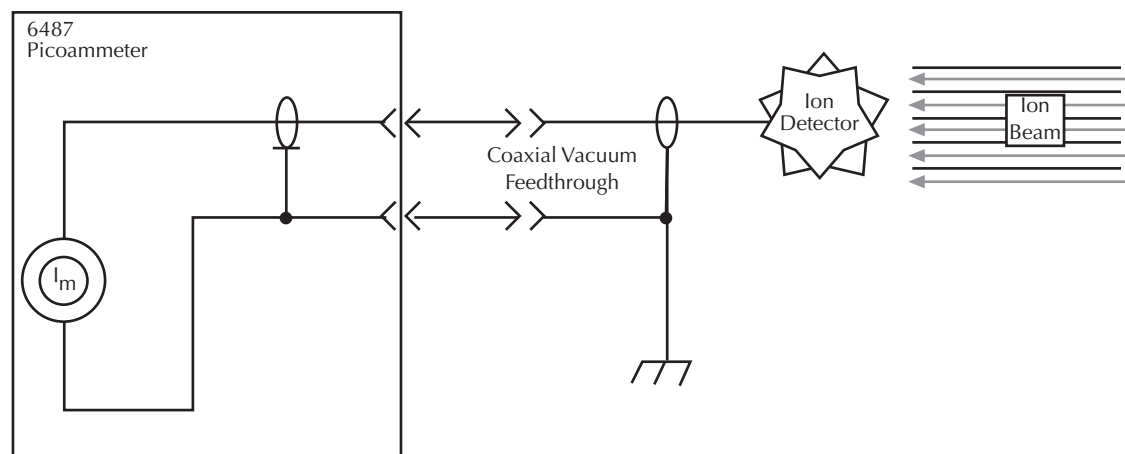
The secondary currents generated by the detectors are very low and require a high degree of accuracy and measurement repeatability. Currents as low as 5 or 6pA are not uncommon; therefore, the measurement device must be capable of achieving resolutions below 1pA.

The Model 6487 is ideal for this application because it offers a wide selection of range settings spanning from 20mA to 2nA. This will result in 5-1/2 digit resolution ranging from 100nA to 10fA. 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 triax 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 G-23).

Figure G-23

Focused Ion Beam signal connections



Using switching systems to measure multiple current sources

Refer to ["External trigger example,"](#) page 7-13.

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