

MP5103 Mainframe

Source-Measure Unit (SMU) Modules

Verification and Adjustment Manual

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Safety precautions

The following safety precautions should be observed before using this product and any associated instrumentation. Although some instruments and accessories would normally be used with nonhazardous voltages, there are situations where hazardous conditions may be present.

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

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

The types of product users are:

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

The  symbol indicates a connection terminal to the equipment frame.

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

Production of this equipment required the extraction and use of natural resources. The equipment may contain substances that could be harmful to the environment or human health if improperly handled at the product's end of life. To avoid release of such substances into the environment and to reduce the use of natural resources, we encourage you to recycle this product in an appropriate system that will ensure that most of the materials are reused or recycled appropriately.



The  symbol indicates that this product complies with the applicable European Union requirements according to Directives 2012/19/EU and 2006/66/EC on waste electrical and electronic equipment (WEEE) and batteries. For information about recycling options, check the Tektronix Web site (www.tek.com/productrecycling).

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

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

The **CAUTION** heading with the  symbol in the user documentation explains hazards that could result in moderate or minor injury or damage the instrument. Always read the associated information very carefully before performing the indicated procedure. Damage to the instrument may invalidate the warranty.

Instrumentation and accessories shall not be connected to humans.

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

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

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

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

This product may contain a small installed lithium metal button cell. Please properly dispose of or recycle the cell at its end of life according to local government regulations.

This product may contain one or more type CR lithium batteries. According to the state of California, CR lithium batteries are classified as perchlorate materials and require special handling. See <http://www.dtsc.ca.gov/hazardouswaste/perchlorate> for additional information.

If present, the small lithium primary button cell contained in this equipment does not exceed 1 gram of lithium metal content per cell, and the cell type has been shown by the manufacturer to comply with the applicable requirements of the UN Manual of Tests and Criteria Part III, Sub-section 38.3. Consult your carrier to determine which lithium battery transportation requirements are applicable to your configuration, including to its re-packaging and re-labeling, prior to reshipment of the product by any mode of transport.

Introduction

Welcome

Thank you for choosing a Tektronix product. Verification and adjustment procedures for the following source-measure units (SMUs) designed for use with the MP5103 Modular Precision Test System are covered in this manual:

- **MSMU60-2:** 2-channel 30 W, 60 V

Extended warranty

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

Contact information

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

Overview of available documentation

The documentation available for the MP5000 Series Modular Precision Test System is available from [tek.com](https://www.tek.com). The documentation includes:

- **User Manual:** Provides initial setup instructions, installation, a description of the instrument controls and connections, basic maintenance, and operational validation procedures.
- **Programmer Manual:** Contains command descriptions for controlling the MP5103 and available modules as well as information on building trigger models, TSP-Link and TSP-Net, and reading buffers.
- **Reference Manuals:** Include advanced operation topics, hardware configuration, additional maintenance information, troubleshooting procedures, and guidelines for measurement considerations and optimization.
- **TSP Toolkit Quick Start Guide:** Provides instructions for the Tektronix TSP™ Toolkit extension for Microsoft™ Visual Studio Code™.
- **Code examples for the MP5000 Series and modules:** [Tektronix GitHub Programmatic Control Examples Repository](#).
- **Accessories information:** Documentation for accessories available for the MP5103 and modules.

In addition to documentation, the website also provides the latest instrument firmware and additional support information.

Communicating with the mainframe and modules

Web interface

You can use the MP5103 web interface to change module settings for verification and adjustment. Some of the module settings you can change through the web interface include:

- Source levels and limits
- Overvoltage and overcurrent protection values
- Turning the power output on and off

See the "Remote communications" section of the *MP5103 Mainframe Reference Manual* for additional details on using the web interface.

TSP commands

Some procedures in this manual require using remote TSP commands to perform adjustment on modules installed in the MP5103 mainframe. Tektronix recommends that these procedures be performed only by trained personnel with knowledge of remote TSP command operation.

See the "Introduction" and "Introduction to TSP" sections of the *MP5000 Series Programmer Manual* for details on configuring your mainframe and module for remote access as well as for information on using TSP commands to configure and control your instruments. Details on the TSP commands used in the verification and adjustment procedures in this manual can be found in [TSP calibration commands](#) (on page 44).

Verification

Verification information

WARNING: The information in this section is intended for qualified service personnel only, as described by the types of product users in the [Safety precautions](#) (on page 5) pages provided at the beginning of this document. Do not attempt these procedures unless you are qualified to do so.

Some of these procedures may expose you to hazardous voltages, that if contacted, could cause personal injury or death. Use appropriate safety precautions when working with hazardous voltages.

Use the procedures in this section to verify that the accuracy of a module is within the limits stated in the instrument specifications. Verification is suggested:

- After receiving the instrument, to ensure that it was not damaged during shipment
- To verify that the instrument meets factory specifications
- To confirm an adjustment procedure

NOTE: If a verification process fails, the equivalent adjustment procedure must be performed.

Verification test conditions and requirements

The verification tests should be performed:

- After installation in an MP5103 Modular Precision Test System
- When the module is in a new test environment
- When the module and mainframe have been warmed-up for at least 30 minutes
- In an indoor, non-residential location
- Out of direct sunlight
- In a dust-free environment
- In a room with a relative humidity less than 70%
- Between temperatures of +18 to 28 °C (64 to 82 °F)
- Remote sense operation enabled

Verification equipment

The following is a list of the recommended verification equipment.

Type	Specifications	Device or instrument
Precision, fixed, resistive loads	0 Ω (short) 1 Ω 10 Ω 50 Ω 100 Ω 150 Ω 200 Ω 1 k Ω 10 k Ω 100 k Ω 1 M Ω 10 M Ω	Various manufacturers, 1% tolerance
Modular test system	Tektronix MP5103	Tektronix MP5103
Digital multimeter	DC V: 10 nV to 1110 V	Keithley DMM7510 or equivalent

WARNING: The input/output connectors of the SMU modules are rated for connection to circuits rated Measurement Category 0 only, with transients rated less than 1500 V_{PEAK}. Do not connect the module terminals to CAT II, CAT III, or CAT IV circuits. Connections of the input/output terminals to circuits higher than CAT 0 can cause damage to the equipment or expose the operator to hazardous voltages.

Voltage verification tests

There are two voltage verification tests. These tests verify:

- Output voltage and measurement accuracy
- Approximate feedback accuracy

Output voltage and measurement accuracy verification

This test verifies that the voltage output and measurement functions of the module are within specifications. This procedure applies to both CH1 and CH2 of the module.

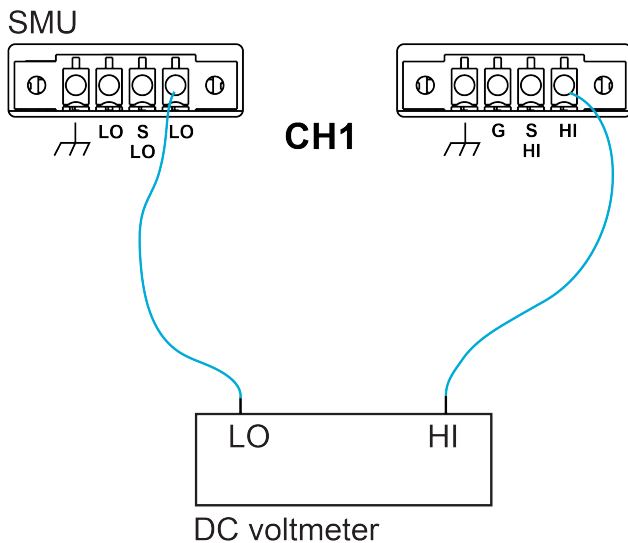
When using TSP commands, you must specify the module slot and channel. For example, to reset channel 1 of the module installed in slot 1 of the mainframe, send

```
slot[1].smu[1].reset()
```

WARNING: Hazardous voltages may be present on all output and guard terminals. To prevent electrical shock that could cause injury or death, never make or break connections while the instrument is powered on. Turn off the equipment from the front panel or disconnect the main power cord before handling cables. Putting the equipment into standby does not guarantee that the outputs are powered off if a hardware or software fault occurs.

Use the following graphic to set up your instruments for verification.

NOTE: The following graphic shows instruments configured for verifying channel 1 of the SMU. Change the output connections to channel 2 before performing verification on that channel.



See [Output voltage and measurement accuracy test record](#) (on page 67) to record results.

To perform output voltage and measurement accuracy verification:

1. Reset the DMM.
2. Reset the module. Send

```
slot[1].smu[1].reset()
```
3. Configure the DMM:
 - **Function:** DC volts
 - **Range:** See table
 - **Resolution:** 6.5 digits
 - **Measurement count:** 20
4. Set the module output voltage level to the values shown in the table for the next verification test step. Send the following command:

```
slot[1].smu[1].source.levelv = valueV
```
5. Enable the module output, then set a delay of 2000 ms. Send

```
slot[1].smu[1].source.output = slot[1].smu[1].ON  
delay(2)
```
6. Make 20 voltage measurements using the DMM and record the readings.
7. Calculate the mean value of the measurements (total of measurements / 20). This value is DVM_{MEAN} .
8. Make 20 voltage measurements using the SMU.

```
slot[1].smu[1].measure.v(slot[1].smu[1].defbuffer1)  
slot[1].smu[1].measure.count = 20
```
9. Turn off the module output. Send

```
slot[1].smu[1].source.output = slot[1].smu[1].OFF
```
10. Calculate the mean value of the measurements (total of measurements / 20). This value is V_{MEAS} .
11. Compare DVM_{MEAN} to the SMU DC voltage output accuracy specifications. If DVM_{MEAN} falls within these limits, the voltage source is accurate.
12. Calculate the limits for the SMU DC voltage measurement accuracy using the following equations:
 - Voltage measurement high limit = $(DVM_{MEAN} \times (1 + \% \text{ of reading})) + \text{offset}$
 - Voltage measurement low limit = $(DVM_{MEAN} \times (1 - \% \text{ of reading})) - \text{offset}$
13. Compare V_{MEAS} to these limits. If V_{MEAS} falls within these limits, the verification passes.

Test Step	CH	Output (V)	DC voltmeter / DMM range (V)	Low test limit	High test limit
Set DC voltage accuracy +100% FS, 100% Pwr	1 and 2	-60	100	-60.018	-59.982
Read DC voltage accuracy +100% FS, 100% Pwr	1 and 2	-60	100	*	**
Set DC voltage accuracy +50% FS, 100% Pwr	1 and 2	-30	100	-30.012	-29.988
Read DC voltage accuracy +50% FS, 100% Pwr	1 and 2	-30	100	*	**
Set DC voltage accuracy +0% FS, 100% Pwr	1 and 2	-0.06	1	-0.066	-0.054
Read DC voltage accuracy +0% FS, 100% Pwr	1 and 2	-0.06	1	*	**
Set DC voltage accuracy +100% FS, 100% Pwr	1 and 2	60	100	59.982	60.018
Read DC voltage accuracy +100% FS, 100% Pwr	1 and 2	60	100	*	**
Set DC voltage accuracy +50% FS, 100% Pwr	1 and 2	30	100	29.988	30.012
Read DC voltage accuracy +50% FS, 100% Pwr	1 and 2	30	100	*	**
Set DC voltage accuracy +0% FS, 100% Pwr	1 and 2	0.06	1	0.054	0.066
Read DC voltage accuracy +0% FS, 100% Pwr	1 and 2	0.06	1	*	**
Set DC voltage accuracy +100% FS, 100% Pwr	1 and 2	-20	100	-20.006	-19.994
Read DC voltage accuracy +100% FS, 100% Pwr	1 and 2	-20	100	*	**
Set DC voltage accuracy +50% FS, 100% Pwr	1 and 2	-10	10	-10.004	-9.996
Read DC voltage accuracy +50% FS, 100% Pwr	1 and 2	-10	10	*	**
Set DC voltage accuracy +0% FS, 100% Pwr	1 and 2	-0.02	0.1	-0.022	-0.018
Read DC voltage accuracy +0% FS, 100% Pwr	1 and 2	-0.02	0.1	*	**
Set DC voltage accuracy +100% FS, 100% Pwr	1 and 2	20	100	19.994	20.006
Read DC voltage accuracy +100% FS, 100% Pwr	1 and 2	20	100	*	**
Set DC voltage accuracy +50% FS, 100% Pwr	1 and 2	10	10	9.996	10.004
Read DC voltage accuracy +50% FS, 100% Pwr	1 and 2	10	10	*	**
Set DC voltage accuracy +0% FS, 100% Pwr	1 and 2	0.02	0.1	0.018	0.022

Test Step	CH	Output (V)	DC voltmeter / DMM range (V)	Low test limit	High test limit
Read DC voltage accuracy +0% FS, 100% Pwr	1 and 2	0.02	0.1	*	**
Set DC voltage accuracy +100% FS, 100% Pwr	1 and 2	-6	10	-6.0021	-5.9979
Read DC voltage accuracy +100% FS, 100% Pwr	1 and 2	-6	10	*	**
Set DC voltage accuracy +50% FS, 100% Pwr	1 and 2	-3	10	-3.0015	-2.9985
Read DC voltage accuracy +50% FS, 100% Pwr	1 and 2	-3	10	*	**
Set DC voltage accuracy +0% FS, 100% Pwr	1 and 2	-0.006	0.1	-0.0069	-0.0051
Read DC voltage accuracy +0% FS, 100% Pwr	1 and 2	-0.006	0.1	*	**
Set DC voltage accuracy +100% FS, 100% Pwr	1 and 2	6	10	5.9979	6.0021
Read DC voltage accuracy +100% FS, 100% Pwr	1 and 2	6	10	*	**
Set DC voltage accuracy +50% FS, 100% Pwr	1 and 2	3	10	2.9985	3.0015
Read DC voltage accuracy +50% FS, 100% Pwr	1 and 2	3	10	*	**
Set DC voltage accuracy +0% FS, 100% Pwr	1 and 2	0.006	0.1	0.0051	0.0069
Read DC voltage accuracy +0% FS, 100% Pwr	1 and 2	0.006	0.1	*	**
Set DC voltage accuracy +100% FS, 100% Pwr	1 and 2	-2	10	-2.0007	-1.9993
Read DC voltage accuracy +100% FS, 100% Pwr	1 and 2	-2	10	*	**
Set DC voltage accuracy +50% FS, 100% Pwr	1 and 2	-1	1	-1.0005	-0.9995
Read DC voltage accuracy +50% FS, 100% Pwr	1 and 2	-1	1	*	**
Set DC voltage accuracy +0% FS, 100% Pwr	1 and 2	-0.002	0.1	-0.0023	-0.0017
Read DC voltage accuracy +0% FS, 100% Pwr	1 and 2	-0.002	0.1	*	**
Set DC voltage accuracy +100% FS, 100% Pwr	1 and 2	2	10	1.9993	2.0007
Read DC voltage accuracy +100% FS, 100% Pwr	1 and 2	2	10	*	**
Set DC voltage accuracy +50% FS, 100% Pwr	1 and 2	1	1	0.9995	1.0005
Read DC voltage accuracy +50% FS, 100% Pwr	1 and 2	1	1	*	**

Test Step	CH	Output (V)	DC voltmeter / DMM range (V)	Low test limit	High test limit
Set DC voltage accuracy +0% FS, 100% Pwr	1 and 2	0.002	0.1	0.0017	0.0023
Read DC voltage accuracy +0% FS, 100% Pwr	1 and 2	0.002	0.1	*	**
Set DC voltage accuracy +100% FS, 100% Pwr	1 and 2	-0.2	1	-0.2002	-0.1998
Read DC voltage accuracy +100% FS, 100% Pwr	1 and 2	-0.2	1	*	**
Set DC voltage accuracy +50% FS, 100% Pwr	1 and 2	-0.1	0.1	-0.10015	-0.09985
Read DC voltage accuracy +50% FS, 100% Pwr	1 and 2	-0.1	0.1	*	**
Set DC voltage accuracy +0% FS, 100% Pwr	1 and 2	-0.002	0.1	-0.000003	-0.000001
Read DC voltage accuracy +0% FS, 100% Pwr	1 and 2	-0.002	0.1	*	**
Set DC voltage accuracy +100% FS, 100% Pwr	1 and 2	0.2	1	0.1998	0.2002
Read DC voltage accuracy +100% FS, 100% Pwr	1 and 2	0.2	1	*	**
Set DC voltage accuracy +50% FS, 100% Pwr	1 and 2	0.1	0.1	0.09985	0.10015
Read DC voltage accuracy +50% FS, 100% Pwr	1 and 2	0.1	0.1	*	**
Set DC voltage accuracy +0% FS, 100% Pwr	1 and 2	0.002	0.1	0.000001	0.000003
Read DC voltage accuracy +0% FS, 100% Pwr	1 and 2	0.002	0.1	*	**

* (Set test result $\times$ (1 + % of reading)) + offset

** (Set test result $\times$ (1 - % of reading)) - offset

Approximate feedback voltage accuracy verification

This test verifies that the approximate feedback voltage accuracy function of the module is within specifications. This procedure applies to both CH1 and CH2 of the module.

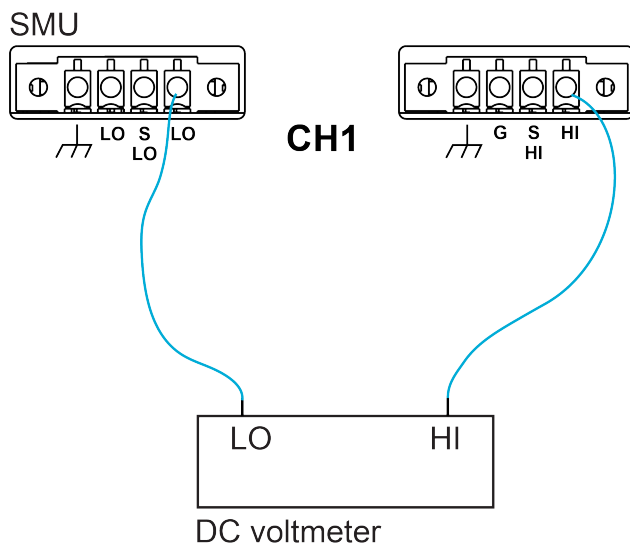
When using TSP commands, you must specify the module slot and channel. For example, to reset channel 1 of the module installed in slot 1 of the mainframe, send

```
slot[1].smu[1].reset()
```

WARNING: Hazardous voltages may be present on all output and guard terminals. To prevent electrical shock that could cause injury or death, never make or break connections while the instrument is powered on. Turn off the equipment from the front panel or disconnect the main power cord before handling cables. Putting the equipment into standby does not guarantee that the outputs are powered off if a hardware or software fault occurs.

Use the following graphic to set up your instruments for verification.

NOTE: The following graphic shows instruments configured for verifying channel 1 of the SMU. Change the output connections to channel 2 before performing verification on that channel.



See [Approximate feedback voltage accuracy verification test record](#) (on page 71) to record results.

To perform approximate feedback voltage accuracy verification:

1. Reset the DMM.
2. Reset the module. Send
`slot[1].smu[1].reset()`

3. Configure the DMM:

- **Function:** DC volts
- **Range:** See table
- **Resolution:** 6.5 digits
- **Measurement count:** 20

4. Unlock calibration for the module.

```
slot[1].smu[1].cal.unlock()
```

5. Set the module output voltage to the values shown in the table. Send the following command:

```
slot[1].smu[1].source.levelv = valueV
```

6. Enable the module output, then set a delay of 2000 ms. Send

```
slot[1].smu[1].source.output = slot[1].smu[1].ON
delay(2)
```

7. Make 20 voltage measurements using the DMM and record the readings.

8. Calculate the mean value (total of measurements / 20). This value is DVM_{MEAN} .9. Compare DVM_{MEAN} to the DC voltage output accuracy specifications. If DVM_{MEAN} falls within these limits, the voltage source is accurate.

10. Turn off the module output. Send

```
slot[1].smu[1].source.output = slot[1].smu[1].OFF
```

Test Step	CH	Output (V)	DC voltmeter / DMM range (V)	Low test limit	High test limit
Set DC voltage AFB accuracy +100% FS	1 and 2	-60	100	-60.018	-59.982
Set DC voltage AFB accuracy +50% FS	1 and 2	-30	100	-30.012	-29.988
Set DC voltage AFB accuracy +0% FS	1 and 2	-0.06	1	-0.066	-0.054
Set DC voltage AFB accuracy +100% FS	1 and 2	60	100	59.982	60.018
Set DC voltage AFB accuracy +50% FS	1 and 2	30	100	29.988	30.012
Set DC voltage AFB accuracy +0% FS	1 and 2	0.06	1	0.054	0.066
Set DC voltage AFB accuracy +100% FS	1 and 2	-20	100	-20.006	-19.994
Set DC voltage AFB accuracy +50% FS	1 and 2	-10	10	-10.004	-9.996
Set DC voltage AFB accuracy +0% FS	1 and 2	-0.02	0.1	-0.022	-0.018
Set DC voltage AFB accuracy +100% FS	1 and 2	20	100	19.994	20.006
Set DC voltage AFB accuracy +50% FS	1 and 2	10	10	9.996	10.004
Set DC voltage AFB accuracy +0% FS	1 and 2	0.02	0.1	0.018	0.022
Set DC voltage AFB accuracy +100% FS	1 and 2	-6	10	-6.00147	-5.99853
Set DC voltage AFB accuracy +50% FS	1 and 2	-3	10	-3.00087	-2.99913
Set DC voltage AFB accuracy +0% FS	1 and 2	-0.006	0.1	-0.00627	-0.00573
Set DC voltage AFB accuracy +100% FS	1 and 2	6	10	5.99853	6.00147
Set DC voltage AFB accuracy +50% FS	1 and 2	3	10	2.99913	3.00087
Set DC voltage AFB accuracy +0% FS	1 and 2	0.006	0.1	0.00573	0.00627

Test Step	CH	Output (V)	DC voltmeter / DMM range (V)	Low test limit	High test limit
Set DC voltage AFB accuracy +100% FS	1 and 2	-2	10	-2.00049	-1.99951
Set DC voltage AFB accuracy +50% FS	1 and 2	-1	1	-1.00029	-0.99971
Set DC voltage AFB accuracy +0% FS	1 and 2	-0.002	0.1	-0.00209	-0.00191
Set DC voltage AFB accuracy +100% FS	1 and 2	2	10	1.99951	2.00049
Set DC voltage AFB accuracy +50% FS	1 and 2	1	1	0.99971	1.00029
Set DC voltage AFB accuracy +0% FS	1 and 2	0.002	0.1	0.00191	0.00209
Set DC voltage AFB accuracy +100% FS	1 and 2	-0.2	1	-0.0200115	-0.199885
Set DC voltage AFB accuracy +50% FS	1 and 2	-0.1	0.1	-0.100065	-0.099935
Set DC voltage AFB accuracy +0% FS	1 and 2	-0.002	0.1	-0.00000215	-0.00000185
Set DC voltage AFB accuracy +100% FS	1 and 2	0.2	1	0.199885	0.0200115
Set DC voltage AFB accuracy +50% FS	1 and 2	0.1	0.1	0.099935	0.100065
Set DC voltage AFB accuracy +0% FS	1 and 2	0.002	0.1	0.00000185	0.00000215

Current verification tests

There are two current verification tests. These tests verify:

- Output current and measurement accuracy
- Approximate feedback current accuracy

Output current and measurement accuracy verification

This test verifies that the current output and measurement functions of the module are within specifications. This procedure applies to both CH1 and CH2 of the module.

When using TSP commands, you must specify the module slot and channel. For example, to reset channel 1 of the module installed in slot 1 of the mainframe, send

```
slot[1].smu[1].reset()
```

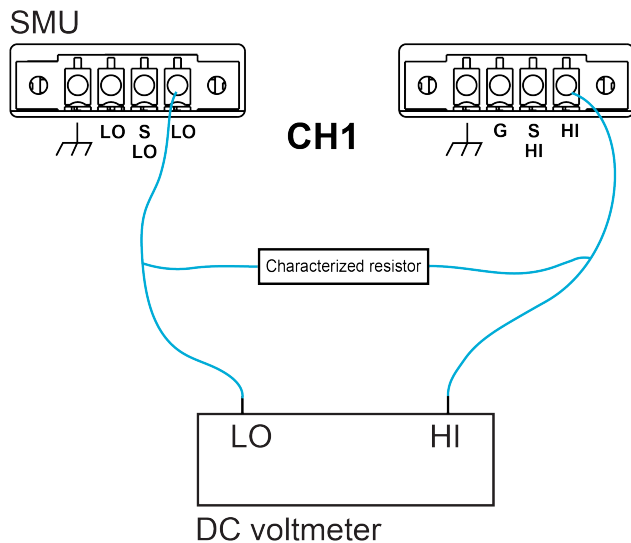
WARNING: Hazardous voltages may be present on all output and guard terminals. To prevent electrical shock that could cause injury or death, never make or break connections while the instrument is powered on. Turn off the equipment from the front panel or disconnect the main power cord before handling cables. Putting the equipment into standby does not guarantee that the outputs are powered off if a hardware or software fault occurs.

This procedure uses a resistor between the HI and LO terminals. The following table shows the resistor value to use for the given range.

Range	Resistor
100 nA	10 M Ω
1 μ A	1 M Ω
10 μ A	100 K Ω
100 μ A	10 K Ω
1 mA	1 K Ω
10 mA	100 Ω
100 mA	10 Ω
1 A	1 Ω
1.5 A	1 Ω

Use the following graphic to set up your instruments for verification.

NOTE: The following graphic shows instruments configured for verifying channel 1 of the SMU. Change the output connections to channel 2 before performing verification on that channel.



See [Output current and measurement accuracy verification test record](#) (on page 73) to record results.

To perform output current and measurement accuracy verification:

1. Reset the DMM.
2. Reset the module. Send

```
slot[1].smu[1].reset()
```
3. Configure the DMM:
 - **Function:** DC volts
 - **Range:** See table
 - **Resolution:** 6.5 digits
 - **Measurement count:** 20
4. Connect the specified resistor between HI and LO of the SMU. See the table for resistor values.
5. Set the module output current limit to the values shown in the table. Send the following command:

```
slot[1].smu[1].source.limiti = valueI
```
6. Enable the module output, then set a delay of 2000 ms. Send

```
slot[1].smu[1].source.output = slot[1].smu[1].ON
```

```
delay(2)
```
7. Make 20 voltage measurements using the DMM across the characterized resistor and record the readings.
8. Calculate the mean value (total of measurements / 20). This value is DVM_{MEAN} .
9. Divide DVM_{MEAN} by the resistor value to calculate the measured current. This value is I_{CALC} .
10. Make 20 current measurements using the SMU.

```
slot[1].smu[1].measure.i(slot[1].smu[1].defbuffer1)
```

```
slot[1].smu[1].measure.count = 20
```
11. Turn off the module output. Send

```
slot[1].smu[1].source.output = slot[1].smu[1].OFF
```

12. Calculate the mean value (total of measurements / 20). This value is I_{MEAS} .

13. Compare I_{CALC} to the DC current output accuracy specifications. If I_{CALC} falls within these limits, the current source is accurate.

14. Calculate the limits for DC current measurement accuracy using I_{CALC} and the DC current output accuracy specifications. If I_{MEAS} falls within these limits, the test passes.

- Current measurement high limit = $(DVM_{MEAN} \times (1 + \% \text{ of reading})) + \text{offset}$
- Current measurement low limit = $(DVM_{MEAN} \times (1 - \% \text{ of reading})) - \text{offset}$

Test Step	CH	Output	DC voltmeter / DMM range (V)	Test load resistance (Ω)	Low test limit	High test limit
Set DC current accuracy +100% FS, 100% Pwr	1 and 2	-1.5 A	10	1	-1.5049	-1.4951
Read DC current accuracy +100% FS, 100% Pwr	1 and 2	-1.5 A	10	1	*	**
Set DC current accuracy +50% FS, 100% Pwr	1 and 2	-0.75 A	1	1	-0.7544	-0.7456
Read DC current accuracy +50% FS, 100% Pwr	1 and 2	-0.75 A	1	1	*	**
Set DC current accuracy +0% FS, 100% Pwr	1 and 2	-0.0015 A	0.1	1	-0.0055	0.0025
Read DC current accuracy +0% FS, 100% Pwr	1 and 2	-0.0015 A	0.1	1	*	**
Set DC current accuracy +100% FS, 100% Pwr	1 and 2	1.5 A	10	1	1.4951	1.5049
Read DC current accuracy +100% FS, 100% Pwr	1 and 2	1.5 A	10	1	*	**
Set DC current accuracy +50% FS, 100% Pwr	1 and 2	0.75 A	1	1	0.7456	0.7544
Read DC current accuracy +50% FS, 100% Pwr	1 and 2	0.75 A	1	1	*	**
Set DC current accuracy +0% FS, 100% Pwr	1 and 2	0.0015 A	0.1	1	-0.0025	0.0055
Read DC current accuracy +0% FS, 100% Pwr	1 and 2	0.0015 A	0.1	1	*	**
Set DC current accuracy +100% FS, 100% Pwr	1 and 2	-1 A	1	1	-1.0015	-0.9985
Read DC current accuracy +100% FS, 100% Pwr	1 and 2	-1 A	1	1	*	**
Set DC current accuracy +50% FS, 100% Pwr	1 and 2	-0.5 A	1	1	-0.50125	-0.49875
Read DC current accuracy +50% FS, 100% Pwr	1 and 2	-0.5 A	1	1	*	**
Set DC current accuracy +0% FS, 100% Pwr	1 and 2	-0.001 A	0.1	1	-0.002	0
Read DC current accuracy +0% FS, 100% Pwr	1 and 2	-0.001 A	0.1	1	*	**
Set DC current accuracy +100% FS, 100% Pwr	1 and 2	1 A	1	1	0.9985	1.0015

Test Step	CH	Output	DC voltmeter / DMM range (V)	Test load resistance (Ω)	Low test limit	High test limit
Read DC current accuracy +100% FS, 100% Pwr	1 and 2	1 A	1	1	*	**
Set DC current accuracy +50% FS, 100% Pwr	1 and 2	0.5 A	1	1	0.49875	0.50125
Read DC current accuracy +50% FS, 100% Pwr	1 and 2	0.5 A	1	1	*	**
Set DC current accuracy +0% FS, 100% Pwr	1 and 2	0.001 A	0.1	1	0	0.002
Read DC current accuracy +0% FS, 100% Pwr	1 and 2	0.001 A	0.1	1	*	**
Set DC current accuracy +100% FS, 100% Pwr	1 and 2	-100 mA	1	10	-100.036	-99.964
Read DC current accuracy +100% FS, 100% Pwr	1 and 2	-100 mA	1	10	*	**
Set DC current accuracy +50% FS, 100% Pwr	1 and 2	-50 mA	1	10	-50.021	-49.979
Read DC current accuracy +50% FS, 100% Pwr	1 and 2	-50 mA	1	10	*	**
Set DC current accuracy +0% FS, 100% Pwr	1 and 2	-0.1 mA	0.1	10	-0.106	-0.094
Read DC current accuracy +0% FS, 100% Pwr	1 and 2	-0.1 mA	0.1	10	*	**
Set DC current accuracy +100% FS, 100% Pwr	1 and 2	100 mA	1	10	99.964	100.036
Read DC current accuracy +100% FS, 100% Pwr	1 and 2	100 mA	1	10	*	**
Set DC current accuracy +50% FS, 100% Pwr	1 and 2	50 mA	1	10	49.979	50.021
Read DC current accuracy +50% FS, 100% Pwr	1 and 2	50 mA	1	10	*	**
Set DC current accuracy +0% FS, 100% Pwr	1 and 2	0.1 mA	0.1	10	0.094	0.106
Read DC current accuracy +0% FS, 100% Pwr	1 and 2	0.1 mA	0.1	10	*	**
Set DC current accuracy +100% FS, 100% Pwr	1 and 2	-10 mA	1	100	-10.0042	-9.9958
Read DC current accuracy +100% FS, 100% Pwr	1 and 2	-10 mA	1	100	*	**
Set DC current accuracy +50% FS, 100% Pwr	1 and 2	-5 mA	1	100	-5.0027	-4.9973
Read DC current accuracy +50% FS, 100% Pwr	1 and 2	-5 mA	1	100	*	**
Set DC current accuracy +0% FS, 100% Pwr	1 and 2	-0.01 mA	0.1	100	-0.01122	-0.0088
Read DC current accuracy +0% FS, 100% Pwr	1 and 2	-0.01 mA	0.1	100	*	**

Test Step	CH	Output	DC voltmeter / DMM range (V)	Test load resistance (Ω)	Low test limit	High test limit
Set DC current accuracy +100% FS, 100% Pwr	1 and 2	10 mA	1	100	9.9958	10.0042
Read DC current accuracy +100% FS, 100% Pwr	1 and 2	10 mA	1	100	*	**
Set DC current accuracy +50% FS, 100% Pwr	1 and 2	5 mA	1	100	4.9973	5.0027
Read DC current accuracy +50% FS, 100% Pwr	1 and 2	5 mA	1	100	*	**
Set DC current accuracy +0% FS, 100% Pwr	1 and 2	0.01 mA	0.1	100	0.0088	0.0112
Read DC current accuracy +0% FS, 100% Pwr	1 and 2	0.01 mA	0.1	100	*	**
Set DC current accuracy +100% FS, 100% Pwr	1 and 2	-1 mA	1	1000	-1.00037	-0.99963
Read DC current accuracy +100% FS, 100% Pwr	1 and 2	-1 mA	1	1000	*	**
Set DC current accuracy +50% FS, 100% Pwr	1 and 2	-0.5 mA	1	1000	-0.50022	-0.49978
Read DC current accuracy +50% FS, 100% Pwr	1 and 2	-0.5 mA	1	1000	*	**
Set DC current accuracy +0% FS, 100% Pwr	1 and 2	-0.001 mA	0.1	1000	-0.00107	-0.00093
Read DC current accuracy +0% FS, 100% Pwr	1 and 2	-0.001 mA	0.1	1000	*	**
Set DC current accuracy +100% FS, 100% Pwr	1 and 2	1 mA	1	1000	0.99963	1.00037
Read DC current accuracy +100% FS, 100% Pwr	1 and 2	1 mA	1	1000	*	**
Set DC current accuracy +50% FS, 100% Pwr	1 and 2	0.5 mA	1	1000	0.49978	0.50022
Read DC current accuracy +50% FS, 100% Pwr	1 and 2	0.5 mA	1	1000	*	**
Set DC current accuracy +0% FS, 100% Pwr	1 and 2	0.001 mA	0.1	1000	0.00093	0.00107
Read DC current accuracy +0% FS, 100% Pwr	1 and 2	0.001 mA	0.1	1000	*	**
Set DC current accuracy +100% FS, 100% Pwr	1 and 2	-100 μ A	1	10000	-100.042	-99.958
Read DC current accuracy +100% FS, 100% Pwr	1 and 2	-100 μ A	1	10000	*	**
Set DC current accuracy +50% FS, 100% Pwr	1 and 2	-50 μ A	1	10000	-50.027	-49.973
Read DC current accuracy +50% FS, 100% Pwr	1 and 2	-50 μ A	1	10000	*	**
Set DC current accuracy +0% FS, 100% Pwr	1 and 2	-0.1 μ A	0.1	10000	-0.112	-0.088

Test Step	CH	Output	DC voltmeter / DMM range (V)	Test load resistance (Ω)	Low test limit	High test limit
Read DC current accuracy +0% FS, 100% Pwr	1 and 2	-0.1 μ A	0.1	10000	*	**
Set DC current accuracy +100% FS, 100% Pwr	1 and 2	100 μ A	1	10000	99.958	100.042
Read DC current accuracy +100% FS, 100% Pwr	1 and 2	100 μ A	1	10000	*	**
Set DC current accuracy +50% FS, 100% Pwr	1 and 2	50 μ A	1	10000	49.973	50.027
Read DC current accuracy +50% FS, 100% Pwr	1 and 2	50 μ A	1	10000	*	**
Set DC current accuracy +0% FS, 100% Pwr	1 and 2	0.1 μ A	0.1	10000	0.088	0.112
Read DC current accuracy +0% FS, 100% Pwr	1 and 2	0.1 μ A	0.1	10000	*	**
Set DC current accuracy +100% FS, 100% Pwr	1 and 2	-10 μ A	1	100000	-10.004	-9.996
Read DC current accuracy +100% FS, 100% Pwr	1 and 2	-10 μ A	1	100000	*	**
Set DC current accuracy +50% FS, 100% Pwr	1 and 2	-5 μ A	1	100000	-5.0025	-4.9975
Read DC current accuracy +50% FS, 100% Pwr	1 and 2	-5 μ A	1	100000	*	**
Set DC current accuracy +0% FS, 100% Pwr	1 and 2	-0.01 μ A	0.1	100000	-0.011	-0.009
Read DC current accuracy +0% FS, 100% Pwr	1 and 2	-0.01 μ A	0.1	100000	*	**
Set DC current accuracy +100% FS, 100% Pwr	1 and 2	10 μ A	1	100000	9.996	10.004
Read DC current accuracy +100% FS, 100% Pwr	1 and 2	10 μ A	1	100000	*	**
Set DC current accuracy +50% FS, 100% Pwr	1 and 2	5 μ A	1	100000	4.9975	5.0025
Read DC current accuracy +50% FS, 100% Pwr	1 and 2	5 μ A	1	100000	*	**
Set DC current accuracy +0% FS, 100% Pwr	1 and 2	0.01 μ A	0.1	100000	0.009	0.011
Read DC current accuracy +0% FS, 100% Pwr	1 and 2	0.01 μ A	0.1	100000	*	**
Set DC current accuracy +100% FS, 100% Pwr	1 and 2	-1 μ A	1	1000000	-1.00065	-0.99935
Read DC current accuracy +100% FS, 100% Pwr	1 and 2	-1 μ A	1	1000000	*	**
Set DC current accuracy +50% FS, 100% Pwr	1 and 2	-0.5 μ A	1	1000000	-0.5004	-0.4996
Read DC current accuracy +50% FS, 100% Pwr	1 and 2	-0.5 μ A	1	1000000	*	**

Test Step	CH	Output	DC voltmeter / DMM range (V)	Test load resistance (Ω)	Low test limit	High test limit
Set DC current accuracy +0% FS, 100% Pwr	1 and 2	-0.001 μ A	0.1	1000000	-0.00115	-0.00085
Read DC current accuracy +0% FS, 100% Pwr	1 and 2	-0.001 μ A	0.1	1000000	*	**
Set DC current accuracy +100% FS, 100% Pwr	1 and 2	1 μ A	1	1000000	0.99935	1.00065
Read DC current accuracy +100% FS, 100% Pwr	1 and 2	1 μ A	1	1000000	*	**
Set DC current accuracy +50% FS, 100% Pwr	1 and 2	0.5 μ A	1	1000000	0.4996	0.5004
Read DC current accuracy +50% FS, 100% Pwr	1 and 2	0.5 μ A	1	1000000	*	**
Set DC current accuracy +0% FS, 100% Pwr	1 and 2	0.001 μ A	0.1	1000000	0.00085	0.00115
Read DC current accuracy +0% FS, 100% Pwr	1 and 2	0.001 μ A	0.1	1000000	*	**
Set DC current accuracy +100% FS, 100% Pwr	1 and 2	-100 nA	1	10000000	-100.22	-99.78
Read DC current accuracy +100% FS, 100% Pwr	1 and 2	-100 nA	1	10000000	*	**
Set DC current accuracy +50% FS, 100% Pwr	1 and 2	-50 nA	1	10000000	-50.12	-49.88
Read DC current accuracy +50% FS, 100% Pwr	1 and 2	-50 nA	1	10000000	*	**
Set DC current accuracy +0% FS, 100% Pwr	1 and 2	-0.1 nA	0.1	10000000	-0.12	-0.08
Read DC current accuracy +0% FS, 100% Pwr	1 and 2	-0.1 nA	0.1	10000000	*	**
Set DC current accuracy +100% FS, 100% Pwr	1 and 2	100 nA	1	10000000	99.78	100.22
Read DC current accuracy +100% FS, 100% Pwr	1 and 2	100 nA	1	10000000	*	**
Set DC current accuracy +50% FS, 100% Pwr	1 and 2	50 nA	1	10000000	49.88	50.12
Read DC current accuracy +50% FS, 100% Pwr	1 and 2	50 nA	1	10000000	*	**
Set DC current accuracy +0% FS, 100% Pwr	1 and 2	0.1 nA	0.1	10000000	0.08	0.12
Read DC current accuracy +0% FS, 100% Pwr	1 and 2	0.1 nA	0.1	10000000	*	**

* (Set test result $\times$ (1 + % of reading)) + offset

** (Set test result $\times$ (1 - % of reading)) - offset

Approximate feedback current accuracy verification

This test verifies that the approximate feedback current accuracy of the module is within specifications. This procedure applies to both CH1 and CH2 of the module.

When using TSP commands, you must specify the module slot and channel. For example, to reset channel 1 of the module installed in slot 1 of the mainframe, send

```
slot[1].smu[1].reset()
```

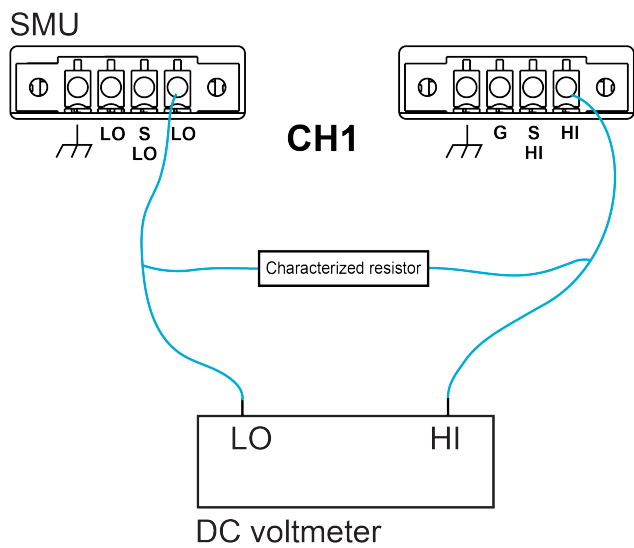
WARNING: Hazardous voltages may be present on all output and guard terminals. To prevent electrical shock that could cause injury or death, never make or break connections while the instrument is powered on. Turn off the equipment from the front panel or disconnect the main power cord before handling cables. Putting the equipment into standby does not guarantee that the outputs are powered off if a hardware or software fault occurs.

This procedure uses a resistor between the HI and LO terminals. The following table shows the resistor value to use for the given range.

Range	Resistor
100 nA	10 M Ω
1 μ A	1 M Ω
10 μ A	100 K Ω
100 μ A	10 K Ω
1 mA	1 K Ω
10 mA	100 Ω
100 mA	10 Ω
1 A	1 Ω
1.5 A	1 Ω

Use the following graphic to set up your instruments for verification.

NOTE: The following graphic shows instruments configured for verifying channel 1 of the SMU. Change the output connections to channel 2 before performing verification on that channel.



See [Approximate feedback current accuracy verification test record](#) (on page 79) to record results.

To perform output current and measurement accuracy verification:

1. Reset the DMM.
2. Reset the module. Send
`slot[1].smu[1].reset()`
3. Configure the DMM:
 - **Function:** DC volts
 - **Range:** See table
 - **Resolution:** 6.5 digits
 - **Measurement count:** 20
4. Connect the specified resistor between HI and LO of the SMU. See the table for resistor values.
5. Unlock calibration for the module.
`slot[1].smu[1].cal.unlock()`
6. Set the module output current limit to the values shown in the table. Send the following command:
`slot[1].smu[1].source.limiti = valueI`
7. Enable the module output, then set a delay of 2000 ms. Send
`slot[1].smu[1].source.output = slot[1].smu[1].ON`
`delay(2)`
8. Make 20 voltage measurements using the DMM across the characterized resistor and record the readings.
9. Calculate the mean value (total of measurements / 20). This value is DVM_{MEAN} .
10. Divide DVM_{MEAN} by the characterized resistor value to calculate the measured current (I_{CALC}).
11. Compare I_{CALC} to the DC current output accuracy specifications. If I_{CALC} falls within these limits, the current source is accurate.

Test Step	CH	Output	DC voltmeter / DMM range (V)	Test load resistance (Ω)	Low test limit	High test limit
Set DC current accuracy +100% FS	1 and 2	-1.5 A	10	1	-1.5649	-1.4351
Set DC current accuracy +50% FS	1 and 2	-0.75 A	1	1	-0.8144	-0.6856

Test Step	CH	Output	DC voltmeter / DMM range (V)	Test load resistance (Ω)	Low test limit	High test limit
Set DC current accuracy +0% FS	1 and 2	-0.0015 A	0.1	1	-0.0655	0.0625
Set DC current accuracy +100% FS	1 and 2	1.5 A	10	1	1.4351	1.5649
Set DC current accuracy +50% FS	1 and 2	0.75 A	1	1	0.6856	0.8144
Set DC current accuracy +0% FS	1 and 2	0.0015 A	0.1	1	-0.0625	0.0655
Set DC current accuracy +100% FS	1 and 2	-1 A	1	1	-1.0155	-0.9845
Set DC current accuracy +50% FS	1 and 2	-0.5 A	1	1	-0.51525	-0.48475
Set DC current accuracy +0% FS	1 and 2	-0.001 A	0.1	1	-0.016	0.014
Set DC current accuracy +100% FS	1 and 2	1 A	1	1	0.9845	1.0155
Set DC current accuracy +50% FS	1 and 2	0.5 A	1	1	0.48475	0.51525
Set DC current accuracy +0% FS	1 and 2	0.001 A	0.1	1	-0.014	0.016
Set DC current accuracy +100% FS	1 and 2	-100 mA	1	10	-104.38	-95.62
Set DC current accuracy +50% FS	1 and 2	-50 mA	1	10	-54.365	-45.635
Set DC current accuracy +0% FS	1 and 2	-0.1 mA	0.1	10	-4.45	4.25
Set DC current accuracy +100% FS	1 and 2	100 mA	1	10	95.62	104.38
Set DC current accuracy +50% FS	1 and 2	50 mA	1	10	45.635	54.365
Set DC current accuracy +0% FS	1 and 2	0.1 mA	0.1	10	-4.25	4.45
Set DC current accuracy +100% FS	1 and 2	-10 mA	1	100	-10.0042	-9.9958
Set DC current accuracy +50% FS	1 and 2	-5 mA	1	100	-5.00278	-4.9973
Set DC current accuracy +0% FS	1 and 2	-0.01 mA	0.1	100	-0.0112	-0.0088
Set DC current accuracy +100% FS	1 and 2	10 mA	1	100	9.9958	10.0042
Set DC current accuracy +50% FS	1 and 2	5 mA	1	100	4.9973	5.0027
Set DC current accuracy +0% FS	1 and 2	0.01 mA	0.1	100	0.0088	0.0112
Set DC current accuracy +100% FS	1 and 2	-1 mA	1	1000	-1.00037	-0.99963

Test Step	CH	Output	DC voltmeter / DMM range (V)	Test load resistance (Ω)	Low test limit	High test limit
Set DC current accuracy +50% FS	1 and 2	-0.5 mA	1	1000	-0.50022	-0.49978
Set DC current accuracy +0% FS	1 and 2	-0.001 mA	0.1	1000	-0.00107	-0.00093
Set DC current accuracy +100% FS	1 and 2	1 mA	1	1000	0.99963	1.00037
Set DC current accuracy +50% FS	1 and 2	0.5 mA	1	1000	0.49978	0.50022
Set DC current accuracy +0% FS	1 and 2	0.001 mA	0.1	1000	0.00093	0.00107
Set DC current accuracy +100% FS	1 and 2	-100 μ A	1	10000	-100.042	-99.958
Set DC current accuracy +50% FS	1 and 2	-50 μ A	1	10000	-50.027	-49.973
Set DC current accuracy +0% FS	1 and 2	-0.1 μ A	0.1	10000	-0.112	-0.088
Set DC current accuracy +100% FS	1 and 2	100 μ A	1	10000	99.958	100.042
Set DC current accuracy +50% FS	1 and 2	50 μ A	1	10000	49.973	50.027
Set DC current accuracy +0% FS	1 and 2	0.1 μ A	0.1	10000	0.088	0.112
Set DC current accuracy +100% FS	1 and 2	-10 μ A	1	100000	-10.004	-9.996
Set DC current accuracy +50% FS	1 and 2	-5 μ A	1	100000	-5.0025	-4.9975
Set DC current accuracy +0% FS	1 and 2	-0.01 μ A	0.1	100000	-0.011	-0.009
Set DC current accuracy +100% FS	1 and 2	10 μ A	1	100000	9.996	10.004
Set DC current accuracy +50% FS	1 and 2	5 μ A	1	100000	4.9975	5.0025
Set DC current accuracy +0% FS	1 and 2	0.01 μ A	0.1	100000	0.009	0.011
Set DC current accuracy +100% FS	1 and 2	-1 μ A	1	1000000	-1.00065	-0.99935
Set DC current accuracy +50% FS	1 and 2	-0.5 μ A	1	1000000	-0.5004	-0.4996
Set DC current accuracy +0% FS	1 and 2	-0.001 μ A	0.1	1000000	-0.00115	-0.00085
Set DC current accuracy +100% FS	1 and 2	1 μ A	1	1000000	0.99935	1.00065
Set DC current accuracy +50% FS	1 and 2	0.5 μ A	1	1000000	0.4996	0.5004
Set DC current accuracy +0% FS	1 and 2	0.001 μ A	0.1	1000000	0.00085	0.00115

Test Step	CH	Output	DC voltmeter / DMM range (V)	Test load resistance (Ω)	Low test limit	High test limit
Set DC current accuracy +100% FS	1 and 2	-100 nA	1	10000000	-100.22	-99.78
Set DC current accuracy +50% FS	1 and 2	-50 nA	1	10000000	-50.12	-49.88
Set DC current accuracy +0% FS	1 and 2	-0.1 nA	0.1	10000000	-0.12	-0.08
Set DC current accuracy +100% FS	1 and 2	100 nA	1	10000000	99.78	100.22
Set DC current accuracy +50% FS	1 and 2	50 nA	1	10000000	49.88	50.12
Set DC current accuracy +0% FS	1 and 2	0.1 nA	0.1	10000000	0.08	0.12

Contact check accuracy verification test

This test verifies that the contact check accuracy is within specified limits. This procedure applies to both CH1 and CH2 of the module.

Contact check measurement accuracy is verified by comparing the current measured by the module to the current measured by an external DMM over a shunt resistor. For the best accuracy, ensure that the DMM and shunt resistor are sufficiently accurate.

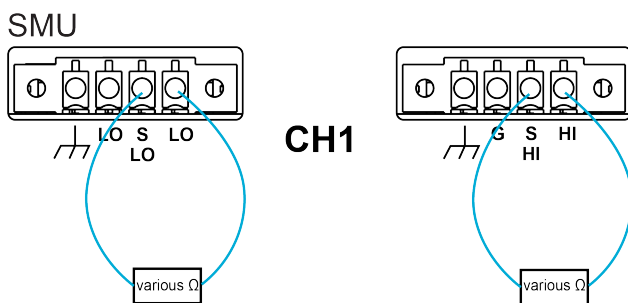
When using TSP commands, you must specify the module slot and channel. For example, to reset channel 1 of the module installed in slot 1 of the mainframe, send

```
slot[1].smu[1].reset()
```

WARNING: Hazardous voltages may be present on all output and guard terminals. To prevent electrical shock that could cause injury or death, never make or break connections while the instrument is powered on. Turn off the equipment from the front panel or disconnect the main power cord before handling cables. Putting the equipment into standby does not guarantee that the outputs are powered off if a hardware or software fault occurs.

Use the following graphic to set up your instruments for verification.

NOTE: The following graphic shows instruments configured for verifying channel 1 of the SMU. Change the output connections to channel 2 before performing verification on that channel.



See [Contact check accuracy verification test record](#) (on page 82) to record results.

To perform contact check accuracy verification:

1. Reset the module. Send

```
slot[1].smu[1].reset()
```

2. Configure the DMM:

- **Function:** DC volts
- **Range:** See table
- **Resolution:** 6.5 digits
- **Measurement count:** 20

3. Connect a 0 Ω resistor (shunt) between HI and SHI of the SMU.

4. Configure the positive and negative source off limit settings.

```
slot[1].smu[1].source.offlimiti = 1e-6
```

5. Measure the contact check resistance. Send:

```
result, hiValue, loValue = slot[1].smu[1].contact.check()
print(hiValue)
```

6. Compare the measurements to the instrument specifications for contact check accuracy. The test passes if the measurement is within the accuracy limits.

7. Repeat steps 3 through 5 with 50 Ω , 100 Ω , and 200 Ω resistors.
8. Connect a 0 Ω resistor (shunt) between LO and SLO of the SMU.
9. Measure the contact check lo resistance. Send:

```
result, hiValue, loValue = slot[1].smu[1].contact.check()  
print(loValue)
```
10. Compare the measurements to the instrument specifications for contact check accuracy. The test passes if the measurement is within the accuracy limits.
11. Repeat steps 7 through 9 with 50 Ω , 100 Ω , and 200 Ω resistors.

Adjustment

Adjustment information

WARNING: The information in this section is intended for qualified service personnel only, as described by the types of product users in the [Safety precautions](#) (on page 5) pages, provided at the beginning of this document. Do not attempt these procedures unless you are qualified to do so.

Some of these procedures may expose you to hazardous voltages, that if contacted, could cause personal injury or death. Use appropriate safety precautions when working with hazardous voltages.

This section contains details on adjustment of the module voltage source and measure functions.

Voltage adjustments

The module is set to four pre-defined voltage calibration points. At each point, the output voltage is measured with no load applied. The measured value is then written back to the module as the voltage calibration point. The voltage calibration points are:

CP1 = -90% of range

CP2 = -1% of range

CP3 = +90% of range

CP4 = +1% of range

Current adjustments

The module is set to four pre-defined current calibration points. At each point, the output current is determined by measuring the voltage across a characterized resistor ($I=V_r/R$). The measured value is written back to the module as the current calibration point. The current calibration points are:

CP1 = -90% of range (-80% of range for approximate feedback)

CP2 = -1% of range (-20% of range for approximate feedback)

CP3 = +90% of range (+80% of range for approximate feedback)

CP4 = +1% of range (+20% of range for approximate feedback)

Contact check adjustments

The module measures contact check with two characterized resistor standards connected between either HI and SHI or between LO and SLO. These measurements are written back to the module as the contact check calibration points. CP1 and CP2 are the contact check hi calibration points, and CP3 and CP4 are the contact check lo calibration points:

CP1 = 200 Ω

CP2 = 0 Ω (short)

CP3 = 200 Ω

CP4 = 0 Ω (short)

Adjustment conditions and requirements

The following conditions are required when performing adjustment:

- A stable ambient temperature controlled to vary less than ± 1 °C during the period of adjustment
- A calibration adjustment temperature (T_{CAL}) of 23 °C. If a different nominal temperature is used, it should be noted on the calibration report
- A relative humidity of less than or equal to 40 %, unless otherwise noted.
- No direct airflow on the input terminals.

Adjustment equipment

The following is a table of the recommended equipment used for adjusting the MSMU60-2.

Type	Specifications	Recommended instrument
Precision, fixed, resistive loads	0 Ω (short) 1 Ω 10 Ω 50 Ω 100 Ω 150 Ω 200 Ω 1 k Ω 10 k Ω 1 M Ω 10 M Ω	Various manufacturers, 1% tolerance
Modular test system	Tektronix MP5103	Tektronix MP5103
Digital multimeter	DC V: 10 nV to 1100 V 2-wire resistance: 1 $\mu\Omega$ to 1.2 G Ω 4-wire resistance: 100 n Ω to 1.2 G Ω	Keithley DMM7510 or equivalent

WARNING: The input/output connectors of the SMU modules are rated for connection to circuits rated Measurement Category 0 only, with transients rated less than 1500 V_{PEAK}. Do not connect the module terminals to CAT II, CAT III, or CAT IV circuits. Connections of the input/output terminals to circuits higher than CAT 0 can cause damage to the equipment or expose the operator to hazardous voltages.

Adjust the output voltage

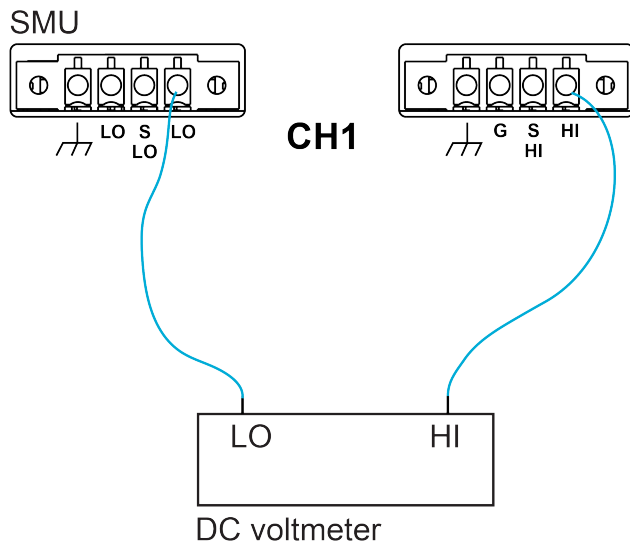
This procedure applies to both CH1 and CH2 of the module.

When using TSP commands, you must specify the module slot and channel. For example, to unlock calibration for channel 1 of the module installed in slot 1 of the mainframe, send

```
slot[1].smu[1].cal.unlock()
```

Use the following graphic to set up your instruments for adjustment.

NOTE: The following graphic shows instruments configured for adjusting channel 1 of the SMU. Change the output connections to channel 2 before performing adjustment on that channel.



Negative voltage range adjustment

To adjust the negative output range:

1. Reset the DC voltmeter.
2. Configure the DC voltmeter as follows:
 - **Function:** DC volts
 - **Range:** As appropriate for calibration point
 - **Resolution:** 6.5 digits
3. Unlock calibration for the module.


```
slot[1].smu[1].cal.unlock()
```
4. Load and activate the nominal calibration set.


```
slot[1].smu[1].cal.restore.(slot[1].smu[1].CALSET_NOMINAL)
```
5. Configure the module output adjustment settings. *Y* represents CP1, -90% of the selected range. The voltage value is *cp1Expected*.


```
slot[1].smu[1].source.levelv = Y
slot[1].smu[1].source.limiti = Y
```
6. Set the module calibration polarity to negative.


```
slot[1].smu[1].cal.polarity = slot[1].smu[1].CAL_NEGATIVE
```
7. Enable the module output.


```
slot[1].smu[1].source.output = slot[1].smu[1].ON
```
8. Measure the output voltage with the DC voltmeter. This value is *cp1Reference*.
9. Measure the output voltage with the SMU. This value is *cp1Measured*.


```
voltageValue = slot[1].smu[1].measure.v()
print(voltageValue)
```
10. Configure the module output adjustment settings. *Y* represents CP2, -1% of the selected range. The voltage value is *cp2Expected*.


```
slot[1].smu[1].source.levelv = Y
slot[1].smu[1].source.limiti = Y
```
11. Enable the module output.


```
slot[1].smu[1].source.output = slot[1].smu[1].ON
```

12. Measure the output voltage with the DC voltmeter. This value is `cp2Reference`.

13. Measure the output voltage with the SMU. This value is `cp2Measured`.

```
voltageValue = slot[1].smu[1].measure.v()
print(voltageValue)
```

14. Activate the calibration constants.

```
slot[1].smu[1].source.calibratev(range, cp1Expected, cp1Reference, cp2Expected, cp2Reference)
slot[1].smu[1].measure.calibratev(range, cp1Measured, cp1Reference, cp2Measured, cp2Reference)
```

15. Continue to the next adjustment procedure or see [Save and lock adjustments](#) (on page 43) if you are finished.

Positive voltage range adjustment

To adjust the positive output range:

1. Reset the DC voltmeter.

2. Configure the DC voltmeter as follows:

- **Function:** DC volts
- **Range:** As appropriate for calibration point
- **Resolution:** 6.5 digits

3. Unlock calibration for the module.

```
slot[1].smu[1].cal.unlock()
```

4. Load and activate the nominal calibration set.

```
slot[1].smu[1].cal.restore.(slot[1].smu[1].CALSET_NOMINAL)
```

5. Configure the module output adjustment settings. *Y* represents CP3, +90% of the selected range. The voltage value is `cp3Expected`.

```
slot[1].smu[1].source.levelv = Y
slot[1].smu[1].source.limiti = Y
```

6. Set the module calibration polarity to positive.

```
slot[1].smu[1].cal.polarity = slot[1].smu[1].CAL_POSITIVE
```

7. Enable the module output.

```
slot[1].smu[1].source.output = slot[1].smu[1].ON
```

8. Measure the output voltage with the DC voltmeter. This value is `cp3Reference`.

9. Measure the output voltage with the SMU. This value is `cp3Measured`.

```
voltageValue = slot[1].smu[1].measure.v()
print(voltageValue)
```

10. Configure the module output adjustment settings. *Y* represents CP4, +1% of the selected range. The voltage value is `cp4Expected`.

```
slot[1].smu[1].source.levelv = Y
slot[1].smu[1].source.limiti = Y
```

11. Enable the module output.

```
slot[1].smu[1].source.output = slot[1].smu[1].ON
```

12. Measure the output voltage with the DC voltmeter. This value is `cp4Reference`.

13. Measure the output voltage with the SMU. This value is `cp4Measured`.

```
voltageValue = slot[1].smu[1].measure.v()
print(voltageValue)
```

14. Activate the calibration constants.

```
slot[1].smu[1].source.calibratev(range, cp3Expected, cp3Reference, cp4Expected, cp4Reference)
slot[1].smu[1].measure.calibratev(range, cp3Measured, cp3Reference, cp4Measured, cp4Reference)
```

15. Continue to the next adjustment procedure or see [Save and lock adjustments](#) (on page 43) if you are finished.

Approximate voltage feedback range adjustment

To adjust the approximate voltage feedback range:

1. Reset the DC voltmeter.

2. Configure the DC voltmeter as follows:

- **Function:** DC volts
- **Range:** As appropriate for calibration point
- **Resolution:** 6.5 digits

3. Unlock calibration for the module.

```
slot[1].smu[1].cal.unlock()
```

4. Load and activate the nominal calibration set.

```
slot[1].smu[1].cal.restore.(slot[1].smu[1].CALSET_NOMINAL)
```

5. Configure the module output adjustment settings. *Y* represents CP1, -90% of the selected range. The voltage value is *cp1Expected*.

```
slot[1].smu[1].source.levelv = Y
slot[1].smu[1].source.limiti = Y
```

6. Set the sense mode for calibration.

```
slot[1].smu[1].sense = slot[1].smu[1].SENSE_CALA
```

7. Set the module calibration polarity to negative.

```
slot[1].smu[1].cal.polarity = slot[1].smu[1].CAL_NEGATIVE
```

8. Enable the module output.

```
slot[1].smu[1].source.output = slot[1].smu[1].ON
```

9. Measure the output voltage with the DC voltmeter. This value is *cp1Reference*.10. Measure the output voltage with the SMU. This value is *cp1Measured*.

```
voltageValue = slot[1].smu[1].measure.v()
print(voltageValue)
```

11. Configure the module output adjustment settings. *Y* represents CP2, -1% of the selected range. The voltage value is *cp2Expected*.

```
slot[1].smu[1].source.levelv = Y
slot[1].smu[1].source.limiti = Y
```

12. Enable the module output.

```
slot[1].smu[1].source.output = slot[1].smu[1].ON
```

13. Measure the output voltage with the DC voltmeter. This value is *cp2Reference*.14. Measure the output voltage with the SMU. This value is *cp2Measured*.

```
voltageValue = slot[1].smu[1].measure.v()
print(voltageValue)
```

15. Activate the calibration constants.

```
slot[1].smu[1].source.calibratev(range, cp1Expected, cp1Reference, cp2Expected, cp2Reference)
slot[1].smu[1].source.calibratev(range, cp1Measured, cp1Reference, cp2Measured, cp2Reference)
```

16. Load and activate the nominal calibration set.

```
slot[1].smu[1].cal.restore.(slot[1].smu[1].CALSET_NOMINAL)
```

17. Configure the module output adjustment settings. *Y* represents CP3, +90% of the selected range. The voltage value is cp3Expected.

```
slot[1].smu[1].source.levelv = Y
slot[1].smu[1].source.limiti = Y
```

18. Set the sense mode for calibration.

```
slot[1].smu[1].sense = slot[1].smu[1].SENSE_CALA
```

19. Set the module calibration polarity to positive.

```
slot[1].smu[1].cal.polarity = slot[1].smu[1].CAL_POSITIVE
```

20. Enable the module output.

```
slot[1].smu[1].source.output = slot[1].smu[1].ON
```

21. Measure the output voltage with the DC voltmeter. This value is cp3Reference.**22. Measure the output voltage with the SMU. This value is cp3Measured.**

```
voltageValue = slot[1].smu[1].measure.v()
print(voltageValue)
```

23. Configure the module output adjustment settings. *Y* represents CP4, +1% of the selected range. The voltage value is cp4Expected.

```
slot[1].smu[1].source.levelv = Y
slot[1].smu[1].source.limiti = Y
```

24. Enable the module output.

```
slot[1].smu[1].source.output = slot[1].smu[1].ON
```

25. Measure the output voltage with the DC voltmeter. This value is cp4Reference.**26. Measure the output voltage with the SMU. This value is cp4Measured.**

```
voltageValue = slot[1].smu[1].measure.v()
print(voltageValue)
```

27. Activate the calibration constants.

```
slot[1].smu[1].source.calibratev(range, cp3Expected, cp3Reference, cp4Expected, cp4Reference)
slot[1].smu[1].source.calibratev(range, cp3Measured, cp3Reference, cp4Measured, cp4Reference)
```

28. Continue to the next adjustment procedure or see [Save and lock adjustments](#) (on page 43) if you are finished.

Adjust the output current

This procedure applies to both CH1 and CH2 of the module.

When using TSP commands, you must specify the module slot and channel. For example, to unlock calibration for channel 1 of the module installed in slot 1 of the mainframe, send

```
slot[1].smu[1].cal.unlock()
```

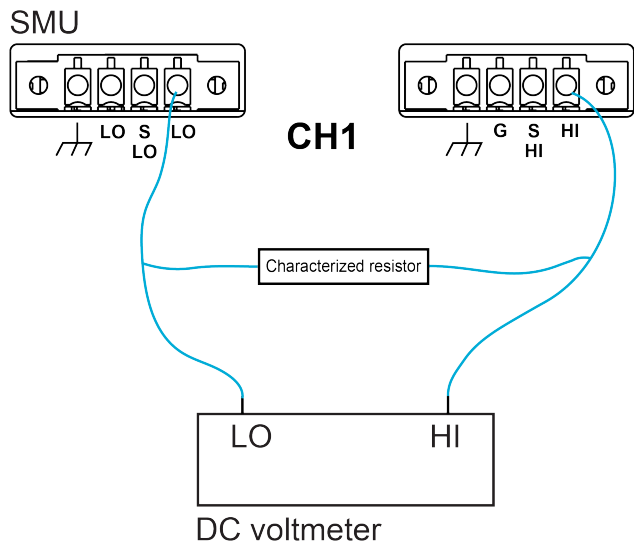
These procedures use a resistor between the HI and LO terminals. The following table shows the resistor value to use for the given range.

Range	Resistor
100 nA	10 MΩ
1 uA	1 MΩ

Range	Resistor
100 nA	10 MΩ
10 uA	100 KΩ
100 uA	10 KΩ
1 mA	1 KΩ
10 mA	100 Ω
100 mA	10 Ω
1 A	1 Ω
1.5 A	1 Ω

Use the following graphic to set up your instruments for adjustment.

NOTE: The following graphic shows instruments configured for adjusting channel 1 of the SMU. Change the output connections to channel 2 before performing adjustment on that channel.



Negative current range adjustment

To adjust the negative output range:

1. Reset the DMM.
2. Configure the DC voltmeter as follows:
 - **Function:** DC volts
 - **Range:** For CP1, 2 V. For CP2, 200 mV
 - **Resolution:** 6.5 digits
3. Connect the specified resistor between HI and LO of the SMU. See the table for resistor values.

4. Unlock calibration for the module.

```
slot[1].smu[1].cal.unlock()
```

5. Load and activate the nominal calibration set.

```
slot[1].smu[1].cal.restore.(slot[1].smu[1].CALSET_NOMINAL)
```

6. Configure the module output adjustment settings. *Y* represents CP1, -90% of the selected range. This value is *cp1Expected*.

```
slot[1].smu[1].source.level1 = Y
```

7. Set the module calibration polarity to negative.

```
slot[1].smu[1].cal.polarity = slot[1].smu[1].CAL_NEGATIVE
```

8. Enable the module output.

```
slot[1].smu[1].source.output = slot[1].smu[1].ON
```

9. Measure the output voltage across the resistor with the DC voltmeter and calculate the current ($I=V_r/R$). This value is *cp1Reference*.10. Measure the output current with the SMU. This value is *cp1Measured*.

```
currentValue = slot[1].smu[1].measure.i()
print(currentValue)
```

11. Configure the module output adjustment settings. *Y* represents CP2, -1% of the selected range. This value is *cp2Expected*.

```
slot[1].smu[1].source.level1= Y
```

12. Enable the module output.

```
slot[1].smu[1].source.output = slot[1].smu[1].ON
```

13. Measure the output voltage across the resistor with the DC voltmeter and calculate the current ($I=V_r/R$). This value is *cp2Reference*.14. Measure the output voltage with the SMU and calculate the current ($I=V_r/R$). This value is *cp2Measured*.

```
currentValue = slot[1].smu[1].measure.i()
print(currentValue)
```

15. Activate the calibration constants.

```
slot[1].smu[1].source.calibratei(range, cp1Expected, cp1Reference, cp2Expected, cp2Reference)
slot[1].smu[1].measure.calibratei(range, cp1Measured, cp1Reference, cp2Measured, cp2Reference)
```

16. Continue to the next adjustment procedure or see [Save and lock adjustments](#) (on page 43) if you are finished.

Positive current range adjustment

To adjust the positive output range:

1. Reset the DMM.

2. Configure the DC voltmeter as follows:

- **Function:** DC volts
- **Range:** For CP3, 2 V. For CP4, 200 mV
- **Resolution:** 6.5 digits

3. Connect the specified resistor between HI and LO of the SMU. See the table for resistor values.

4. Unlock calibration for the module.

```
slot[1].smu[1].cal.unlock()
```

5. Load and activate the nominal calibration set.

```
slot[1].smu[1].cal.restore.(slot[1].smu[1].CALSET_NOMINAL)
```

6. Configure the module output adjustment settings. Y represents CP3, +90% of the selected range. This value is `cp3Expected`.
`slot[1].smu[1].source.level1 = Y`
7. Set the module calibration polarity to positive.
`slot[1].smu[1].cal.polarity = slot[1].smu[1].CAL_POSITIVE`
8. Enable the module output.
`slot[1].smu[1].source.output = slot[1].smu[1].ON`
9. Measure the output voltage across the resistor with the DC voltmeter and calculate the current ($I=V_r/R$). This value is `cp3Reference`.
10. Measure the output current with the SMU. This value is `cp3Measured`.
`currentValue = slot[1].smu[1].measure.i()`
`print(currentValue)`
11. Configure the module output adjustment settings. Y represents CP4, +1% of the selected range. This value is `cp4Expected`.
`slot[1].smu[1].source.level1 = Y`
12. Enable the module output.
`slot[1].smu[1].source.output = slot[1].smu[1].ON`
13. Measure the output voltage across the resistor with the DC voltmeter and calculate the current ($I=V_r/R$). This value is `cp4Reference`.
14. Measure the output voltage with the SMU and calculate the current ($I=V_r/R$). This value is `cp4Measured`.
`currentValue = slot[1].smu[1].measure.i()`
`print(currentValue)`
15. Activate the calibration constants.
`slot[1].smu[1].source.calibrate1(range, cp3Expected, cp3Reference, cp4Expected, cp4Reference)`
`slot[1].smu[1].measure.calibrate1(range, cp3Measured, cp3Reference, cp4Measured, cp4Reference)`
16. Continue to the next adjustment procedure or see [Save and lock adjustments](#) (on page 43) if you are finished.

Approximate current feedback range adjustment

To adjust the approximate current feedback range:

1. Reset the DMM.
2. Configure the DC voltmeter as follows:
 - **Function:** DC volts
 - **Range:** As appropriate for calibration point
 - **Resolution:** 6.5 digits
3. Connect the specified resistor between HI and LO of the SMU. See the table for resistor values.
4. Unlock calibration for the module.
`slot[1].smu[1].cal.unlock()`
5. Load and activate the nominal calibration set.
`slot[1].smu[1].cal.restore(slot[1].smu[1].CALSET_NOMINAL)`
6. Configure the module output adjustment settings. Y represents CP1, -90% of the selected range. This value is `cp1Expected`.
`slot[1].smu[1].source.level1 = Y`
7. Set the sense mode for calibration.
`slot[1].smu[1].sense = slot[1].smu[1].SENSE_CALA`

8. Set the module calibration polarity to negative.

```
slot[1].smu[1].cal.polarity = slot[1].smu[1].CAL_NEGATIVE
```

9. Enable the module output.

```
slot[1].smu[1].source.output = slot[1].smu[1].ON
```

10. Measure the output voltage across the resistor with the DC voltmeter and calculate the current ($I=V_r/R$). This value is cp1Reference.**11. Measure the output current with the SMU. This value is cp1Measured.**

```
currentValue = slot[1].smu[1].measure.i()  
print(currentValue)
```

12. Configure the module output adjustment settings. Y represents CP2, -1% of the selected range. This value is cp2Expected.

```
slot[1].smu[1].source.level1 = Y
```

13. Enable the module output.

```
slot[1].smu[1].source.output = slot[1].smu[1].ON
```

14. Measure the output voltage across the resistor with the DC voltmeter and calculate the current ($I=V_r/R$). This value is cp2Reference.**15. Measure the output voltage with the SMU and calculate the current ($I=V_r/R$). This value is cp2Measured.**

```
currentValue = slot[1].smu[1].measure.i()  
print(currentValue)
```

16. Activate the calibration constants.

```
slot[1].smu[1].source.calibratei(range, cp1Expected, cp1Reference, cp2Expected, cp2Reference)  
slot[1].smu[1].source.calibratei(range, cp1Measured, cp1Reference, cp2Measured, cp2Reference)
```

17. Load and activate the nominal calibration set.

```
slot[1].smu[1].cal.restore.(slot[1].smu[1].CALSET_NOMINAL)
```

18. Configure the module output adjustment settings. Y represents CP3, +90% of the selected range. This value is cp3Expected.

```
slot[1].smu[1].source.level1 = Y
```

19. Set the sense mode for calibration.

```
slot[1].smu[1].sense = slot[1].smu[1].SENSE_CALA
```

20. Set the module calibration polarity to positive.

```
slot[1].smu[1].cal.polarity = slot[1].smu[1].CAL_POSITIVE
```

21. Enable the module output.

```
slot[1].smu[1].source.output = slot[1].smu[1].ON
```

22. Measure the output voltage across the resistor with the DC voltmeter and calculate the current ($I=V_r/R$). This value is cp3Reference.**23. Measure the output current with the SMU. This value is cp3Measured.**

```
currentValue = slot[1].smu[1].measure.i()  
print(currentValue)
```

24. Configure the module output adjustment settings. Y represents CP4, +1% of the selected range. This value is cp4Expected.

```
slot[1].smu[1].source.level1 = Y
```

25. Enable the module output.

```
slot[1].smu[1].source.output = slot[1].smu[1].ON
```

26. Measure the output voltage across the resistor with the DC voltmeter and calculate the current ($I=V_r/R$). This value is cp4Reference.

27. Measure the output voltage with the SMU and calculate the current ($I=V/R$). This value is `cp4Measured`.

```
currentValue = slot[1].smu[1].measure.i()
print(currentValue)
```

28. Activate the calibration constants.

```
slot[1].smu[1].source.calibratei(range, cp3Expected, cp3Reference, cp4Expected, cp4Reference)
slot[1].smu[1].measure.calibratei(range, cp3Measured, cp3Reference, cp4Measured, cp4Reference)
```

29. Continue to the next adjustment procedure or see [Save and lock adjustments](#) (on page 43) if you are finished.

Contact check adjustment

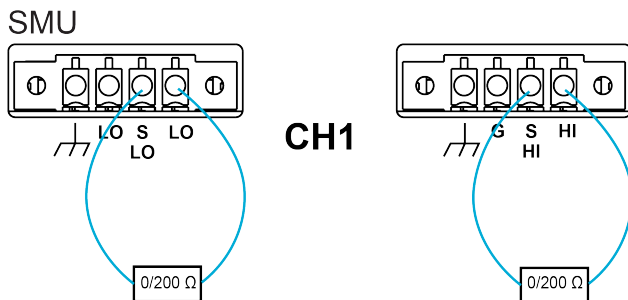
This procedure applies to both CH1 and CH2 of the module.

When using TSP commands, you must specify the module slot and channel. For example, to unlock calibration for channel 1 of the module installed in slot 1 of the mainframe, send

```
slot[1].smu[1].cal.unlock()
```

Use the following graphic to set up your instruments for adjustment.

NOTE: The following graphic shows instruments configured for adjusting channel 1 of the SMU. Change the output connections to channel 2 before performing adjustment on that channel.



To perform contact check adjustment:

1. Reset the module. Send

```
slot[1].smu[1].reset()
```

2. Connect the 200 Ω resistor between HI and SHI of the SMU.

3. Configure the positive and negative source off limit settings.

```
slot[1].smu[1].source.offlimiti = 1e-6
```

4. Unlock calibration for the module.

```
slot[1].smu[1].cal.unlock()
```

5. Load and activate the nominal calibration set.

```
slot[1].smu[1].cal.restore.(slot[1].smu[1].CALSET_NOMINAL)
```

6. Measure the contact check hi resistance. This value is `cp1Measured`. The characterized value of the resistor is `cp1Reference`. Send:

```
result, hiValue, loValue = slot[1].smu[1].contact.check()
cp1Measured = hiValue
```

7. Connect the 0 Ω resistor between HI and SHI of the SMU.

8. Measure the contact check hi resistance. This value is `cp2Measured`. The characterized value of the resistor is `cp2Reference`. Send:

```
result, hiValue, loValue = slot[1].smu[1].contact.check()
cp2Measured = hiValue
```

9. Activate the calibration constants.

```
slot[1].smu[1].contact.calibratehi(300, cp1Measured, cp1Reference, cp2Measured, cp2Reference)
```

10. Connect the 200 Ω resistor between LO and SLO of the SMU.

11. Measure the contact check lo resistance. This value is `cp1Measured`. The characterized value of the resistor is `cp1Reference`. Send:

```
result, hiValue, loValue = slot[1].smu[1].contact.check()  
cp1Measured = loValue
```

12. Connect the 0 Ω resistor between LO and SLO of the SMU.

13. Measure the contact check lo resistance. This value is `cp2Measured`. The characterized value of the resistor is `cp2Reference`. Send:

```
result, hiValue, loValue = slot[1].smu[1].contact.check()  
cp2Measured = loValue
```

14. Activate the calibration constants.

```
slot[1].smu[1].contact.calibratelo(300, cp1Measured, cp1Reference, cp2Measured, cp2Reference)
```

15. Continue to the next adjustment procedure or see [Save and lock adjustments](#) (on page 43) if you are finished.

Save and lock adjustments

Once all adjustments are done, set the adjustment date, then save and lock the calibration data to the module.

Replace the `slot` and `smu` values with the applicable module slot and channel that you have adjusted. Each module channel must be independently adjusted, saved, and locked.

```
slot[1].smu[1].cal.date = os.time()  
slot[1].smu[1].cal.save()  
slot[1].smu[1].cal.lock()
```

TSP calibration commands

slot[Z].smu[X].acal.adjust()

This function runs the selected automatic calibration procedure.

Type	TSP-Link accessible	Affected by	Where saved	Default value
Function	Yes			

Usage

```
slot[Z].smu[X].acal.adjust(procedure)
```

<i>Z</i>	Module slot number
<i>X</i>	Module channel number
<i>procedure</i>	The automatic calibration procedure: ▪ Current source offset: <code>slot[Z].smu[X].ACAL_I_SOURCE_OFFSET</code> ▪ Current measure offset: <code>slot[Z].smu[X].ACAL_I_MEASURE_OFFSET</code> ▪ Use a known zero and reference voltage to characterize the auxiliary ADC: <code>slot[Z].smu[X].ACAL_AUX_ADC</code> ▪ Run all autocalibration procedures: <code>slot[Z].smu[X].ACAL_ADJUST_ALL</code>

Details

Runs the automatic calibration procedure specified by the function parameter.

<code>slot[Z].smu[X].ACAL_I_SOURCE_OFFSET</code>	Learns the ADC setting that outputs nearest to 0 A for each current source range, then adjusts the source calibration constants accordingly.
<code>slot[Z].smu[X].ACAL_I_MEASURE_OFFSET</code>	Applies 0 A to the current measure circuit and learns the offset of each range, then adjusts the measure calibration constants accordingly.
<code>slot[Z].smu[X].ACAL_AUX_ADC</code>	Uses a known zero and reference voltage to characterize the auxiliary ADC, then adjusts the ADC calibration constants accordingly. This ADC is used for the guard measurement and internal measurements.
<code>slot[Z].smu[X].ACAL_ADJUST_ALL</code>	Runs all autocalibration commands sequentially.

When the specified calibration procedure is completed, the adjusted calibration constants are independently saved for each procedure with the time and temperature. These constants are used to update the recommended due date for the procedure and to determine when the automatic calibration constants expire.

If a procedure fails, an error message is returned and the calibration data is not changed. If a failure occurs while running `slot[Z].smu[X].ACAL_ADJUST_ALL`, the data is not updated for any procedure.

Each procedure requires the user to put the SMU into a high impedance output state before running `slot[Z].smu[X].acal.adjust()`. This prevents the user from needing to disconnect the output leads when performing automatic calibration. An error message will be generated if the SMU is not in a high impedance state when the command runs.

When performing a standard calibration routine, the relevant automatic calibration adjustments are reset to nominal values, and the recommended automatic calibration due date is updated. For example, running `slot[Z].smu[X].measure.calibratei()` will reset the auto calibration data associated with `slot[Z].smu[X].ACAL_I_MEASURE_OFFSET`.

Example

```
slot[3].smu[1].acal.adjust(slot[3].smu[1].ACAL_I_MEASURE_OFFSET)
```

Performs an automatic calibration adjustment procedure for current measure offset.

Also see

[slot\[Z\].smu\[X\].acal.adjustdate\(\)](#) (on page 45)

slot[Z].smu[X].acal.adjustdate()

This function returns the date when a calibration procedure was last run.

Type	TSP-Link accessible	Affected by	Where saved	Default value
Function	Yes			

Usage

`date = slot[Z].smu[X].acal.adjustdate(procedure)`

<i>date</i>	Date of last adjustment in seconds since January 1, 1970, 12:00 AM (UTC)
<i>Z</i>	Module slot number
<i>X</i>	Module channel number
<i>procedure</i>	The procedure to report a date for: - slot[Z].smu[X].ACAL_I_SOURCE_OFFSET - slot[Z].smu[X].ACAL_I_MEASURE_OFFSET - slot[Z].smu[X].ACAL_AUX_ADC

Details

Returns the last run date of the specified automatic calibration procedure in seconds since January 1, 1970, 12:00 AM (UTC). This date is automatically updated after the specified procedure completes successfully.

Example

```
print(os.date('%m-%d-%Y %H:%M:%S', slot[3].smu[1].acal.adjustdate(slot[3].smu[1].ACAL_I_MEASURE_OFFSET)))
```

Returns the date and time of the last automatic calibration procedure for current measurement offset. For example:

05-20-2025 23:17:00

Also see

[slot\[Z\].smu\[X\].acal.adjust\(\)](#) (on page 44)
[slot\[Z\].smu\[X\].acal.due\(\)](#) (on page 46)

slot[Z].smu[X].acal.due()

This function returns the date that an automatic calibration procedure is due.

Type	TSP-Link accessible	Affected by	Where saved	Default value
Function	Yes			

Usage

```
date = slot[Z].smu[X].acal.due(procedure)
```

<i>date</i>	The calibration due date in seconds since January 1, 1970, 12:00 AM (UTC)
<i>Z</i>	Module slot number
<i>X</i>	Module channel number
<i>procedure</i>	Procedure to report due status for: - slot[Z].smu[X].ACAL_I_SOURCE_OFFSET - slot[Z].smu[X].ACAL_I_MEASURE_OFFSET - slot[Z].smu[X].ACAL_AUX_ADC

Details

This function returns the due date of the specified automatic calibration procedure in seconds since January 1, 1970, 12:00 AM (UTC). The procedure should be run again after this time for best performance.

The `slot[Z].smu[X].acal.valid()` function returns `false` if the present time and date is later than this due date.

This date is automatically updated to 30 days after the specified procedure completes successfully.

Example

```
print(os.date('%m-%d-%Y %H:%M:%S', slot[3].smu[1].acal.due(slot[3].smu[1].ACAL_I_MEASURE_OFFSET)))
```

Returns the date and time that the next calibration procedure should be run for current measurement offset.
For example:

```
06-03-2025 10:00:P00
```

Also see

[slot\[Z\].smu\[X\].acal.adjust\(\)](#) (on page 44)

[slot\[Z\].smu\[X\].acal.adjustdate\(\)](#) (on page 45)

[slot\[Z\].smu\[X\].acal.valid\(\)](#) (on page 48)

slot[Z].smu[X].acal.temperaturedelta()

This function returns the temperature delta between the present and last time a procedure was run.

Type	TSP-Link accessible	Affected by	Where saved	Default value
Function	Yes			

Usage

```
temperature = slot[Z].smu[X].acal.temperaturedelta(procedure)
```

<i>temperature</i>	The temperature difference in degrees Celsius
<i>Z</i>	Module slot number
<i>X</i>	Module channel number
<i>procedure</i>	Procedure to report temperature delta for: - slot[Z].smu[X].ACAL_I_SOURCE_OFFSET - slot[Z].smu[X].ACAL_I_MEASURE_OFFSET - slot[Z].smu[X].ACAL_AUX_ADC

Details

This function returns the difference between the present SMU temperature and the temperature recorded at the completion of the specified automatic calibration procedure.

The `slot[Z].smu[X].acal.valid()` function returns `false` if the difference is ± 5 °C from the last recorded temperature.

Example

```
print(tostring(slot[3].smu[1].acal.temperaturedelta(slot[3].smu[1].ACAL_I_MEASURE_OFFSET)))
```

Might return the following result, indicating that the internal temperature of the SMU is presently approximately 5.9 degrees lower than it was the last time the current measurement offset automatic calibration procedure was run:

```
-5.9214274814984
```

Also see

[slot\[Z\].smu\[X\].acal.adjust\(\)](#) (on page 44)

[slot\[Z\].smu\[X\].acal.valid\(\)](#) (on page 48)

slot[Z].smu[X].acal.valid()

This function determines if the automatic calibration constants are valid.

Type	TSP-Link accessible	Affected by	Where saved	Default value
Function	Yes			

Usage

```
valid = slot[Z].smu[X].acal.valid(procedure)
```

<i>valid</i>	The validity of the constants: - Valid: <code>true</code> - Invalid: <code>false</code>
<i>Z</i>	Module slot number
<i>X</i>	Module channel number
<i>procedure</i>	The procedure to report constants for: - Current source offset: <code>slot[Z].smu[X].ACAL_I_SOURCE_OFFSET</code> - Current measure offset: <code>slot[Z].smu[X].ACAL_I_MEASURE_OFFSET</code> - Auxiliary ADC: <code>slot[Z].smu[X].ACAL_AUX_ADC</code>

Details

This function determines if the calibration constants are valid. The function returns `true` if the constants are valid, and `false` if the constants have expired. If `false`, the specified procedure should be run.

Constants are valid within 30 days of the last autocalibration run, and within ± 5 °C of the last recorded autocalibration temperature.

To research a false return, you can use the `slot[Z].smu[X].acal.adjustdate()`, `slot[Z].smu[X].acal.due()`, and `slot[Z].smu[X].acal.temperaturedelta()` functions when `slot[Z].smu[X].acal.valid()` is run.

To check the status of autocalibration, you can use `slot[Z].status.questionable.ACAL`.

Example

```
print(slot[3].smu[1].acal.valid(slot[3].smu[1].ACAL_I_MEASURE_OFFSET))
```

In this example, the constants for the current measurement offset calibration procedure have expired, so the current measurement offset procedure should be run again.

Example output:

```
false
```

Also see

[slot\[Z\].smu\[X\].acal.adjustdate\(\)](#) (on page 45)

[slot\[Z\].smu\[X\].acal.due\(\)](#) (on page 46)

[slot\[Z\].smu\[X\].acal.temperaturedelta\(\)](#) (on page 47)

slot[Z].smu[X].cal.adjustdate

This attribute stores the date of the last calibration adjustment.

Type	TSP-Link accessible	Affected by	Where saved	Default value
Attribute (RW)	Yes	Calibration restore	Nonvolatile memory	Factory calibration date

Usage

```
adjustDate = slot[Z].smu[X].cal.adjustdate
slot[Z].smu[X].cal.adjustdate = adjustDate
```

<i>adjustDate</i>	Date of the last adjustment
<i>Z</i>	Module slot number
<i>X</i>	Module channel number

Details

This attribute stores the adjustment date associated with the active calibration set. The adjustment date can be read at any time but can only be assigned a new value when calibration has been enabled with the `slot[Z].smu[X].cal.unlock()` function.

You cannot change the adjustment date without first making a change to the calibration constants.

Once you change a calibration constant, you must set the adjustment date before you can save the calibration data to the nonvolatile memory of the SMU.

This attribute is stored with the active calibration set. If a different calibration set is restored, this attribute reflects the date stored with that set.

This attribute must be set using the UTC time and date. The date is stored as the number of seconds since UTC, 12:00 am Jan 1, 1970.

Example

```
slot[1].smu[2].cal.adjustdate = os.time()
```

Sets the adjustment date to the current time set on the instrument for channel 2 of the SMU 2 installed in slot 1.

Also see

[slot\[Z\].smu\[X\].cal.date](#) (on page 50)

[slot\[Z\].smu\[X\].cal.due](#) (on page 51)

slot[Z].smu[X].cal.count

This attribute returns the number of times a calibration set has been written to nonvolatile memory.

Type	TSP-Link accessible	Affected by	Where saved	Default value
Attribute (R)	Yes	Never	Nonvolatile memory	0

Usage

```
count = slot[Z].smu[X].cal.count
```

<i>count</i>	Number of times a calibration set has been written to nonvolatile memory
<i>Z</i>	Module slot number
<i>X</i>	Module channel number

Details

This read-only attribute indicates the number of times a calibration set has been written to nonvolatile memory. A 0 indicates that no calibration has been performed.

Example

```
print(slot[1].smu[2].cal.count)
```

Reads the number of times a calibration set has been written in nonvolatile memory for channel 2 of the SMU installed in slot 1.

Also see

[slot\[Z\].smu\[X\].cal.restore\(\)](#) (on page 53)

[slot\[Z\].smu\[X\].cal.save\(\)](#) (on page 54)

slot[Z].smu[X].cal.date

This attribute stores the calibration date of the active calibration set.

Type	TSP-Link accessible	Affected by	Where saved	Default value
Attribute (RW)	Yes	Calibration restore	Nonvolatile memory	Factory calibration date

Usage

```
calDate = slot[Z].smu[X].cal.date
slot[Z].smu[X].cal.date = calDate
```

<i>calDate</i>	Date of the last adjustment
<i>Z</i>	Module slot number
<i>X</i>	Module channel number

Details

This attribute stores the calibration date that is associated with the active calibration set. The calibration date can be read at any time but can only be assigned a new value when calibration has been enabled with the `slot[Z].smu[X].cal.unlock()` function. It is typically set to the date when the instrument was calibrated.

This attribute is stored with the active calibration set. If a different calibration set is restored, this attribute reflects the date stored with that set.

This attribute must be set using the UTC time and date. The date is stored as the number of seconds since UTC 12:00 am Jan 1, 1970.

Example

```
slot[1].smu[2].cal.date = os.time()
```

Sets the calibration date to the present time set on the instrument for channel 2 of the SMU installed in slot 1.

Also see

[slot\[Z\].smu\[X\].cal.adjustdate](#) (on page 49)

[slot\[Z\].smu\[X\].cal.due](#) (on page 51)

slot[Z].smu[X].cal.due

This attribute stores the next calibration due date.

Type	TSP-Link accessible	Affected by	Where saved	Default value
Attribute (RW)	Yes	Calibration restore	Nonvolatile memory	Factory calibration date

Usage

```
calDue = slot[Z].smu[X].cal.date
slot[Z].smu[X].cal.date = calDue
```

<i>calDate</i>	Due date of next calibration
<i>Z</i>	Module slot number
<i>X</i>	Module channel number

Details

This attribute stores the calibration date that is associated with the active calibration set. The calibration due date can be read at any time but can only be assigned a new value when calibration has been enabled with the `slot[Z].smu[X].cal.unlock()` function. It is typically set to the date when the next calibration should be performed.

This attribute is stored with the active calibration set. If a different calibration set is restored, this attribute reflects the date stored with that set.

This attribute must be set using the UTC time and date. The date is stored as the number of seconds since UTC 12:00 am Jan 1, 1970.

Example

```
slot[1].smu[2].cal.due = os.time() + 365 * 24 * 60 * 60
```

Sets the calibration due equal to one year from the present time set on channel 2 of the SMU installed in slot 1.

Also see

[slot\[Z\].smu\[X\].cal.adjustdate](#) (on page 49)

slot[Z].smu[X].cal.lock()

This function disables the commands that change calibration settings.

Type	TSP-Link accessible	Affected by	Where saved	Default value
Function	Yes			

Usage

```
slot[Z].smu[X].cal.lock()
```

Z	Module slot number
X	Module channel number

Details

Before you can lock calibration, the calibration constants must be written to nonvolatile memory or a previous calibration set must be restored. Error code 5012, "Cal data not saved - save or restore before lock," results if this function is called when the calibration state is `slot[Z].smu[X].CALSTATE_CALIBRATING`.

Example

```
slot[1].smu[1].cal.lock()
```

Disables calibration functions for channel 1 of the SMU installed in slot 1.

Also see

[slot\[Z\].smu\[X\].cal.restore\(\)](#) (on page 53)

[slot\[Z\].smu\[X\].cal.save\(\)](#) (on page 54)

[slot\[Z\].smu\[X\].cal.state](#) (on page 55)

[slot\[Z\].smu\[X\].cal.unlock\(\)](#) (on page 55)

slot[Z].smu[X].cal.polarity

This attribute controls which calibration constants are used for all subsequent measurements.

Type	TSP-Link accessible	Affected by	Where saved	Default value
Attribute (RW)	Yes	Instrument reset SMU reset SMU cal. lock Recall setup	Not saved	0 (slot[Z].smu[X].CAL_AUTO)

Usage

```
calPolarity = slot[Z].smu[X].cal.polarity
```

```
slot[Z].smu[X].cal.polarity = calPolarity
```

<i>calPolarity</i>	The polarity to use for measurements. Set to one of the following values: 0 or <code>slot[Z].smu[X].CAL_AUTO</code>: Automatic polarity detection 1 or <code>slot[Z].smu[X].CAL_POSITIVE</code>: Measure with positive polarity calibration constants 2 or <code>slot[Z].smu[X].CAL_NEGATIVE</code>: Measure with negative polarity calibration constants
Z	Module slot number
X	Module channel number

Details

This attribute controls which polarity calibration constants are used to make all subsequent measurements.

This attribute does not affect the `slot[Z].smu[X].measure.calibrateY()` command. The polarity for `slot[Z].smu[X].measure.calibrateY()` is dictated by the range parameter that is defined for it. The measurement calibration commands require the measurements provided to have been made using the polarity being calibrated.

When making measurements for calibration points far away from zero, the correct polarity constants are inherently used. However, when making measurements near zero, it is possible that the instrument could use the calibration constants from the wrong polarity. Setting `slot[Z].smu[X].cal.polarity` to positive or negative forces measurements to be made using the calibration constants for a given polarity, rather than basing the choice on the raw measurement data.

This attribute can only be set to positive or negative when calibration is unlocked. This attribute is automatically set to `slot[Z].smu[X].CAL_AUTO` when calibration is locked.

Example

```
slot[1].smu[1].cal.polarity = slot[1].smu[1].CAL_POSITIVE
```

Selects positive calibration constants for all subsequent measurements for channel 1 of the SMU installed in slot 1.

Also see

[slot\[Z\].smu\[X\].cal.lock\(\)](#) (on page 52)

[slot\[Z\].smu\[X\].cal.unlock\(\)](#) (on page 55)

[slot\[Z\].smu\[X\].measure.calibrateY\(\)](#) (on page 62)

`slot[Z].smu[X].reset()`

[slot\[Z\].smu\[X\].source.calibrateY\(\)](#) (on page 64)

slot[Z].smu[X].cal.restore()

This function loads a stored set of calibration constants.

Type	TSP-Link accessible	Affected by	Where saved	Default value
Function	Yes			

Usage

```
slot[Z].smu[X].cal.restore()
slot[Z].smu[X].cal.restore(calset)
```

<i>Z</i>	Module slot number
<i>X</i>	Module channel number
<i>calset</i>	The calibration set to be loaded; set <i>calset</i> to one of the following values: <code>slot[Z].smu[X].CALSET_NOMINAL</code>: A set of calibration constants that are uncalibrated, but set to nominal values to allow rudimentary functioning of the instrument <code>slot[Z].smu[X].CALSET_DEFAULT</code>: The normal calibration set <code>slot[Z].smu[X].CALSET_PREVIOUS</code>: The calibration set that was used before the last default set was overwritten

Details

This function overwrites the present set of calibration constants with constants read from nonvolatile memory.

This function is disabled until a successful call to `slot[Z].smu[X].cal.unlock()` is made.

If a calibration set is not specified, `slot[Z].smu[X].CALSET_DEFAULT` is used.

Example

```
slot[1].smu[1].cal.restore()
```

Restores factory calibration constants for channel 1 of the SMU installed in slot 1.

Also see

[slot\[Z\].smu\[X\].cal.lock\(\)](#) (on page 52)

[slot\[Z\].smu\[X\].cal.unlock\(\)](#) (on page 55)

slot[Z].smu[X].cal.save()

This function stores the active calibration constants to nonvolatile memory.

Type	TSP-Link accessible	Affected by	Where saved	Default value
Function	Yes			

Usage

```
slot[Z].smu[X].cal.save()
```

<i>Z</i>	Module slot number
<i>X</i>	Module channel number

Details

This function stores the active set of calibration constants to nonvolatile memory. The previous calibration constants (from the default calibration set) are copied to the previous calibration set (`slot[Z].smu[X].CALSET_PREVIOUS`) before overwriting the default calibration set.

This function is disabled until a successful call to `slot[Z].smu[X].cal.unlock()` is made.

If any of the calibration constants have been changed, this function is disabled unless the calibration date, the calibration due date, and the calibration adjust date have been assigned new values.

Example

```
slot[1].smu[1].cal.save()
```

Stores calibration constants in nonvolatile memory for channel 1 of the SMU installed in slot 1.

Also see

[slot\[Z\].smu\[X\].cal.lock\(\)](#) (on page 52)

[slot\[Z\].smu\[X\].cal.restore\(\)](#) (on page 53)

[slot\[Z\].smu\[X\].cal.unlock\(\)](#) (on page 55)

slot[Z].smu[X].cal.state

This attribute returns the present calibration state.

Type	TSP-Link accessible	Affected by	Where saved	Default value
Attribute (R)	Yes	Never	Nonvolatile memory	Locked

Usage

```
calState = slot[Z].smu[X].cal.state
```

<i>calState</i>	The present calibration state. - slot[Z].smu[X].CALSTATE_LOCKED: Calibration is locked - slot[Z].smu[X].CALSTATE_CALIBRATING: The calibration constants or dates have been changed but not yet saved to nonvolatile memory - slot[Z].smu[X].CALSTATE_UNLOCKED: Calibration is unlocked but none of the calibration constants or dates have changed since the last save or restore
<i>Z</i>	Module slot number
<i>X</i>	Module channel number

Details

This attribute indicates the calibration state of the instrument.

Example

```
print(slot[1].smu[2].cal.state)
```

Reads calibration state for channel 2 of the SMU installed in slot 1.

Also see

[slot\[Z\].smu\[X\].cal.restore\(\)](#) (on page 53)

[slot\[Z\].smu\[X\].cal.save\(\)](#) (on page 54)

slot[Z].smu[X].cal.unlock()

This function enables the commands that change calibration settings.

Type	TSP-Link accessible	Affected by	Where saved	Default value
Function	Yes			

Usage

```
slot[Z].smu[X].cal.unlock()
```

<i>Z</i>	Module slot number
<i>X</i>	Module channel number

Details

This function enables the calibration functions to change the calibration settings.

Example

```
slot[1].smu[1].cal.unlock()
```

Unlocks calibration for channel 1 of the SMU installed in slot 1.

Also see

[slot\[Z\].smu\[X\].cal.lock\(\)](#) (on page 52)

[slot\[Z\].smu\[X\].cal.restore\(\)](#) (on page 53)

[slot\[Z\].smu\[X\].cal.save\(\)](#) (on page 54)

slot[Z].smu[X].contact.calibratehi()

This function generates and activates HI and SHI contact check measurement constants.

Type	TSP-Link accessible	Affected by	Where saved	Default value
Function	Yes			

Usage

`slot[Z].smu[X].contact.calibratehi(range, cp1Measured, cp1Reference, cp2Measured, cp2Reference)`

<i>Z</i>	Module slot number
<i>X</i>	Module channel number
<i>range</i>	The contact check range to calibrate
<i>cp1Measured</i>	The measured value for calibration point 1
<i>cp1Reference</i>	The reference measurement for calibration point 1 as measured externally
<i>cp2Measured</i>	The measured value for calibration point 2
<i>cp2Reference</i>	The reference measurement for calibration point 2 as measured externally

Details

This function generates and activates new calibration constants for the given range.

All four measurements (*cp1Measured*, *cp1Reference*, *cp2Measured*, *cp2Reference*) must be made with the active calibration set. Do not change the active calibration set before issuing this command. Corruption of the calibration constants may result.

The new calibration constants are activated immediately, but they are not written to nonvolatile memory. Use `slot[Z].smu[X].cal.save()` to save the new constants to nonvolatile memory. Otherwise, the active calibration constants stay in effect until the instrument is power cycled or a calibration set is loaded from nonvolatile memory with the `slot[Z].smu[X].cal.restore()` function.

This function is disabled until calibration is unlocked with `slot[Z].smu[X].cal.unlock()`.

Example

```
slot[1].smu[1].contact.calibratehi(300, 2, 1, 297, 299)
```

Generates contact check HI measurement constants for channel 1 of the SMU installed in mainframe slot 1 using the following values:

- 300 Ω range
- 2 Ω zero SMU measurement reading
- 1 Ω for zero external DMM measurement reading
- 297 Ω for positive, full-scale SMU measurement reading
- 299 Ω for positive, full-scale external DMM measurement reading

Also see

[slot\[Z\].smu\[X\].contact.calibrate.lo\(\)](#) (on page 57)

slot[Z].smu[X].contact.calibratelo()

This function generates and activates LO and SLO contact check measurement constants.

Type	TSP-Link accessible	Affected by	Where saved	Default value
Function	Yes			

Usage

`slot[Z].smu[X].contact.calibratelo(range, cp1Measured, cp1Reference, cp2Measured, cp2Reference)`

<i>Z</i>	Module slot number
<i>X</i>	Module channel number
<i>range</i>	The contact check range to calibrate
<i>cp1Measured</i>	The measured value for calibration point 1
<i>cp1Reference</i>	The reference measurement for calibration point 1 as measured externally
<i>cp2Measured</i>	The measured value for calibration point 2
<i>cp2Reference</i>	The reference measurement for calibration point 2 as measured externally

Details

This function generates and activates new calibration constants for the given range.

All four measurements (*cp1Measured*, *cp1Reference*, *cp2Measured*, *cp2Reference*) must be made with the active calibration set. Do not change the active calibration set before issuing this command. Corruption of the calibration constants may result.

The new calibration constants are activated immediately, but they are not written to nonvolatile memory. Use `slot[Z].smu[X].cal.save()` to save the new constants to nonvolatile memory. Otherwise, the active calibration constants stay in effect until the instrument is power cycled or a calibration set is loaded from nonvolatile memory with the `slot[Z].smu[X].cal.restore()` function.

This function is disabled until calibration is unlocked with `slot[Z].smu[X].cal.unlock()`.

Example

```
slot[1].smu[1].contact.calibratelo(3000, 2, 1, 2995, 2998)
```

Generates contact check LO measurement constants for channel 1 of the SMU installed in mainframe slot 1 using the following values:

- 3000 Ω range
- 2 Ω zero SMU measurement reading
- 1 Ω for zero external DMM measurement reading
- 2995 Ω for positive, full-scale SMU measurement reading
- 2998 Ω for positive, full-scale external DMM measurement reading

Also see

[slot\[Z\].smu\[X\].contact.calibrate.hi\(\)](#) (on page 56)

slot[Z].smu[X].contact.zero.adjust()

This function runs the contact check zero procedure.

Type	TSP-Link accessible	Affected by	Where saved	Default value
Function	Yes			

Usage

```
slot[Z].smu[X].contact.zero.adjust(procedure)
```

<i>Z</i>	Module slot number
<i>X</i>	Module channel number
<i>procedure</i>	slot[Z].smu[X].CONTACT_HI

Details

This function runs the contact check HI zero procedure. This function automatically corrects for any offset in the contact check HI measurement circuit and applies the correction to the contact check function.

This function requires the user to remove all output connections before beginning, otherwise an error will be returned, or an invalid adjustment will result.

The adjustment is saved along with the present time and temperature. These are used to update the calibration due date and determine if the adjustment is valid.

If the correction fails, an error message is returned, and the adjustment data is not changed.

The `slot[Z].smu[X].contact.calibratehi()` function will reset the adjustment data.

Example

```
slot[3].smu[1].contact.zero.adjust(slot[3].smu[1].CONTACT_HI)
```

Corrects the measurement offset for contact check HI for channel 1 of the the SMU in slot 3.

Also see

[slot\[Z\].smu\[X\].contact.calibratehi\(\)](#) (on page 56)

[slot\[Z\].smu\[X\].contact.zero.adjustdate\(\)](#) (on page 58)

slot[Z].smu[X].contact.zero.adjustdate()

This function returns the last run date of the contact check zero procedure.

Type	TSP-Link accessible	Affected by	Where saved	Default value
Function	Yes			

Usage

```
date = slot[Z].smu[X].contact.zero.adjustdate(procedure)
```

<i>date</i>	The last adjustment date in seconds since January 1, 1970 12:00 AM (UTC)
<i>Z</i>	Module slot number
<i>X</i>	Module channel number
<i>procedure</i>	slot[Z].smu[X].CONTACT_HI

Details

Returns the last run date of the contact check zero procedure in seconds since January 1, 1970 12:00 AM (UTC). This date is automatically updated after the completion of `slot[Z].smu[X].contact.zero.adjust()`.

Example

```
print(os.date('%m-%d-%Y %H:%M:%S', slot[3].smu[1].contact.zero.adjustdate(slot[3].smu[1].CONTACT_HI)))
```

Might return

05-22-2025 00:38:00

This indicates that the contact check zero adjust procedure for channel 1 of the SMU located in channel 3 last run on May 21, 2025 at 12:38 AM.

Also see

[slot\[Z\].smu\[X\].contact.zero.adjust\(\)](#) (on page 58)

[slot\[Z\].smu\[X\].contact.zero.due\(\)](#) (on page 59)

slot[Z].smu[X].contact.zero.due()

This function returns the contact check procedure due date.

Type	TSP-Link accessible	Affected by	Where saved	Default value
Function	Yes			

Usage

`date = slot[Z].smu[X].contact.zero.due(procedure)`

<i>date</i>	The last adjustment date in seconds since January 1, 1970 12:00 AM (UTC)
<i>Z</i>	Module slot number
<i>X</i>	Module channel number
<i>procedure</i>	<code>slot[Z].smu[X].CONTACT_HI</code>

Details

Returns the due date of the contact check zero procedure in seconds since January 1, 1970 12:00 AM (UTC). This date is automatically updated after the completion of `slot[Z].smu[X].contact.zero.adjust()`.

The `slot[Z].smu[X].contact.zero.valid()` function returns `false` if the current time and date is later than this due date.

Example

```
print(os.date('%m-%d-%Y %H:%M:%S', slot[3].smu[1].acal.adjustdate(slot[3].smu[1].CONTACT_HI)))
```

Might return

05-22-2026 00:38:00

This indicates that the next contact check zero adjust procedure for channel 1 of the SMU located in channel 3 should be run on May 22, 2026 at 12:38 AM.

Also see

[slot\[Z\].smu\[X\].contact.zero.adjust\(\)](#) (on page 44)

[slot\[Z\].smu\[X\].contact.zero.adjustdate\(\)](#) (on page 45)

[slot\[Z\].smu\[X\].contact.zero.valid\(\)](#) (on page 61)

slot[Z].smu[X].contact.zero.temperaturedelta()

This function returns the temperature delta between the present and the last time the contact check zero adjustment was performed.

Type	TSP-Link accessible	Affected by	Where saved	Default value
Function	Yes			

Usage

```
temperature = slot[Z].smu[X].contact.zero.temperaturedelta(procedure)
```

<i>temperature</i>	The temperature in degrees Celsius
<i>Z</i>	Module slot number
<i>X</i>	Module channel number
<i>procedure</i>	slot[Z].smu[X].CONTACT_HI

Details

Returns the difference between the present SMU temperature and the temperature recorded at the completion of `slot[Z].smu[X].contact.zero.adjust()`.

The `slot[Z].smu[X].contact.zero.valid()` function returns *false* if this difference is outside of the allowed window.

Example

```
print(tostring(slot[3].smu[1].acal.temperaturedelta(slot[3].smu[1].CONTACT_HI))
```

Might return

2.4

This indicates that the internal temperature of channel 1 of the SMU in slot 3 is currently 2.4 degrees Celsius higher than it was the last time the contact check HI zero adjust procedure was run.

Also see

[slot\[Z\].smu\[X\].contact.zero.adjust\(\)](#) (on page 58)

[slot\[Z\].smu\[X\].contact.zero.valid\(\)](#) (on page 61)

slot[Z].smu[X].contact.zero.valid()

This function returns the validity state of the contact check zero adjustment.

Type	TSP-Link accessible	Affected by	Where saved	Default value
Function	Yes			

Usage

`valid = slot[Z].smu[X].contact.zero.valid(procedure)`

<i>valid</i>	If calibration constants are valid, <code>true</code> . Otherwise, <code>false</code> .
<i>Z</i>	Module slot number
<i>X</i>	Module channel number
<i>procedure</i>	<code>slot[Z].smu[X].CONTACT_HI</code>

Details

This function returns `true` if the contact check zero adjustments are valid or `false` if expired. If `false`, the `slot[Z].smu[X].CONTACT_HI` specified procedure should be run again.

The `slot[Z].smu[X].contact.zero.adjustdate()`, `slot[Z].smu[X].contact.zero.due()`, and `slot[Z].smu[X].contact.zero.temperaturedelta()` functions can be used to determine the reason for this function to return `false`.

Example

<pre>print(slot[3].smu[1].contact.zero.valid(slot[3].smu[1].CONTACT_HI))</pre>
Might return <pre>true</pre> This indicates that the contact check adjustments for channel 1 of the SMU installed in slot 3 are valid.

Also see

- [slot\[Z\].smu\[X\].contact.zero.adjustdate\(\)](#) (on page 58)
- [slot\[Z\].smu\[X\].contact.zero.due\(\)](#) (on page 59)
- [slot\[Z\].smu\[X\].contact.zero.temperaturedelta\(\)](#) (on page 60)

slot[Z].smu[X].measure.calibrateY()

This function generates and activates new measurement calibration constants.

Type	TSP-Link accessible	Affected by	Where saved	Default value
Function	Yes			

Usage

```
slot[Z].smu[X].measure.calibrateY(range, cp1Measured, cp1Reference, cp2Measured, cp2Reference)
```

<i>Z</i>	Module slot number
<i>X</i>	Module channel number
<i>Y</i>	SMU measurement function: - Voltage: <i>v</i> - Current: <i>i</i>
<i>range</i>	The measurement range to adjust
<i>cp1Measured</i>	The value measured by this SMU for point 1
<i>cp1Reference</i>	The reference measurement for point 1 as measured externally
<i>cp2Measured</i>	The value measured by this SMU for point 2
<i>cp2Reference</i>	The reference measurement for point 2 as measured externally

Details

This function generates and activates new calibration constants for the given range.

The positive and negative polarities of the instrument must be adjusted separately. Use a positive value for the range parameter to adjust the positive polarity and a negative value for the range parameter to adjust the negative polarity.

All four measurements (*cp1Measured*, *cp1Reference*, *cp2Measured*, and *cp2Reference*) must be made with the calibration set that is active. Corruption of the calibration constants may result if this is ignored.

The new calibration constants are activated immediately but they are not written to nonvolatile memory. Use the `slot[Z].smu[X].cal.save()` function to save the new constants to nonvolatile memory. The active calibration constants stay in effect until the instrument is power cycled or a calibration set is loaded from nonvolatile memory with the `slot[Z].smu[X].cal.restore()` function.

This function is only available when calibration is unlocked using `slot[Z].smu[X].cal.unlock()`.

Example

```
slot[1].smu[1].measure.calibratev(1, 1e-4, 1e-5, 0.92, 0.903)
```

Adjust channel 1 voltage measurement of the SMU installed in slot 1 of the MP5000 mainframe using the following values:

- 1 V calibration range
- 1e-4 for +zero measurement reading
- 1e-5 for +zero DMM measurement reading
- 0.92 for +FS measurement reading
- 0.903 for the +FS DMM measurement reading

Also see

[slot\[Z\].smu\[X\].cal.lock\(\)](#) (on page 52)
[slot\[Z\].smu\[X\].cal.restore\(\)](#) (on page 53)
[slot\[Z\].smu\[X\].cal.save\(\)](#) (on page 54)
[slot\[Z\].smu\[X\].cal.unlock\(\)](#) (on page 55)
[slot\[Z\].smu\[X\].source.calibrateY\(\)](#) (on page 64)

slot[Z].smu[X].measure.getcalY()

This function returns the measurement calibration constants for the active calibration set.

Type	TSP-Link accessible	Affected by	Where saved	Default value
Function	Yes			

Usage

```
gain, offset = slot[Z].smu[X].measure.getcalY(range)
```

<i>gain</i>	The gain calibration constant for the measurement range
<i>offset</i>	The offset calibration constant for the measurement range
<i>Z</i>	Module slot number
<i>X</i>	Module channel number
<i>Y</i>	The measurement function; <i>v</i> = voltage, <i>i</i> = current
<i>range</i>	The measure range: - Voltage ranges: 200 mV, 2 V, 6 V, 20 v , 60 V - Current ranges: 100 nA, 1 uA, 10 uA, 100 uA, 1 mA, 10 mA, 100 mA, 1 A, and 1.5 A

Details

This function returns the gain and offset calibration constants for the active calibration set for a given range and measurement function.

The `range` parameter can be any valid measurement level. The best measurement range for that level will be used. The `range` parameter also determines the polarity of the calibration constants to return; if the `range` parameter is positive, the positive calibration constants will be returned, otherwise, the negative calibration constants will be returned.

The active calibration set can be changed using `slot[Z].smu[X].cal.restore()`.

Example

```
gain, offset = slot[1].smu[1].measure.getcali(0.004)
```

The positive gain and offset calibration constants are returned for the 10 mA measure range for channel 1 of the SMU installed in slot 1 of the mainframe, based on the active calibration set.

Also see

[slot\[Z\].smu\[X\].cal.restore\(\)](#) (on page 53)

slot[Z].smu[X].source.calibrateY()

This function generates and activates new source calibration constants.

Type	TSP-Link accessible	Affected by	Where saved	Default value
Function	Yes			

Usage

```
slot[Z].smu[X].source.calibrateY(range, cp1Expected, cp1Reference, cp2Expected, cp2Reference)
```

<i>Z</i>	Module slot number
<i>X</i>	Module channel number
<i>Y</i>	SMU source function: - Voltage: <i>v</i> - Current: <i>i</i>
<i>range</i>	The measurement range to adjust
<i>cp1Expected</i>	The source value set for point 1
<i>cp1Reference</i>	The reference measurement for point 1 as measured externally
<i>cp2Expected</i>	The source value set for point 2
<i>cp2Reference</i>	The reference measurement for point 2 as measured externally

Details

This function generates and activates new calibration constants for the given range.

The positive and negative polarities of the source must be adjusted separately. Use a positive value for range to adjust the positive polarity and a negative value for range to adjust the negative polarity. Do not use 0.0 for a negative point; 0.0 is considered to be a positive number.

Typically, the two points that are used are near zero for point 1 and 90% of full scale for point 2. Full scale for point 2 should be avoided if the source of the SMU is substantially out of calibration.

The two reference measurements must be made with the source using the active calibration set. For example, source a value, measure it, and do not change the active calibration set before issuing this command.

The new calibration constants are activated immediately but they are not written to nonvolatile memory. Use the `slot[Z].smu[X].cal.save()` function to save the new constants to nonvolatile memory. The active calibration constants stay in effect until the instrument is power cycled or a calibration set is loaded from nonvolatile memory with the `slot[Z].smu[X].cal.restore()` function.

This function is only available when calibration is unlocked using `slot[Z].smu[X].cal.unlock()`.

Example

```
slot[1].smu[1].source.calibratev(6, 1.2e-2, 1.2e-3, 5.8, 5.84)
```

Generates and activates the following new source calibration constants for channel 1 of the SMU installed in slot 1:

- 6 V calibration range
- 1.2e-2 for +zero source output value
- 1.2e-3 for +zero external DMM measurement reading
- 5.8 for +FS source output value
- 5.84 for +FS external DMM measurement reading

Also see

[slot\[Z\].smu\[X\].cal.restore\(\)](#) (on page 53)

[slot\[Z\].smu\[X\].cal.save\(\)](#) (on page 54)

[slot\[Z\].smu\[X\].cal.unlock\(\)](#) (on page 55)

[slot\[Z\].smu\[X\].measure.calibrateY\(\)](#) (on page 62)

slot[Z].smu[X].source.getcalY()

This function returns the source calibration constants for the active calibration set.

Type	TSP-Link accessible	Affected by	Where saved	Default value
Function	Yes			

Usage

```
gain, offset = slot[Z].smu[X].source.getcalY(range)
```

<i>gain</i>	The gain calibration constant for the source range
<i>offset</i>	The offset calibration constant for the source range
<i>Z</i>	Module slot number
<i>X</i>	Module channel number
<i>Y</i>	The source function; <i>v</i> = voltage, <i>i</i> = current
<i>range</i>	The source range: ▪ Voltage ranges: 200 mV, 2 V, 6 V, 20 v , 60 V ▪ Current ranges: 100 nA, 1 uA, 10 uA, 100 uA, 1 mA, 10 mA, 100 mA, 1 A, and 1.5 A

Details

This function returns the gain and offset calibration constants for the active calibration set for a given range and source function.

The *range* parameter can be any valid source level. The best source range for that level will be used. The *range* parameter also determines the polarity of the calibration constants to return; if the *range* parameter is positive, the positive calibration constants will be returned, otherwise, the negative calibration constants will be returned.

The active calibration set can be changed using `slot[Z].smu[X].cal.restore()`.

Example

```
gain, offset = slot[1].smu[1].source.getcalv(-6)
```

Returns the negative gain and offset calibration constants for the 6 V source range for channel 1 of the module installed in slot 1 of the mainframe, based on the active calibration set.

Also see

[slot\[Z\].smu\[X\].cal.restore\(\)](#) (on page 53)

Verification test record forms

Output voltage and measurement accuracy verification test record

Model	☐	☐	☐
Serial number			
Verified by	Name:		
	Company and contact:		
	Year:	Month:	Day:
Environment	Temperature (C/F):	Humidity (%):	

Test Step	CH	Output (V)	Measurement result	Low test limit	High test limit	Pass/fail
Set DC voltage accuracy +100% FS, 100% Pwr		-60		-60.018	-59.982	
Read DC voltage accuracy +100% FS, 100% Pwr		-60		*	**	
Set DC voltage accuracy +50% FS, 100% Pwr		-30		-30.012	-29.988	
Read DC voltage accuracy +50% FS, 100% Pwr		-30		*	**	
Set DC voltage accuracy +0% FS, 100% Pwr		-0.06		-0.066	-0.054	
Read DC voltage accuracy +0% FS, 100% Pwr		-0.06		*	**	
Set DC voltage accuracy +100% FS, 100% Pwr		60		59.982	60.018	
Read DC voltage accuracy +100% FS, 100% Pwr		60		*	**	
Set DC voltage accuracy +50% FS, 100% Pwr		30		29.988	30.012	
Read DC voltage accuracy +50% FS, 100% Pwr		30		*	**	
Set DC voltage accuracy +0% FS, 100% Pwr		0.06		0.054	0.066	
Read DC voltage accuracy +0% FS, 100% Pwr		0.06		*	**	
Set DC voltage accuracy +100% FS, 100% Pwr		-20		-20.006	-19.994	

Test Step	CH	Output (V)	Measurement result	Low test limit	High test limit	Pass/fail
Read DC voltage accuracy +100% FS, 100% Pwr		-20		*	**	
Set DC voltage accuracy +50% FS, 100% Pwr		-10		-10.004	-9.996	
Read DC voltage accuracy +50% FS, 100% Pwr		-10		*	**	
Set DC voltage accuracy +0% FS, 100% Pwr		-0.02		-0.022	-0.018	
Read DC voltage accuracy +0% FS, 100% Pwr		-0.02		*	**	
Set DC voltage accuracy +100% FS, 100% Pwr		20		19.994	20.006	
Read DC voltage accuracy +100% FS, 100% Pwr		20		*	**	
Set DC voltage accuracy +50% FS, 100% Pwr		10		9.996	10.004	
Read DC voltage accuracy +50% FS, 100% Pwr		10		*	**	
Set DC voltage accuracy +0% FS, 100% Pwr		0.02		0.018	0.022	
Read DC voltage accuracy +0% FS, 100% Pwr		0.02		*	**	
Set DC voltage accuracy +100% FS, 100% Pwr		-6		-6.0021	-5.9979	
Read DC voltage accuracy +100% FS, 100% Pwr		-6		*	**	
Set DC voltage accuracy +50% FS, 100% Pwr		-3		-3.0015	-2.9985	
Read DC voltage accuracy +50% FS, 100% Pwr		-3		*	**	
Set DC voltage accuracy +0% FS, 100% Pwr		-0.006		-0.0069	-0.0051	
Read DC voltage accuracy +0% FS, 100% Pwr		-0.006		*	**	
Set DC voltage accuracy +100% FS, 100% Pwr		6		5.9979	6.0021	
Read DC voltage accuracy +100% FS, 100% Pwr		6		*	**	
Set DC voltage accuracy +50% FS, 100% Pwr		3		2.9985	3.0015	
Read DC voltage accuracy +50% FS, 100% Pwr		3		*	**	
Set DC voltage accuracy +0% FS, 100% Pwr		0.006		0.0051	0.0069	
Read DC voltage accuracy +0% FS, 100% Pwr		0.006		*	**	

Test Step	CH	Output (V)	Measurement result	Low test limit	High test limit	Pass/fail
Set DC voltage accuracy +100% FS, 100% Pwr		-2		-2.0007	-1.9993	
Read DC voltage accuracy +100% FS, 100% Pwr		-2		*	**	
Set DC voltage accuracy +50% FS, 100% Pwr		-1		-1.0005	-0.9995	
Read DC voltage accuracy +50% FS, 100% Pwr		-1		*	**	
Set DC voltage accuracy +0% FS, 100% Pwr		-0.002		-0.0023	-0.0017	
Read DC voltage accuracy +0% FS, 100% Pwr		-0.002		*	**	
Set DC voltage accuracy +100% FS, 100% Pwr		2		1.9993	2.0007	
Read DC voltage accuracy +100% FS, 100% Pwr		2		*	**	
Set DC voltage accuracy +50% FS, 100% Pwr		1		0.9995	1.0005	
Read DC voltage accuracy +50% FS, 100% Pwr		1		*	**	
Set DC voltage accuracy +0% FS, 100% Pwr		0.002		0.0017	0.0023	
Read DC voltage accuracy +0% FS, 100% Pwr		0.002		*	**	
Set DC voltage accuracy +100% FS, 100% Pwr		-0.2		-0.2002	-0.1998	
Read DC voltage accuracy +100% FS, 100% Pwr		-0.2		*	**	
Set DC voltage accuracy +50% FS, 100% Pwr		-0.1		-0.10015	-0.09985	
Read DC voltage accuracy +50% FS, 100% Pwr		-0.1		*	**	
Set DC voltage accuracy +0% FS, 100% Pwr		-0.002		-0.000003	-0.000001	
Read DC voltage accuracy +0% FS, 100% Pwr		-0.002		*	**	
Set DC voltage accuracy +100% FS, 100% Pwr		0.2		0.1998	0.2002	
Read DC voltage accuracy +100% FS, 100% Pwr		0.2		*	**	
Set DC voltage accuracy +50% FS, 100% Pwr		0.1		0.09985	0.10015	
Read DC voltage accuracy +50% FS, 100% Pwr		0.1		*	**	
Set DC voltage accuracy +0% FS, 100% Pwr		0.002		0.000001	0.000003	

Test Step	CH	Output (V)	Measurement result	Low test limit	High test limit	Pass/fail
Read DC voltage accuracy +0% FS, 100% Pwr		0.002		*	**	

* (Set test result $\times$ (1 + % of reading)) + offset

** (Set test result $\times$ (1 - % of reading)) - offset

Approximate feedback voltage accuracy verification test record

Model			
Serial number			
Verified by	Name:		
	Company and contact:		
	Year:	Month:	Day:
Environment	Temperature (C/F):	Humidity (%):	

Test Step	CH	Output (V)	Measurement result	Low test limit	High test limit	Pass/fail
Set DC voltage AFB accuracy +100% FS		-60		-60.018	-59.982	
Set DC voltage AFB accuracy +50% FS		-30		-30.012	-29.988	
Set DC voltage AFB accuracy +0% FS		-0.06		-0.066	-0.054	
Set DC voltage AFB accuracy +100% FS		60		59.982	60.018	
Set DC voltage AFB accuracy +50% FS		30		29.988	30.012	
Set DC voltage AFB accuracy +0% FS		0.06		0.054	0.066	
Set DC voltage AFB accuracy +100% FS		-20		-20.006	-19.994	
Set DC voltage AFB accuracy +50% FS		-10		-10.004	-9.996	
Set DC voltage AFB accuracy +0% FS		-0.02		-0.022	-0.018	
Set DC voltage AFB accuracy +100% FS		20		19.994	20.006	
Set DC voltage AFB accuracy +50% FS		10		9.996	10.004	
Set DC voltage AFB accuracy +0% FS		0.02		0.018	0.022	
Set DC voltage AFB accuracy +100% FS		-6		-6.00147	-5.99853	
Set DC voltage AFB accuracy +50% FS		-3		-3.00087	-2.99913	
Set DC voltage AFB accuracy +0% FS		-0.006		-0.00627	-0.00573	

Test Step	CH	Output (V)	Measurement result	Low test limit	High test limit	Pass/fail
Set DC voltage AFB accuracy +100% FS		6		5.99853	6.00147	
Set DC voltage AFB accuracy +50% FS		3		2.99913	3.00087	
Set DC voltage AFB accuracy +0% FS		0.006		0.00573	0.00627	
Set DC voltage AFB accuracy +100% FS		-2		-2.00049	-1.99951	
Set DC voltage AFB accuracy +50% FS		-1		-1.00029	-0.99971	
Set DC voltage AFB accuracy +0% FS		-0.002		-0.00209	-0.00191	
Set DC voltage AFB accuracy +100% FS		2		1.99951	2.00049	
Set DC voltage AFB accuracy +50% FS		1		0.99971	1.00029	
Set DC voltage AFB accuracy +0% FS		0.002		0.00191	0.00209	
Set DC voltage AFB accuracy +100% FS		-0.2		-0.0200115	-0.199885	
Set DC voltage AFB accuracy +50% FS		-0.1		-0.100065	-0.099935	
Set DC voltage AFB accuracy +0% FS		-0.002		-0.00000215	-0.00000185	
Set DC voltage AFB accuracy +100% FS		0.2		0.199885	0.0200115	
Set DC voltage AFB accuracy +50% FS		0.1		0.099935	0.100065	
Set DC voltage AFB accuracy +0% FS		0.002		0.00000185	0.00000215	

Output current and measurement accuracy verification test record

Model			
Serial number			
Verified by	Name:		
	Company and contact:		
	Year:	Month:	Day:
Environment	Temperature (C/F):	Humidity (%):	

Test Step	CH	Output	Measurement result	Test load resistance (Ω)	Low test limit	High test limit	Pass/fail
Set DC current accuracy +100% FS, 100% Pwr		-1.5 A		1	-1.5049	-1.4951	
Read DC current accuracy +100% FS, 100% Pwr		-1.5 A		1	*	**	
Set DC current accuracy +50% FS, 100% Pwr		-0.75 A		1	-0.7544	-0.7456	
Read DC current accuracy +50% FS, 100% Pwr		-0.75 A		1	*	**	
Set DC current accuracy +0% FS, 100% Pwr		-0.0015 A		1	-0.0055	0.0025	
Read DC current accuracy +0% FS, 100% Pwr		-0.0015 A		1	*	**	
Set DC current accuracy +100% FS, 100% Pwr		1.5 A		1	1.4951	1.5049	
Read DC current accuracy +100% FS, 100% Pwr		1.5 A		1	*	**	
Set DC current accuracy +50% FS, 100% Pwr		0.75 A		1	0.7456	0.7544	
Read DC current accuracy +50% FS, 100% Pwr		0.75 A		1	*	**	
Set DC current accuracy +0% FS, 100% Pwr		0.0015 A		1	-0.0025	0.0055	
Read DC current accuracy +0% FS, 100% Pwr		0.0015 A		1	*	**	
Set DC current accuracy +100% FS, 100% Pwr		-1 A		1	-1.0015	-0.9985	
Read DC current accuracy +100% FS, 100% Pwr		-1 A		1	*	**	

Test Step	CH	Output	Measurement result	Test load resistance (Ω)	Low test limit	High test limit	Pass/fail
Set DC current accuracy +50% FS, 100% Pwr		-0.5 A		1	-0.50125	-0.49875	
Read DC current accuracy +50% FS, 100% Pwr		-0.5 A		1	*	**	
Set DC current accuracy +0% FS, 100% Pwr		-0.001 A		1	-0.002	0	
Read DC current accuracy +0% FS, 100% Pwr		-0.001 A		1	*	**	
Set DC current accuracy +100% FS, 100% Pwr		1 A		1	0.9985	1.0015	
Read DC current accuracy +100% FS, 100% Pwr		1 A		1	*	**	
Set DC current accuracy +50% FS, 100% Pwr		0.5 A		1	0.49875	0.50125	
Read DC current accuracy +50% FS, 100% Pwr		0.5 A		1	*	**	
Set DC current accuracy +0% FS, 100% Pwr		0.001 A		1	0	0.002	
Read DC current accuracy +0% FS, 100% Pwr		0.001 A		1	*	**	
Set DC current accuracy +100% FS, 100% Pwr		-100 mA		10	-100.036	-99.964	
Read DC current accuracy +100% FS, 100% Pwr		-100 mA		10	*	**	
Set DC current accuracy +50% FS, 100% Pwr		-50 mA		10	-50.021	-49.979	
Read DC current accuracy +50% FS, 100% Pwr		-50 mA		10	*	**	
Set DC current accuracy +0% FS, 100% Pwr		-0.1 mA		10	-0.106	-0.094	
Read DC current accuracy +0% FS, 100% Pwr		-0.1 mA		10	*	**	
Set DC current accuracy +100% FS, 100% Pwr		100 mA		10	99.964	100.036	
Read DC current accuracy +100% FS, 100% Pwr		100 mA		10	*	**	
Set DC current accuracy +50% FS, 100% Pwr		50 mA		10	49.979	50.021	
Read DC current accuracy +50% FS, 100% Pwr		50 mA		10	*	**	
Set DC current accuracy +0% FS, 100% Pwr		0.1 mA		10	0.094	0.106	
Read DC current accuracy +0% FS, 100% Pwr		0.1 mA		10	*	**	
Set DC current accuracy +100% FS, 100% Pwr		-10 mA		100	-10.0042	-9.9958	

Test Step	CH	Output	Measurement result	Test load resistance (Ω)	Low test limit	High test limit	Pass/fail
Read DC current accuracy +100% FS, 100% Pwr		-10 mA		100	*	**	
Set DC current accuracy +50% FS, 100% Pwr		-5 mA		100	-5.0027	-4.9973	
Read DC current accuracy +50% FS, 100% Pwr		-5 mA		100	*	**	
Set DC current accuracy +0% FS, 100% Pwr		-0.01 mA		100	-0.01122	-0.0088	
Read DC current accuracy +0% FS, 100% Pwr		-0.01 mA		100	*	**	
Set DC current accuracy +100% FS, 100% Pwr		10 mA		100	9.9958	10.0042	
Read DC current accuracy +100% FS, 100% Pwr		10 mA		100	*	**	
Set DC current accuracy +50% FS, 100% Pwr		5 mA		100	4.9973	5.0027	
Read DC current accuracy +50% FS, 100% Pwr		5 mA		100	*	**	
Set DC current accuracy +0% FS, 100% Pwr		0.01 mA		100	0.0088	0.0112	
Read DC current accuracy +0% FS, 100% Pwr		0.01 mA		100	*	**	
Set DC current accuracy +100% FS, 100% Pwr		-1 mA		1000	-1.00037	-0.99963	
Read DC current accuracy +100% FS, 100% Pwr		-1 mA		1000	*	**	
Set DC current accuracy +50% FS, 100% Pwr		-0.5 mA		1000	-0.50022	-0.49978	
Read DC current accuracy +50% FS, 100% Pwr		-0.5 mA		1000	*	**	
Set DC current accuracy +0% FS, 100% Pwr		-0.001 mA		1000	-0.00107	-0.00093	
Read DC current accuracy +0% FS, 100% Pwr		-0.001 mA		1000	*	**	
Set DC current accuracy +100% FS, 100% Pwr		1 mA		1000	0.99963	1.00037	
Read DC current accuracy +100% FS, 100% Pwr		1 mA		1000	*	**	
Set DC current accuracy +50% FS, 100% Pwr		0.5 mA		1000	0.49978	0.50022	
Read DC current accuracy +50% FS, 100% Pwr		0.5 mA		1000	*	**	
Set DC current accuracy +0% FS, 100% Pwr		0.001 mA		1000	0.00093	0.00107	
Read DC current accuracy +0% FS, 100% Pwr		0.001 mA		1000	*	**	

Test Step	CH	Output	Measurement result	Test load resistance (Ω)	Low test limit	High test limit	Pass/fail
Set DC current accuracy +100% FS, 100% Pwr		-100 μ A		10000	-100.042	-99.958	
Read DC current accuracy +100% FS, 100% Pwr		-100 μ A		10000	*	**	
Set DC current accuracy +50% FS, 100% Pwr		-50 μ A		10000	-50.027	-49.973	
Read DC current accuracy +50% FS, 100% Pwr		-50 μ A		10000	*	**	
Set DC current accuracy +0% FS, 100% Pwr		-0.1 μ A		10000	-0.112	-0.088	
Read DC current accuracy +0% FS, 100% Pwr		-0.1 μ A		10000	*	**	
Set DC current accuracy +100% FS, 100% Pwr		100 μ A		10000	99.958	100.042	
Read DC current accuracy +100% FS, 100% Pwr		100 μ A		10000	*	**	
Set DC current accuracy +50% FS, 100% Pwr		50 μ A		10000	49.973	50.027	
Read DC current accuracy +50% FS, 100% Pwr		50 μ A		10000	*	**	
Set DC current accuracy +0% FS, 100% Pwr		0.1 μ A		10000	0.088	0.112	
Read DC current accuracy +0% FS, 100% Pwr		0.1 μ A		10000	*	**	
Set DC current accuracy +100% FS, 100% Pwr		-10 μ A		100000	-10.004	-9.996	
Read DC current accuracy +100% FS, 100% Pwr		-10 μ A		100000	*	**	
Set DC current accuracy +50% FS, 100% Pwr		-5 μ A		100000	-5.0025	-4.9975	
Read DC current accuracy +50% FS, 100% Pwr		-5 μ A		100000	*	**	
Set DC current accuracy +0% FS, 100% Pwr		-0.01 μ A		100000	-0.011	-0.009	
Read DC current accuracy +0% FS, 100% Pwr		-0.01 μ A		100000	*	**	
Set DC current accuracy +100% FS, 100% Pwr		10 μ A		100000	9.996	10.004	
Read DC current accuracy +100% FS, 100% Pwr		10 μ A		100000	*	**	
Set DC current accuracy +50% FS, 100% Pwr		5 μ A		100000	4.9975	5.0025	
Read DC current accuracy +50% FS, 100% Pwr		5 μ A		100000	*	**	
Set DC current accuracy +0% FS, 100% Pwr		0.01 μ A		100000	0.009	0.011	

Test Step	CH	Output	Measurement result	Test load resistance (Ω)	Low test limit	High test limit	Pass/fail
Read DC current accuracy +0% FS, 100% Pwr		0.01 μ A		100000	*	**	
Set DC current accuracy +100% FS, 100% Pwr		-1 μ A		1000000	-1.00065	-0.99935	
Read DC current accuracy +100% FS, 100% Pwr		-1 μ A		1000000	*	**	
Set DC current accuracy +50% FS, 100% Pwr		-0.5 μ A		1000000	-0.5004	-0.4996	
Read DC current accuracy +50% FS, 100% Pwr		-0.5 μ A		1000000	*	**	
Set DC current accuracy +0% FS, 100% Pwr		-0.001 μ A		1000000	-0.00115	-0.00085	
Read DC current accuracy +0% FS, 100% Pwr		-0.001 μ A		1000000	*	**	
Set DC current accuracy +100% FS, 100% Pwr		1 μ A		1000000	0.99935	1.00065	
Read DC current accuracy +100% FS, 100% Pwr		1 μ A		1000000	*	**	
Set DC current accuracy +50% FS, 100% Pwr		0.5 μ A		1000000	0.4996	0.5004	
Read DC current accuracy +50% FS, 100% Pwr		0.5 μ A		1000000	*	**	
Set DC current accuracy +0% FS, 100% Pwr		0.001 μ A		1000000	0.00085	0.00115	
Read DC current accuracy +0% FS, 100% Pwr		0.001 μ A		1000000	*	**	
Set DC current accuracy +100% FS, 100% Pwr		-100 nA		10000000	-100.22	-99.78	
Read DC current accuracy +100% FS, 100% Pwr		-100 nA		10000000	*	**	
Set DC current accuracy +50% FS, 100% Pwr		-50 nA		10000000	-50.12	-49.88	
Read DC current accuracy +50% FS, 100% Pwr		-50 nA		10000000	*	**	
Set DC current accuracy +0% FS, 100% Pwr		-0.1 nA		10000000	-0.12	-0.08	
Read DC current accuracy +0% FS, 100% Pwr		-0.1 nA		10000000	*	**	
Set DC current accuracy +100% FS, 100% Pwr		100 nA		10000000	99.78	100.22	
Read DC current accuracy +100% FS, 100% Pwr		100 nA		10000000	*	**	
Set DC current accuracy +50% FS, 100% Pwr		50 nA		10000000	49.88	50.12	
Read DC current accuracy +50% FS, 100% Pwr		50 nA		10000000	*	**	

Test Step	CH	Output	Measurement result	Test load resistance (Ω)	Low test limit	High test limit	Pass/fail
Set DC current accuracy +0% FS, 100% Pwr		0.1 nA		10000000	0.08	0.12	
Read DC current accuracy +0% FS, 100% Pwr		0.1 nA		10000000	*	**	

* (Set test result $\times$ (1 + % of reading)) + offset

** (Set test result $\times$ (1 - % of reading)) - offset

Approximate feedback current accuracy verification test record

Model			
Serial number			
Verified by	Name:		
	Company and contact:		
	Year:	Month:	Day:
Environment	Temperature (C/F):	Humidity (%):	

Test Step	CH	Output	Measurement result	Low test limit	High test limit	Pass/fail
Set DC current accuracy +100% FS		-1.5 A		-1.5649	-1.4351	
Set DC current accuracy +50% FS		-0.75 A		-0.8144	-0.6856	
Set DC current accuracy +0% FS		-0.0015 A		-0.0655	0.0625	
Set DC current accuracy +100% FS		1.5 A		1.4351	1.5649	
Set DC current accuracy +50% FS		0.75 A		0.6856	0.8144	
Set DC current accuracy +0% FS		0.0015 A		-0.0625	0.0655	
Set DC current accuracy +100% FS		-1 A		-1.0155	-0.9845	
Set DC current accuracy +50% FS		-0.5 A		-0.51525	-0.48475	
Set DC current accuracy +0% FS		-0.001 A		-0.016	0.014	
Set DC current accuracy +100% FS		1 A		0.9845	1.0155	
Set DC current accuracy +50% FS		0.5 A		0.48475	0.51525	
Set DC current accuracy +0% FS		0.001 A		-0.014	0.016	
Set DC current accuracy +100% FS		-100 mA		-104.38	-95.62	
Set DC current accuracy +50% FS		-50 mA		-54.365	-45.635	
Set DC current accuracy +0% FS		-0.1 mA		-4.45	4.25	

Test Step	CH	Output	Measurement result	Low test limit	High test limit	Pass/fail
Set DC current accuracy +100% FS		100 mA		95.62	104.38	
Set DC current accuracy +50% FS		50 mA		45.635	54.365	
Set DC current accuracy +0% FS		0.1 mA		-4.25	4.45	
Set DC current accuracy +100% FS		-10 mA		-10.0042	-9.9958	
Set DC current accuracy +50% FS		-5 mA		-5.00278	-4.9973	
Set DC current accuracy +0% FS		-0.01 mA		-0.0112	-0.0088	
Set DC current accuracy +100% FS		10 mA		9.9958	10.0042	
Set DC current accuracy +50% FS		5 mA		4.9973	5.0027	
Set DC current accuracy +0% FS		0.01 mA		0.0088	0.0112	
Set DC current accuracy +100% FS		-1 mA		-1.00037	-0.99963	
Set DC current accuracy +50% FS		-0.5 mA		-0.50022	-0.49978	
Set DC current accuracy +0% FS		-0.001 mA		-0.00107	-0.00093	
Set DC current accuracy +100% FS		1 mA		0.99963	1.00037	
Set DC current accuracy +50% FS		0.5 mA		0.49978	0.50022	
Set DC current accuracy +0% FS		0.001 mA		0.00093	0.00107	
Set DC current accuracy +100% FS		-100 μ A		-100.042	-99.958	
Set DC current accuracy +50% FS		-50 μ A		-50.027	-49.973	
Set DC current accuracy +0% FS		-0.1 μ A		-0.112	-0.088	
Set DC current accuracy +100% FS		100 μ A		99.958	100.042	
Set DC current accuracy +50% FS		50 μ A		49.973	50.027	
Set DC current accuracy +0% FS		0.1 μ A		0.088	0.112	
Set DC current accuracy +100% FS		-10 μ A		-10.004	-9.996	
Set DC current accuracy +50% FS		-5 μ A		-5.0025	-4.9975	

Test Step	CH	Output	Measurement result	Low test limit	High test limit	Pass/fail
Set DC current accuracy +0% FS		-0.01 μ A		-0.011	-0.009	
Set DC current accuracy +100% FS		10 μ A		9.996	10.004	
Set DC current accuracy +50% FS		5 μ A		4.9975	5.0025	
Set DC current accuracy +0% FS		0.01 μ A		0.009	0.011	
Set DC current accuracy +100% FS		-1 μ A		-1.00065	-0.99935	
Set DC current accuracy +50% FS		-0.5 μ A		-0.5004	-0.4996	
Set DC current accuracy +0% FS		-0.001 μ A		-0.00115	-0.00085	
Set DC current accuracy +100% FS		1 μ A		0.99935	1.00065	
Set DC current accuracy +50% FS		0.5 μ A		0.4996	0.5004	
Set DC current accuracy +0% FS		0.001 μ A		0.00085	0.00115	
Set DC current accuracy +100% FS		-100 nA		-100.22	-99.78	
Set DC current accuracy +50% FS		-50 nA		-50.12	-49.88	
Set DC current accuracy +0% FS		-0.1 nA		-0.12	-0.08	
Set DC current accuracy +100% FS		100 nA		99.78	100.22	
Set DC current accuracy +50% FS		50 nA		49.88	50.12	
Set DC current accuracy +0% FS		0.1 nA		0.08	0.12	

Contact check accuracy verification test record

Contact check measurement accuracy is verified by comparing the current measured by the module to the current measured by an external DMM over a shunt resistor. For the best accuracy, ensure that the DMM and shunt resistor are sufficiently accurate.

Model			
Serial number			
Verified by	Name:		
	Company and contact:		
	Year:	Month:	Day:
Environment	Temperature (C/F):	Humidity (%):	

Test step	CH	Test load resistance (Ω)	Measurement result	Low test limit (Ω)	High test limit (Ω)	Pass/fail
Verify HI/SHI		0		-1.02	2.55	
Verify HI/SHI		50		45.88	55.44	
Verify HI/SHI		100		93.56	108.14	
Verify HI/SHI		200		188.47	213.04	
Verify LO/SLO		0		-1.11	2.46	
Verify LO/SLO		50		45.87	55.44	
Verify LO/SLO		100		93.47	108.05	
Verify LO/SLO		200		188.38	212.94	