

# Model 2182/2182A Nanovoltmeter

## Quick Reference Guide

2182A-903-01 Rev. A / June 2004

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**Keithley Instruments, Inc.**

**Corporate Headquarters** • 28775 Aurora Road • Cleveland, Ohio 44139 • 440-248-0400 • Fax: 440-248-6168 • 1-888-KEITHLEY (534-8453) • [www.keithley.com](http://www.keithley.com)

**Belgium:** Sint-Pieters-Leeuw • 02-363 00 40 • Fax: 02-363 00 64 • [www.keithley.nl](http://www.keithley.nl)

**China:** Beijing • 8610-82251886 • Fax: 8610-82251892 • [www.keithley.com.cn](http://www.keithley.com.cn)

**Finland:** Helsinki • 09-5306-6560 • Fax: 09-5306-6565 • [www.keithley.com](http://www.keithley.com)

**France:** Saint-Aubin • 01-64 53 20 20 • Fax: 01-60 11 77 26 • [www.keithley.fr](http://www.keithley.fr)

**Germany:** Germering • 089/84 93 07-40 • Fax: 089/84 93 07-34 • [www.keithley.de](http://www.keithley.de)

**Great Britain:** Theale • 0118 929 7500 • Fax: 0118 929 7519 • [www.keithley.co.uk](http://www.keithley.co.uk)

**India:** Bangalore • 91-80 2212 8027 • Fax: 91-80 2212 8005 • [www.keithley.com](http://www.keithley.com)

**Italy:** Milano • 02-48 39 16 01 • Fax: 02- 48 39 16 28 • [www.keithley.it](http://www.keithley.it)

**Japan:** Tokyo • 81-3-5733-7555 • Fax: 81-3-5733-7556 • [www.keithley.jp](http://www.keithley.jp)

**Korea:** Seoul • 82-2-574-7778 • Fax: 82-2-574-7838 • [www.keithley.com](http://www.keithley.com)

**Netherlands:** Gorinchem • 0183-635333 • Fax: 0183-630821 • [www.keithley.nl](http://www.keithley.nl)

**Singapore:** Singapore • 65-6747-9077 • Fax: 65-6747-2991 • [www.keithley.com](http://www.keithley.com)

**Sweden:** Solna • 08-509 04 600 • Fax: 08-655 26 10 • [www.keithley.com](http://www.keithley.com)

**Taiwan:** Hsinchu • 886-3-572-9077 • Fax: 886-3-572-9031 • [www.keithley.com.tw](http://www.keithley.com.tw)

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# Model 2182/2182A Nanovoltmeter Quick Reference Guide

*This Quick Reference Guide supports both the Models 2182 and 2182A. References to the Model 2182 also apply to the Model 2182A.*

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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-903-01) ..... June 2004

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.

# Model 2182/2182A Nanovoltmeter Quick Reference Guide

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## Introduction

This guide is designed to familiarize users with fundamental operation (front panel and remote) of the Keithley Model 2182 Nanovoltmeter. For comprehensive information on all aspects of Nanovoltmeter operation, refer to the Model 2182 User's Manual.

Operation information in this guide is divided into three parts: (1) Basic operation, (2) Settings to optimize performance, and (3) Features to enhance DUT testing. This format allows a new user to easily progress from basic simple operation to more complex procedures.

**Remote command programming** — For the various Model 2182 operating modes covered in this guide, the related SCPI commands for remote operation are summarized in tables. Most commands have a query form. For example, :OUTPut ON turns the analog output on, while :OUTPut? requests the present state of the analog output. Note that the Model 2182 must be addressed to talk after sending a query command.

For operations where command sequence is important, programming examples are provided. The exact programming syntax will depend on the test program language.

**NOTE** *The Model 2182A and later versions of the Model 2182 (firmware version A10 or higher) can be used with the Model 622x to perform Delta and Differential Conductance measurements. The Model 2182A can also be used with the Model 6221 to perform Pulse Delta measurements.*

*Delta, Pulse Delta, and Differential Conductance are documented in Section 5 of the Model 622x User's Manual, and Section 5 of the Model 622x Reference Manual.*

## Measurement capabilities

- Two voltage measurement channels.
- Measure voltage from 1nV to 120V (channel 1); 10nV to 12V (channel 2).
- Temperature measurements
- Ratio, delta,  $mX + b$ , and percent math operations.

## Front and rear panels

The front and rear panels of the Model 2182 are shown in Figures 1 and 2. The use of the various instrument controls and connectors will be explained throughout this guide.

Figure 1  
Front panel

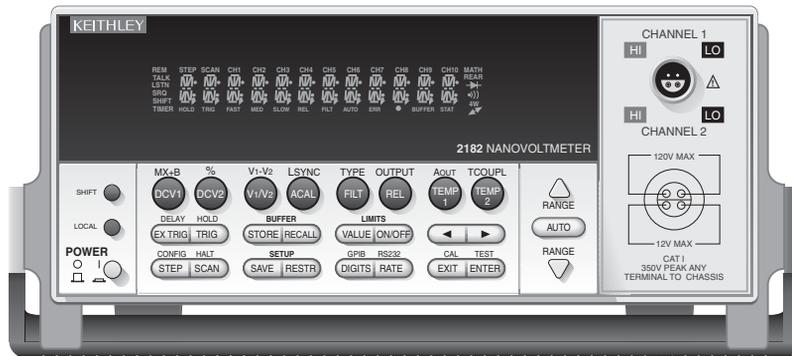
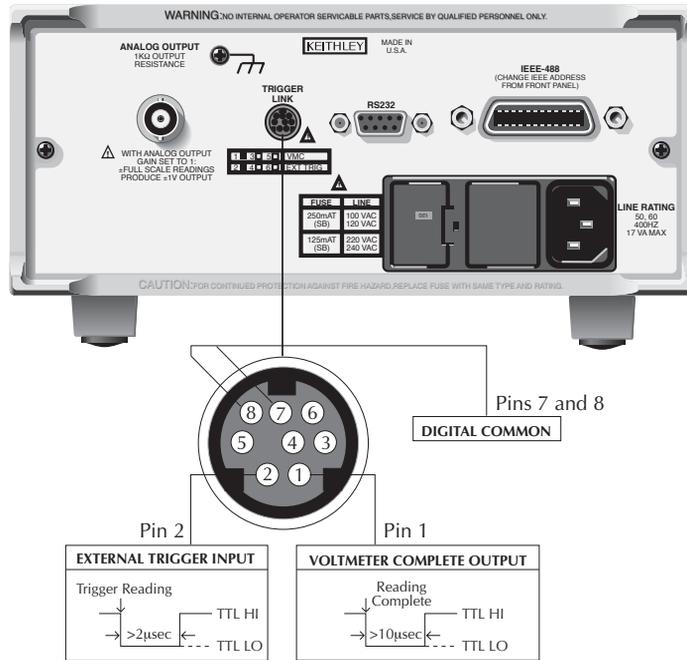


Figure 2  
Rear panel



## Basic connections

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

**CAUTION** Maximum Channel 1 voltage measurement is 120V peak. Maximum Channel 2 measurement is 12V peak.

## Optimizing connections

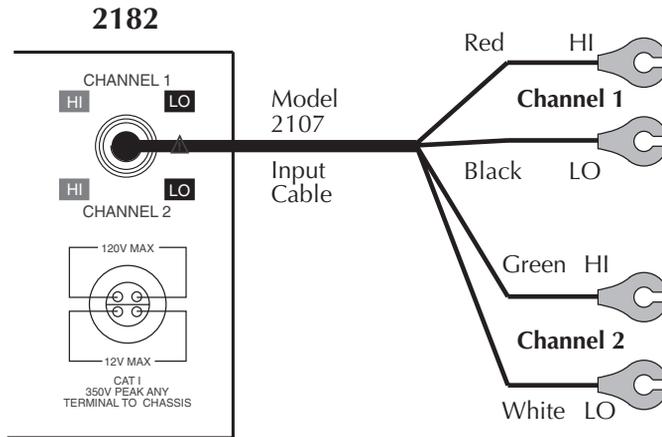
To ensure measurement integrity, observe the following when making connections:

- Use copper-to-copper connections when possible to minimize thermal EMFs.
- Any solder connections should use silver solder to minimize thermal EMFs.
- Clean all connector terminals free of oxidation using a small amount of DeoxIT.

## Model 2107 input cable

Figure 3 shows the terminal designations of the supplied Model 2107 input cable. This cable can be used to make voltage measurements and temperature measurements that use an external simulated reference junction. The red and black wires connect HI and LO of Channel 1, and the green and white wires connect HI and LO of Channel 2.

*Figure 3*  
**Model 2107 input cable**



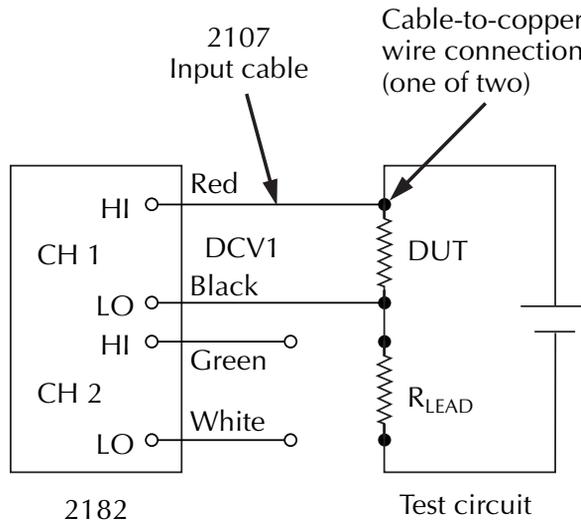
## Voltage measurement connections

### Single channel measurement connections

Connections for single channel voltage measurements using a Model 2107 cable to connect Channel 1 are shown in Figure 4.

Figure 4

#### *Single-channel measurement connections*

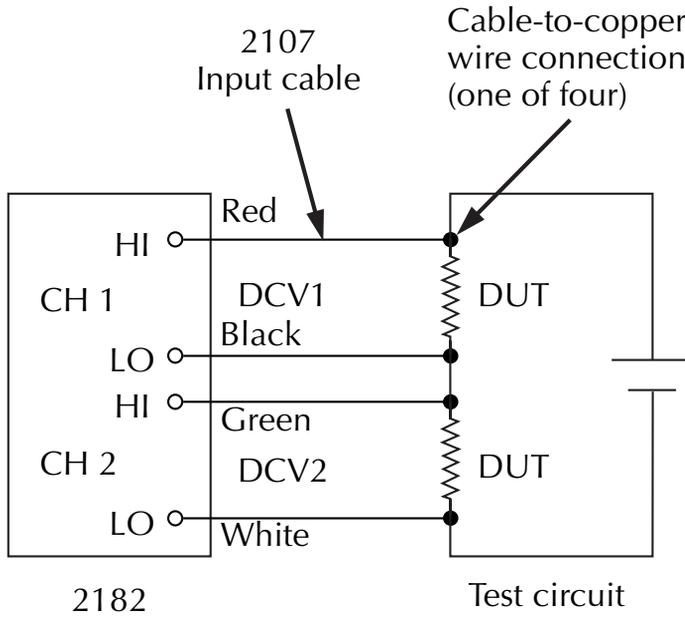


## Dual channel measurement connections

Connections for dual channel voltage measurements using a Model 2107 cable to connect both Channel 1 and Channel 2 are shown in Figure 5.

Figure 5

### Dual-channel measurement connections



# Temperature connections

Figure 6 shows connections for temperature measurements using the internal reference junction, while Figure 7 shows connections that use an ice bath as a simulated reference junction. Note that the connection points for the input cable and thermocouple wires are immersed in the ice bath.

Figure 6  
**Internal reference temperature connections**

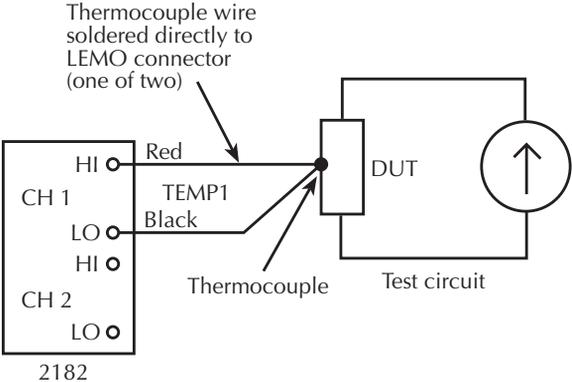
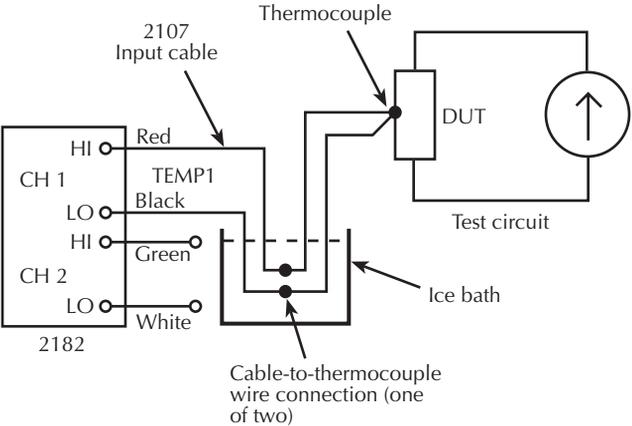


Figure 7  
**External reference temperature connections**



# Basic operation

## Selecting operating modes

Most front panel keys have a dual operation or function. The nomenclature on a key indicates its primary or unshifted function or operation. The nomenclature in blue above a key indicates its shifted function or operation. To select a primary function press the corresponding key. To select a shifted function, press SHIFT first and then the desired key. For example, press DCV1 to select the Channel 1 voltage measurement function. Press SHIFT then MX+B to choose the mX + b function.

## Making voltage measurements

The basic procedure to make voltage measurements is provided in Table 1. It assumes that the DUT is already connected to the Model 2182 as explained in *Basic connections*.

Table 1

### Voltage measurement procedure

Procedure	Details
1. Connect DUT.	See Figure 4 or Figure 5 for Channel 1 or 2.
2. Select channel and function.	Press DCV1 to measure voltage on Channel 1. Press DCV2 to measure voltage on Channel 2.
3. Select range.	Use RANGE ▲ and ▼ keys to manually select range. Or press AUTO RANGE (AUTO annunciator on) to enable auto range.
4. Take readings from display.	Observe the voltage reading on the front panel.

## Making temperature measurements

The basic procedure to make temperature measurements is provided in Table 2. It assumes that the DUT is already connected to the Model 2182 as explained in *Basic connections*.

Table 2

### Temperature measurement procedure

Procedure	Details
1. Connect DUT.	See Figure 6 or Figure 7.
2. Configure temperature.	Press SHIFT then TCOUP, then select: UNITS: °C, °F, or K SENS: TCOUPLE or INTERNAL TYPE: J, K, T, E, R, S, B, or N JUNC: INTERNAL or SIM
3. Select channel and function.	Press TEMP1 to measure temperature on Channel 1. Press TEMP2 to measure temperature on Channel 2.
4. Take readings from display.	Observe the temperature reading on the front panel.

## Measurement considerations

For sensitive measurements, keep these points in mind to maximize measurement accuracy:

- Use only clean, copper-to-copper connections to minimize thermal EMFs.
- Use the REL mode to null out offsets:
  - Connect the circuit, but leave the source disconnected.
  - Select DCV1 or DCV2 as appropriate.
  - Press REL to null offsets.
  - Repeat for other channel if needed.
  - Connect the source, and make the measurement.
- Keep the Model 2182 and test circuit away from electrical noise sources, and shield if necessary.

## Remote command programming

### Data string

The :READ? command is typically used to trigger a reading and request the data string. The data string is sent to the computer when the Model 2182 is addressed to talk. The data string can be made of up to three elements separated by commas. The first element is the voltage or temperature reading, the second is the channel, and the third is the units. A single element (reading-only) data string is the default condition. See Section 14, *FORMAT subsystem*, of the Model 2182 User's Manual for details on all aspects of the data format.

### SCPI commands

SCPI commands to measure voltage and temperature are provided in Table 3.

Table 3

**SCPI commands for voltage and temperature measurements**

Command	Description
:SENSe:FUNCTION <name>	Select function: 'VOLTage' or 'TEMPerature'.
:SENSe:CHANnel <chan>	Select channel: 0 (internal temperature sensor), 1, or 2.
:SENSe:VOLTage:CHANnel1:RANGe <n>	Select channel 1 measure range; <n> = range.
:SENSe:VOLTage:CHANnel1:RANGe:AUTO <b>	Enable/disable channel 1 auto range; (ON or OFF).
:SENSe:VOLTage:CHANnel2:RANGe <n>	Select channel 2 measure range; <n> = range.
:SENSe:VOLTage:CHANnel2:RANGe:AUTO <b>	Enable/disable channel 2 auto range; (ON or OFF).
:SENSe:TEMPerature:TRANsducer <name>	Choose sensor type: TCouple or INTernal.
:SENSe:TEMPerature:RJUNction:RSElect <name>	Select reference: SIMulated or INTernal.
:SENSe:TEMPerature:RJUNction:SIMulated <n>	Set simulated reference temperature in °C: 0 to 60.
:SENSe:TEMPerature:TCouple <type>	Set thermocouple type: J, K, T, E, R, S, B, or N.
:UNIT:TEMPerature <name>	Set temperature units: C, F, or K.
:READ?	Trigger and acquire one data string.

## Programming examples

**Voltage measurement example** — Table 4 shows a typical command sequence to measure voltage on channel 1 using auto range.

**Temperature measurement example** — Table 5 shows a typical command sequence to measure temperature on channel 1 using a simulated junction with 0°C reference temperature and a type J thermocouple.

Table 4

### Command sequence for voltage measurement example

Command <sup>1</sup>	Comments
*RST :SENS:FUNC 'VOLT' :SENS:CHAN 1 :SENS:VOLT:CHAN1:RANG:AUTO ON :READ?	Restore GPIB defaults. Select voltage measurement function. Select channel 1. Enable channel 1 auto range. Trigger and acquire one voltage reading.

1. Model 2182 must be addressed to talk after sending :READ? to trigger and acquire data.

Table 5

### Command sequence for temperature measurement example

Command <sup>1</sup>	Comments
*RST :SENS:FUNC 'TEMP' :SENS:CHAN 1 :SENS:TEMP:TRAN TC :SENS:TEMP:RJUN:RSEL SIM :SENS:TEMP:RJUN:SIM 0 :SENS:TEMP:TC J :UNIT:TEMP F :READ?	Restore GPIB defaults. Select temperature measurement function. Select channel 1 for measurement. Select thermocouple sensor. Choose simulated junction. Set simulated junction temperature to 0°C. Select type J thermocouple. Select °F temperature units. Trigger and acquire one temperature reading.

1. Model 2182 must be addressed to talk after sending :READ? to trigger and acquire data.

## Settings to optimize performance

### Range

To achieve the best accuracy, the Model 2182 should be on the lowest possible measurement range. In most situations, auto range can be used to automatically select the best range. Auto range is controlled (enabled/disabled) by the AUTO range key (AUTO annunciator indicates auto range is enabled).

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. There is no range selection for temperature (TEMP1 and TEMP2) measurements. Temperature measurements are performed on a single, fixed range.

The RANGE ▲ and ▼ keys are used for manual range selection. Note that pressing either of these keys disables auto range.

## 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).

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.

## 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.

## 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.

### 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).

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.

### Configuring filters

To configure the filters, press **SHIFT TYPE**, and then choose your selections as needed. You can turn the analog and digital filters ON or OFF, and set digital filter window, count, and select average or repeat type filters. See Section 3 of the Model 2182 User's Manual for details on filter parameters.

## REL key

The **REL** key sets a rel value for the selected function (**DCV1**, **DCV2**, **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 can be a zero offset reading that you want to null out, or it can 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.

## Remote command programming

The SCPI commands for speed, digits, filter, and rel are listed in Table 6. The commands for ranging are listed in Table 3.

Table 6

### Rate, digits, filter, and rel SCPI commands

Command	Description
<p><i>Rate commands:</i></p> <p>:SENSE:VOLTage:NPLCycles &lt;n&gt;</p> <p>:SENSE:VOLTage:APERture &lt;n&gt;</p> <p>:SENSE:TEMPerature:NPLCycles &lt;n&gt;</p> <p>:SENSE:TEMPerature:APERture &lt;n&gt;</p>	<p>Set voltage rate in PLCs: 0.01 to 60.<sup>1</sup></p> <p>Set voltage rate in sec.: 166.7<math>\mu</math>sec to 1sec.<sup>2</sup></p> <p>Set temp. rate in PLCs: 0.01 to 60.<sup>1</sup></p> <p>Set temp. rate in sec.: 166.7<math>\mu</math>sec to 1sec.<sup>2</sup></p>
<p><i>Digits commands:</i></p> <p>:SENSE:VOLTage:DIGits &lt;n&gt;</p> <p>:SENSE:TEMPerature:DIGits &lt;n&gt;</p>	<p>Set DCV1/DCV2 resolution: 4 to 8.</p> <p>Set TEMP1/TEMP2 resolution: 4 to 7.</p>
<p><i>Filter commands:</i><sup>3</sup></p> <p>:SENSE:VOLTage[:CHANnel1]:LPASs &lt;b&gt;</p> <p>:SENSE:VOLTage[:CHANnel1]:DFILter[:STATe] &lt;b&gt;</p> <p>:SENSE:VOLTage:CHANnel2:LPASs &lt;b&gt;</p> <p>:SENSE:VOLTage:CHANnel2:DFILter[:STATe] &lt;b&gt;</p> <p>:SENSE:TEMPerature[:CHANnel1]:LPASs &lt;b&gt;</p> <p>:SENSE:TEMPerature[:CHANnel1]:DFILter[:STATe] &lt;b&gt;</p> <p>:SENSE:TEMPerature:CHANnel2:LPASs &lt;b&gt;</p> <p>:SENSE:TEMPerature:CHANnel2:DFILter[:STATe] &lt;b&gt;</p>	<p>Enable/disable DCV1 analog filter.</p> <p>Enable/disable DCV1 digital filter.</p> <p>Enable/disable DCV2 analog filter.</p> <p>Enable/disable DCV2 digital filter.</p> <p>Enable/disable TEMP1 analog filter.</p> <p>Enable/disable TEMP1 digital filter.</p> <p>Enable/disable TEMP2 analog filter.</p> <p>Enable/disable TEMP2 digital filter.</p>
<p><i>Rel commands:</i><sup>4</sup></p> <p>:SENSE:VOLTage[:CHANnel1]:REFerence:STATe &lt;b&gt;</p> <p>:SENSE:VOLTage:CHANnel2:REFerence:STATe &lt;b&gt;</p> <p>:SENSE:TEMPerature[:CHANnel1]:REFerence:STATe &lt;b&gt;</p> <p>:SENSE:TEMPerature:CHANnel2:REFerence:STATe &lt;b&gt;</p>	<p>Enable/disable DCV1 rel.</p> <p>Enable/disable DCV2 rel.</p> <p>Enable/disable TEMP1 rel.</p> <p>Enable/disable TEMP2 rel.</p>

1. 0.01 to 50 for 50Hz.

2. 200 $\mu$ sec to 1 sec for 50Hz.

3. Does not include commands to set digital filter parameters. See Section 3 of Model 2182 User's Manual.

4. Does not include commands to set and acquire rel values. See Section 4 of Model 2182 User's Manual.

# Features to enhance DUT testing

## Buffer

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). 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.

## Storing readings

To store readings, press STORE, key in the number of readings to store, and press ENTER. The star (\*) annunciator indicates that the buffer is enabled. 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.

## Recalling readings

To recall readings, press the RECALL key. The BUFFER annunciator turns on to indicate that stored readings are being displayed. The arrow annunciator ( $\leftrightarrow$ ) also turns on to indicate that additional data is available for viewing. Use the RANGE and cursor 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. To return to the normal display, press EXIT.

## Buffer statistics

- **MIN** and **MAX** provide the minimum and maximum readings stored in the buffer. It also indicates the buffer location of these readings.
- The **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.

## Remote buffer programming

### SCPI commands

SCPI commands to configure and control the buffer and buffer statistics are listed in Table 7.

Table 7

#### Buffer SCPI commands

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

### Programming example

Table 8 shows a typical command sequence to store and recall readings and mean buffer statistics.

Table 8  
**Command sequence for buffer example**

Command*	Comments
:TRAC:POIN 20	Set buffer size to 20.
:TRAC:FEED SENS	Set to store raw readings.
:TRAC:FEED:CONT NEXT	Start storing readings.
:TRAC:DATA?	Request all stored readings.*
:CALC2:FORM MEAN	Select mean calculation.
:CALC2:STAT ON	Enable mean calculation.
:CALC2:IMM?	Perform calculation and request result.*

\*Model 2182 must be addressed to talk after sending :TRAC:DATA? and :CALC2:IMM? to acquire data.

## Limit testing

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. Factory defaults are:

Limit 1: HI1 = +1V and LO1 = -1V  
Limit 2: HI2 = +2V and LO2 = -2V

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.

**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.

## Setting limit values

To enter high and low limit values, press the Limits VALUE key to view the present HI1 limit value. Use the cursor and RANGE keys to display the desired value, then press ENTER. Repeat the process to set LO1, HI2, and LO2 values.

## Enabling limits

Press the Limits ON/OFF key to view the present beeper status, then change as necessary. Press ENTER to return to the normal display. The HI/IN/LO status is displayed along with the reading. To disable Limits, press the ON/OFF key.

## Remote limits programming

### SCPI commands

SCPI commands for basic limit testing are listed in Table 9.

Table 9

**Limit testing SCPI commands**

Command	Description
:CALCulate3:LIMit:STATe <b>	Enable/disable Limit 1 test: <b> = ON or OFF.
:CALCulate3:LIMit:LOWer <n>	Set lower limit for Limit 1: <n> = limit; -100e6 to 100e6.
:CALCulate3:LIMit:UPPer <n>	Set upper limit for Limit 1: <n> = limit; -100e6 to 100e6.
:CALCulate3:LIMit:FAIL?	Query Limit 1 test result (0 = pass, 1 = fail).
:CALCulate3:LIMit:CLEar[:IMMediate]	Clear Limit 1 fail indication.
:CALCulate3:LIMit:CLEar:AUTO <b>	Enable/disable Limit 1 auto clear.
:CALCulate3:LIMit2:STATe <b>	Enable/disable Limit 2 test: <b> = ON or OFF.
:CALCulate3:LIMit2:LOWer <n>	Set lower limit for Limit 2: <n> = limit; -100e6 to 100e6.
:CALCulate3:LIMit2:UPPer <n>	Set upper limit for Limit 2: <n> = limit; -100e6 to 100e6.
:CALCulate3:LIMit2:FAIL?	Query Limit 2 test result (0 = pass, 1 = fail).
:CALCulate3:LIMit2:CLEar[:IMMediate]	Clear Limit 2 fail indication.
:CALCulate3:LIMit2:CLEar:AUTO <b>	Enable/disable Limit 2 auto clear.

### Programming example

The programming example in Table 10 tests limits on a voltage input to Channel 1. Limit 1 values are  $\pm 0.1$ , and Limit 2 values are  $\pm 1$ .

Table 10

#### Command sequence for limit test example

Command <sup>1</sup>	Comments
*RST	Restore GPIB defaults.
:CALC3:LIM:LOW -0.1	Set Limit 1 lower limit to -0.1.
:CALC3:LIM:UPP 0.1	Set Limit 1 upper limit to 0.1.
:CALC3:LIM:STAT ON	Enable Limit 1 test.
:CALC3:LIM2:LOW -1	Set Limit 2 lower limit to -1.
:CALC3:LIM2:UPP 1	Set Limit 2 upper limit to 1.
:CALC3:LIM2:STAT ON	Enable Limit 2 test.
:READ?	Trigger and request a reading. <sup>1</sup>
:CALC3:LIM:FAIL?	Request Limit 1 test result. <sup>1</sup>
:CALC3:LIM2:FAIL?	Request Limit 2 test result. <sup>1</sup>

1. Model 2182 must be addressed to talk after sending :READ?, :CALC3:LIM:FAIL?, and :CALC3:LIM2:FAIL? to acquire test result.

## Math operations

Model 2182 math operations include ratio, delta,  $mX + b$ , and percent.

### 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)

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.

### 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:

$$\text{Delta} = \frac{V_{1t1} - V_{1t2}}{2}$$

where:  $V_{1t1}$  is the voltage measurement on the positive phase of the current source.  
 $V_{1t2}$  is the voltage measurement on the negative phase of the current source.

Delta Calculation using Filter and Rel:

$$\text{Delta} = \frac{\text{Filt}V_{1t1} - \text{Filt}V_{1t2}}{2} - \text{Rel}V_1$$

where:

- $\text{Filt}V_{1t1}$  and  $\text{Filt}V_{1t2}$  are filtered voltage measurements on the positive and negative phases of the current source. The “FILT” annunciator will be on when Filter is enabled.
- $\text{Rel}V_1$  is the Rel value established for DCV1. The “REL” annunciator will be on when Rel is enabled.

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.

**NOTE** *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. See Section 5 of the Model 2182 User’s Manual for details.*

## Remote ratio and delta programming

### SCPI commands

Table 11 summarizes commands used for ratio and delta.

Table 11

#### Ratio and delta SCPI commands

Command	Description
:SENSe:FUNCTION 'VOLTage'	Select voltage function.
:SENSe:CHANnel <chan>	Select range control channel: 1 or 2.
:SENSe:VOLTage[:DC]:RATio <b>	Enable or disable Ratio (V1/V2).
:SENSe:VOLTage[:DC]:DELTA <b>	Enable or disable Delta. Not valid with TEMP1 or TEMP2 selected.
:SYSTem:FAZero[:STATE] <b>	Enable or disable Front Autozero. To double the speed of Delta, disable Front Autozero.

### Programming example

The command sequence in Table 12 enables Ratio and displays the result on the computer CRT.

Table 12

#### Command sequence for ratio measurement example

Command*	Comments
:SENS:FUNC 'VOLT'	Select voltage function.
:SENS:CHAN 1	Select channel 1 for range control.
:SENS:VOLT:RATIO ON	Enable ratio function.
:READ?	Trigger and request reading.

\*Model 2182 must be addressed to talk after sending :READ? to acquire reading.

### 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 enable mX + b, press SHIFT and then MX+B to display the present scale factor. Enter the desired M, B, and UNITS values at the prompts, and press ENTER. The MATH annunciator will turn on to indicate that mX+b is enabled. Press SHIFT then MX+B again to disable the function. The MATH annunciator will turn off.

### Percent (%)

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

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

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

To configure and enable the percent function, press SHIFT then %. Enter the desired REF value, then press ENTER. The MATH annunciator will turn on to indicate that percent is enabled. Press SHIFT then % again to disable the function. The MATH annunciator will turn off.

## Remote $mX+b$ and percent programming

### SCPI commands

Table 13 summarizes commands used for  $mX+b$  and percent.

Table 13  
 **$mX+b$  and percent SCPI commands**

Command	Description
:CALCulate:FORMat <name>	Select calculation: NONE, MXB or PERCent.
:CALCulate:KMATH:MMFactor <NRf>	Specify scale factor (M) for $mX+b$ : $-100e6$ to $100e6$ .
:CALCulate:KMATH:MBFactor <NRf>	Specify offset (B) for $mX+b$ : $-100e6$ to $100e6$ .
:CALCulate:KMATH:MUNits <name>	Specify units for $mX+b$ (one or two characters enclosed in single or double quotes).
:CALCulate:KMATH:PERcent <NRf>	Specify reference value for Percent: $-100e6$ to $100e6$ .
:CALCulate:KMATH:PERcent:ACQuire	Use input signal as reference value.
:CALCulate:STATe <b>	Enable or disable the selected calculation.
:CALCulate:DATA[:LATEST]?	Query last calculation result.
:CALCulate:DATA:FRESH?	Trigger a reading and query the calculation result.

### Programming example

The command sequence in Table 14 programs the  $mX+b$  function and requests the result.

Table 14  
**Command sequence for  $mX+b$  measurement example**

Command*	Comments
:CALC:FORM MXB	Select $mX+b$ function.
:CALC:KMAT:MMF 2	$M = 2$ .
:CALC:KMAT:MBF 0.5	$B = 0.5$
:CALC:STAT ON	Enable $mX+b$ .
:CALC:DATA:FRES?	Trigger reading and request $mX+b$ result.

\*Model 2182 must be addressed to talk after sending :CALC:DATA:FRES? to acquire reading.



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**Keithley Instruments, Inc.**

**Corporate Headquarters** • 28775 Aurora Road • Cleveland, Ohio 44139 • 440-248-0400 • Fax: 440-248-6168 • 1-888-KEITHLEY (534-8453) • [www.keithley.com](http://www.keithley.com)

**Belgium:** Sint-Pieters-Leeuw • 02-363 00 40 • Fax: 02-363 00 64 • [www.keithley.nl](http://www.keithley.nl)

**China:** Beijing • 8610-82251886 • Fax: 8610-82251892 • [www.keithley.com.cn](http://www.keithley.com.cn)

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