

Model 2182/2182A Nanovoltmeter

User's Manual

2182A-900-01 Rev. A / June 2004



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Model 2182 and 2182A Nanovoltmeter User's Manual

This User's Manual supports both the Models 2182 and 2182A:

References to the Model 2182 apply to both the Models 2182 and 2182A.

References to the Model 2182/2182A apply to the Model 2182 with firmware version A10 or higher, and the Model 2182A with firmware version C01 or higher.

References to the Model 2182A applies to the Model 2182A with firmware version C01 or higher.

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Manual Print History

The print history shown below lists the printing dates of all Revisions and Addenda created for this manual. The Revision Level letter increases alphabetically as the manual undergoes subsequent updates. Addenda, which are released between Revisions, contain important change information that the user should incorporate immediately into the manual. Addenda are numbered sequentially. When a new Revision is created, all Addenda associated with the previous Revision of the manual are incorporated into the new Revision of the manual. Each new Revision includes a revised copy of this print history page.

Revision A (Document Number 2182A-900-01) June 2004

All Keithley product names are trademarks or registered trademarks of Keithley Instruments, Inc.
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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 manual for complete product specifications.

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

The types of product users are:

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

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

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

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

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

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

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

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

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

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

For maximum safety, do not touch the product, test cables, or any other instruments while power is applied to the circuit under test. ALWAYS remove power from the entire test system and discharge any capacitors before: connecting or disconnecting ca-

bles or jumpers, installing or removing switching cards, or making internal changes, such as installing or removing jumpers.

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


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


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


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


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

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

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

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

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

The  symbol indicates a connection terminal to the equipment frame.

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

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

Instrumentation and accessories shall not be connected to humans.

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

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

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

Table of Contents

1 Getting Started

General information	1-3
Warranty information	1-3
Contact information	1-3
Safety symbols and terms	1-3
Inspection	1-3
Options and accessories	1-4
Nanovoltmeter features	1-6
Front and rear panel familiarization	1-7
Front panel summary	1-7
Rear panel summary	1-11
Cleaning input connectors	1-13
Power-Up	1-14
Line power connection	1-14
Setting line voltage and replacing fuse	1-15
Power-up sequence	1-15
Line frequency	1-16
Display	1-16
Status and error messages	1-16
Default settings	1-16

2 Voltage and Temperature Measurements

Measurement overview	2-3
Voltage measurements	2-3
Temperature measurements	2-3
Performance considerations	2-5
Warm-up	2-5
ACAL (calibration)	2-5
Autozeroing modes	2-6
LSYNC (line cycle synchronization)	2-8
Pumpout current (low charge injection mode)	2-9
SCPI programming - ACAL, Front Autozero, Autozero, LSYNC, and Low Charge Injection	2-10
Connections	2-12
Connection techniques	2-12
Voltage only connections	2-14
Temperature only connections	2-15
Voltage and temperature connections	2-16
Cleaning test circuit connectors	2-17

Temperature configuration	2-18
Measuring voltage and temperature	2-19
SCPI programming - voltage and temperature measurements	2-20
Low-level considerations	2-22
Thermal EMFs	2-22
Noise	2-22
Applications	2-23
Low-resistance measurements	2-23
Standard cell comparisons	2-26
Heated Zener Reference and Josephson Junction Array comparisons	2-27

3 Range, Digits, Rate, and Filter

Range	3-3
Maximum readings	3-3
Manual ranging	3-3
Autoranging	3-4
SCPI programming - range	3-4
Digits	3-5
SCPI programming - digits	3-5
Rate	3-6
SCPI programming - rate	3-7
Filter	3-8
Analog filter	3-8
Digital filter	3-8
SCPI programming - filter	3-12

4 Relative, mX+b, and Percent (%)

Relative	4-3
REL Key	4-3
SCPI programming - relative	4-4
mX+b and percent (%)	4-6
mX+b	4-6
Percent (%)	4-7
SCPI programming - mX+b and percent	4-8

5 Ratio and Delta

Ratio	5-2
Basic procedure	5-2
Filter, Rel, and Ranging considerations	5-4
Delta	5-6
Selecting Delta	5-9
Delta measurement procedure using a SourceMeter	5-9
Filter considerations	5-15

SCPI programming - ratio and delta	5-16
Programming examples	5-16
Applications	5-18
Testing superconductor materials	5-19

6 Buffer

Buffer operations	6-2
Store	6-2
Recall	6-3
Buffer statistics	6-4
SCPI programming - buffer	6-5
Programming example	6-6

7 Triggering

Trigger model	7-3
Idle	7-3
Control source and event detection	7-4
Delay	7-4
Device action	7-5
Output trigger	7-5
Reading hold (autosettle)	7-6
Hold example	7-6
External triggering	7-7
External trigger	7-8
Voltmeter complete	7-8
External triggering example	7-9
External triggering with BNC connections	7-12
SCPI programming - triggering	7-13
Trigger model (remote operation)	7-13
Trigger model operation	7-15
Triggering commands	7-16
Programming example	7-17

8 Limits

Limit operations	8-3
Setting limit values	8-4
Enabling limits	8-4
SCPI programming - limits	8-5
Application	8-7
Sorting resistors	8-7

9	Stepping and Scanning	
	Step/Scan overview	9-3
	Internal Stepping/Scanning (Channels 1 and 2)	9-3
	External Stepping/Scanning	9-3
	Front panel trigger models	9-4
	Internal scanning	9-4
	Other Stepping/Scanning operations	9-6
	Stepping/Scanning controls	9-6
	Step/Scan configuration	9-7
	Stepping/Scanning examples	9-8
	Internal scanning	9-8
	Internal stepping	9-9
	External scanning	9-10
	SCPI programming - stepping and scanning	9-12
	Programming example	9-13
	Application — I-V curves using internal scan	9-14
	SCAN for IV curves [Measure V, sweep I, constant H (magnetic field) or T (temperature)]	9-14
10	Analog Output	
	Overview	10-3
	Operation	10-5
	Analog output connections	10-5
	Configure and control analog output	10-5
	Analog output rel	10-5
	SCPI programming - analog output	10-6
	Programming example	10-6
11	Remote Operation	
	Selecting and configuring an interface	11-3
	Interfaces	11-3
	Languages	11-3
	Interface selection and configuration procedures	11-4
	GPIB operation and reference	11-6
	GPIB bus standards	11-6
	GPIB bus connections	11-6
	Primary address selection	11-8
	QuickBASIC programming	11-8
	General bus commands	11-9
	Front panel GPIB operation	11-12
	Status structure	11-13
	Programming syntax	11-21

RS-232 interface reference	11-27
Sending and receiving data	11-27
Baud rate, flow control and terminator	11-27
RS-232 connections	11-29
Error messages	11-30

12 Common Commands

*CLS — Clear Status Clear status registers and error queue	12-3
*ESE <NRf> – Event Enable Program the standard event enable register ...	12-4
*ESE? – Event Enable Query Read the standard event register	12-4
*ESR? – Event Status Register Query Read register and clear it	12-6
*IDN? – Identification Query Read the identification code	12-7
*OPC – Operation Complete Set the OPC bit in the standard event register after all pending commands are complete	12-8
*OPC? – Operation Complete Query Place a “1” in the output queue after all pending operations are completed	12-10
*RCL – Recall Return to setup stored in memory	12-11
*RST – Reset Return 2182 to *RST defaults	12-12
*SAV – Save Save present setup in memory	12-12
*SRE <NRf> – Service Request Enable Program service request enable register	12-12
*SRE? – Service Request Enable Query Read service request enable register	12-12
*STB? – Status Byte Query Read status byte register	12-14
*TRG – Trigger Send bus trigger to 2182	12-15
*TST? – Self-Test Query Run self test and read result	12-15
*WAI – Wait-to-Continue Prevent execution of commands until previous commands are completed	12-16

13 SCPI Signal Oriented Measurement Commands

:CONFigure:<function>	13-2
:FETCh?	13-3
:READ?	13-3
:MEASure:<function>?	13-4

14 SCPI Reference Tables

15 Additional SCPI Commands

DISPlay subsystem	15-3
:TEXT commands	15-3
FORMat subsystem	15-4
:DATA command	15-4
:BORDER command	15-6
:ELEMENTs command	15-6
STATus subsystem	15-7
[:EVENT]? command	15-7
:ENABLE command	15-11
:CONDITION? command	15-13
:PRESet command	15-14
:QUEue commands	15-14
:SYSTem subsystem	15-16
:PRESet command	15-16
Performance commands	15-16
:BEEPer command	15-18
:KCLICK command	15-18
:POSetup <name> command	15-18
:VERSion? command	15-19
:ERRor? command	15-19
:CLEar command	15-19
:KEY <NRf> command	15-20

A Specifications

B Status and Error Messages

C Measurement Considerations

Measurement considerations	C-2
Thermoelectric potentials	C-2
Thermoelectric generation	C-3
Source resistance noise	C-4
Magnetic fields	C-6
Radio frequency interference	C-6
Ground loops	C-6
Shielding	C-8
Meter loading	C-9

D	Model 182 Emulation Commands	
E	Example Programs	
	Program examples	E-2
	Changing function and range	E-2
	One-shot triggering	E-4
	Generating SRQ on buffer full	E-5
	Storing readings in buffer	E-6
	Taking readings using the :READ? command	E-7
	Controlling the Model 2182 via the RS-232 COM2 port	E-8
F	IEEE-488 Bus Overview	
	Introduction	F-2
	Bus description	F-2
	Bus lines	F-4
	Data lines	F-4
	Bus management lines	F-4
	Handshake lines	F-5
	Bus commands	F-6
	Uniline commands	F-7
	Universal multiline commands	F-8
	Addressed multiline commands	F-9
	Address commands	F-9
	Unaddress commands	F-9
	Common commands	F-10
	SCPI commands	F-10
	Command codes	F-10
	Typical command sequences	F-11
	IEEE command groups	F-12
	Interface function codes	F-13
G	IEEE-488 and SCPI Conformance Information	
	Introduction	G-2
H	Measurement Queries	
	:FETCh?	H-2
	What it does	H-2
	Limitations	H-2
	Where appropriate	H-2
	:READ?	H-2
	What it does	H-2
	Limitations	H-3
	When appropriate	H-3

:MEASure[:<function>]?	H-3
What it does	H-3
Limitations	H-3
When appropriate	H-3
[:SENSe[1]]:DATA:FRESH?	H-4
What it does	H-4
Limitations	H-4
When appropriate	H-4
[:SENSe[1]]:DATA[:LAtest]?	H-4
What it does	H-4
Limitations	H-4
When appropriate	H-4
Examples	H-5
One-shot reading, DC volts, no trigger, fastest rate	H-5
One-shot reading, DC volts, bus trigger, auto ranging	H-5
One-shot reading, external trigger, auto delay enabled	H-5

I Delta, Pulse Delta, and Differential Conductance

Overview	I-2
Keithley instrumentation requirements	I-2
Operation overview	I-3
Test system configurations	I-5
Delta measurement process	I-6
Pulse Delta process	I-9
Pulse Delta measurements	I-9
Pulse Delta outputs	I-11
Differential Conductance process	I-14
Differential Conductance calculations	I-16

List of Illustrations

1 Getting Started

Figure 1-1	Model 2182 front panel	1-7
Figure 1-2	Model 2182 rear panel	1-11
Figure 1-3	Power module	1-14

2 Voltage and Temperature Measurements

Figure 2-1	Line cycle synchronization	2-8
Figure 2-2	Model 2107 input cable	2-13
Figure 2-3	LEMO connector - terminal identification	2-13
Figure 2-4	Connections - single channel voltage	2-14
Figure 2-5	Connections - dual channel voltage	2-15
Figure 2-6	Connections - temperature (internal reference)	2-15
Figure 2-7	Connections - temperature (simulated reference)	2-16
Figure 2-8	Connections - voltage and temperature (internal reference)	2-16
Figure 2-9	Connections - voltage and temperature (simulated reference)	2-17
Figure 2-10	4-Wire low-resistance measurement technique	2-23
Figure 2-11	Measuring switch contact resistance	2-24
Figure 2-12	Measuring switch contact resistance and temperature	2-25
Figure 2-13	Standard cell comparison measurements	2-26
Figure 2-14	Heated Zener characterization	2-27

3 Range, Digits, Rate, and Filter

Figure 3-1	Speed vs. noise characteristics	3-6
Figure 3-2	Moving and repeating filters	3-10

5 Ratio and Delta

Figure 5-1	Test circuit using constant current source	5-7
Figure 5-2	Delta measurement using bipolar source	5-8
Figure 5-3	Delta measurement connections	5-11
Figure 5-4	Triggering timing diagram	5-14
Figure 5-5	Calibrating 1:10 divider	5-18
Figure 5-6	Test circuit—Fixed I (Vary H)	5-20
Figure 5-7	H-V Curve (Fixed I)	5-21
Figure 5-8	SourceMeter output—2-point custom sweep	5-21
Figure 5-9	I-V Curve (Fixed H)	5-22
Figure 5-10	Test circuit—Fixed H (Vary I)	5-23
Figure 5-11	SourceMeter output—30-point custom sweep	5-25
Figure 5-12	Trigger link connections using two Model 2182s	5-26

6	Buffer	
Figure 6-1	Buffer locations	6-3
7	Triggering	
Figure 7-1	Front panel trigger model (without Stepping/Scanning)	7-3
Figure 7-2	Device action	7-5
Figure 7-3	Rear panel pinout	7-7
Figure 7-4	Trigger link input pulse specifications (EXT TRIG)	7-8
Figure 7-5	Trigger link output pulse specifications (VMC)	7-8
Figure 7-6	DUT test system	7-9
Figure 7-7	Trigger link connections	7-9
Figure 7-8	Operation model for triggering example	7-10
Figure 7-9	DIN to BNC trigger cable	7-12
Figure 7-10	Trigger model (remote operation)	7-13
8	Limits	
Figure 8-1	Default limits	8-3
Figure 8-2	Setup to test 10Ω resistors	8-7
Figure 8-3	Limits to sort 10Ω resistors (1%, 5%, and >5%)	8-8
9	Stepping and Scanning	
Figure 9-1	Front panel triggering (internal scanning)	9-5
Figure 9-2	Front panel triggering (other step/scan operations)	9-5
Figure 9-3	External scanning example with Model 7001	9-11
Figure 9-4	Waveform to be programmed into Model 2400	9-14
Figure 9-5	Setup of Model 2182 and Model 2400	9-15
11	Remote Operation	
Figure 11-1	IEEE-488 connector	11-6
Figure 11-2	IEEE-488 connections	11-7
Figure 11-3	IEEE-488 connector location	11-7
Figure 11-4	Model 2182 status model structure	11-14
Figure 11-5	Standard event status	11-16
Figure 11-6	Operation event status	11-16
Figure 11-7	Measurement event status	11-17
Figure 11-8	Questionable event status	11-17
Figure 11-9	Status byte and service request	11-19
Figure 11-10	RS-232 interface connector	11-29

12	Common Commands	
Figure 12-1	Standard event enable register	12-5
Figure 12-2	Standard event status register	12-7
Figure 12-3	Service request enable register	12-13
Figure 12-4	Status byte register	12-15

15	Additional SCPI Commands	
Figure 15-1	ASCII data format	15-4
Figure 15-2	IEE754 single precision data format (32 data bits)	15-5
Figure 15-3	IEEE754 double precision data format (64 data bits)	15-5
Figure 15-4	Measurement event register	15-8
Figure 15-5	Questionable event register	15-9
Figure 15-6	Operation event register	15-10
Figure 15-7	Measurement event enable register	15-12
Figure 15-8	Questionable event enable register	15-12
Figure 15-9	Operation event enable register	15-13
Figure 15-10	Key-press codes	15-21

C	Measurement Considerations	
Figure C-1	Thermal EMF generation	C-3
Figure C-2	Power line ground loops	C-7
Figure C-3	Eliminating ground loops	C-7
Figure C-4	Shielding example	C-8
Figure C-5	Meter loading	C-9

F	IEEE-488 Bus Overview	
Figure F-1	IEEE-488 bus configuration	F-3
Figure F-2	IEEE-488 handshake sequence	F-5
Figure F-3	Command codes	F-8

I	Delta, Pulse Delta and Differential Conductance	
Figure I-1	Delta, Pulse Delta, and Differential Conductance measurements	I-4
Figure I-2	Test system configurations	I-5
Figure I-3	Delta measurement technique	I-6
Figure I-4	Pulse Delta 3-point measurement technique	I-9
Figure I-5	Pulse timing	I-12
Figure I-6	Pulse sweep output examples	I-13
Figure I-7	Differential Conductance measurement process	I-15



List of Tables

1 Getting Started

Table 1-1	Fuse ratings	1-15
Table 1-2	Factory defaults	1-17

2 Voltage and Temperature Measurements

Table 2-1	Measurement channels	2-3
Table 2-2	SCPI commands - ACAL, Front Autozero, Autozero, LSYNC, and Low Charge Injection	2-10
Table 2-3	SCPI commands - voltage and temperature measurements	2-20

3 Range, Digits, Rate, and Filter

Table 3-1	SPCI commands - range	3-4
Table 3-2	SPCI commands - digits	3-5
Table 3-3	SCPI commands - rate	3-7
Table 3-4	SCPI commands - filter	3-12

4 Relative, $mX+b$, and Percent (%)

Table 4-1	SCPI commands - relative	4-4
Table 4-2	SCPI commands - $mX+b$ and percent	4-8

5 Ratio and Delta

Table 5-1	SCPI commands - ratio and delta	5-16
-----------	---------------------------------------	------

6 Buffer

Table 6-1	SCPI commands - buffer	6-5
-----------	------------------------------	-----

7 Triggering

Table 7-1	Auto delay times	7-4
Table 7-2	SCPI commands - triggering	7-16

8 Limits

Table 8-1	SCPI commands - limits	8-5
-----------	------------------------------	-----

9 Stepping and Scanning

Table 9-1	SCPI commands - stepping and scanning	9-12
-----------	---	------

10 Analog Output

Table 10-1	Analog output examples*	10-3
Table 10-2	SCPI commands - analog output	10-6

11 Remote Operation

Table 11-1	General bus commands and associated statements	11-9
Table 11-2	RS-232 connector pinout	11-29
Table 11-3	PC serial port pinout	11-30

12 Common Commands

Table 12-1	IEEE-488.2 common commands and queries	12-2
------------	--	------

13 SCPI Signal Oriented Measurement Commands

Table 13-1	Signal oriented measurement command summary	13-2
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14 SCPI Reference Tables

Table 14-1	CALCulate command summary	14-3
Table 14-2	CALibration command summary (user accessible)	14-4
Table 14-3	DISPlay command summary	14-5
Table 14-4	FORMat command summary	14-5
Table 14-5	OUTPut command summary	14-6
Table 14-6	ROUTE command summary	14-6
Table 14-7	SENSE command summary	14-7
Table 14-8	STATus command summary	14-11
Table 14-9	SYSTem command summary	14-12
Table 14-10	TRACe command summary	14-12
Table 14-11	Trigger command summary	14-13
Table 14-12	UNIT command summary	14-14

B Status and Error Messages

Table B-1	Status and error messages	B-2
-----------	---------------------------------	-----

C Measurement Considerations

Table C-1	Material thermoelectric coefficients	C-2
-----------	--	-----

D Model 182 Emulation Commands

Table D-1	Model 182 device-dependent command summary	D-2
-----------	--	-----

F	IEEE-488 Bus Overview	
Table F-1	IEEE-488 bus command summary	F-7
Table F-2	Hexadecimal and decimal command codes	F-10
Table F-3	Typical addressed bus sequence	F-11
Table F-4	Typical addressed common command sequence	F-11
Table F-5	IEEE command groups	F-12
Table F-6	Model 2182 interface function codes	F-13

G	IEEE-488 and SCPI Conformance Information	
Table G-1	IEEE-488 documentation requirements	G-2
Table G-2	Coupled commands	G-3



1 Getting Started

NOTE *This User's Manual supports both the Models 2182 and 2182A:*

References to the Model 2182 apply to both the Models 2182 and 2182A.

References to the Model 2182/2182A apply to the Model 2182 with firmware version A10 or higher, and the Model 2182A with firmware version C01 or higher.

References to the Model 2182A applies to the Model 2182A with firmware version C01 or higher.

- **General information** — Covers general information that includes warranty information, contact information, safety symbols and terms, inspection, and available options and accessories.
- **Nanovoltmeter features** — Summarizes the features of the Model 2182.
- **Front and rear panel familiarization** — Summarizes the controls and connectors of the instrument.
- **Cleaning input connector terminals** — Explains how to clean the contacts of the input LEMO connectors.
- **Power-Up** — Covers line power connection, line voltage setting, fuse replacement, and the power-up sequence.
- **Display** — Provides information about the display of the Model 2182.
- **Default settings** — Covers the two instrument setup configurations available to the user; user defined or factory default.

General information

Warranty information


Warranty information is located at the front of this manual. Should your Model 2182 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 an instrument shows that high voltage may be present on the terminal(s). Use standard safety precautions to avoid personal contact with these voltages.

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

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

Inspection

The Model 2182 was carefully inspected electrically and mechanically before shipment. After unpacking all items from the shipping carton, check for any obvious signs of physical damage that may have occurred during transit. (There may be a protective film over the display lens, which can be removed). Report any damage to the shipping agent immediately. Save the original packing carton for possible future shipment. The following items are included with every Model 2182 order:

- Model 2182 Nanovoltmeter with line cord.
- Model 2107-4 Input Cable.
- Four alligator clips that attach to the copper lugs of the Model 2107 Input Cable.
- DeoxIt copper cleaning solution.
- Accessories as ordered.
- Certificate of calibration.
- Model 2182 User's Manual (P/N 2182-900-00).
- Model 2182 Service Manual (P/N 2182-902-00).
- Manual Addenda (pertains to any improvements or changes concerning the instrument or manual).

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

Options and accessories

The following options and accessories are available from Keithley for use with the Model 2182.

Cables, connectors, and adapters

Models 2107-4 and 2107-30 Input Cable — Connect the Model 2182 Nanovoltmeter to DUT using one of these input cables. The input cable is terminated with a LEMO connector (for connection to the Model 2182) on one end and four copper spade lugs (for connection to DUT) on the other. The Model 2107-4 (which is a supplied accessory to the Model 2182) is 1.2m (4 ft) in length and the Model 2107-30 is 9m (30 ft) in length. Also included are four copper alligator clips that attach to the copper lugs of the cable, and DeoxIt copper cleaning solution.

Model 2182-KIT Low Thermal Connector — Consists of a low-thermal LEMO connector and strain relief. Includes all the connector parts required to build a custom input cable for the Model 2182 Nanovoltmeter.

Model 2187-4 Input Cable — Low-thermal input cable for the Model 2182/2182A. Terminated with a LEMO connector on one end and four banana plugs on the other. The cable is 4 ft (1.2m) in length.

Model 2188 Low-Thermal Calibration Shorting Plug — This input shorting plug is required to calibrate the Model 2182 Nanovoltmeter.

Models 7007-1 and 7007-2 Shielded GPIB Cables — Connect the Model 2182 to the GPIB bus using shielded cables and connectors to reduce electromagnetic interference (EMI). The Model 7007-1 is 1m long; the Model 7007-2 is 2m long.

Model 7009-5 Shielded RS-232 Cable — 1.5m (5 ft) RS-232 cable terminated with a male DB-9 connector on one end and a female DB-9 connector on the other end. It is wired as a straight through (not null modem) cable.

Models 8501-1 and 8501-2 Trigger Link Cables — Connect the Model 2182 to other instruments with Trigger Link connectors (e.g., Model 7001 Switch System). The Model 8501-1 is 1m long; the Model 8501-2 is 2m long.

Model 8502 Trigger Link Adapter — Lets you connect any of the six Trigger Link lines of the Model 2182 to instruments that use the standard BNC trigger connectors.

Model 8503 DIN to BNC Trigger Cable — Lets you connect Trigger Link lines one (Voltmeter Complete) and two (External Trigger) of the Model 2182 to instruments that use BNC trigger connectors. The Model 8503 is 1m long.

Silver solder

2182-325A — Use this Keithley part number to order a 20-foot length of silver solder. Also included is an MSDS sheet listing the solder chemical contents.

Rack mount kits

Model 4288-1 Single Fixed Rack Mount Kit — Mounts a single Model 2182 in a standard 19-inch rack.

Model 4288-2 Side-by-Side Rack Mount Kit — Mounts two instruments (Models 182, 428, 486, 487, 2000, 2001, 2002, 2010, 2182, 2400, 2410, 2420, 6517, 7001) side-by-side in a standard 19-inch rack.

Model 4288-4 Side-by-Side Rack Mount Kit — Mounts a Model 2182 and a 5.25-inch instrument (Models 195A, 196, 220, 224, 230, 263, 595, 614, 617, 705, 740, 775, etc.) side-by-side in a standard 19-inch rack.

Carrying case

Model 1050 Padded Carrying Case — A carrying case for a Model 2182. Includes handles and shoulder strap.

Nanovoltmeter features

The Model 2182 is a 7½-digit high-performance digital nanovoltmeter. It has two input channels to measure voltage and temperature. The measurement capabilities of the Model 2182 are explained in [Section 2](#) of this manual (see “[Measurement overview](#)”).

Features of the Model 2182 Nanovoltmeter include:

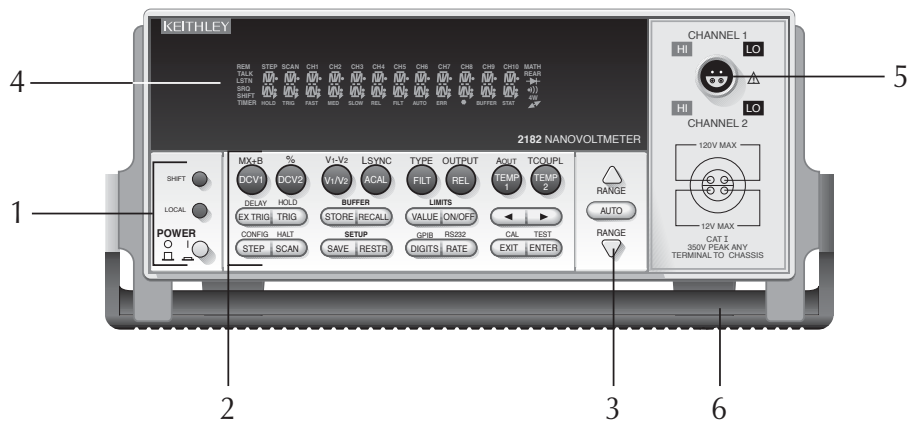
- **Ratio** — Provides comparison readings between two voltage inputs. Ratio performs $V1/V2$.
- **Delta** — Provides average difference of Channel 1 inputs. Delta performs $(V1t1-V1t2)/2$.
- **Enhanced Delta, Pulse Delta, and Differential Conductance** — The following tests can be performed when using a Model 2182/2182A with a Model 6220 or 6221 Current Source:
 - **Delta** - Uses a square wave output and a 3-point measurement algorithm to cancel the effects of thermal EMFs.
 - **Pulse Delta (6221 and 2182A only)** - Provides a pulse output and a 3-point (or 2-point) measurement algorithm for testing of temperature sensitive Device Under Test (DUT).
 - **Differential Conductance** - Uses a differential current output and a 3-point moving average algorithm to perform differential measurements.
- **mX+b and Percent** — These calculations provide mathematical manipulation of readings.
- **Relative** — Null offsets or establish baseline values.
- **Buffer** — Store up to 1024 readings in the internal buffer.
- **Limits** — Set high and low reading limits to test devices.
- **Internal Scanning** — Scan the two input channels of the Model 2182.
- **External Scanning** — Scan the channels or matrix points of Keithley Model 7001/7002 switching cards.
- **Setup Storage** — Two instrument setups (user and factory defaults) can be saved and recalled.
- **Analog Output** — With analog output gain set to one, a full range input will result in a 1V analog output.
- **Remote Interface** — The Model 2182 can be controlled using the IEEE-488 interface (GPIB) or the RS-232 interface.
- **GPIB Programming Language** — When using the GPIB, the instrument can be programmed using the SCPI or Model 182 (DDCs) programming language.
- **Closed-cover Calibration** — The Model 2182 can be calibrated from either the front panel or the GPIB.

Front and rear panel familiarization

Front panel summary

The front panel of the Model 2182 is shown in [Figure 1-1](#). This figure includes important abbreviated information that should be reviewed before operating the instrument.

Figure 1-1
Model 2182 front panel



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

1 Special keys and power switch

SHIFT	Use to select a shifted function or operation.
LOCAL	Cancels GPIB remote mode.
POWER	Power switch. In position turns 2182 on (1), out position turns it off (0).

2 Function and operation keys

Top Row

Un-shifted

DCV1	Selects Channel 1 voltage measurement function.
DCV2	Selects Channel 2 voltage measurement function.
V1/V2	Selects Ratio (Channel 1 voltage reading / Channel 2 voltage reading).
ACAL	Selects automatic gain calibration.
FILT	Enables/disables filter for selected measurement function.
REL	Enables/disables relative for selected measurement function.
TEMP1	Selects Channel 1 temperature measurement function.
TEMP2	Selects Channel 2 temperature measurement function.

Shifted

MX+B	Multiplies a scale factor (M) to the reading (X) and then adds an offset (B).
%	Calculates percent deviation from a specified reference.
V1-V2	Selects Delta; $(V1t1 - V1t2)/2$.
LSYNC	Enables/disables line cycle synchronization. When enabled, noise induced by the power line is reduced at the expense of speed.
TYPE	Select filter (analog and/or digital) and configure digital filter (window, count and type).
OUTPUT	Enables/disables relative for Analog Output.
AOUT	Enables/disables Analog Output.
TCOUP	Configure temperature measurement (units, junction type, thermocouple type, sensor type).

Middle Row

Un-shifted

EX-TRIG	Selects external triggering (front panel, bus or trigger link) as trigger source.
TRIG	Triggers a measurement from the front panel.
STORE	Sets reading count for buffer and enables buffer.
RECALL	Displays stored readings (including maximum, minimum, peak-to-peak, average, and standard deviation). The ▲ and ▼ range keys scroll through the buffer, and the ◀ and ▶ key toggles between reading number and reading.
VALUE	Set the upper and lower limits for limit testing.
ON/OFF	Enables/disables limit testing, and selects beeper mode for limit testing.
◀ and ▶	Controls cursor position for making selections or editing values.

Shifted

DELAY	Sets user delay between trigger and measurement.
HOLD	Holds reading when the specified number of samples is within the selected tolerance.

Bottom RowUn-shifted

STEP	Steps through channels; sends a trigger after each channel.
SCAN	Scans through channels; sends a trigger after last channel.
SAVE	Saves present configuration for power-on user default.
RESTR	Restores factory or user default configuration.
DIGITS	Changes number of digits of reading resolution.
RATE	Changes reading rate; number of power line cycles (PLC).
EXIT	Cancels selection, moves back to measurement display.
ENTER	Accepts selection, moves to next choice or back to measurement display.

Shifted

CONFIG	Configures a scan (type, timer, channel count, and reading count).
HALT	Turns off step/scan operation.
GPIB	Enables/disables GPIB, sets address, and selects language.
RS232	Enables/disables RS-232 interface, selects baud rate, flow control, and terminator.
CAL	Accesses calibration.
TEST	Tests display annunciators and front panel keys.

3 Range keys

AUTO

Selects the next higher voltage measurement range.
Selects the next lower voltage measurement range.
Enables/disables autorange.

4 Display annunciators

* (asterisk)	Readings being stored in buffer.
↔ (more)	Indicates additional selections are available.
))) (speaker)	Beeper on for limit testing.
AUTO	Autorange enabled.
BUFFER	Recalling readings stored in buffer.
CH1	Channel 1 input displayed.
CH2	Channel 2 input displayed.
CH1 and CH2	Ratio (V1/V2) reading displayed.
ERR	Questionable reading, or invalid cal step.
FAST	Fast (0.1 PLC) reading rate selected.
FILT	Filter enabled.
HOLD	Instrument in hold mode.
LSTN	Instrument addressed to listen over GPIB.
MATH	mX+b or Percent (%) calculation enabled.
MED	Medium (1 PLC) reading rate selected.
REAR	Indicates that Analog Output is on.
REL	Relative enabled for present measurement function.
REM	Instrument in GPIB remote mode.
SCAN	Scan mode selected.
SHIFT	Accessing a shifted key.
SLOW	Slow (5 PLC) reading rate selected.
SRQ	Service request over GPIB.
STAT	Displaying buffer statistics.
STEP	Step mode selected.
TALK	Instrument addressed to talk over GPIB bus.
TIMER	Timer controlled scans in use.
TRIG	External triggering (front panel, bus or trigger link) selected.

5 Input connector

CHANNEL 1	Measure voltage or temperature. Volts Ranges: 10mV, 100mV, 1V, 10V, and 100V.
CHANNEL 2	Measure voltage or temperature. Volts Ranges: 100mV, 1V, and 10V.

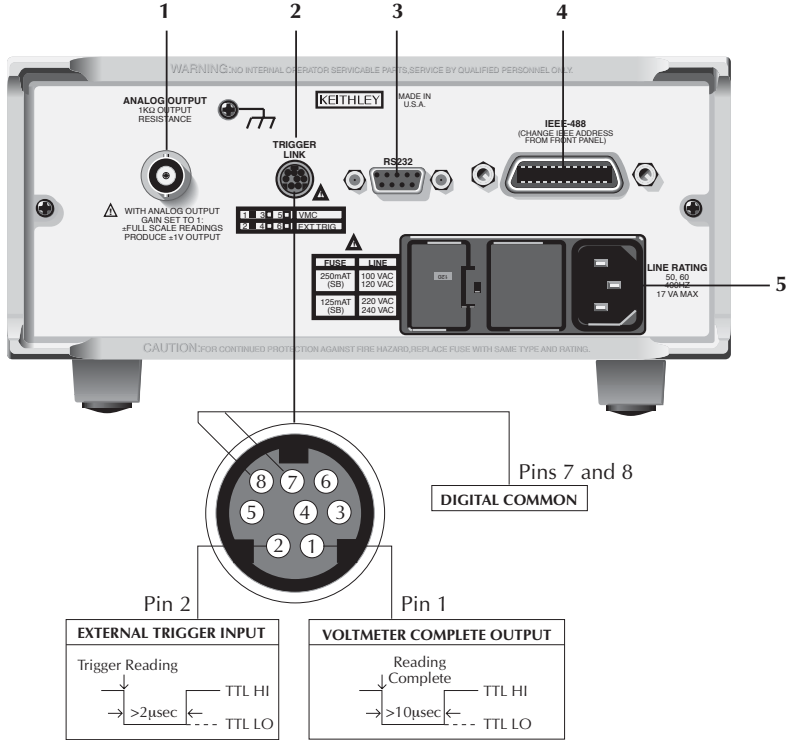
6 Handle

Pull out and rotate to desired position.

Rear panel summary

The rear panel of the Model 2182 is shown in Figure 1-2. This figure includes important abbreviated information that should be reviewed before operating the instrument.

Figure 1-2
Model 2182 rear panel



1 ANALOG OUTPUT

Provides a scaled non-inverting DC voltage. With analog output gain set to one, a full range input will result in a 1V analog output.

2 TRIGGER LINK

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

3 RS-232

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

4 IEEE-488

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

5 Power Module

Contains the AC line receptacle, power line fuse, and line voltage setting. The instrument can be configured for line voltages of 100V/120V/220V/240VAC at line frequencies of 45Hz to 66Hz or 360Hz to 440Hz.

Cleaning input connectors

The two-channel LEMO connector on the front panel is used to connect the Model 2182 to external test circuits. This connector mates to the LEMO connector on the Model 2107 input cable or to the LEMO connector that is included with the Model 2182-KIT.

The contacts of the LEMO connectors are made of copper. These copper-to-copper connections minimize thermal EMFs. However, exposed copper is susceptible to oxidation, which could cause measurement errors. A small bottle of DeoxIT is supplied with the Model 2182. This fluid is used to remove oxidation from copper.

Before connecting a LEMO connector to the LEMO input connector on the instrument, clean the copper contacts of the connectors as follows:

1. Turn off the Model 2182 and, at the rear panel, disconnect the line cord and any other cables or wires connected to the instrument.
2. Stand the Model 2182 on end such that the front panel is facing up.
3. Apply one drop of DeoxIT to each of the four contacts of the LEMO input connector on the Model 2182. You can use a clean wire (such as a resistor lead) to carry a drop of the solution from the bottle of DeoxIT to the connector.
4. Wipe off any excess DeoxIT using a clean cloth.
5. To clean the contacts of the mating LEMO connector, connect and disconnect it to the Model 2182 several times to spread the DeoxIT around.

NOTE *To minimize the accumulation of oxides on LEMO contacts, always keep the LEMO input connectors mated whenever possible. However, cleaning should still be performed after an extended period of time.*

Power-Up

Line power connection

Perform the following procedure to connect the Model 2182 to line power and turn on the instrument.

1. Check to be sure the line voltage setting on the power module (see [Figure 1-3](#)) is correct for the operating voltage in your area. If not, refer to the next procedure, “[Setting line voltage and replacing fuse](#)” on page 1-15.

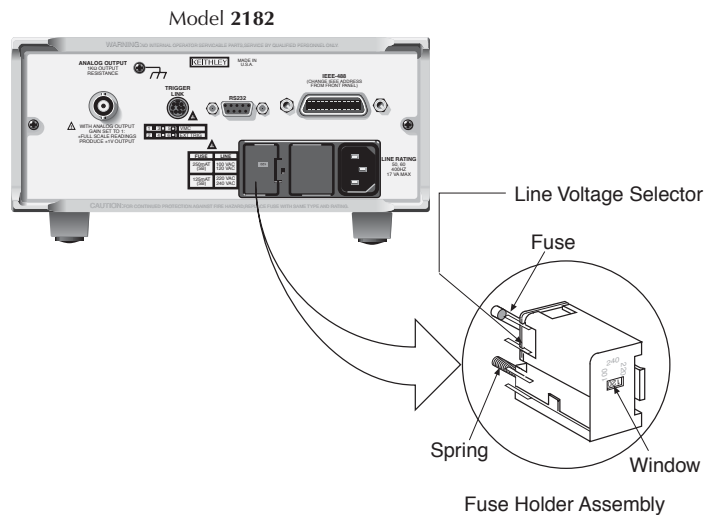
CAUTION Operating the instrument on an incorrect line voltage may cause damage to the instrument, possibly voiding the warranty.

2. Before plugging in the power cord, make sure the front panel power switch is in the off (0) 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 2182 contains a separate ground wire for use with grounded outlets. When proper connections are made, instrument chassis is connected to power line ground through the ground wire in the power cord. Failure to use a grounded outlet may result in personal injury or death due to electric shock.

4. Turn on the instrument by pressing the front panel power switch to the on (1) position.

Figure 1-3
Power module



Setting line voltage and replacing fuse

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

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

1. Place the tip of a flat-blade screwdriver into the power module by the fuse holder assembly (see [Figure 1-3](#)). Gently push in and move 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 1-1](#).

CAUTION For continued protection against fire or instrument damage, only replace the fuse with the type and rating listed. If the instrument repeatedly blows fuses, locate and correct the cause of the trouble before replacing the fuse. See the Model 2182 Service Manual for troubleshooting information.

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 1-1
Fuse ratings

Line Voltage	Fuse Rating	Keithley P/N
100/120V	0.25A, slow-blow, 5x20mm	FU-96-4
220/240V	0.125A, slow-blow, 5x20mm	FU-91

Power-up sequence

On power-up, the Model 2182 performs self-tests on its EPROM and RAM, and momentarily lights all digit segments and annunciators. 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.

If the instrument passes the self-tests, the firmware revision levels are displayed. For example:

REV: A01 A02

where: A01 is the main board ROM revision.

A02 is the display board ROM revision.

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

Line frequency

On power-up, the Model 2182 detects the line power frequency and automatically selects the proper line frequency setting. The line frequency setting can be checked using the following command:

```
:SYSTem:LFRequency?
```

The response message will be 50 or 60. The value 50 indicates that the line frequency is set for 50Hz (or 400Hz), while 60 indicates that it is set for 60Hz.

Display

The display of the Model 2182 is primarily used to display readings, along with the units and type of measurement. Annunciators are located at the top, bottom, left, and right of the reading or display message. The annunciators indicate various states of operation. See “[Front panel summary](#)” (presented earlier in this section) for a complete listing of display annunciators.

NOTE *The Display and Keys Test allows you to test display digit segments and annunciators, and check the functionality of front panel keys. These tests are accessed by pressing SHIFT and then TEST. Refer to the Model 2182 Service Manual for details.*

Status and error messages

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

Default settings

There are two default setup configurations; factory and user. As shipped from the factory, the Model 2182 powers up to the factory default settings listed in [Table 1-2](#). The Model 2182 can instead be set to power up to a user default setup. The power-on default setup will be the last configuration you saved. The SAVE key saves the present configuration as the USER power-on setup. The RESTR key restores the instrument to the factory defaults or the user-saved defaults.

Perform the following steps to save the present setup as the power-on default configuration:

1. Configure the instrument for your measurement application.
2. Press SAVE.
3. Use the ▲ and ▼ keys to display YES or NO.
4. Press ENTER. The instrument will power-on to this USER default setup.

NOTE *To assure that the proper filter state is recalled, set the analog and digital filters before saving the user setup. See [Section 3](#).*

To restore factory or user settings:

1. Press RESTR.
2. Use the ▲ and ▼ keys to display FACT (factory) or USER defaults.
3. Press ENTER.

NOTE The basic measurement procedure in the next section ([Section 2](#)) assumes factory defaults ([Table 1-2](#)). Reset the instrument to the factory default settings when following that step-by-step procedure.

Table 1-2
Factory defaults

Setting	Factory Default
Analog output	On
Gain (M)	1.0
Offset (B)	0
Relative (REL)	Off
Autozeroing modes	
Front Autozero	On
Autozero	On
LSYNC	Off
Buffer	No effect
Delta	Off
Function	DCV1
GPIB	No effect (On at factory)
Address	No effect (7 at factory)
Language	No effect (SCPI at factory)
Key click	On
Limits	Off
Beeper	Never
High limit 1	+1
Low limit 1	-1
High limit 2	+2
Low limit 2	-2
mX+b	Off
Scale factor (M)	1.0
Offset (B)	0.0
Percent (%)	Off
Reference	1.0
Ratio (V1/V2)	Off
RS-232	Off
Baud rate	No effect
Flow control	No effect
Terminator (Tx)	No effect

Table 1-2
Factory defaults (cont.)

Setting	Factory Default
Scanning	Off
Type	Internal
Timer	Off
Channel 1 count	1
Reading count	2
TEMP1 and TEMP2	
Digits	6
Filter	On
Analog filter	Off
Digital filter	On
Count	10
Mode	Moving average
Window	0.01%
Rate	5 PLC (Slow)
Reference junction	Internal
Relative (REL)	Off
Sensor	Thermocouple
Thermocouple type	Type J
Units	C
Triggers	
Continuous	On
Delay	Auto
Control Source	Immediate
DCV1 and DCV2	
Digits	7.5
Filter	On
Analog filter	Off
Digital filter	On
Count	10
Mode	Moving average
Window	0.01%
Hold	Off
Count	5
Window	1%
Range	Auto
Rate	5 PLC (Slow)
Relative (REL)	Off

2 Voltage and Temperature Measurements

- **Measurement overview** — Explains the voltage and temperature measurement capabilities of the Model 2182.
- **Performance considerations** — Covers various aspects of operation that affect accuracy and speed. These include warm-up, ACAL (calibration), autozero, and LSYNC (line cycle synchronization). Includes the SCPI commands for remote operation.
- **Connections** — Covers test circuit connection to the Model 2182.
- **Temperature configuration** — Explains how to configure the Model 2182 for temperature measurements.
- **Measuring voltage and temperature** — Provides the basic step-by-step procedure to make measurements. Includes the SCPI commands for remote operation.
- **Low-level considerations** — Explains two external factors that can corrupt low-level measurements; thermal EMFs and noise.
- **Applications** — Provides some typical applications for the Model 2182. These include Testing Switch Contacts.

Measurement overview

The Model 2182 provides two input channels for DC voltage and temperature measurements. [Table 2-1](#) lists the measurements that can be performed by the two channels.

NOTE *Measurement queries are used to trigger and/or return readings. Details are provided in [Section 7](#), [Section 13](#), and [Appendix H](#).*

Table 2-1
Measurement channels

Measurement	Input Channel(s) To Use
Voltage	Channel 1
Temperature	Channel 1
Voltage and Voltage	Channel 1 and Channel 2
Voltage and Temperature	Channel 1 and Channel 2

Channel 1 is used as the fundamental measurement channel, while Channel 2 provides sense measurements. Because of this operational relationship between the two channels, Channel 2 cannot be used as an independent, stand-alone measurement channel. Its inputs must be referenced to Channel 1 LO.

NOTE *As a general rule, use Channel 1 whenever possible for low voltage (<1V) measurements. If using Channel 2 for measurements below 1V and the impedance between Channel 2 LO and Channel 1 LO is $\geq 100k\Omega$, pumpout current could be high enough to corrupt measurements. For details, see “[Performance considerations, Pumpout current \(low charge injection mode\)](#)” (in this section).*

Voltage measurements

The Model 2182 has two voltage measurement functions: DCV1 and DCV2. DCV1 is available for input Channel 1, and DCV2 is available for Channel 2.

DCV1 (Channel 1) has five measurement ranges (10mV, 100mV, 1V, 10V, and 100V) and can measure voltage from 1nV to 120V. DCV2 (Channel 2) has three measurement ranges (100mV, 1V, and 10V) and can measure voltage from 10nV to 12V. Accuracy for each channel is listed in the specifications ([Appendix A](#)).

Temperature measurements

The Model 2182 has two temperature measurement functions: TEMP1 and TEMP2. TEMP1 is available for input Channel 1 and TEMP2 is available for Channel 2.

Depending on which thermocouple type is used (J, K, T, E, R, S, B, or N), the Model 2182 can measure temperature from -200°C to 1820°C. The specifications ([Appendix A](#)) provide the measurement ranges for the various thermocouple types.

NOTE *The Model 2182 can also measure its internal temperature. Whenever the internal temperature changes more than 1 degree, an ACAL must be performed to maintain specified accuracy. See “Performance considerations, ACAL procedure” (in this section) for details.*

In order to make accurate temperature measurements, the thermocouple connections (reference junction) have to be maintained at a known temperature. You have the option to use the internal reference junction, or an external simulated reference junction. These reference junctions are discussed as follows:

Internal Reference Junction — The internal reference junction of the Model 2182 is the input connector. A temperature sensor is located inside the unit, adjacent to the input connector. The sensor is measured continuously to maintain accuracy.

Thermocouple connections (reference junction) have to be made at the input connector of the Model 2182. To utilize the internal reference junction, the thermocouple wires must be soldered directly to a LEMO connector that mates to the input connector.

A disadvantage of using the internal reference junction is the connection requirements. You cannot use the supplied input cable as is. You will have to modify the cable or use a separate LEMO connector (Model 2182-KIT).

Simulated Reference Junction — An external apparatus, such as an ice bath, can instead be used for the reference junction. The thermocouple wires are connected to the copper lugs of the supplied input cable. The connection points are then immersed in the ice bath. The temperature of the ice bath must be entered into the Model 2182 as the simulated reference temperature.

Performance considerations

The following aspects of operation affect accuracy and speed.

Warm-up

After the Model 2182 is turned on, it must be allowed to warm up for at least 2½ hours to allow the internal temperature to stabilize. After the warm-up period, an ACAL must be performed if the present internal temperature and TCAL differ by more than 1°C. TCAL is the internal temperature reading stored for the last ACAL (see “ACAL”).

ACAL (calibration)

ACAL is a special front-end gain calibration for the 10mV and 100V ranges. It needs to be performed whenever the internal temperature and TCAL vary by more than 1°C. TCAL is the internal temperature reading at the time of the last ACAL. For example, if ACAL was performed at 28°C and the internal temperature changes to 29.1°C, another ACAL will be required to maintain specified accuracy. The procedures to measure internal temperature and TCAL are located after the “ACAL Procedure.”

When the internal temperature and TCAL differ by more than 1°C, Bit 9 in the Questionable Event Condition Register will set to indicate a questionable ACAL. See “[Status structure](#)” in [Section 11](#) for more information.

NOTE *Do not confuse this partial calibration (to be performed by the user) with the complete instrument calibration that is to be performed by a qualified service technician. The complete calibration procedure is located in the Model 2182 Service Manual.*

There are two ACAL options. FULL ACAL calibrates the 10mV and 100V ranges, while LOW-LVL (low-level) ACAL only calibrates the 10mV range. If you are not going to use the 100V range, it is recommended that you only perform LOW-LVL ACAL.

NOTES *FULL ACAL requires that there not be any connectors or cables connected to the LEMO input connector of the Model 2182. Whenever LEMO connections are broken for an extended period of time, the contacts must be cleaned before reconnecting. See “[Cleaning input connectors](#)” in [Section 1 \(Getting Started\)](#).*

For LOW-LVL ACAL, you do not need to remove the input cable, break any connections, or remove power.

ACAL procedure

Perform the following steps to perform LOW-LVL or FULL ACAL:

1. Press the ACAL key to access the menu.
2. Use ▲ or ▼ key to display desired ACAL (LOW-LVL or FULL).

3. Press ENTER. The message “ACAL” will be displayed while calibration is in process. It takes around five minutes to complete LOW-LVL ACAL and a little more than five minutes to complete FULL ACAL. When finished, the instrument returns to the normal display state.

Measuring internal temperature

Perform the following steps to measure the internal temperature of the Model 2182:

1. Press SHIFT and then TCOUPL to display the present units designator (C, F, or K) for temperature measurements.
2. To change the units designator, press the ► key to place the blinking cursor on the units designator, and press the ▲ or ▼ key to display the desired units.
3. Press ENTER. The present sensor selection (TCOUPLE or INTERNAL) is displayed. The internal (INTERNAL) sensor is used for measuring internal temperature.
4. To change the sensor selection, press the ► key to place the blinking cursor on TCOUPLE and press the ▲ or ▼ key to display INTERNAL.
5. Press ENTER to return to the normal display state.
6. Press TEMP1 or TEMP2 to measure and display the internal temperature of the Model 2182. Note that when displaying the internal temperature, both the “CH1” and “CH2” annunciators are off.

NOTE *As long as the INTERNAL sensor is selected, TEMP1 and TEMP2 will only measure and display the internal temperature of the Model 2182.*

Checking TCAL temperature

Perform the following steps to determine the internal temperature at the time of the last ACAL:

1. Press SHIFT and then CAL to access the calibration menu.
2. Use ▲ or ▼ key to display “CAL: TEMP”.
3. Press ENTER. The temperature (in °C) at the time of the last ACAL is displayed.
4. Use the EXIT key to back out of the menu structure.

Autozeroing modes

An A/D measurement cycle measures the input signal, and will periodically measure internal voltages that correspond to offsets (zero) and amplifier gains, and the internal reference temperature. These measurements help maintain stability and accuracy over time and changes in temperature. The signal, offset, gain, and temperature measurements are then used in an algorithm to calculate the reading of the input signal. This process is known as autozeroing.

Internally, the Model 2182 has two amplifiers that have an impact on speed, noise, drift, and offset. These performance aspects can be controlled to some degree by controlling the available autozeroing modes. The front-end amplifier is controlled by Front Autozero, and the second amplifier is controlled by Autozero.

Front Autozero

With Front Autozero for the front-end amplifier enabled (which is the default setting), the Model 2182 performs two A/D measurement cycles for each reading. The first one is a normal measurement cycle, and the second one is performed with the polarity of the amplifier reversed. This two-cycle, polarity-reversal measurement technique is used to cancel internal offsets in the amplifier. With Front Autozero disabled, the second A/D measurement cycle is not performed.

Benefits of Front Autozero disabled:

- Twice as fast
- Lower Pumpout Current noise

Drawbacks of Front Autozero disabled:

- High drift ($20\mu\text{V}/^\circ\text{C}$) in normal voltage mode
- High offset voltage ($\pm 500\mu\text{V}$) in normal voltage mode

***NOTE** To increase the speed of Delta measurements, disable Front Autozero. The two-measurement cycle, polarity-reversal technique used by Front Autozero is *not* required for Delta. Delta uses its own polarity-reversal technique to cancel offsets. Delta measurements are covered in [Section 5](#).*

Autozero

When Autozero for the second amplifier is disabled, the offset, gain, and internal reference temperature measurements are not performed. This increases measurement speed (a few % at 1PLC). However, the zero, gain, and temperature reference points will eventually drift resulting in inaccurate readings for the input signal. It is recommended that Autozero only be disabled for short periods of time.

When Autozero is enabled after being off for a long period of time, the internal reference points will not be updated immediately. This will initially result in inaccurate measurements, especially if the ambient temperature has changed by several degrees. A faster update of reference points can be forced by setting a faster integration rate.

Rate — With Autozero disabled, pressing the front panel RATE key will change the speed setting, and will also enable Autozero. Rate changes using remote programming have no effect on the state of Autozero.

To force a single rapid update of the internal reference points when Autozero is enabled, set the integration rate to FAST (or 0.01 PLC for remote programming), and then back to the desired rate (i.e., MED; 1.0 PLC). Details on Rate are covered in [Section 3](#).

Controlling autozeroing modes

For front panel operation, the two autozeroing modes are controlled from the SHIFT > CONFIG menu as follows:

NOTE For remote programming, the commands to control the two autozeroing modes are listed in Table 2-2.

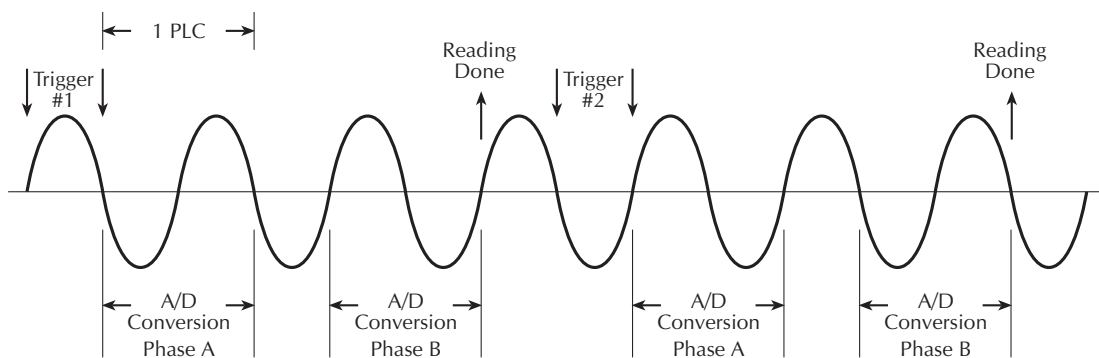
1. Press SHIFT and then CONFIG to display the present state of Front Autozero; Y = yes (enabled), N = no (disabled).
2. To change the FRONT AZERO setting, use the ▲ or ▼ key to display Y or N.
3. If you do not wish to view or change the Autozero setting, jump to step 6. Otherwise, proceed to the next step.
4. Press the ► key to display the present state of Autozero; YES (enabled), NO (disabled).
5. To change the AUTOZERO setting, use the ▲ or ▼ key to display YES or NO.
6. Press ENTER to enter the setting(s) and exit from the menu structure.

NOTE The factory default setting for Front Autozero and Autozero is ON (enabled). The settings can be saved in the user default setup (see “Default settings” in Section 1).

LSYNC (line cycle synchronization)

Synchronizing A/D conversions with the frequency of the power line increases common mode and normal mode noise rejection. When line cycle synchronization is enabled, the measurement is initiated at the first positive- or negative-going zero crossing of the power line cycle after the trigger. Figure 2-1 shows the measurement process that consists of two A/D conversions. If the trigger occurs during the positive cycle of the power line (as shown in Figure 2-1), the first A/D conversion starts with the negative-going zero crossing of the power line cycle. If the next trigger (Trigger #2) occurs during the negative cycle, then the measurement process starts with the positive-going zero crossing.

Figure 2-1
Line cycle synchronization



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

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

NOTE *Line cycle synchronization is not available for integration rates <1 PLC, regardless of the LSYNC setting.*

Pumpout current (low charge injection mode)

Pumpout current for Channel 1 is very low (0.5 μ A peak-to-peak) and therefore, does not adversely affect instrument performance. Channel 2 can make the same claim as long as Channel 2 LO is connected to Channel 1 LO. This pumpout current is due to internal switch transitions, and occurs between A/D conversions. Settling for the transition occurs on the next A/D conversion. Whenever the impedance between Channel 2 LO and Channel 1 LO is >100k Ω , pumpout current could be high enough to corrupt measurements below 1V. Above 1V measurements, pumpout current is not significant.

Low Charge Injection Mode — If you must use Channel 2 for measurements below 1V and the impedance between Channel 2 LO and Channel 1 LO is >100k Ω , you can enable the Low Charge Injection Mode to reduce the pumpout current. However, this mode increases measurement noise by up to 8 times.

The Low Charge Injection Mode can be enabled or disabled from the GPIB or RS-232 interface. The command to control low charge injection is listed in [Table 2-2](#). Low charge injection cannot be enabled from the front panel. However, it can be disabled from the front panel by restoring factory default conditions.

SCPI programming - ACAL, Front Autozero, Autozero, LSYNC, and Low Charge Injection

Table 2-2

SCPI commands - ACAL, Front Autozero, Autozero, LSYNC, and Low Charge Injection

Commands	Description	Default
For ACAL: :CALibration :UNPRotected :ACALibration :INITiate :STEP1 :STEP2 :DONE :TEMPerature?	CALibration Subsystem: ACAL: Prepare 2182 for ACAL. Perform full ACAL (100V and 10mV). Perform low level ACAL (10mV only). Exit ACAL (see Note). Read the internal temperature (in °C) at the time of the last ACAL.	
:SENSe :TEMPerature :RTEMPerature?	SENSe Subsystem: Measure the present internal temperature (in °C).	
For Front Autozero: :SYSTEM :FAZero [state] 	SYSTEM Subsystem: Enable or disable Front Autozero.	ON
For Autozero: :SYSTEM :AZERo [state] 	SYSTEM Subsystem: Enable or disable Autozero.	ON
For LYSNC: :SYSTEM :LSYNc [state] 	SYSTEM Subsystem: Enable or disable line cycle synchronization.	OFF
For Low Charge Injection: :SENSe:VOLTage :CHANnel2 :LQMode 	SENSe Subsystem: Enable or disable Low Charge Injection Mode for Channel 2 (see “ Pumpout current (low charge injection mode) ” for details).	OFF

Note: After sending :DONE, the 2182 goes into the idle state. An INITiate command is needed to trigger readings (see Program Example 1).

Programming examples - ACAL, Autozero, and LSYNC

Program Example 1 — This program fragment performs low-level ACAL:

NOTE: After sending the following commands, the :DONE and :INIT commands will not execute until calibration is completed.

```
CALL SEND(7,":cal:unpr:acal:init",status%) ' Prepares 2182 for ACAL.
CALL SEND(7,":cal:unpr:acal:step2",status%) ' Performs low-level ACAL.
CALL SEND(7,":cal:unpr:acal:done",status%) ' Exits ACAL mode.
CALL SEND(7,":init:cont on", status%) ' Starts continuous
                                     ' triggering.
```

Program Example 2 - This program fragment disables autozero:

```
CALL SEND(7,":syst:azer off",status%) ' Disables autozero.
```

Program Example 3 - This program fragment enables line cycle synchronization:

```
CALL SEND(7,":syst:lsync on",status%) ' Enables LSYNC.
```

Program Example 4 - This program fragment enables low charge injection for Channel 2:

```
CALL SEND(7,":sens:volt:chan2:lqm on",status%) ' Enables low charge
                                               ' injection.
```

Connections

WARNING A hazardous voltage condition exists at or above 42V peak. To prevent electric shock that could result in injury or death, NEVER make or break connections while hazardous voltage is present.

CAUTION Exceeding the following limits may cause instrument damage not covered by the warranty:

- Channel 1 HI and LO inputs have a maximum measurement capability of 120V peak. These inputs are protected to 150V peak to any terminal or 350V peak to chassis.
- Channel 2 HI and LO inputs have a maximum measurement capability of 12V peak. Channel 2 HI is protected to 150V peak to any terminal, and Channel 2 LO is protected to 70V peak to Channel 1 LO. Both inputs are protected to 350V peak to chassis.

NOTE As a general rule, use Channel 1 whenever possible to measure voltage below 1V. If using Channel 2 to measure <1V and the impedance between Channel 2 LO and Channel 1 LO is >100k Ω , pumpout current may be high enough to corrupt measurements. In this case, the Low Charge Injection mode can be enabled to reduce pumpout current (at the expense of increased measurement noise). See “Performance considerations, Pumpout current (low charge injection mode)” for details.

Connection techniques

Copper-to-copper connections should be used wherever possible in the test circuit to minimize thermal EMFs that could corrupt measurements (see “Measurement error - external causes” for information on thermal EMFs).

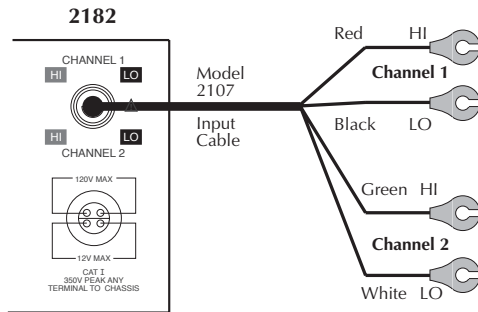
Any solder connections to your test circuit require the use of silver solder to minimize thermal EMFs. You can order a 20-foot length of silver solder from Keithley (part number 2182-325A). Included with the solder is an MSDS sheet listing the solder chemical contents.

CAUTION Silver solder has a high temperature melting point. Take care not to damage a LEMO connector (or any other device) by applying excessive heat.

Model 2107 input cable

The Model 2107 Input Cable, which is a supplied accessory, is terminated with a LEMO connector on one end and copper lugs on the other end. The cable is shielded to chassis ground when connected to the Model 2182. The cable wires are made from twisted silver wire. The input cable is shown in [Figure 2-2](#). This cable can be used to make voltage measurements and temperature measurements that use an external simulated reference junction.

Figure 2-2
Model 2107 input cable



Voltage Connections — Mechanically connect (clamp) the cleaned copper lugs of the cable to the cleaned copper connectors of the test circuit. For the test circuit, use clean #10 copper bus wire wherever possible. Clean copper-to-copper connections minimize thermal EMFs which could corrupt a measurement. See “[Cleaning test circuit connectors](#)” (located in this section).

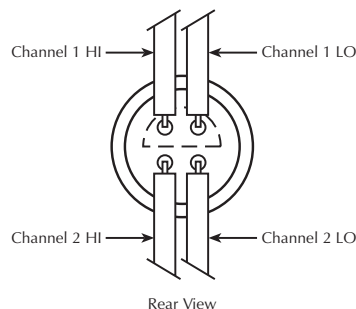
If necessary, you can cut the copper lugs off the Model 2107 Input Cable and connect the wires directly to your test circuit. If soldering, use silver solder to minimize thermal EMFs.

Temperature (Simulated Reference) Connections — For temperature measurements using an external simulated reference junction, simply wrap (or clamp) the thermocouple wires around the copper lugs (or bare wires) of the input cable.

Customized connections

Temperature measurements using the internal reference junction require that the thermocouple wires be soldered directly to a LEMO connector that mates to the input of the Model 2182. Silver solder should be used to minimize thermal EMFs. [Figure 2-3](#) shows terminal identification for a LEMO connector.

Figure 2-3
LEMO connector - terminal identification



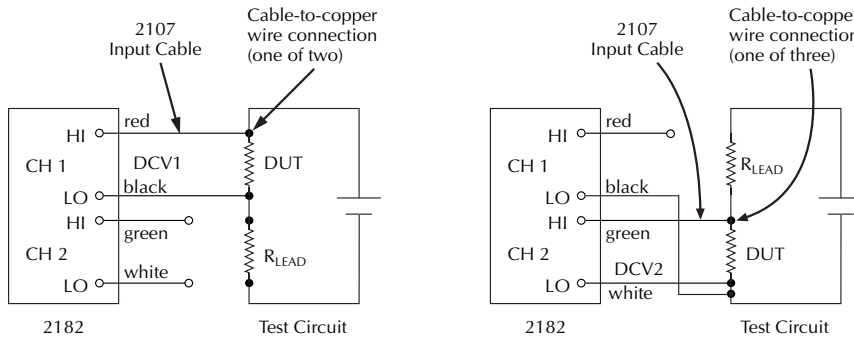
To make these customized connections, you can modify the supplied input cable, or you can use the LEMO connector that is included with the optional Model 2182-KIT.

CAUTION Silver solder has a high temperature melting point. Take care not to damage the LEMO connector by applying excessive heat.

Voltage only connections

Single Channel Measurement Connections — Figure 2-4 shows typical connections to measure a DUT using a single channel. When using Channel 2, its inputs must be referenced to Channel 1 LO as shown in Figure 2-4B.

Figure 2-4
Connections - single channel voltage



A. Channel 1 Measurements

B. Channel 2 Measurements

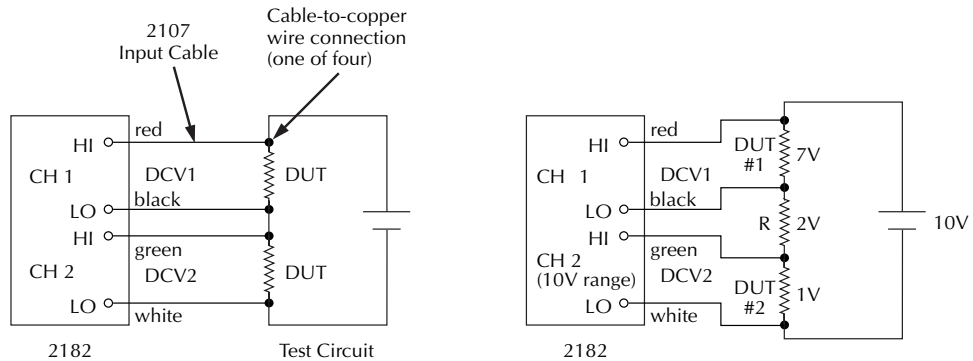
Dual Channel Measurement Connections — The dual channel feature of the Model 2182 allows you to make comparison measurements within a test circuit. Figure 2-5A shows typical connections to make comparison measurements of two devices in a test circuit. For this measurement configuration, there is no voltage differential between the two measurement channels. Channel 2 HI is connected directly to Channel 1 LO.

Figure 2-5B shows a measurement configuration that has a voltage differential between two channels. The differential is the 2V drop across R. Channel 1 measures voltage across DUT #1 and Channel 2 measures voltage across DUT #2. Internally, the A/D converter references Channel 2 measurements to Channel 1 LO. For example, if 1V is being input to Channel 2 and there is a 2V differential between the two channels, 3V will be applied to the A/D converter. Therefore, if Channel 2 is on the 1V range, the 3V applied to the A/D converter will cause it to overflow. The 1V measurement on Channel 2 can only be performed on the 10V range.

Also note that channel voltage differential reduces the maximum measurement capability of Channel 2. Normally, Channel 2 can measure up to 12V. However, a 2V differential reduces the maximum measurement capability of Channel 2 to 10V. In [Figure 2-5A](#), a >10V input to Channel 2 will cause an overflow condition.

NOTE Channel 2 HI or LO cannot be more than 12V peak from Channel 1 LO.

Figure 2-5
Connections - dual channel voltage



Note: Channel 2 HI or LO must not exceed 12V from Channel 1 LO.

A. Typical Measurement Configuration

B. Voltage Differential Between Channels

Temperature only connections

Channel 1 of the Model 2182 can be used to make temperature measurements. [Figure 2-6](#) shows connections using the internal reference junction. Keep in mind that the thermocouple wires must be soldered directly to a LEMO connector as previously explained.

Figure 2-6
Connections - temperature (internal reference)

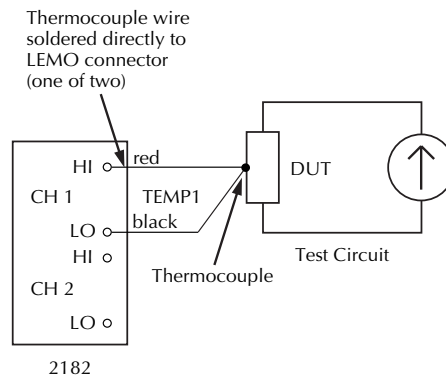
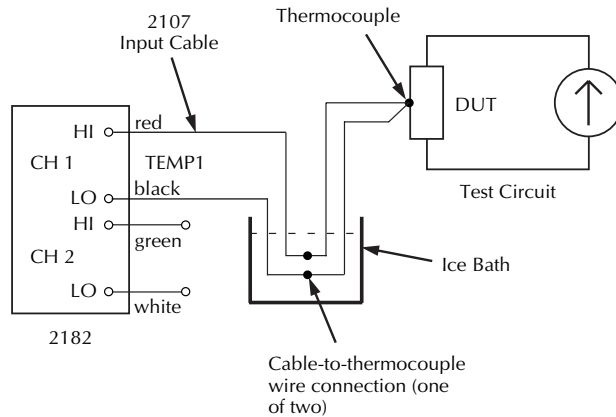


Figure 2-7 shows temperature only connections using an ice bath as a simulated reference junction. Note that the connection points for the input cable and the thermocouple wires are immersed in the ice bath.

Figure 2-7
Connections - temperature (simulated reference)



Voltage and temperature connections

Channel 1 should be used for voltage measurements since it supports a wider range of measurements, leaving Channel 2 to measure temperature.

A connection example using the internal reference junction for temperature measurements is shown in Figure 2-8. In this example, Channel 1 measures the voltage drop across the DUT and Channel 2 measures the temperature of the DUT. Notice the jumper wire from the thermocouple to test circuit low. If the case of the DUT is metal and already connected to test circuit low, the jumper would not be needed. Also, if there is enough thermal bonding between the DUT and test circuit low, the thermocouple can be connected directly to low.

Figure 2-8
Connections - voltage and temperature (internal reference)

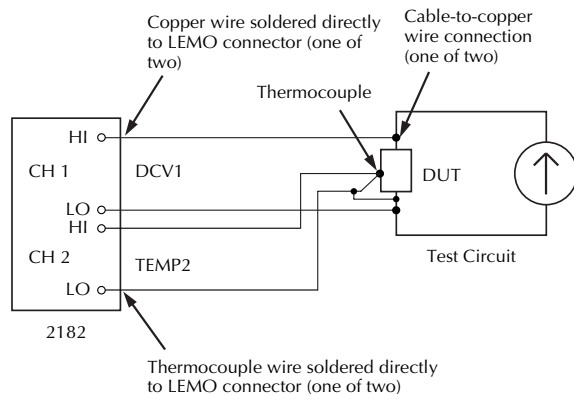
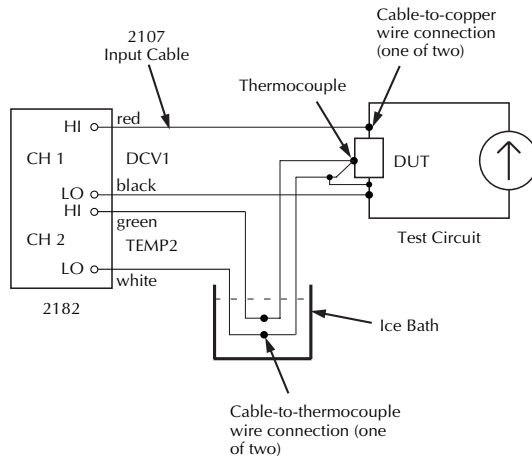


Figure 2-9 shows the same test except that a simulated reference junction (ice bath) is used.

Figure 2-9

Connections - voltage and temperature (simulated reference)



Cleaning test circuit connectors

Wherever possible, copper-to-copper connections should be used throughout your test circuit(s) to minimize thermal EMFs. However, exposed copper is susceptible to oxidation which could corrupt the measurement. Make sure that the copper contact surfaces are free of oxidation before making the connection. DeoxIT can be used to clean copper connectors. A small bottle of DeoxIT is supplied with the Model 2182.

The Model 2107 Input Cable is terminated with copper lugs, and the connection terminals of a LEMO connector are copper. Perform the following steps to clean the copper connectors used in your test circuit.

1. Using a lint-free foam swab (or other applicator), soak up a small amount of DeoxIT.
2. Apply the DeoxIT sparingly to connector/contact. Only a thin coating is required.

NOTE After cleaning, make your test circuit connections in a timely manner to prevent oxidation from forming on exposed connector surfaces.

Temperature configuration

If you are going to perform temperature measurements, you have to configure the Model 2182 appropriately from the temperature configuration menu:

Temperature configuration menu

The items of the temperature configuration menu are explained as follows:

- **UNITS** — Select the desired units designator for temperature readings (°C, °F, or K).
- **SENS** — Select the thermocouple (TCOUPLE) to perform temperature measurements at the thermocouple. The internal (INTERNL) sensor is used to measure the internal temperature of the Model 2182.
- **TYPE** — Select the thermocouple type that you are using to measure temperature (J, K, T, E, R, S, B, or N).
- **JUNC** — Select INTRNL to reference measurements to the internal reference junction. Select SIM to reference measurements to an external simulated reference. After selecting SIM, you will be prompted to enter the simulated reference temperature.

After pressing SHIFT and then TCOUP to access the menu, use the following rules to configure temperature:

- There are four menu items; UNITS, SENS, TYPE, and JUNC. Along with each menu item, the present option is displayed. For example, if °C is the present units option, then “UNITS: C” is displayed.
- Blinking characters indicate cursor position. The cursor can be on a menu item name (i.e. “UNITS” blinking) or on a menu item option (i.e. “C” blinking). Cursor position is controlled by the ◀ and ▶ keys.
- With the cursor on a menu item name, you can use the ▲ or ▼ key to scroll through the other menu items. Pressing ENTER will select the displayed option and move on to the next menu item (or exit if at end of menu).
- With the cursor on a menu item option, you can use the ▲ or ▼ key to display one of the other options for that menu item. Pressing ENTER will select the displayed option and move on to the next menu item (or exit if at end of menu). An exception is the SIM menu item. After selecting SIM, you will be prompted to enter the simulated temperature. Use the arrow keys to display the value and press ENTER.
- Pressing EXIT leaves the menu and returns to the normal display state.

Measuring voltage and temperature

NOTES *The following procedure assumes factory default conditions (see Table 1-2 in Section 1). Details on using other settings and front panel operations are provided in Section 3 through Section 8 of this manual.*

Any time the internal temperature of the Model 2182 changes by 1 °C or more, the 10mV and 100V ranges will need to be calibrated (see “Performance considerations, ACAL procedure” for details).

Whenever the LEMO connector of the Model 2107 Input Cable (or customized cable) is disconnected from the input of the Model 2182 for a long period of time, the input connectors will have to be cleaned to remove oxidation (see “Cleaning input connectors” in Section 1).

Do not use both channels to measure temperature. The electrical connection between the two thermocouples will cause erratic temperature readings.

Clean copper-to-copper connections minimize thermal EMFs. However, when measuring very low voltages, there may still be enough thermal EMFs to corrupt the measurement. In this case, use the Relative feature of the Model 2182 to null out that offset. See “Nulling thermal EMFs” which follows the basic measurement procedure.

Step 1 Connect test circuit to Model 2182

As explained in “Connections”, connect the test circuit to the input of the Model 2182. Figure 2-4 through Figure 2-9 show connections for voltage and temperature measurements.

Step 2 Configure temperature (if applicable)

If temperature measurements are going to be performed, configure temperature as previously explained in “Temperature configuration.”

Step 3 Measure Channel 1

If Channel 1 is connected to measure voltage, press DCV1. If connected to measure temperature, press TEMP1. Observe the reading on the display. The “CH1” annunciator indicates that Channel 1 is selected.

Step 4 Measure Channel 2 (if applicable)

NOTE *Channel 2 inputs must be referenced to Channel 1 LO.*

If Channel 2 is connected to measure voltage, press DCV2. If connected to measure temperature, press TEMP2. Observe the reading on the display. The “CH2” annunciator indicates that Channel 2 is selected.

Nulling thermal EMFs

The following procedure nulls out thermal EMFs using the Relative feature of the Model 2182. For more information on thermal EMFs, see “[Low-level considerations](#); [Thermal EMFs](#).” Details on Relative are provided in [Section 4](#).

1. Connect the test circuit but leave the source (voltage or current) disconnected or in stand-by.
2. Select the appropriate voltage function; DCV1 or DCV2.
3. If not using AUTO range, select the lowest possible measurement range to display the voltage offset.
4. On the Model 2182, press the REL key to zero the display.
5. If applicable, repeat steps 2 through 4 for the other channel.
6. Connect the source. Subsequent readings will not include the thermal EMFs that were nulled out.

SCPI programming - voltage and temperature measurements

Table 2-3

SCPI commands - voltage and temperature measurements

Commands	Description	Default
:SENSe		
:FUNCTION <name>	Select function: ‘VOLTage’ or ‘TEMPerature’.	VOLT
:CHANnel <chan>	Select measurement channel: 0, 1 or 2 (see Note).	1
:DATA	Return 2182 readings:	
[:LATest]?	Return the last reading.	
:FRESH?	Return a new (fresh) reading.	
:TEMPerature	Configure temperature measurements:	
:TRANsducer <name>	Select sensor: TCouple or INTernal.	TCouple
:RJUNCTION	Configure reference junction:	
:RSElect <name>	Select reference: SIMulated or INTernal.	INTernal
:SIMulated <n>	Specify simulated reference temperature in °C: 0 to 60.	23
:TCouple <type>	Specify thermocouple type: J, K, T, E, R, S, B, or N.	J
:UNIT		
:TEMPerature <name>	Select units designator: C, F, or K.	C

Note: Channel 0 is the internal temperature sensor. With a temperature function selected, reading Channel 0 returns the internal temperature reading. With a voltage function selected, reading Channel 0 returns the voltage reading of the internal temperature sensor.

Programming Example - measure voltage and temperature

The following program fragments will measure voltage on Channel 1 and temperature on Channel 2. Temperature is configured using a simulated reference junction (i.e., ice bath) and a type K thermocouple.

```
' Configure Temperature:
CALL SEND(7,":sens:temp:trans tc",status%) 'Select thermocouple
                                          'sensor.
CALL SEND(7,":sens:temp:rjun:rjel sim",status%) 'Select simulated
                                          'reference.
CALL SEND(7,":sens:temp:rjun:rjel:sim 0",status%) 'Set reference to
                                          '0°C.
CALL SEND(7,":sens:temp:TC K",status%) 'Set for type K
                                          thermocouple.
CALL SEND(7,":unit:temp F",status%) 'Read in °F.

' Measure voltage on Channel 1:
CALL SEND(7,":sens:chan 1",status%) 'Select Channel 1.
CALL SEND(7,":sens:func 'volt'",status%) 'Select DCV1.
CALL SEND(7,":sens:data:fres?",status%) 'Request a fresh
                                          'reading.
reading$ = SPACE$(80)
CALL ENTER(reading$, length%, 7, status%) 'Address 2182 to talk.
PRINT reading$ 'Display reading on CRT.

' Measure temperature on Channel 2:
CALL SEND(7,":sens:chan 2",status%) 'Select Channel 2.
CALL SEND(7,":sens:func 'temp'",status%) 'Select TEMP2.
CALL SEND(7,":sens:data:fres?",status%) 'Request a fresh
                                          'reading.
reading$ = SPACE$(80)
CALL ENTER(reading$, length%, 7,status%) 'Address 2182 to talk.
PRINT reading$ 'Display reading on CRT.
```

Low-level considerations

For sensitive measurements, external considerations beyond the Model 2182 affect accuracy. Effects not noticeable when working with higher voltages are significant in nanovolt signals. The Model 2182 reads only the signal received at its input; therefore, it is important that this signal be properly transmitted from the source. Two principal factors that can corrupt measurements are thermal EMFs and noise induced by AC interference.

NOTE *More detailed information on thermal EMFs and other factors that affect low-level measurements are explained in [Appendix C](#). Also, for comprehensive information on low-level measurements, see the “Low level measurements” handbook, which is available from Keithley.*

Thermal EMFs

Thermal EMFs (thermoelectric potentials) are generated by thermal differences between the junctions of dissimilar metals. These voltages can be large compared to the signal that the Model 2182 is trying to measure. Thermal EMFs can cause the following conditions:

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

To minimize thermal EMFs, use clean copper-to-copper connections wherever possible in the test circuit. See “[Connections](#)” for details on connection techniques and cleaning.

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

The REL (Relative) control can be used to null out constant offset voltage. The basic procedure to use REL is found in “[Measuring voltage and temperature](#),” and details on Relative are provided in [Section 4](#).

Noise

AC voltages that are extremely large compared with the DC signal to be measured may be induced into the input of the Model 2182 and corrupt the measurement. AC interference can cause the Model 2182 to behave in one or more of the following ways:

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

To minimize AC pick-up, keep the test circuit source and the Model 2182 away from strong AC magnetic sources. The voltage induced due to magnetic flux is proportional to the area of the loop formed by the input leads. Therefore, minimize the loop area of the input leads and connect each signal at only one point.

Shielding also helps minimize AC interference. The metal shield should enclose the test circuit and be connected to Channel 1 LO or to the chassis ground screw on the rear panel.

Applications

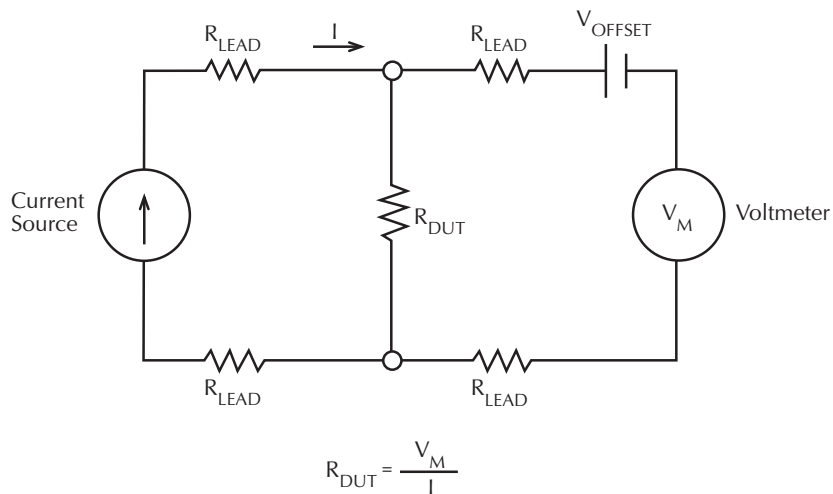
Low-resistance measurements

The Model 2182 can be used with a current source to measure resistances at levels well below the capabilities of most conventional instruments. The following paragraphs discuss low-resistance measurement techniques and include some applications to test switches.

Measurement techniques

Techniques used to measure resistances in the normal range are not generally suitable for making low-resistance measurements because of errors caused by voltage drops across the test leads. To overcome these limitations, low resistance measurements are usually made using the 4-wire (Kelvin) connections shown in [Figure 2-10](#). A current source forces the current (I) through an unknown resistance, developing a voltage across that device. Even though the test lead resistance, R_{LEAD} , is present, it does not affect the current through R_{DUT} because I is assumed to be a constant current source with high output impedance. Also, since the voltmeter has a very high input resistance (very low leakage current), the current through the sense leads will be negligible, and the voltage drop across R_{LEAD} will be essentially zero. Thus, the voltage measured by the meter will be essentially the same as the voltage across the unknown resistance, R_{DUT} .

Figure 2-10
4-Wire low-resistance measurement technique



Since the current through the measured resistance and the voltage across the device are both known, the value of that resistance can easily be determined from Ohm's law:

$$R_{DUT} = V_M/I$$

Compensating for thermal EMFs — Although the 4-wire measurement method minimizes the effects of lead resistances, other factors can affect low-resistance measurement accuracy. Thermal EMFs, and other effects can add an extraneous DC offset voltage (V_{OFFSET} in Figure 2-10) to the measured voltage.

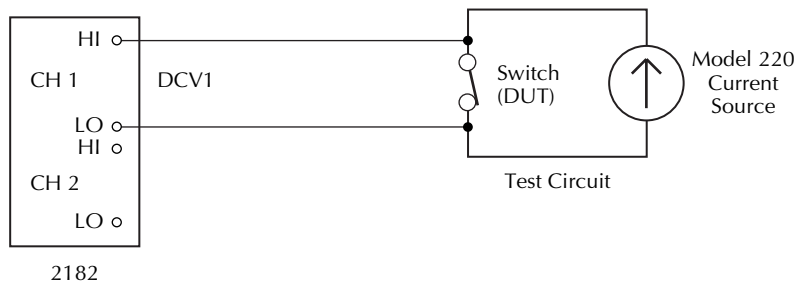
The Relative feature of the Model 2182 can be used to null out the offset voltage. In general, this is done by disconnecting the current source and zeroing the reading on the Model 2182 by pressing the REL key (see “[Measuring voltage and temperature, Nulling thermal EMFs](#)”). The DC offset voltage is effectively cancelled as long as it remains comparatively steady. If the offset voltage varies, the DC current-reversal technique should instead be used.

The DC current-reversal technique to cancel the effects of thermal EMFs requires a source that can output currents equal in magnitude, but opposite in polarity. In general, a voltage measurement is performed on both the positive and negative alternations of the current source. The averaged difference of those two readings cancels out the thermal EMF component of the measurements. The Model 2182 can automatically perform the measurements, and then calculate and display the result by using the Delta measurement mode. For Delta measurements, a Keithley SourceMeter (Model 2400, 2410, or 2420) or the Keithley Model 220 Current Source can be used to provide current-reversal. Details on performing Delta measurements are provided in [Section 5](#).

Testing switch contacts

Low power switches — [Figure 2-11](#) shows how the Model 2182 can be used to measure the resistance of a switch contact. The constant current is provided by the Keithley Model 220 current source, which can source up to 100mA. To avoid oxide puncture, the voltage across the switch contact should be $\leq 20\text{mV}$. Voltage is limited by choosing a current that will not result in a larger voltage drop than 20mV. For example, with a contact resistance specified at $500\text{m}\Omega$, the current should be no larger than 40mA.

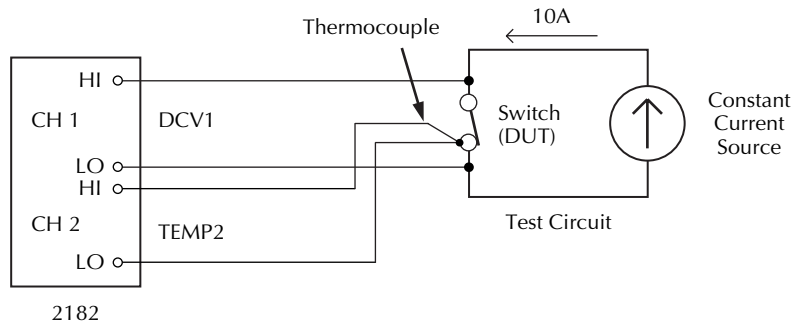
Figure 2-11
Measuring switch contact resistance



With current known and voltage measured, resistance can be calculated using Ohms Law:
 $R = V/I$.

High power switches — Heat is a factor in high power switching. As the temperature of the switch increases, so does the contact resistance. In [Figure 2-12](#) heat is generated in the switch by sourcing a constant high current (i.e., 10A) through it.

Figure 2-12
Measuring switch contact resistance and temperature

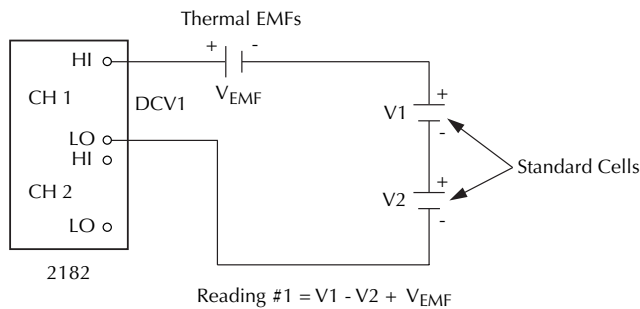


The Model 2182 measures both the voltage across the switch contact and the temperature. These measurements allow you to develop a resistance vs. temperature profile. With current known and voltage measured, resistance can be calculated using Ohms Law: $R = V/I$.

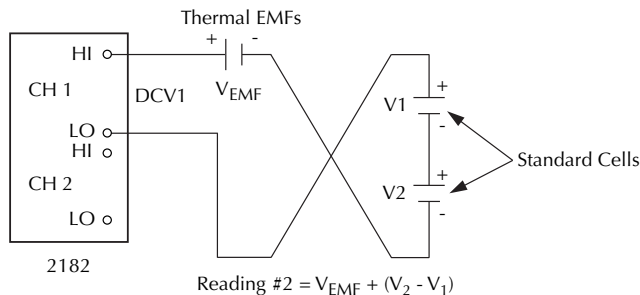
Standard cell comparisons

Standard cell comparisons are conducted by measuring the potential difference between a reference and an unknown standard cell. All cell differences are determined in series opposition configuration. The positive terminals of the standard cells (V1 and V2) are connected to the HI and LO inputs of the nanovoltmeter, as shown in Figure 2-13A. The Model 2107 Input Cable (supplied with the Model 2182) should be used to connect the cells to the nanovoltmeter in order to minimize errors caused by thermal EMFs (V_{EMF}).

Figure 2-13
Standard cell comparison measurements



A) Reading #1



B) Reading #2

Once the measurement connections have been made, care must be taken to avoid errors from thermally generated potentials. To minimize the effects of thermal EMFs, a second measurement is taken with the nanovoltmeter leads reversed, as shown in Figure 2-13B. The small voltage difference is calculated by averaging the absolute values of the two readings. Calculation of standard deviation across several redundant readings will help provide this assurance.

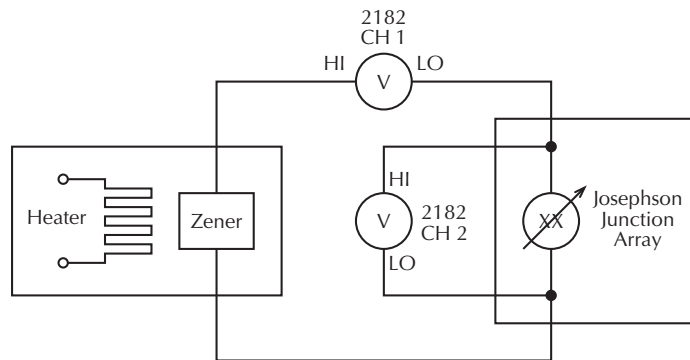
Once stability has been achieved, the actual voltage difference between the cells is measured. For each comparison, several readings are usually averaged. This process of comparing is then repeated each week, month, or year, depending upon the standards laboratory. The results can then be plotted and compared over time.

Heated Zener Reference and Josephson Junction Array comparisons

The performance of a Heated Zener Reference can be analyzed by comparing it to a Josephson Junction (JJ) Array using both channels of the Model 2182. In a cryogenic environment, the JJ Array provides an output voltage in precise, stable 175 μ V steps.

The test circuit for this application is shown in [Figure 2-14](#). The JJ Array is adjusted until Channel 1 of the Model 2182 measures 0V \pm 10 μ V. The null condition indicates that the Heated Zener Reference voltage is the same as the JJ Array voltage. Channel 2 of the Model 2182 is used to determine the exact step that the JJ Array is on. Channel 1 can then be monitored to study noise and drift characteristics of the Heated Zener Reference.

Figure 2-14
Heated Zener characterization



3 Range, Digits, Rate, and Filter

- **Range** — Provides details on measurement range selection for DCV1 and DCV2. Includes the SCPI commands for remote operation.
- **Digits** — Provides details on selecting display resolution for voltage and temperature measurements. Includes the SCPI commands for remote operation.
- **Rate** — Provides details on reading rate selection. Includes the SCPI commands for remote operation.
- **Filter** — Provides details on Filter configuration and control. Includes the SCPI commands for remote operation.

Range

The selected range affects both accuracy of the voltage measurement as well as the maximum voltage that can be measured. The DCV1 function has five measurement ranges; 10mV, 100mV, 1V, 10V, and 100V. The DCV2 function has three measurement ranges; 100mV, 1V, and 10V. The range setting (fixed or AUTO) is remembered by each voltage function.

NOTE *The available voltage ranges for Ratio (V1/V2) depend on which channel is presently selected when Ratio is enabled. If Channel 1 is presently selected, DCV1 ranges will be available when Ratio is enabled. If Channel 2 is presently selected, DCV2 ranges will be available when Ratio is enabled. Complete information on ranging for Ratio is provided in [Section 5](#).*

There is no range selection for temperature (TEMP1 and TEMP2) measurements. Temperature measurements are performed on a single, fixed range. The DIGITS key sets reading resolution.

Maximum readings

The full scale readings for every voltage range are 20% over range. For example, on the 10V range, the maximum input voltage is $\pm 12V$.

Depending on which type of thermocouple is being used, the maximum temperature readings range from $-200^{\circ}C$ to $1820^{\circ}C$. The Specifications ([Appendix A](#)) list the reading range for each thermocouple type.

Input values that exceed the maximum readings cause the overflow message (“OVRFLW”) to be displayed.

Manual ranging

To select a range, press the RANGE ▲ or ▼ key. The instrument changes one range per key-press. The selected range is displayed for one second. Note that the manual range keys have no effect on temperature (TEMP1 and TEMP2).

If the instrument displays the “OVRFLW” 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

To enable autoranging, press the AUTO key. The AUTO annunciator turns on when autoranging is selected. While autoranging is enabled, the instrument automatically selects the best range to measure the applied signal. Autoranging should not be used when optimum speed is required. Note that the AUTO key has no effect on temperature (TEMP1 and TEMP2).

Up-ranging occurs at 120% of range, while down-ranging occurs at 10% of nominal range.

To disable autoranging, press AUTO the RANGE ▲ or ▼ key. Pressing AUTO to disable autoranging leaves the instrument on the present range.

SCPI programming - range

Table 3-1

SPCI commands - range

Commands	Description	Default
:SENSe: :VOLtAge [:CHANnel1] :RANGe [:UPPer] <n> : AUTO 	SENSe Subsystem: Volts function: Channel 1 (DCV1): Range selection: Specify expected reading: 0 to 120 (volts). Enable or disable auto range.	120
:CHANnel2 :RANGe [:UPPer] <n> : AUTO 	Channel 2 (DCV2): Range selection: Specify expected reading: 0 to 12 (volts). Enable or disable auto range.	12

Programming example

The following program fragment enables autoranging for DCV1 and sets DCV2 to the 1V range:

```
CALL SEND(7,":sens:volt:rang:auto on",status%) 'Enable autorange for DCV1.
CALL SEND(7,":sens:volt:chan2:rang 0.5",status%) 'Set DCV2 to 1V range.
```


Digits

The DIGITS key sets display resolution for the Model 2182. Display resolution for voltage readings can be set from 3½ to 7½ digits. For temperature readings, resolution can be set from 4 to 7 digits.

You can have a separate digits setting for voltage and temperature functions. The digits setting for a voltage function applies to the other voltage function. For example, if you set DCV1 for 5½ digits, DCV2 will also be set for 5½ digits. Similarly, the digits setting for a temperature function applies to the other temperature function. Setting TEMP1 for 6 digits, also sets TEMP2 for 6 digits.

Digits has no effect on the remote reading format. The number of displayed digits does not affect accuracy or speed. Those parameters are controlled by the RATE setting.

Perform the following steps to set display resolution:

1. Select the desired function.
2. Press the DIGITS key until the desired number of digits is displayed.

SCPI programming - digits

Table 3-2

SCPI commands - digits

Commands	Description	Default
:SENSe :VOLTage :DIGits <n>	SENSe Subsystem: DCV1 and DCV2: Specify display resolution: 4 to 8.	8
:TEMPerature :DIGits <n>	TEMP1 and TEMP2: Specify display resolution: 4 to 7.	6

Programming example - digits

The following program fragment selects 3½-digit resolution for voltage readings, and 5½-digit resolution for temperature readings:

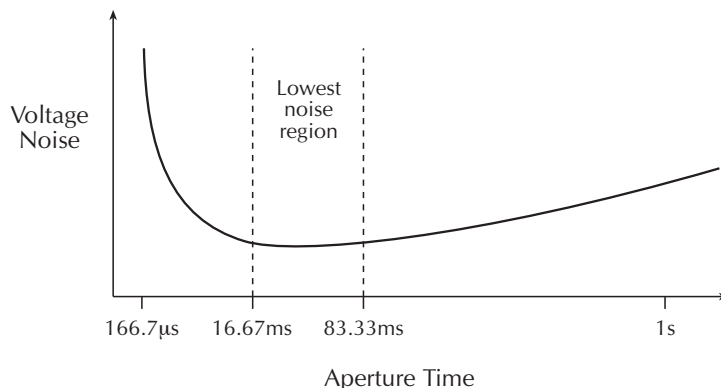
```
CALL SEND(7,":sens:volt:digits 4",status%)      'Set volts for 3½ digits.
CALL SEND(7,":sens:temp:digits 5",status%)     'Set temp for 5½ digits.
```

Rate

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

In general, the Model 2182 has a parabola-like shape for its speed vs. noise characteristics and is shown in [Figure 3-1](#). The Model 2182 is optimized for the 1 PLC to 5 PLC reading rate. At these speeds (Lowest noise region in the graph), the Model 2182 will make corrections for its own internal drift and still be fast enough to settle a step response <100ms.

Figure 3-1
Speed vs. noise characteristics



You can have a separate rate setting for voltage and temperature functions. The rate setting for a voltage function applies to the other voltage function. For example, if you set DCV1 for 0.1 PLC (fast), DCV2 will also be set for 0.1 PLC (fast). Similarly, the rate setting for a temperature function applies to the other temperature function. Setting TEMP1 for 5 PLC (slow), also sets TEMP2 for 5 PLC (slow).

Front panel RATE selections are explained as follows:

- 0.1 PLC — Selects the fastest front panel integration time. Select 0.1 PLC (fast) if speed is of primary importance (at the expense of increased reading noise).
- 1 PLC — Selects a medium integration time. Select 1 PLC (medium) when a compromise between noise performance and speed is acceptable.
- 5 PLC — Selects the slowest front panel integration time. Selecting 5 PLC (slow) provides better noise performance at the expense of speed.

NOTE For remote operation, the integration time can be set from 0.01 PLC to 60 PLC (50 PLC for 50Hz line power). Integration time can instead be set as an aperture time from 166.67 μ sec (200 μ sec for 50Hz) to 1 second.

Perform the following steps to set the integration rate:

1. Select the desired function.
2. Press the RATE key until the desired number of power line cycles (PLC) is displayed. The appropriate annunciator will turn on (FAST, MED, or SLOW).

NOTE Pressing the front panel RATE key will enable Autozero if it was off. For remote programming, the rate commands have no effect on the state of Autozero. For details, see "Autozeroing modes" in Section 2.

SCPI programming - rate

Table 3-3

SCPI commands - rate

Commands	Description	Default
:SENSe :VOLTagE :NPLCycles <n>	SENSe Subsystem: DCV1 and DCV2: Specify integration rate in PLCs: 0.01 to 60 (60Hz) 0.01 to 50 (50Hz)	5
:APERture <n>	Specify integration rate in seconds: 166.67 μ sec to 1 sec (60Hz) 200 μ sec to 1 sec (50Hz)	83.33msec
:TEMPerature :NPLCycles <n>	TEMP1 and TEMP2: Specify integration rate in PLCs: 0.01 to 60 (60Hz) 0.01 to 50 (50Hz)	5
:APERture <n>	Specify integration rate in seconds: 166.67 μ sec to 1 sec (60Hz) 200 μ sec to 1 sec (50Hz)	83.33msec

Programming example - rate

The following program fragment sets the voltage reading rate to 2 PLC and the temperature reading rate to 5 PLC:

```
CALL SEND(7,":sens:volt:nplc 2",status%)      'Set volts for 2 PLC.
CALL SEND(7,":sens:temp:nplc 5",status%)      'Set temp for 5 PLC.
```

Filter

The Model 2182 has an analog filter and a digital filter. When Filter is enabled by pressing the FILT key (FILT annunciator on), it assumes the combination of analog and digital filter configuration for the present measurement function (DCV1, DCV2, TEMP, TEMP2). Filter state (enabled or disabled) and configuration is saved by each function.

Analog filter

With the low-pass Analog Filter ON, the normal-mode noise rejection ratio of the instrument is increased at 60Hz. This filters out noise induced by the power line. The Analog Filter attenuates frequency at 20dB/decade starting at 18Hz.

A primary use of the Analog Filter is to keep the high-gain input stage of the Model 2182 from saturating due to the presence of high AC and DC voltage. Note, however, that the filter only attenuates AC voltages for the 10mV range of the Model 2182.

The Analog Filter adds approximately 125msec of settling between A/D conversions. The additional settling time may be required when using a high-impedance ($\geq 100k\Omega$) source in the test circuit.

The increased settling time causes the reading rate of the Model 2182 to be greatly reduced. Therefore, if the Analog Filter is not needed, turn it OFF.

Digital filter

The digital filter is used to stabilize noisy measurements. The displayed, stored or transmitted reading is a windowed-average of a number of reading conversions (from 1 to 100).

Digital filter characteristics

In general, the digital filter places a specified number of A/D conversions (Filter Count) into a memory stack. These A/D conversions must occur consecutively within a selected reading window (Filter Window). The readings in the stack are then averaged to yield a single filtered reading. The stack can be filled in two ways (Filter Type); moving or repeating. The moving filter keeps adding and removing a single A/D conversion from the stack before taking the average, while the repeating filter only averages a stack that is filled with new A/D conversions.

Details on digital filter characteristics are provided as follow:

Filter count — The filter count specifies how many consecutive A/D conversions (within the filter window) to place in the memory stack. When the stack is full, the A/D conversions are averaged to calculate the final filtered reading. The filter count can be set from 1 to 100. Note that with a filter count of 1, no averaging is done. However, only readings within the filter window will be displayed, stored or transmitted.

Filter window — The digital filter uses a window to control filter threshold. As long as the input signal remains within the selected window, A/D conversions continue to be placed in the stack. If the signal changes to a value outside the window, the filter resets, and the filter starts processing again starting with a new initial conversion value from the A/D converter.

The five window selections from the front panel are 0.01%, 0.1%, 1%, 10% of range, and NONE (no window). For remote operation, the window can be set to any value from 0.01% to 10% or NONE.

For voltage, the filter window is expressed as a percent of range. For example, on the 10V range, a 10% window means that the filter window is $\pm 1V$. For temperature, the filter window is expressed as a percent of the maximum temperature reading. The maximum temperature depends on which thermocouple is being used. For example, for a Type J thermocouple, the maximum reading is 760°C; a 10% window means that the filter window is $\pm 76^\circ C$.

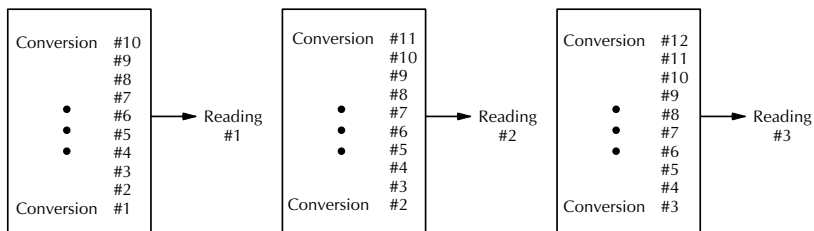
Filter type — There are two digital filter types; moving and repeating. The moving average filter uses a first-in, first-out stack. When the stack becomes full, the measurement conversions are averaged, yielding a reading. For each subsequent conversion placed in the stack, the oldest conversion is discarded, and the stack is re-averaged, yielding a new reading. This process is depicted in [Figure 3-2A](#).

For the repeating filter, the stack is filled and the conversions are averaged to yield a reading. The stack is then cleared and process starts over (see [Figure 3-2B](#)). Choose this filter for scanning so readings from other channels are not averaged with the present channel.

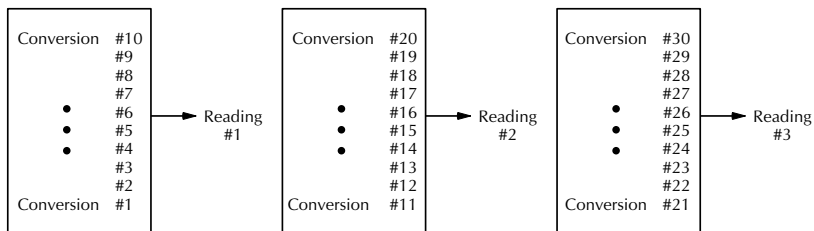
NOTES *The repeating filter cannot be used with Delta measurements. If the repeating filter is selected when Delta is enabled, the instrument will default to the moving filter. Delta measurements are covered in [Section 5](#).*

The moving filter cannot be used when stepping or scanning. If the moving filter is selected when a step or scan is enabled, the instrument will default to the repeating filter. Stepping and scanning are covered in [Section 9](#).

Figure 3-2
Moving and repeating filters



A. Type - Moving Average, Readings = 10



B. Type - Repeating, Readings = 10

Digital filter example

Filter Count = 10

Filter Window = 0.01% of range

Filter Type = Moving

Ten readings fill the stack to yield a filtered reading. Now assume the next reading (which is the 11th) is outside the window. A reading will be processed (displayed); however, the stack will be loaded with that same reading. Each subsequent valid reading will then displace one of the loaded readings in the stack. The FILT annunciator will flash until 10 new readings fill the stack.

NOTE Bit 8 of the Operation Event Status Register sets when the filter window has properly settled. See “Status structure” in Section 11 for details.

Filter control and configuration

The FILT key toggles the state of the Filter. When the Filter is enabled, the FILT annunciator is on. When disabled, the FILT annunciator is off. The analog and digital filters can be configured while the Filter is enabled or disabled.

Perform the following steps to configure the Filter:

1. Select the desired function (DCV1, DCV2, TEMP1, or TEMP2).
2. Press SHIFT and then TYPE. The present state of the analog filter (on or off) is displayed.
3. If you wish to change the state of the analog filter, place the cursor on “ON” or “OFF” and press the RANGE ▲ or ▼ key. Note that the cursor is controlled by the ◀ and ▶ keys.
4. Press ENTER. The present state of the digital filter (on or off) is displayed.
5. If you wish to change the state of the digital filter, place the cursor on “ON” or “OFF” and press the RANGE ▲ or ▼ key.
6. Press ENTER. The present digital filter window (0.01%, 0.1%, 1%, 10%, or NONE) will be displayed.
7. Use the RANGE ▲ or ▼ keys to display the desired window.
8. Press ENTER. The present digital filter count (1 to 100) will be displayed.
9. If you wish to change the digital filter count, use the cursor keys and the RANGE ▲ or ▼ keys to display the desired count.
10. Press ENTER. The present digital filter type (moving average or repeat) will be displayed.
11. If you wish to change the digital filter type, place the cursor on the type name and press the RANGE ▲ or ▼ key.
12. Press ENTER. The instrument returns to the normal measurement display state.

NOTES *While the Filter is enabled (FILT annunciator on), changes to the configuration take effect as soon as they are made. With Filter disabled, (FILT annunciator off), changes to the configuration take place when the Filter is enabled.*

If both the analog and digital filters are configured to be off, the digital filter will automatically turn on if (or when) the Filter is enabled (FILT annunciator on). This ensures that filtering (analog and/or digital) is being applied whenever the FILT annunciator is on.

While the filtering operation is in progress, the FILT annunciator blinks. Readings will continue to be processed (i.e., displayed, stored, sent over the bus, sent to analog output), but they could be questionable. When the FILT annunciator stops blinking, the filter has settled.

Changing function or range causes the Filter to reset. The Filter then assumes the state (enabled or disabled) and configuration for that function or range.

When both channels are being measured for Ratio, the Filter state (enabled or disabled) and configuration for channel 1 (DCV1) is used.

SCPI programming - filter

NOTE All the filter commands are part of the SENSE Subsystem.

Table 3-4

SCPI commands - filter

Commands	Description	Default
For DCV1: :SENSe: :VOLTage [:CHANnel1] :LPASs :DFILter :WINDow <n> :COUNT <n> :TCONtrol <name> [:STATe] 	SENSE Subsystem: Volts function: Channel 1 (DCV1): Enable or disable analog filter. Configure and control digital filter: Specify filter window (in %): 0 to 10. Specify filter count: 1 to 100. Select filter type: MOVing or REPEAT. Enable or disable digital filter.	OFF 0.01 10 MOVing ON
For DCV2: :SENSe: :VOLTage :CHANnel2 :LPASs :DFILter :WINDow <n> :COUNT <n> :TCONtrol <name> [:STATe] 	SENSE Subsystem: Volts function: Channel 2 (DCV2): Enable or disable analog filter. Configure and control digital filter: Specify filter window (in %): 0 to 10. Specify filter count: 1 to 100. Select filter type: MOVing or REPEAT. Enable or disable digital filter.	OFF 0.01 10 MOVing ON
For TEMP1: :SENSe: :TEMPerature [:CHANnel1] :LPASs :DFILter :WINDow <n> :COUNT <n> :TCONtrol <name> [:STATe] 	SENSE Subsystem: Temperature function: Channel 1 (TEMP1): Enable or disable analog filter. Configure and control digital filter: Specify filter window (in %): 0 to 10. Specify filter count: 1 to 100. Select filter type: MOVing or REPEAT. Enable or disable digital filter.	OFF 0.01 10 MOVing ON
For TEMP2: :SENSe: TEMPerature :CHANnel2 :LPASs :DFILter :WINDow <n> :COUNT <n> :TCONtrol <name> [:STATe] 	SENSE Subsystem: Temperature function: Channel 2 (TEMP2): Enable or disable analog filter. Configure and control digital filter: Specify filter window (in %): 0 to 10. Specify filter count: 1 to 100. Select filter type: MOVing or REPEAT. Enable or disable digital filter.	OFF 0.01 10 MOVing ON

Programming example

The following program fragment configures the Filter for Channel 2 voltage (DCV2). It disables the analog filter and enables the digital filter (5% window, count 10, moving).

```
'Analog Filter:
CALL SEND(7,":sens:volt:chan2:lpas off",status%) 'Disable analog filter.

' Digital Filter:
CALL SEND(7,":sens:volt:chan2:dfil:wind 5",status%) 'Set window to 5%.
CALL SEND(7,":sens:volt:chan2:dfil:coun 10",status%) 'Set count to 10.
CALL SEND(7,":sens:volt:chan2:dfil:tcon mov",status%) 'Select moving
'filter.
CALL SEND(7,":sens:volt:chan2:dfil:stat on",status%) 'Enable digital
'filter.
```

4 Relative, $mX+b$, and Percent (%)

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

Relative

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

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

Once a rel value is established for a measurement function, the value is the same for all ranges. For example, if 5V is set as the rel value on the 10V range for DCV1, the rel value is also 5V on the 100V, 1V, 100mV, and 10mV ranges.

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 10V range, the Model 2182 still overflows for a 12V input.

NOTE *Rel'ed readings are used for Ratio and Delta calculations. See Section 5 for more information on using Relative with Ratio and Delta.*

For offsets that vary, the DC current-reversal technique should be used instead of REL. This technique uses the Delta measurement mode of the Model 2182 to cancel offsets. See “Delta” in Section 5 for details.

REL Key

The REL key sets a rel value for the selected function (DCV1, DCV1, TEMP1, and TEMP2). Note that a unique rel value can be established for each measurement function.

Perform the following steps to set a rel value:

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

NOTE *You can manually set a rel value using the $mX+b$ function. Set M for 1 and B for the desired rel value. See “ $mX+b$ ” for more information.*

Analog Output Rel — A rel value can also be established for analog output. When Analog Output Rel is turned ON, the present analog output voltage is used as the rel value. Subsequent analog output readings will be the difference between the actual analog output and the rel value.

To enable Analog Output Rel, press SHIFT and then OUTPUT. The message “AOUT REL ON” will be displayed briefly to indicate that it is enabled. To disable Analog Output REL, press SHIFT and then OUTPUT a second time. The message “AOUT REL OFF” will be displayed briefly.

See Section 10 (Analog Output) for more information on Analog Output.

SCPI programming - relative

Table 4-1
SCPI commands - relative

Commands	Description	Default
For DCVI and DCV2:		
:SENSe :VOLTagE [:CHANnel1] :REFerence <n> :STATe :ACQuire	SENSe Subsystem: Volts function: Channel 1 (DCV1): Specify rel value: -120 to 120 (volts). Enable or disable relative. Use input signal as rel value.	0 OFF
:CHANnel2 :REFerence <n> :STATe :ACQuire	Channel 2 (DCV2): Specify rel value: -12 to 12 (volts). Enable or disable relative. Use input signal as rel value.	0 OFF
For TEMP1 and TEMP2:		
:SENSe :TEMPerature [:CHANnel1] :REFerence <n> :STATe :ACQuire	SENSe Subsystem: Temperature function: Channel 1 (TEMP1): Specify rel value: -273 to 1800. Enable or disable relative. Use input signal as rel value.	0 OFF
:CHANnel2 :REFerence <n> :STATe :ACQuire	Channel 2 (TEMP2): Specify rel value: -273 to 1800. Enable or disable relative. Use input signal as rel value.	0 OFF
For Analog Output:		
:OUTPut :RELative 	OUTPut Subsystem: Enabling (ON) relative uses the analog output voltage as the rel value. Sending ON with rel already enabled acquires a new rel value.	OFF

Programming examples - relative

Program Example 1 — This program fragment shows how to null out zero offset for the DCV1 function. Be sure to short the Channel 1 input.

```
CALL SEND(7,":syst:pres",status%)           'Selects DCV1 and enables
                                              'autorange.
CALL SEND(7,":fetch?",status%)              'Fetches Channel 1 offset.
reading$ = SPACE$(80)
CALL ENTER(reading$,length%,7,status%)      'Gets offset reading.
CALL SEND(7,":sens:volt:ref:acq",status%)    'Acquires Rel Value.
CALL SEND(7,":sens:volt:ref:stat on",status%) 'Enables relative for 'DCV1.
```

Program Example 2 — This program fragment shows how to establish a +1V baseline for the DCV1 function. For this baseline value, a +1V input will be displayed as 0V.

```
CALL SEND(7,":syst:pres",status%)           'Selects DCVI function and
                                              'enables autorange.
CALL SEND(7,":sens:volt:ref 1",status%)      'Sets a 1V rel value.
CALL SEND(7,":sens:volt:ref:stat on",status%) 'Enables relative for 'DCV1.
```

$mX+b$ and percent (%)

$mX+b$

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

$$Y = mX+b$$

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

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

1. Press SHIFT and then MX+B to display the present scale factor:
 M: +1.0000000 ^ (factory default)
2. Key in a scale factor value. The ◀ and ▶ keys control cursor position and the ▲ and ▼ range keys increment and decrement the digit value. To change range, place the cursor on the multiplier and use the ▲ and ▼ keys (m = $\times 0.001$, ^ = $\times 1$, K = $\times 1000$, and M = $\times 1,000,000$). With the cursor on the polarity sign, the ▲ and ▼ keys toggle polarity.
3. Press ENTER to enter the M value and display the B value:
 B: +00.000000 m (factory default)
4. Key in the offset value.
5. Press ENTER to enter the B value and display the two-character UNITS designator:
 UNITS: MX (factory default)
6. Use the cursor keys and the ▲ or ▼ key if you wish to change the units designator. Each character can be any letter in the alphabet (A through Z), the degrees symbol ($^{\circ}$), or the ohms symbol (Ω).
7. Press ENTER. The MATH annunciator will turn on, and the result of the calculation will be displayed. Note that the calculation will be applied to all measurement functions.
8. To disable $mX+b$, again press SHIFT and then MX+B. The MATH annunciator will turn off.

NOTE *$mX+b$ does not affect analog output. Analog output has its own gain and offset settings (see [Section 10](#) for details).*

$mX+b$ Relative — The $mX+b$ function can be used to manually establish a relative (rel) value. To do this, set the scale factor (M) to 1 and set the offset (B) to the rel value. Each subsequent reading will be the difference between the actual input and the rel value (offset). See “[Relative](#)” for more information.

Percent (%)

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

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

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

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

1. Press SHIFT and then % to display the present reference value:
REF: +1.000000 ^ (factory default)
2. Key in a reference value. The ◀ and ▶ keys control cursor position and the ▲ and ▼ range keys increment and decrement the digit value. To change range, place the cursor on the multiplier and use the ▲ and ▼ keys (m = $\times 0.001$, ^ = $\times 1$, K = $\times 1000$, and M = $\times 1,000,000$). With the cursor on the polarity sign, the ▲ and ▼ keys toggle polarity.
3. Press ENTER. The MATH annunciator will turn on, and the result of the calculation will be displayed. Note that the calculation will be applied to all measurement functions.
4. To disable percent, again press SHIFT and then %. The MATH annunciator will turn off.

NOTES *The result of the percent calculation is positive when the input exceeds the reference and negative when the input is less than the reference.*

The result of the percent calculation may be displayed in exponential notation. For example a displayed reading of + 2.500E+03% is equivalent to 2500% (2.5K %).

SCPI programming - $mX+b$ and percent

Table 4-2

SCPI commands - $mX+b$ and percent

Commands	Description	Default
:CALCulate		
:FORMat <name>	Select calculation; NONE, MXB or PERCent.	NONE
:KMATH	Path to configure $mX+b$ and Percent:	
:MMFactor <NRf>	Specify scale factor (M) for $mX+b$: $-100e6$ to $100e6$.	1
:MBFactor <NRf>	Specify offset (B) for $mX+b$: $-100e6$ to $100e6$.	0
:MUNits <name>	Specify units for $mX+b$: see “ Setting $mX+b$ units. ”	MX
:PERCent <NRf>	Specify reference value for Percent: $-100e6$ to $100e6$.	1
:ACQuire	Use input signal as reference value.	
:STATe 	Enable or disable the selected calculation.	OFF
:DATA		
[:LATest]?	Query last calculation result.	
:FRESH?	Trigger a reading and query the calculation result.	

Setting $mX+b$ units

The <name> parameter for CALCulate:KMATH:MUNits can be one or two characters enclosed in single or double quotes. A character can be any letter of the alphabet, the degrees symbol ($^{\circ}$) or the ohms symbol (Ω).

The ohms symbol (Ω) and the degrees symbol ($^{\circ}$) are not ASCII characters and therefore, must be substituted with the '[' and '\ ' characters as follows:

CALCulate:KMATH:MUNits '[' Use ohms symbol (Ω) as units designator.

CALCulate:KMATH:MUNits '\ ' Use degrees symbol ($^{\circ}$) as units designator.

Programming examples - $mX+b$ and percent

Program Example 1 — This program fragment shows how to configure and enable the $mX+b$ calculation.

```
CALL SEND(7,":calc:form mxb",status%)           'Selects  $mX+b$  calculation.
CALL SEND(7,":calc:kmat:mmf 2",status%)        'Sets scale factor (M) to 2.
CALL SEND(7,":calc:kmat:mbf 0.5",status%)      'Sets offset (B) to 0.5.
CALL SEND(7,":calc:kmat:mun cd",status%)       'Sets units to "CD".
CALL SEND(7,":calc:stat on",status%)          'Enables calculation.
```

Program Example 2 — This program fragment shows how to configure and enable the Percent calculation.

```
CALL SEND(7,":calc:form perc",status%)        'Selects percent calculation.
CALL SEND(7,":calc:kmat:perc:acq",status%)    'Uses input signal as
                                                'reference.
CALL SEND(7,":calc:stat on",status%)          'Enables calculation.
```

5 Ratio and Delta

NOTE *When using the Model 2182/2182A with the Model 6220 or 6221 Current Source, enhanced Delta and Differential Conductance measurements can be performed.*

When using the Model 2182A with the Model 6220 Current Source, Pulsed Delta measurements can be performed.

See Section I for details on enhanced Delta, Pulsed Delta, and Differential Conductance.

- **Ratio** — Covers the Ratio calculation, and the effects of Filter, Rel and Ranging.
- **Delta** — Explains how to perform Delta measurements, which are used to cancel the effects of thermal EMFs in the test leads. Features the use of a Keithley SourceMeter with the Model 2182 to perform Delta measurements. Includes the effects of Filter on Delta measurements.
- **SCPI programming** — Covers the SCPI commands used to control Ratio and Delta, and includes programming examples.
- **Applications** — Provides applications that use Ratio and Delta.

Ratio

Ratio (V1/V2) displays the proportional relationship between the two voltage input channels (DCV1 and DCV2). Ratio is calculated as follows:

$$\text{Ratio} = V1/V2$$

Where: V1 is the voltage reading for Channel 1 (DCV1)
V2 is the voltage reading for Channel 2 (DCV2)

Basic procedure

Ratio is selected by pressing the V1/V2 key. The “CH1 / CH2” message appears briefly before displaying the result of the calculation. The “RA” message is displayed while in Ratio. Ratio is disabled by selecting a single measurement function (DCV1, DCV2, TEMP1 or TEMP2) or by selecting Delta.

- NOTES**
- *When Ratio is selected, one of the channel annunciators (CH1 or CH2) will turn on briefly. This indicates the channel that can be controlled by the manual range key. After that both the CH1 and CH2 annunciators will turn on. See “Ranging considerations” for details.*
 - *If an overflow condition (OVRFLW) occurs, the range that overflowed will format the display.*
 - *Ratio readings can be stored in the buffer. See Section 6 for details on using the buffer.*
 - *Reading HOLD cannot be used with Ratio. Selecting Ratio (or Delta) disables HOLD.*
 - *LSYNC (line cycle integration) must be enabled when RATIO is selected. LSYNC turns on automatically when RATIO is selected and turns off automatically when exiting RATIO.*

Step 1 Connect voltages to be measured to the Model 2182.

Details on connecting the Model 2182 to the voltages to be measured are provided in [Section 2](#) (see “Connections”).

WARNING A hazardous voltage condition exists at or above 42V peak. To prevent electric shock that could result in injury or death, NEVER make or break connections while hazardous voltage is present.

CAUTION Exceeding the following limits may cause instrument damage not covered by the warranty:

- Channel 1 HI and LO terminals have a maximum measurement capability of 120V peak. These inputs are protected to 150V peak to any terminal or 350V peak to chassis.
- Channel 2 HI and LO terminals have a maximum measurement capability of 12V peak to Channel 1 LO. Channel 2 HI is protected to 150V peak to any terminal. Channel 2 LO is protected to 70V peak to Channel 1 LO. Both inputs are protected to 350V peak to chassis.

Step 2 Configure Channel 1 and Channel 2 for voltage measurements.

Configure each channel (DCV1 and DCV2) for the desired voltage measurement. Unique settings for each channel include Range, Filter, and Rel.

Step 3 Verify on-scale readings for DCV1 and DCV2.

Verify that DCV1 and DCV2 are displaying on-scale readings. If an “OVRFLW” message is displayed for any channel, select a higher range until an on-scale reading is displayed (or press AUTO to enable autoranging).

Step 4 Select the range control channel.

If you want the manual range keys to control Channel 1 ranges, select (press) DCV1 just before going into Ratio. If you want the manual range keys to control Channel 2 ranges, select DCV2 just before going into Ratio. For more information, see “[Ranging considerations](#)” for Ratio.

NOTE After Ratio is enabled (next step), pressing the AUTO range key will either enable autorange for both channels or disable autorange for both channels.

Step 5 Enable Ratio.

To enable Ratio, press the V1/V2 key. The “CH1 / CH2” message will be displayed briefly. While in Ratio, the “RA” message is displayed, and both the “CH1” and “CH2” annunciators are on.

NOTE If an overflow condition (OVRFLW) occurs, the range that overflowed will format the display.

Step 6 Take Ratio readings from display.

Filter, Rel, and Ranging considerations

Filter considerations

As explained in [Section 3](#), a unique Filter configuration can be established for each voltage channel. However, the Filter configuration for Channel 1 is applied to both channels when Ratio is enabled. The Filter state and configuration for Channel 2 are ignored. Channel 1 Filter has priority because it has the most sensitive measurement range (10mV) and may therefore be configured to provide more filtering than Channel 2.

When the FILT annunciator is on while in Ratio, the Channel 1 (DCV1) Filter settings are applied to both input channels. When the FILT annunciator is off, filtering is not used.

When using Filter, Ratio is calculated as follows:

$$\text{Ratio} = \text{Filt V1} / \text{Filt V2}$$

where: Filt V1 is the filtered reading for Channel 1 voltage input.
Filt V2 is the filtered reading for Channel 2 voltage input.

Keep in mind that the Filter settings are applied to the input channels, not on the result of Ratio.

The FILT key is operational while in Ratio. Pressing FILT will either disable Filter for both channels or enable Filter for both channels (FILT annunciator turns on). However, remember that even though Filter can be enabled for both channels, only the Channel 1 Filter settings are used.

NOTE *The filter configuration menu cannot be accessed while in Ratio. To make filter configuration changes, you must first disable Ratio. This can be done by returning to Channel 1 (press DCV1).*

Rel (Relative) considerations

As explained in [Section 3](#), a separate Rel value can be established for each voltage channel. When Ratio is enabled, any established Rel values are applied to the respective channels before the calculation is performed.

Ratio is calculated as follows:

$$\text{Ratio} = (\text{Filt V1} - \text{V1 Rel}) / (\text{Filt V2} - \text{V2 Rel})$$

where: Filt V1 is the filtered reading for Channel 1 voltage input.
V1 Rel is the Rel value established for Channel 1.
Filt V2 is the filtered reading for Channel 2 voltage input.
V2 Rel is the Rel value established for Channel 2.

NOTE *The previous calculation shows Filter enabled. If Filter is not used, remove the “Filt” component from the calculation.*

When Ratio is enabled, the state (on or off) of the REL annunciator depends on which measurement function was last selected. If on DCV1 when Ratio is enabled, the state of the REL annunciator (on or off) will indicate the state (enabled or disabled) of Rel for DCV1. If on DCV2 when Ratio is enabled, the state of the REL annunciator will indicate the state of Rel for DCV2.

The REL key is operational while in Ratio. Pressing REL will either disable Rel for both channels or enable Rel for both channels (REL annunciator turns on). When Rel is enabled, the instrument acquires the input signal from each of the two channels as Rel values. Each Rel value is then applied to the respective channel. Keep in mind that the Rel operations are performed on the input channels, not on the result of Ratio.

Ranging considerations

As explained in [Section 3](#), a separate range setting (fixed or AUTO) can be used for each voltage channel. When Ratio is enabled, the range setting for each channel is retained. For example, Channel 1 could be set for autoranging, and Channel 2 could be fixed on the 10V range.

Range control — The manual range keys can only control one of the two channels. If the instrument is on DCV1, TEMP1, or TEMP2 when Ratio is enabled, the manual range keys will control Channel 1 (DCV1). The manual range keys will have no effect on Channel 2 (DCV2). If on DCV2 (Channel 2) when Ratio is enabled, range control will apply to Channel 2 (DCV2). The manual range keys will have no effect on Channel 1 (DCV1).

- NOTES**
- *When Ratio is selected, the range control channel will be displayed while the “CH1 / CH2” message is being displayed.*
 - *When a range key is pressed, the channel number annunciator for the range controlled channel remains on. The other channel annunciator turns off for a brief moment.*
 - *The state (on or off) of the AUTO range annunciator indicates the state (enabled or disabled) of autorange for the voltage channel that is under range control.*
 - *With Ratio already enabled, pressing the AUTO range key will either disable autorange for both channels or enable autorange for both channels (AUTO annunciator turns on).*

Delta

Delta provides the measurements and calculation for the DC current-reversal technique to cancel the effects of thermal EMFs in the test leads. Each Delta reading is calculated from two voltage measurements on Channel 1; one on the positive phase of an alternating current source, and one on the negative phase.

Basic Delta Calculation:

$$\text{Delta} = \frac{V1t1 - V1t2}{2}$$

where: V1t1 is the voltage measurement on the positive phase of the current source.
V1t2 is the voltage measurement on the negative phase of the current source.

Delta Calculation using Filter and Rel:

$$\text{Delta} = \frac{\text{Filt}V1t1 - \text{Filt}V1t2}{2} - \text{Rel}V1$$

where:

- Filt V1t1 and Filt V1t2 are filtered voltage measurements on the positive and negative phases of the current source. The “FILT” annunciator will be on when Filter is enabled.
- Rel V1 is the Rel value established for DCV1. The “REL” annunciator will be on when Rel is enabled.

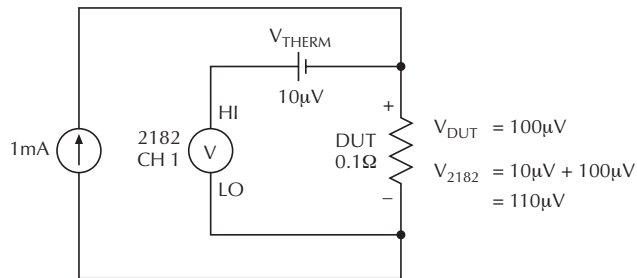
The Model 2182 is optimized to provide low-noise readings when measurement speed is set from 1 to 5 PLC. At 1 PLC, current can be reversed after 100msec. At 5 PLC, current can be reversed after 333msec. At these reading rates, noise induced by the power line should be insignificant. Filtering can be used to reduce peak-to-peak reading variations. For more information on Filter in regard to Delta measurements, see “[Filter considerations](#)” in this section.

The following example shows how a bipolar current source and Delta can be used to cancel the effects of thermal EMFs:

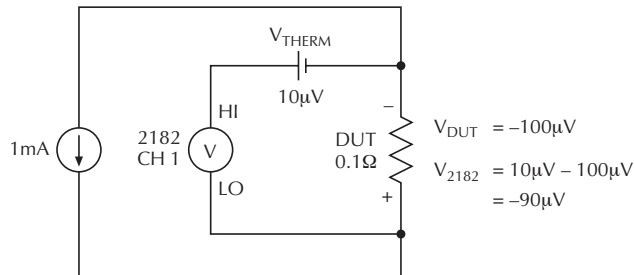
In [Figure 5-1A](#), a constant 1mA is being sourced to a 0.1Ω DUT. Under ideal conditions, the Model 2182 would measure 100μV across the DUT (1mA × 0.1Ω = 100μV). However, connection points and temperature fluctuations may generate thermal EMFs in the test leads. Note that the thermal EMFs drift with temperature. [Figure 5-1](#) shows 10μV of thermal EMF (V_{THERM}). Therefore, the Model 2182 will measure 110μV instead of 100μV:

$$\begin{aligned} V_{2182} &= V_{\text{THERM}} + V_{\text{DUT}} \\ &= 10\mu\text{V} + 100\mu\text{V} \\ &= 110\mu\text{V} \end{aligned}$$

Figure 5-1
Test circuit using constant current source



A. Positive Current Source



B. Negative Current Source

Figure 5-1B shows what happens when the current is reversed. The measurement by the Model 2182 still includes the $10\mu\text{V}$ of thermal EMF, but the voltage across the DUT is now negative. Therefore, the Model 2182 will measure $90\mu\text{V}$:

$$\begin{aligned}
 V_{2182} &= V_{THERM} + V_{DUT} \\
 &= 10\mu\text{V} - 100\mu\text{V} \\
 &= -90\mu\text{V}
 \end{aligned}$$

As demonstrated in Figure 5-1, neither measurement by the Model 2182 accurately measured the voltage across the DUT. However, if you take a simple average of the magnitudes of the two readings ($110\mu\text{V}$ and $90\mu\text{V}$), the result is $100\mu\text{V}$, which is the actual voltage drop across the DUT. This is what the calculation for Delta does.

To use the DC current-reversal technique, replace the constant current source with a bipolar current source as shown in [Figure 5-2](#). The current source will alternate between +1mA and -1mA. When using Delta, the Model 2182 performs the first voltage measurement (V_{1t1}) while sourcing +1mA. The second voltage measurement (V_{1t2}) is performed while sourcing -1mA:

NOTE When using the Model 2182 to perform Delta measurements, RATE must be set to 1 PLC or 5 PLC to optimize measurement performance. At 1 PLC or 5 PLC, Delta measurements will cancel thermal EMFs to a <50nV level.

$$\begin{aligned} V_{1t1} &= V_{\text{THERM}} + V_{\text{DUT}} & V_{1t2} &= V_{\text{THERM}} - V_{\text{DUT}} \\ &= 10\mu\text{V} + 100\mu\text{V} = 110\mu\text{V} & &= 10\mu\text{V} - 100\mu\text{V} \\ &= 110\mu\text{V} & &= -90\mu\text{V} \end{aligned}$$

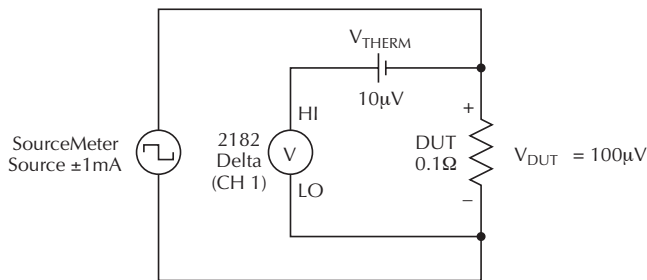
Delta is then calculated as follows:

$$\text{Delta} = \frac{V_{1t1} - V_{1t2}}{2} = \frac{110\mu\text{V} - (-90\mu\text{V})}{2} = \frac{200\mu\text{V}}{2} = 100\mu\text{V}$$

Using Delta with a bipolar source effectively canceled the 10 μV thermal EMF.

External triggering is required to control the timing between voltage measurements and current source reversals. Trigger synchronization between the source and the Model 2182 is explained in [“Model 2182 and SourceMeter trigger synchronization”](#) which follows the [“Delta measurement procedure using a SourceMeter.”](#)

Figure 5-2
Delta measurement using bipolar source



At +1mA:

$$\begin{aligned} V_{1t1} &= 10\mu\text{V} + 100\mu\text{V} \\ &= 110\mu\text{V} \end{aligned}$$

At -1mA:

$$\begin{aligned} V_{1t2} &= 10\mu\text{V} - 100\mu\text{V} \\ &= -90\mu\text{V} \end{aligned}$$

$$V_{\text{DELTA}} = \frac{V_{1t1} - V_{1t2}}{2} = \frac{110\mu\text{V} - (-90\mu\text{V})}{2} = 100\mu\text{V}$$

$$V_{\text{DELTA}} = V_{\text{DUT}}$$

Selecting Delta

Delta is selected by pressing the SHIFT key and then the V1-V2 key. The “(Vt1-Vt2) / 2” message appears briefly before displaying the result of the calculation. Delta is disabled by selecting a single measurement function (DCV1, DCV2, TEMP1, or TEMP2) or by selecting Ratio.

NOTES

- To double the speed of Delta measurements, disable Front Autozero as follows:
*Press **SHIFT** > Press **CONFIG** > Set **FRONT AUTOZERO** to **N** > Press **ENTER***
For details on Front Autozero, see “Autozeroing modes” in Section 2.
- Delta reading is indicated by a small “d” on the display (after the reading).
- Delta performs voltage measurements on Channel 1. If on Channel 2, the Model 2182 will automatically go to Channel 1 when Delta is selected.
- Delta readings can be stored in the buffer. See Section 6 for details on using the buffer.
- Delta cannot be selected if stepping or scanning.
- Reading HOLD cannot be used with Delta.

Delta measurements by the Model 2182 require the use of an alternating polarity source. The source must have external triggering capabilities that are compatible with the external triggering capabilities of the Model 2182. The following procedure shows how to use a Keithley SourceMeter with the Model 2182 to perform Delta measurements.

Delta measurement procedure using a SourceMeter

A Keithley SourceMeter (Model 2400, 2410, or 2420) can be used as a bipolar source by configuring it to perform a custom sweep. In general, a custom sweep is made up of number of specified source points. To provide current reversal, the positive current value(s) are assigned to the even numbered points, and the negative current value(s) are assigned to the odd numbered points. For details on custom sweep, see the User’s Manual for the SourceMeter.

Applications that use Delta measurements require either a fixed current or a growing amplitude current. When a fixed current is required, the SourceMeter can be configured to output a bipolar 2-point custom sweep. That sweep can be run a specified number of times or it can run continuously. For example, if a fixed current of 1mA is required for the test, the two bipolar sweep points for the custom sweep would be +1mA and -1mA.

When a growing-amplitude current is required, the custom sweep can be configured to include all the current values required for the test. For example, assume the test requires two Delta measurements at each of three current levels; 1mA, 2mA, and 5mA. That test would require the following 12-point custom sweep to produce the six Delta measurements:

P0000 = +1mA	P0001 = -1mA
P0002 = +1mA	P0003 = -1mA
P0004 = +2mA	P0005 = -2mA
P0006 = +2mA	P0007 = -2mA
P0008 = +5mA	P0009 = -5mA
P0010 = +5mA	P0011 = -5mA

The following procedure uses the SourceMeter as a bipolar fixed-amplitude current source. It outputs a 2-point custom sweep to provide current reversal that is required for Delta measurements by the Model 2182.

- NOTES**
- When using the Model 2182 to perform Delta measurements, RATE must be set to 1 PLC or 5 PLC to optimize measurement performance. At 1 PLC or 5 PLC, Delta measurements will cancel thermal EMFs to a <50nV level.
 - The SourceMeter SPEED must be set to FAST (0.01 PLC). Using a slower speed will result in trigger synchronization problems with the Model 2182.
 - The following procedure assumes SourceMeter firmware version C11 or later.

Step 1 Connect the Delta measurement test circuit.

Connect the SourceMeter and Model 2182 to the DUT as shown in [Figure 5-3](#). Also connect a trigger link cable (Model 8501) from the Model 2182 to the SourceMeter.

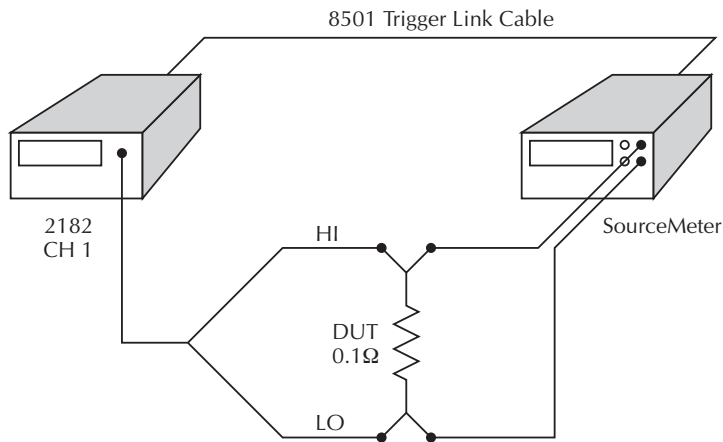
NOTE This procedure assumes that the Model 2182 is using the factory default Trigger Link line configuration; Line 1 is VMC (output), Line 2 is EXT TRIG (input).

Step 2 Return the SourceMeter to BENCH defaults.

BENCH defaults are restored from the Main Menu, which is accessed by pressing MENU:

MAIN MENU→SAVESETUP→GLOBAL→RESET→BENCH

Figure 5-3
Delta measurement connections



Step 3 Configure the trigger model of the SourceMeter.

The menu structure to configure triggers is accessed by pressing CONFIG and then TRIG. Configure the trigger model as follows:

Arm-Layer:

Arm-In Event	IMMEDIATE
Arm-Out TLink Line	#3
Arm-Out Events	OFF
Arm Count	INFINITE

Trig-Layer:

Trigger-In:

Trigger-In Source	TRIGGER LINK
Trig-In TLink Line	#1
Event Detect Bypass	NEVER
Trigger In Events	SOURCE=ON DELAY=OFF MEAS=OFF

Trigger-Out:

Trigger-Out TLink Line	#2
Trigger Out Events	SOURCE=ON DELAY=OFF MEAS=OFF

Delay

000.0000 s

Trig-Count

0002 (trigger count must equal the number of sweep points)

Step 4 Set up the SourceMeter to source current and measure voltage.

- A. On the SourceMeter, select Source I and Measure V.
- B. Select an appropriate current source range. For example, if your current reversal values are going to $\pm 1\text{mA}$, select the 1mA source range.
- C. Press SPEED and select FAST. SourceMeter measurements are not used in this test, but it must run as fast as possible to avoid synchronization problems with the Model 2182.

Step 5 Configure the SourceMeter to perform a 2-point custom sweep.

- A. The menu to configure a sweep is accessed by pressing CONFIG and then SWEEP. From the menu, select TYPE and then select CUSTOM.
Set the #-POINTS to two, and set ADJUST-POINTS (P0000 and P0001) to the positive and negative current source values. For example, if the test requires 1mA, set P0000 to +1mA and set P0001 to -1mA.
- B. Also from the sweep configuration menu, specify the number of 2-point sweeps to perform:
Selecting INFINITE allows the SourceMeter to continuously source the current reversal sweep. Select FINITE if you wish to perform a specific number of 2-point sweeps.

Step 6 Return the Model 2182 to FACTory defaults.

Return the nanovoltmeter to its factory default conditions, by pressing RESTR and selecting FACT.

Step 7 Configure the Model 2182 for Delta measurements.

- A. Press RATE to select 1 PLC (MED annunciator on) or 5 PLC (SLOW annunciator on).
- B. Enable Delta measurements by pressing SHIFT and then V1-V2.

NOTE For fast Delta measurements (2x speed), disable Front Autozero (SHIFT > CONFIG > FRONT AUTOZERO N).

- C. Press EX TRIG to place the instrument in the external trigger mode. This will halt measurements.
- D. If a longer settling time is required before performing each measurement, set a manual delay from the Model 2182. Press SHIFT and then DELAY to select and set delay.

NOTE Do not set a delay on the SourceMeter, as this may adversely affect trigger synchronization between the SourceMeter and the Model 2182.

Step 8 Turn on the SourceMeter output and reset the trigger model.

- A. Turn on the output by pressing the OUTPUT ON/OFF key (“ARM” annunciator turns on).
- B. Reset the trigger model as follows:
 1. Press CONFIG and then TRIG to access the trigger configuration menu.
 2. Select HALT to place the SourceMeter in the idle state (“ARM” annunciator turns off).
 3. Press EXIT to return to the normal display.

Step 9 Set up the Model 2182 to store readings in the buffer (optional).

On the Model 2182, press STORE and set the number of Delta readings to store in the buffer. Press ENTER to enable the buffer.

Step 10 Start the sweep from the SourceMeter.

- A. To arm the sweep, press SWEEP.
- B. To start the sweep, press TRIG.

At the end of each 2-point sweep, a Delta reading will be calculated and displayed, and stored in the buffer if it is enabled.

NOTES

- *A sweep in progress can be aborted by pressing EXIT on the SourceMeter.*
- *If you are done sweeping, turn off the source by pressing the ON/OFF OUTPUT key on the SourceMeter. Turning the source off prevents heat from building up in the DUT.*
- *Delta readings stored in the buffer can be accessed by pressing RECALL on the Model 2182.*

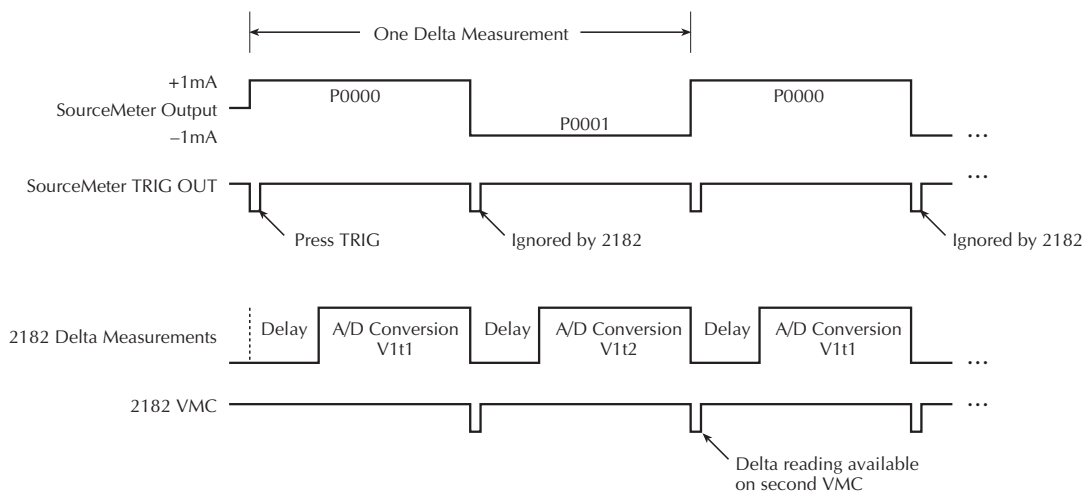
Step 11 Repeating the sweep.

- A. On the Model 2182, press EX TRIG twice to disable and then re-enable external triggering. The “TRIG” annunciator indicates that the Model 2182 is in the external triggering mode.
- B. Repeat Steps 8, 9, and 10. However, if the SourceMeter output is already on, skip Step 8A.

Model 2182 and SourceMeter trigger synchronization

The timing diagram in Figure 5-4 shows trigger synchronization between the SourceMeter and the Model 2182 for a 2-point custom sweep. As shown in the timing diagram, the SourceMeter will output a trigger after every source sweep point, and the Model 2182 will output a trigger after every A/D conversion.

Figure 5-4
Triggering timing diagram



When the TRIG key on the SourceMeter is pressed, it starts the sweep (outputs +1mA) and triggers the Model 2182 to start a Delta measurement. After the delay period, the Model 2182 performs an A/D conversion for the V1t1 phase of the Delta measurement, and then triggers the SourceMeter to output the second point of the sweep (-1mA). At this point, the Model 2182 does not wait for the return trigger from the SourceMeter to perform the V1t2 phase of the Delta measurement. That second trigger from the SourceMeter is ignored. After the A/D conversion for the V1t2 phase, the Delta reading is calculated and displayed.

If programmed for another sweep, the trigger from the Model 2182 to the SourceMeter will again start the sweep to perform another Delta measurement.

Filter considerations

The filter configuration for DCV1 is applied separately to each measurement phase (V1t1 and V1t2) of the Delta process.

NOTE *The repeating filter cannot be used for Delta measurements. When Delta is selected, the Filter will automatically switch to the moving filter if the repeating filter was enabled.*

Moving filter — After filtering yields a reading for V1t1, an output trigger is sent. After filtering yields a reading for V1t2, another output trigger is sent. The Delta calculation is performed and the reading is displayed.

For example, assume the filter count for the Moving Filter is 5. Two filter stacks are used: one for V1t1 readings and one for V1t2 readings. The filter stack for V1t1 readings is filled with five measurement conversions. The five readings are averaged to yield the V1t1 value and an output trigger is sent on each V1t1 A/D conversion. The filter stack for V1t2 readings is then filled with five measurement conversions. The five readings are averaged to yield the V1t2 value and an output trigger is sent. On each V1t2 A/D conversion, the Delta calculation is performed using the filtered V1t1 and V1t2 values and the result is displayed on the Model 2182.

For every subsequent Delta measurement, the operation is basically the same except that each stack only requires one reading to fill it. The oldest reading in each stack is discarded.

NOTE *The filter configuration menu cannot be accessed while in Delta. To make filter configuration changes, you must first disable Delta. This can be done by selecting Channel 1 (press Delta).*

SCPI programming - ratio and delta

Table 5-1

SCPI commands - ratio and delta

Commands	Description	Default
:SENSe[1]	SENSe Subsystem:	
:FUNCTion <name>	Select voltage function; 'VOLTage'.	VOLT
:CHANnel <chan>	Select range control channel; 1 or 2.	
:VOLTage[:DC]	Path to configure DC volts:	
:RATio 	Enable or disable Ratio (V1/V2).	OFF
:DELTA 	Enable or disable Delta. Not valid with TEMP1 or TEMP2 selected.	OFF
:SYSTem:FAZero[:STATe] 	Enable or disable Front Autozero. To double the speed of Delta, disable Front Autozero.	ON

Note: Enabling Ratio disables Delta and conversely, enabling Delta disables Ratio.

Programming examples

Ratio programming example — The following program fragment enables Ratio and displays the result on the computer CRT.

```
CALL SEND (7, ":sens:volt:func 'volt'", status%) ' Select voltage function.
CALL SEND (7, ":sens:volt:chan 1", status%) ' Select Channel 1 (DCV1) for
' range control.
CALL SEND (7, ":sens:volt:ratio", status%) ' Enable Ratio.
CALL SEND (7, ":sens:data:fresh?", status%) ' Request a fresh reading.
reading$ = SPACE$(80)
CALL ENTER(reading$, length%, 7, status%) ' Address 2182 to talk.
PRINT reading$ ' Display Ratio reading on CRT.
```

Delta programming example — The following program fragment uses a SourceMeter (SM) with the Model 2182 to perform Delta measurements. External triggering (via Trigger Link) is used to synchronize the source-measure operations between the two instruments. Also, Front Autozero is disabled to double the speed of Delta.

Three Delta measurements will be performed; one at a source value of 10 μ A, one at 20 μ A, and one at 50 μ A. The three readings will be stored in the buffer of the Model 2182.

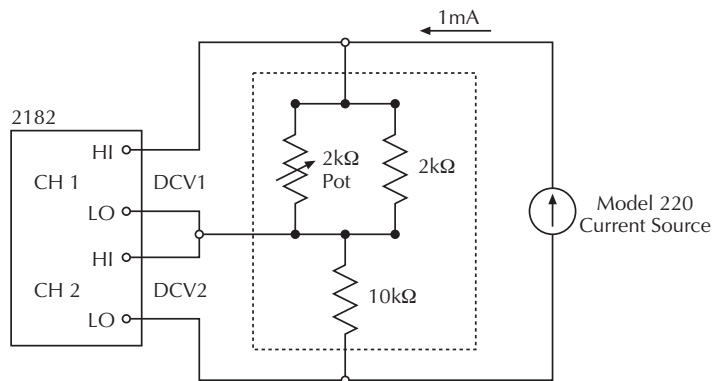
```
CALL SEND (7, ":syst:pres", status%)           ' 2182 - System preset
                                                ' defaults.
CALL SEND (7, ":trig:del 1", status%)          ' 2182 - 1sec delay.
CALL SEND (7, ":sens:volt:delta on", status%)  ' 2182 - Enable Delta.
CALL SEND (7, ":syst:faz off", status%)        ' Disable Front Autozero to
                                                ' double Delta speed.
CALL SEND (7, ":trig:sour ext", status%)       ' 2182 - External triggering.
CALL SEND (7, ":trac:poin 3", status%)        ' 2182 - Buffer size 3.
CALL SEND (7, ":trac:feed:cont next", status%) ' 2182 - Enable buffer.
CALL SEND (24, "*rst", status%)               ' SM - RST defaults.
CALL SEND (24, ":trig:sour tlin", status%)     ' SM - Select trigger link.
CALL SEND (24, ":trig:dir sour", status%)      ' SM - Enable source bypass.
CALL SEND (24, ":trig:outp sour", status%)     ' SM - Output trigger after
                                                ' source.
CALL SEND (24, ":trig:coun 6", status%)        ' SM - Trig count 6.
CALL SEND (24, ":sour:func curr", status%)     ' SM - Source current.
CALL SEND (24, ":func 'volt'", status%)       ' SM - Measure voltage
CALL SEND (24, ":volt:nplc 0.01, status%)     ' SM - Fast measurements
CALL SEND (24, ":sour:list:curr 10e-6, -10e-6,
          20e-6, -20e-6, 50e-6, -50e-6", status%) ' SM - Current list values
CALL SEND (24, ":outp on", status%)           ' SM - Turn output on.
CALL SEND (24, ":sour:curr:mode list", status%) ' SM - Enable list mode.
CALL SEND (24, ":init", status%)              ' SM - Start sweep.
```

Applications

Calibrating resistor network dividers

Ratio can be used to calibrate resistor network dividers. The 1:10 divider network in [Figure 5-5](#) is made up of nominal resistances of 1kΩ and 10kΩ. The 1kΩ resistance is the result of the parallel combination of the 2kΩ pot and the 2kΩ resistor. The pot provides fine tuning of the network.

Figure 5-5
Calibrating 1:10 divider



The Keithley Model 220 is used to source a constant current of 1mA. Channel 1, which is used to measure the 1kΩ resistance component of the network, should be set to the 1V range (1kΩ × 1mA = 1V) or autorange. Channel 2, which is used to measure the 10kΩ resistance component, should be set to the 10V range (or autorange).

When Ratio is enabled, the Model 2182 will display the result of V1 (≈1V) divided by V2 (≈10V):

$$\text{Ratio} = \frac{\text{Filt V1}}{\text{Filt V2}} = \frac{\approx 1\text{V}}{\approx 10\text{V}} = \approx 0.1$$

The above calculation includes Channel 1 Filter. If Filter is not used, remove the “Filt” component from the calculation.

The network can then be calibrated by adjusting the network pot until a reading of 0.10000 is displayed.

For even greater precision, the Relative feature of the Model 2182 can be used to null out thermal EMFs, which can corrupt low voltage measurements. Use Rel as follows:

1. While displaying the Ratio result, disconnect the current source from the network.
2. Press the REL key on the Model 2182. The voltages at each input, which are thermal EMFs, are nulled out.
3. Reconnect the current source and take the result of Ratio from the display.

When using Rel, Ratio is calculated as follows:

$$\text{Ratio} = \frac{\text{Filt V1-V1 Rel}}{\text{Filt V2-V2 Rel}}$$

The above calculation includes Channel 1 Filter. If Filter is not used, remove the “Filt” component from the calculation.

Testing superconductor materials

A superconductor sample is typically tested by either varying the current through it or varying the magnetic field that surrounds it.

NOTE *The following applications use H (magnetic field) as one of the test parameters. The applications can easily be modified to substitute temperature (T) for H as a test parameter.*

When varying the magnetic field (H), the current (I) that flows through the DUT is fixed. When varying the current (I) through the superconductor material (DUT), the magnetic field (H) that surrounds it is held constant.

For the following two applications, the Model 2182 is used to measure voltage and a Keithley SourceMeter (Model 2400, 2410, or 2420) is used to source a known current(s). Therefore, whether varying the magnetic field or varying the current, the actual resistance of the DUT can be calculated using Ohm’s Law: $R = V/I$.

Thermal EMFs — Test leads that connect the Model 2182 to the superconductor sample (DUT) in a cryostat are typically 30 feet or longer. The test lead connections, and the wide temperature range (from ~0K at the DUT to the ambient temperature of the lab) create substantial thermal EMFs in the test leads. The effects of these thermal EMFs must be canceled to achieve accurate voltage measurements.

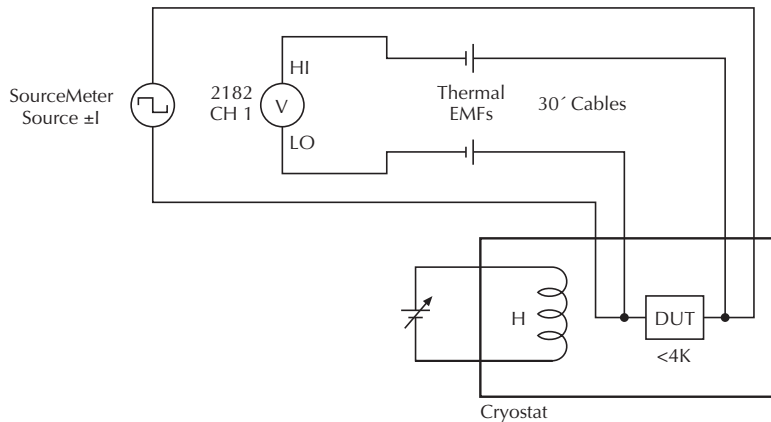
To cancel the effects of thermal EMFs, the DC current-reversal measurement technique must be used. This measurement technique requires a source that can provide a bipolar output. When using a SourceMeter, a custom sweep can be configured to provide a bipolar output.

By enabling Delta measurements on the Model 2182, the effects of thermal EMFs in the test leads will automatically be canceled during the source-measure process. For details on the DC current-reversal technique, see “Delta.”

Superconductor Application #1 - fixed current

A typical test on a superconductor sample (DUT) is to vary the magnetic field (H) while maintaining a fixed current (I) through the DUT. Such a test system is shown in Figure 5-6. A Keithley SourceMeter (Model 2400, 2410, or 2420) is used to source current through the DUT and the Model 2182 measures the voltage across the DUT. Keep in mind that the I-Source of the SourceMeter is a constant current source. Therefore, the current through the DUT will remain constant as the resistance of the DUT increases.

Figure 5-6
Test circuit—Fixed I (Vary H)



After measuring the DUT voltage (V) at a series of increasing magnetic field values (H), you can graph H vs. V. The example H-V curve in Figure 5-7 shows that the measured voltage across the DUT remains at ~0V in low magnetic fields. This is the flat portion of the curve where the DUT remains at 0Ω. At some point, the voltage drop across the DUT will start increasing as the magnetic field increases. The actual resistance of the DUT can be calculated at any magnetic field point using Ohm's law:

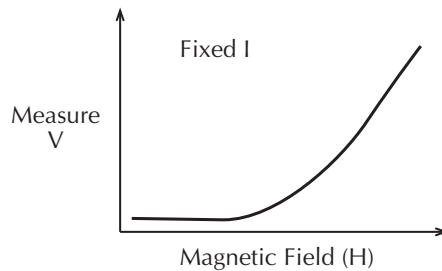
$$R = V/I$$

where: R is actual resistance of the DUT.

V is the measured voltage across the DUT.

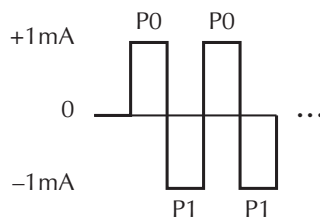
I is the known current that flows through the DUT.

Figure 5-7
H-V Curve (Fixed I)



Delta measurements — As previously explained, the DC current reversal measurement technique must be used to cancel the effects of thermal EMFs in the test leads. By configuring a custom sweep, the SourceMeter can function as a bipolar, fixed amplitude source. For example, if the test requires a fixed current of 1mA, the custom sweep can be configured to alternate between +1mA and -1mA (see Figure 5-8). By enabling Delta measurements on the Model 2182, the effects of thermal EMFs in the test leads will automatically be canceled during the source-measure process.

Figure 5-8
SourceMeter output—2-point custom sweep



The procedure to use the SourceMeter and Model 2182 to perform Delta measurements is provided in “[Delta measurement procedure using a SourceMeter.](#)” That procedure (presented earlier in this section under “Delta”) uses a 2-point custom sweep, which is required for this application.

Superconductor Application #2 - fixed magnetic field

Another typical test on a superconductor sample (DUT) is to source an increasing-amplitude current (I) through the DUT, while maintaining the magnetic field (H) at a fixed level. The I-V curve in [Figure 5-9](#) shows that the measured voltage across the DUT remains at ~0V for low currents (I). This is the flat portion of the curve where the DUT remains at 0Ω. At some point, the voltage drop across the DUT will start increasing as current through the DUT increases. The actual resistance of the DUT can be calculated at any current source point using Ohm's law:

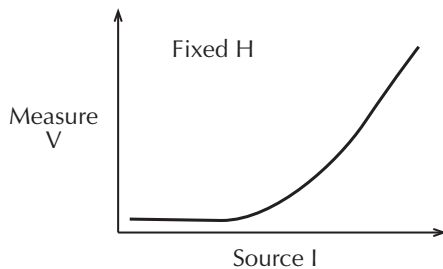
$$R = V/I$$

where: R is actual resistance of the DUT.

V is the measured voltage across the DUT.

I is the known current that flows through the DUT.

Figure 5-9
I-V Curve (Fixed H)

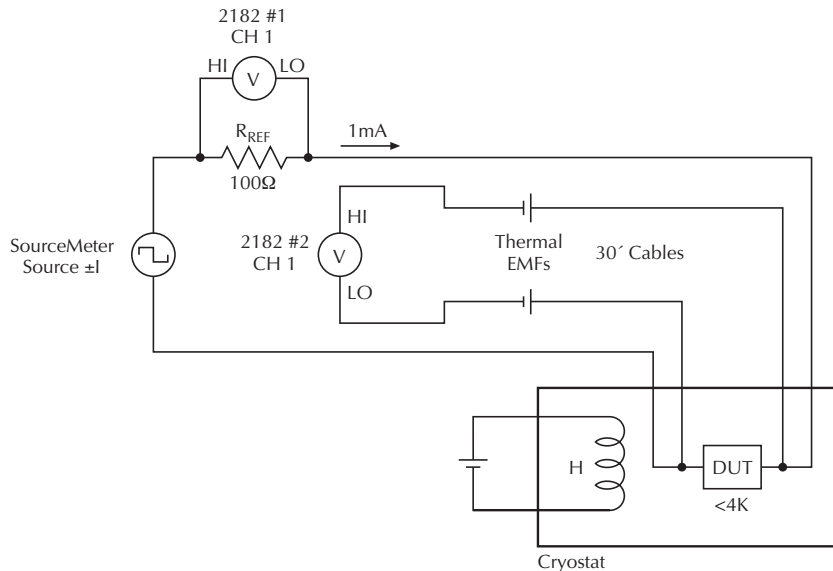


Such a test system is shown in [Figure 5-10](#). A Keithley SourceMeter (Model 2400, 2410, or 2420) is used to source current through the DUT and two Model 2182s are used to provide simultaneous voltage measurements.

Model 2182 #1 measures the voltage across a precision reference resistor (R_{REF}) and stores the readings in its buffer. These stored readings allow you to reference current amplitudes to the voltage measurements of the DUT. Model 2182 #2 measures voltage across the DUT and stores the readings in its buffer.

For example, assume you want to measure DUT voltage at current sweep values of 10μA, 20μA, and 50μA. When the sweep is started (10μA output), Model 2182 #1 measures 1mV (10μA × 100Ω = 1mV) and stores the reading in its buffer at location 1. At the same time, Model 2182 #2 measures the DUT and stores that reading in its buffer at location 1. At the next sweep point (20μA), Model 2182 #1 measures 2mV and stores the reading in its buffer at location 2, and Model 2182 #2 measures the DUT and stores the reading in its buffer at location 2. At the last sweep point (50μA), Model 2182 #1 measures 5mV and stores the reading in its buffer at location 3, and Model 2182 #2 measures the DUT and stores the reading in its buffer at location 3.

Figure 5-10
 Test circuit—Fixed H (Vary I)



The readings in the buffer of Model 2182 #1 correspond to the current sweep values. You can then use the buffer location numbers to reference DUT readings to current amplitudes:

Model 2182 #1 Buffer

RDG NO. 1 = 1mV ⇒ 10μA

RDG NO. 2 = 2mV ⇒ 20μA

RDG NO. 3 = 5mV ⇒ 50μA

Model 2182 #2 Buffer

RDG NO. 1 = DUT measurement

RDG NO. 2 = DUT measurement

RDG NO. 3 = DUT measurement

Delta measurements — As previously explained, the DC current reversal measurement technique must be used to cancel the effects of thermal EMFs in the test leads. By configuring a custom sweep, the SourceMeter can function as a bipolar, growing amplitude source.

For example, if the test requires current steps of 10μA, 20μA, and 50μA, the 6- point custom sweep would be configured as follows:

P0000 = +10μA

P0002 = +20μA

P0004 = +50μA

P0001 = -10μA

P0003 = -20μA

P0005 = -50μA

By enabling Delta measurements on the Model 2182, the effects of thermal EMFs in the test leads will automatically be canceled during the source-measure process.

To check measurement repeatability, you may wish to perform more than one Delta measurement at each current amplitude. In [Figure 5-11](#), the SourceMeter outputs five bipolar steps for each amplitude. The result will be five Delta measurements for each amplitude. When configuring the custom sweep, $\pm 10\mu\text{A}$ would be assigned to the first 10 points of the sweep, $\pm 20\mu\text{A}$ would be assigned to the next 10 points, and $\pm 50\mu\text{A}$ would be assigned to the last 10 points. Therefore, the custom sweep in [Figure 5-11](#) would be made up of 30 points (P0 through P29).

The procedure to use the SourceMeter and Model 2182 to perform Delta measurements is provided in “[Delta measurement procedure using a SourceMeter](#).” That procedure (presented earlier in this section under “[Delta](#)”) uses a 2-point custom sweep and will have to be modified for this application as follows:

- This application uses two Model 2182s. Therefore, both nanovoltmeters must be configured exactly the same.
- In Step 3 of the procedure, change the Trigger Count to equal the number of points in the custom sweep. For example, if using the 30-point custom sweep in [Figure 5-11](#), set the Trigger Count to 30.
- In Step 5, assign current values to the sweep points. For the example 30-point sweep, the current values for points P0 through P29 are shown in [Figure 5-11](#).
- In Step 7, enable line synchronization on both Model 2182s. To access control, press SHIFT and then LSYNC.

NOTE *Optimum synchronization among all instruments is achieved when Model 2182 line synchronization is enabled, and autozero is disabled. Autozero cannot be disabled from the front panel of the Model 2182. When controlling this application over the bus, use the following commands for the Model 2182s:*

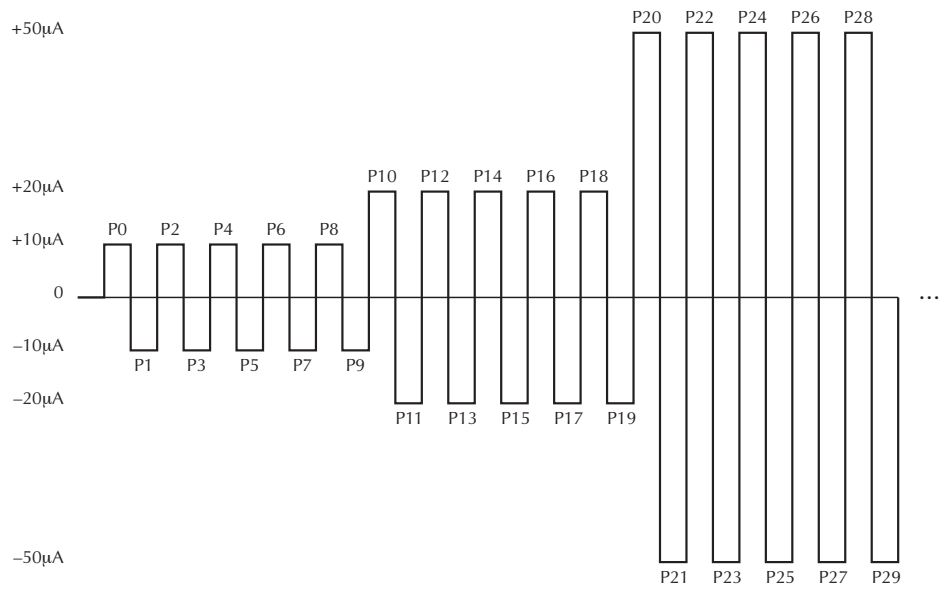
```
:SYSTem:LSYNc:STATe ON      Enable 2182 Line Synchronization  
:SYSTem:AZERo:STATe OFF     Disable 2182 Autozero
```

Autozero should only be disabled for short periods of time. After performing a sweep, re-enable Autozero. For details on Autozero, see [Section 2](#).

- In Step 9, set the buffers of both Model 2182s to store the Delta readings. If performing a 30-point sweep, set both buffers to store 30 Delta readings.

Log sweep — If your test requires currents that span two or more decades, you can configure the SourceMeter to output a log sweep. The 30-point sweep in [Figure 5-11](#) is confined to the $10\mu\text{A}$ - $100\mu\text{A}$ decade. If, for example, you want to expand the sweep to span three current decades, the next 30 sweep points would be used for the $100\mu\text{A}$, $200\mu\text{A}$, and the $500\mu\text{A}$ amplitudes. The last 30 sweep points would be used for the 1mA , 2mA , and 5mA amplitudes. The I-V data points can then be graphed using a logarithmic/linear scale.

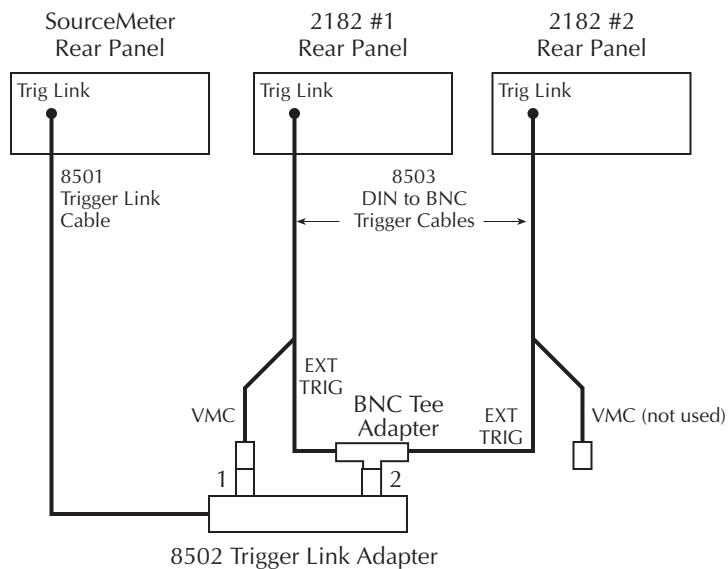
Figure 5-11
SourceMeter output—30-point custom sweep



Trigger link connections — External triggering is used to synchronize source-measure operations among the instruments. The SourceMeter must trigger both Model 2182s to achieve simultaneous measurements. In turn, only one of the Model 2182s must trigger the SourceMeter to output the next source value.

The trigger link connections required for this application are shown in Figure 5-12. Notice that the output trigger (VMC) required from the Model 2182s is provided by unit #1. VMC from unit #2 must not be used.

Figure 5-12
Trigger link connections using two Model 2182s



6 Buffer

- **Buffer operations** — Explains how to store and recall readings including buffer statistics (minimum, maximum, peak-to-peak, average, and standard deviation).
- **SCPI programming** — Covers the SCPI commands used to control buffer operations.

Buffer operations

The Model 2182 has a buffer to store from two to 1024 readings and units. It also stores the channel number for step/scan readings and overflow readings. In addition, recalled data includes statistical information (minimum, maximum, peak-to-peak, average, and standard deviation).

NOTE *Statistics are not calculated when an overflow reading has been stored in the buffer.*

The buffer fills with the specified number of readings and stops. Readings are placed in the buffer after any math operations are performed. Math operations include Relative, Ratio or Delta, and $mX+b$ or Percent.

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

NOTE *Measurements performed during stepping or scanning are automatically stored in the buffer. There is no need to configure and enable the buffer. Stepping and scanning is covered in [Section 9](#).*

NOTE *When changing the interface (GPIB to RS-232, or vice versa), all data in the buffer clears.*

Store

Perform the following steps to store readings:

1. Set up the instrument for the desired configuration.
2. Press the STORE key.
3. Use the cursor keys (◀ and ▶), and the RANGE ▲ and ▼ keys to set the number of readings to store (2 to 1024).
4. Press ENTER to enable the buffer. If in the immediate trigger mode, the storage process will start immediately. If in the external trigger mode, each input trigger (or press of TRIG key) will store a reading.

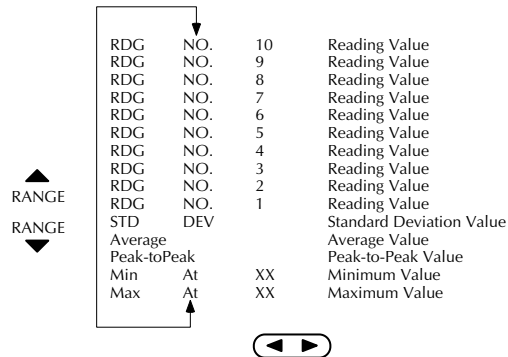
NOTE *The asterisk (*) annunciator turns on to indicate that the data storage operation is enabled. It will turn off when the storage process is finished (buffer full).*

Recall

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

1. Press RECALL. The BUFFER annunciator turns on to indicate that stored readings are being displayed. The arrow annunciator (↔) also turns on to indicate that additional data is available for viewing.
2. As shown in [Figure 6-1](#), use the RANGE ▲ and ▼ keys, and the cursor ◀ and ▶ keys to navigate through the reading numbers, reading values, and buffer statistics. For any of the buffer statistics (maximum, minimum, peak-to-peak, average, standard deviation), the STAT annunciator is on.
3. To return to the normal display, press EXIT.

Figure 6-1
Buffer locations



Buffer statistics

- **MIN** and **MAX** provides the minimum and maximum readings stored in the buffer. It also indicates the buffer location of these readings.
- The **Peak-to-Peak** reading is the absolute value of the difference between the MAX and MIN readings. It is calculated as follows:

$$\text{Peak-to-Peak} = |\text{MAX} - \text{MIN}|$$

- **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. The equation used to calculate the standard deviation is:

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

where: X_i is a stored reading.
 n is the number of stored readings.

NOTE The Model 2182 uses IEEE-754 floating point format for math calculations.

SCPI programming - buffer

Buffer commands are summarized in [Table 6-1](#). TRACe subsystem commands are used to store and recall readings in the buffer, and CALCulate2 commands are used to obtain statistics from the buffer data. Additional information on these commands is provided after the table.

Table 6-1
SCPI commands - buffer

Commands	Description	Default
:TRACe :CLEar :FREE? :POINts <n> :FEED <name> :CONTrol <name> :DATA?	TRACe Subsystem: Clear readings from buffer. Query bytes available and bytes in use. Specify number of readings to store; 2 to 1024. Select source of readings; SENSE, CALCulate, or NONE. Select buffer control mode; NEVER or NEXT. Read all readings in buffer.	See Note
:CALCulate2 :FORMat <name> :STATe :IMMediate :IMMediate? :DATA?	CALCulate2 Subsystem: Select buffer statistic; MINimum, MAXimum, MEAN, SDEViation or NONE. Enable or disable statistic calculation. Recalculate raw input data in buffer. Perform calculation and read result. Read result of statistic calculation.	NONE OFF

Note: SYSTem:PRESet and *RST have no effect on :TRACe commands.

TRACe subsystem — The FEED command controls the source of the readings. With the SENSE parameter selected, raw input readings are stored in the buffer. With the CALCulate parameter selected, results of the mX+b or Percent (%) calculation are stored in the buffer. Commands to control and configure the mX+b and Percent calculations are summarized in [Table 4-2](#) in [Section 4](#).

FEED:CONTrol is used to control the storage process. NEXT starts the storage process and NEVER stops it. After storage is completed, buffer control automatically returns to NEVER.

CALCulate2 subsystem — After the selected statistic is enabled, IMMediate or IMMediate? must be sent to calculate the statistic from the data in the buffer. The DATA? command does not initiate a calculate operation. It simply returns the result of the last calculation. If new data is stored in the buffer, you must again send the IMMediate or IMMediate? to recalculate the statistic from that new data.

There is no SCPI command to obtain the Peak-to-Peak statistic. To get the Peak-to-Peak statistic, your program will have to calculate it from the MAX and MIN statistics.

NOTE *Since CALC2:IMM and CALC2:IMM? are slow responding when performing the standard deviation calculation on large buffers, *OPC or *OPC? should be used with them. Details on *OPC and *OPC? are provided in [Section 12](#).*

Programming example

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

```
' Store Readings:
CALL SEND(7,":trac:poin 20",status%)           'Set buffer size to 20.
CALL SEND(7,":trac:feed sens",status%)        'Store raw input readings.
CALL SEND(7,":trac:feed:cont next", status%)   'Start storing readings.
CALL SEND(7,":trac:data?",status%)            'Request all stored
                                              'readings.

reading$ = SPACE$(80)
CALL ENTER(reading$, length%, 7, status%)      'Address 2182 to talk.
PRINT reading$                                'Display all buffer
                                              'readings on CRT.

' Calculate Mean of Buffer Readings:
CALL SEND(7,":calc2:form mean",status%)       'Select mean calculation.
CALL SEND(7, " :calc2:stat on",status%)       'Enable mean calculation.
CALL SEND(7, " :calc2:imm?",status%)          'Perform calculation and
                                              'request result.

reading$ = SPACE$(80)
CALL ENTER(reading$, length%, 7,status%)      'Address 2182 to talk.
PRINT reading$                                'Display all buffer
                                              'readings on CRT
```

7 Triggering

- **Trigger model** — Explains the various components of the front panel trigger model, which controls the triggering operations of the instrument.
- **Reading hold** — Explains the Reading Hold feature which is used to screen out readings that are not within a specified reading window.
- **External triggering** — Explains external triggering which allows the Model 2182 to trigger other instruments, and be triggered by other instruments.
- **SCPI programming** — Covers remote operation for triggering including the GPIB trigger model and the SCPI commands.

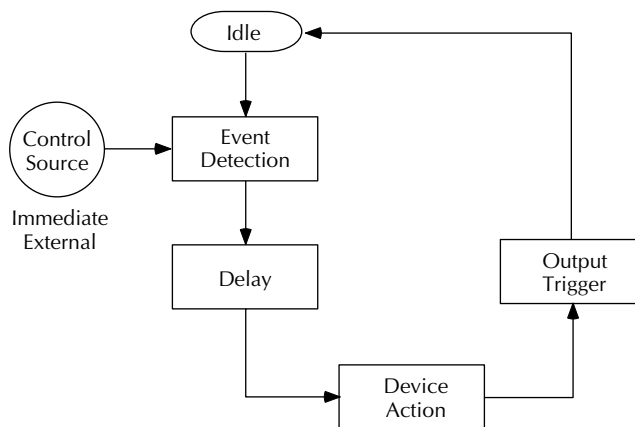
Trigger model

NOTE Additional information on measurement query commands to trigger and/or return readings are provided in [Section 13](#) and [Appendix H](#).

The flowchart in [Figure 7-1](#) summarizes triggering as viewed from the front panel. It is called a trigger model because it is modeled after the SCPI commands used to control triggering. Note that for stepping and scanning, the trigger model has additional control blocks. These are described in [Section 9](#).

NOTE The complete trigger model, which is based on bus operation, is shown and discussed later in this section (see “[SCPI programming - triggering](#)”). Keep in mind that there is only one trigger model. The ones shown [Figure 7-1](#) and in [Section 9](#) are abbreviated versions to illustrate front panel operation.

Figure 7-1
Front panel trigger model (without Stepping/Scanning)



Idle

The instrument is considered to be in the idle state whenever it is not performing any measurements or scanning operations. From the front panel, the unit is considered idle at the end of a step or scan operation when the reading for the last channel remains displayed. To restore triggers, press SHIFT and then HALT.

Once the Model 2182 is taken out of idle, operation proceeds through the trigger model.

Control source and event detection

The control source holds up operation until the programmed event occurs and is detected. The control sources are described as follows:

- **Immediate** — With this control source, event detection is immediately satisfied allowing operation to continue.
- **External** — Event detection is satisfied for any of the following three conditions:
 - An input trigger via the Trigger Link line EXT TRIG is received.
 - The front panel TRIG key is pressed. (The Model 2182 must be taken out of remote before it will respond to the TRIG key. Use the LOCAL key or send LOCAL 707 over the bus.)
 - Trigger command (*TRG or GET) received over the bus.

Delay

A programmable delay is available after event detection. It can be set manually or an auto delay can be used. With auto delay, the Model 2182 selects a delay based on the selected voltage range. The auto delays are listed in [Table 7-1](#). There is no auto delay for temperature measurements. Auto Delay is typically used for external scanning. The nominal delay will be just long enough to allow each relay to settle before making the measurement.

Table 7-1
Auto delay times

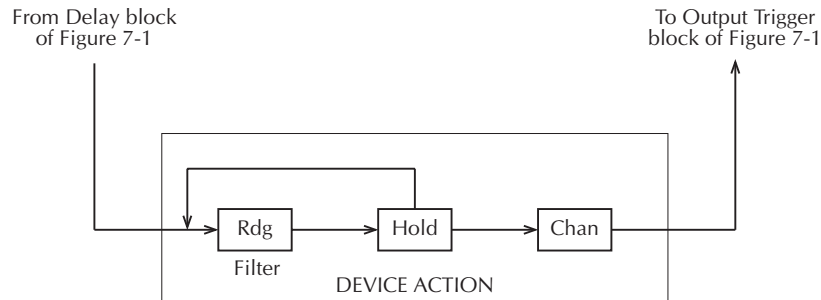
Range	Delay Time	
	DCV1	DCV2
10mV	1ms	–
100mV	1ms	1ms
1V	1ms	1ms
10V	1ms	1ms
100V	5ms	–

The delay function is accessed by pressing SHIFT and then DELAY. The present delay setting (AUTO or MANual) is displayed. Press the ▲ or ▼ key to display the desired setting and press ENTER. If MANual is chosen, also enter the duration of the delay using the ◀, ▶, ▲, and ▼ keys. The maximum is 99H:99M:99.999S. Press ENTER to accept the delay or EXIT for no change.

Device action

The primary device action is a measurement. However, the device action block could include the following additional actions (refer to [Figure 7-2](#)):

Figure 7-2
Device action



- **Filtering** — If the repeating filter is enabled, the instrument samples the specified number of reading conversions to yield single filtered reading. Only one reading conversion is performed if the filter is disabled, or after the specified number of reading conversions for a moving average filter is reached. After a reading (Rdg) is procured, operation proceeds to Hold.
- **Hold** — The Hold feature is used to screen out reading anomalies. When enabled, the user selects a window and count for Hold. In general, when a reading is outside the window it is rejected; operation loops back to be beginning of the Device Action as shown in [Figure 7-2](#). The hold count specifies how many readings have to be within the window before it is accepted. See “[Reading hold \(autosettle\)](#)” for operation details. After a Hold Reading is acquired, operation proceeds to Channel Closure.
- **Channel closure** — When stepping or scanning, the last device action is channel control. Using the hold feature provides an auto settling time for switching relays. Each open/close transition will restart the hold process and a reading for each channel will not occur until the relay settles.

Output trigger

After the device action, an output trigger occurs and is available at the rear panel Trigger Link connector. This trigger can be used to trigger another instrument to perform an operation (e.g., select the next channel for an external scan).

Reading hold (autosettle)

With hold enabled (HOLD annunciator on), the first processed reading becomes the “seed” reading and operation loops back within the device action block. After the next reading is processed, it is checked to see if it is within the selected hold window (0.01%, 0.1%, 1%, 10%) of the “seed” reading. If the reading is within the window, operation again loops back within the device action block. This looping continues until the specified number (2 to 100) of consecutive readings are within the window. If one of the readings is not within the window, the instrument acquires a new “seed” reading and the hold process continues.

When a hold reading is acquired, an audible beep is sounded (if enabled) and the reading is considered a “true measurement.” The reading is held on the display until an “out of window” reading occurs to restart the hold process.

For remote operation or when scanning, the hold process seeks a new “seed” once it has been satisfied and the readings have been released. For basic front panel operation, the hold process does not seek a new “seed” until the held condition is removed.

NOTE *Hold can only be used with Channel 1. Whenever Hold is enabled, Channel 2 becomes inoperative.*

Hold example

1. Press SHIFT and then HOLD to display the present window (0.01%, 0.1%, 1%, or 10%).
2. To change the window, press the ▲ or ▼ key to display the desired window.
3. Press ENTER. The present hold count is displayed (2 to 100).
4. To change the hold count, use the ◀, ▶, ▲, and ▼ keys to display the desired count.
5. Press DCV1 to measure voltage on Channel 1.
6. Apply the test signal to Channel 1 of the Model 2182. Once the signal becomes stable enough to satisfy the hold condition, the reading is released and the beeper sounds (if enabled).
7. Remove the hold condition by disconnecting the signal from Channel 1. Hold will then seek a new “seed.”
8. To disable HOLD, press SHIFT and then HOLD.

Beeper control

The beeper for Hold can be enabled or disabled from the ON/OFF LIMITS menu as follows:

1. Press ON/OFF to display the beeper selections (NEVER, OUTSIDE, and INSIDE).
2. Perform step A or B:
 - A. To enable the beeper, use the ▲ or ▼ to key to display OUTSIDE or INSIDE.
 - B. To disable the beeper, use the ▲ or ▼ to key to display NEVER.
3. Press ENTER. The instrument returns to the normal display state. However, limit testing is enabled.
4. If you wish to disable limit testing, press ON/OFF. Limit testing is covered in [Section 8](#).

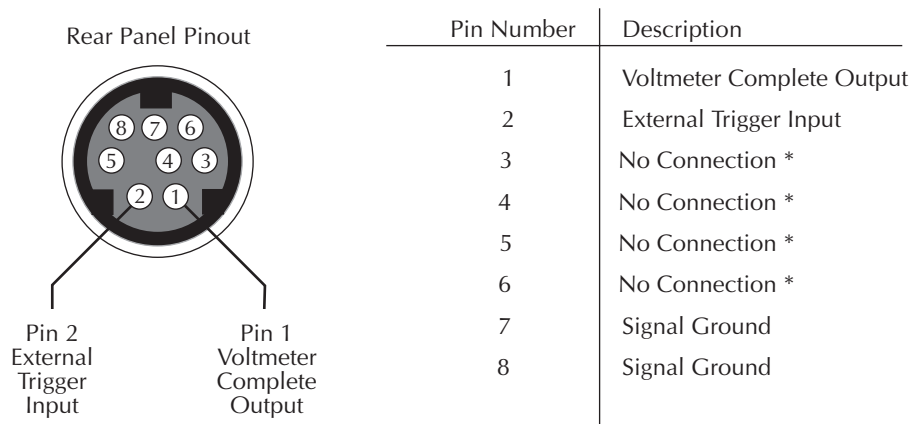
External triggering

The EX TRIG key selects triggering from two external sources: trigger link and the TRIG key. When EX TRIG is pressed, the TRIG annunciator lights and dashes are displayed to indicate the instrument is waiting for an external trigger. From the front panel, press the TRIG key to trigger a single reading. Pressing the EX TRIG key again toggles back to continuous triggers.

The Model 2182 uses two lines of the Trigger Link rear panel connector as External Trigger (EXT TRIG) input and Voltmeter Complete (VMC) output. The EXT TRIG line allows the Model 2182 to be triggered by other instruments. The VMC line allows the Model 2182 to trigger other instruments.

At the factory, line 1 is configured as VMC and line 2 as EXT TRIG. (Changing this configuration is described in the Model 2182 Service Manual.) A connector pinout is shown in Figure 7-3.

Figure 7-3
Rear panel pinout

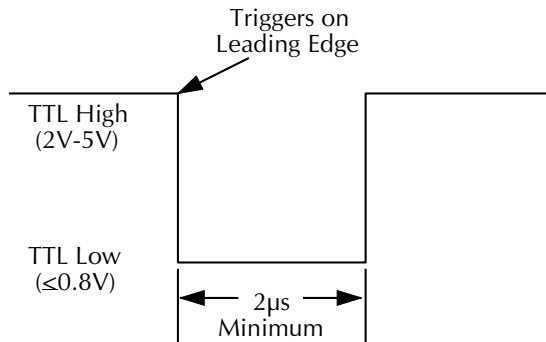


* Either pin 3 or 5 may be configured as an output instead of pin 1. Either pin 4 or 6 may be configured as an input instead of pin 2. See the Model 2182 Service Manual for details.

External trigger

The EXT TRIG input requires a falling-edge, TTL-compatible pulse with the specifications shown in [Figure 7-4](#). In general, external triggers can be used to control measure operations. For the Model 2182 to respond to external triggers, the trigger model must be configured for it.

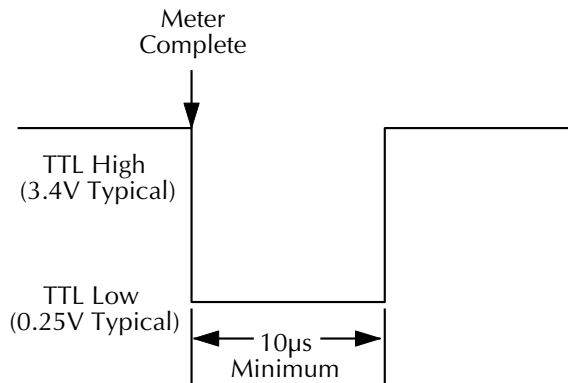
Figure 7-4
Trigger link input pulse specifications (EXT TRIG)



Voltmeter complete

The VMC output provides a TTL-compatible output pulse that can be used to trigger other instruments. The specifications for this trigger pulse are shown in [Figure 7-5](#). Typically, you would want the Model 2182 to output a trigger after the settling time of each measurement.

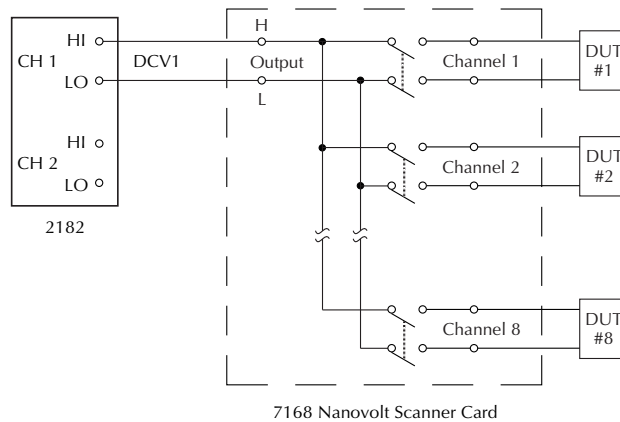
Figure 7-5
Trigger link output pulse specifications (VMC)



External triggering example

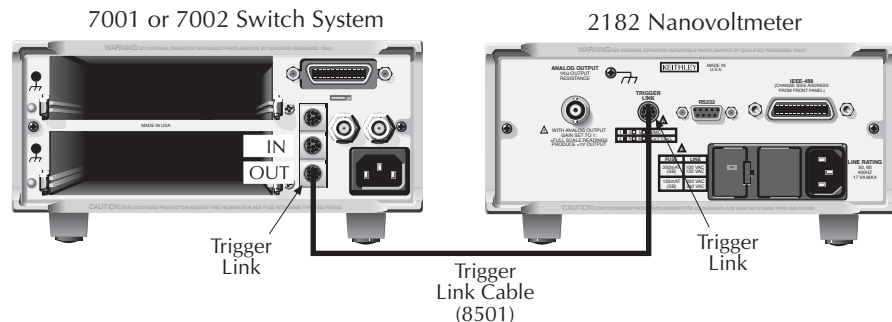
In a typical test system, you may want to close a channel and then measure the DUT connected to the channel with the Model 2182. Such a test system is shown in [Figure 7-6](#), which uses a Model 2182 to measure eight DUTs switched by a Model 7168 Nanovolt Scanner Card in a Model 7001/7002 Switch System. See [Section 9](#) for details on external scanning.

Figure 7-6
DUT test system



The Trigger Link connections for this test system are shown in [Figure 7-7](#). Trigger Link of the Model 2182 is connected to Trigger Link (either IN or OUT) of the Model 7001/7002. Note that with the default trigger settings on the Model 7001/7002, line #1 is an input and line #2 is an output. This complements the trigger lines on the Model 2182.

Figure 7-7
Trigger link connections



For this example, the Models 2182 and 7001/7002 are configured as follows:

Model 2182:

Factory defaults restored (accessed from SHIFT-SETUP)

External scanning, channels 1 - 8, no timer, 8 readings (accessed from SHIFT-CONFIG)

External triggers (accessed from EX TRIG)

Model 7001 or 7002:

Factory defaults restored

Scan list = 1!1-1!8,

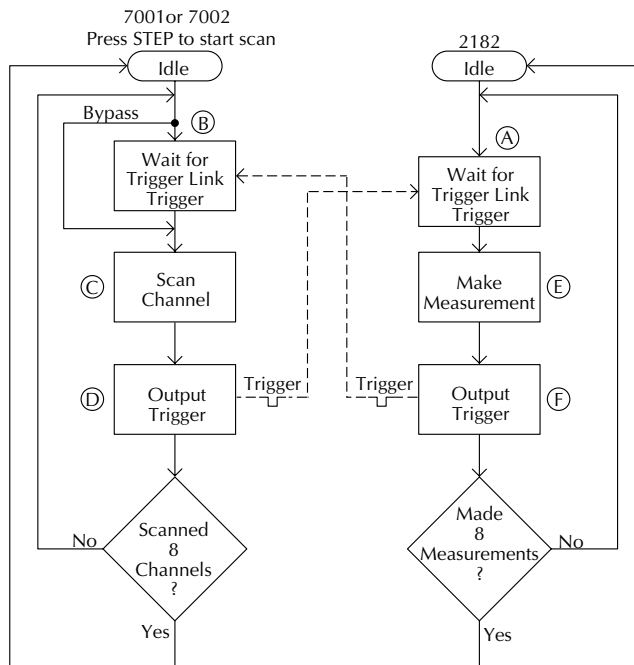
Number of scans = 1

Channel spacing = TrigLink

To run the test and store readings in the Model 2182 with the unit set for external triggers, press STEP or SCAN. The Model 2182 waits (with the asterisk annunciator lit) for an external trigger from the Model 7001/7002.

Press STEP on the Model 7001/7002 to take it out of idle and start the scan. The scanner's output pulse triggers the Model 2182 to take a reading, store it, and send a trigger pulse. The following explanation on operation is referenced to the operation model shown in [Figure 7-8](#).

Figure 7-8
Operation model for triggering example



- A. Pressing EX TRIG then STEP or SCAN on the Model 2182 places it at point A in the flowchart, where it is waiting for an external trigger.
- B. Pressing STEP on the Model 7001/7002 takes it out of the idle state and places operation at point B in the flowchart.
- C. For the first pass through the model, the scanner does not wait at point B for a trigger. Instead, it closes the first channel.
- D. After the relay settles, the Model 7001/7002 outputs a Channel Ready pulse. Since the instrument is programmed to scan eight channels, operation loops back up to point B, where it waits for an input trigger.
- E. & F. Model 2182 operation is at point A waiting for a trigger. The output Channel Ready pulse from the Model 7001/7002 triggers the nanovoltmeter to measure DUT #1 (point E). After the measurement is complete, the Model 2182 outputs a completion pulse (point F) and then loops back to point A, where it waits for another input trigger.

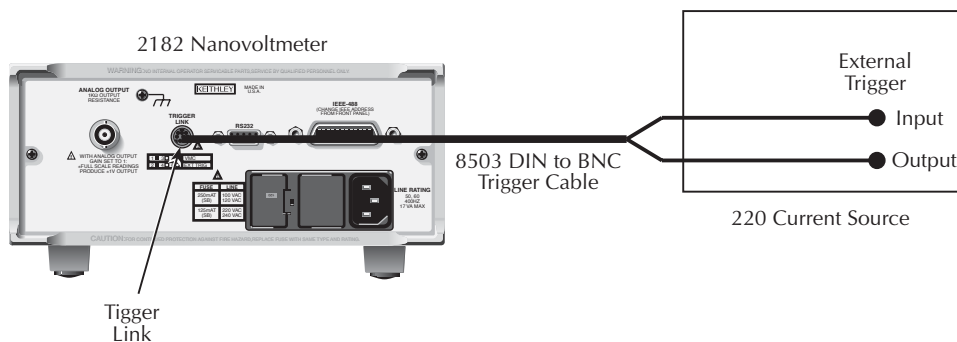
The trigger applied to the Model 7001/7002 from the Model 2182 closes the next channel in the scan. This triggers the nanovoltmeter to measure the next DUT. The process continues until all eight channels are scanned and measured.

External triggering with BNC connections

An adapter cable is available to connect the micro-DIN Trigger Link of the Model 2182 to instruments with BNC trigger connections. The Model 8503 DIN to BNC Trigger Cable has a micro-DIN connector at one end and two BNC connectors at the other end. The BNC cables are labeled VMC (trigger line 1) and EXT TRIG (trigger line 2).

Figure 7-9 shows how a Keithley Model 220 Current Source can be connected to the Trigger Link of the Model 2182 using the adapter cable. When used with the STEP mode of the Model 220, you can perform synchronized source-measure operations without the use of a computer. Whenever the Model 220 receives a trigger from the Model 2182, it will step to the next current source value.

Figure 7-9
DIN to BNC trigger cable



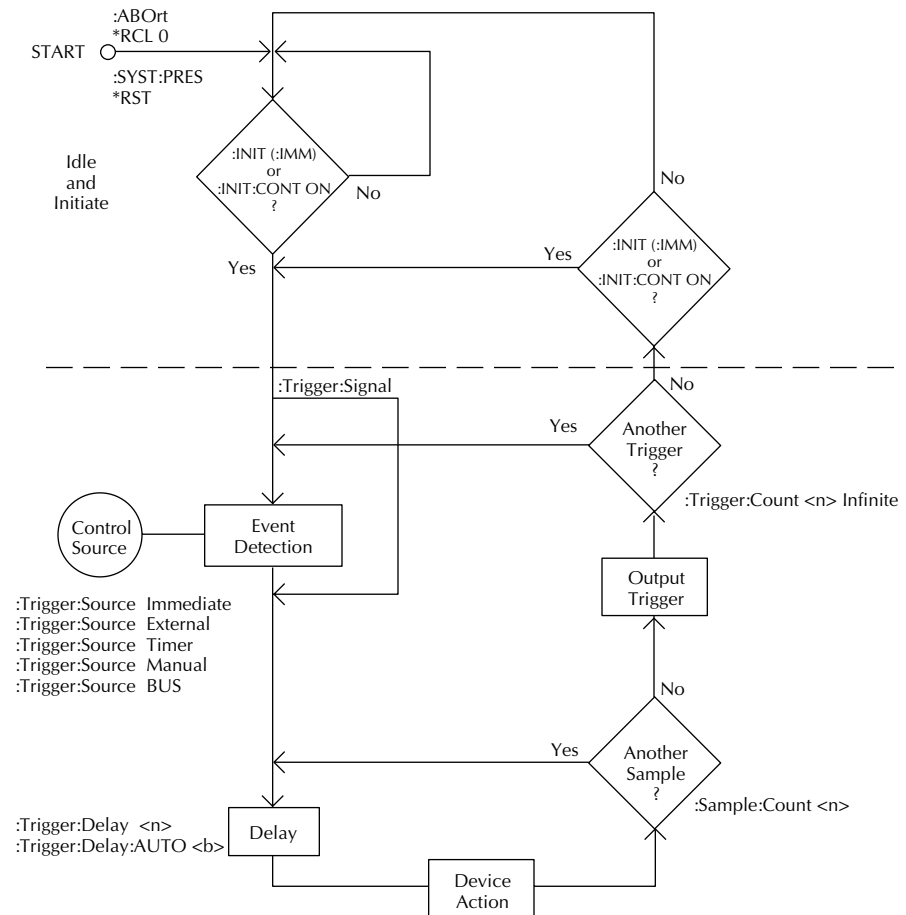
NOTE *If the Model 2182 trigger line configuration has been changed from the factory setting, the Model 8502 Trigger Link Adapter must be used to interface with instruments having BNC trigger connections. It has two micro-DIN connectors and six BNC connectors, one for each trigger line.*

SCPI programming - triggering

Trigger model (remote operation)

The following paragraphs describe how the Model 2182 operates for remote operation. The flowchart in [Figure 7-10](#) summarizes operation over the bus. The flowchart is called the trigger model because operation is controlled by SCPI commands from the Trigger subsystem. Key SCPI commands are included in the trigger model.

Figure 7-10
Trigger model (remote operation)



Idle and initiate

The instrument is considered to be in the idle state whenever operation is at the top of the trigger model. As shown in [Figure 7-10](#), initiation needs to be satisfied to take the instrument out of idle. While in the idle state, the instrument cannot perform any measure or step/scan operations.

The following commands will return operation to the top of the trigger model (idle) at the START point of the trigger model:

- :ABORt
- *RCL 0
- :SYSTem:PREset
- *RST

What happens next depends on the state of initiation. If continuous initiation is already enabled, the instrument will leave the idle state. SYSTem:PREset enables continuous initiation. Therefore, operation will immediately leave the idle state when it is sent. The *RCL 0 command will do the same if INITiation:CONTInuous ON is a user saved default. *RST disables continuous initiation. Therefore, the instrument will remain in the idle state.

Either of the following two initiate commands will take the instrument out of the idle state:

- :INITiate
- :INITiate:CONTInuous ON

NOTES *While in remote, pressing the LOCAL key restores continuous front panel operation.*

When switching from the 182 language to the SCPI language, the instrument will go into the idle state and stay there. You can take the instrument out of idle by pressing the TRIG key or by sending an initiate command.

Trigger model operation

Once the instrument is taken out of idle, operation proceeds through the trigger model down to the device action. In general, the device action includes a measurement and, when stepping/scanning, closes the next channel.

Control source — As shown in [Figure 7-10](#), a control source is used to hold up operation until the programmed event occurs. The control source options are as follows:

- **IMMediate** — Event detection is immediately satisfied allowing operation to continue.
- **MANual** — Event detection is satisfied by pressing the TRIG key. The Model 2182 must be in LOCAL mode for it to respond to the TRIG key. Press the LOCAL key or send LOCAL 7 over the bus to remove the instrument from the remote mode.
- **TIMER** — Event detection is immediately satisfied on the initial pass through the loop. Each subsequent detection is satisfied when the programmed timer interval (0 to 999999.999 sec.) elapses. The timer source is only available during step/scan operation. The timer resets to its initial state when the instrument goes into the normal mode of operation or into the idle state.
- **EXTernal** — Event detection is satisfied when an input trigger via the TRIGGER LINK connector is received by the Model 2182.
- **BUS** — Event detection is satisfied when a bus trigger (GET or *TRG) is received by the Model 2182.

Delay and device action — These blocks of the trigger model operate the same for both front panel and GPIB operation. See the front panel “[Trigger model](#)” (located at the beginning of this section) for operating information on these trigger model blocks. Also see “[Reading hold \(autosettle\)](#)” for details on Hold.

Counters — Programmable counters are used to repeat operations within the trigger model. For example, if performing a 10-channel scan, the sample counter would be set to 10. Operation will continue until all 10 channels are scanned and measured. If you wanted to repeat the scan three times, you would set the trigger counter to three.

For a sample count value >1, the sample readings will automatically be stored in the buffer. For example, with sample count set to 5, the five measured readings will be stored in the buffer. If the trigger model is configured to repeat the sample readings (i.e. trigger count = 2), those five new readings will overwrite the original five readings in the buffer.

Output trigger — The Model 2182 will send one or more output triggers. The output trigger is applied to the Trigger Link connector on the rear panel. It can be used to trigger an external instrument to perform an operation.

The trigger model can be configured to output a trigger after the completion of a series of measurements, or after every measurement. For example, with the sample counter set to 10 and the trigger counter set to one, a trigger will be sent after the 10 measurements are performed. If instead, the trigger counter is set to 10 and the sample counter is set to 1, a trigger will be sent after each measurement.

Triggering commands

Commands for triggering are summarized in [Table 7-2](#). Information not covered in the table or in “Trigger model (GPIB operation)” is provided after the table. The Ref column provides reference for this information.

Table 7-2

SCPI commands - triggering

Commands	Description	Ref	Default
:ABORt	Reset trigger system.	A	
:INITiate [:IMMediate]	Initiation: Initiate one trigger cycle.	B	
:CONTInuous 	Enable or disable continuous initiation.	C	(Note 1)
:FETCh?	Request the last reading(s).	D	
:READ?	Perform an ABORt, INITiate and a FETCh?	E	
:TRIGger :SOURce <name>	Trigger commands: Select control source; IMMediate, TIMer, MANual, BUS, or EXTernal.	F	IMMediate
:TIMer <n>	Set timer interval; 0 to 999999.999 (sec.).		0.1
:COUNt <n>	Set trigger count; 1 to 9999 or INF.		(Note 2)
:DELay <n>	Set delay; 0 to 999999.999 (sec.).		0
:AUTO 	Enable or disable auto delay.	G	
:SIGNal	Loop around control source.	H	
:SAMPle :COUNt <n>	Sample counter: Set sample count; 1 to 1024.	I	1
:SENSe :HOLD :WINDow <n> :COUNt <n> :STATe 	SENSe Subsystem: Reading Hold commands: Set Hold window in %; 0.01 to 20. Set Hold count; 2 to 100 Enable or disable Hold.	J	1 5 OFF
:SYSTem :BEEPer :STATe 	SYSTem Subsystem: Beeper control: Enable or disable the beeper.		ON
*RST	Restore *RST defaults (see “Default” column of this table). Places 2182 in the idle state.		

Notes:

- Defaults for continuous initiation:
 SYSTem:PRESet enables continuous initiation.
 *RST disables continuous initiation.
- Defaults for trigger count:
 SYSTem:PRESet sets the count to INF (infinite).
 *RST sets the count to 1.

Reference:

- A. **ABORt** — With continuous initiation disabled, the 2182 goes into the idle state. With continuous initiation enabled, operation continues at the top of the trigger model.
- B. **INITiate** — Whenever the instrument is operating within the trigger model, sending this command causes an error and will be ignored.
- C. **INITiate:CONTinuous** — With continuous initiation enabled, you cannot use the **READ?** command or set sample count (**SAMPlE:COUNT**) greater than one.
- D. **FETCh?** — See [Section 13](#) for details on this Signal Oriented Measurement Command.
- E. **READ?** — Use this one query command to perform the tasks of the three commands. See [Section 13](#) for details on this Signal Oriented Measurement Command.
- F. **TRIGger:SOURce** — With the timer control source selected, use the **TRIGger:TIMer** command to set the interval.
- G. **DELAy:AUTO** — Auto delay period is 5msec for the 100V range, and 1msec for all other voltage ranges. Disabling auto delay sets the delay time to 0.
- H. **TRIGger:SIGNal** — Send this action command to bypass the control source when you do not wish to wait for the programmed event to occur. The instrument must be waiting at the control source for the event when this command is sent. Otherwise, an error occurs and the command is ignored.
- I. **SAMPlE:COUNT** — A sample count >1 specifies how many readings will automatically be stored in the buffer. However, with continuous initiation enabled, you cannot set the sample count greater than one.
- J. **SENSe:HOLD** — See “[Reading hold \(autosettle\)](#)”, located in this section, for details on using Hold.

Programming example

The following program fragment triggers (and stores in the buffer) 10 readings, which are then displayed on the computer CRT.

```
CALL SEND(7,"*rst",status%)           'Restore *RST defaults.
CALL SEND(7,":trig:del 0.5",status%)  'Set delay for 0.5sec.
CALL SEND(7,":samp:coun 10",status%)  'Set sample count to 10.
CALL SEND(7,":read?",status%)         'Trigger and request readings.
reading$ = SPACE$(80)
CALL ENTER(reading$, length%, 7,status%) 'Address 2182 to talk.
PRINT reading$                        'Display the 10 readings on
                                     'the CRT.
```

8 Limits

- **Limit operations** — Explains Limit 1 and Limit 2 testing operations.
- **SCPI programming** — Covers the SCPI commands for remote operation.
- **Application** — Provides an application that sorts resistors by tolerances.

Limit operations

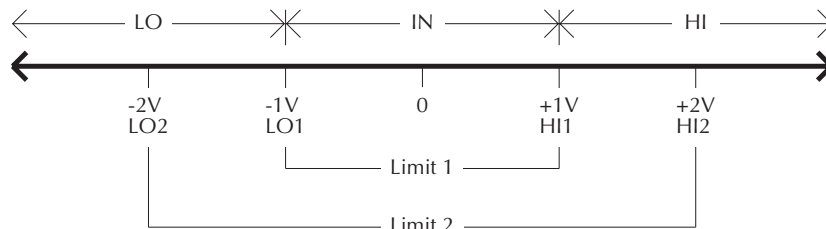
Limit operations set and control the values that determine the HI/IN/LO status of subsequent measurements. The limit test is performed on the result of an enabled Rel, mX+b, or Percent operation.

There are two sets of limits. Limit 1 uses high and low limits (HI1 and LO1) as does Limit 2 (HI2 and LO2). However, the HI/IN/LO status message only applies to Limit 1. [Figure 8-1](#) illustrates the following limits which are the factory defaults:

Limit 1: HI1 = +1V and LO1 = -1V

Limit 2: HI2 = +2V and LO2 = -2V

Figure 8-1
Default limits



For the limits shown in [Figure 8-1](#), a reading of 1.5V is outside Limit 1 (which is the primary limit). Therefore, the message “HI” will be displayed.

A beeper is also available for limit testing. There are three beeper options: NEVER, OUTSIDE and INSIDE. These options are explained as follows:

NEVER — With this option, the beeper is disabled. Only the HI/IN/LO status message is used for the Limit 1 test.

OUTSIDE — With this option, the beeper sounds when the reading is outside (HI or LO) of Limit 1. Again referring to [Figure 8-1](#), a 1.5V reading is outside (HI) Limit 1. Therefore the beeper will sound.

INSIDE — With this option, the beeper sounds when the reading is inside Limit 1 and/or Limit 2. If the reading is inside Limit 1, the beeper will sound at its normal pitch. If the reading is outside Limit 1 but inside Limit 2, the beeper will sound at a lower pitch. The beeper will not sound for readings outside Limit 2. For the limits shown in [Figure 8-1](#), a 0.5V reading will sound the beeper at its normal pitch, a 1.5V reading will sound the beeper at a lower pitch, and for a 2.5V reading, the beeper will not sound.

NOTE To use the Limit 2 test, the INSIDE beeper mode must be selected. With NEVER or OUTSIDE selected, Limit 2 is (in effect) disabled.

Setting limit values

Use the following steps to enter high and low limit values:

1. Press the Limits VALUE key to view the present HI1 limit value:

HI1:+1.000000 ^ (default)

2. To change the HI1 limit, use the cursor keys (◀ and ▶) and the manual range keys (▲ and ▼) to display the desired value. Move the cursor to the rightmost position (^) and use the (▲ and ▼) keys to move the decimal point. Note that with the cursor on the polarity sign, pressing ▲ or ▼ toggles the polarity of the value.
3. Press ENTER to view the present LO1 limit value:

LO1:-1.000000 ^ (default)

4. Enter the desired value for this low limit.
5. Press ENTER to view the present HI2 limit value:

HI2:+2.000000 ^ (default)

6. Enter the desired value for this high limit.
7. Press ENTER to view the present LO2 limit value:

LO2:-2.000000 ^ (default)

8. Enter the desired value for this low limit and press ENTER to return to the normal display.

Enabling limits

Use the following procedure to turn on the limits operation:

1. Press the Limits ON/OFF key to view the present beeper status:

BEEP: NEVER (default)

2. To change the beeper setting, use the ▲ and ▼ keys to display NEVER, OUTSIDE, or INSIDE.
3. Press ENTER to return to the normal display. The HI/IN/LO status is displayed along with the reading.
4. To disable Limits, press the ON/OFF key.

SCPI programming - limits

For remote operation, the testing capabilities of Limit 1 and Limit 2 are the same. Limit 1 and/or Limit 2 can be enabled. The commands to configure and control limit testing are listed in Table 8-1.

NOTE When testing limits remotely, keep in mind that the front panel HI/IN/LO status messages only apply to Limit 1. Also, if the front panel beeper is set for OUTSIDE or INSIDE, it will operate according to its front panel definition as previously explained.

Table 8-1
SCPI commands - limits

Commands	Description	Default	Note
:CALCulate3	CALCulate3 Subsystem:		
:LIMit	Configure and control Limit 1:		
:UPPer <n>	Set upper (HI1) limit; -100e6 to 100e6.	1	
:LOWer <n>	Set lower (LO1) limit; -100e6 to 100e6.	-1	
:STATe 	Enable or disable Limit 1 test.	OFF	
:FAIL?	Query test result; 0 = pass, 1 = fail.		1
:CLEar	Path to clear fail indication:		2
[:IMMEDIATE]	Clear fail indication.		
:AUTO 	Enable or disable auto clear.	ON	
:LIMit2	Configure and control Limit 2:		
:UPPer <n>	Set upper (HI2) limit; -100e6 to 100e6.	2	
:LOWer <n>	Set lower (LO2) limit; -100e6 to 100e6.	-2	
:STATe 	Enable or disable Limit 2 test.	OFF	
:FAIL?	Query test result; 0 = pass, 1 = fail.		1
:CLEar	Path to clear fail indication:		2
[:IMMEDIATE]	Clear fail indication.		
:AUTO 	Enable or disable auto clear.	ON	
:IMMEDIATE	Re-perform limit tests.		3

- NOTES**
1. The fail message ("0") for a limit test indicates that the reading is outside the specified limits.
 2. With auto clear enabled, the fail message ("0") is cleared when the instrument goes back into the idle state. If programmed not to go back into idle, you can manually clear the fail condition by sending the `CLEar[:IMMEDIATE]` command. With auto clear disabled, the fail condition will have to be cleared manually.
 3. When not in a continuous measurement mode (waiting for a trigger), you can change the limits and re-test the last reading. After changing the limits, send `CALCulate3:IMMEDIATE` to re-perform the limit tests on the last reading. Note that sending `IMMEDIATE` does not initiate (trigger) a reading. It simply repeats the limit tests on the last reading.

Programming example

The following program fragment performs limit tests on a voltage input to Channel 1:

```
'Configure 2182 for one-shot DCV1 measurements:
CALL SEND(7, "rst",status%)           'Put 2182 in a one-shot mode.

' Configure limit tests:
CALL SEND(7,":calc3:lim:upp 0.1",status%)   'Set HI1 limit to 0.1.
CALL SEND(7,":calc3:lim:low -0.1",status%)  'Set LO1 limit to -0.1.
CALL SEND(7,":calc3:lim2:upp 1",status%)    'Set HI2 limit to 1.
CALL SEND(7,":calc3:lim2:low -1",status%)   'Set LO2 limit to -1.
CALL SEND(7,":calc3:lim:stat on",status%)   'Enable Limit 1 test.
CALL SEND(7,":calc3:lim2:stat on",status%)  'Enable Limit 2 test.

'Trigger one reading and display it:
CALL SEND(7,":read?",status%)              'Trigger and request a
                                           'reading.

reading$ = SPACE$(80)
CALL ENTER(reading$, length%, 7,status%)   'Address 2182 to talk.
PRINT reading$                             'Display reading on CRT.
'Check result of Limit 1 test:
CALL SEND(7,":calc3:lim:fail?",status%)    'Request result of
                                           'Limit 1 test.

reading$ = SPACE$(80)
CALL ENTER(reading$, length%, 7, status%)  'Address 2182 to talk.
PRINT reading$                             'Display result of
                                           'Limit 1 test.

'Check result of Limit 2 test:
CALL SEND (7, ":calc3:lim2:fail?", status%) 'Request result of
                                           'Limit 2 test.

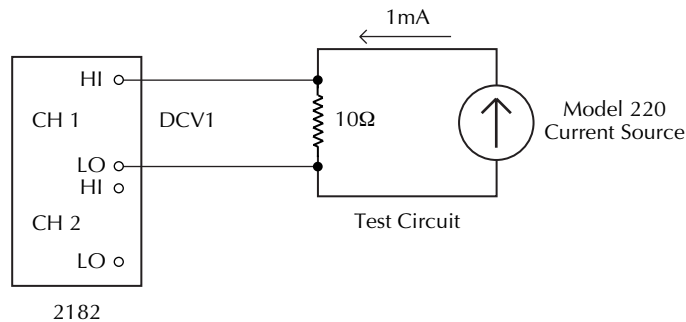
reading$ = SPACE$(80)
CALL ENTER(reading$, length%, 7,status%)   'Address 2182 to talk.
PRINT reading$                             'Display result of
                                           'Limit 2 test.
```

Application

Sorting resistors

Limits can be used to sort resistors. [Figure 8-2](#) shows a basic setup to test 10Ω resistors. The Model 220 is used to source a constant 1mA through the resistor and the Model 2182 measures the voltage drop.

Figure 8-2
Setup to test 10Ω resistors



For this application, the idea is to sort a batch of 10Ω resistors into three bins. Bin 1 is for resistors that are within 1% of the nominal value. Bin 2 is for resistors that exceed 1% tolerance, but are within 5%. Bin 3 is for resistors that exceed 5% tolerance.

Limit 1 will be used to test for the 1% tolerance and Limit 2 will be used to test for the 5% tolerance. The Model 2182 does not directly measure resistance, so the tolerances have to be converted to voltage values.

The voltage drop across a nominal 10Ω resistor is calculated as follows:

$$\begin{aligned} V_{\text{NOM}} &= 10\Omega \times 1\text{mA} \\ &= 10\text{mV} \end{aligned}$$

The voltage values for the 1% and 5% tolerances are calculated as follows:

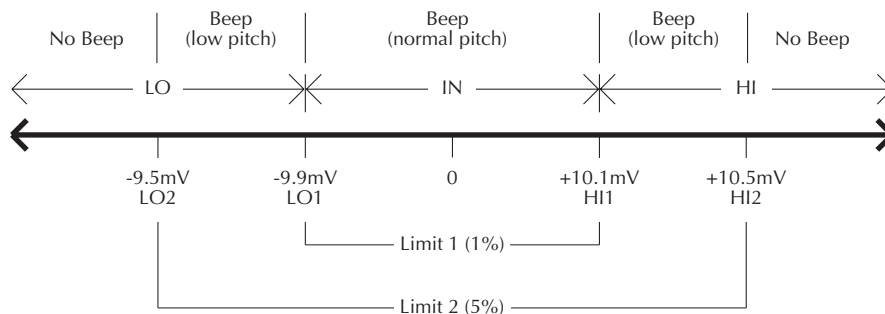
$$\begin{aligned} V_{1\%} &= 10\text{mV} \times 1\% \\ &= 10\text{mV} \times 0.01 \\ &= 0.1\text{mV} \end{aligned} \qquad \begin{aligned} V_{5\%} &= 10\text{mV} \times V_{5\%} \\ &= 10\text{mV} \times 0.05 \\ &= 0.5\text{mV} \end{aligned}$$

Finally, the high and low limits are calculated as follows:

$$\begin{aligned} \text{HI Limit 1} &= 10\text{mV} + V_{1\%} & \text{HI Limit 2} &= 10\text{mV} + V_{5\%} \\ &= 10\text{mV} + 0.1\text{mV} & &= 10\text{mV} + 0.5\text{mV} \\ &= 10.1\text{mV} & &= 10.5\text{mV} \\ \text{LO Limit 1} &= 10\text{mV} - V_{1\%} & \text{LO Limit 2} &= 10\text{mV} - V_{5\%} \\ &= 10\text{mV} - 0.1\text{mV} & &= 10\text{mV} - 0.5\text{mV} \\ &= 9.9\text{mV} & &= 9.5\text{mV} \end{aligned}$$

The limits are illustrated in [Figure 8-3](#).

Figure 8-3
Limits to sort 10Ω resistors (1%, 5%, and >5%)



Beeper Mode: INSIDE

Front panel operation — For front panel operation, the INSIDE beeper mode must be used. A normal pitch beep and the message “IN” indicates that the resistor is within the 1% tolerance limit (see Figure 8-3). This 1% resistor belongs in Bin 1. A low pitch beep and the “HI” or “LO” message indicates that the resistor is >1% tolerance but <5% tolerance. This 5% resistor belongs in Bin 2. For resistors >5%, no beep will sound. Place these resistors in Bin 3.

Remote operation — For remote operation, make sure both Limit 1 and Limit 2 are enabled. The following table evaluates the three possible pass/fail combinations for this application.

Limit 1 Result	Limit 2 Result	Resistor Tolerance	Bin Assignment
Pass	Pass	1%	1
Fail	Pass	5%	2
Fail	Fail	>5%	3

Keep in mind that a fail condition must be reset before testing the next resistor. Fail can be reset manually or automatically (see CLEAR command in Table 8-1).

Nulling thermal EMFs — To maximize handling speed, quick-disconnect test clips are typically used for the resistor connections. Unfortunately, these connections may contribute enough thermal EMFs to corrupt the measurement. The Relative feature of the Model 2182 can be used to null out this offset as follows:

1. Connect the test circuit shown in Figure 8-1, but leave the current source disconnected.
2. Using the lowest possible range (or autorange) measure the offset voltage.
3. Press REL to zero the display of the Model 2182.
4. Connect the current source and test the resistors.

NOTE As long as all the resistor leads in the batch are made of the same metal, the Rel value obtained for the first resistor should be satisfactory for each subsequent resistor.

9 Stepping and Scanning

- **Step/Scan overview** — Summarizes the stepping and scanning operations.
- **Front panel trigger models** — Uses the trigger model to illustrate how stepping and scanning operates.
- **Stepping/Scanning controls** — Covers the front panel keys used to configure and control stepping/scanning.
- **Stepping/Scanning examples** — Provides examples for internal stepping and scanning, and external scanning.
- **SCPI programming** — Covers the SCPI commands used for stepping and scanning.
- **Application** — Uses internal scanning to produce an I-V curve for a DUT.

Step/Scan overview

The Model 2182 can step or scan its two input channels or be used with external scanner cards installed in switching mainframes such as Models 707, 7001, and 7002. The following paragraphs summarize the various aspects of stepping/scanning using the Model 2182.

NOTE Step and Scan operations are illustrated by trigger models (see “[Front panel trigger models](#)” in this section).

Internal Stepping/Scanning (Channels 1 and 2)

When stepping or scanning the two input channels of the Model 2182, Channel 2 is selected (measured) first and then Channel 1 is selected (measured). For every step/scan cycle, Channel 2 is measured once, and Channel 1 can be measured from 1 to 1023 times. Measured readings are automatically stored in the buffer.

External Stepping/Scanning

When using external switching cards, the switching mainframe controls the opening and closing of individual channels. Up to 800 external channels can be stepped/scanned and measured by Channel 1 of the Model 2182 (Channel 2 cannot be used for external stepping or scanning). Measured readings are automatically stored in the buffer.

To synchronize Model 2182 measurements with external channel closures, connect the Trigger Link lines of the nanovoltmeter and switching mainframe. Refer to [Section 7 \(Triggering\)](#) for details and an example on using external triggering.

NOTE Channel annunciators do not turn on during an external step or scan.

Front panel trigger models

The front panel trigger models for stepping and scanning are shown in [Figure 9-1](#) and [Figure 9-2](#). These are expansions of the basic front panel trigger model that is presented and explained in [Section 7](#) (see [Figure 7-1](#)). The following discussions focus on the stepping and scanning operations. Be sure to refer to [Section 7](#) for additional information on the various components of trigger models.

Internal scanning

[Figure 9-1](#) shows the front panel trigger model for internal scanning. The components of the trigger model are explained as follows:

- **Control source:**
 - **Immediate** — With immediate triggering, event detection occurs immediately allowing operation to drop down to the next trigger model block (Delay).
 - **Timer** — The timer is used to control the time interval between internal scans. It has no effect on the time interval between each measurement in a scan cycle. When SCAN is pressed, the timer starts and event detection occurs immediately allowing operation to drop down to Delay. If configured for an additional scan, operation will later loop back to this control source, where it will wait until the timer interval expires. If the timer interval is already expired, event detection will be satisfied immediately.
 - **External trigger** — After the internal scan is configured, pressing the EX TRIG key places the instrument in the external trigger mode. When the SCAN key is pressed, the internal scan is enabled. However, it doesn't start until an external trigger is received or the TRIG key is pressed. After the trigger occurs, operation drops down to the Delay block.
- **Delay** — If a delay (auto or manual) is being used, operation will hold up at this block until the delay period expires.
- **Device action** — Measurements are performed at this block. The first measurement is performed on Channel 2 of the Model 2182. Subsequent measurements are performed on Channel 1. Note that every reading is automatically stored in the buffer.
- **Sample counter** — For each scan cycle, Channel 2 is measured once and Channel 1 is measured a specified number of times. Therefore, the sample count is the sum of those two values (CH1 COUNT +1). Operation will continue to loop back to Delay and Device Action until all the sample readings are taken.
- **Output trigger** — After the last Channel 1 measurement is performed, an output trigger is applied to the rear panel Trigger Link connector.
- **Trigger counter** — The value of this counter determines how many scan cycles will be performed. If configured for another scan, operation will loop back to the control source for another pass through the trigger model.

Figure 9-1
Front panel triggering (internal scanning)

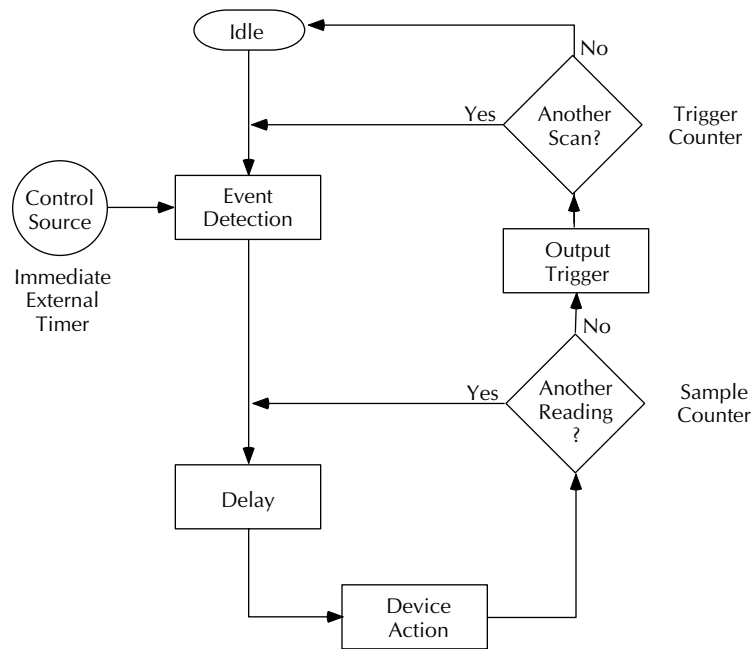
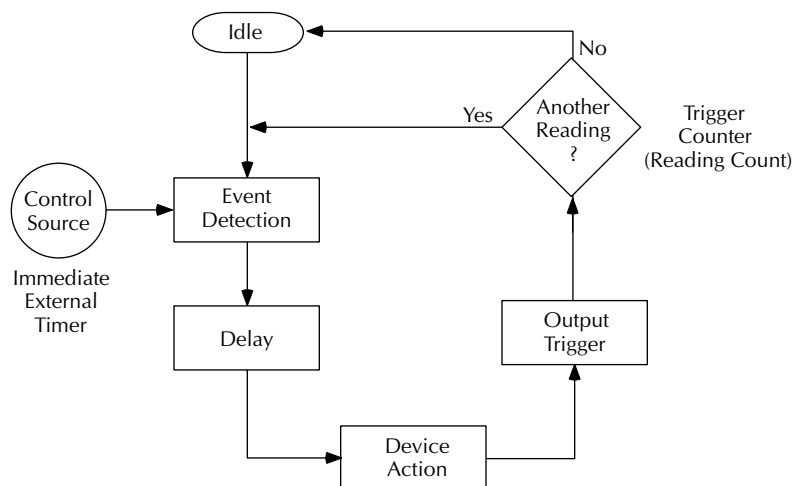


Figure 9-2
Front panel triggering (other step/scan operations)



Other Stepping/Scanning operations

- **Control source:**
 - **Immediate** — With immediate triggering, event detection occurs immediately allowing operation to drop down to the next trigger model block (Delay).
 - **Timer** — The timer is used to set a time interval between channels in a step/scan cycle. When STEP or SCAN is pressed, the timer starts and event detection occurs immediately allowing operation to drop down to Delay. When operation later loops back to this control source, it waits until the timer interval expires. If the timer interval is already expired, event detection will be satisfied immediately.
 - **External trigger** — After the stepping or scanning operation is configured, pressing the EX TRIG key places the instrument in the external trigger mode. When STEP or SCAN key is pressed, the step/scan is enabled. However, it doesn't start until an external trigger is received or the TRIG key is pressed. After the trigger occurs, operation drops down to the Delay block.
- **Delay** — If a delay (auto or manual) is being used, operation will hold up at this block until the delay period expires.
- **Device action** — Measurements are performed at this block. For internal stepping, the first measurement is performed on Channel 2 of the Model 2182. Subsequent measurements are performed on Channel 1. For internal scanning and external scanning, each measurement corresponds to a channel in the step/scan list. All readings are automatically stored in the buffer.
- **Output trigger** — After each measurement is performed, an output trigger is applied to the rear panel Trigger Link connector.
- **Trigger counter** — Reading Count specifies the total number of measurements to perform. If another measurement is to be performed, operation loops back to the control source.

Stepping/Scanning controls

- **SHIFT-CONFIG** — Selects and configures internal or external scanning. See [“Step/Scan configuration”](#) for details.
- **EX TRIG** — Selects the External Trigger control source.
- **TRIG** — Satisfies event detection for the External Trigger control source.
- **STEP and SCAN** — Enables a stepping or scanning operation of consecutive channels.
- **SHIFT - HALT** — Stops stepping or scanning and restores the trigger model to a non-stepping/scanning mode.

Step/Scan configuration

Internal Stepping/Scanning

The settings for internal stepping and scanning are explained as follows:

Timer — The maximum timer interval is 99H:99M:99.999S (Hour:Minute:Second format).

Channel 1 Count — This specifies the number of measurements to be performed while on Channel 1. Keep in mind that for each step/scan cycle, only one measurement is performed on Channel 2. Channel 1 Count can be set from 1 to 1023.

Reading Count — This indicates the total number of measurements that will be performed for each step/scan cycle. For example, if Channel 1 Count is set to 3, the Reading Count will initially set to 4 (the extra reading is for Channel 2). For each additional step/scan cycle, simply add 4 to the Reading Count. Therefore, to perform three step/scan cycles, set the Reading Count to 12. Reading Count can be set from 2 to 1024.

- NOTES**
- *If you change the Reading Count, it must be a multiple of the initial count value. For example, if the initial Reading Count is 3, you can change it to 6 (or 9, or 12, etc.). If you enter a non-multiple value, the instrument will select the next lower value that is a multiple.*
 - *Reading Count can be set to a value >1024 or INFinite, but only the first 1024 readings will be stored in the buffer.*

Perform the following steps to configure internal stepping or scanning:

1. Press SHIFT and then CONFIG. Use the ► key to display the present SCANNING type (INTernal or EXTernal).
2. Press the ▲ or ▼ key to display INT, and press ENTER.
3. The present state of the timer is displayed (OFF or ON). Press ▲ or ▼ to display the desired timer state, and press ENTER.
4. If you turned the timer on, the timer interval will be displayed. Use the edit keys (◀, ▶, ▲, and ▼) to set the timer interval, and press ENTER.
5. The present Channel 1 Count (CH1 CNT) is displayed. Use the edit keys to set the number of measurements for Channel 1, and press ENTER.
6. The Present Reading Count (RNG CNT) is displayed (it will be CH1 CNT + 1). If you wish to increase the Reading Count, use the edit keys to display the value, and press ENTER to return to the normal display state.

External Stepping/Scanning

The settings for external stepping/scanning are explained as follows:

Min/Max Values — These two values specify the beginning and ending channels for the step/scan list. Valid values for Min is 1 to 799, and valid values for Max is 2 to 800. However, the Max value must be larger than the Min value.

Timer — The maximum timer interval is 99H:99M:99.999S (Hour:Minute:Second format).

Reading Count — This indicates the total number of measurements that will be performed for each step/scan cycle. For example, if Min is set to 1 and Max is set to 10, the Reading Count will automatically set to 10. For each additional step/scan cycle, simply add 10 to the Reading Count. Therefore, to perform three step/scan cycles, set the Reading Count to 30. Reading Count can be set from 2 to 1024.

Perform the following steps to configure external stepping or scanning:

1. Press SHIFT and then CONFIG. Use the ► key to display the present SCANNING type (INTERNAL or EXTERNAL).
2. Press the ▲ or ▼ key to display EXT, and press ENTER.
3. The minimum channel (MIN CHAN) to step/scan is displayed. Use the edit keys (◀, ▶, ▲, and ▼) to specify the Min channel, and press ENTER.
4. The maximum channel (MAX CHAN) is then displayed. Use the edit keys to specify the Max channel, and press ENTER.
5. The present state of the timer is displayed (OFF or ON). Press ▲ or ▼ to display the desired timer state, and press ENTER.
6. If you turned the timer on, the timer interval will be displayed. Use the edit keys (◀, ▶, ▲, and ▼) to set the timer interval, and press ENTER.
7. The Present Reading Count (RNG CNT) is displayed. It will be $(\text{Max} - \text{Min}) + 1$. If you wish to increase the Reading Count, use the edit keys to display the value, and press ENTER to return to the normal display state.

Stepping/Scanning examples

Internal scanning

Settings: Control Source = Immediate (timer off)
 Delay = Auto
 Channel 1 Count = 4
 Reading Count = 10

Overview: With Channel 1 count set to 4, each scan cycle will measure Channel 2 once and Channel 1 four times, for a total of five measurements. This sets the Sample Counter in [Figure 9-1](#) to 5. The Reading Count 10 indicates that the five measurement scan will be performed twice. This sets the Trigger Counter to 2. A total of 10 measurements will be performed. All ten readings will be stored in the buffer.

Operation: When the SCAN key is pressed, operation proceeds to Device Action where a measurement on Channel 2 is performed. The sample counter is decremented to 4 causing operation to loop back to Device Action for a measurement on Channel 1. Operation loops back to Device Action three more times to complete the scan cycle.

After the scan cycle, the trigger counter is decremented to 1 and an output trigger is sent. Operation loops back to the control source, where it immediately falls through and repeats the five measurement scan. An output trigger is again sent, and the instrument then goes into the idle state.

Internal stepping

Settings: Control Source = Immediate (timer off)
Delay = Auto
Channel 1 Count = 4
Reading Count = 10

Overview: A Reading Count of ten sets the Trigger Counter in [Figure 9-2](#) to 10. A total of ten measurements will be performed and stored in the buffer. The 1st and 6th measurements will be performed on Channel 2, and the rest will be performed on Channel 1.

Operation: When the STEP key is pressed, operation proceeds to Device Action where a measurement on Channel 2 is performed. An output trigger is sent and the Trigger Counter is decremented to 9. Operation then loops back to Device Action four more times to perform four measurements on Channel 1. Note that an output trigger is sent after every measurement.

At this point, the Trigger Counter is set to 5. Operation continues to loop until Channel 2 is again measured one time, and Channel 1 is again measured four times. After the last measurement is performed, the instrument goes into idle.

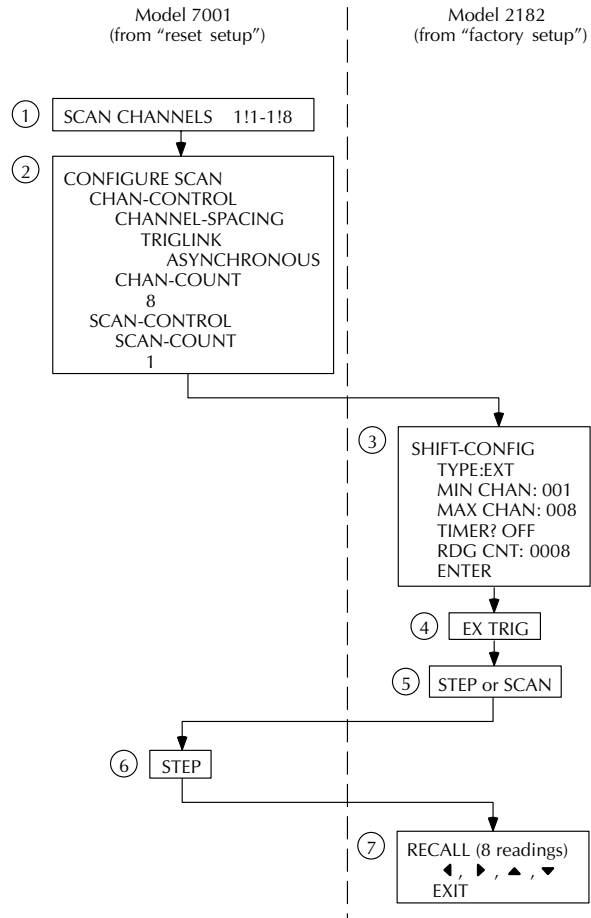
External scanning

Figure 9-3 summarizes the front panel operations to configure a scan for the “[External triggering example](#)” provided in [Section 7](#). In that example, the Model 2182 is used to scan and measure eight DUTs switched by a Model 7168 Nanovolt Scanner card installed in a Model 7001/7002 Switch System. [Figure 7-6](#) and [Figure 7-7](#) show the signal and trigger connections, while [Figure 7-8](#) shows trigger model operation for the test.

Both instrument setups assume factory defaults. Note that Channel 1 of the Model 2182 must be used for external scanning.

1. On the Model 7001 Switch System, enter a scan list of channels 1 to 8 on card 1.
2. Also on the Model 7001, configure the instrument for Trigger Link triggers and one scan of eight channels.
3. On the Model 2182, configure an external scan of the first eight channels.
4. Set the Model 2182 for external triggers by pressing EX TRIG.
5. Press STEP or SCAN on the Model 2182. The asterisk and STEP or SCAN annunciator will light.
6. Press STEP on the Model 7001 to start channel closures.
7. After the scan, you can recall eight readings from the Model 2182 buffer.

Figure 9-3
External scanning example with Model 7001



SCPI programming - stepping and scanning

Commands to scan are listed in [Table 9-1](#). Notice that many commands from the TRIGGER Subsystem are used for scanning. See [Section 7](#) for details on triggering.

Table 9-1
SCPI commands - stepping and scanning

Commands	Description	Default
For ROUTe Subsystem:		
:ROUTE	ROUTE Subsystem:	
:SCAN	Scanning:	
:INTERNAL	Internal Scan:	
:CCOunt <n>	Specify number of Channel 1 readings; 1 to 1023	1
[:EXTernal] <list>	Specify external scan list: 2 to 800 (see note 1).	1-10
:LSElect <name>	Select scan operation: NONE, INTERNAL or EXTERNAL (see Note 2).	NONE
For TRIGGER Subsystem:		
:TRIGGER	Trigger commands:	
:SOURCE <name>	Select control source: IMMEDIATE, TIMER, MANUAL, BUS, or EXTERNAL.	IMMEDIATE
:TIMER <n>	Set timer interval: 0 to 999999.999 (sec.).	0.1
:COUNT <n>	Set trigger count: 1 to 9999 or INF.	(see Note 3)
:DELAY <n>	Set delay: 0 to 999999.999 (sec.).	0
:AUTO 	Enable or disable auto delay.	
:SAMPLE	Sample Counter	
:COUNT <n>	Set sample count: 1 to 1024.	1

Notes:

- The <list> parameter is formatted as follows:
 <list> = (@X:Y)
 Where: X is the Min channel
 Y is the Max channel
- The parameters are explained as follows:
 NONE - Disables all operations associated with a scan.
 INTERNAL - Enables an internal scan.
 EXTERNAL - Enables an external scan.
- Defaults for trigger count:
 SYSTEM:PRESET sets the count to INF (infinite).
 *RST sets the count to 1.

Programming example

The following program fragment performs a five measurement internal scan. The five readings are stored in the buffer and displayed on the computer CRT.

```
CALL SEND(7,"*rst",status%)           'Restore *RST defaults.
CALL SEND(7,":samp:coun 5",status%)    'Set sample count to 5.
CALL SEND(7,":rout:scan:int:cco 4",status%) 'Set channel 1 count to 4.
CALL SEND(7,":rout:scan:lssel int",status%) 'Enable internal scan.
CALL SEND(7,":read?",status%)          'Trigger scan and request
                                       'readings.

reading$ = SPACE$ (80)
CALL ENTER (reading$,length%,7,status%) 'Address 2182 to talk.
PRINT reading$                          'Display the 5 readings on
                                       'the CRT.
```

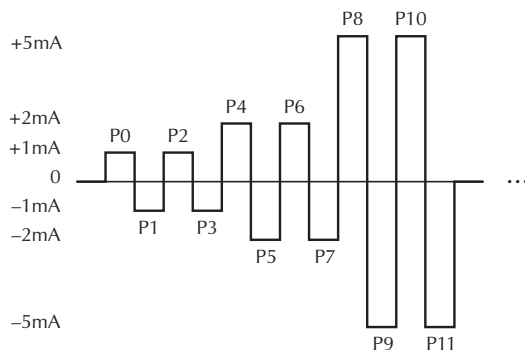
Application — I-V curves using internal scan

SCAN for IV curves [Measure V, sweep I, constant H (magnetic field) or T (temperature)]

SCAN can be used to measure V, while sweeping the current through a sample with a constant magnetic field or a constant temperature. With the use of a Keithley Model 2400 SourceMeter and a Model 8501 Trigger Link cable, (see [Section 7](#) for more details on triggering), the 2400 can be programmed to sweep the current in a bipolar, (DC current-reversal technique) growing amplitude fashion. See waveform in [Figure 9-4](#). This sweep will store into the 2182 memory and can be recalled at the end of the sweep. By having the 2400 and 2182 in a tight hardware control, the DC current-reversal technique can be run at a rate of 8/sec. at a 1PLC integration time. This will greatly reduce any thermal EMFs in the system by being able to reverse the DC current before any temperature effects can occur. Looking for critical currents I_C can be accomplished at a faster reading rate.

NOTE *Channel 1 is used to measure the voltage across the sample, while Channel 2 measures the voltage across a known reference (R_{REF}) resistor to determine the current in the sample.*

Figure 9-4
Waveform to be programmed into Model 2400



Set up 2182

Restore factory defaults

Filters: off

Rate: 1 plc

Ch1: 10mV

Ch2: 1V

Ext Trigger: on

Delay: Set to time needed for cable settling

Config SCAN: INT

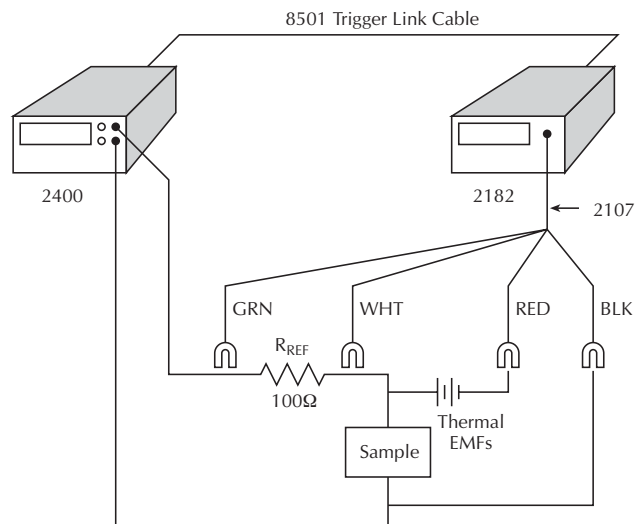
Timer off

Ch1 Count 3 ; Note Ch1 will store 3 readings / 2400 programmed current level.

Ch2 will store 1 reading / 2400 programmed current level.

Rdg Count 48

Figure 9-5
Setup of Model 2182 and Model 2400



Set up 2400

Menu: Savesetup: Global: Reset: Bench

Meas: V

Source: I

Config Trig: ARM-LAYER: ARM-IN: IMMEDIATE

ARM-OUT : LINE: #3

: EVENTS: TRIG-LAYER-DONE= OFF

TRIG-LAYER: TRIGGER-IN: TRIGGER-LINK: #1: EVENT DETECT BYPASS

NEVER: TRIGGER IN EVENTS: SOURCE= ON all others off

TRIG-LAYER: TRIGGER-OUT: LINE: #2

: EVENTS :TRIGGER OUT EVENTS:

SOURCE = ON, all others off.

: COUNT 12

Config Sweep: TYPE: CUSTOM : #-POINTS: 12

: ADJUST-POINTS: see waveform

: COUNT: INFINITE

Speed: 0.01plc

Turn output: On

SWEEP :exit

TRIG: HALT

ON the 2182, enable SCAN (Note: Memory buffer annunciator comes on).

ON the 2400, enable SWEEP (Note: Arm annunciator comes on).

Press Trig on 2400.

After completion of the sweep, recall the data from the 2182 using the “TRACe” command.

To remove thermal EMFs from the readings, do the following math on the recalled data:

$$\text{CH2 Rdg \#1} = (\text{Buffer Rdg \#1} - \text{Buffer Rdg \#5}) / 2$$

$$\text{CH2 Rdg \#2} = (\text{Buffer Rdg \#9} - \text{Buffer Rdg \#13}) / 2$$

repeat.

$$\text{CH1 Rdg_Pos \#1} = (\text{Buffer Rdg \#2} + \text{Buffer Rdg \#3} + \text{Buffer Rdg \#4}) / 3$$

$$\text{CH1 Rdg_Neg \#1} = (\text{Buffer Rdg \#6} + \text{Buffer Rdg \#7} + \text{Buffer Rdg \#8}) / 3$$

$$\text{CH1 Rdg\#1} = (\text{CH1 Rdg_Pos \#1} - \text{CH1 Rdg_Neg \#1}) / 2$$

$$\text{CH1 Rdg_Pos \#2} = (\text{Buffer Rdg \#10} + \text{Buffer Rdg \#11} + \text{Buffer Rdg \#12}) / 3$$

$$\text{CH1 Rdg_Neg \#2} = (\text{Buffer Rdg \#14} + \text{Buffer Rdg \#15} + \text{Buffer Rdg \#16}) / 3$$

$$\text{CH1 Rdg\#2} = (\text{CH1 Rdg_Pos \#2} - \text{CH1 Rdg_Neg \#2}) / 2$$

repeat.

A loop program can be written to extract the data as follows:

```
' This is for Channel 2 Data'
Let NumRdgsPerStep = 4      ; 1 Ch2 and 3 Ch1 readings stored in the buffer
                             / 2400 current level.
Let CalcRdgs = 6           ; Total number of positive or negative current
                             levels out of the 2400.

Let k = 1
For j =1 to CalcRdgs
  CH2 Rdg#( j ) = Buffer Rdg#( k )- Buffer Rdg#( k + NumRdgsPerStep )
  CH2 Rdg#( j ) = CH2 Rdg#( k ) / 2
  k = k + ( NumRdgsPerStep * 2 )
Next j

' This for For Channel 1 Data'
Let NumRdgsPerStep = 4
Let CalcRdgs = 6
Let k = 1
For j = 1 to CalcRdgs
  Let CH1 Rdg#_pos = 0
  Let CH1 Rdg#_neg = 0
For m =1 to NumRdgsPerStep - 1
  CH1 Rdg#_pos = CH1 Rdg#_pos + Buffer Rdg#( k +m )
  CH1 Rdg#_neg = CH1 Rdg#_neg + Buffer Rdg#( k +m + NumRdgsPerStep )
Next m
  CH1 Rdg#( j ) = ( CH1 Rdg#_pos - CH1 Rdg#_neg ) /
    ( (NumRdgsPerStep - 1) * 2)
Next j
```

An example program using “QBASIC ” was written that sets up an Array for all the data out of the 2182 buffer, parses the comma separated data into the array, and calculates the DC current reversal data for both Channel 1 and Channel 2.

```
CONST Addr = 7           'Represents the address of the 2182
CONST NumRdgsPerStep = 4 'Represents the total number of CH1 & CH2
                           'readings at each positive or negative current
                           'step
CONST CalcReadings = 6   'Represents number of paired positive & negative
                           'steps in 2400

CONST NumRdgs = (NumRdgsPerStep * 2 * CalcReadings)
                           'NumRdgs represents the number of readings to
                           'store in 2182's buffer
                           'The 2 accounts for positive and negative steps

DIM DataCH2$(CalcReadings) 'array represents total number of channel 2
                           'readings
DIM DataCH1$(CalcReadings) 'array represents total number of channel 1
                           'readings
FOR i = 1 TO (CalcReadings) 'allocates space for each channel reading
  DataCH2$(i) = SPACE$(18)
  DataCH1$(i) = SPACE$(18)
NEXT i

'CODE for Parsing single string of buffer response into 48 individual
                           readings
OneReading$ = SPACE$(20)   'represents 1 reading from buffer string
                           'response
OneCharacter$ = SPACE$(2)  'represents 1 character from buffer string
                           'response
```

```

AsciiRdgsBuf$ = SPACE$(18 * NumRdgs)
DIM Readings!(1 TO NumRdgs)
' represents the string of buffer response
' array of the 48 individual readings in
' numerical representation form - converted from
' ASCII

CALL send(Addr, "TRACE:DATA?", status%)
' ask 2182 for the buffer response
CALL enter(AsciiRdgsBuf$, length%, Addr, status%)
' read in buffer response
' Start Parsing the data readings...
ParseLength = 1
' represents how many characters to extract from
' response string
CurrentPosition% = 1
' represents which character on in response
' string
OneReading$ = ""
' clear out string contents
ReadingOn% = 1
' represents the individual reading on
DO
  OneCharacter$ = MID$(AsciiRdgsBuf$, CurrentPosition%, ParseLength)
  ' above line reads in the next character for the
  ' buffer response
  IF (OneCharacter$ = ",") THEN
    ' found an individual reading so store it as such
    Readings!(ReadingOn%) = VAL(OneReading$)
    OneReading$ = ""
    ' clear out so able to read next individual
    ' reading
    ReadingOn% = ReadingOn% + 1
    ' increment counter for next individual reading
  ELSE
    ' still building an individual reading so add on
    ' the next character
    OneReading$ = OneReading$ + OneCharacter$
  END IF
  CurrentPosition% = CurrentPosition% + 1
  ' increment character on in the buffer response
LOOP UNTIL (CurrentPosition% > length%)
' loop until pass the number of characters read
' in with the buffer response
Readings!(ReadingOn%) = VAL(OneReading$)
' store last individual reading since it will not
' be separated by a comma

' Calculate DataIC and DataV values
' where Chan2! is the CH2 numerical representation for string CH2 data
' and Chan1! is the CH1 numerical representation for string CH1 data
' CH1pos! is the positive portion for channel 1
' CH1neg! is the negative portion for channel 1
k% = 1
' represents the reading in Reading! to use in
' calculation

```

```
FOR j = 1 TO (CalcReadings)
  Chan2! = Readings!(k%) - Reading!(k% + NumRdgsPerStep)
  Chan2! = Chan2! / 2
  DataCH2$(j) = STR$(Chan2!)
  CH1pos! = 0!
  CH1neg! = 0!
  FOR i = 1 TO (NumRdgsPerStep - 1)
    CH1pos! = CH1pos! + Reading!(k% + i)
    CH1neg! = CH1neg! + Reading!(k% + i + NumRdgsPerStep)
  NEXT i
  Chan1! = ((CH1pos! - CH1neg!) / ((NumRdgsPerStep - 1) * 2))
  DataCH1$(j) = STR$(Chan1!)
  k% = k% + (NumRdgsPerStep * 2)
NEXT j

'Printing results to a file
OPEN "chan1.xls" FOR OUTPUT AS #1 'this will place chan1.xls in your
                                  'current working directory
OPEN "chan2.xls" FOR OUTPUT AS #2 'this will place chan2.xls in your
                                  'current working directory

FOR i = 1 TO CalcReadings
  PRINT #2, DataCH2$(i)
  PRINT #1, DataCH1$(i)
NEXT i
CLOSE #1 'close the chan1.xls file
CLOSE #2 'close the chan2.xls file
```

10 Analog Output

- **Overview** — Covers the capabilities of the Analog Output.
- **Operation** — Explains how to configure and control the Analog Output.
- **SCPI programming** — Covers the SCPI commands associated with the Analog Output.

Overview

The ANALOG OUTPUT provides a scaled, non-inverting voltage output up to $\pm 1.2\text{V}$. It is typically used to drive a chart recorder. The Analog Output voltage is calculated as follows:

$$\text{Analog Output} = (\text{Gain} \times \text{Rdg}/\text{Rng}) - \text{Offset}$$

where: Gain is the user entered gain factor.
Rdg is the reading on the Model 2182.
Rng is the measurement range.
Offset is the user entered offset value.

NOTE Gain and offset for Analog Output are not related to gain and offset for the $mX+b$ calculation (see [Section 4](#)).

Gain provides amplification for small analog output voltage signals, while offset allows you to adjust the analog output to keep it between $\pm 1.2\text{V}$ (maximum output) or reference the voltage output to a specific value, such as zero.

For example, assume you are measuring 100mV on the 1V range. With gain set to 1, the analog output would be 100mV. You can increase analog output sensitivity by setting gain to 10. This increases the analog output to 1V. You can then set Offset to 1V to reference the 1V analog output to zero. The Analog Output calculation looks like this:

$$\text{Analog Output} = (10 \times 100\text{mV}/1\text{V}) - 1\text{V} = 0\text{V}$$

NOTE Analog Output Rel can be used to automatically reference the analog output voltage to zero. See [“Analog output rel.”](#)

The factory default for Gain is 1 and the factory default for Offset is 0. Therefore, when using the factory defaults, Gain and Offset drop out of the equation:

$$\text{Analog Output} = \text{Rdg}/\text{Rng}$$

[Table 10-1](#) shows analog output examples with Gain set to 1 and Offset set to 0.

Table 10-1

Analog output examples*

Reading	Range	Analog Output Voltage
1V	1V	+1V
-1V	1V	-1V
1V	10V	0.1V
12V	10	1.2V
50mV	100mV	0.5V
-1mV	1V	-1mV

* Gain = 1, Offset = 0

Temperature

The analog output voltage for temperature measurements depends on thermocouple type and the selected units (°C, °F, or K). The 1.2V analog output is scaled to the maximum positive temperature reading. For example, the measurement range for the Type J thermocouple is -200°C to +760°C. For a 760°C reading, the analog output voltage will be 1.2V, and for a -200°C reading, the analog output voltage will be -0.316V. The measurement ranges (in °C) for the various thermocouple types are listed in the specifications (see [Appendix A](#)).

With Gain set to 1 and Offset set to 0, analog output voltage for temperature measurements is calculated as follows:

$$\text{Analog Output} = 1.2 \times \text{Rdg/Rng}^*$$

* Rng is a magnitude. Therefore, it is always a positive value.

Example Calculations:

Type J, 100°C Reading

$$\begin{aligned}\text{Analog Output} &= 1.2 \times 100/760 \\ &= 158\text{mV}\end{aligned}$$

Type J, -100°C Reading

$$\begin{aligned}\text{Analog Output} &= 1.2 \times (-100/760) \\ &= -158\text{mV}\end{aligned}$$

When using Gain and Offset, the calculation is expanded as follows:

$$\text{Analog Output} = (\text{Gain} \times 1.2 \times \text{Rdg/Rng}) - \text{Offset}$$

Ratio

Analog Output can be used with Ratio. When enabled, the analog output voltage is scaled to a Ratio value of 1. That is, the analog output will be 1V for a Ratio result of 1. If, for example, the Ratio is 0.4, analog output voltage will be 0.4V. Gain, Offset, and Analog Output Rel can also be used. However, the maximum analog output is $\pm 1.2\text{V}$.

Operation

Analog output connections

The analog output is accessed from the rear panel BNC connector that is labeled “ANALOG OUTPUT.” This connector requires a cable that is terminated with a standard male BNC connector.

Output resistance — The output resistance of Analog Output is $1\text{k}\Omega \pm 5\%$. To minimize the effects of loading, the input resistance of the device connected to Analog Output should be as high as possible. For example, with a device with an input resistance of $10\text{M}\Omega$, the error due to loading will be approximately 0.01%.

Configure and control analog output

1. Press SHIFT and then AOUT to display the Gain (M) factor:
M +1.0000000^ (factory default)
2. Gain can be set from -100e6 to 100e6. The ◀ and ▶ keys control cursor position and the ▲ and ▼ range keys increment and decrement the digit value. To change range, place the cursor on the multiplier and use the ▲ and ▼ keys (m = $\times 0.001$, ^ = $\times 1$, K = $\times 1000$, and M = $\times 1,000,000$). With the cursor on the polarity sign, the ▲ and ▼ keys toggle polarity.
3. Press ENTER to enter the Gain value and display the Offset value:
B: +00.000000 (factory default)
4. Key in the Offset value.
5. Press ENTER to enter the Offset value and enable Analog Output. The instrument returns to the normal display state.
6. To disable Analog Output, press SHIFT and then AOUT.

Analog output rel

With analog output enabled, Analog Output Rel is used to automatically reference the analog output voltage to zero. When Analog Output Rel is turned ON, the present analog output voltage is used as the Rel value. This sets the analog output voltage to zero. Subsequent analog output readings will be the difference between the actual analog output and the Rel value.

To enable Analog Output Rel, press SHIFT and then OUTPUT. The message “AOUT REL ON” will be displayed briefly to indicate that it is enabled. To disable Analog Output REL, press SHIFT and then OUTPUT a second time. The message “AOUT REL OFF” will be displayed briefly.

NOTE A new Rel value for analog output can be established at any time by first disabling Analog Output Rel and then re-enabling it.

SCPI programming - analog output

Commands for analog output are summarized in [Table 10-2](#). Additional information on these commands follows the table. The Ref column in the table provides reference for this information.

Table 10-2

SCPI commands - analog output

Commands	Description	Ref	Default
:OUTPut	OUTPut Subsystem:		
:GAIN <NRf>	Specify gain factor (M); 1e-9 to 1e6.	A	1
:OFFSet <NRf>	Specify offset (B); -1.2 to 1.2.	A	0
[:STATe] 	Enable or disable Analog Output.	B	0
:RELative 	Enable or disable Analog Output Relative.	C	0

Reference:

- A. GAIN and OFFSet — Gain and offset changes do not take affect until the next reading is triggered.
- B. STATe — OFF (0) forces analog output to 0V immediately. ON (1) does not take effect until next reading is triggered.
- C. RELative — Sending ON (1) while Rel is enabled acquires a new Rel value.

Programming example

The following program fragment assumes that you are using analog output to monitor a 1mV signal on the 10mV range. Analog output gain is set to 10 to increase sensitivity. Therefore, 1mV will result in a 1V analog output. Finally, Analog Output Rel is enabled to reference the 1V analog output to zero.

```
CALL SEND (7, ":syst:pres", status%)           ' Restore System Preset
                                                ' defaults.
CALL SEND (7, ":sens:volt:rang 0.01", status%) ' Select 10mV range.
CALL SEND (7, ":outp:gain 10", status%)        ' Set analog output gain
                                                ' to 10.
CALL SEND (7, ":outp on", status%)             ' Enable analog output.
CALL SEND (7, ":outp:rel on", status%)        ' Enable analog output
                                                ' rel.
```

11 Remote Operation

- **Selecting and configuring an interface** — Explains how to select and configure an interface: GPIB or RS-232.
- **GPIB operation and reference** — Covers the following GPIB topics:
 - GPIB Bus Standards
 - GPIB Bus Connections
 - Primary Address Selection
 - QuickBASIC Programming
 - General Bus Commands
 - Front Panel GPIB Operation
 - Status Structure
 - 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 2182 Nanovoltmeter 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 2182 must be assigned to a unique address. At the factory the address is set to 07, 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 182 language to program the instrument.

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

***NOTE** When changing the interface (GPIB to RS-232, or vice versa), all data in the buffer clears.*

Languages

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

- SCPI Language
- 182 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 2182 using the SCPI language.

182 Language — The Model 2182 implements most commands (DDCs) available in the Keithley Model 182 Sensitive Digital Voltmeter. The commands (along with programming limitations) are provided in [Appendix D](#). See the Model 182 Instruction Manual.

***NOTE** The 182 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.*

Interface selection and configuration procedures

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

GPIB interface

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

- Primary address (0 to 30)
- Language (SCPI or 182)

Perform the following steps to select and configure the GPIB interface:

NOTE *To retain a present GPIB setting, press ENTER with the setting displayed. You can exit from the menu structure at any time by pressing EXIT.*

1. Press SHIFT and then GPIB to access the GPIB menu. The present state (on or off) of the GPIB is displayed.
2. To enable the GPIB interface:
 - A. Place the cursor on the on/off selection by pressing the ► key.
 - B. Press the ▲ or ▼ key to toggle the selection to ON.
 - C. Press ENTER. The present GPIB address is displayed.
3. To change the GPIB address:
 - A. Use the ◀, ▶, ▲, and ▼ keys to display a valid address value.
 - B. Press ENTER. The present language selection is displayed.
4. To change the programming language:
 - A. Place the cursor on the present language selection.
 - B. Press the ▲ or ▼ key to toggle the selection.
 - C. Press ENTER. The instrument returns to the normal display state.

RS-232 interface

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

- Baud rate (19.2k, 9600, 4800, 2400, 1200, 600, or 300)
- Flow control (none or XonXoff)
- Terminator (CR, LF, CRLF, or LFCR)

NOTE *See “RS-232 interface reference” (located at the end of this section) for information on the these settings and connections to the computer.*

Perform the following steps to select and configure the RS-232 interface:

NOTE *To retain a present RS-232 setting, press ENTER with the setting displayed. You can exit from the menu structure at any time by pressing EXIT.*

1. Press SHIFT and then RS232 to access the RS-232 menu. The present state (on or off) of the RS-232 is displayed.
2. To enable the RS-232 interface:
 - A. Place the cursor on the on/off selection by pressing the ► key.
 - B. Press the ▲ or ▼ key to toggle the selection to ON.
 - C. Press ENTER. The present baud rate is displayed.
3. To change baud rate:
 - A. Place the cursor on the baud rate value.
 - B. Use the ▲ and ▼ keys to display the desired baud rate value.
 - C. Press ENTER. The present flow control setting is displayed.
4. To change flow control:
 - A. Place the cursor on the present flow control selection.
 - B. Press the ▲ or ▼ key to toggle the selection.
 - C. Press ENTER. The present terminator is displayed.
5. To change the terminator:
 - A. Place the cursor on the present terminator selection.
 - B. Press the ▲ or ▼ key to display the desired terminator.
 - C. Press ENTER. The instrument returns to the normal display.

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

GPIB operation and reference

GPIB bus standards

The GPIB bus is the IEEE-488 instrumentation data bus with hardware and programming standards originally adopted by the IEEE (Institute of Electrical and Electronic Engineers) in 1975. The Model 2182 conforms to these standards:

- IEEE-488-1987.1
- IEEE-488-1987.2

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

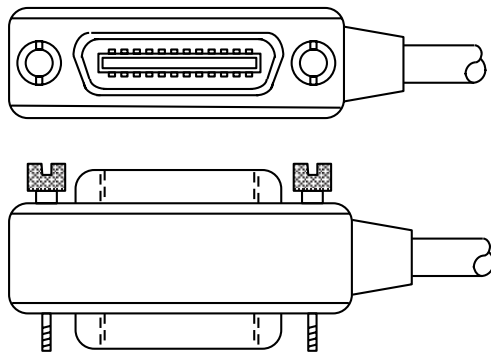
- SCPI 1991 (Standard Commands for Programmable Instruments)

This standard defines a command language protocol. It goes one step farther than IEEE-488-1987.2 and defines a standard set of commands to control every programmable aspect of an instrument.

GPIB bus connections

To connect the Model 2182 to the GPIB bus, use a cable equipped with standard IEEE-488 connectors as shown in [Figure 11-1](#).

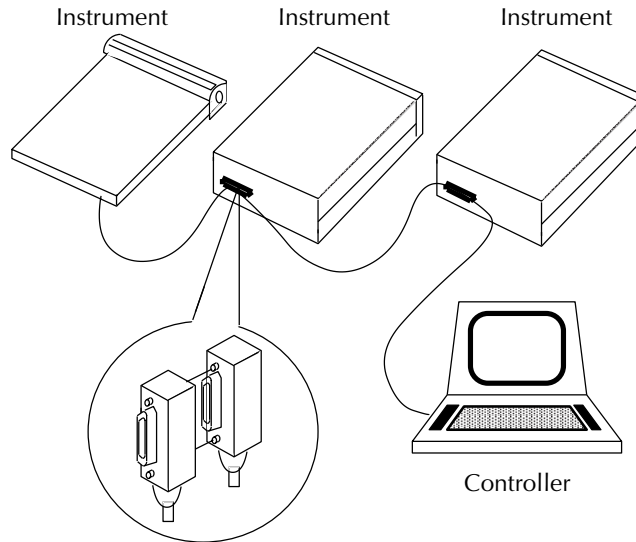
Figure 11-1
IEEE-488 connector



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 2182, because it is designed for metric threads.

[Figure 11-2](#) shows a typical connecting scheme for a multi-unit test system.

Figure 11-2
IEEE-488 connections



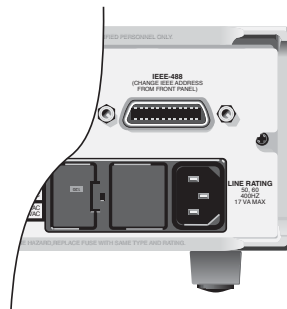
To avoid possible mechanical damage, stack no more than three connectors on any one unit.

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

To connect the Model 2182 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 11-3](#) shows the location of the IEEE-488 connector.

Figure 11-3
IEEE-488 connector location



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

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

Primary address selection

The Model 2182 ships from the factory with a GPIB address of 07. When the instrument powers up, it momentarily displays the primary address. You can set the address to a value of 0-30. Do not assign the same address to another device or to a controller that is on the same GPIB bus.

Usually controller addresses are 0 or 21, but see the controllers instruction manual for details. Make sure the address of the controller is the same as that specified in the controllers' programming language.

The primary address is checked or changed from the GPIB menu, which is accessed by pressing SHIFT and then GPIB. Press the ▲ or ▼ key to display the present address (i.e. ADDR: 07).

To change the GPIB address:

1. Press SHIFT and then GPIB to access the GPIB configuration menu.
2. Use the ▲ or ▼ key to display the present address (i.e. ADDR: 07).
3. Use the ◀, ▶, ▲, and ▼ keys to display a valid address value, and press ENTER.
4. Return to the main display by pressing EXIT.

QuickBASIC programming

Programming examples used throughout this manual presume Microsoft QuickBASIC version 4.5 (or higher) and a Keithley KPC-488.2 or Capital Equipment Corporation IEEE interface with CEC driver 2.11 or higher. The Model 2182 must be set to address 07 for the IEEE-488 bus.

About program fragments

Program fragments are used to demonstrate proper programming syntax. Only a fragment of the whole program is used to avoid redundancy.

At the beginning of each program, you will have to edit the following line to include the QuickBASIC libraries on your computer:

```
$INCLUDE: 'c:\qb45\ieeeqb.bi'
```

Then initialize the interface card as address 21:

```
CALL INITIALIZE (21, 0)
```

Initialize also sends out an interface clear (IFC) to the entire GPIB system to initialize the other devices (see “[General bus commands, IFC \(interface clear\)](#)”).

A typical program fragment includes a CALL SEND command and a CALL ENTER command. The CALL SEND command sends a program message (command string) to the Model 2182. If the program message includes a query command, then the CALL ENTER command is required to get the response message from the Model 2182. The CALL ENTER command addresses the Model 2182 to talk. The following example program fragment demonstrates how CALL SEND and CALL ENTER commands are used. Note that the commands assume address 07, which is the factory-set address of the Model 2182.

```
CALL SEND (7, "*rst", status%)
CALL SEND (7, ":read?", status%)
```

To display the response message on the CRT, the computer has to read the message and then “print” it to the computer display as follows:

```
reading$ = SPACE$(80)
CALL ENTER (reading?, length%, 7, status%)
PRINT reading$
```

The following programming example shows how all the above statements are used together:

```
$INCLUDE: 'c:\qb45\ieeeqb.bi      ' Include QuickBASIC libraries.
CALL INITIALIZE (21, 0)           ' Initialize card as address 21.
CALL SEND (7, "*rst", status%)   ' Restore 2182 to *RST defaults.
CALL SEND (7, ":read?", status%) ' Trigger and request a reading.
reading$ = SPACE$(80)           ' Allocate room for data.
CALL ENTER (reading?, length%, 7, status%) ' Address 2182 to talk.
PRINT reading$                  ' Display reading on CRT.
```

General bus commands

Commands and associated statements

General commands are those commands, such as DCL, that have the same general meaning regardless of the instrument. [Table 11-1](#) lists the general bus commands along with the programming statement for each command.

Table 11-1

General bus commands and associated statements

Command	Programming Statement	Effect On Model 2182
REN	REN	Goes into remote when next addressed to listen.
IFC	CALL INITIALIZE	Reset interface; all devices go into talker and listener idle states.
LLO	LLO	LOCAL key locked out.
GTL	GTL	Cancel remote; restore front panel operation for the 2182.
DCL	DCL	Return all devices to known conditions.
SDC	SDC	Returns Model 2182 to known conditions.
GET	GET	Initiates a trigger.
SPE, SPD	SPOLL	Serial Polls the Model 2182.

Transmit — A transmit routine is used to send General Bus Commands. It contains a series of GPIB commands to be carried out. In addition to the commands listed in [Table 11-1](#), there are other commands used in the transmit command string. Some of the more frequently used ones are explained as follows (refer to the User's Manual for the interface card for details on all the commands):

UNL	Unlisten — Disables any listeners that may exist.
UNT	Untalk — Disables the current talker, if any
LISTEN 7	Listen — Assigns the device at address 7 (2182) to be a listener
MTA	My Talk Address — Assigns the computer as the talker

The General Bus Commands are explained as follows:

REN (remote enable)

The remote enable command is sent to the Model 2182 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.

Program Fragment

```
CALL TRANSMIT ("MTA LISTEN 7 REN", status%) ' Place Model 2182 in remote;  
                                             ' turn on REM annunciator.
```

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 initialize routine (CALL INITIALIZE) uses this command internally.

The Model 2182 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.

Program Fragment

```
CALL INITIALIZE (21, 0) ' Initialize GPIB system (sends IFC) and set  
                       ' interface card address to 21.
```

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.

Program Fragment

```
CALL TRANSMIT ("UNL LISTEN 7 LLO", status%) ' Lock out front panel.
CALL TRANSMIT ("UNL LISTEN 7 GTL", status%) ' Lock out 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.

Program Fragment

```
CALL TRANSMIT ("MTA LISTEN 7 REN", status%) ' Place 2182 in remote.
CALL TRANSMIT ("UNL LISTEN 7 GTL", status%) ' Place 2182 in local mode
```

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 2182 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.

Program fragment

```
CALL TRANSMIT ("DCL", status%) ' Clears all devices.
```

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.

Program fragment

```
CALL TRANSMIT ("UNL LISTEN 7 SDC", status%) ' Clears 2182.
```

GET (group execute trigger)

GET is a GPIB trigger that is used as an event to control operation. The Model 2182 reacts to this trigger if it is the programmed control source. The control source is programmed from the SCPI TRIGger subsystem.

With the instrument programmed and waiting for a GPIB trigger, the following program fragment will provide the GET:

Program fragment

```
CALL TRANSMIT ("UNL LISTEN 7 GET", status%) ' Trigger 2182 from over
the bus.
```

When the command is executed, the trigger event for the 2182 occurs. Any other listeners ignore the trigger.

SPE, SPD (serial polling)

Use the serial polling sequence to obtain the Model 2182 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 2182.

Program Fragment

```
WaitSRQ:
  CALL S POLL (7, poll%, status%)           ' Serial poll the 2182.
  IF (poll% AND 64) = 0 THEN GOTO WaitSRQ   ' Loop back if no SRQ.
```

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 an UNT (Untalk) command, addressing it to listen, or sending the IFC (Interface Clear) command.
- LSTN – This indicator is on when the Model 2182 is in the listener active state, which is activated by addressing the instrument to listen with the correct MLA (My Listen Address) command. LSTN is off when the unit is in the listener idle state. Place the unit in the listener idle state by sending UNL (Unlisten), addressing it to talk, or sending the IFC (Interface Clear) command over the bus.
- SRQ – You can program the instrument to generate a service request (SRQ) when one or more errors or conditions occur. When this indicator is on, a service request has been generated. This indicator stays on until the serial poll byte is read or all the conditions that caused SRQ have ceased to exist.

LOCAL key

The LOCAL key cancels the remote state and restores local operation of the instrument. Pressing the LOCAL key also turns off the REM indicator and returns the display to normal if a user-defined message was displayed.

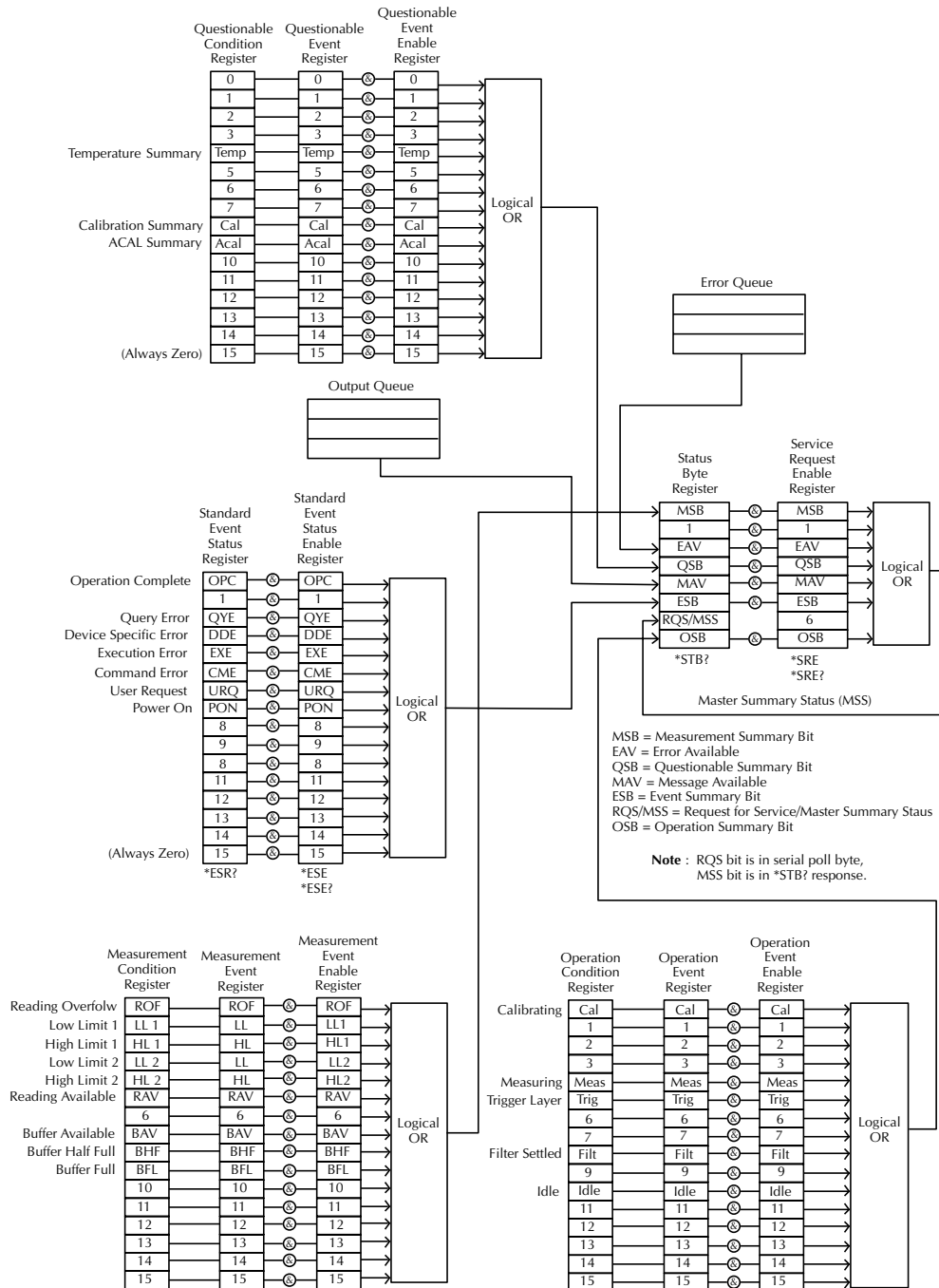
If the LLO (Local Lockout) command is in effect, the LOCAL key is also inoperative.

Status structure

See [Figure 11-4](#) for the Model 2182's status structure. Instrument events, such as errors, are monitored and manipulated by four status register sets. Notice that these status register sets feed directly into the Status Byte Register. More detailed illustrations of these register sets are provided in [Figure 11-5](#) through [Figure 11-9](#).

*NOTE The status structures registers are configured and controlled by STATus Subsystem commands (see [Section 15](#)) and Common Commands (see *ESE, *ESR?, *SRE and *STB in [Section 12](#)).*

Figure 11-4
Model 2182 status model structure



Condition registers

As [Figure 11-4](#) shows, some register sets have 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 a measurement is being performed, bit B4 (Meas) of the Operation Condition Register is set. When the measurement is completed, bit B4 clears.

Use the :CONDition? query commands in the STATus Subsystem to read the condition registers. See [Section 14](#) for more information.

Event registers

As [Figure 11-4](#) shows, each status register set has an event register. An event register is a latched, read-only register whose bits are set by the corresponding condition register. Once a bit in an event register is set, it remains set (latched) until the register is cleared by a specific clearing operation. The bits of an event register are logically ANDed with the bits of the corresponding enable register and applied to an OR gate. The output of the OR gate is applied to the Status Byte Register.

Use the *ESR? Common Command to read the Standard Event Register. All other event registers are read using the EVENT? query commands in the STATus Subsystem. See [Section 14](#) for more information.

An event register is cleared when it is read. The following operations clear all event registers:

- Cycling power
- Sending *CLS

Enable registers

As [Figure 11-4](#) shows, each status register set has an enable register. An enable register is programmed by you and serves as a mask for the corresponding event register. An event bit is masked when the corresponding bit in the enable register is cleared (0). When masked, a set bit in an event register cannot set a bit in the Status Byte Register ($1 \text{ AND } 0 = 0$).

To use the Status Byte Register to detect events (i.e., serial poll), you must unmask the events by setting (1) the appropriate bits of the enable registers.

To program and query the Standard Event Status Register, use the *ESE and *ESE? Common Commands respectively. All other enable registers are programmed and queried using the :ENABLE and :ENABLE? commands in the STATus Subsystem. See [Section 14](#) for more information.

An enable register is not cleared when it is read. The following operations affect the enable registers:

- Cycling power — Clears all enable registers
- :STATus:PRESet clears the following enable registers:
 - Operation Event Enable Register
 - Questionable Event Enable Register
 - Measurement Event Enable Register
- *ESE 0 — Clears the Standard Event Status Enable Register

Figure 11-5
Standard event status

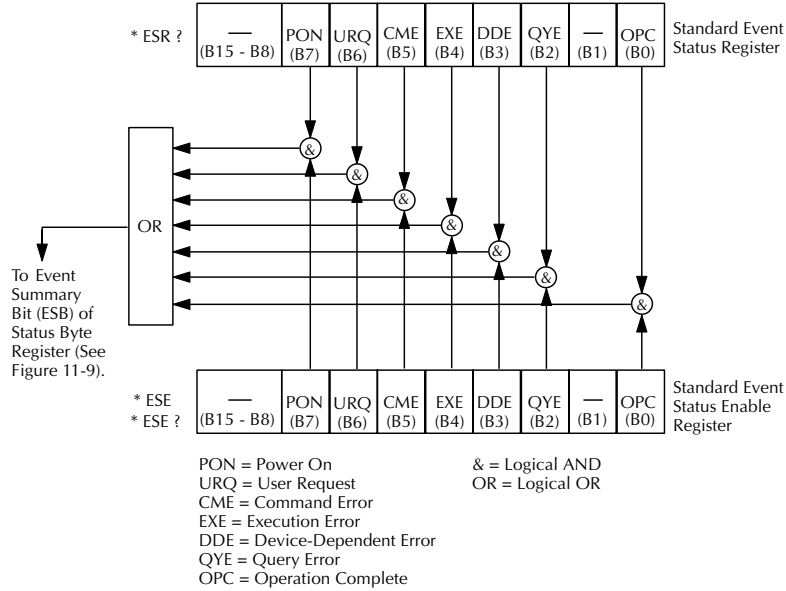


Figure 11-6
Operation event status

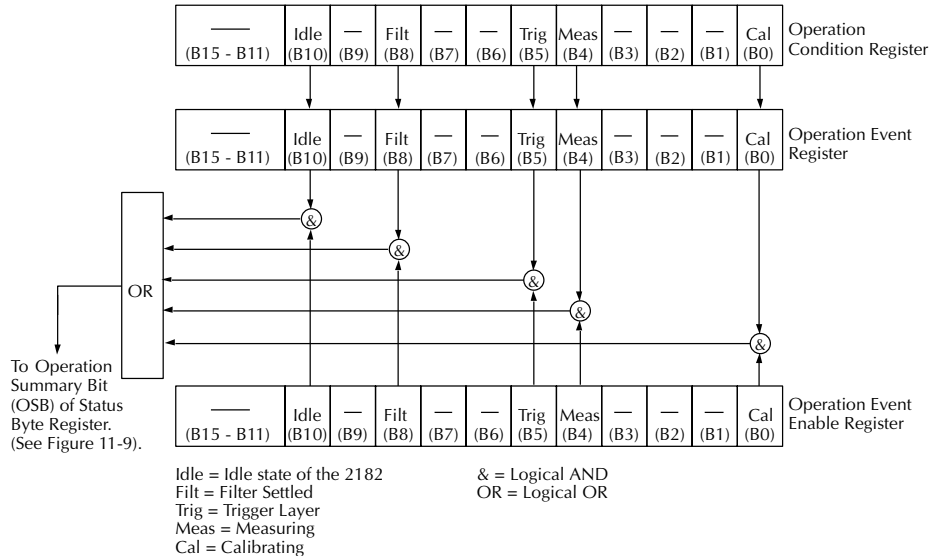


Figure 11-7
Measurement event status

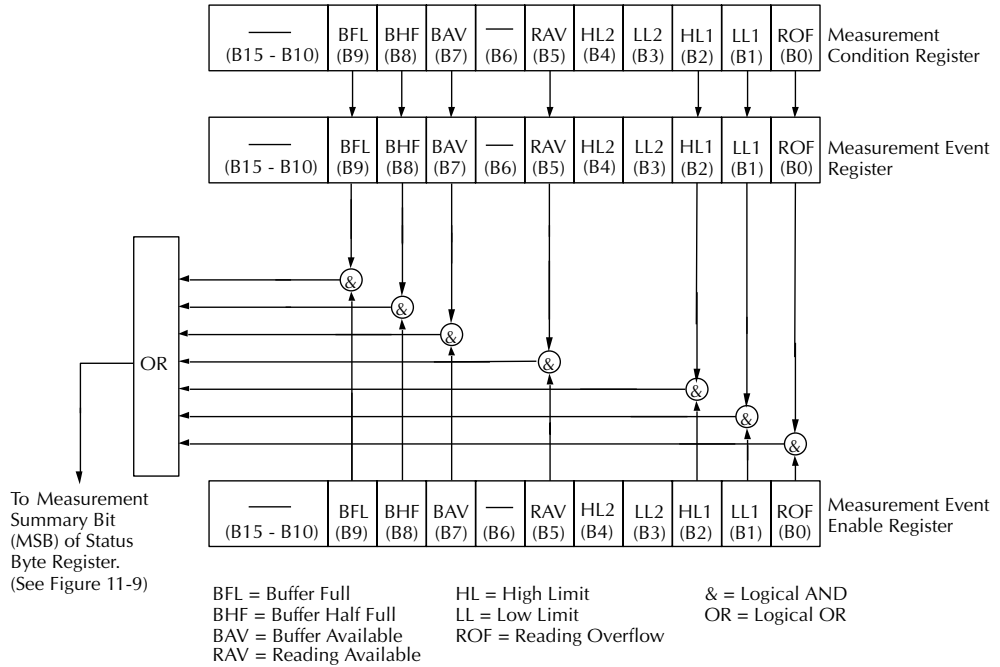
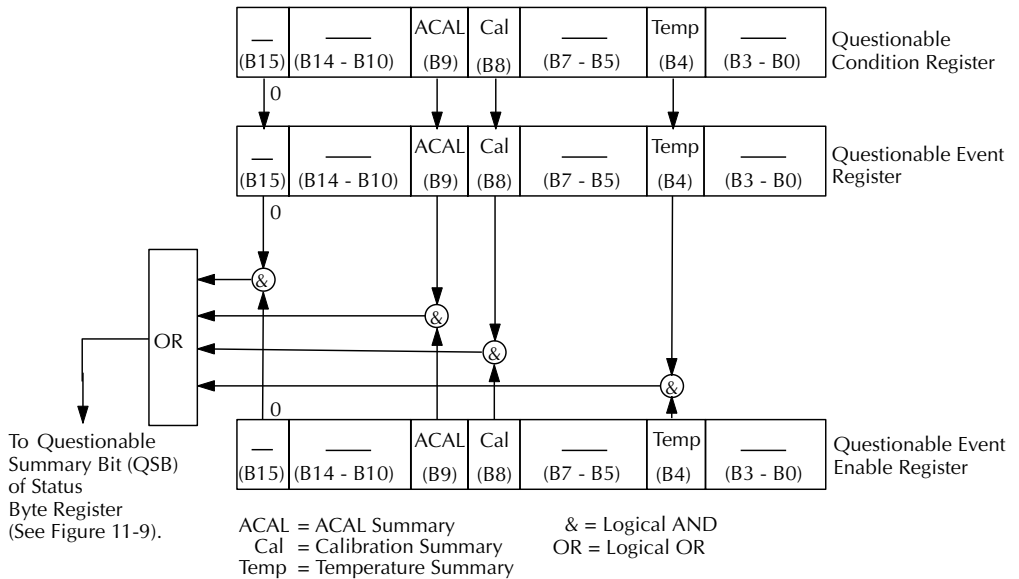


Figure 11-8
Questionable event status



Queues

The Model 2182 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 2182 status model (Figure 11-4) 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.

Read a message from the Output Queue by addressing the Model 2182 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. This queue will hold up to 10 messages.

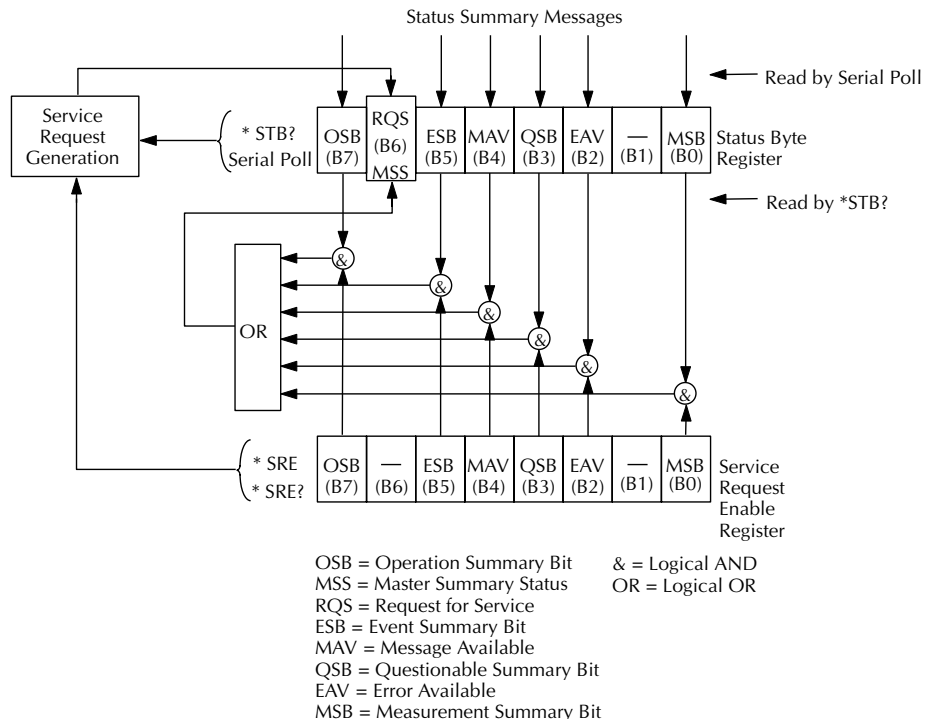
When a message is placed in the Error Queue, the Error Available (EAV) bit in the Status Byte Register is set. An error message is cleared from the Error/Status Queue when it is read. The Error Queue is considered cleared when it is empty. An empty Error Queue clears the EAV bit in the Status Byte Register. Read an error message from the Error Queue by sending either of the following SCPI query commands and then addressing the Model 2182 to talk:

- :SYSTem:ERRor?
- :STATus:QUEue?

Status byte and service request (SRQ)

Service request is controlled by two 8-bit registers: the Status Byte Register and the Service Request Enable Register. Figure 11-9 shows the structure of these registers.

Figure 11-9
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 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 Status Register is read, its register will clear. As a result, its summary message will reset to 0, which in turn will clear the ESB bit in the Status Byte Register.

Bit B6 in the Status Byte Register is one of the following:

- The Master Summary Status (MSS) bit, sent in response to the *STB? command, indicates the status of any set bits with corresponding enable bits set.
- The Request for Service (RQS) bit, sent in response to a serial poll, indicates which device was requesting service by polling on the SRQ line.

For a description of the other bits in the Status Byte Register, see [Section 12, "Common Commands."](#)

The IEEE-488.2 standard uses the *STB? common query command to read the Status Byte Register.

When reading the Status Byte Register using the *STB? command, bit B6 is called the MSS bit. None of the bits in the Status Byte Register are cleared when using the *STB? command to read it.

The IEEE-488.1 standard has a serial poll sequence that also reads the Status Byte Register and is better suited to detect a service request (SRQ). When using the serial poll, bit B6 is called the RQS bit. Serial polling causes bit B6 (RQS) to reset. Serial polling is discussed in more detail later in this section.

Any of the following operations clear all bits of the Status Byte Register:

- Cycling power.
- Sending the *CLS common command

NOTE *The MAV bit may or may not be cleared.*

Service request enable register

This register is programmed by you and serves as a mask for the Status Summary Message bits (B0, B2, B3, B4, B5, and B7) of the Status Byte Register. When masked, a set summary bit in the Status Byte Register cannot set bit B6 (MSS/RQS) of the Status Byte Register. Conversely, when unmasked, a set summary bit in the Status Byte Register sets bit B6.

A Status Summary Message bit in the Status Byte Register is masked when the corresponding bit in the Service Request Enable Register is cleared (0). When the masked summary bit in the Status Byte Register sets, it is ANDed with the corresponding cleared bit in the Service Request Enable Register. The logic $\bar{0}1\bar{0}$ output of the AND gate is applied to the input of the OR gate and, thus, 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 <NRf> 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 (n) value of zero is sent with the *SRE command (*SRE 0).

Serial poll and SRQ

Any enabled event summary bit that goes from 0 to 1 will set RQS and generate a service request (SRQ). In your test program, you can periodically read the Status Byte Register to check if a service request (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, service requests (SRQs) are managed by the serial poll sequence of the Model 2182. 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.

A serial poll clears RQS but does not clear MSS. The MSS bit stays set until all Status Byte event summary bits are cleared.

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.
:INITiate:CONTinuous 	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.
 - :OUTPut:RELative ON Enable Analog Output Rel
 - <name> Name Parameter – Select a parameter name from a listed group.
 - = 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
 - <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.
 - :TRIGger:TIMer 0.1 Sets timer to 100 msec.
 - :TRIGger:TIMer DEFault Sets timer to 0.1 sec.
 - :TRIGger:TIMer MINimum Sets timer to 1 msec.
 - :TRIGger:TIMer MAXimum Sets timer to 999999.999 sec.
 - <list> List – Specifies one or more switching channels.
 - :ROUte:SCAN (@1:10) Specify external scan list (1-10)
- Angle Brackets <> – Used to denote a parameter type. Do not include the brackets in the program message.
 - :SENSe:HOLD:STATe

The indicates that a Boolean type parameter is required. Thus, to enable the Hold feature, you must send the command with the ON or 1 parameter as follows.

 - :SENSe:HOLD:STATe 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.

:TRIGger:TIMer? Queries the timer interval

Most commands that require a numeric parameter(<n>) can also use the DEFault, MINimum, and MAXimum parameters for the query form. These query forms are used to determine the *RST default value and the upper and lower limits for the fundamental command.

:TRIGger:TIMer? DEFault	Queries the *RST default value
:TRIGger:TIMer? MINimum	Queries the lowest allowable value
:TRIGger:TIMer? MAXimum	Queries the largest allowable value

Case sensitivity

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

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

Long-form and short-form versions

A SCPI command word can be sent in its long-form or short-form version. The command subsystem tables in [Section 14](#) are in the long-form version. However, the short-form version is indicated by upper case characters.

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

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

Short-form rules

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

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

:auto = :auto

These rules apply to command words that exceed four letters:

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

immediate = :imm

- Rule exception – The short form version of the following command uses only the first two letters of the word:

:TCouple = :tc

- 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 (*). SCPI commands are categorized in the :STATus subsystem and 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 back 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:

```
:rout:scan (@1:5) <PMT>
```

Command execution rules

- Commands execute in the order that they are presented in the program message.
- An invalid command generates an error and, of course, is not executed.
- Valid commands that precede an invalid command in a multiple command program message are executed.
- Valid commands that follow an invalid command in a multiple command program message are ignored.

Response messages

A response message is the message sent by the instrument to the computer in response to a query command program message.

Sending a response message

After sending a query command, the response message is placed in the Output Queue. When the Model 2182 is addressed to talk, the response message is sent from the Output Queue to the computer.

Multiple response messages

If you send more than one query command in the same program message (see “[Multiple command messages](#)”), the multiple response messages for all the queries is sent to the computer when the Model 2182 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 2182 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 2182 to talk.

Rule 2. The complete response message must be received by the computer before another program message can be sent to the Model 2182.

RS-232 interface reference

Sending and receiving data

The RS-232 interface transfers data using eight data bits, one stop bit, and no parity. Make sure the controller you connect to the Model 2182 also uses these settings.

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

Baud rate, flow control and terminator

NOTE *The procedure to select and configure the RS-232 interface is provided in “[Selecting and configuring an interface](#)” located at the beginning of this section.*

Baud rate

The baud rate is the rate at which the Model 2182 and the programming terminal communicate. Choose one of the following available rates:

- 19.2k
- 9600
- 4800
- 2400
- 1200
- 600
- 300

The factory selected baud rate is 9600.

Make sure that the programming terminal that you are connecting to the Model 2182 can support the baud rate you selected. Both the Model 2182 and the other device must be configured for the same baud rate. To select a baud rate, follow these steps:

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 2182 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 2182 becomes more than 3/4 full, the instrument issues an X_OFF command. The control program should respond to this and stop sending characters until the Model 2182 issues the X_ON, which it will do once its input buffer has dropped below half-full. The Model 2182 recognizes X_ON and X_OFF sent from the controller. An X_OFF will cause the Model 2182 to stop outputting characters until it sees an X_ON. Incoming commands are processed after the <CR> character is received from the controller.

*NOTE For RS-232 operation, *OPC or *OPC? should be used with slow responding commands. A list of the slowest responding commands and details on *OPC and *OPC? are provided in [Section 12](#).*

If NONE is the selected flow control, then there will be no signal handshaking between the controller and the Model 2182. Data will be lost if transmitted before the receiving device is ready.

Terminator

The Model 2182 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
- LF CR line feed, carriage return
- CR LF carriage return, line feed

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 11-10](#) shows the rear panel connector for the RS-232 interface, and [Table 11-2](#) shows the pinout for the connector.

If your computer uses a DB-25 connector for the RS-232 interface, you will need a cable or adapter with a DB-25 connector on one end and a DB-9 connector on the other, wired straight through (not null modem). [Table 11-3](#) provides pinout identification for the 9-pin (DB-9) or 25-pin (DB-25) serial port connector on the computer (PC).

Figure 11-10
RS-232 interface connector

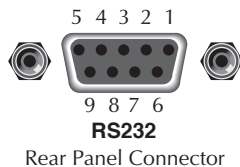


Table 11-2
RS-232 connector pinout

Pin Number	Description
1	No connection
2	TXD, transmit data
3	RXD, receive data
4	No connection
5	GND, signal ground
6	No connection
7	RTS, ready to send*
8	CTS, clear to send*
9	No connections

* RTS and CTS are not used.

Table 11-3
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.

12 Common Commands

Common commands (summarized in Table 12-1) are device commands that are common to all devices on the bus. These commands are designated and defined by the IEEE-488.2 standard.

Table 12-1
IEEE-488.2 common commands and queries

Mnemonic	Name	Description
*CLS	Clear status	Clears all event registers and Error Queue.
*ESE <NRf>	Event enable command	Program the Standard Event Enable Register.
*ESE?	Event enable query	Read the Standard Event Enable Register.
*ESR?	Event status register query	Read the Standard Event Enable Register and clear it.
*IDN?	Identification query	Returns the manufacturer, model number, serial number, and firmware revision levels of the unit.
*OPC	Operation complete command	Set the Operation Complete bit in the Standard Event Status Register after all pending commands have been executed.
*OPC?	Operation complete query	Places an ASCII "1" into the output queue when all pending selected device operations have been completed.
*RCL <NRf>	Recall command	Returns the 2182 to the user-saved setup.
*RST	Reset command	Returns the 2182 to the *RST default conditions.
*SAV <NRf>	Save command	Saves the present setup as the user-saved setup.
*SRE <NRf>	Service request enable command	Programs the Service Request Enable Register.
*SRE?	Service request enable query	Reads the Service Request Enable Register.
*STB?	Status byte query	Reads the Status Byte Register.
*TRG	Trigger command	Sends a bus trigger to the 2182.
*TST?	Self-test query	Performs a checksum test on ROM and returns the result.
*WAI	Wait-to-continue command	Wait until all previous commands are executed.

CLS — Clear Status*Clear status registers and error queue****Description**

Use the *CLS command to clear (reset to 0) the bits of the following registers in the Model 2182:

- Standard Event Register
- Operation Event Register
- Error Queue
- Measurement Event Register
- Questionable Event Register

This command also forces the instrument into the operation complete command idle state and operation complete query idle state.

***ESE <NRf> – Event Enable**

Program the standard event enable register

***ESE? – Event Enable Query**

Read the standard event register

Parameters

<NRf>	=	0	Clear register
		1	Set OPC (B0)
		4	Set QYE (B2)
		8	Set DDE (B3)
		16	Set EXE (B4)
		32	Set CME (B5)
		64	Set URQ (B6)
		128	Set PON (B7)
		255	Set all bits

Description

Use the *ESE command to program the Standard Event Enable Register. This command is sent with the decimal equivalent of the binary value that determines the desired state (0 or 1) of the bits in the register. This register is cleared on power-up.

This register is used as a mask for the Standard Event Register. When a standard event is masked, the occurrence of that event will not set the Event Summary Bit (ESB) in the Status Byte Register. Conversely, when a standard event is unmasked (enabled), the occurrence of that event sets the ESB bit. For information on the Standard Event Register and descriptions of the standard event bits, see the following section.

A cleared bit (0) in the enabled register prevents (masks) the ESB bit in the Status Byte Register from setting when the corresponding standard event occurs. A set bit (1) in the enable register allows (enables) the ESB bit to set when the corresponding standard event occurs.

The Standard Event Enable Register is shown in [Figure 12-1](#) and includes the decimal weight of each bit. The sum of the decimal weights of the bits that you wish to be set is the parameter value that is sent with the *ESE command. For example, to set the CME and QYE bits of the Standard Event Enable Register, send the following command:

```
*ESE 36
```

Where:	CME (bit B5)	=	Decimal	32
	QYE (bit B2)	=	Decimal	<u>4</u>
	<NRf>	=		36

If a command error (CME) occurs, bit B5 of the Standard Event Status Register sets. If a query error (QYE) occurs, bit B2 of the Standard Event Status Register sets. Since both of these events are unmasked (enabled), the occurrence of any of them causes the ESB bit in the Status Byte Register to set.

Read the Standard Event Status Register using the *ESE? query command.

Figure 12-1
Standard event enable register

Bit Position	B7	B6	B5	B4	B3	B2	B1	B0
Event	PON	URQ	CME	EXE	DDE	QYE	—	OPC
Decimal Weighting	128 (2 ⁷)	64 (2 ⁶)	32 (2 ⁵)	16 (2 ⁴)	8 (2 ³)	4 (2 ²)	—	1 (2 ⁰)
Value	0/1	0/1	0/1	0/1	0/1	0/1	—	0/1

Note: Bits B8 through B15 are not shown since they are not used.

Value : 1 = Event Bit Set
0 = Event Bit Cleared

Events : PON = Power On
URQ = User Request
CME = Command Error
EXE = Execution Error
DDE = Device-Dependent Error
QYE = Query Error
OPC = Operation Complete

***ESR? – Event Status Register Query** Read register and clear it**Description**

Use this command to acquire the value (in decimal) of the Standard Event Register (see [Figure 12-2](#)). The binary equivalent of the returned decimal value determines which bits in the register are set. The register is cleared on power-up or when *CLS is sent.

A set bit in this register indicates that a particular event has occurred. For example, for an acquired decimal value of 48, the binary equivalent is 00110000. From this binary value, bits B4 and B5 of the Standard Event Status Register are set. These bits indicate that a device-dependent error and command error have occurred.

The bits of the Standard Event Status Register are described as follows:

- Bit B0, Operation Complete – A set bit indicates that all pending selected device operations are completed and the Model 2182 is ready to accept new commands. This bit only sets in response to the *OPC? query command.
- Bit B1 – Not used
- Bit B2, Query Error (QYE) – A set bit indicates that you attempted to read data from an empty Output Queue.
- Bit B3, Device-Dependent Error (DDE) – A set bit indicates that an instrument operation did not execute properly due to some internal condition.
- Bit B4, Execution Error (EXE) – A set bit indicates that the Model 2182 detected an error while trying to execute a command.
- Bit B5, Command Error (CME) – A set bit indicates that a command error has occurred.
- Command errors include:
 - IEEE-488.2 syntax error – Model 2182 received a message that does not follow the defined syntax of the IEEE-488.2 standard.
 - Semantic error – Model 2182 received a command that was misspelled or received an optional IEEE-488.2 command that is not implemented.
 - The instrument received a Group Execute Trigger (GET) inside a program message.

- Bit B6, User Request (URQ) – A set bit indicates that the LOCAL key on the Model 2182 front panel was pressed.
- Bit B7, Power ON (PON) – A set bit indicates that the Model 2182 has been turned off and turned back on since the last time this register has been read.

Figure 12-2
Standard event status register

Bit Position	B7	B6	B5	B4	B3	B2	B1	B0
Event	PON	URQ	CME	EXE	DDE	QYE	—	OPC
Decimal Weighting	128 (2 ⁷)	64 (2 ⁶)	32 (2 ⁵)	16 (2 ⁴)	8 (2 ³)	4 (2 ²)	—	1 (2 ⁰)
Value	0/1	0/1	0/1	0/1	0/1	0/1	—	0/1

Note: Bits B8 through B15 are not shown since they are not used.

Value : 1 = Event Bit Set
0 = Event Bit Cleared

Events : PON = Power On
URQ = User Request
CME = Command Error
EXE = Execution Error
DDE = Device-Dependent Error
QYE = Query Error
OPC = Operation Complete

***IDN? – Identification Query Read the identification code**

Description

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 2182, xxxxxxx, yyyy/zzzz

Where: xxxxxxx is the serial number.
yyyy/zzzz is the firmware revision levels of the digital board ROM and display board ROM.

*OPC – Operation Complete

Set the OPC bit in the standard event register after all pending commands are complete

Description

After the *OPC command is sent, the Operation Complete bit (bit B0) of the Standard Event Status Register will set immediately after the last pending command is completed. If the corresponding bit (bit B0) in the Standard Event Enable Register and Bit 5 (Event Summary Bit) of the Service Request Enable Register is set, the RQS/MSS (Request for Service/Master Summary Status) bit in the Status Byte Register will set.

When used with the immediate initiation command (:INITiate), the OPC bit in the Standard Event Status Register will not set until the Model 2182 goes back into the idle state. The :INIT command operation is not considered finished until the Model 2182 goes back into the idle state. See the description for *WAI for more information on command execution.

When used with the *TRG command, the OPC bit will not set until the operations associated with the *TRG command (and the initiate command) are finished. The *TRG command is considered to be finished when the Device Action completes or when operation stops a control source to wait for an event (see “[Trigger model](#),” in [Section 7](#)).

To use the *OPC exclusively with the *TRG command, first force the completion of the initiate command so that only the *TRG command is pending. Do this by sending the :ABORt command to place the instrument in idle, which (by definition) completes the initiate command. Since continuous initiation is on, operation continues into the Trigger Model. After sending the *TRG command, the OPC bit sets when the *TRG command is finished.

Program example

The first group of commands send the *OPC command after the :INITiate command and verifies that the OPC bit in the Standard Event Status Register does not set while the instrument continues to make measurements (not in idle). The second group of commands returns the Model 2182 to the idle state and verifies that the OPC bit did set.

```

SYST : PRES          ' Return 2182 to default setup.
INIT : CONT OFF      ' Disables continuous initiation.
ABORT                ' Aborts operation. Places 2182 in idle.
INIT : IMM           ' Initiate one trigger cycle.
*OPC                 ' Sends the OPC command
*ESR?                ' Reads the Standard Event Status Register.

```

After addressing the Model 2182 to talk, the returned value of 0 denotes that the bit (bit 0) is not set indicating that the :INITiate operation is not complete.

```

ABORT                ' Aborts operation. Places 2182 in idle.
*ESR?                ' Reads the Standard Event Status Register.

```

After addressing the Model 2182 to talk, the returned value of 1 denotes that the bit (bit 1) is set indicating that the :INITiate operation is now complete.

```

SYST : PRES          ' Returns 2182 to default setup.

```

NOTE *The following commands take a long time to process and may benefit from using *OPC or OPC?:*

**RST and SYST:PRES*

**RCL and *SAV*

CALC2:IMM and CALC2:IMM? – Only when performing the standard deviation calculation on a large buffer.

*RS-232 operation can also benefit from *OPC.*

***OPC? – Operation Complete Query** **Place a “1” in the output queue after all pending operations are completed**

Description

When this common command is sent, an ASCII “1” will be placed in the Output Queue after the last pending operation is completed. When the Model 2182 is then addressed to talk, the “1” in the Output Queue will be sent to the computer.

The “1” in the Output Queue will set the MAV (Message Available) bit (B4) of the Status Byte Register. If the corresponding bit (B4) in the Service Request Enable Register is set, the RQS/MSS (Request for Service/Master Summary Status) bit in the Status Byte Register will set.

When used with the Initiate Immediately command (:INITiate), a “1” will not be placed into the Output Queue until the Model 2182 goes back into the idle state. The :INIT command operation is not considered finished until the Model 2182 goes back into the idle state. See the description for *WAI for more information on command execution.

The execution of OPC? is not completed until it has placed the “1” in the Output Queue.

To use *OPC? exclusively with the *TRG command, first force the completion of the initiate command so that only the *TRG command is pending. To do this, send the :ABORT command to place the instrument in idle, which (by definition) completes the initiate command. Since continuous initiation is on, operation continues on into the Trigger Model. After sending the *TRG command, an ASCII “1” is placed in the Output Queue and the MAV bit sets when the *TRG command is finished.

After *OPC? is executed, additional commands cannot be sent to the Model 2182 until the pending overlapped commands are finished. For example, :INITiate:CONTinuous ON followed by *OPC? locks up the instrument and requires a device clear (DCL or SDC) before it will accept any more commands.

*NOTE See *OPC, *TRG, and *WAI for more information.*

Programming example – The following command sequence demonstrates how to use *OPC? to signal the end of a measurement process:

```

SYST : PRES           ' Returns 2182 to default setup.
INIT : CONT OFF       ' Disables continuous initiation.
ABORT                 ' Aborts operation. Places 2182 in idle.
TRIG : COUN 1         ' These two commands configure the 2182
SAMP : COUN 5         ' to perform five measurements.
INIT                 ' Starts measurement process.
*OPC?                 ' Sends the OPC? command

```

After all five measurements are performed and the instrument returns to idle state, an ASCII ‘1’ will be placed in the Output Queue. After addressing the Model 2182 to talk, the ‘1’ from the Output Queue is sent to the computer.

```

SYST : PRES           ' Returns 2182 to default setup.

```

NOTE *The following commands take a long time to process and may benefit from using *OPC or OPC?:*

**RST and SYST:PRES*

**RCL and *SAV*

CALC2:IMM and CALC2:IMM? – Only when performing the standard deviation calculation on a large buffer.

*RS-232 operation can also benefit from *OPC?.*

Comments:

1. Resets the Model 2182 to default operating conditions.
2. Disables continuous initiation and aborts operation. Places 2182 in the idle state.
3. Configures the Model 2182 to perform five measurements.
4. Performs an immediate initiation (:INITiate) to restart the measurement process and sends the *OPC? command.

After all five measurements are performed and the instrument has returned to the idle state, an ASCII '1' will be placed in the Output Queue.

5. Addresses the Model 2182 to talk. This sends the '1' from the Output Queue to the computer.
6. Displays the '1' on the monitor.
7. Resets the Model 2182 to default operating conditions.

***RCL – Recall**

Return to setup stored in memory

Parameters

<NRf>=0

Description

Use this command to return the Model 2182 to the configuration stored in memory. The *SAV command is used to store the setup configuration in memory location.

Only one setup configuration can be saved and recalled.

The Model 2182 ships from the factory with :SYSTem:PRESet defaults loaded into the available setup memory. If a recall error occurs, the setup memory defaults to the :SYSTem:PRESet values.

NOTE: *For RS-232 operation (and in some cases, GPIB operation), *OPC or *OPC? should be used with *RCL, which is a slow responding command. Details on *OPC and *OPC? are provided in [Section 12](#).*

RST – Reset*Return 2182 to *RST defaults****Description**

When the *RST command is sent, the Model 2182 performs the following operations:

1. Returns the Model 2182 to the *RST default conditions (see SCPI tables).
2. Cancels all pending commands.
3. Cancels response to any previously received *OPC and *OPC? commands.

*NOTE: For RS-232 operation (and in some cases, GPIB operation), *OPC or *OPC? should be used with *RST, which is a slow responding command. Details on *OPC and *OPC? are provided in [Section 12](#).*

SAV – Save*Save present setup in memory****Parameters**

<NRf>=0

Description

Use the *SAVE 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.

Only one setup configuration can be saved and recalled.

*NOTE: For RS-232 operation (and in some cases, GPIB operation), *OPC or *OPC? should be used with *SAV, which is a slow responding command. Details on *OPC and *OPC? are provided in [Section 12](#).*

SRE <NRf> – Service Request Enable** Program service request enable registerSRE? – Service Request Enable Query** Read service request enable register**Parameters**

<NRf>	=	0	Clears enable register
		1	Set MSB bit (Bit 0)
		4	Set EAV bit (Bit 2)
		8	Set QSB bit (Bit 3)
		16	Set MAV bit (Bit 4)
		32	Set ESB (Bit 5)
		128	Set OSB (Bit 7)
		255	Set all bits

Description

Use the *SRE command to program the Service Request Enable Register. Send this command with the decimal equivalent of the binary value that determines the desired state (0 or 1) of each bit in the register. This register is cleared on power-up.

This enable register is used along with the Status Byte Register to generate service requests (SRQ). With a bit in the Service Request Enable Register set, an SRQ occurs when the corresponding bit in the Status Byte Register is set by an appropriate event. For more information on register structure, see the information presented earlier in this section.

The Service Request Enable Register is shown in [Figure 12-3](#). Notice that the decimal weight of each bit is included in the illustration. The sum of the decimal weights of the bits that you wish to set is the value that is sent with the *SRE command. For example, to set the ESB and MAV bits of the Service Request Enable Register, send the following command:

```
*SRE 48
```

```
Where:  ESB (bit B5) = Decimal  32
        MAV (bit B4) = Decimal  16
        <NRf>       =           48
```

The contents of the Service Request Enable Register can be read using the *SRE? query command.

Figure 12-3
Service request enable register

Bit Position	B7	B6	B5	B4	B3	B2	B1	B0
Event	OSB	—	ESB	MAV	QSB	EAV	—	MSB
Decimal Weighting	128 (2 ⁷)	—	32 (2 ⁵)	16 (2 ⁴)	8 (2 ³)	4 (2 ²)	—	1 (2 ⁰)
Value	0/1	—	0/1	0/1	0/1	0/1	—	0/1

Value: 1 = Enable Service
Request Event

0 = Disable (Mask)
Service Request Event

Events : OSB = Operation Summary Bit
ESB = Event Summary Bit
MAV = Message Available
QSB = Questionable Summary Bit
EAV = Error Available
MSB = Measurement Summary Bit

*STB? – Status Byte Query

Read status byte register

Description

Use the *STB? query command to acquire the value (in decimal) of the Status Byte Register. The Status Byte Register is shown in [Figure 12-4](#). The binary equivalent of the decimal value determines which bits in the register are set.

All bits, except Bit B6, in this register are set by other event registers and queues. Bit 6 sets when one or more enabled conditions occur.

The *STB? query command does not clear the status byte register. This register can only be cleared by clearing the related registers and queues.

For example, for an acquired decimal value of 48, the binary equivalent is 00110000. This binary value indicates that bits 4 and 5 of the Status Byte Register are set.

The bits of the Status Byte Register are described as follows:

- Bit 0, Measurement Status (MSB) – A set bit indicates that a measurement event has occurred. The event can be identified by reading the Measurement Event Status Register using the :STATus:MEASurement? command (see [Section 5](#) for details).
- Bit 1 – Not used.
- Bit 2, Error Available (EAV) – A set bit indicates that an error or status message is present in the Error Queue. The message can be read using one of the following SCPI commands:
 - :SYSTem:ERRor?
 - :STATus:QUEue?
- See [Section 15](#) for more information.
- Bit 3, Questionable Summary Bit (QSB) – A set bit indicates that a calibration error has occurred.
- Bit 4, Message Available (MAV) – A set bit indicates that a message is present in the Output Queue. The message is sent to the computer when the Model 2182 is addressed to talk.
- Bit 5, Event Summary Bit (ESB) – A set bit indicates that an enabled standard event has occurred. The event can be identified by reading the Standard Event Status Register using the *ESE? query command.
- Bit 6, Master Summary Status (MSS)/Request Service (RQS) – A set bit indicates that one or more enabled Status Byte conditions have occurred. Read the MSS bit by using the STB? query command, or perform a serial poll to detect the occurrence of a service request (RQS bit set).
- Bit 7, Operation Summary (OSB) – A set bit indicates that an enabled operation event has occurred. The event can be identified by reading the Operation Event Status Register using the :STATus:OPERation? query command (see [Section 15](#) for details).

Figure 12-4
Status byte register

Bit Position	B7	B6	B5	B4	B3	B2	B1	B0
Event	OSB	MSS, RQS	ESB	MAV	QSB	EAV	—	MSB
Decimal Weighting	128 (2 ⁷)	64 (2 ⁶)	32 (2 ⁵)	16 (2 ⁴)	8 (2 ³)	4 (2 ²)	—	1 (2 ⁰)
Value	0/1	0/1	0/1	0/1	0/1	0/1	—	0/1

Value : 1 = Event Bit Set
0 = Event Bit Cleared

Events : OSB = Operation Summary Bit
MSS = Master Summary Status
RQS = Request Service
ESB = Event Summary Bit
MAV = Message Available
QSB = Questionable Summary Bit
EAV = Error Available
MSB = Measurement Summary Bit

*TRG – Trigger

Send bus trigger to 2182

Description

Use the *TRG command to issue a GPIB trigger to the Model 2182. It has the same effect as a group execute trigger (GET).

Use the *TRG command as an event to control operation. The Model 2182 reacts to this trigger if BUS is the programmed control source. The control source is programmed from the TRIGger subsystem (see [Section 14](#)).

*TST?– Self-Test Query

Run self test and read result

Description

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 2182 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.

***WAI – Wait-to-Continue**

Prevent execution of commands until previous commands are completed

Description

Two types of device commands exist:

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

Use the *WAI command to suspend the execution of subsequent commands until the device operations of all previous Overlapped commands are finished. The *WAI command is not needed for Sequential commands.

The Model 2182 has three overlapped commands:

- :INITiate
- :INITiate:CONTinuous ON
- *TRG

NOTE See *OPC, *OPC?, and *TRG for more information.

The :INITiate commands remove the Model 2182 from the idle state. The device operations of :INITiate are not considered complete until the Model 2182 returns to idle. By sending the *WAI command after the :INITiate command, all subsequent commands will not execute until the Model 2182 goes back into idle.

The *TRG command issues a bus trigger that could be used to provide the arm, scan, and measure events for the Trigger Model. By sending the *WAI command after the *TRG command, subsequent commands will not be executed until the pointer for the Trigger Model has finished moving in response to *TRG and has settled at its next state.

Program fragment

```
CALL SEND (7, ":syst:pres", staus%)
CALL SEND (7, ":init:cont off; :abort", status%)      'Place 2182 in idle.
CALL SEND (7, ":trig:coun 1;sour tim, status%)
CALL SEND (7, ":samp:coun 30", status%)              'Program for 30
                                                    'measurements then stop
CALL SEND (7, ":init; *wai", status%)                'Start measurements and send
                                                    '*WAI
CALL SEND (7, ":data?", status%)                     'Query a reading.
reading$ = SPACE$(80)
CALL ENTER (reading$, length%, 7, status%)           'Get a response when 2182
                                                    'goes into idle.
PRINT reading$                                       'Display the reading.
```

13

SCPI Signal Oriented Measurement Commands

The signal oriented measurement commands are used to acquire readings. You can use these high level instructions to control the measurement process. These commands are summarized in [Table 13-1](#).

Table 13-1
Signal oriented measurement command summary

Command	Description
CONFigure:<function>	Places the Model 2182 in a “one-shot” measurement mode for the specified function.
:FETCh?	Requests the latest reading.
:READ?	Performs an :ABORt, :INITiate, and a :FETCh?.
MEASure[:<function>]?	Performs an :ABORt, :CONFigure:<function>, and a :READ?.

NOTE *Appendix H provides additional information on the measurement query commands. This appendix describes what each command does, its limitations, and appropriate situations for its use.*

:CONFigure:<function>

Parameters

<function> = VOLTage[:DC] Voltage
TEMPerature Temperature

Query

:CONFigure? Query the selected function.

Description

This command configures the instrument for subsequent measurements on the specified function. Note that the input channel does not change. For example, if TEMP2 (Channel 2) is presently selected, sending CONFigure:VOLT selects DCV2 (Channel 2).

This command places the instrument in a “one-shot” measurement mode. You can then use the :READ? command to trigger a measurement and acquire a reading (see :READ?).

When this command is sent, the Model 2182 will be configured as follows:

- The function specified by this command is selected. Input channel remains the same.
- All controls related to the selected function are defaulted to the *RST values.
- Continuous initiation is disabled (:INITiate:CONTinuous OFF).
- The control source of the Trigger Model is set to Immediate.
- The count values of the Trigger Model are set to one.
- The delay of the Trigger Model is set to zero.
- The Model 2182 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 set to the *RST default value.
- All operations associated with stepping or scanning are disabled.

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

Program fragment

```
CALL SEND (7, ":conf:volt", status%)      ' Perform CONFigure operations.
CALL SEND (7, ":trig:del 0.5", status%)   ' Set delay for 0.5sec.
CALL SEND (7, ":samp:coun 10", status%)   ' Set sample count to 10.
CALL SEND (7, ":read?", status%)          ' Trigger and request readings.
reading$ = SPACE$(80)
CALL ENTER(reading$, length%, 7, status%) ' Address 2182 to talk.
PRINT reading$                             ' Display the 10 readings on the
                                           ' CRT.
```

:FETCh?

Description

This command requests the latest post-processed reading. After sending this command and addressing the Model 2182 to talk, the reading is sent to the computer. This command does not affect the instrument setup.

This command does not trigger a measurement. The command simply requests the last available reading. Note that this command can repeatedly return the same reading. Until there is a new reading, this command continues to return the old reading. If your application requires a “fresh” reading, use the :DATA:FRESH? command (see the SENSE Subsystem command).

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

:READ?

Description

This command is typically used with the instrument in the “one-shot” measurement mode to trigger and acquire a specified number of readings. The :SAMPLE:COUNT command is used to specify the number of readings (see Trigger Subsystem). Note that the readings are stored in the buffer.

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

```
:ABORt
:INITiate
:FETCh?
```

When :ABORt is executed, the instrument goes into the idle state if continuous initiation is disabled. If continuous initiation is enabled, the operation re-starts at the beginning of the Trigger Model.

If the instrument is in the idle state, :INITiate takes the instrument out of the idle state. If continuous initiation is enabled, (:INITiate:CONTinuous ON), then the :INITiate command generates an error and ignores the command.

NOTE You cannot use the :READ? command if sample count >1 (see Trigger subsystem) and there are readings stored in the buffer (error -225, out of memory). Either set sample count to one or clear the buffer.

See [Appendix C](#) for an example program using the READ? command.

:MEASure:<function>?

Parameters

<function>	=	VOLTage[:DC]	Voltage
		TEMPerature	Temperature

Description

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.

```
:ABORt  
:CONFigure:<function>  
:READ?
```

When :ABORt is executed, the instrument goes into the idle state if continuous initiation is disabled. If continuous initiation is enabled, the operation re-starts at the beginning of the Trigger Model.

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

When :READ? is executed, its operations will then be performed. In general, another :ABORt is performed, then an :INITiate, and finally a :FETCh? to acquire the reading. See “:READ?” for more details.

14 SCPI Reference Tables

- [Table 14-1](#) — CALCulate command summary
- [Table 14-2](#) — CALibrate command summary
- [Table 14-3](#) — DISPlay command summary
- [Table 14-4](#) — FORMat command summary
- [Table 14-5](#) — OUTPut command summary
- [Table 14-6](#) — ROUTe command summary
- [Table 14-7](#) — SENSE command summary
- [Table 14-8](#) — STATus command summary
- [Table 14-9](#) — SYSTem command summary
- [Table 14-10](#) — TRACe command summary
- [Table 14-11](#) — Trigger command summary
- [Table 14-12](#) — UNIT command summary

General notes

- Brackets ([]) are used to denote optional character sets. These optional characters do not have to be included in the program message. Do not use brackets in the program message.
- Angle brackets (< >) are used to indicate parameter type. Do not use angle brackets in the program message.
- The Boolean parameter () is used to enable or disable an instrument operation. 1 or ON enables the operation, and 0 or OFF disables the operation.
- Upper case characters indicate the short-form version for each command word.
- Default Parameter — Listed parameters are both the *RST and SYSTem:PRESet defaults, unless noted otherwise. Parameter notes are located at the end of each table.
- Ref — 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	SCPI
:CALCulate[1]	Path to configure and control KMATH calculations.		Sec 4	√
:FORMat <name>	Select math format; NONE, MXB or PERCent.	NONE		√
:FORMat?	Query math format.			√
:KMATH	Configure math calculations:			
:MMFactor <NRf>	Set “m” for mX+b calculation; -100e6 to 100e6.	1		
:MMFactor?	Query “m” factor.			
:MBFactor <NRf>	Set “b” for mX+b calculation; -100e6 to 100e6.	0		
:MBFactor?	Query “b” factor.			
:MUNits <name>	Specify units for mX+b result, up to 2 characters; ‘A’ through ‘Z’, ‘\` = degrees (°) symbol, ‘[’ = ohms (Ω) symbol.	MX		
:MUNits?	Query units.			
:PERCent <NRf>	Set target value for PERcent math calculation.	1		
:ACQuire	Use input signal as target value.			
:PERCent?	Query target value for PERcent math calculation.			
:STATe 	Enable or disable KMATH calculation.	OFF		
:STATe?	Query state of KMATH calculation.			√
:DATA	Path to acquire calculation result:			√
[:LATest]?	Return last calculation result.			√
:FRESH?	Trigger a reading and return the calculation result.			√
:CALCulate2	Path to configure and control math calculations on buffer data:		Sec 6	√
:FORMat <name>	Select math calculation; MEAN, SDEVIation, MAXimum, MINimum or NONE.	NONE		√
:FORMat?	Query math calculation.			√
:STATe 	Enable or disable math calculation.	OFF		√
:STATe?	Query state of math calculation.			√
:DATA?	Read result of Calc2.			√
:IMMediate	Recalculate using raw input data in buffer.			√
:IMMediate?	Recalculate and return result of Calc2.			√
:CALCulate3	Path to configure and control limit testing:		Sec 8	√
:LIMit[1]	Limit 1 Testing:			√
:UPPer	Configure upper limit:			√
[:DATA] <n>	Specify limit; -100e6 to 100e6.	1		√
[:DATA]?	Query upper limit.			√
:LOWer	Configure lower limit:			√
[:DATA] <n>	Specify limit; -100e6 to 100e6.	-1		√
[:DATA]?	Query lower limit.			√
: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).			√
:CLEar	Clear test results:			√

Table 14-1*CALCulate command summary (cont.)*

Command	Description	Default Parameter	Ref	SCPI
:IMMEDIATE]	Clear limit test results.			√
:AUTO 	Enable or disable clearing of limit test results when a new trigger model cycle starts.	ON		√
:AUTO?	Query state of auto clear.			√
:LIMit2	Limit 2 Testing:			√
:UPPer	Configure upper limit:			√
[:DATA] <n>	Specify limit; -100e6 to 100e6.	2		√
[:DATA]?	Query upper limit.			√
:LOWer	Configure lower limit:			√
[:DATA] <n>	Specify limit; -100e6 to 100e6.	-2		√
[:DATA]?	Query lower limit.			√
: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).			√
:CLEar	Clear test results:			√
[:IMMEDIATE]	Clear limit test results.			√
:AUTO 	Enable or disable clearing of limit test results when a new trigger model cycle starts.	ON		√
:AUTO?	Query state of auto clear.			√
:IMMEDIATE	Recalculate limit tests.			√

Table 14-2*CALibration command summary (user accessible)*

Command	Description	Default Parameter	Ref	SCPI
:CALibration	See Note.			
:UNPRotected	Calibration accessible to operator:			
:ACALibration	ACAL procedure:		Sec 2	
:INITiate	Prepares 2182 for ACAL.			
:STEP1	Performs a full ACAL (100V and 10mV).			
:STEP2	Performs a limited ACAL (10mV only).			
:DONE	Exit ACAL mode.			
:TEMPerature?	Queries the internal temperature at the time of last ACAL. If present internal temperature differs from the last ACAL temperature by more than 1°C, perform another ACAL.			

Note: The above table only provides the commands to perform ACAL, which is a procedure to be performed by the operator. The formal calibration is to be performed by qualified service personnel and is provided in the Model 2182 Service Manual.

Table 14-3*DISPlay command summary*

Command	Description	Default Parameter	Ref	SCPI
:DISPlay			Sec 15	
:ENABLE 	Turn front panel display on or off.	(Note 1)		√
:ENABLE?	Query display state.			√
[:WINDow[1]]	Path to control user test 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:

- *RST and SYSTem:PRESet have no effect on the display circuitry. Pressing LOCAL or cycling power enables (ON) the display circuit.
- *RST and SYSTem:PRESet have no effect on a user-defined message. Pressing LOCAL or cycling power cancels all user-defined messages.
- *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 14-4*FORMat command summary*

Command	Description	Default Parameter	Ref	SCPI
:FORMat			Sec 15	
[:DATA] <type>[,<length>]	Specify data format; ASCii, SREal or DREal.	ASCii		√
[:DATA]?	Query data format.			√
:BORDER <name>	Specify byte order; NORMal or SWAPped.	SWAPped		√
:BORDER?	Query byte order.			√
:ELEMENTs <name>	Specify data elements; READING, CHANNEL and UNITS.	READING		√
:ELEMENTs?	Query data format elements.			√

Table 14-5*OUTPut command summary*

Command	Description	Default Parameter	Ref	SCPI
:OUTPut			Sec 10	
:GAIN <NRf>	Set analog output gain (M); -100e6 to 100e6	1		
:GAIN?	Query analog output gain.			
:OFFSet <NRf>	Set analog output offset (B); -1.2 to 1.2.	0		
:OFFSet?	Query analog output offset.			
[:STATe] 	Enable or disable analog output (OFF forces 0V).	ON		
[:STATe]?	Query state of analog output.			
:RELative 	ON uses the present analog output voltage as the Rel value. OFF disables analog output Rel.	OFF		
:RELative?	Query state of Rel.			

Table 14-6*ROUTe command summary*

Command	Description	Default Parameter	Ref	SCPI
:ROUTe			Sec 9	
:SCAN	Path to configure and control scanning:			√
:INTernal	Internal scanning:			
:CCOunt <n>	Specify number of readings on Channel 1; 1 to 1023.			
:CCOunt?	Query Channel 1 count.			
[:EXTernal] <list>	Specify external scan list.	(@1:10)		
:LSElect <name>	Select and enable scan operation; INTernal, EXTernal or NONE.			
:LSElect?	Query selected scan operation.			

Table 14-7

SENSe command summary

Command	Description	Default Parameter	Ref	SCPI
:SENSe[1]				
:FUNction <name>	Select function; 'VOLTage[:DC]' or 'TEMPerature'.	'VOLT'	Sec 2	√
:FUNction?	Query measurement function.			√
:DATA	Path to return instrument readings:		Sec 2	√
[:LATest]?	Return the last instrument reading.			√
:FRESH?	Return a new (fresh) reading.			√
:CHANnel <n>	Select channel to measure; 0, 1 or 2 (0 = internal temperature sensor).	1	Sec 2	
:CHANnel?	Query selected channel.			
:HOLD	Path to configure and control Hold:		Sec 7	
:WINDow <n>	Set Hold window; 0.01 to 20 (%).	1		
:WINDow?	Query Hold window.			
:COUNt <n>	Set Hold count; 2 to 100.	5		
:COUNt?	Query Hold count.			
:STATe 	Enable or disable Hold.	OFF		
:STATe?	Query state of Hold.			
:VOLTage[:DC]	Path to configure DC volts:			√
:NPLCycles <n>	Set integration rate in line cycles (PLC); 0.01 to 60 (60Hz) or 0.01 to 50 (50Hz).	5	Sec 3	√
:NPLCycles?	Query NPLC.			√
:APERture <n>	Set integration rate in seconds; 166.67e-6 to 1 (60Hz) or 200e-6 to 1 (50Hz).	83.33		
:APERture?	Query Aperture.			
:DIGits <n>	Set display resolution; 4 to 8.	8	Sec 3	
:DIGits?	Query display resolution.			
:RATio 	Enable or disable Ratio; V1/V2.	OFF	Sec 5	
:RATio?	Query state of Ratio.			
:DELTA 	Enable or disable Delta; (V1t1 - V1t2)/2.	OFF	Sec 5	
:DELTA?	Query state of Delta.			
[:CHANnel1]	Channel 1 voltage commands:			
:RANGe	Configure measurement range:		Sec 3	√
[:UPPer] <n>	Select range; 0 to 120 (volts).	120		√
[:UPPer]?	Query range value.			√
:AUTO 	Enable or disable autorange.	ON		√
:AUTO?	Query state of autorange.			√
:REFERence <n>	Specify reference (Rel) value for Channel 1; -120 to 120 (volts).	0	Sec 4	√
:STATe 	Enable or disable Rel.	OFF		√
:STATe?	Query state of Rel.			√
:ACQuire	Use input signal as Rel.			

Table 14-7

SENSe command summary (cont.)

Command	Description	Default Parameter	Ref	SCPI
:REfERENCE?	Query Rel value.			√
:LPASS	Control analog filter for DCV1:		Sec 3	
[:STATe] 	Enable or disable analog filter.	OFF		
[:STATe]?	Query state of analog filter.			
:DFILter	Configure and control digital filter:		Sec 3	
:WINDow <n>	Specify filter window (in %); 0 to 10.	0.01		
:WINDow?	Query filter window.			
:COUNT <n>	Specify filter count; 1 to 100.	10		
:COUNT?	Query filter count.			
:TCONtrol <name>	Select filter type; MOVing or REPeat.	MOVing		
:TCONtrol?	Query filter type.			
[:STATe] 	Enable or disable digital filter.	ON		
[:STATe]?	Query state of digital filter.			
:CHANnel2	Channel 2 voltage commands:	OFF		
:LQMode 	Enable or disable low charge-injection mode.		Sec 2	
:LQMode?	Query state of low charge-injection mode.			
:RANGe	Configure channel 2 measurement range:		Sec 3	√
[:UPPer] <n>	Select range; 0 to 12 (volts).	12		√
[:UPPer]?	Query range value.			√
:AUTO 	Enable or disable autorange.	ON		√
:AUTO?	Query state of autorange.			√
:REfERENCE <n>	Specify reference (Rel) value for Channel 2; -12 to 12 (volts).	0	Sec 4	√
:STATe 	Enable or disable Rel.	ON		√
:STATe?	Query state of Rel.			√
:ACQuire	Use the voltage on Channel 2 as Rel.			
:REfERENCE?	Query Rel value.			√
:LPASS	Control analog filter for DCV2:		Sec 3	
[:STATe] 	Enable or disable analog filter.	OFF		
[:STATe]?	Query state of analog filter.			
:DFILter	Configure and control digital filter:		Sec 3	
:WINDow <n>	Specify filter window (in %); 0 to 10.	0.01		
:WINDow?	Query filter window.			
:COUNT <n>	Specify filter count; 1 to 100.	10		
:COUNT?	Query filter count.			
:TCONtrol <name>	Select filter type; MOVing or REPeat.	MOVing		
:TCONtrol?	Query filter type.			
[:STATe] 	Enable or disable digital filter.	ON		
[:STATe]?	Query state of digital filter.			

Table 14-7

SENSe command summary (cont.)

Command	Description	Default Parameter	Ref	SCPI
:TEMPerature	Path to configure temperature:			
:TRANsducer <name>	Specify transducer; TCouple or INTernal.	TCouple	Sec 2	
:TRANsducer?	Query transducer.			
:TCouple	Thermocouple (TC):			
[:TYPE] <type>	Set TC type; J, K, T, E, R, S, B or N.	J		
[:TYPE]?	Query TC type.			
:RJUNction	Reference junction:			
:RSElect <name>	Set reference type; SIMulated or INTernal.	INTernal		
:RSElect?	Query reference type.			
:SIMulated <n>	Specify simulated temperature in °C; 0 to 60.	23		
:SIMulated?	Query simulated temperature.			
:RTEMPerature?	Query internal temperature.		Sec 2	
:NPLCycles <n>	Set integration rate in line cycles (PLC); 0.01 to 60 (60Hz) or 0.01 to 50 (50Hz).	5	Sec 3	
:NPLCycles?	Query NPLC.			
:APERture <n>	Set integration rate in seconds; 166.67e-6 to 1 (60Hz) or 200e-6 to 1 (50Hz).	83.33		
:APERture?	Query Aperture.			
:DIGits <n>	Set display resolution; 4 to 7.	6	Sec 3	
:DIGits?	Query display resolution.			
[:CHANnel1]	Channel 1 temperature commands:			
:REFerence <n>	Specify reference (Rel) value for Channel 1; -328 to 3310	0	Sec 4	
:STATe 	Enable or disable Rel.	OFF		
:STATe?	Query state of Rel.			
:ACQuire	Use input signal as Rel.			
:REFerence?	Query Rel value.			
:LPASS	Control analog filter for TEMP1:			
[:STATe] 	Enable or disable analog filter.	OFF	Sec 3	
[:STATe]?	Query state of analog filter.			
:DFILter	Configure and control digital filter:			
:WINDow <n>	Specify filter window (in %); 0 to 10.	0.01	Sec 3	
:WINDow?	Query filter window.			
:COUNT <n>	Specify filter count; 1 to 100.	10		
:COUNT?	Query filter count.			
:TCONtrol <name>	Select filter type; MOVing or REPeat.	MOVing		
:TCONtrol?	Query filter type.			
[:STATe] 	Enable or disable digital filter.	ON		
[:STATe]?	Query state of digital filter			

Table 14-7*SENSe command summary (cont.)*

Command	Description	Default Parameter	Ref	SCPI
:CHANnel2	Channel 2 temperature commands:			
:REFerence <n>	Specify reference (Rel) value for Channel 2; -328 to 3310.	0	Sec 4	
:STATe 	Enable or disable Rel.	OFF		
:STATe?	Query state of Rel.			
:ACQuire	Use the voltage on Channel 2 as Rel.			
:REFerence?	Query Rel value.			
:LPASs	Control analog filter for TEMP2:		Sec 3	
[:STATe] 	Enable or disable analog filter.	OFF		
[:STATe]?	Query state of analog filter.			
:DFILter	Configure and control digital filter:		Sec 3	
:WINDow <n>	Specify filter window (in %); 0 to 10.	0.01		
:WINDow?	Query filter window.			
:COUNT <n>	Specify filter count; 1 to 100.	10		
:COUNT?	Query filter count.			
:TCONtrol <name>	Select filter type; MOVing or REPeat.	MOVing		
:TCONtrol?	Query filter type.			
[:STATe] 	Enable or disable digital filter.	ON		
[:STATe]?	Query state of digital filter.			

Table 14-8

STATus command summary

Command	Description	Default Parameter	Ref	SCPI
:STATus		(Note 1)	Sec 15	
:MEASurement	Measurement event registers:			
[:EVENT]?	Read the event register.	(Note 2)		
:ENABLE <NRf>	Program the enable register.	(Note 3)		
:ENABLE?	Read the enable register.			
:CONDition?	Read the condition register.			
:OPERation	Operation event registers:			
[:EVENT]?	Read the event register.	(Note 2)		
:ENABLE <NRf>	Program the enable register.	(Note 3)		
:ENABLE?	Read the enable register.			
:CONDition?	Read the condition register.			
:QUESTionable	Questionable event registers:			
[:EVENT]?	Read the event register.	(Note 2)		
:ENABLE <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	Path to access Error Queue:			
[:NEXT]?	Read the most recent message.	(Note 4)		
:ENABLE <list>	Specify error and status messages for Error Queue.	(Note 5)		
:ENABLE?	Read the enabled messages.			
:DISable <list>	Specify messages not to be placed in queue.	(Note 5)		
:DISable?	Read the disabled messages.			
:CLEar	Clears all messages from Error Queue.			

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 clears all bits of the registers.
5. Error Queue Messages — Power-up clears list of messages. *CLS and STATus:PRESet have no effect.

Table 14-9*SYSTem command summary*

Command	Description	Default Parameter	Ref	SCPI
:SYSTem			Sec 15	
:PRESet	Return to SYSTem:PRESet defaults.			√
:FAZero	Path to control Front Autozero.			
[:STATE] 	Enable or disable Front Autozero.	ON		
[:STATE]?	Query state of Front Autozero.			
:AZERo	Path to control Autozero:			
[:STATE] 	Enable or disable Autozero.	ON		
[:STATE]?	Query state of Autozero.			
:LSYNc	Path to control line cycle synchronization.			
[:STATE] 	Enable or disable line cycle synchronization.	OFF		
[:STATE]?	Query state of line cycle synchronization.			
:LFRequency?	Query the power line frequency setting (50 = 50 or 400Hz, 60 = 60Hz)			
:POSetup <name>	Select power-on setup; RST, PRESet or SAV0.			
:POSetup?	Query power-on setup.			
:VERsion?	Query SCPI revision level.			√
:ERRor?	Query system error queue.	(see Note)		
:CLear	Clear messages from error queue.			
:KCLick 	Enable or disable key click feature.	ON		
:KCLick?	Query key click status.			
:BEEPer	Path to control beeper:			√
[:STATE] 	Enable or disable beeper for limit tests.	ON		√
[:STATE]?	Query state of beeper.			√
:KEY <NRf>	Simulate key-press.			√
:KEY?	Query the last “pressed” key.			√

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 14-10*TRACe command summary*

Command	Description	Default Parameter	Ref	SCPI
:TRACel:DATA	Use :TRACe or :DATA as root command.	(see Note)	Sec 6	√
:DATA?	Read the contents of the buffer (data store).			√
:CLear	Clear readings from buffer.			
:FREE?	Query bytes available and bytes in use.			√
:POINts <n>	Specify size of buffer; 2 to 1024.			√
:POINts?	Query buffer size.			√
:FEED <name>	Select source of readings for buffer; SENSE[1], CALCulate[1], or NONE.			√
:CONTRol <name>	Select buffer control mode (NEXT or NEVer).			√
:CONTRol?	Query buffer control mode.			√
:FEED?	Query source of readings for buffer.			√

Note: SYSTem:PRESet and *RST have no effect on the commands in this subsystem.

Table 14-11
Trigger command summary

Command	Description	Default Parameter	Ref	SCPI
:INITiate	Path to Initiate measurement cycle(s):		Sec 7	√
[:IMMediate]	Initiate one cycle.			√
:CONTinuous 	Enable or disable continuous initiation.	(see Note 1)		√
:CONTinuous?	Query state of continuous initiation.			√
:ABORt	Reset trigger system (goes to idle state).			√
:TRIGger	Path to configure Trigger Layer:			√
[:SEQuence[1]]				√
:SOURce <name>	Select control source; IMMEDIATE, TIMER, MANUAL, BUS, or EXTERNAL.	IMMEDIATE		√
:SOURce?	Query control source.			√
:SIGNal	Loop around control source.			√
:COUNt <n>	Set measure count; 1 to 9999 or INF.	(see Note 2)		√
:COUNt?	Query measure count.			√
:DELay <n>	Set trigger delay; 0 to 999999.999 (sec).	0		√
:AUTO 	Enable or disable auto delay.	ON		√
:AUTO?	Query state of auto delay.			√
:DELay?	Query delay value.			√
:TIMER <n>	Set timer interval for TIMER control source; 0 to 999999.999 (sec).	0.1		√
:TIMER?	Query timer interval.			√
:SAMPLE	Sample Counter:			
:COUNt <n>	Specify sample count; 1 to 1024.	1		
:COUNt?	Query sample count.			

Notes: 1. Defaults for continuous initiation:
 SYSTem:PRESet enables continuous initiation.
 *RST disables continuous initiation.

2. Defaults for Trigger Count:
 SYSTem:PRESet sets count to INF (infinite).
 *RST sets count to 1.

Table 14-12*UNIT command summary*

Command	Description	Default Parameter	Ref	SCPI
:UNIT				
:TEMPerature <name>	Select temperature units; C, F, or K.	C		√
:TEMPerature?	Query temperature units.			√

15 Additional SCPI Commands

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

DISPlay subsystem

The commands in this subsystem are used to control the display of the Model 2182 and are summarized in [Table 14-3](#).

:ENABle

:DISPlay:ENABle Control display circuitry

Parameters

 =	0 or OFF	Disable display circuitry
	1 or ON	Enable display circuitry

Description

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

All front panel controls (except LOCAL) are disabled. Normal display operation can be resumed by using the :ENABle command to enable the display or by putting the Model 2182 into local mode (press LOCAL).

:TEXT commands

:DATA <a>

:DISPlay[:WINDow[1]]:TEXT:DATA <a> Define message for display

Parameter

<a> = ASCII characters for the message (maximum of 12 characters). The characters must be enclosed in either double quotes (“ ”) or single quotes (‘ ’).

Description

These commands define the text message for display. A message can be as long as 12 characters. A space counts as a character. Excess message characters results in an error.

:STATe

:DISPlay[WINDow[1]]:TEXT:STATe Control (on/off) message

Parameters

 =	0 or OFF	Disable text message
	1 or ON	Enable text message

Description

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

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

FORMat subsystem

The commands in this subsystem are used to select the data format for transferring instrument readings over the bus. The BORDer command and DATA command only affect readings transferred from the buffer (i.e., SENSE:DATA? or CALC:DATA? are always sent in ASCII). These commands are summarized in [Table 14-4](#).

:DATA command

[[:DATA] <type>

:FORMat[:DATA] <type> Specify data format

Parameters

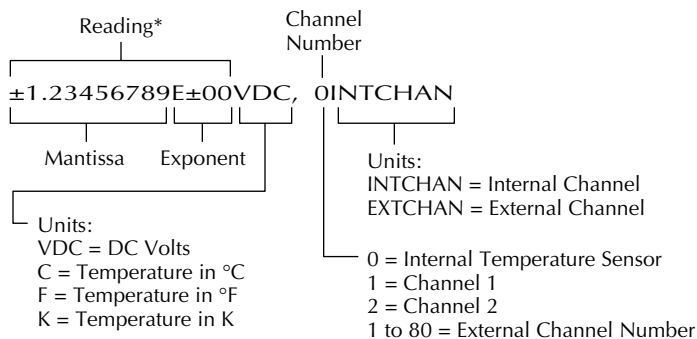
<type> =	ASCii	ASCII format
	SREal	IEEE754 single precision format
	DREal	IEEE754 double precision format

Description

This command is used to select the data format for transferring readings over the bus. For every reading conversion, the data string sent over the bus contains the elements specified by the :ELEMents command. The specified elements are sent in a particular order.

The ASCII data format is in a direct readable form for the operator. Most BASIC languages easily convert ASCII mantissa and exponent to other formats. However, some speed is compromised to accommodate the conversion. [Figure 15-1](#) shows the ASCII format that includes all the data elements.

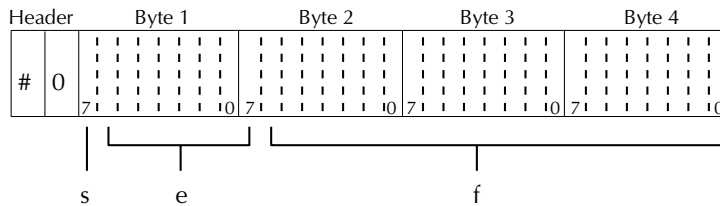
Figure 15-1
ASCII data format



* An overflow reading is displayed as +9.9E37 with no units

SREal will select the binary IEEE754 single precision data format. Figure 15-2 shows the normal byte order format for each data element. For example, if three valid elements are specified, the data string for each reading conversion is made up of three 32-bit data blocks. Note that the data string for each reading conversion is preceded by a 2-byte header that is the binary equivalent of an ASCII # sign and 0.

Figure 15-2
IEEE754 single precision data format (32 data bits)



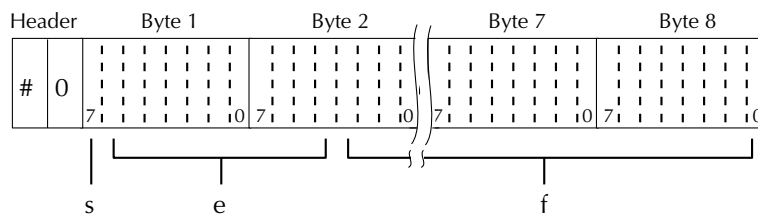
s = sign bit (0 = positive, 1 = negative)
e = exponent bits (8)
f = fraction bits (23)

Normal byte order shown. For swapped byte order,
bytes sent in reverse order: Header, Byte 4, Byte 3
Byte 2, Byte 1.

The Header is only sent once for each measurement conversion.

DREal selects the binary IEEE754 double precision data format and is shown in Figure 15-3 (normal byte order shown). This format is similar to the single precision format except that it is 64 bits long.

Figure 15-3
IEEE754 double precision data format (64 data bits)



Bytes 3, 4, 5, and 6 not shown.

s = sign bit (0 = positive, 1 = negative)
e = exponent bits (11)
f = fraction bits (52)

Normal byte order shown. For swapped byte order,
bytes sent in reverse order: Header, Byte 8,
Byte 7 Byte 1.

The Header is only sent once for each measurement conversion.

:BORDER command

:BORDER <name>

:FORMat:BORDER <name> Specify binary byte order

Parameters

<name> =	NORMAL	Normal byte order for binary formats
	SWAPped	Reverse byte order for binary formats

Description

This command is used to control the byte order for the IEEE754 binary formats. For normal byte order, the data format for each element is sent as follows:

Byte 1	Byte 2	Byte 3	Byte 4	(Single precision)
Byte 1	Byte 2	...	Byte 8	(Double precision)

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

Byte 4	Byte 3	Byte 2	Byte 1	(Single precision)
Byte 8	Byte 7	...	Byte 1	(Double precision)

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.

:ELEMENTS command

:ELEMENTS <item list>

:FORMat:ELEMENTS <item list> Specify elements to include in data string

Parameters

<item list>:	READING	Includes reading in data string
	CHANnel	Includes channel number
	UNITs	Includes units

NOTE Each item in the list must be separated by a comma (,).

Description

This command is used to specify the elements to be included in the data string for each measurement conversion. You can specify from one to all three elements. Each element in the list must be separated by a comma (,). These elements, shown in [Figure 15-1](#), are explained in the following paragraphs.

READING: Instrument reading. The resolution of this reading tracks the display resolution of the instrument. An overflow reading reads as +9.9e37 with no units.

CHANnel: Corresponds the instrument reading to the channel number. Channel 0 corresponds to the sensor used to measure the internal temperature of the Model 2182. Channel 1 and Channel 2 corresponds to the two input channels of the instrument. For external scanning, the number corresponds to the channel number of the switching card.

UNITs: This element attaches the function unit to the reading and the channel unit (internal or external) to the channel number. An external channel refers to the channel for an external switch system. This element is not available for the binary formats.

The ASCII format in [Figure 15-1](#) shows the byte order of the data string. Remember that the byte order can only be reversed for the binary formats.

When using this command to add an element, you must include all elements that you want in the format. For example, if the reading is already specified and you want to add the channel, you must include the READing parameter:

```
:form:elem chan, read
```

Data elements for the item list can be listed in any order, but they are always sent in the order shown in [Figure 15-1](#).

STATus subsystem

The STATus subsystem is used to control the status registers of the Model 2182. The commands in this subsystem are summarized in [Table 14-8](#).

NOTE The status structure of Model 2182 is explained in [Section 12](#).

[[:EVENT]? command

[[:EVENT]?

:STATus:MEASurement[:EVENT]?	Read Measurement Event Register
:STATus:OPERation[:EVENT]?	Read Operation Event Register
:STATus:QUESTionable[:EVENT]?	Read Questionable Event Register

Description

These query commands are used to read the event registers. After sending one of these commands and addressing the Model 2182 to talk, a decimal value is sent to the computer. The binary equivalent of this value determines which bits in the appropriate register are set. The event registers are shown in [Figure 15-4](#), [Figure 15-5](#), and [Figure 15-6](#). Note that reading an event register clears the bits in that register.

For example, assume that reading the Measurement Event Register results in an acquired decimal value of 544. The binary equivalent is 0000001000100000. For this binary value, bits B5 and B9 of the Measurement Event Register are set.

Measurement Event Register:

Bit B0, Reading Overflow (ROF) – Set bit indicates that the reading exceeds the measurement range of the instrument.

Bit B1, Low Limit1 (LL1) – Set bit indicates that the reading is less than the Low Limit 1 setting.

Bit B2, High Limit1 (HL1) – Set bit indicates that the reading is greater than the High Limit 1 setting.

Bit B3, Low Limit 2 (LL2) – Set bit indicates that the reading is less than the Low Limit 2 setting.

Bit B4, High Limit 2 (HL2) – Set bit indicates that the reading is greater than the High Limit 2 setting.

Bit B5, Reading Available (RAV) – Set bit indicates that a reading was taken and processed.

Bit B6 – Not used.

Bit B7, Buffer Available (BAV) – Set bit indicates that there are at least two readings in the trace buffer.

Bit B8, Buffer Half Full (BHF) – Set bit indicates that the trace buffer is half full.

Bit B9, Buffer Full (BFL) – Set bit indicates that the trace buffer is full.

Bits B10 through B15 – Not used.

Figure 15-4
Measurement event register

Bit Position	B15 - B10	B9	B8	B7	B6	B5	B4	B3	B2	B1	B0
Event	—	BFL	BHF	BAV	—	RAV	HL2	LL2	HL1	LL1	ROF
Decimal Weighting	—	512 (2 ⁹)	256 (2 ⁸)	128 (2 ⁷)	—	32 (2 ⁵)	16 (2 ⁴)	8 (2 ³)	4 (2 ²)	2 (2 ¹)	1 (2 ⁰)
Value	—	0/1	0/1	0/1	—	0/1	0/1	0/1	0/1	0/1	0/1

Value : 1 = Measurement Event Set
0 = Measurement Event Cleared

Events : BFL = Buffer Full
BHF = Buffer Half Full
BAV = Buffer Available
RAV = Reading Available
HL1 = High Limit 1
HL2 = High Limit 2
LL1 = Low Limit 1
LL2 = Low Limit 2
ROF = Reading Overflow

Questionable Event Register:**Bits B0 through B3** – Not used.**Bit B4, Temperature Summary (Temp)** – Set bit indicates that an invalid reference junction measurement has occurred for thermocouple temperature measurements.**Bits B5 through B7** – Not used.**Bit B8, Calibration Summary (Cal)** – Set bit indicates that an invalid calibration constant was detected during the power-up sequence. The instrument will instead use a default calibration constant. This error will clear after successful calibration of the instrument.**Bit B9, ACAL Summary (ACAL)** – Set bit indicates that an invalid ACAL was performed. This error will clear after a successful ACAL is performed.**Bits B10 through B15** – Not used.

NOTE Whenever a questionable event occurs, the ERR annunciator will turn on. The annunciator will turn off when the questionable event clears.

Figure 15-5
Questionable event register

Bit Position	B15 - B10	B9	B8	B7 - B5	B4	B3 - B0
Event	—	ACAL	Cal	—	Temp	—
Decimal Weighting	—	512 (2 ⁹)	256 (2 ⁸)	—	16 (2 ⁴)	—
Value	—	0/1	0/1	—	0/1	—

Value : 1 = Operation Event Set
 0 = Operation Event Cleared

Events : ACAL = ACAL Summary
 Cal = Calibration Summary
 Temp = Temperature Summary

Operation Event Register:

Bit B0, Calibrating (Cal) – Set bit indicates that the instrument is calibrating.

Bits B1 through B3 – Not used.

Bit B4, Measuring (Meas) – Set bit indicates that the instrument is performing a measurement.

Bit B5, Trigger Layer (Trig) – Set bit indicates that the instrument is waiting in the Trigger Layer of the Trigger Model.

Bits B6 and B7 – Not used.

Bit B8, Filter Settled (Filt) – Set bit indicates that the filter has settled.

Bit B9 – Not used.

Bit B10, Idle – Set bit indicates that the instrument is in the idle state.

Bits B11 through B15 – Not used.

Figure 15-6
Operation event register

Bit Position	B15 - B11	B10	B9	B8	B7,B6	B5	B4	B3 - B1	B0
Event	—	Idle	—	Filt	—	Trig	Meas	—	Cal
Decimal Weighting	—	1024 (2 ¹⁰)	—	256 (2 ⁸)	—	32 (2 ⁵)	16 (2 ⁴)	—	1 (2 ⁰)
Value	—	0/1	—	0/1	—	0/1	0/1	—	0/1

Value : 1 = Operation Event Set
0 = Operation Event Cleared

Events : Idle = Idle state of the 2182
Filt = Filter Settled
Trig = Trigger Layer
Meas = Measuring
Cal = Calibrating

:ENABLE command

:ENABLE <NRf>

:STATus:MEASurement:ENABLE <NRf> Program Measurement Event Enable Register
 :STATus:QUESTionable:ENABLE <NRf> Program Questionable Event Enable Register
 :STATus:OPERation:ENABLE <NRf> Program Operation Event Enable Register

Parameters

<NRf> = 0	Clear register	<NRf> = 128	Set bit B7
1	Set bit B0	256	Set bit B8
2	Set bit B1	512	Set bit B9
4	Set bit B2	1024	Set bit B10
16	Set bit B4	16384	Set bit B14
32	Set bit B5	65535	Set all bits
64	Set bit B6		

Description

These commands are used to set the contents of the event enable registers (see [Figure 15-7](#), [Figure 15-8](#), and [Figure 15-9](#)). An :ENABLE command is sent with the decimal equivalent of the binary value that determines the desired state (0 or 1) of each bit in the appropriate register.

Each event enable register is used as a mask for events (see [:EVENT] for descriptions of events). When a bit in an event enable register is cleared (0), the corresponding bit in the event register is masked, and thus cannot set the corresponding summary bit of the next register set in the status structure. Conversely, when a bit in an event enable register is set (1), the corresponding bit in the event register is unmasked. When the unmasked bit in the event register sets, the summary bit of the next register set in the status structure will set.

The decimal weighting of the bits for each event enable register are included in [Figure 15-7](#), [Figure 15-8](#), and [Figure 15-9](#). The sum of the decimal weights of the bits that you wish to set is sent as the parameter (<NRf>) for the appropriate :ENABLE command. For example, to set the BFL and RAV bits of the Measurement Event Enable Register, send the following command:

```
:stat:meas:enab 544
```

where: BFL (bit B9) = Decimal 512

RAV (bit B5) = Decimal 32

<NRf> = 544

Figure 15-7
Measurement event enable register

Bit Position	B15 - B10	B9	B8	B7	B6	B5	B4	B3	B2	B1	B0
Event	—	BFL	BHF	BAV	—	RAV	HL2	LL2	HL1	LL1	ROF
Decimal Weighting	—	512 (2 ⁹)	256 (2 ⁸)	128 (2 ⁷)	—	32 (2 ⁵)	16 (2 ⁴)	8 (2 ³)	4 (2 ²)	2 (2 ¹)	1 (2 ⁰)
Value	—	0/1	0/1	0/1	—	0/1	0/1	0/1	0/1	0/1	0/1

Value : 1 = Measurement Event Set
0 = Measurement Event Cleared

Events : BFL = Buffer Full
BHF = Buffer Half Full
BAV = Buffer Available
RAV = Reading Available
HL2 = High Limit 2
LL2 = Low Limit 2
HL1 = High Limit 1
LL1 = Low Limit 1
ROF = Reading Overflow

Figure 15-8
Questionable event enable register

Bit Position	B15 - B10	B9	B8	B7 - B5	B4	B3 - B0
Event	—	ACAL	Cal	—	Temp	—
Decimal Weighting	—	512 (2 ⁹)	256 (2 ⁸)	—	16 (2 ⁴)	—
Value	—	0/1	0/1	—	0/1	—

Value : 1 = Operation Event Set
0 = Operation Event Cleared

Events : ACAL = ACAL Summary
Cal = Calibration Summary
Temp = Temperature Summary

Figure 15-9
Operation event enable register

Bit Position	B15 - B11	B10	B9	B8	B7, B6	B5	B4	B3-B1	B0
Event	---	Idle	---	Filt	---	Trig	Meas	---	Cal
Decimal Weighting	---	1024 (2 ¹⁰)	---	256 (2 ⁸)	---	32 (2 ⁵)	16 (2 ⁴)	---	1 (2 ⁰)
Value	---	0/1	---	0/1	---	0/1	0/1	---	0/1

Value : 1 = Enable Operation Event
0 = Disable (Mask) Operation Event

Events : Idle = Idle state of the 2182
Filt = Filter Settled
Trig = Trigger Layer
Meas = Measuring
Cal = Calibrating

:CONDition? command

:CONDition?

:STATus:MEASurement:CONDition? Read Measurement Condition Register

:STATus:QUESTionable:CONDition? Read Questionable Condition Register

:STATus:OPERation:CONDition? Read Operation Condition Register

Description

These query commands are used to read the contents of the condition registers. Each set of event registers (except the Standard Event register set) has a condition register. A condition register is similar to its corresponding event register, except that it is a real-time register that constantly updates to reflect the present operating status of the instrument. See [:EVENT] for register bit descriptions.

After sending one of these commands and addressing the Model 2182 to talk, a decimal value is sent to the computer. The binary equivalent of this decimal value indicates which bits in the register are set.

For example, if sending :stat:meas:cond? returns a decimal value of 512 (binary 0000001000000000), bit B9 of the Measurement Condition Register is set indicating that the trace buffer is full.

:PRESet command

:PRESet

:STATus:PRESet Return registers to default conditions

Description

When this command is sent, all bits of the following registers are cleared to zero (0):

- Questionable Event Enable Register
- Measurement Event Enable Register
- Operation Event Enable Register

NOTE Registers not included in the above list are not affected by this command.

:QUEue commands

[:NEXT]?

:STATus:QUEue[:NEXT]? Read Error Queue

Description

As error and status messages occur, they are placed into the Error Queue. This query command is used to read those messages.

The Error Queue is a first-in, first-out (FIFO) register. Each time you read the queue, the “oldest” message is read and that message is then removed from the queue. The queue will hold up to ten messages. If the queue becomes full, the “350, Queue Overflow” message will occupy the last memory location in the register. On power-up, the Error Queue is empty. When the Error Queue is empty, the “0, No error” message is placed in the Error Queue.

The messages in the queue are preceded by a 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](#).

After this command is sent and the Model 2182 is addressed to talk, the “oldest” message in the queue is sent to the computer.

NOTE The :STATus:QUEue[:NEXT]? query command performs the same function as the :SYSTem:ERRor? query command (see System subsystem).

:CLEar

:STATus:QUEue:CLEar Clear Error Queue

Description

This action command is used to clear the Error Queue of messages.

:ENABLE <list>

:STATus:QUEue:ENABle <list> Enable messages for Error Queue

Parameter

<list> = (numlist)

where numlist is a specified list of messages that you wish to enable for the Error Queue.

Description

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. This command is used to specify which messages you want enabled. Messages not specified will be disabled and prevented from entering the queue.

When this command is sent, all messages will first be disabled, then the messages specified in the list will be enabled. Thus, the returned list (:ENABle?) will contain all the enabled messages.

Messages are specified by numbers (see [Appendix B](#)). The following examples show various forms for expressing a message numlist.

Numlist = -110	Single message.
-110, -140, -222	Messages separated by commas.
-110:-222	Range of messages (-110 through -222).
-110:-222, -230	Range entry and single entry separated by a comma.

NOTE To disable all messages from entering the Error Queue, send the following command:
:stat:que:enab ()

:DISable <list>

:STATus:QUEue:DISABle <list> Disable messages for Error Queue

Parameter

<list> = (numlist)

where numlist is a specified list of messages that you wish to disable for the Error Queue.

Description

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. This command is used to specify which messages you want disabled. Disabled messages are prevented from going into the Error Queue.

Messages are specified by numbers (see [Appendix B](#)). See :QUEue:ENABle for examples to express a numlist.

:CLEar

:STATus:QUEue:CLEar Clears all messages from Error Queue

Description

This command is used to clear the Error Queue of all messages.

:SYSTem subsystem

The SYSTem subsystem commands are summarized in [Table 14-9](#).

:PRESet command**:PRESet**

:SYSTem:PRESet Return to :SYSTem:PRESet defaults

Description

This command returns the instrument to states optimized for front panel operation. :SYSTem:PRESet defaults are listed in the SCPI tables ([Table 14-1](#) through [Table 14-12](#)).

Performance commands

**:FAZero[:STATe] **

:SYSTem:FAZero[:STATe] Control Front Autozero

Parameters

= 0 or OFF	Disable Front Autozero
1 or ON	Enable Front Autozero

Description

With Front Autozero enabled (which is the default setting), the instrument performs two A/D measurement cycles for each reading. The first one is a normal measurement cycle. The second measurement cycle is performed with the polarity of the front-end amplifier reversed. This current-reversal measurement technique is used to cancel internal offsets in the amplifier. With Front Autozero disabled, the second measurement cycle is not performed.

The speed for Delta measurements can be doubled by disabling Front Autozero. Delta uses its own current-reversal technique to cancel offsets. Therefore, the dual measurement technique of Front Autozero is not required.

See “[Autozeroing modes](#)” in [Section 2](#) for more information (including benefits and drawbacks) on Front Autozero.

**:AZERo[:STATe] **

:SYSTem:AZERo[:STATe] Control Autozero

Parameters

= 0 or OFF	Disable Autozero
1 or ON	Enable Autozero

Description

With autozero disabled, measurement speed is increased. However, the zero and gain reference points will eventually drift resulting in inaccurate readings of the input signal. It is recommended that autozero only be disabled for short periods of time.

NOTE See “*Performance considerations*” in *Section 2* for more information on autozero.

**:LSYNc **

:SYSTem:LSYNc Control line cycle synchronization

Parameters

= 0 or OFF	Disable line cycle synchronization
1 or ON	Enable line cycle synchronization

Description

When enabled, A/D conversions are synchronized with the power line frequency. This reduces noise at the expense of speed. Line cycle synchronization (LSYNC) is not available for integration rates <1 PLC, regardless of the LSYNC setting.

NOTE See “*Performance considerations*” in *Section 2* for more information on LSYNC.

:LFRrequency?

:SYSTem:LFRrequency? Read power line frequency setting

Description

On power-up, the Model 2182 detects the line power frequency and automatically selects the proper line frequency setting. The line frequency setting can be checked using this command.

The response message will be 50 or 60. The value 50 indicates that the line frequency is set for 50Hz (or 400Hz), while 60 indicates that it is set for 60Hz.

:BEEPer command

**:STATe **

:SYSTem:BEEPer:STATe Enable or disable beeper

Parameters

 = 1 or ON Enable beeper
 0 or OFF Disable beeper

Description

This command is used to enable or disable the beeper for limit tests and HOLD.

:KCLick command

**:KCLick **

:SYSTem:KCLick Enable or disable keyclick

Parameters

 = 1 or ON Enable keyclick
 0 or OFF Disable keyclick

Description

This command is used to enable or disable the keyclick. The keyclick can also be enabled or disabled from the front panel by pressing SHIFT then LOCAL.

:POSetup <name> command

:POSetup <name>

:SYSTem:POSetup <name> Program power-on defaults

Parameters

<name> = RST Select *RST defaults on power up
 PRESet Select :SYSTem:PRESet defaults on power up
 SAV0 Select saved defaults on power up

Description

This command is used to select the power-on defaults. With RST selected, the instrument powers up to the *RST default conditions. With PRES selected, the instrument powers up to the :SYSTem:PRESet default conditions. Default conditions are listed in the SCPI tables (Table 14-1 through Table 14-12).

With the SAV0 parameter selected, the instrument powers-on to the setup that is saved in the specified location using the *SAV command.

:VERSion? command

:VERSion?

:SYSTem:VERSion? Read SCPI version

Description

This query command is used to read the version of the SCPI standard being used by the Model 2182. Example code:

```
1991.0
```

The above response message indicates the version of the SCPI standard.

:ERRor? command

:ERRor?

:SYSTem:ERRor? Read Error Queue

Description

As error and status messages occur, they are placed in the Error Queue. This query command is used to read those messages. The Error Queue is a first-in, first-out (FIFO) register that can hold up to ten messages. Each time you read the queue, the “oldest” message is read, and that message is then removed from the queue.

If the queue becomes full, the “350, Queue Overflow” message occupies the last memory location in the register. On power-up, the queue is empty. When the Error Queue is empty, the “0, No error” message is placed in the Error Queue.

The messages in the queue are preceded by a number. Negative (–) numbers are used for SCPI defined messages, and positive (+) numbers are used for Keithley defined messages. [Appendix B](#) lists the messages.

NOTE *The :SYSTem:ERRor? query command performs the same function as the :STATus:QUEue? query command (see STATus subsystem).*

:CLEar command

:CLEar

:SYSTem:CLEar Clear Error Queue

Description

This action command is used to clear the Error Queue of messages.

:KEY <NRf> command

:KEY

:SYSTem:KEY <NRf> Simulate key-press

Parameters

<NRf> =	1	SHIFT key	<NRf> =	17	LOCAL key
	2	DCV1 key		18	EX-TRIG key
	3	DCV2 key		19	TRIG key
	4	RATIO key		20	STORE key
	5	ACAL key		21	RECALL key
	6	FILT key		22	VALUE key
	7	REL key		23	ON/OFF key
	8	TEMP1 key		24	left arrow key
	9	—		25	—
	10	—		26	STEP key
	11	up arrow key		27	SCAN key
	12	AUTO key		28	SAVE
	13	down arrow key		29	RESTORE key
	14	ENTER key		30	DIGITS key
	15	right arrow key		31	RATE key
	16	TEMP2 key		32	EXIT key

Description

This command is used to simulate front panel key presses. For example, to select RATIO you can send the following command to simulate pressing the RATIO key:

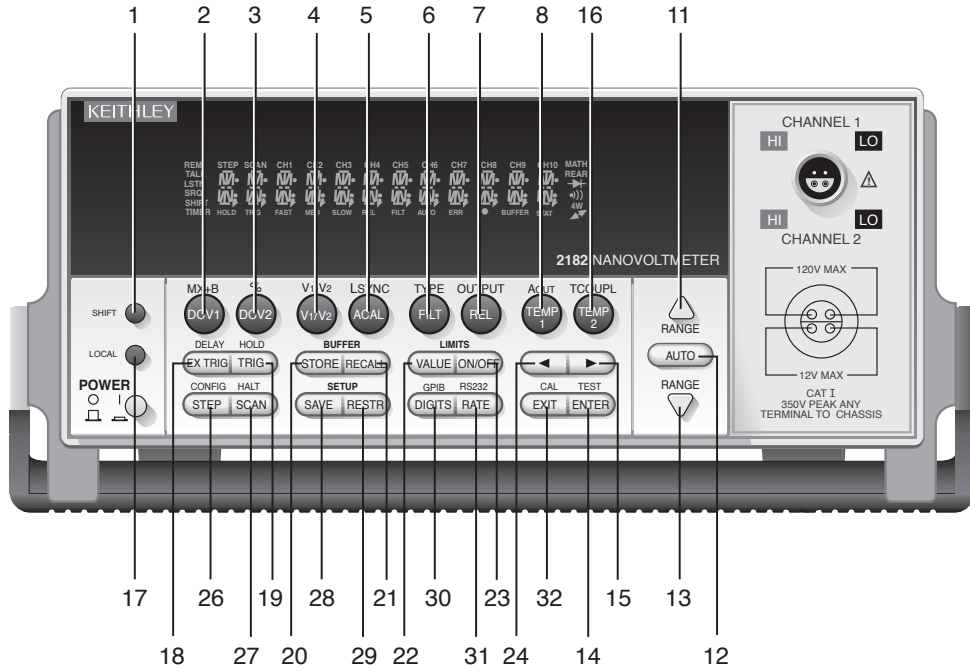
```
:syst:key 4
```

The parameter listing provides the key-press code in numeric order. [Figure 15-10](#) also illustrates the key-press codes.

The queue for the :KEY? query command can only hold one key-press. When :KEY? is sent over the bus, and the Model 2182 is addressed to talk, the key-press code number for the last key pressed (either physically or with :KEY) is sent to the computer.

NOTE :SYST:KEY should not be used to put the Model 2182 into the local mode; use GTL instead.

Figure 15-10
Key-press codes



A Specifications

2182A Nanovoltmeter Specifications

VOLTS SPECIFICATIONS (20% OVER RANGE)

CONDITIONS: 1PLC with 10 reading digital filter or 5PLC with 2 reading digital filter.

CHANNEL 1 RANGE	RESOLUTION	INPUT RESISTANCE	ACCURACY: \pm (ppm of reading + ppm of range) (ppm = parts per million) (e.g., 10ppm = 0.001%)				TEMPERATURE COEFFICIENT 0°-18°C & 28°-50°C
			24 Hour ¹ T _{CAL} \pm 1°C	90 Day T _{CAL} \pm 5°C	1 Year T _{CAL} \pm 5°C	2 Year T _{CAL} \pm 5°C	
10.000000 mV ^{2,3,4}	1 nV	>10 GΩ	20 + 4	40 + 4	50 + 4	60 + 4	(1 + 0.5)/°C
100.00000 mV	10 nV	>10 GΩ	10 + 3	25 + 3	30 + 4	40 + 5	(1 + 0.2)/°C
1.0000000 V	100 nV	>10 GΩ	7 + 2	18 + 2	25 + 2	32 + 3	(1 + 0.1)/°C
10.000000 V	1 μV	>10 GΩ	2 + 1 ⁵	18 + 2	25 + 2	32 + 3	(1 + 0.1)/°C
100.00000 V ⁴	10 μV	10 MΩ \pm 1%	10 + 3	25 + 3	35 + 4	52 + 5	(1 + 0.5)/°C
CHANNEL 2^{6,10}							
100.00000 mV	10 nV	>10 GΩ	10 + 6	25 + 6	30 + 7	40 + 7	(1 + 1)/°C
1.0000000 V	100 nV	>10 GΩ	7 + 2	18 + 2	25 + 2	32 + 3	(1 + 0.5)/°C
10.000000 V	1 μV	>10 GΩ	2 + 1 ⁵	18 + 2	25 + 2	32 + 3	(1 + 0.5)/°C

CHANNEL 1/CHANNEL 2 RATIO: Ratio accuracy = $\frac{\pm \text{channel 2 reading (accuracy channel 1 range)} + \text{channel 1 reading (accuracy channel 2 range)}}{(\text{channel 2 reading})^2}$

DELTA (hardware-triggered coordination with 24XX series or 622X series current sources for low noise R measurement): accuracy = accuracy of selected Channel 1 range plus accuracy of I source range.

DELTA measurement noise with 6220 or 6221: Typical 3nVRMS/ $\sqrt{\text{Hz}}$ (10mV range)²¹. 1 Hz achieved with 1PLC, delay = 1ms, RPT filter = 23 (20 if 50Hz)

PULSE-MODE (with 6221): line synchronized voltage measurements within current pulses from 50us to 12ms, pulse repetition rate up to 12 Hz

Pulse measurement noise: (typical RMS noise, R_{DUT}<10 ohms) (0.009ppm of range²²)/meas_time/ $\sqrt{\text{pulse_avg_count}} + 3\text{nV}/\sqrt{(2 \cdot \text{meas_time} \cdot \text{pulse_avg_count})}$ for 10mV range**

* 0.0028ppm for the 100mV range, 0.0016ppm for ranges 1V and above **8nV/ $\sqrt{\text{Hz}}$ for ranges above 10mV meas_time(sec) = pulsewidth – pulse_meas_delay in 33us incr.

DC NOISE PERFORMANCE⁷ (DC NOISE EXPRESSED IN VOLTS PEAK-TO-PEAK)

Response time = time required for reading to be settled within noise levels from a stepped input, 60Hz operation.

CHANNEL 1 RESPONSE TIME	NPLC, FILTER	RANGE						
		10mV	100mV	1V	10V	100V	NMRR ⁸	CMRR ⁹
25.0 s	5, 75	6 nV	20 nV	75 nV	750 nV	75 μV	110 dB	140 dB
4.0 s	5, 10	15 nV	50 nV	150 nV	1.5 μV	75 μV	100 dB	140 dB
1.0 s	1, 18	25 nV	175 nV	600 nV	2.5 μV	100 μV	95 dB	140 dB
667 ms	1, 10 or 5, 2	35 nV	250 nV	650 nV	3.3 μV	150 μV	90 dB	140 dB
60 ms	1, Off	70 nV	300 nV	700 nV	6.6 μV	300 μV	60 dB	140 dB
CHANNEL 2^{6,10}								
25.0 s	5, 75	-	150 nV	200 nV	750 nV	-	110 dB	140 dB
4.0 s	5, 10	-	150 nV	200 nV	1.5 μV	-	100 dB	140 dB
1.0 s	1, 10 or 5, 2	-	175 nV	400 nV	2.5 μV	-	90 dB	140 dB
85 ms	1, Off	-	425 nV	1 μV	9.5 μV	-	60 dB	140 dB

VOLTAGE NOISE VS. SOURCE RESISTANCE¹¹ (DC NOISE EXPRESSED IN VOLTS PEAK-TO-PEAK)

SOURCE RESISTANCE	NOISE	ANALOG FILTER	DIGITAL FILTER
0 Ω	6 nV	Off	100
100 Ω	8 nV	Off	100
1 kΩ	15 nV	Off	100
10 kΩ	35 nV	Off	100
100 kΩ	100 nV	On	100
1 MΩ	350 nV	On	100

2182A Nanovoltmeter Specifications

Temperature (Thermocouples)¹²

(DISPLAYED IN °C, °F, OR K. ACCURACY BASED ON ITS-90, EXCLUSIVE OF THERMOCOUPLE ERRORS.)

TYPE	RANGE	RESOLUTION	ACCURACY
			90 Day/1 Year 23° ±5°C Relative to Simulated Reference Junction
J	-200 to +760°C	0.001°C	±0.2°C
K	-200 to +1372°C	0.001°C	±0.2°C
N	-200 to +1300°C	0.001°C	±0.2°C
T	-200 to +400°C	0.001°C	±0.2°C
E	-200 to +1000°C	0.001°C	±0.2°C
R	0 to +1768°C	0.1°C	±0.2°C
S	0 to +1768°C	0.1°C	±0.2°C
B	+350 to +1820°C	0.1°C	±0.2°C

OPERATING CHARACTERISTICS^{13,14} 60HZ (50HZ) OPERATION

FUNCTION	DIGITS	READINGS/s	PLCs
DCV Channel 1,	7.5	3 (1.2)	5
Channel 2,	7.5 ^{17,19}	6 (1.7)	5
Thermocouple	6.5 ^{18,19}	18 (5.5)	1
	6.5 ^{18,19,20}	45 (7.2)	1
	5.5 ^{17,19}	80 (20.9)	0.1
	4.5 ^{16,17,19}	115 (28.0)	0.01
Channel 1/Channel 2,	7.5	1.5 (1.2)	5
(Ratio),	7.5 ^{17,19}	2.3 (1.7)	5
Delta with 24XX,	6.5 ¹⁸	8.5 (5.5)	1
Scan	6.5 ^{18,20}	20 (7.2)	1
	5.5 ¹⁷	30 (20.9)	0.1
	4.5 ¹⁷	41 (28.0)	0.01
Delta with 622X	6.5	47 (40) ²²	1

SYSTEM SPEEDS^{13,15}

RANGE CHANGE TIME¹⁴: <40 ms (<50 ms).

FUNCTION CHANGE TIME¹⁴: <45 ms (<55 ms).

AUTORANGE TIME¹⁴: <60 ms (<70 ms).

ASCII READING TO RS-232 (19.2K Baud): 40/s (40/s).

MAX. INTERNAL TRIGGER RATE¹⁴: 120/s (120/s).

MAX. EXTERNAL TRIGGER RATE¹⁶: 120/s (120/s).

MEASUREMENT CHARACTERISTICS

A-D LINEARITY: 0.8ppm of reading + 0.5ppm of range.

FRONT AUTOZERO OFF ERROR: 10mV – 10V: Add ±(8ppm of reading + 500µV) for <10 minutes and ±1°C.

NOTE: Offset voltage error does not apply for Delta Mode.

AUTOZERO OFF ERROR

10mV: Add ±(8ppm of reading + 100nV) for <10 minutes and ±1°C.

100mV-100V: Add ±(8ppm of reading + 10µV) for <10 minutes and ±1°C.

NOTE: Offset voltage error does not apply for Delta Mode.

INPUT IMPEDANCE

10mV-10V: >10GΩ, in parallel with <1.5nF. (Front Filter ON)

10mV-10V: >10GΩ, in parallel with <0.5nF. (Front Filter OFF)

100V: 10MΩ±1%

DC INPUT BIAS CURRENT:

<60pA @ 23°C, -10V to 5V.

<120pA @ 23°C, 5 V to 10V.

COMMON MODE CURRENT: <50nA p-p at 50Hz or 60Hz.

INPUT PROTECTION: 150V peak to any terminal, 70V peak Channel 1 LO to Channel 2 LO.

CHANNEL ISOLATION: >10GΩ.

EARTH ISOLATION: 350V peak, >10GΩ and <150pF any terminal to earth. Add 35pF/ft with Model 2107 Low Thermal Input Cable.

2182A Nanovoltmeter Specifications

ANALOG OUTPUT

MAXIMUM OUTPUT: $\pm 1.2V$.

ACCURACY: $\pm(0.1\% \text{ of output} + 1mV)$.

OUTPUT RESISTANCE: $1k\Omega \pm 5\%$.

GAIN: Adjustable from 10^9 to 10^6 . With gain set to 1, a full range input will produce a 1V output.

OUTPUT REL: Selects the value of input that represents 0V at output. The reference value can be either programmed value or the value of the previous input.

TRIGGERING AND MEMORY

WINDOW FILTER SENSITIVITY: 0.01%, 0.1%, 1%, 10%, or full scale range (none).

READING HOLD SENSITIVITY: 0.01%, 0.1%, 1%, or 10% of reading.

TRIGGER DELAY: 0 to 99 hours (1ms step size).

EXTERNAL TRIGGER DELAY: 2ms + <1ms jitter with auto zero off, trigger delay = 0.

MEMORY SIZE: 1024 readings.

MATH FUNCTIONS

Rel, Min/Max/Average/Std. Dev/Peak-to-Peak (of stored reading), Limit Test, %, and mX+b with user defined units displayed.

REMOTE INTERFACE

Keithley 182 emulation.

GPIB (IEEE-488.2) and RS-232C.

SCPI (Standard Commands for Programmable Instruments).

GENERAL SPECIFICATIONS

POWER SUPPLY: 100V/120V/220V/240V.

LINE FREQUENCY: 50Hz, 60Hz, and 400Hz, automatically sensed at power-up.

POWER CONSUMPTION: 22VA

OPERATING ENVIRONMENT: Specified for 0° to 50°C. Specified to 80% RH at 35°C.

MAGNETIC FIELD DENSITY: 10mV range 4.0s response noise tested to 500 gauss.

STORAGE ENVIRONMENT: -40° to 70°C.

WARRANTY: 3 years.

SAFETY: Complies with European Union Directive 73/23/EEC (low voltage directive); meets EN61010-1 safety standard. Installation category I.

EMC: Complies with European Union Directive 89/336/EEC (CE marking requirement), FCC part 15 class B, CISPR 11, IEC 801-2, IEC-801-3, IEC 801-4.

VIBRATION: MIL-PRF-28800E Type III, Class 5.

WARM-UP: 2.5 hours to rated accuracy.

DIMENSIONS: Rack Mounting: 89mm high x 213mm wide x 370mm deep (3.5in x 8.375in x 14.563in). Bench Configuration (with handles and feet): 104mm high x 238mm wide x 370mm deep (4.125in x 9.375in x 14.563in).

SHIPPING WEIGHT: 5kg (11 lbs).

ACCESSORIES SUPPLIED

2107-4: Low Thermal Input Cable with spade lugs, 1.2m (4 ft).

User manual, service manual, contact cleaner, line cord, alligator clips.

ACCESSORIES AVAILABLE

2107-30: Low Thermal Input Cable with spade lugs, 9.1m (30 ft)

2182-KIT: Low Thermal Connector with strain relief

2188: Low Thermal Calibration Shorting Plug

2187-4: Input Cable with safety banana plugs

4288-1: Single Fixed Rack Mount Kit

4288-2: Dual Fixed Rack Mount Kit

7007-1: Shielded GPIB Cable, 1m (3.2 ft)

7007-2: Shielded GPIB Cable, 2m (6.5 ft)

7009-5: Shielded RS-232 Cable 1.5m (5 ft)

8501-1: Trigger-Link Cable 1m (3.2 ft)

8501-2: Trigger-Link Cable 2m (6.5 ft)

8502: Trigger-Link Adapter to 6 female BNC connectors

8503: Trigger-Link Cable to 2 male BNC connectors

Notes:

- Relative to calibration accuracy.
- With Analog Filter on, add 20ppm of reading to listed specification.
- When properly zeroed using REL function. If REL is not used, add 100nV to the range accuracy.
- Specifications include the use of ACAL function. If ACAL is not used, add 9ppm of reading/°C from T_{CAL} to the listed specification. T_{CAL} is the internal temperature stored during ACAL.
- For 5PLC with 2-reading Digital Filter. Use $\pm(4ppm \text{ of reading} + 2ppm \text{ of range})$ for 1PLC with 10-reading Digital Filter.
- Channel 2 must be referenced to Channel 1. Channel 2 HI must not exceed 125% (referenced to Channel 1 LO) of Channel 2 range selected.
- Noise behavior using 2188 Low Thermal Short after 2.5 hour warm-up, $\pm 1^\circ C$. Analog Filter off. Observation time = 10X response time or 2 minutes, whichever is less.
- For L_{SYNC} On, line frequency $\pm 0.1\%$. If L_{SYNC} Off, use 60dB.
- For $1k\Omega$ unbalance in LO lead. AC CMRR is 70dB.
- For Low Q mode On, add the following to DC noise and range accuracy at stated response time: 200nV p-p @ 25s, 500nV p-p @ 4.0s, 1.2 μV p-p @ 1s, and 5 μV p-p @ 85ms.
- After 2.5 hour warm-up, $\pm 1^\circ C$, 5PLC, 2 minute observation time, Channel 1 10mV range only.
- For Channel 1 or Channel 2, add 0.3°C for external reference junction. Add 2°C for internal reference junction.
- Speeds are for 60Hz (50Hz) operation using factory defaults operating conditions (*RST). Autorange Off, Display Off, Trigger Delay = 0, Analog Output off.
- Speeds include measurements and binary data transfer out the GPIB. Analog Filter On, 4 readings/s max.
- Auto Zero Off, NPLC = 0.01.
- 10mV range, 80 readings/s max.
- Sample count = 1024, Auto Zero Off.
- For L_{SYNC} On, reduce reading rate by 15%.
- For Channel 2 Low Q mode Off, reduce reading rate by 30%.
- Front Auto Zero Off, Auto Zero Off.
- Applies to measurements of room temperature resistances $< 10k\Omega$, Isource range $\leq 20\mu A$
- Display off, delay 1ms

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	SYS
-350	Queue overflow	SYS
-330	Self-test failed	EE
-314	Save/recall memory lost	EE
-315	Configuration memory lost	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
-158	String data not allowed	EE
-154	String too long	EE
-151	Invalid string data	EE
-150	String data error	EE

Table B-1 (cont.)
Status and error messages

Number	Description	Event
-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
+101	Operation complete	SE
+121	Device calibrating	SE
+125	Device measuring	SE
+171	Waiting in trigger layer	SE
+174	Re-entering the idle layer	SE
+180	Filter settled	SE
+301	Reading overflow	SE
+302	Low limit 1 event	SE
+303	High limit 1 event	SE
+304	Low limit 2 event	SE
+305	High limit 2 event	SE
+306	Reading available	SE

Table B-1 (cont.)
Status and error messages

Number	Description	Event
+308	Buffer available	SE
+309	Buffer half full	SE
+310	Buffer full	SE
	Calibration messages:	
+400	10m vdc zero error	EE
+401	1 vdc zero error	EE
+402	10 vdc zero error	EE
+403	100 vdc zero error	EE
+404	10 vdc full scale error	EE
+405	-10 vdc full scale error	EE
+406	100 vdc full scale error	EE
+408	10 vdc ch2 high zero error	EE
+409	10 vdc ch2 low zero error	EE
+410	B_7_div100 ACAL error	EE
+411	B_0_div100 ACAL error	EE
+412	B_7_1 ACAL error	EE
+413	B_0_1 ACAL error	EE
+414	B_1_1 ACAL error	EE
+415	B_1_10 ACAL error	EE
+416	B_0_10 ACAL error	EE
+417	B_P1_10 ACAL error	EE
+418	B_P1_100 ACAL error	EE
+419	B_0_10 ACAL error	EE
+420	Analog output zero error	EE
+421	Analog positive gain error	EE
+422	Analog negative gain error	EE
+423	B_0_100 ACAL error	EE
+430	Precal selection error	EE
+432	ACAL Temperature Error	EE
+438	Date of calibration not set	EE
+439	Next date of calibration not set	EE
+440	Gain aperture correction error	EE
+449	10 vdc ch2 Low-Q zero error	EE
+500	Calibration data invalid	EE
+510	Reading buffer data lost	EE
+511	GPIB address lost	EE
+512	Power-on state lost	EE
+514	DC calibration data lost	EE
+515	Calibration dates lost	EE
+516	Linearity precal lost	EE
+522	GPIB communication language lost	EE

*Table B-1 (cont.)
Status and error messages*

Number	Description	Event
+610	Questionable Calibration	EE
+611	Questionable Temperature Measurement	EE
+612	Questionable ACAL	SE
+800	RS-232 Framing Error detected	EE
+802	RS-232 Overrun detected	EE
+803	RS-232 Break detected	EE
+805	Invalid system communication	EE
+806	RS-232 Settings Lost	EE
+807	RS-232 OFLO: Characters Lost	EE
+808	ASCII only with RS-232	EE
+900	Internal System Error	EE
+953	DDC Uncalibrated Error	EE
	DDC Status Model:	
+960	DDC Mode IDDC Error	EE
+961	DDC Mode IDDCO Error	EE
	Keithley 182 Serial Poll Byte Events:	
+962	DDC Ready	SE
+963	DDC Reading Done	SE
+964	DDC Buffer Half Full	SE
+965	DDC Buffer Full	SE
+966	DDC Reading overflow	SE

EE = error event

SE = status event

SYS = system error event

C Measurement Considerations

Measurement considerations

Low-level voltage measurements made using the Model 2182 can be adversely affected by various types of noise or other unwanted signals that can make it very difficult to obtain accurate voltage readings. Some of the phenomena that can cause unwanted noise include thermoelectric effects (thermocouple action), source resistance noise, magnetic fields, and radio frequency interference. The following paragraphs discuss the most important of these effects and ways to minimize them.

NOTE For comprehensive information on low-level measurements, see the “Low Level Measurements” handbook, which is available from Keithley.

Thermoelectric potentials

Thermoelectric potentials (thermal EMFs) are small electric potentials generated by differences in temperature at the junction of dissimilar metals. The following paragraphs discuss how such thermals are generated and ways to minimize their effects.

Thermoelectric coefficients

As shown in [Table C-1](#), the magnitude of thermal EMFs generated depends on the particular materials involved. Best results are obtained with clean copper-to-copper connections as indicated in the table.

Table C-1

Table C-2 Material thermoelectric coefficients

Material	Thermoelectric Potential
Copper-Copper	0.2 μ V/ $^{\circ}$ C
Copper-Silver	0.3 μ V/ $^{\circ}$ C
Copper-Gold	0.3 μ V/ $^{\circ}$ C
Copper-Cadmium/Tin	0.3 μ V/ $^{\circ}$ C
Copper-Lead/Tin	1–3 μ V/ $^{\circ}$ C
Copper-Kovar	40 μ V/ $^{\circ}$ C
Copper-Silicon	400 μ V/ $^{\circ}$ C
Copper-Copper Oxide	1000 μ V/ $^{\circ}$ C

Thermoelectric generation

Figure C-1 shows a representation of how thermal EMFs are generated. The test leads are made of the A material, while the source under test is the B material. The temperatures between the junctions are shown as T_1 and T_2 . To determine the thermal EMF generated, the following relationship may be used:

$$E_T = Q_{AB} (T_1 - T_2)$$

where: E_T = Generated thermal EMF

Q_{AB} = Thermoelectric coefficient of material A with respect to material B ($\mu\text{V}/^\circ\text{C}$)

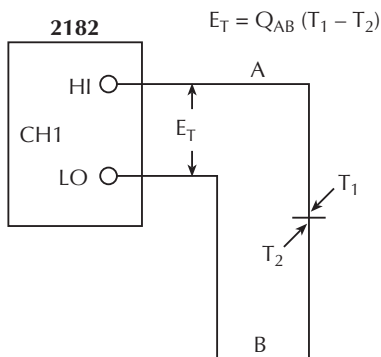
T_1 = Temperature of B junction ($^\circ\text{C}$ or K)

T_2 = Temperature of A junction ($^\circ\text{C}$ or K)

In the unlikely event that the two junction temperatures are identical, no thermal EMFs will be generated. More often, the two junction temperatures will differ, and considerable thermal EMFs will be generated.

A typical test setup will probably have several copper-to-copper junctions. As pointed out earlier, each junction can have a thermoelectric coefficient as high as $0.2\mu\text{V}/^\circ\text{C}$. Since the two materials will frequently have a several degree temperature differential, it is easy to see how thermal potentials of several microvolts can be generated even if reasonable precautions are taken.

Figure C-1
Thermal EMF generation



Minimizing thermal EMFs

To minimize thermal EMFs, use only copper wires, lugs, and test leads for the entire test setup. Also, it is imperative that all connecting surfaces are kept clean and free of oxides. As noted in [Table C-1](#), copper-to-copper oxide junctions can result in thermal EMFs as high as 1mV/°C.

Even when low-thermal cables and connections are used, thermal EMFs can still be a problem in some cases. It is especially important to keep the two materials forming the junction at the same temperature. Keeping the two junctions close together is one way to minimize such thermal problems. Also, keep all junctions away from air currents; in some cases, it may be necessary to thermally insulate sensitive junctions to minimize temperature variations. When a Cu–Cu connection is made, sufficient pressure must be applied to ensure the connection is gas tight to prevent future oxidation.

In some cases, connecting the two thermal junctions together with good thermal contact to a common heat sink may be required. Unfortunately, most good electrical insulators are poor conductors of heat. In cases where such low thermal conductivity may be a problem, special insulators that combine high electrical insulating properties with high thermal conductivity may be used. Some examples of these materials include hard anodized aluminum, sapphire, and diamond.

Nulling residual thermal offsets

Even if all reasonable precautions are taken, some residual thermal offsets may still be present. These offsets can be minimized by using the Model 2182 Relative feature to null them out. To do so, place the instrument on the 3mV range and short the end of the connecting cable nearest the measured source (first disconnect the cable from the source to avoid shorting out the source). After allowing the reading to settle, press the front panel REL button to null the offset. Select the appropriate range, and make your measurement as usual.

If the offset voltage varies, the DC current-reversal technique should be used instead of REL. The DC current-reversal technique requires a source that can output currents equal in magnitude but opposite in polarity. In general, a voltage measurement is performed on both the positive and negative alternations of the current source. The averaged difference of those two readings cancels the thermal EMF component of the measurements. The Model 2182 can automatically perform the measurements and calculate and display the result by using the Delta measurement mode. See “Delta” in [Section 5](#) for details.

Source resistance noise

Noise present in the source resistance is often the limiting factor in the ultimate resolution and accuracy of Model 2182 measurements. The paragraphs below discuss the generation of Johnson noise as well as ways to minimize such noise.

Johnson noise equation

The amount of noise present in a given resistance is defined by the Johnson noise equation as follows:

$$E_{\text{RMS}} = \sqrt{4kTRF}$$

where: E_{RMS} = rms value of the noise voltage
 k = Boltzmann's constant (1.38×10^{-23} J/K)
 T = Temperature (K)
 R = Source resistance (ohms)
 F = Noise bandwidth (Hz)

At a room temperature of 293K (20°C), the above equation simplifies to:

$$E_{\text{RMS}} = 1.27 \times 10^{-10} \sqrt{RF}$$

Since the peak to peak noise is five times the rms value 99% of the time, the peak to peak noise can be equated as follows:

$$E_{\text{p-p}} = 6.35 \times 10^{-10} \sqrt{RF}$$

For example, with a source resistance of 10k Ω , the noise over a 0.5Hz bandwidth at room temperature will be:

$$E_{\text{p-p}} = 6.35 \times 10^{-10} \sqrt{(10 \times 10^3)(0.5)}$$

$$E_{\text{p-p}} = 45\text{nV}$$

Minimizing source resistance noise

From the above examples, it is obvious that noise can be reduced in several ways: (1) lower the temperature; (2) reduce the source resistance; and (3) narrow the bandwidth. Of these three, lowering the resistance is the least practical because the signal voltage will be reduced more than the noise. For example, decreasing the resistance of a current shunt by a factor of 100 will also reduce the voltage by a factor of 100, but the noise will be decreased only by a factor of 10.

Very often, cooling the source is the only practical method available to reduce noise. Again, however, the available reduction is not as large as it might seem because the reduction is related to the square root of the change in temperature. For example, to cut the noise in half, the temperature must be decreased from 293K to 73.25K, a four-fold decrease.

Magnetic fields

When a conductor loop cuts through magnetic lines of force, a very small current is generated. This phenomenon will frequently cause unwanted signals to occur in the test leads of a test system. If the conductor has sufficient length or cross-sectional area, even weak magnetic fields such as those of the earth can create sufficient signals to affect low-level measurements.

Three ways to reduce these effects are: (1) reduce the lengths of the connecting cables, (2) minimize the exposed circuit area, and (3) change the orientation of the leads or cables. In extreme cases, magnetic shielding may be required. Special metal with high permeability at low flux densities (such as mu metal) are effective at reducing these effects.

Even when the conductor is stationary, magnetically-induced signals may still be a problem. Fields can be produced by various sources such as the AC power line voltage. Large inductors such as power transformers can generate substantial magnetic fields, so care must be taken to keep the Model 2182 voltage source and connecting cables a good distance away from these potential noise sources.

Radio frequency interference

RFI (Radio Frequency Interference) is a general term used to describe electromagnetic interference over a wide range of frequencies across the spectrum. Such RFI can be particularly troublesome at low signal levels, but it can also affect measurements at high levels if the fields are of sufficient magnitude.

RFI can be caused by steady-state sources such as radio or TV signals, or some types of electronic equipment (microprocessors, high speed digital circuits, etc.), or it can result from impulse sources, as in the case of arcing in high-voltage environments. In either case, the effect on the measurement can be considerable if enough of the unwanted signal is present.

RFI can be minimized in several ways. The most obvious method is to keep the Model 2182 voltage source and signal leads as far away from the RFI source as possible. Additional shielding of the instrument, signal leads, sources, and other measuring instruments will often reduce RFI to an acceptable level. In extreme cases, a specially-constructed screen room may be required to sufficiently attenuate the troublesome signal.

The Model 2182 digital filter may help to reduce RFI effects in some situations. In some cases, additional external filtering may also be required. Keep in mind, however, that filtering may have detrimental effects such as increased settling time on the desired signal.

Ground loops

When two or more instruments are connected together, care must be taken to avoid unwanted signals caused by ground loops. Ground loops usually occur when sensitive instrumentation is connected to other instrumentation with more than one signal return path such as power line ground. As shown in [Figure C-2](#), the resulting ground loop causes current to flow through the

instrument LO signal leads and then back through power line ground. This circulating current develops a small but undesirable voltage between the LO terminals of the two instruments. This voltage will be added to the source voltage, affecting the accuracy of the measurement.

Figure C-2
Power line ground loops

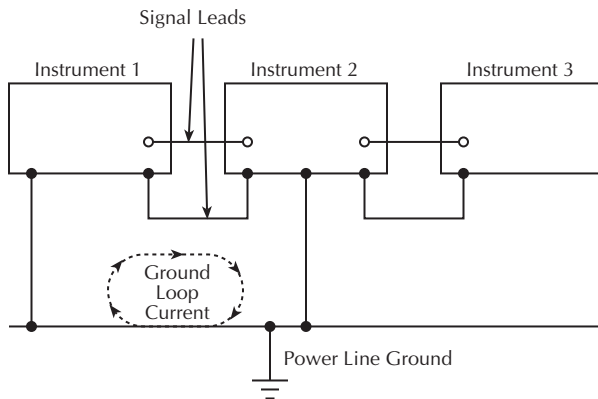
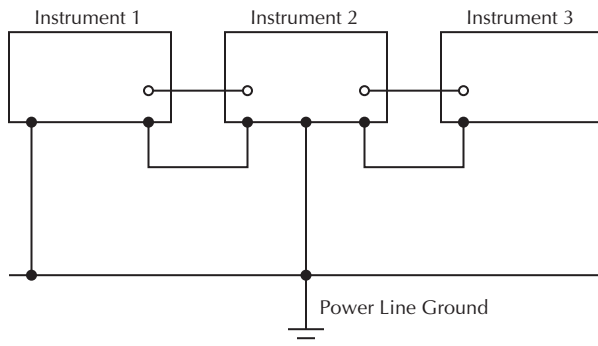


Figure C-3 shows how to connect several instruments together to eliminate this type of ground loop problem. Here, only one instrument is connected to power line ground.

Ground loops are not normally a problem with instruments like the Model 2182 that have isolated LO terminals. However, all instruments in the test setup may not be designed in this manner. When in doubt, consult the manual for all instrumentation in the test setup.

Figure C-3
Eliminating ground loops



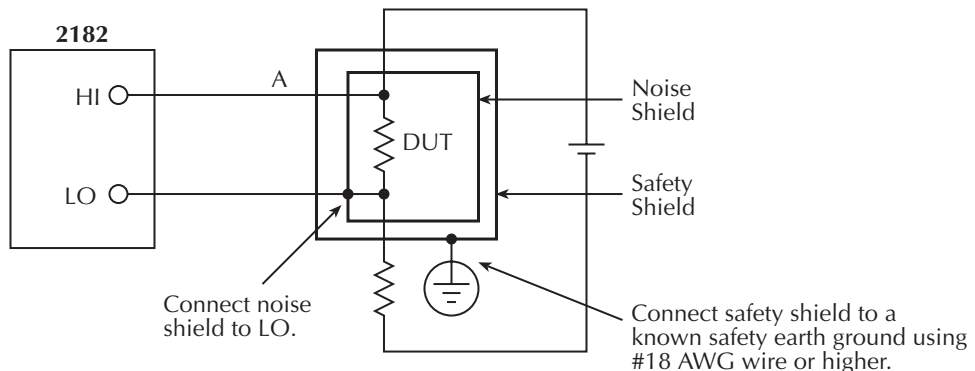
Shielding

Proper shielding of all signal paths and sources being measured is important to minimize noise pickup in virtually any low-level measurement situation. Otherwise, interference from such noise sources as line frequency and RF fields can seriously corrupt measurements, rendering experimental data virtually useless.

In order to minimize noise, a closed metal shield surrounding the source may be necessary, as shown in the example of [Figure C-4](#). This shield should be connected to input LO in most cases, although better noise performance may result with the shield connected to chassis ground in some situations.

WARNING Do not float input LO more than 30V rms, 424V peak above earth ground with an exposed shield connected to input LO. To avoid a possible shock hazard, surround the LO shield with a second safety shield that is insulated from the inner shield. Connect this safety shield to safety earth ground using #18 AWG minimum wire before use.

Figure C-4
Shielding example



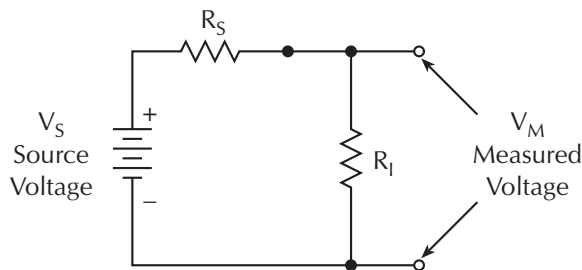
WARNING: Safety shield required when floating noise shield >30V rms above chassis ground.

Meter loading

Loading of the voltage source by the Model 2182 becomes a consideration for high source resistance values. As the source resistance increases, the error caused by meter loading increases.

Figure C-5 shows the method used to determine the percent error due to meter loading. The voltage source, V_S , has a source resistance, R_S , while the input resistance of the Model 2182 is R_I , and the voltage measured by the nanovoltmeter is V_M .

Figure C-5
Meter loading



The voltage actually measured by the meter is attenuated by the voltage divider action of R_S and R_I , and it can be calculated as follows:

$$V_M = \frac{V_S R_I}{R_I + R_S}$$

This relationship can be modified to directly compute for percent error:

$$\text{Percent error} = \frac{100 R_S}{R_I + R_S}$$

From the above equation, it is obvious that the input resistance of the Model 2182 must be at least 999 times the value of source resistance if loading error is to be kept to within 0.1%.

D Model 182 Emulation Commands

The Model 2182 can be configured to accept device-dependent commands of the Keithley Model 182 Sensitive Digital Voltmeter. The commands for controlling the Model 2182 with the 182 language are provided in Table D-1. For details on Model 182 operation, refer to the Model 182 Instruction Manual.

Since the architecture of the Model 2182 differs from that of the Model 182, 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 182 language is intended to be used only over the IEEE-488 bus. Using front panel controls in conjunction with this language may cause erratic operation. In this case, results cannot be guaranteed.

Table D-1

Model 182 device-dependent command summary

Mode	Command	Description	Note
Display ASCII String	A0	Restore display to normal	1
	A1,string	Display string (up to 12 characters)	
Display Resolution	B0	5½-digit resolution	
	B1	6½-digit resolution	
	B2	3½-digit resolution	
	B3	4½-digit resolution	
Calibration	None	C (Calibration) commands not supported	2
Filter Damping	D0	Configure filter damping off (same as P2)	
	D1	Configure filter damping on (same as P3)	
Reading Source	F0	Latest reading from A/D converter	
	F1	One reading from buffer	
	F2	All readings in buffer	
	F3	Maximum value in buffer	
	F4	Minimum value in buffer	
Reading Format	G0	Reading only	3
	G1	Reading with prefix	
	G2	Reading with buffer location	
	G3	Reading with buffer location and prefix	
Immediate Trigger	H0	Initiate manual trigger	4
Buffer Configuration	I0	Disable buffer	5
	I1,value	Buffer on, value = buffer size	
Analog Output Relative	J0	Disable analog output relative	6
	J1	Enable analog output relative using last reading as Rel value	
	J2,value	Enable analog output relative using value ($\pm 1e-9$ to ± 120)	
	J3	Enable analog output relative	
EOI, Bus Hold-off	K0	Enable EOI, enable bus hold-off on X	
	K1	Disable EOI, enable bus hold-off on X	

Table D-1*Model 182 device-dependent command summary (cont'd)*

Mode	Command	Description	Note
	K2	Enable EOI, disable bus hold-off on X	
	K3	Disable EOI, disable bus hold-off on X	
Save/Recall Setup	L0	Save current setup as power-on	
	L1	Recall factory default setup	
	L2	Recall power-on setup	
SRQ Mask	M0	Disable SRQ	
	M1	Reading done	
	M2	Buffer half full	
	M4	Buffer full	
	M8	Reading overflow	
	M16	Ready for command	
	M32	Error	
	M128	Ready for trigger	
Enable/Disable Filter	N0	Enable Filter	
	N1	Disable Filter	
Analog Filter Configuration	O0	Configure analog filter off	
	O1	Configure analog filter on	
Digital Filter Configuration	P0	Configure digital filter off	
	P1	Configure fast response	
	P2	Configure medium response	
	P3	Configure slow response	
Trigger Interval	Qvalue	Interval = value in msec (10 to 999999msec)	
Range	R0	Enable auto-range	
	R1	10mV range	
	R2	100mV range	
	R3	1V range	
	R4	10V range	
	R5	100V range	
	R6	NO-OP (no operation)	
	R7	NO-OP	
	R8	Disable auto-range	
Integration Period	S0	Line cycle integration period	7
	S1	3msec integration period	
	S2	100msec integration period	
	S3	1 second integration period	
Trigger Mode	T0	Multiple on talk	8
	T1	One-shot on talk	
	T2	Multiple on GET	
	T3	One-shot on GET	

Table D-1*Model 182 device-dependent command summary (cont'd)*

Mode	Command	Description	Note
	T4 T5 T6 T7 T8 T9 T10	Multiple on X One-shot on X Multiple on external One-shot on external Multiple on manual (TRIG key) or bus H0X One-shot on manual (TRIG key) or bus H0X Disable all triggers	
Alternate Output	U0 U1 U2 U3 U4 U5 U6 U7 U8 U9 U10 U12 U13	Send machine status Send error conditions Send firmware revision Send buffer length Send buffer average Send buffer standard deviation Send reading relative value Send analog output relative value Send analog output gain value Send trigger interval Send trigger delay Send calibration lock status Send Model 181-like machine status	9
Analog Output	V0,gain	Analog output gain (0.001 to 999999.999)	10
Trigger Delay	W0 Wvalue	Disable trigger delay Enable trigger delay; delay = value (1msec to 999999msec)	
Execute	X	Execute other device-dependent commands	
Terminators	Y0 Y1 Y2 Y3 Y10 Y13	<CR LF> <LF CR> <CR> <LF> <CR LF> <LF CR>	
Reading Relative	Z0 Z1 Z2,value Z3	Disable reading relative Enable reading relative using next reading Enable reading relative using value ($\pm 1e-9$ to ± 120) Enable reading relative, use present value	11

NOTES:

1. **“A” Commands** — The maximum number of characters for the A1 command string is 12. The A2 and A3 commands are not supported.
2. **“C” Commands** — Calibration commands are not supported by the 182 language. You must use the SCPI language to calibrate the Model 2182 over the bus.
3. **“G” Commands** — The G4 through G7 commands are not supported by the 182 language. The Model 182 does not use time stamp.
4. **“H” Commands** — The H1 command is not supported by the 182 language.
5. **“I” Commands** — The minimum buffer size for the Model 2182 is 2, while the minimum buffer size for the Model 182 is 1. Therefore, to set minimum buffer size, I1,0 is valid for the Model 182 and I1,2 is valid for the Model 2182. The I2 command (circular buffer) is not supported.
6. **“J” Commands** — For the Model 2182, J1 uses the last reading as the Rel value (whereas, the J1 command for the Model 182 uses the next reading as the Rel value). The J3 command simply enables analog output relative and uses the present Rel value.
7. **“S” Commands** — The S3 command has been added to include a 1 second integration period.
8. **“T” Commands** — The front panel TRIG key is always operational, even when T10X is sent to disable all triggers.
9. **“U” Commands:**
 - **U1** - For the Model 2182, the U1 error status word only supports the IDDC (Invalid Device-Dependent Command) error (bit 0), the IDDCO (Invalid Device-Dependent Command Option) error (bit 2), and the Uncalibrated Error (bit 8). All other bits remain at zero.
 - **U2** - The Model 2182 uses two processors, while the Model 182 uses three processors. Therefore, the U2 command will be formatted to only provide revision levels for the Front Panel Processor and the Main Processor.
10. **U11 and U14** — Not supported.
11. **“V” Commands** — The V1 command is not supported.
12. **“Z” Commands** — For the Model 2182, Z1 uses the last reading as the Rel value (whereas, the Z1 command for the Model 182 uses the next reading as the Rel value). The Z3 command simply enables reading relative and uses the present Rel value.

E Example Programs

Program examples

All examples presume QuickBASIC version 4.5 or higher and a CEC IEEE-488 interface card with CEC driver version 2.11 or higher, with the Model 2182 at address 7 on the IEEE-488 bus.

Changing function and range

The Model 2182 has independent range control for each of its two voltage measurement functions. This means, for example, that autorange can be turned on for DCV1 while leaving it off for DCV2.

Another difference is in the parameter to the range command. In other instruments, a single number was used to denote each range. The parameter of the SCPI RANGE command is given as "the maximum value to measure." The instrument interprets this parameter and goes to the appropriate range. When you query the range with RANGE? the instrument sends back the full-scale value of its present range.

The following example program illustrates changing function and range. It sets the range for several functions, and then takes readings on each of those functions.

Note that the Model 2182 rounds the range parameter to an integer before choosing the appropriate range. Sending SENSE:VOLTage:CHANnel1:RANGE 20.45 will set Channel 1 of the Model 2182 to the 100V range.

```
'Example program to demonstrate changing voltage function and range,  
'taking readings on DCV1 and DCV2  
'For QuickBASIC 4.5 and CEC PC488 interface card  
'Edit the following line to where the QuickBASIC  
'libraries are on your computer  
'$INCLUDE: 'c:\qb45\ieeeqb.bi'  
  
'Initialize the CEC interface as address 21  
CALL initialize(21, 0)  
  
'Reset the SENSE1 subsystem settings, along with the trigger  
'model, each READ? will cause one trigger  
CALL SEND("*rst", status%)  
  
'Set DCV1 for 100V range and DCV2 for 10Vrange  
CALL SEND(7, "sens:volt:chan1:rang 100"status%)  
CALL SEND(7, "sens:volt:chan2:rang 10", status%)  
  
'Switch to DCV2 (Channel 2 volts) and take reading  
CALL SEND(7, "sens:func 'volt'", status%)  
CALL SEND(7, "sens:chan 2; :read?", status%)  
reading$$ = SPACE$(80)  
CALL ENTER(reading$, length%, 7, status%)  
PRINT reading$  
  
'Switch to DCV1 (Channel 1 volts) and take reading  
CALL SEND(7, "sens:func 'volt'", status%)  
CALL SEND(7, "sens:chan 1; :read?", status%)  
reading$$ = SPACE$(80)  
CALL ENTER(reading$, length%, 7, status%)  
PRINT reading$
```

One-shot triggering

Other voltmeters generally have two types of triggering: one-shot and continuous. In one-shot, each activation of the selected trigger source causes one reading. In continuous, the voltmeter is idle until the trigger source is activated, at which time it begins taking readings at a specified rate. Typical trigger sources are:

- IEEE-488 talk
- IEEE-488 Group Execute Trigger (GET)
- "X" command
- External trigger (rear panel BNC)

Arming the instrument to respond to triggers is implicit in the non-SCPI voltmeters. Sending a command to a non-SCPI voltmeter to change any of the trigger controls causes the instrument to arm itself for triggers.

The SCPI trigger model implemented in the Model 2182 gives:

- Explicit control over the trigger source (the TRIGger subsystem).
- A way for completely disabling triggers.

Changing any of the settings in the TRIGger subsystem does not automatically arm the Model 2182 for triggers.

The following program sets up the Model 2182 to take one reading each time it receives an external trigger pulse.

```
'Example program to demonstrate one-shot external triggering
'For QuickBASIC 4.5 and CEC PC488 interface card
'Edit the following line to where the QuickBASIC
'libraries are on your computer
'$INCLUDE: 'c:\qb45\ieeegb.bi'
'Initialize the CEC interface as address 21
CALL initialize(21, 0)
'Reset controls and put trigger model in IDLE state
CALL SEND(7, "*rst", status%)
CALL SEND(7, "trig:sour ext;coun inf", status%)
'start everything
CALL SEND(7, "init", status%)
```

After the Model 2182 receives the INITiate command, it stops at the control source in the trigger model, waiting for a trigger pulse. Each time a pulse arrives at the Trigger Link connector, the Model 2182 takes one reading. Because TRIGger:COUNt has been set to INFinity, the instrument never enters the idle state. You can send the ABORt command to put the instrument in the idle state, disabling triggers until another INITiate command is sent.

Generating SRQ on buffer full

When your program must wait until the Model 2182 has completed an operation, it is more efficient to program the Model 2182 to assert the IEEE-488 SRQ line when it is finished, rather than repeatedly serial polling the instrument. An IEEE-488 controller will typically address the instrument to talk and then unaddress it each time it performs a serial poll. Repeated polling of the Model 2182 will generally reduce its overall reading throughput. Therefore, use the `srq%()` function call.

The Model 2182 provides a status bit for almost every operation it performs. It can be programmed to assert the IEEE-488 SRQ line whenever a status bit becomes true or false. The IEEE-488 controller (your computer) can examine the state of the SRQ line without performing a serial poll, thereby detecting when the Model 2182 has completed its task without interrupting it in the process.

The following example program segment sets up the Model 2182 to assert SRQ when the reading buffer has completely filled and then arms the reading buffer, initiates readings, and waits for the Model 2182 to indicate that the buffer is full.

This is not a complete program. The commands to configure the trigger model and the reading buffer (see the next example) are not shown. The example shown here can be modified for any event in the Model 2182 status reporting system.

```
'Reset STATus subsystem (not affected by *RST)
CALL SEND(7, "stat:pres;*cls", status%)

CALL SEND(7, "stat:meas:enab 512", status%)          'enable BFL
CALL SEND(7, "*sre 1" status%)                      'enable MSB
CALL SEND(7, "trac:feed:cont next", status%)

'Start everything
CALL SEND(7, "init", status%)

WaitSRQ:
IF (NOT(srq%())) THEN GOTO WaitSRQ
CALL SPOLL(7, poll%, status%)
IF (poll% AND 64)=0 THEN GOTO WaitSRQ
```

After the program has detected an asserted SRQ line, it serial polls the Model 2182 to determine if it is the device requesting service. This is necessary for two reasons:

- Serial polling the Model 2182 causes it to stop asserting the SRQ line.
- In test systems that have more than one IEEE-488 instrument programmed to assert SRQ, your program must determine which instrument is actually requesting service.

Once an event register has caused a service request, it cannot cause another service request until you clear it by reading it (in this case using `STATus:MEASurement[:EVENT]?`) or by sending the `*CLS` command.

Storing readings in buffer

The reading buffer in the Model 2182 is flexible and capable. It has three controls, which are found in the TRACe subsystem. There are commands to control:

- The size of the buffer (in readings).
TRACe:POINts <Nrf>
- Where the data is coming from (before or after the CALCulate1 math post-processing).
TRACe:FEED SENSE1 store unprocessed readings
TRACe:FEED CALCulate1 store math processed readings
- Select buffer control mode.
TRACe:FEED:CONTRol NEVER immediately stop storing readings
TRACe:FEED:CONTRol NEXT start now, stop when buffer is full

The following example program sets up the Model 2182 to take 20 readings as fast as it can into the buffer, and then reads the data back after the buffer has filled.

```
'Example program to demonstrate the reading buffer
'For QuickBASIC 4.5 and CEC PC488 interface card
'Edit the following line to where the QuickBASIC
'libraries are on your computer
'$INCLUDE: 'c:\qb45\ieeeqb.bi'
'Initialize the CEC interface as address 21
CALL initialize(21, 0)
'Reset controls and put trigger model in IDLE state
CALL SEND(7, "*rst", status%)
'Reset STATus subsystem (not affected by *RST)
CALL SEND(7, "stat:pres;*cls", status%)
CALL SEND(7, "stat:meas:enab 512", status%)           'enable BFL
CALL SEND(7, "*sre 1", status%)                     'enable MSB
CALL SEND(7, "trig:coun 20", status%)
'TRACe subsystem is not affected by *RST
CALL SEND(7, "trac:poin 20", status%)
CALL SEND(7, "trac:feed sens1;feed:cont next", status%)
'Start everything
CALL SEND(7, "init", status%)
'Initialize reading$ while the 2182 is busy taking readings
reading$ = SPACE$(4000)
WaitSRQ:
IF (NOT(srq%)) THEN GOTO WaitSRQ
CALL SPOLL(7, poll%, status%)
IF (poll% AND 64)=0 THEN GOTO WaitSRQ
CALL SEND(7, "stat:meas?", status%)
CALL ENTER(S$, length%, 16, status%)

CALL SEND(7, "form:elem read,unit" status%)
CALL SEND(7, "trac:data?", status%)
CALL ENTER(reading$, length%, 16, status%)
PRINT reading$
```

NOTE: To repeat buffer storage, send the following command and then repeat the steps following the “Start everything” comment in the previous example.

```
CALL SEND(7, "feed:cont next", status%)
```

Taking readings using the :READ? command

This programming example demonstrates a simple method for taking and displaying (on the computer CRT) a specified number of readings. The number of readings is specified by the :SAMPLE:COUNT command. When :READ? is asserted, the specified number of readings is taken. After all the readings are taken, they are sent to the computer. Note that these readings are also stored in the buffer.

The following program takes 10 readings on the DCV1 function and displays them on the computer CRT.

```
' For QuickBASIC 4.5 and CEC PC488 interface card
' edit the following line to where the QuickBASIC libraries are
' on your computer
' $INCLUDE: 'c:\qb45\ieeeqb.bi

' Initialize the CEC interface as address 21
CALL initialize(21, 0)

' Reset controls, clear buffer and place 2182 in idle
CALL SEND(7, "*rst", status%)
CALL SEND(7, "trac:cle", status%)

CALL SEND(7, "sample:coun 10", status%)
CALL SEND(7, "form:elem read,unit", status%)
CALL SEND(7, "read?", status%)
reading$ = SPACE$ (300)
CALL ENTER(reading$, length%, 16, status%)
PRINT reading$
```

Controlling the Model 2182 via the RS-232 COM2 port

This example program illustrates the use of the Keithley Model 2182 interfaced to the RS-232 COM2 port. The Model 2182 is set up to take 100 readings at the fastest possible rate (2000 per second). The readings are taken, sent across the serial port, and displayed on the screen.

```
' Example program controlling the Model 2182 via the RS-232 COM2 port
' For QuickBASIC 4.5 and CEC PC488 interface card
RD$=SPACE$(1500)           ' Set string space
CLS                         ' Clear screen
PRINT "Set COM2 baud rate to 19200"
PRINT "Set no flow control, and CR as Terminator"

' Configure serial port parameters
ComOpen$="COM2:19200,N,8,1,ASC,CD0,CS0,DS0,LF,OP0,RS,TB8192,RB8192"
OPEN ComOpen$ FOR RANDOM AS #1

' Model 2182 setup commands
' Note Serial communications only operate with SCPI mode....
PRINT #1, "*RST"           ' Clear registers
PRINT #1, "*CLS"           ' Clear Model 2182
PRINT #1, ":INIT:CONF OFF;:ABORT" ' Init off
PRINT #1, ":SENS:FUNC 'VOLT:DC" ' DCV
PRINT #1, ":SENS:CHAN 1"   ' Channel 1
PRINT #1, ":SYST:AZER:STAT OFF" ' Auto zero off
PRINT #1, ":SENS:VOLT:CHAN1:LPAS:STAT OFF" ' Analog filter off
PRINT #1, ":SENS:VOLT:CHAN1:DFIL:STAT OFF" ' Digital filter off
PRINT #1, ":SENS:VOLT:DC:NPLC 0.01" ' NPLC = 0.1
PRINT #1, ":SENS:VOLT:CHAN1:RANG 10" ' 10V range
PRINT #1, ":SENS:VOLT:DC:DIG 4" ' 4 digit
PRINT #1, ":FORM:ELEM READ" ' Reading only
PRINT #1, ":TRIG:COUN 1"   ' Trig count 1
PRINT #1, ":SAMP:COUN 100" ' Sample count 100
PRINT #1, ":TRIG:DEL 0"   ' No trigger delay
PRINT #1, ":TRIG:SOUR IMM" ' Immediate trigger
PRINT #1, ":DISP:ENAB OFF" ' No display
PRINT #1, ":INIT"         ' Send init
SLEEP 1                    ' Wait one second
PRINT #1, ":FETCH?"       ' Read query
LINE INPUT #1, RD$        ' Get data
PRINT RD$                 ' Display data
PRINT #1, ":DISP:ENAB ON" ' Turn on display
PRINT #1, ":SYST:AZER:STAT ON" ' Auto zero on

'Clean up and quit.
finish:
CLOSE #1                   ' Close file
CLEAR                      ' Interface clear
END
```

F IEEE-488 Bus Overview

Introduction

The IEEE-488 bus is a communication system between two or more electronic devices. A device can be either an instrument or a computer. When a computer is used on the bus, it serves as a supervisor of the communication exchange between all the devices and is known as the controller. Supervision by the controller consists of determining which device will talk and which device will listen. As a talker, a device will output information and as a listener, a device will receive information. To simplify the task of keeping track of the devices, a unique address number is assigned to each.

On the bus, only one device can talk at a time and is addressed to talk by the controller. The device that is talking is known as the active talker. The devices that need to listen to the talker are addressed to listen by the controller. Each listener is then referred to as an active listener. Devices that do not need to listen are instructed to unlisten. The reason for the unlisten instruction is to optimize the speed of bus information transfer since the task of listening takes up bus time.

Through the use of control lines, a handshake sequence takes place in the transfer process of information from a talker to a listener. This handshake sequence helps ensure the credibility of the information transfer. The basic handshake sequence between an active controller (talker) and a listener is as follows:

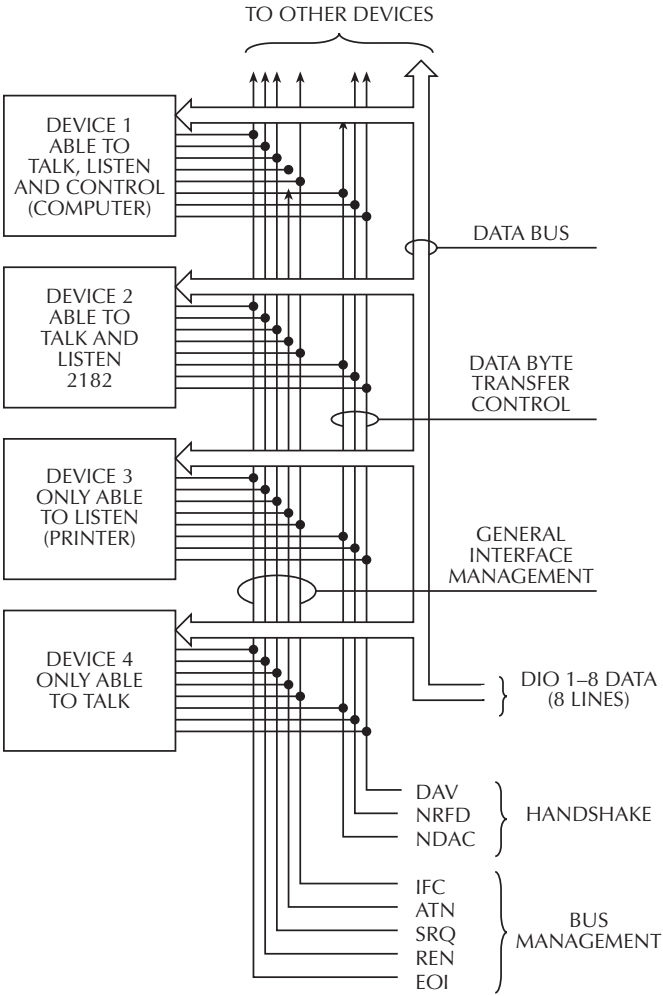
1. The listener indicates that it is ready to listen.
2. The talker places the byte of data on the bus and indicates that the data is available to the listener.
3. The listener, aware that the data is available, accepts the data and then indicates that the data has been accepted.
4. The talker, aware that the data has been accepted, stops sending data and indicates that data is not being sent.
5. The listener, aware that there is no data on the bus, indicates that it is ready for the next byte of data.

Bus description

The IEEE-488 bus, which is also referred to as the GPIB (General Purpose Interface Bus), was designed as a parallel transfer medium to optimize data transfer without using an excessive number of bus lines. In keeping with this goal, the bus has only eight data lines that are used for both data and with most commands. Five bus management lines and three handshake lines round out the complement of bus signal lines.

A typical setup for controlled operation is shown in [Figure F-1](#). Generally, a system will contain one controller and a number of other instruments to which the commands are given. Device operation is categorized into three operators: controller, talker, and listener. The controller controls the instruments on the bus. The talker sends data, while a listener receives data. Depending on the type of instrument, any particular device can be a talker only, a listener only, or both a talker and listener.

Figure F-1
IEEE-488 bus configuration



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 \$7, the actual listen address is \$27 ($\$27 = \$7 + \20). In a similar manner, the talk address is obtained by ORing the primary address with \$40. With the present example, the talk address derived from a primary address of \$7 would be \$47 ($\$47 = \$7 + \$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 2182, 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.

Bus lines

The signal lines on the IEEE-488 bus are grouped into three different categories: data lines, management lines, and handshake lines. The data lines handle bus data and commands, while the management and handshake lines ensure that proper data transfer and operation takes place. Each bus line is active low, with approximately zero volts representing a logic 1 (true). The following paragraphs describe the operation of these lines.

Data lines

The IEEE-488 bus uses eight data lines that transfer data one byte at a time. DIO1 (Data Input/Output) through DIO8 (Data Input/Output) are the eight data lines used to transmit both data and multiline commands and are bi-directional. The data lines operate with low true logic.

Bus management lines

The five bus management lines help to ensure proper interface control and management. These lines are used to send the uniline commands.

ATN (Attention) — The ATN state determines how information on the data bus is to be interpreted.

IFC (Interface Clear) — The IFC line controls clearing of instruments from the bus.

REN (Remote Enable) — The REN line is used to place the instrument on the bus in the remote mode.

EOI (End or Identify) — The EOI line is used to mark the end of a multi-byte data transfer sequence.

SRQ (Service Request) — The SRQ line is used by devices when they require service from the controller.

Handshake lines

The bus handshake lines operate in an interlocked sequence. This method ensures reliable data transmission regardless of the transfer rate. Generally, data transfer will occur at a rate determined by the slowest active device on the bus.

One of the three handshake lines is controlled by the source (the talker sending information), while the remaining two lines are controlled by accepting devices (the listener or listeners receiving the information). The three handshake lines are:

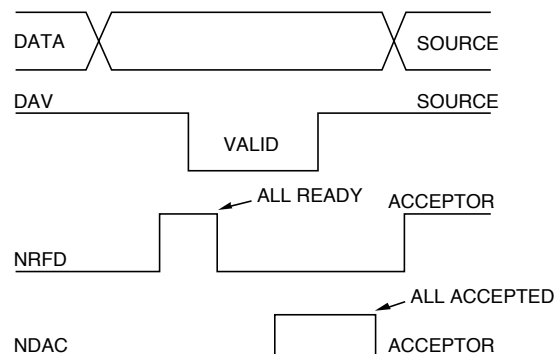
DAV (DATA VALID) — The source controls the state of the DAV line to indicate to any listening devices whether or not data bus information is valid.

NRFD (Not Ready For Data) — The acceptor controls the state of NRFD. It is used to signal to the transmitting device to hold off the byte transfer sequence until the accepting device is ready.

NDAC (Not Data Accepted) — NDAC is also controlled by the accepting device. The state of NDAC tells the source whether or not the device has accepted the data byte.

The complete handshake sequence for one data byte is shown in [Figure F-2](#). Once data is placed on the data lines, the source checks to see that NRFD is high, indicating that all active devices are ready. At the same time, NDAC should be low from the previous byte transfer. If these conditions are not met, the source must wait until NDAC and NRFD have the correct status. If the source is a controller, NRFD and NDAC must be stable for at least 100ns after ATN is set true. Because of the possibility of a bus hang up, many controllers have time-out routines that display messages in case the transfer sequence stops for any reason.

Figure F-2
IEEE-488 handshake sequence



Once all NDAC and NRFD are properly set, the source sets DAV low, indicating to accepting devices that the byte on the data lines is now valid. NRFD will then go low, and NDAC will go high once all devices have accepted the data. Each device will release NDAC at its own rate, but NDAC will not be released to go high until all devices have accepted the data byte.

The previous sequence is used to transfer both data, talk and listen addresses, as well as multiline commands. The state of the ATN line determines whether the data bus contains data, addresses, or commands as described in the following paragraphs.

Bus commands

The instrument may be given a number of special bus commands through the IEEE-488 interface. The following paragraphs briefly describe the purpose of the bus commands which are grouped into the following three categories.

1. Uniline commands — Sent by setting the associated bus lines true. For example, to assert REN (Remote Enable), the REN line would be set low (true).
2. Multiline commands — General bus commands which are sent over the data lines with the ATN line true (low).
3. Common commands — Commands that are common to all devices on the bus; sent with ATN high (false).
4. SCPI commands — Commands that are particular to each device on the bus; sent with ATN (false).

These bus commands and their general purpose are summarized in [Table F-1](#).

Table F-1
IEEE-488 bus command summary

Command type	Command	State of ATN line	Comments
Uniline	REN (Remote Enable)	X	Set up devices for remote operation.
	EOI	X	Marks end of transmission.
	IFC (Interface Clear)	X	Clears interface.
	ATN (Attention)	Low	Defines data bus contents.
	SRQ	X	Controlled by external device.
Multiline Universal	LLO (Local Lockout)	Low	Locks 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.
Unaddressed	UNL (Unlisten)	Low	Removes all listeners from the bus.
	UNT (Untalk)	Low	Removes any talkers from the bus.
Common	—	High	Programs IEEE-488.2 compatible instruments for common operations.
SCPI	—	High	Programs SCPI compatible instruments for particular operations.

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.

Figure F-3
Command codes

D ₇ D ₆ D ₅ D ₄	D ₃ ↓	D ₂ ↓	D ₁ ↓	D ₀ ↓	Column → Row ↓	X	Command	X	Command	X	Primary Address	X	Primary Address	X	Primary Address	X	Primary Address	X	Primary Address	X	Primary Address	X	Primary Address	X	Primary Address	
						0	0 (A)	0 (B)	1 (A)	1 (B)	2 (A)	3 (A)	3 (B)	4 (A)	4 (B)	5 (A)	5 (B)	6 (A)	6 (B)	7 (A)	7 (B)					
0	0	0	0	0	0	NUL	DLE	0	SP	0	0	@	0	P	16	P										
0	0	0	0	1	1	SOH	DC1	1	!	1	1	A	1	Q	17	q										
0	0	0	1	0	2	STX	DC2	2	"	2	2	B	2	R	18	r										
0	0	0	1	1	3	ETX	DC3	3	#	3	3	C	3	S	19	s										
0	1	0	0	0	4	EOT	DC4	4	\$	4	4	D	4	T	20	t										
0	1	0	0	1	5	ENQ	NAK	5	%	5	5	E	5	U	21	u										
0	1	1	0	0	6	ACK	SYN	6	&	6	6	F	6	V	22	v										
0	1	1	1	1	7	BEL	ETB	7	'	7	7	G	7	W	23	w										
1	0	0	0	0	8	BS	CAN	8	(	8	8	H	8	X	24	x										
1	0	0	0	1	9	HT	EM	9	)	9	9	I	9	Y	25	y										
1	0	1	0	0	10	LF	SUB	10	•	10	10	J	10	Z	26	z										
1	0	1	1	1	11	VT	ESC	11	+	11	11	K	11	I	27	{										
1	1	0	0	0	12	FF	FS	12	,	12	12	L	12	\	28	:										
1	1	0	1	0	13	CR	GS	13	-	13	13	M	13	]	29	}										
1	1	1	1	0	14	SO	RS	14	.	14	14	N	14	^	30	=										
1	1	1	1	1	15	SI	US	15	/	15	15	O	15	_	UNT	o										

ADDRESS
COMMAND
GROUP
(ACG)

UNIVERSAL
COMMAND
GROUP
(UCG)

LISTEN
ADDRESS
GROUP
(LAG)

TALK
ADDRESS
GROUP
(TAG)

PRIMARY
COMMAND
GROUP
(PCG)

SECONDARY
COMMAND
GROUP
(SDC)

*PPC (PARALLEL POLL CONFIGURE) PPU (PARALLEL POLL UNCONFIGURE),
and TCT (TAKE CONTROL) not implemented by Model 2182.
Note: D₀ = DIO1 ... D₇ = DIO8; X = Don't Care.

Addressed multiline commands

Addressed commands are multiline commands that must be preceded by the device listen address before that instrument will respond to the command in question. Note that only the addressed device will respond to these commands. Both the commands and the address preceding it are sent with ATN true.

SDC (Selective Device Clear) — The SDC command performs essentially the same function as the DCL command except that only the addressed device responds. Generally, instruments return to their power-up default conditions when responding to the SDC command.

GTL (Go To Local) — The GTL command is used to remove instruments from the remote mode. With some instruments, GTL also unlocks front panel controls if they were previously locked out with the LLO command.

GET (Group Execute Trigger) — The GET command is used to trigger devices to perform a specific action that depends on device configuration (for example, take a reading). Although GET is an addressed command, many devices respond to GET without addressing.

Address commands

Addressed commands include two primary command groups and a secondary address group. ATN is true when these commands are asserted. The commands include:

LAG (Listen Address Group) — These listen commands are derived from an instrument's primary address and are used to address devices to listen. The actual command byte is obtained by ORing the primary address with \$20.

TAG (Talk Address Group) — The talk commands are derived from the primary address by ORing the address with \$40. Talk commands are used to address devices to talk.

SCG (Secondary Command Group) — Commands in this group provide additional addressing capabilities. Many devices (including the Model 2182) do not use these commands.

Unaddress commands

The two unaddress commands are used by the controller to remove any talkers or listeners from the bus. ATN is true when these commands are asserted.

UNL (Unlisten) — Listeners are placed in the listener idle state by the UNL command.

UNT (Untalk) — Any previously commanded talkers will be placed in the talker idle state by the UNT command.

Common commands

Common commands are commands that are common to all devices on the bus. These commands are designated and defined by the IEEE-488.2 standard.

Generally, these commands are sent as one or more ASCII characters that tell the device to perform a common operation, such as reset. The IEEE-488 bus treats these commands as data in that ATN is false when the commands are transmitted.

SCPI commands

SCPI commands are commands that are particular to each device on the bus. These commands are designated by the instrument manufacturer and are based on the instrument model defined by the Standard Commands for Programmable Instruments (SCPI) Consortium's SCPI standard.

Generally, these commands are sent as one or more ASCII characters that tell the device to perform a particular operation, such as setting a range or closing a relay. The IEEE-488 bus treats these commands as data in that ATN is false when the commands are transmitted.

Command codes

Command codes for the various commands that use the data lines are summarized in [Figure F-3](#). Hexadecimal and the decimal values for the various commands are listed in [Table F-2](#).

Table F-2
Hexadecimal and decimal command codes

Command	Hex value	Decimal value
GTL	01	1
SDC	04	4
GET	08	8
LLO	11	17
DCL	14	20
SPE	18	24
SPD	19	25
LAG	20-3F	32-63
TAG	40-5F	64-95
SCG	60-7F	96-127
UNL	3F	63
UNT	5F	95

Typical command sequences

For the various multiline commands, a specific bus sequence must take place to properly send the command. In particular, the correct listen address must be sent to the instrument before it will respond to addressed commands. [Table F-3](#) lists a typical bus sequence for sending the addressed multiline commands. In this instance, the SDC command is being sent to the instrument. UNL is generally sent as part of the sequence to ensure that no other active listeners are present. Note that ATN is true for both the listen command and the SDC command byte itself.

Table F-3
Typical addressed bus sequence

Step	Command	ATN state	Data bus		
			ASCII	Hex	Decimal
1	UNL	Set low	?	3F	63
2	LAG*	Stays low	'	27	39
3	SDC	Stays low	EOT	04	4
4		Returns high			

*Assumes primary address = 7.

[Table F-4](#) gives a typical common command sequence. In this instance, ATN is true while the instrument is being addressed, but it is set high while sending the common command string.

Table F-4
Typical addressed common command sequence

Step	Command	ATN state	Data bus		
			ASCII	Hex	Decimal
1	UNL	Set low	?	3F	63
2	LAG*	Stays low	'	27	39
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 = 7.

IEEE command groups

Command groups supported by the Model 2182 are listed in [Table F-5](#). Common commands and SCPI commands are not included in this list.

Table F-5

IEEE command groups

HANDSHAKE COMMAND GROUP	
	NDAC = NOT DATA ACCEPTED 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

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 2182 are listed in [Table F-6](#).

Table F-6
Model 2182 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 2182 capabilities as follows:

SH (Source Handshake Function) — SH1 defines the ability of the instrument to initiate the transfer of message/data over the data bus.

AH (Acceptor Handshake Function) — AH1 defines the ability of the instrument to guarantee proper reception of message/data transmitted over the data bus.

T (Talker Function) — The ability of the instrument to send data over the bus to other devices is provided by the T function. Instrument talker capabilities (T5) exist only after the instrument has been addressed to talk.

L (Listener Function) — The ability for the instrument to receive device-dependent data over the bus from other devices is provided by the L function. Listener capabilities (L4) of the instrument exist only after it has been addressed to listen.

SR (Service Request Function) — SR1 defines the ability of the instrument to request service from the controller.

RL (Remote-Local Function) — RL1 defines the ability of the instrument to be placed in the remote or local modes.

PP (Parallel Poll Function) — The instrument does not have parallel polling capabilities (PP0).

DC (Device Clear Function) — DC1 defines the ability of the instrument to be cleared (initialized).

DT (Device Trigger Function) — DTI defines the ability of the Model 2182 to have readings triggered.

C (Controller Function) — The instrument does not have controller capabilities (C0).

TE (Extended Talker Function) — The instrument does not have extended talker capabilities (TE0).

LE (Extended Listener Function) — The instrument does not have extended listener capabilities (LE0).

E (Bus Driver Type) — The instrument has open-collector bus drivers (E1).

G IEEE-488 and SCPI Conformance Information

Introduction

The IEEE-488.2 standard requires specific information about how the Model 2182 implements the standard. Paragraph 4.9 of the IEEE-488.2 standard (Std 488.2-1987) lists the documentation requirements. [Table G-1](#) provides a summary of the requirements and provides the information or references the manual for that information. [Table G-2](#) lists the coupled commands used by the Model 2182.

The Model 2182 complies with SCPI version 1991.0. [Table 14-2](#) through [Table 14-11](#) list the SCPI confirmed commands and the non-SCPI commands implemented by the Model 2182.

Table G-1
IEEE-488 documentation requirements

	Requirements	Description or reference
(1)	IEEE-488 Interface Function Codes.	See Appendix F .
(2)	Behavior of 2182 when the address is set outside the range 0-30.	Cannot enter an invalid address.
(3)	Behavior of 2182 when valid address is entered.	Address changes and bus resets.
(4)	Power-On Setup Conditions.	Determine by :SYSTem:POSetup (Section 15).
(5)	Message Exchange Options:	
(a)	Input buffer size.	256 bytes.
(b)	Queries that return more than one response message unit.	None.
(c)	Queries that generate a response when parsed.	All queries (Common Commands and SCPI).
(d)	Queries that generate a response when read.	None.
(e)	Coupled commands.	See Table G-2 .
(6)	Functional elements required for SCPI commands.	Contained in SCPI command subsystems tables (see Table 14-1 through Table 14-12).
(7)	Buffer size limitations for block data.	Block display messages: 12 characters max.
(8)	Syntax restrictions.	See “ Programming syntax ” in Section 11 .
(9)	Response syntax for every query command.	See “ Programming syntax ” in Section 11 .
(10)	Device-to-device message transfer that does not follow rules of the standard.	None.
(11)	Block data response size.	See “ DISPlay subsystem ” in Section 15 .
(12)	Common Commands implemented by 2182.	See “ Common Commands ” in Section 12 .
(13)	Calibration query information.	
(14)	Trigger macro for *DDT.	Not applicable.

Table G-1 (cont.)*IEEE-488 documentation requirements*

	Requirements	Description or reference
(15)	Macro information.	Not applicable.
(16)	Response to *IDN (identification).	See “Common Commands” in Section 12.
(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 12.
(20)	*TST information.	See “Common Commands” in Section 12.
(21)	Status register structure.	See Status Structure in Section 11.
(22)	Sequential or overlapped commands.	All are sequential except :INIT and :INIT:CONT ON, which are overlapped.
(23)	Operation complete messages.	*OPC, *OPC? and *WAI; see “Common Commands” in Section 12.

Table G-2*Coupled commands*

Command	Also changes	To
:TRAC:POIN	:TRAC:FEED:CONT	NEV
:TRAC:CLE	:TRAC:FEED:CONT	NEV
Sense Subsystem Commands:		
...:RANG:UPP	...:RANG:AUTO	OFF
...:REF:ACQ	...:REF	presently displayed reading
:SENS:VOLT:DC:RAT ON	:SENS:VOLT:DC:DELT	OFF
	:SENS:HOLD:STAT	OFF
:SENS:VOLT:DC:DELT ON	:SENS:VOLT:DC:RAT	OFF
	:SENS:HOLD:STAT	OFF
	:SENS:VOLT:DC:CHAN1:DFILT:TCON REP	MOV

... = Valid function command words (i.e., :VOLT:DC, :VOLT:AC, etc.)

H Measurement Queries

:FETCh?

What it does

This command will simply return the latest available reading from an instrument.

Limitations

If the instrument does not have a reading available (indicated by dashes in the display), sending this command will cause a -230, "Data corrupt or stale" error. This query will not cause the box to trigger a reading, nor will it "wait" for a result if a reading is in progress. It is possible to get the same reading over and over using this query. It will continue to give the same result until one of two things has happened:

- A new reading has been triggered
- The old reading has been invalidated by changing ranges, or by changing function.

Where appropriate

Since this query does not trigger a reading, and can give duplicate results, there are not many cases where this command should be used. The ":DATA:FRESh?" query (see page H-4) is often a better choice. If this query is used, the following conditions should be met:

- A reading has been triggered, either by free running (:INIT:CONT ON and :TRIG:SOUR IMM), by some event such as a bus trigger (*TRG), or by an external trigger (:TRIG:SOUR EXT).
- It is confirmed that the reading is completed, either by the setting of the RAV bit in the status model, or by allowing sufficient time to pass for the reading to complete.

:READ?

What it does

This command performs three actions. It will reset the trigger model to the idle layer (equivalent to the :ABORT command), take the trigger model out of idle (equivalent to the :INIT command), and return a reading (equivalent to a "FETCh?" query). This command will always return a new reading, since aborting the trigger model will invalidate any old readings and trigger a new one. This query will "wait" for a new reading to become available before the instrument sends a result back.

Limitations

This command won't work if the trigger source is set for BUS or EXTERNAL. This will cause a -214, "Trigger deadlock" error. Under this condition, one should use a ":FETCh?" query or a ":DATA:FRESh?" query (see page H-4). If the trigger model is continuously initiating (:INIT:CONT ON), sending this query may cause a -213, "Init ignored" error, but will still give a new reading.

When appropriate

If the Model 2182 receives a *RST command, then it defaults to :INIT:CONT OFF, :TRIG:SOUR IMM, and :TRIG:COUNT 1. Sending a ":READ?" query under these conditions will trigger a new reading.

:MEASure[:<function>]?

What it does

This query will reconfigure the instrument to the function specified in the query, set the trigger source for immediate, set the trigger count to 1, and configure the measurement parameters to *RST defaults. It will then trigger a single reading, and return the result.

Limitations

This query is much slower than a ":READ?" or ":FETCh?" query because it has to reconfigure the instrument each time it is sent. It will reset the NPLC, autoranging, and averaging to default settings.

When appropriate

This is an ideal command for taking one-shot measurements if the default settings for a measurement are appropriate and speed is not a requirement.

[[:SENSe[1]]]:DATA:FRESH?

What it does

This query is similar to the “:FETCh?” in that it returns the latest reading from the instrument, but has the advantage of making sure that it does not return the same reading twice.

Limitations

Like the “:FETCh?” query, this command does not trigger a reading.

When appropriate

This is a much better choice than the “:FETCh?” query because it can’t return the same reading twice. This would be a good query to use when triggering by BUS or EXTERNAL, because it will wait for a reading to complete if a reading is in progress.

The “:CALC:DATA:FRESH?” query is similar to the “:DATA:FRESH?” query, but applies to readings which have math applied to them (e.g.:MX+B scaling).

[[:SENSe[1]]]:DATA[:LATest]?

What it does

This query will return the last reading the instrument had, regardless of what may have invalidated that reading, such as changing ranges or functions.

Limitations

This query is fully capable of returning meaningless, old data.

When appropriate

If, for some reason, the user wanted the last completed reading, even after changing ranges or other measurement settings, which would invalidate the old reading.

The “:CALC:DATA:LATest?” query is similar to the “:DATA:LAT?” query, but applies to readings which have math applied to them (e.g.: MX+B scaling).

Examples

One-shot reading, DC volts, no trigger, fastest rate

```

*RST
:INITiate:CONTinuous OFF;:ABORT
:SENSe:FUNCTion 'VOLTagE:DC'
:SENSe:VOLTagE:DC:RANGe 10 // Use fixed range for fastest readings.
:SENSe:VOLTagE:DC:NPLC 0.01 // Use lowest NPLC setting for fastest readings.
:DISPlay:ENABle OFF // Turn off display to increase speed.
:SYSTem:AZERo:STATe OFF // Disable autozero to increase speed, but may cause
// drift over time.

:SENSe:VOLTagE:DC:LPASs OFF // Turn off analog filter for speed.
:SENSe:VOLTagE:DC:DFILter OFF // Turn off digital filter for speed.
:TRIGger:COUNT 1
:READ?
(Enter reading)

```

One-shot reading, DC volts, bus trigger, auto ranging

```

*RST
:INITiate:CONTinuous OFF;:ABORT
:TRIGger:SOURce BUS
:SENSe:FUNCTion 'VOLTagE:DC'
:SENSe:VOLTagE:DC:RANGe:AUTO ON
:TRIGger:COUNT 1
:INITiate
*TRG -or- GPIB GET command // Triggers reading.
:SENSe:DATA:FRESH?
(Enter reading)

```

One-shot reading, external trigger, auto delay enabled

```

*RST
:INITiate:CONTinuous OFF;:ABORT
:TRIGger:SOURce EXTernal
:TRIGger:DELay:AUTO ON // Note: Auto trigger delay only takes effect with
// trigger source set for BUS or EXTernal.

:SENSe:FUNCTion 'VOLTagE:DC'
:SENSe:VOLTagE:DC:RANGe:AUTO ON
:INITiate
(external trigger)
:SENSe:DATA:FRESH?
(Enter reading) // This step will time out if the trigger hasn't occurred.

```

Delta, Pulse Delta, and Differential Conductance

Overview

NOTE *With the use of a bi-polar current source, the Model 2182 can perform basic Delta measurements. See Section 5 of this manual for details on basic Delta measurements.*

This appendix summarizes the enhanced Delta, Pulse Delta, and Differential Conductance measurement processes that can be performed with the use of the Keithley Model 622x Current Source. It does NOT provide the procedures to configure and perform these measurements.

Detailed information on all aspects of Delta, Pulse Delta, and Differential Conductance operation are provided in the Model 622x Reference Manual (Section 5). An abbreviated version of this information is provided in the Model 622x User's Manual (Section 5).

You can use supplied example software that is available on the Keithley website (www.keithley.com) as a learning tool to configure and run Delta, Pulse Delta, and Differential Conductance. With the use of any PC, simple mouse clicks on a virtual front panel of the Model 622x are used to control operation. For details, see "Using the example software" in Section 10 of the Model 622x Reference Manual.

Keithley instrumentation requirements

Keithley instrumentation requirements for Delta, Pulse Delta, and Differential Conductance are as follows:

- **Models 6220 and 2182** – Delta and Differential Conductance measurements.
- **Models 6220 and 2182A** – Delta and Differential Conductance measurements.
- **Models 6221 and 2182** – Delta and Differential Conductance measurements.
- **Models 6221 and 2182A** – Delta, Pulse Delta, and Differential Conductance measurements.

NOTE *The firmware version of the Model 2182 must be A10 or higher.*

The firmware version of the Model 2182A must be C01 or higher.

Operation overview

The Model 6220 or 6221 Current Source can be used with a Model 2182/2182A Nanovoltmeter to perform Delta and Differential Conductance. The Model 2182A/6221 combination can also perform Pulse Delta. These operations use a delta current-reversal technique to cancel the effects of thermal EMFs.

The Model 622x provides a bipolar output current and the Model 2182/2182A performs A/D conversions (measurements) at source high and source low points. An averaging algorithm is then used to calculate the delta reading.

Delta – The Model 622x provides a square wave current output, and the Model 2182/2182A performs A/D conversions (measurements) at each high and low output level. A 3-point moving-average algorithm is used to calculate Delta readings.

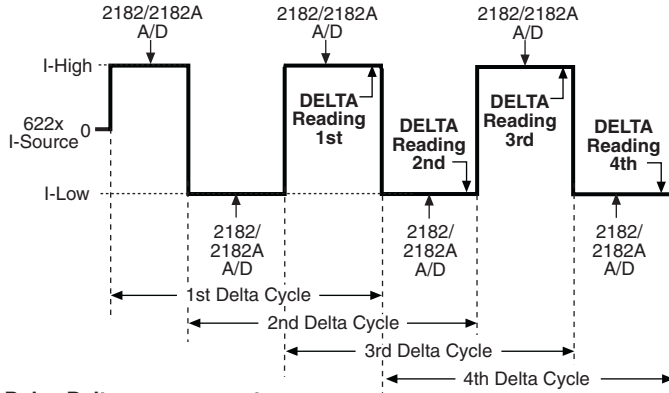
As shown in [Figure I-1A](#), the first three Model 2182/2182A A/D conversions (measurements) yields the first Delta reading. Each subsequent Model 2182/2182A A/D conversion then yields a single Delta reading. Every Delta reading uses the three previous A/Ds to calculate Delta.

Pulse Delta – The Model 6221 outputs pulses and uses 3-point repeating-average measurements to calculate Pulse Delta voltage. For each pulse, the Model 2182A performs an A/D conversion (measurement) at pulse low, pulse high, and pulse low. Each set of three A/D readings yield a single Pulse Delta reading. [Figure I-1B](#) shows Pulse Delta measurements. If device heating is a concern, 2-point measurements can instead be used (2nd low pulse not measured due to corruption from heat).

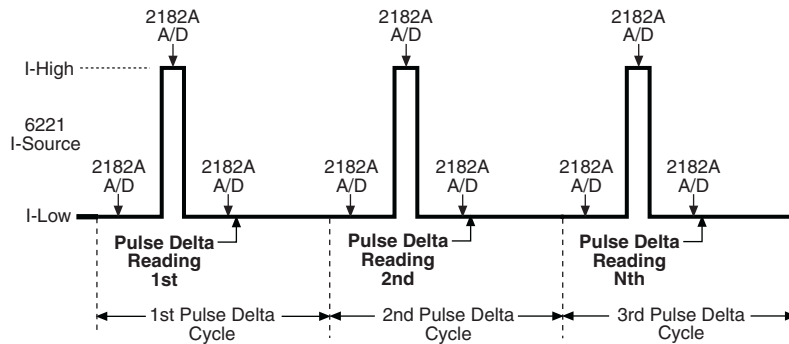
Differential Conductance – The Model 622x outputs a differential current (dI) sweep and measures differential voltage (dV). This function uses a 3-point moving average algorithm to calculate dV. With dI known and dV calculated, the Model 622x can then calculate differential conductance (dG) or differential resistance (dR). [Figure I-1C](#) shows Differential Conductance measurements.

Figure I-1
Delta, Pulse Delta, and Differential Conductance measurements

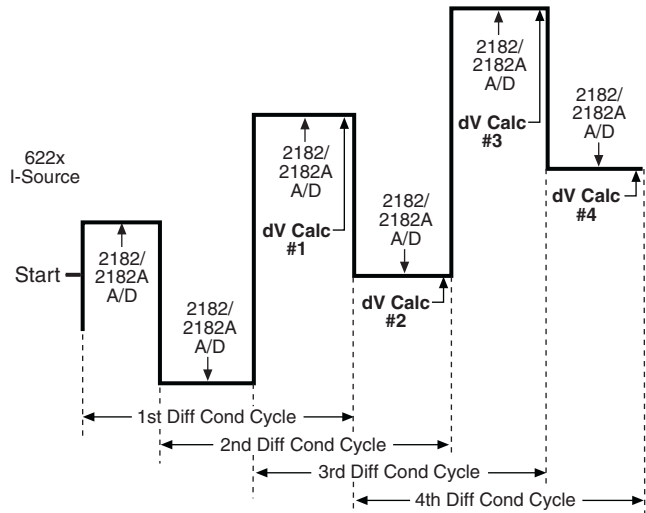
A) Delta measurements



B) Pulse Delta measurements



C) Differential Conductance measurements



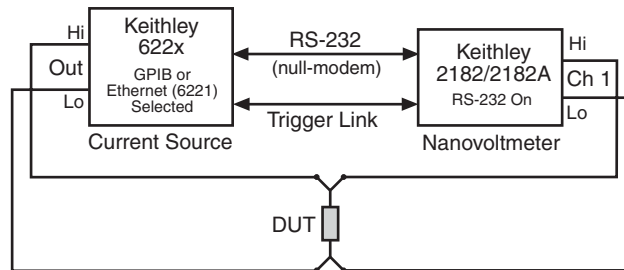
Test system configurations

There are two test system configurations that can be used for Delta, Pulse Delta, and Differential Conductance measurements and are shown in [Figure I-2](#). One is for front panel stand-alone operation and the other is for remote programming (PC control system).

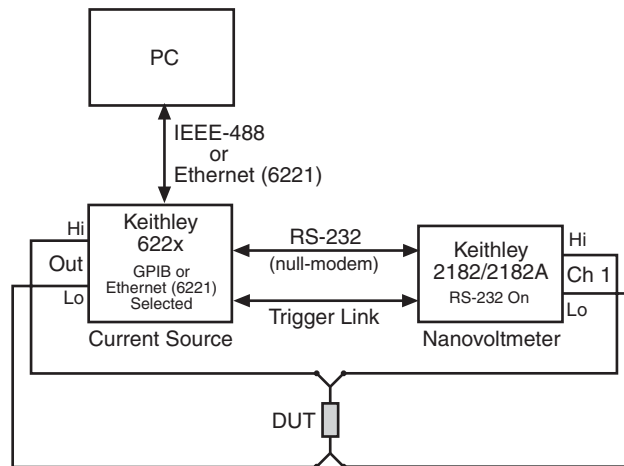
Both systems use serial communications (via RS-232 interface) between the Model 622x and the Model 2182/2182A. The Model 622x sends setup commands to the Model 2182/2182A, and the Model 2182/2182A sends Delta, Pulse Delta, or Differential Conductance readings to the buffer of the Model 622x. Once the test is started, trigger synchronization between the two instruments is controlled by the Trigger Link.

Figure I-2
Test system configurations

A) Stand-alone system (front panel operation)



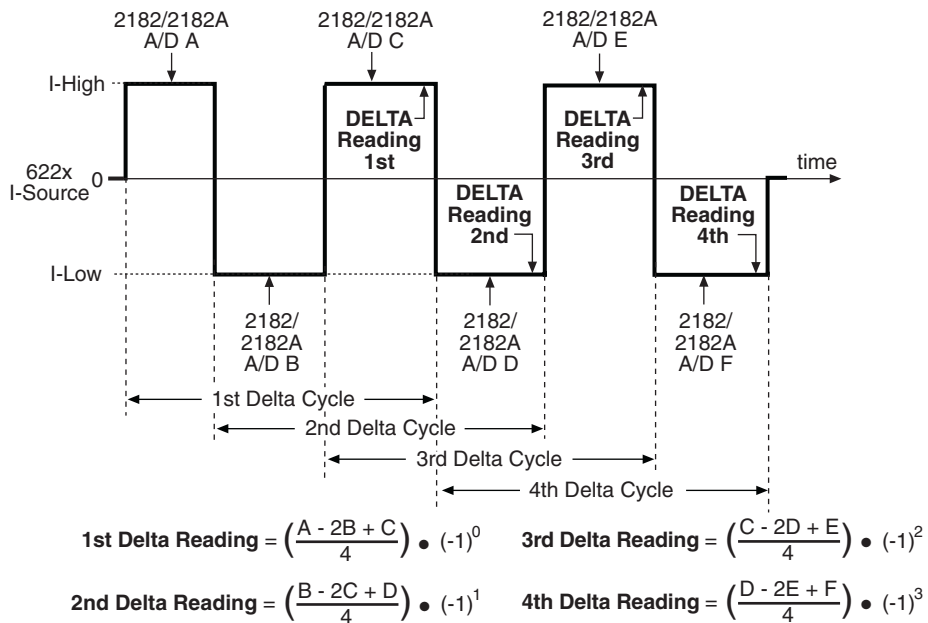
B) PC control of 6220/21



Delta measurement process

The Delta process is shown in [Figure I-3](#). As shown, three Model 2182/2182A A/D conversions are performed to yield a single Delta reading. When Delta starts, three Model 2182/2182A A/Ds (A, B, and C) are performed and the Delta reading is calculated. After the 1st Delta cycle, the moving-average technique is then used. As shown, a Delta reading is yielded for every subsequent Model 2182/2182A A/D. The new A/D replaces the oldest A/D in the Delta calculation.

Figure I-3
Delta measurement technique



The following equation can be used to calculate any Delta reading:

$$Delta = \left(\frac{X - 2Y + Z}{4} \right) \cdot (-1)^n$$

Where: X, Y, and Z are the three A/D measurements for a Delta reading.

n = Delta Cycle Number - 1

Example – Calculate the 21st Delta reading:

X, Y, and Z are the three A/D measurements for the 21st Delta reading.

n = Delta Cycle Number - 1

= 21 - 1

= 20

Therefore,

$$\begin{aligned} Delta &= \left(\frac{X - 2Y + Z}{4} \right) \cdot (-1)^{20} \\ &= \frac{X - 2Y + Z}{4} \end{aligned}$$

The $(-1)^n$ term in the Delta calculation is used for polarity reversal of every other calculated Delta reading. This makes all calculated Delta readings in the test the same polarity.

Delta calculation example

Assume you wish to measure the voltage across a 1Ω DUT using a constant $+10\text{mA}$ current source and a voltmeter. Ideally, the measured voltage would be 10mV ($V = I \times R$). However, due to a $10\mu\text{V}$ thermal EMF in the test leads, the voltmeter actually reads 10.01mV (0.1% error due to EMF).

The error contributed by EMF can be eliminated by using Delta. Assume the square wave output of the Model 622x is set to 10mA (high) and -10mA (low) and the following Model 2182/2182A measurement conversions (A/Ds) are made for the first Delta cycle.

$$\text{A/D A} = 10.01\text{mV}$$

$$\text{A/D B} = -9.99\text{mV}$$

$$\text{A/D C} = 10.01\text{mV}$$

The first Delta reading is calculated as follows:

$$\begin{aligned} \text{Delta} &= \left(\frac{A - 2B + C}{4} \right) \cdot (-1)^0 \\ &= \left(\frac{10.01\text{mV} - 2(-9.99\text{mV}) + 10.01\text{mV}}{4} \right) \cdot 1 \\ &= \left(\frac{40\text{mV}}{4} \right) \\ &= 10\text{mV} \end{aligned}$$

The 10mV Delta reading effectively cancelled the $10\mu\text{V}$ EMF to provide a more accurate measurement.

Measurement units

The fundamental measurement for Delta is voltage (Volts; V). However, the voltage reading can be converted into a conductance (Siemens; S), resistance (Ohms; Ω), or power (Watts; W) reading by the Model 622x.

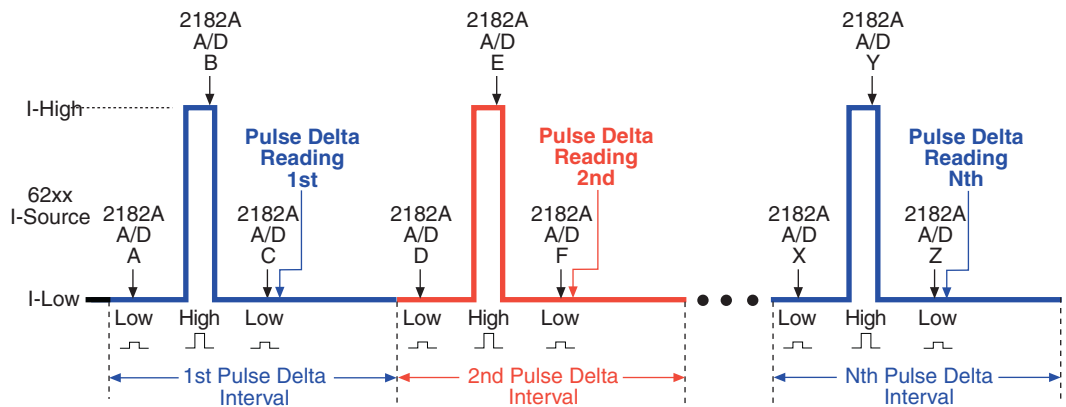
Pulse Delta process

Pulse Delta measurements

For Pulse Delta, the Model 6221 outputs current pulses. Current pulses that have a short pulse width are ideal to test a low-power DUT that is heat sensitive.

By default, Pulse Delta uses a 3-point repeating-average algorithm to calculate readings. Each Pulse Delta reading is calculated using A/D measurements for a low pulse, a high pulse, and another low pulse. The Model 6221 outputs the pulses and the Model 2182A performs the A/D measurements. As shown in Figure I-4, every three pulses yields a single Pulse Delta voltage reading.

Figure I-4
Pulse Delta 3-point measurement technique



$$\text{1st Pulse Delta Reading} = \left(\frac{2B - A - C}{2} \right)$$

$$\text{Nth Pulse Delta Reading} = \left(\frac{2Y - X - Z}{2} \right)$$

Where:

$$\text{2nd Pulse Delta Reading} = \left(\frac{2E - D - F}{2} \right)$$

X, Y, and Z are the A/Ds for the first low, high, and second low pulses for the Pulse Delta cycle.

In cases where the high pulse will cause heating of the DUT, the measurement at the second low pulse could be adversely affected by the heat caused by the high pulse. In that case, the measurement at the second low pulse can be disabled. This does not change the overall timing of the pulse output. Eliminating the second low pulse measurement changes the basic calculation to the following:

$$\text{Pulse Delta} = (2Y - 2X) / 2$$

Where: Y is the measurement at the high pulse.

X is the measurement at the first low pulse.

Pulse Delta calculation example

3-point measurement technique – Assume you want to measure the voltage across a low power 1Ω DUT. The Pulse Delta process will reduce DUT heating and eliminate the effects of thermal EMFs.

Assume the Model 6221 is configured to output +10mA and 0mA pulses. Due to a $10\mu\text{V}$ thermal EMF in the test leads, the following Model 2182A measurement conversions (A/Ds) are made for the first Pulse Delta cycle.

$$\text{A/D A} = 0.01\text{mV}$$

$$\text{A/D B} = 10.01\text{mV}$$

$$\text{A/D C} = 0.01\text{mV}$$

The first Pulse Delta reading (using the 3-point measurement technique) is calculated as follows:

$$\begin{aligned} \text{PulseDelta} &= \left(\frac{2B - A - C}{2} \right) \cdot (-1)^0 \\ &= \frac{2(10.01) - (0.01) - (0.01)}{2} \\ &= \frac{20\text{mV}}{2} \\ &= 10\text{mV} \end{aligned}$$

The above 3-point measurement technique effectively eliminated the $10\mu\text{V}$ thermal EMF from the Pulse Delta reading.

2-point measurement technique – Assume for the above example that DUT heating causes the A/D measurement at point C to be 1.01mV . Using the 3-point measurement technique, Pulse Delta (by calculation) would instead be 9.5mV . This results in 5% measurement error due to heating.

The affects of heating can be eliminated by not performing the measurement at point C (low pulse). For this 2-point measurement technique, Pulse Delta is calculated as follows:

$$\begin{aligned} \text{PulseDelta} &= \left(\frac{2B - 2A}{2} \right) \cdot (-1)^0 \\ &= \frac{2(10.01) - 2(0.01)}{2} \\ &= \frac{20\text{mV}}{2} \\ &= 10\text{mV} \end{aligned}$$

Measurement units

The fundamental Pulse Delta measurement explained on the previous page is in volts. The reading can instead be converted into an Ohms (W), Siemens (S), or Power (W) reading by the Model 622x.

With Power (W) units selected, a Pulse Delta reading can be expressed (and displayed) as a Peak power reading or an Average power reading:

$$W \text{ (peak power)} = I \times V$$

$$W \text{ (Average power)} = I \times V \times \text{Duty Cycle}$$

Pulse Delta outputs

Pulse Delta output is made up of one or more Pulse Delta cycles. Each cycle is made up of three output pulses (low, high, and low). The time period for a cycle is adjustable and is the same for all cycles. The output pulses have an adjustable pulse width, which is the same for all pulses.

There are two basic Pulse Delta output types: Fixed output and Sweep output. For Fixed output, all high and low pulses are fixed for all Pulse Delta cycles in the test. For Sweep output, the sweep (SWP) function of the Model 6221 is used to output a staircased, logarithmic or user-specified (custom) pulse sweep.

Fixed output

Figure I-5 shows one Pulse Delta cycle for a Fixed output. As shown, the Model 6221 outputs a low pulse, a high pulse and then another low pulse during every Pulse Delta cycle. The pulse width is adjustable and is the same for all high and low pulses. The cycle interval is also adjustable and is based on the set number of power line cycles. The Pulse Delta interval shown in Figure I-5 is set for 5 PLC (power line cycles), which is the default setting. After the set interval expires, the next Pulse Delta cycle starts (if pulse count is >1).

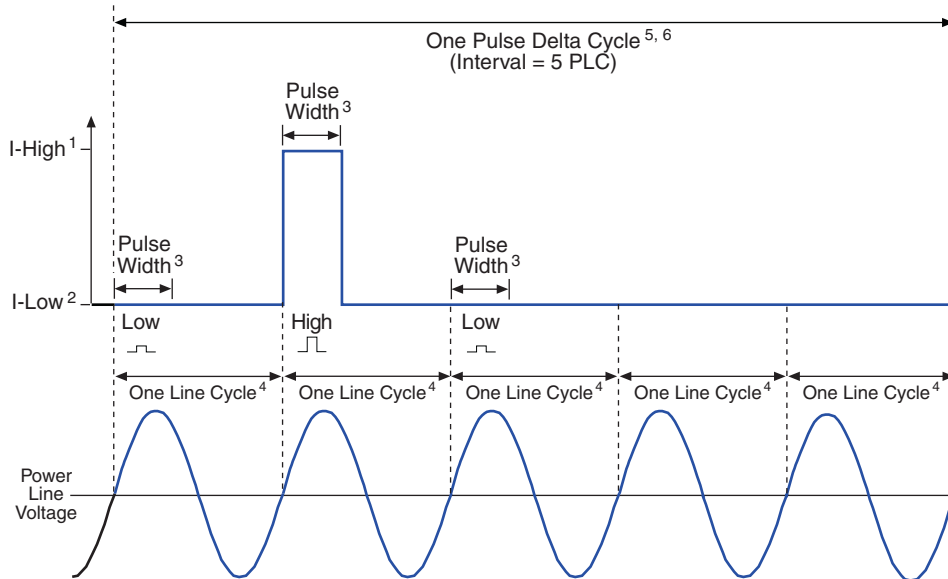
Pulses are synchronized to the frequency of the power line voltage. When Pulse Delta is started, the three pulses (low, high, and low) are generated on the positive-going edges of the first three power line cycles. For the remaining power line cycles in the interval, the output remains at the I-Low level.

Sweep output

The sweep feature of the Model 6221 can be used to output a series of pulses that allow the use of different levels for the high pulses. Each high pulse returns to the programmed low pulse level. The low level is the same for all pulses.

Like the Fixed output shown in Figure I-5, a Sweep output is synchronized to the frequency of the power line voltage, and the pulse width is adjustable and is the same for all pulses.

Figure I-5
Pulse timing



- 1) I-High can be set from -105mA to +105mA (default is 1mA).
- 2) I-Low can be set from -105mA to +105mA (default is 0mA).
- 3) Pulse Width can be set from 50 μ s to 12ms (default is 110 μ s).
- 4) One 60Hz power line cycle = 16.667ms (1/60)
One 50Hz power line cycle = 20ms (1/50)
- 5) With Interval set to 5 PLC (power line cycles):
60Hz: One Pulse Delta cycle = 83.33ms (5/60)
50Hz: One Pulse Delta cycle = 100ms (5/50)
- 6) Interval can be set from 5 to 999999 PLC (default is 5 PLC).

The three available sweeps include (1) staircase sweep, (2) logarithmic sweep and (3) custom sweep. Examples of these Sweep outputs are shown in [Figure I-6](#).

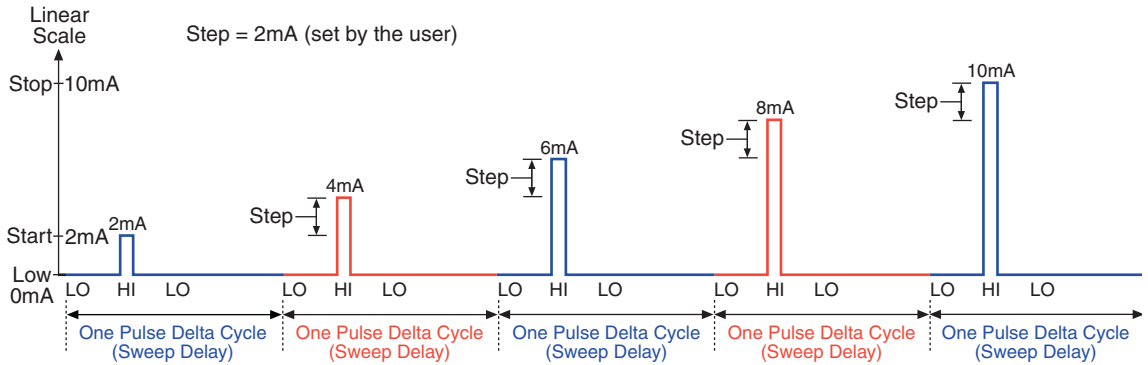
Staircase sweep – [Figure I-6A](#) shows an example of a staircase Sweep output. The sweep is configured to start high pulses at 2mA and staircase to 10mA in 2mA steps. The low pulse level for this sweep is 0mA.

Logarithmic sweep – [Figure I-6B](#) shows an example of a logarithmic Sweep output. The sweep is configured to output five high pulses (points). The first high pulse starts at 1mA and logarithmically steps to 10mA. The low pulse level for this sweep is 0mA.

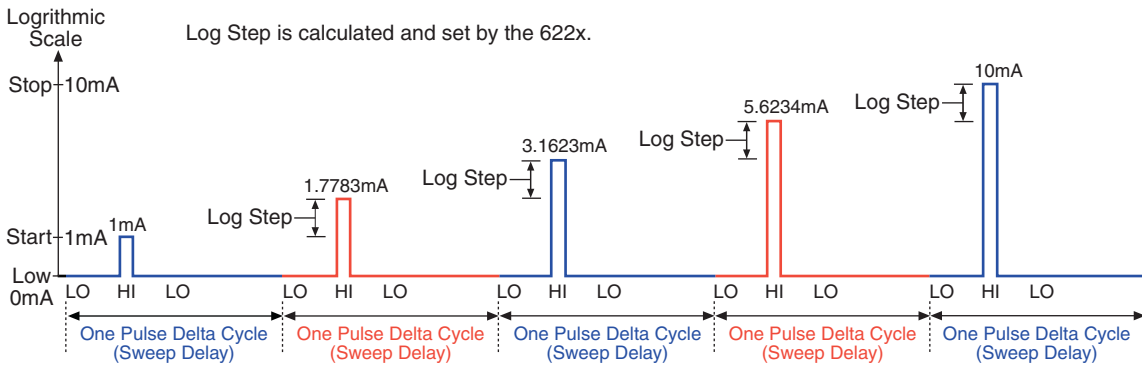
Custom sweep – [Figure I-6C](#) shows an example of a custom Sweep output. The sweep is configured to output five high pulses (points). The level for each high pulse is specified by the user. The high pulse levels for this output are 1mA, 2mA, 4mA, 8mA and 16mA. The low pulse level for this sweep is 0mA.

Figure I-6
Pulse sweep output examples

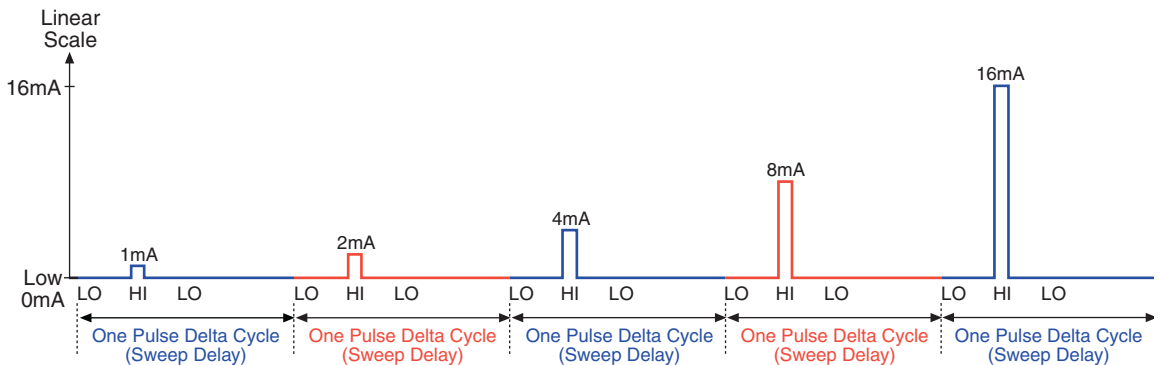
A) Staircase sweep pulse train: 2 to 10mA in 2mA steps



B) Logarithmic sweep pulse train: 1 to 10mA using 5 logarithmic



C) Custom sweep pulse train: 1mA, 2mA, 4mA, 8mA and 16mA (5 points)



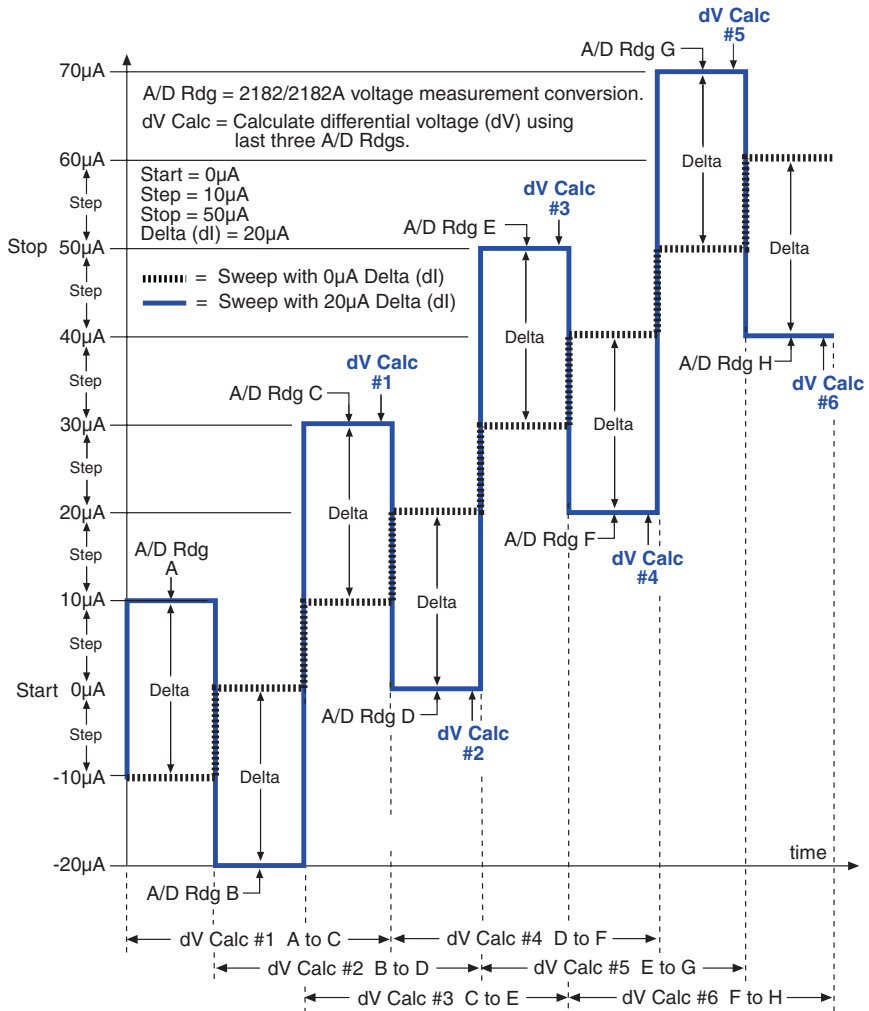
Differential Conductance process

Differential measurements can be used to study the individual slopes of an I-V (or V-I) curve. By applying a known differential current (dI) to a device, differential voltage (dV) measurements can be performed. With dI and dV known, differential conductance (dG) (and differential resistance dR) can be calculated.

This differential measurement process is shown in [Figure I-7](#). The Model 622x is configured to output a stepped sweep with a specified Delta, which is the differential current (dI). As shown in the illustration, Delta is added to and subtracted from each subsequent step in the sweep. The solid line in [Figure I-7](#) is the actual output of the Model 622x.

As shown, each differential voltage calculation (dV Calc) uses the three previous Model 2182/2182A A/D measurement conversions. Keep in mind that dI (Delta) is the same for all calculated points. With dI known and dV calculated, the Model 622x can also calculate, display, and store the differential conductance (dG) or differential resistance (dR) for each calculated point.

Figure I-7
Differential Conductance measurement process



dV Calculations – The following equations are used by the 622x to calculate differential voltage (dV). To calculate dV, points A through H are 2182/2182A voltage measurements (A/D readings).

$$dV \#1 = \frac{[(A-B)/2] + [(C-B)/2]}{2} \bullet (-1)^0 \qquad dV \#4 = \frac{[(D-E)/2] + [(F-E)/2]}{2} \bullet (-1)^3$$

$$dV \#2 = \frac{[(B-C)/2] + [(D-C)/2]}{2} \bullet (-1)^1 \qquad dV \#5 = \frac{[(E-F)/2] + [(G-F)/2]}{2} \bullet (-1)^4$$

$$dV \#3 = \frac{[(C-D)/2] + [(E-D)/2]}{2} \bullet (-1)^2 \qquad dV \#6 = \frac{[(F-G)/2] + [(H-G)/2]}{2} \bullet (-1)^5$$

dG and dR Calculations – With dl known (dl = Delta) and dV calculated, the 622x can then calculate differential conductance (dG) or differential resistance (dR).

With G units selected, readings are calculated as follows: dG = dl/dV.
With R units selected, readings are calculated as follows: dR = dV/dl.

Differential Conductance calculations

dV calculations

While the dV calculations for the first six dV readings are shown in [Figure I-7](#), the following formula can be used to calculate any dV reading in the test:

$$dV = \frac{\frac{(X - Y)}{2} + \frac{(Z - Y)}{2}}{2} \cdot (-1)^n$$

Where: X, Y, and Z are the three A/D measurements for a dV reading.
n = Reading Number - 1

Example – Calculate the 21st dV reading:

X, Y, and Z are the three A/D measurements for the 21st dV reading.

$$\begin{aligned} n &= \text{Reading Number} - 1 \\ &= 21 - 1 \\ &= 20 \end{aligned}$$

Therefore;

$$\begin{aligned} dV &= \frac{\frac{(X - Y)}{2} + \frac{(Z - Y)}{2}}{2} \cdot (-1)^{20} \\ &= \frac{\frac{(X - Y)}{2} + \frac{(Z - Y)}{2}}{2} \end{aligned}$$

The $(-1)^n$ term in the dV calculation is used for polarity reversal of every other calculated dV reading. This makes all calculated dV readings in the test the same polarity.

Simplified dV calculation

The above dV calculation can be simplified as follows:

$$dV = \frac{\frac{X - Y + Z - Y}{2}}{2} \cdot (-1)^n$$

$$dV = \frac{X - 2Y + Z}{4} \cdot (-1)^n$$

Measurement units

The fundamental measurement for Differential Conductance is differential voltage (dV). However, the dV reading can be converted into a differential conductance (dG), differential resistance (dR), or power (Watts) reading by the Model 622x.

With Ohms (dR) or Siemens (dG) measurement units selected, the reading is calculated as follows:

$$dR = dV/dI$$

$$dG = dI/dV$$

With Power measurement units selected, power is calculated using Average Voltage and Average Current and is explained in the following paragraphs.

Average Voltage and Power

Average Voltage calculation

Average Voltage is the average bias voltage that was present across the device when the corresponding Differential Conductance reading was taken. For remote operation, the Average Voltage reading for Differential Conductance can be included in the returned data string.

Average Voltage is calculated as follows:

$$AvgVolt = \frac{\frac{(X + Y)}{2} + \frac{(Z + Y)}{2}}{2}$$

$$AvgVolt = \frac{X + 2Y + Z}{4}$$

Where: AvgVolt is the Average Voltage corresponding to a given the differential voltage (dV) reading.

X, Y, and Z are the three A/D measurements for the dV reading.

Power calculation

With WATTS (power) measurement units selected, power for Differential Conductance is calculated using Average Voltage (see “[Average Voltage calculation](#)”) and Average Current. Average Current is calculated by the Model 622x as follows:

$$AvgCurr = \frac{\frac{(X + Y)}{2} + \frac{(Z + Y)}{2}}{2} \quad \boxed{AvgCurr = \frac{X + 2Y + Z}{4}}$$

Where: AvgCurr is the Average Current corresponding to a given Differential Conductance reading.

X, Y, and Z are the three current levels for the Differential Conductance reading.

With Average Voltage and Average Current known (calculated by the Model 622x), power is then calculated as follows:

$$\boxed{Power = AvgVolt \times AvgCurr}$$

Index

Symbols

- *CLS — Clear Status 12-3
- *ESE – Event Enable 12-4
- *ESE? – Event Enable Query 12-4
- *ESR? – Event Status Register Query 12-6
- *IDN? – Identification Query 12-7
- *OPC – Operation Complete 12-8
- *OPC? – Operation Complete Query 12-10
- *RCL – Recall 12-11
- *RST – Reset 12-12
- *SAV – Save 12-12
- *SRE – Service Request Enable 12-12
- *SRE? – Service Request Enable Query 12-12
- *STB? – Status Byte Query 12-14
- *TRG – Trigger 12-15
- *TST? – Self-Test Query 12-15
- *WAI – Wait-to-Continue 12-16

Numerics

- 4-Wire low-resistance measurement 2-23

A

- ACAL (calibration) 2-5
- Additional SCPI Commands 15-1
- Address commands F-9
- Addressed multiline commands F-9
- Analog filter 3-8
- Analog Output 10-1
- Analog output connections 10-5
- Analog output rel 10-5
- Application - I-V curves using internal scan 9-14
- Applications 2-23
- Autorangeing 3-4
- Autozeroing modes 2-6

B

- Baud rate, flow control and terminator 11-27
- Bipolar source 5-8
- Buffer 6-1
- Buffer operations 6-2
- Buffer statistics 6-4
- Bus commands F-6
- Bus description F-2
- Bus lines F-4
- Bus management lines F-4

C

- Cables, connectors, and adapters 1-4
- CALCulate command summary 14-3
- Calibrating resistor network dividers 5-18
- CALibration command summary (user accessible) 14-4
- Carrying case 1-5
- Changing function and range E-2
- Cleaning input connectors 1-13
- Cleaning test circuit connectors 2-17
- Command codes F-10
- Common Commands F-10
- Common commands F-10
- Configure and control analog output 10-5
- Connection techniques 2-12
- Connections 2-12
- Contact information 1-3
- Control source and event detection 7-4
- Controlling the Model 2182 via the RS-232 COM2 port E-8
- Cryostat 5-20, 5-23
- Custom sweep 5-9, 5-21, 5-25

D

- Data lines F-4
- DC current reversal measurement technique 5-21, 5-23
- DC current-reversal measurement technique 5-19
- DC current-reversal technique 2-24, 5-6, 5-8, 9-14
- Default settings 1-16
- Delay 7-4
- Delta 5-6, I-3, I-6
 - Measurement units I-8
- Delta measurement procedure using a SourceMeter 5-9
- Delta programming example 5-17
- Device action 7-5
- Differential Conductance I-3
 - Average Voltage I-18
 - Calculations I-16
 - Measurement units I-17
 - Power I-18
- Digital filter 3-8
- Digits 3-5
- Display 1-16
- DISPlay command summary 14-5
- DISPlay subsystem 15-3

E

Enabling limits 8-4
Example Programs E-1
External Stepping/Scanning 9-3
External trigger 7-8
External triggering 7-7
External triggering example 7-9
External triggering with BNC connections 7-12

F

Filter 3-8
Filter considerations 5-15
Filter, Rel and Ranging considerations 5-4
FORMat command summary 14-5
FORMat subsystem 15-4
Front and rear panel familiarization 1-7
Front panel GPIB operation 11-12
Front panel summary 1-7
Front panel trigger models 9-4

G

General bus commands 11-9
General information 1-3
Generating SRQ on buffer full E-5
Getting Started 1-1
GPIB bus connections 11-6
GPIB bus standards 11-6
GPIB operation and reference 11-6
Ground loops C-6

H

Handshake lines F-5
Heated Zener Reference 2-27
High power switches 2-25
Hold example 7-6

I

ice bath 2-16, 2-17
Idle 7-3
IEEE command groups F-12
IEEE-488 and SCPI Conformance Information G-1
IEEE-488 Bus Overview F-1
Inspection 1-3
Interface function codes F-13
Interface selection and configuration procedures 11-4
Interfaces 11-3
Internal scanning 9-4, 9-8
Internal stepping 9-9
Internal Stepping/Scanning (Channels 1 and 2) 9-3
IV curves 9-14

J

Josephson Junction Arra 2-27

L

Languages 11-3
Limit operations 8-3
Limits 8-1
Line power connection 1-14
Log sweep 5-24
Low power switches 2-24
Low-level considerations 2-22
Low-resistance measurement 2-23
LSYNC (line cycle synchronization) 2-8

M

magnetic field 5-20, 5-22, C-6
Manual ranging 3-3
Maximum readings 3-3
Measurement Considerations C-1
Measurement considerations C-2
Measurement overview 2-3
Measurement Queries H-1
Measuring voltage and temperature 2-19
Meter loading C-9
Model 182 Emulation Commands D-1
Model 2107 input cable 2-12
mX+b 4-6
mX+b and percent (%) 4-6

N

Nanovoltmeter features 1-6
Noise 2-22

O

One-shot reading, DC volts, bus trigger, auto ranging H-5
One-shot reading, DC volts, no trigger, fastest rate H-5
One-shot reading, external trigger, auto delay enabled H-5
One-shot triggering E-4
Options and accessories 1-4
Other Stepping/Scanning operations 9-6
OUTPut command summary 14-6
Output trigger 7-5

P

- Percent (%) 4-7
- Performance commands 15-16
- Performance considerations 2-5
- Power-Up 1-14
- Power-up sequence 1-15
- Primary address selection 11-8
- Program examples E-2
- Pulse Delta 1-3
 - Fixed output I-11
 - Measurement units I-11
- Pumpout current (low charge injection mode) 2-9

Q

- QuickBASIC programming 11-8

R

- Rack mount kits 1-5
- Radio frequency interference C-6
- Range 3-3
- Range, Digits, Rate, and Filter 3-1
- Rate 3-6
- Ratio 5-2
- Ratio and Delta 5-1
- Ratio programming example 5-16
- Reading hold (autosettle) 7-6
- Rear panel summary 1-11
- Recall 6-3
- REL Key 4-3
- Relative 4-3
- Relative, $mX+b$, and Percent (%) 4-1
- Remote Operation 11-1
- ROUTe command summary 14-6
- RS-232 connections 11-29
- RS-232 interface reference 11-27

S

- Safety symbols and terms 1-3
- SCPI commands F-10
- SCPI programming - ACAL, Front Autozero, Autozero, LSYNC and Low Charge Injection 2-10
- SCPI programming - analog output 10-6
- SCPI programming - buffer 6-5
- SCPI programming - digits 3-5
- SCPI programming - filter 3-12
- SCPI programming - limits 8-5
- SCPI programming - $mX+b$ and percent 4-8
- SCPI programming - range 3-4
- SCPI programming - rate 3-7

- SCPI programming - ratio and delta 5-16
- SCPI programming - relative 4-4
- SCPI programming - stepping and scanning 9-12
- SCPI programming - triggering 7-13
- SCPI programming - voltage and temperature measurements 2-20
- SCPI Reference Tables 14-1
- SCPI Signal Oriented Measurement Commands 13-1
- Selecting and configuring an interface 11-3
- Selecting Delta 5-9
- Sending and receiving data 11-27
- SENSE command summary 14-7
- Setting limit values 8-4
- Setting line voltage and replacing fuse 1-15
- Shielding C-8
- Sorting resistors 8-7
- Source resistance noise C-4
- SourceMeter 5-10, 5-14, 9-14
- Specifications A-1
- Speed vs. noise characteristics 3-6
- Standard cell comparisons 2-26
- Status and Error Messages B-1
- Status and error messages 1-16
- STATus command summary 14-11
- Status structure 11-13
- STATus subsystem 15-7
- Step/Scan configuration 9-7
- Step/Scan overview 9-3
- Stepping and Scanning 9-1
- Stepping/Scanning controls 9-6
- Stepping/Scanning examples 9-8
- Store 6-2
- Storing readings in buffer E-6
- SYSTEM command summary 14-12

T

- Taking readings using the READ? command E-7
- Temperature configuration 2-18
- Temperature configuration menu 2-18
- Temperature only connections 2-15
- Test systems I-5
- Testing superconductor materials 5-19
- Testing switch contacts 2-24
- Thermal EMFs 2-22
- Thermoelectric generation C-3
- Thermoelectric potentials C-2
- TRACe command summary 14-12
- Trigger command summary 14-13
- Trigger model 7-3

Trigger model (remote operation) [7-13](#)
Trigger model operation [7-15](#)
trigger synchronization [5-14](#)
Triggering [7-1](#)
Triggering commands [7-16](#)
Typical command sequences [F-11](#)

U

Unaddress commands [F-9](#)
UNIT command summary [14-14](#)

V

Voltage and temperature connections [2-16](#)
Voltage and Temperature Measurements [2-1](#)
Voltage measurements [2-3](#)
Voltage only connections [2-14](#)
Voltmeter complete [7-8](#)

W

Warm-up [2-5](#)
Warranty information [1-3](#)

Service Form

Model No. _____ Serial No. _____ Date _____

Name and Telephone No. _____

Company _____

List all control settings, describe problem and check boxes that apply to problem. _____

Intermittent Analog output follows display Particular range or function bad; specify _____

IEEE failure Obvious problem on power-up Batteries and fuses are OK

Front panel operational All ranges or functions are bad Checked all cables

Display or output (check one)

Drifts Unable to zero Unstable

Overload Will not read applied input

Calibration only Certificate of calibration required Data required

(attach any additional sheets as necessary)

Show a block diagram of your measurement including all instruments connected (whether power is turned on or not). Also, describe signal source.

Where is the measurement being performed? (factory, controlled laboratory, out-of-doors, etc.) _____

What power line voltage is used? _____ Ambient temperature? _____ °F

Relative humidity? _____ Other? _____

Any additional information. (If special modifications have been made by the user, please describe.)

Be sure to include your name and phone number on this service form.





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