Model 2450
Interactive SourceMeter® Instrument

Calibration Manual

2450-905-01

A Greater Measure Of Confidence

KEITHLEY

A Tektronix Company

Model 2450

Interactive SourceMeter® Instrument

Calibration Manual

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

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

The types of product users are:

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

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

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

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

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

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

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

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

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

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

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

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

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

For safety, instruments and accessories must be used in accordance with the operating instructions. If the instruments or

accessories are used in a manner not specified in the operating instructions, the protection provided by the equipment may be impaired.

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

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

Chassis connections must only be used as shield connections for measuring circuits, NOT as 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 danger. 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 caution, 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 (Hg) symbol is on a product, it indicates that mercury is present in the display lamp. Please note that the lamp must be properly disposed of according to federal, state, and local laws.

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

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

Instrumentation and accessories shall not be connected to humans.

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

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

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

Safety precaution revision as of January 2013.

Table of Contents

Performance verification

In this section:

Introduction

Use the procedures in this section to verify that Model 2450 accuracy is within the limits stated in the instrument's one-year accuracy specifications. You can perform these verification procedures:

- When you first receive the instrument to make sure that it was not damaged during shipment.
- To verify that the unit meets factory specifications.
- To determine if calibration is required.
- Following calibration to make sure it was performed properly.

⚠ WARNING

The information in this section is intended for qualified service personnel only. Do not attempt these procedures unless you are qualified to do so. Some of these procedures may expose you to hazardous voltages, which could cause personal injury or death if contacted. Use standard safety precautions when working with hazardous voltages.

NOTE

If the instrument is still under warranty and its performance is outside specified limits, please contact your local Keithley Instruments office, sales partner, or distributor, or call Keithley Instruments corporate headquarters (toll-free inside the U.S. and Canada only) at 1-888-KEITHLEY (1-888-534-8453), or from outside the U.S. at +1-440-248-0400. For worldwide contact numbers, visit the Keithley Instruments website (*http://www.keithley.com*).

Verification test requirements

Be sure that you perform the verification tests:

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

Environmental conditions

Conduct your performance verification procedures in a test environment with:

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

Warm-up period

Allow the Model 2450 to warm up for at least one hour before conducting the verification procedures.

If the instrument has been subjected to temperature extremes (those outside the ranges stated above), allow additional time for the instrument's internal temperature to stabilize. Typically, allow one extra hour to stabilize a unit that is 10 °C (18 °F) outside the specified temperature range.

Also, allow the test equipment to warm up for the minimum time specified by the manufacturer.

Line power

The Model 2450 requires a line voltage of 100 V to 240 V and a line frequency of 50 Hz or 60 Hz. Verification tests should be performed within this range.

Recommended test equipment

The following table summarizes recommended verification equipment. You can use alternate equipment as long as that equipment has specifications at least as good as those listed in the table below. Keep in mind, however, that test equipment uncertainty will add to the uncertainty of each measurement. Generally, test equipment uncertainty should be at least four times better than corresponding Model 2450 specifications. The following table lists the uncertainties of the recommended test equipment.

Recommended verification equipment

Description	Manufacturer/Model	Accuracy*		
Digital multimeter	Hewlett Packard HP3458A	DC voltage	20 mV:	± 15 ppm
			200 mV:	± 15 ppm
			2 V:	± 6 ppm
			20 V:	± 9 ppm
			200 V:	± 7 ppm
		DC current	1 µA:	± 55 ppm
			10 µA:	± 25 ppm
			100 µA:	± 23 ppm
			1 mA:	± 20 ppm
			10 mA:	± 20 ppm
			100 mA:	± 35 ppm
			1 A:	± 110 ppm
Model 6430 Sub-Femtoamp Remote SourceMeter® (used for 100 nA and 10 nA ranges ONLY)	Keithley Instruments	DC current	10 nA:	± 110 ppm
			100 nA:	± 110 ppm
Resistance calibrator	Fluke 5700A	Resistance**	19 Ω	± 26 ppm
			190 Ω	± 17 ppm
			1.9 kΩ	± 12 ppm
			19 kΩ	± 11 ppm
			190 kΩ	± 13 ppm
			1.9 MΩ	± 19 ppm
			19 MΩ	± 47 ppm
			100 MΩ	± 120 ppm
2450 Calibration Fixture (Model 2450-CAL-KIT)***	Keithley Instruments	n/a		

*   90-day specifications show accuracy at specified measurement point.
**   Nominal resistance values shown.
*** Required accessory.

Verification limits

The verification limits stated in this section have been calculated using only the Model 2450 one-year accuracy specifications, and they do not include test equipment uncertainty. If a particular measurement falls outside the allowable range, recalculate new limits based both on Model 2450 specifications and corresponding test equipment specifications.

Example limits calculation

As an example of how verification limits are calculated, assume you are testing the 20 V DC output range using a 20 V output value. Using the Model 2450 one-year accuracy specification for 20 V DC output of ±(0.015 % of output + 2.4 mV offset), the calculated output limits are:

Output limits = 20 V ± [(20 V × 0.015 %) + 2.4 mV]
Output limits = 20 V ± (0.003 + 0.0024)
Output limits = 20 V ± 0.0054 V
Output limits = 19.9946 V to 20.0054 V

Resistance limits calculation

When verifying the ohms function, you may find it necessary to recalculate resistance limits based on the actual calibrator resistance values. You can calculate resistance reading limits in the same manner described above, but be sure to use the actual calibrator resistance values and the Model 2450 normal accuracy specifications for your calculations.

As an example, assume that you are testing the 20 kΩ range, and the actual value of the nominal 19 kΩ calibrator resistor is 19.025 kΩ. Using the Model 2450 one-year normal accuracy specifications of ±(0.063 % of reading + 3 Ω), the recalculated reading limits are:

Reading limits = 19.025 kΩ ±[(19.025 kΩ × 0.063 %) + 3 Ω]
Reading limits = 19.025 kΩ ±14.99 Ω
Reading limits = 19.01001 kΩ to 19.0399 kΩ

Performing the verification test procedures

Test summary

- DC voltage output accuracy (on page 1-6)
- DC voltage measurement accuracy (on page 1-9)
- DC current output accuracy (on page 1-12)
- DC current measurement accuracy (on page 1-19)
- Resistance measurement accuracy (on page 1-20)

If the Model 2450 is not within specifications and not under warranty, see the calibration procedures in Calibration (on page 2-1) for information about calibrating the unit.

Test considerations

When performing the verification procedures:

- Make sure that the test equipment is properly warmed up and connected to the Model 2450 input/output jacks. Also ensure that the rear-panel jacks are selected with the TERMINALS FRONT/REAR button.
- Make sure the Model 2450 is set to the correct source range.
- Be sure the Model 2450 output is turned on before making measurements.
- Be sure the test equipment is set up for the proper function and range.
- Allow the Model 2450 output signal to settle before making a measurement.
- Do not connect test equipment to the Model 2450 through a scanner, multiplexer, or other switching equipment.

⚠ WARNING

The maximum common-mode voltage (voltage between LO and chassis ground) is 250 V peak. Exceeding this value may cause a breakdown in insulation, creating a shock hazard.

The front and rear terminals of the Model 2450 are rated for connection to circuits rated Installation Category I only. Do not connect the Model 2450 terminals to CAT II, CAT III, or CAT IV circuits. Connection of the SourceMeter® instrument input/output terminals to circuits higher than CAT I can cause damage to the equipment or expose the operator to hazardous voltage.

Hazardous voltages may be present on the output and guard terminals. To prevent electrical shock that could cause injury or death, NEVER make or break connections to the Model 2450 while the unit is on. Power off the equipment from the front panel or disconnect the main power cord from the rear of the Model 2450 before handling cables connected to the outputs. Putting the equipment into standby mode does not guarantee the outputs are not powered if a hardware or software fault occurs.

⚠ CAUTION

The maximum voltage between input/output HI and LO or 4-wire sense HI and LO is 210 V peak. The maximum voltage between input/output HI and 4-wire sense HI or between input/output LO and 4-wire sense LO is 5 V. Exceeding these voltages may result in instrument damage.

Setting the source range and output value

Before testing each verification point, you must properly set the source range and output value as outlined below.

1. Press the **HOME** key.
2. Press the **MENU** key.
3. Press the **QuickSet** on-screen button.
4. Press the **Function** on-screen button.
5. Press either **Source Voltage and Measure Voltage** or **Source Current and Measure Current**, depending on which function you wish to verify.
6. On the SOURCE area of the Home screen, set the source range to the lowest possible range for the value to be sourced by pressing the **Range** button and selecting the range.
7. While on the Home screen, select the exact source voltage by pressing the **Source** button and selecting a voltage.
8. The source value will be updated immediately after pressing the **OK** button on the Voltage Source Value window.
9. Press the **OUTPUT ON/OFF** button to turn on the output.

For example, you should use the 20 V source range to output a 19 V or 20 V source value. With a 20 V source value and the 20 V range selected, the source voltage display will appear as follows:

Range: 20 V   Source: +20.0000 V

Setting the measurement range

When simultaneously sourcing and measuring either voltage or current, the measure range is coupled to the source range, and you cannot independently control the measure range. Thus, it is not necessary for you to set the range when testing voltage or current measurement accuracy.

When selecting the source range, you should also ensure that the limit is set to the appropriate maximum value for that range.

Taking the Model 2450 out of limit

Verification measurements should not be made when the Model 2450 is in overflow. For purposes of the verification tests, the Model 2450 can be taken out of overflow by raising the limit value in the source window.

NOTE
Do not take the unit out of overflow by decreasing the source value or changing the range. Always use the recommended range and source settings when performing the verification tests.

DC voltage output accuracy

Follow the steps below to verify that Model 2450 output voltage accuracy is within specified limits. This test involves setting the output voltage to each full-range value and measuring the voltages with a precision digital multimeter.

1. With the power off, connect the digital multimeter to the Model 2450 input/output rear jacks, as shown in the following figure.

Figure 1: Voltage verification rear-panel connections

Model 2450

Digital multimeter
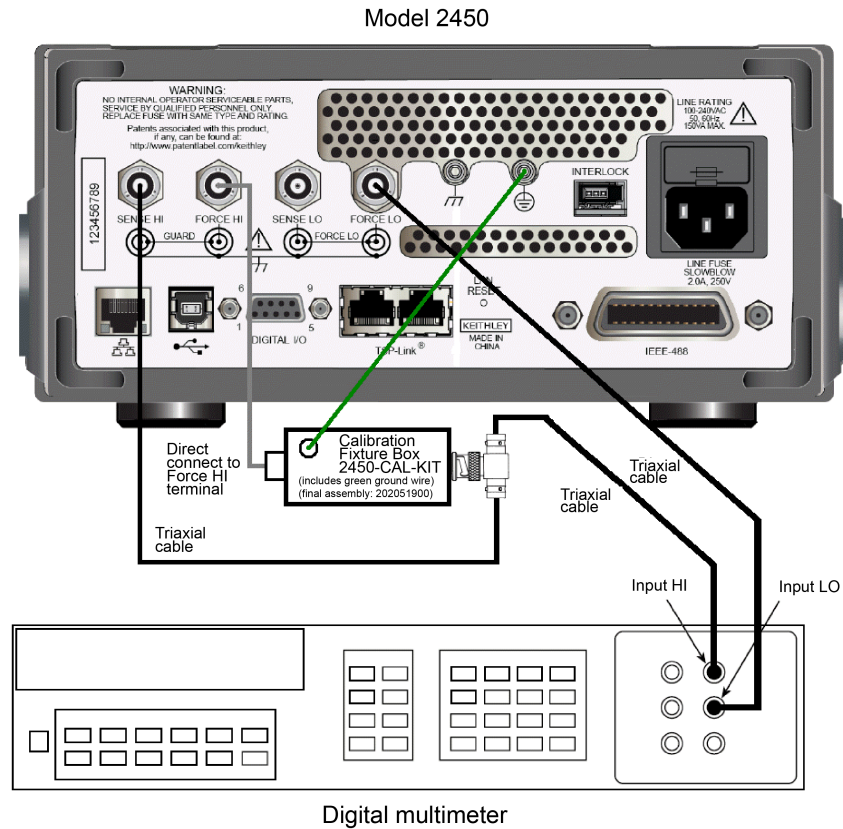
2. Select the multimeter DC volts measuring function.

NOTE

The default voltage source protection value is 40 V. Before testing the 200 V range, be sure to assert the interlock. Without the interlock asserted and the green interlock light on, the Model 2450 will be limited to 40 V. For more information on the Model 2450 interlock, see the "Using the Interlock" section in the Model 2450 Reference Manual.

3. Press the **HOME** key.
4. Press the **MENU** key.
5. Press the **QuickSet** on-screen button.
6. Press the **Function** on-screen button.

7. Press **Source Voltage and Measure Voltage**.

8. In the SOURCE area of the Home screen, set the source range to the lowest possible range for the value to be sourced by pressing the **Range** button and selecting the range.

9. In the SOURCE area of the Home screen, select the exact source voltage by pressing the on-screen **Source** button and selected a voltage.

10. The source value will be updated immediately after pressing the **OK** button on the Voltage Source Value window.

11. Press the **OUTPUT ON/OFF** button to turn on the output.

    For example, you should use the 20 V source range to output a 19 V or 20 V source value. With a 20 V source value and the 20 V range selected, the SOURCE VOLTAGE display will appear as follows:

    Range 20V   Source +20.0000V

12. Verify output voltage accuracy for each of the voltages listed in the following table. For each test point:

    ▪ Select the correct source range.
    ▪ Set the Model 2450 output voltage to the indicated value.
    ▪ Verify that the multimeter reading is within the limits given in the table.

13. Repeat the procedure for negative output voltages with the same magnitudes as those listed in the following table.

Output voltage accuracy limits

Model 2450 source range	Model 2450 output voltage setting	Output voltage limits (1 year, 18 ºC to 28 ºC)
20 mV	20.0000 mV	19.7800 mV to 20.2200 mV
200 mV	200.000 mV	199.770 mV to 200.230 mV
2 V	2.00000 V	1.99930 V to 2.00070 V
20 V	20.0000 V	19.9946 V to 20.0054 V
200 V	200.000 V	199.946 V to 200.05 V

14. Repeat the entire procedure using the front-panel input/output jacks. Be sure to select the front-panel jacks with the front-panel **TERMINALS FRONT/REAR** key. See the following figure for the front-panel wiring diagram.

Figure 2: Voltage verification front-panel connections

Model 2450

Digital multimeter
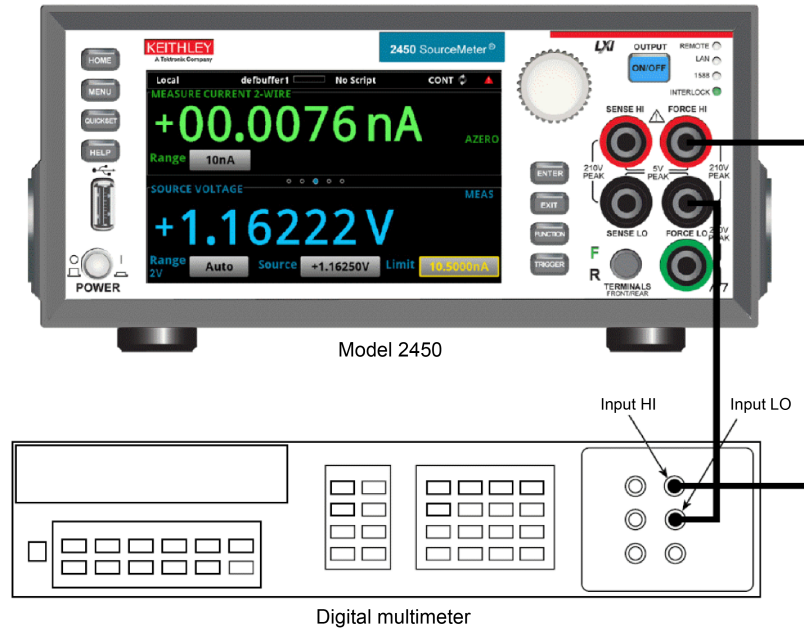
DC voltage measurement accuracy

Follow the steps below to verify that Model 2450 voltage measurement accuracy is within specified limits. The test involves setting the source voltage to 95 percent of full-range values, as measured by a precision digital multimeter, and then verifying that the Model 2450 voltage readings are within required limits.

1. With the power off, connect the digital multimeter to the Model 2450 input/output rear jacks, as shown in the following figure.

Figure 3: Voltage verification rear-panel connections

Model 2450

Digital multimeter
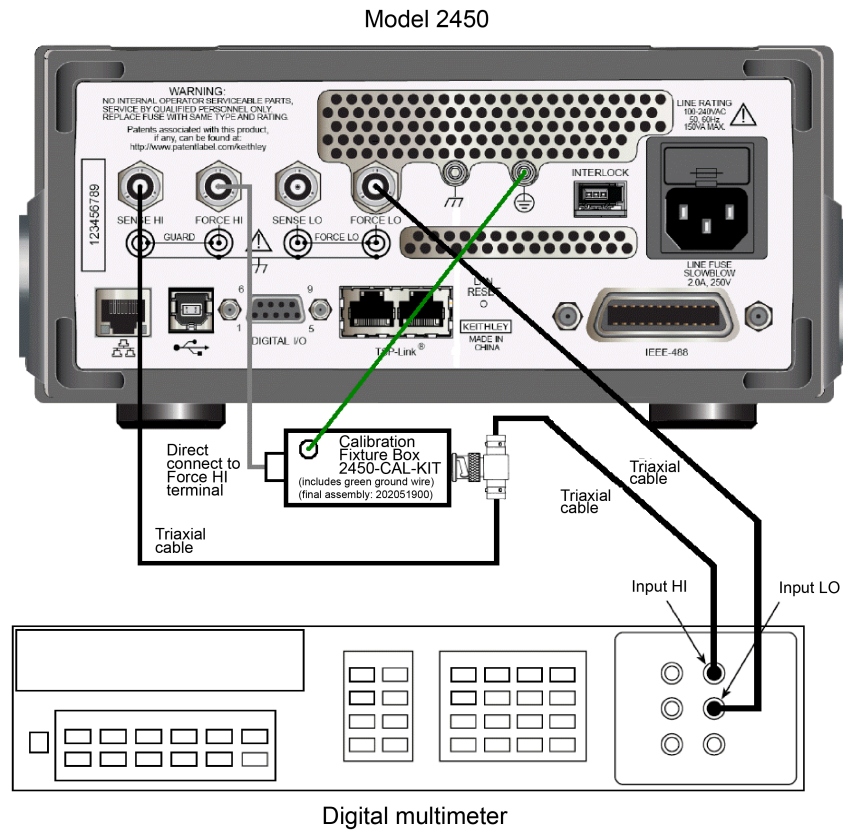
2. Select the multimeter DC volts function.

NOTE

The default voltage source protection value is 40 V. Before testing the 200 V range, be sure to assert the interlock. Without the interlock asserted and the green interlock light on, the Model 2450 will be limited to 40 V. For more information on the Model 2450 interlock, see the "Using the interlock" section in the Model 2450 Reference Manual.

---

3. Press the **HOME** key.
4. Press the **MENU** key.
5. Press the **QuickSet** on-screen button.
6. Press the **Function** on-screen button.
7. Press **Source Voltage and Measure Voltage**.

8. In the SOURCE area of the Home screen, set the source range to the lowest possible range for the value to be sourced by pressing the **Range** button and selecting the range.

9. While on the Home screen, select the exact source voltage by pressing the on-screen **Source** button and selecting a voltage.

10. The source value will be updated immediately after pressing the **OK** button on the Voltage Source Value window.

11. Press the **OUTPUT ON/OFF** button to turn on the output.

    For example, you should use the 20 V source range to output a 19 V or 20 V source value. With a 20 V source value and the 20 V range selected, the source voltage display will appear as follows:

    Range 20V   Source +20.0000V

12. Verify output voltage accuracy for each of the voltages listed in the following table. For each test point:

    ▪   Select the correct source range.
    ▪   Set the Model 2450 output voltage to the indicated value.
    ▪   Verify that the multimeter reading is within the limits given in the table.

NOTE

It may not be possible to set the voltage source to the specified value. Use the closest possible setting, and modify reading limits accordingly.

13. Repeat the procedure for negative source voltages with the same magnitudes as those listed in the following table.

Voltage measurement accuracy limits

Model 2450 source and measure range*	Source voltage**	Model 2450 voltage reading limits (1 year, 18 ⁰C to 28 ⁰C)
20 mV	19.0000 mV	18.8310 mV to 19.1690 mV
200 mV	190.000 mV	189.777 mV to 190.223 mV
2 V	1.90000 V	1.89742 V to 1.90258 V
20 V	19.0000 V	18.9962 V to 19.0039 V
200 V	190.000 V	189.9615 V to 190.0385 V

* Measure range coupled to source range when simultaneously sourcing and measuring voltage.
** As measured by precision digital multimeter. Use closest possible value and modify reading limits if necessary.

14. Repeat the entire procedure using the front-panel input/output jacks. Be sure to select the front-panel jacks with the front-panel **TERMINALS FRONT/REAR** key. See the following figure for the front-panel wiring diagram.

**Figure 4: Voltage verification front-panel connections**

Model 2450

Digital multimeter
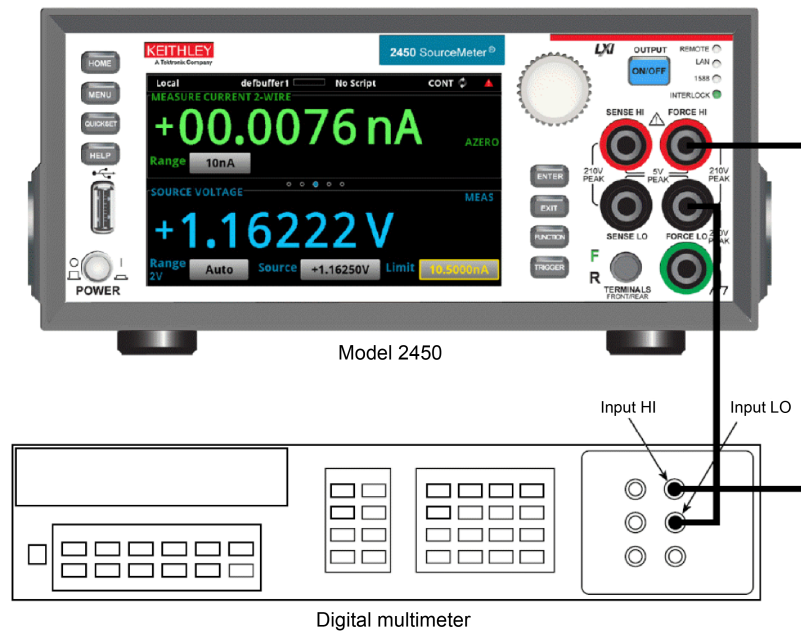
DC current output accuracy

Follow the steps below to verify that Model 2450 output current accuracy is within specified limits. The test involves setting the output current to each full-range value and measuring the currents with a precision digital multimeter.

1. With the power off, connect the digital multimeter to the Model 2450 input/output rear jacks, as shown the following figure.

Figure 5: Current verification rear-panel connections
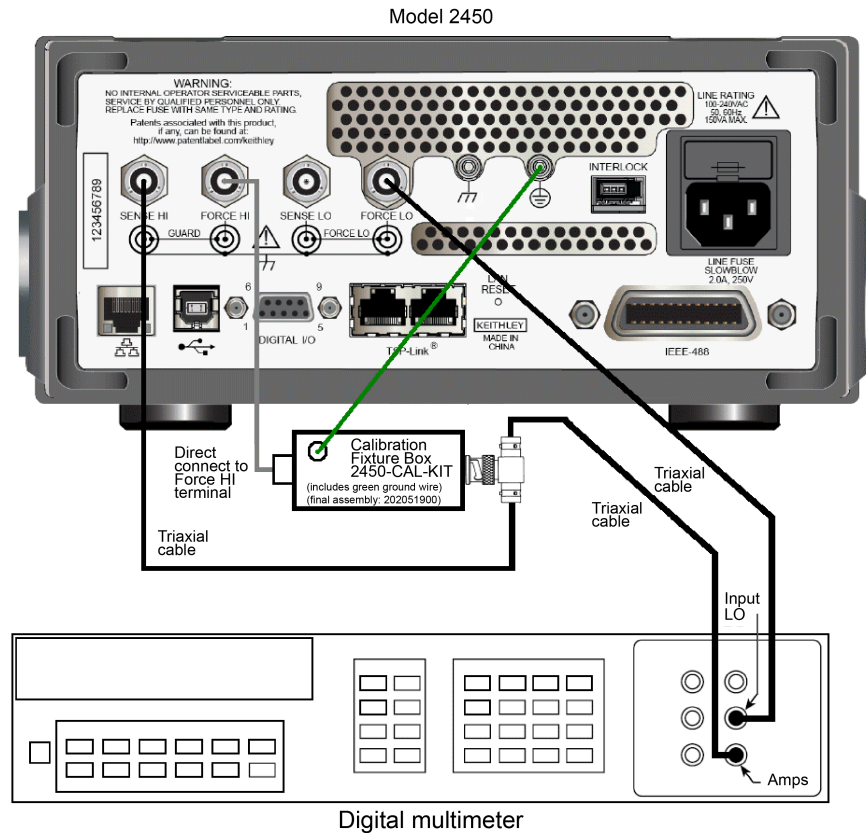
2. Select the multimeter DC current measuring function.
3. Press the **HOME** key.
4. Press the **MENU** key.
5. Press the **QuickSet** on-screen button.
6. Press the **Function** on-screen button.
7. Press **Source Current and Measure Current**.
8. In the SOURCE area of the Home screen, set the source range to the lowest possible range for the value to be sourced by pressing the **Range** button and selecting the range.
9. While on the Home screen, select the exact source voltage by pressing the on-screen **Source** button and selecting a current.
10. The source value will be updated immediately after pressing the **OK** button on the Current Source Value window.
11. Press the **OUTPUT ON/OFF** button to turn on the output.

12. Verify output current accuracy for each of the currents listed in the following table. For each test point:

13. Select the correct source range.

14. Set the Model 2450 output current to the correct value.

15. Verify that the multimeter reading is within the limits given in the table.

Output current accuracy limits

Model 2450 source range	Model 2450 output current setting	Output current limits (1 year, 18 ºC to 28 ºC)
10 nA*	10.0000 nA*	9.98990 µA to 10.0101 µA
100 nA*	100.000 nA*	99.9399 µA to 100.060 µA
1 µA	1.00000 µA	0.99935 µA to 1.00065 µA
10 µA	10.0000 µA	9.99600 µA to 10.0040 µA
100 µA	100.000 µA	99.9650 µA to 100.035 µA
1 mA	1.00000 mA	0.99965 mA to 1.00035 mA
10 mA	10.0000 mA	9.99650 mA to 10.0035 mA
100 mA	100.000 mA	99.9600 mA to 100.040 mA
1 A	1.00000 A	0.99843 A to 1.00157 A

* The 100 nA and 10 nA ranges must be measured using the Keithley Model 6430 ONLY.

NOTE

For the 100 nA and 10 nA ranges, make connections according to the following figure and follow steps 1 through 14 for these two ranges ONLY.

The 100 nA and 10 nA ranges are guaranteed on the REAR terminal with proper triaxial cables ONLY.

Figure 6: Current verification rear-panel connections (10 nA and 100 nA ranges ONLY)
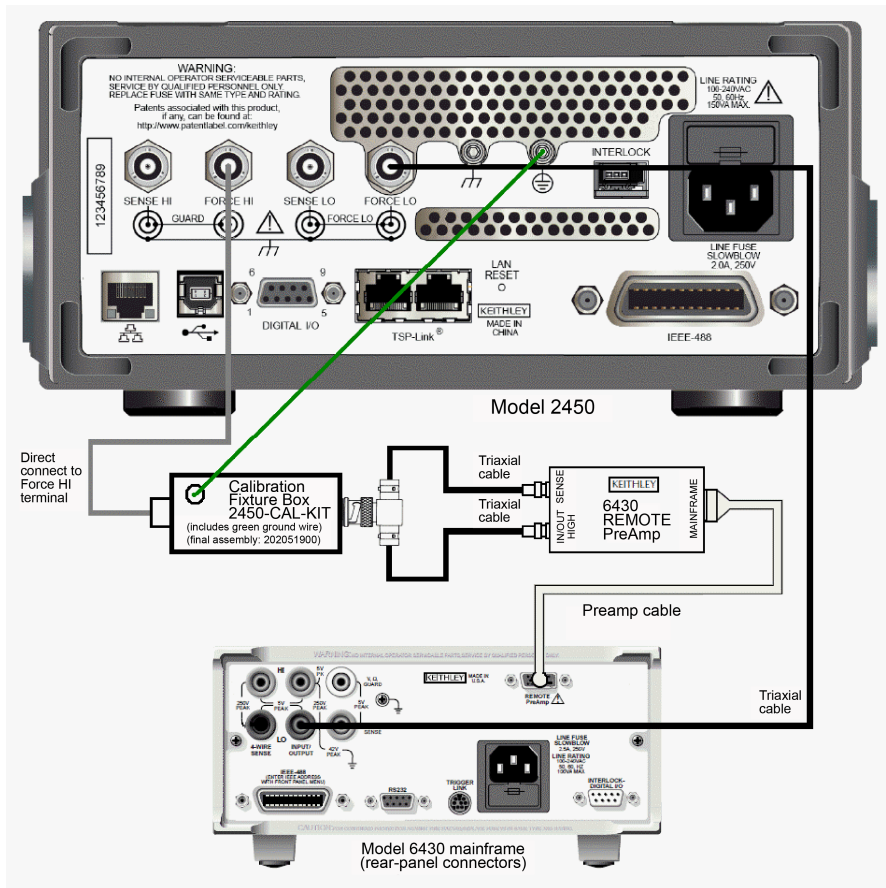
16. Repeat the procedure for negative output currents with the same magnitudes as those listed in the table above.

17. Repeat the entire procedure using the front-panel input/output jacks. Be sure to select the front-panel jacks with the front-panel **TERMINALS FRONT/REAR** key. See the following figure for the front-panel wiring diagram.

**Figure 7: Current verification front-panel connections**

Model 2450

Digital multimeter
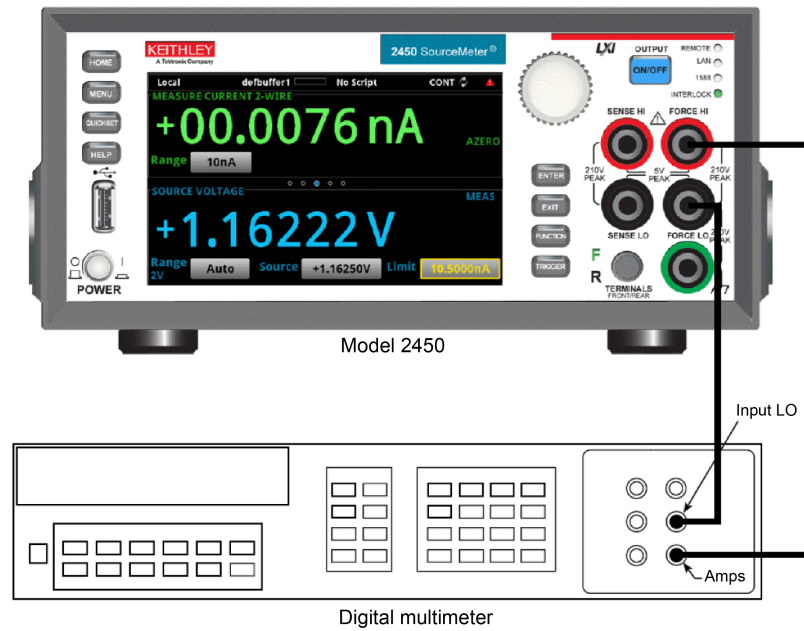
Special instructions for current source/measure of 100 nA and 10 nA accuracy

Follow the steps below to verify that Model 2450 current measurement accuracy is within specified limits. The procedure involves applying accurate currents from the Model 2450 current source and then verifying that Model 2450 current measurements are within required limits. The Keithley Model 6430 must be used for the 100 nA and 10 nA ranges.

1. With the power off, connect the digital multimeter to the Model 2450 input/output rear jacks as shown in the following figure.

Figure 8: Current verification rear-panel connections (10 nA and 100 nA ranges ONLY)

2. Select the multimeter DC current function and press the **HOME** key.

3. Press the **MENU** key.

4. Press the **QuickSet** on-screen button.

5. Press the **Function** on-screen button.

6. Press **Source Current and Measure Current**.

7. In the SOURCE area of the HOME screen, set the source range to the lowest possible range for the value to be sourced by pressing the **Range** button and selecting the range.

8. While on the HOME screen, select the exact source voltage by pressing the on-screen **Source** button and selecting a current.

9. The source value will be updated immediately after pressing the **OK** button on the Current Source Value window.

10. Press the **OUTPUT ON/OFF** button to turn on the output.

11. Verify measure current accuracy for each of the currents listed the following table. For the 100 nA and 10 nA ranges:
    - Select the correct source range.
    - Set the Model 2450 source output to the correct value as measured by the digital multimeter.
    - Verify that the Model 2450 current reading is within the limits given in the table.

NOTE

Use only the REAR terminals for measuring the 100 nA and 10 nA ranges.

Current measurement accuracy limits

Model 2450 source and measure range*	Source current**	Model 2450 current reading limits (1 year, 18 ⁰C to 28 ⁰C)
10 nA***	9.5000 nA***	9.49045 µA to 9.50955 µA
100 nA***	95.000 nA***	94.9429 µA to 95.0571 µA
1 µA	0.95000 µA	0.94946 µA to 0.95054 µA
10 µA	9.5000 µA	9.49693 µA to 9.50308 µA
100 µA	95.000 µA	94.9750 µA to 95.0250 µA
1 mA	0.95000 mA	0.94975 mA to 0.95025 mA
10 mA	9.5000 mA	9.49750 mA to 9.50250 mA
100 mA	95.000 mA	94.9703 mA to 95.0298 mA
1 A	0.95000 A	0.94922 A to 0.95079 A

*   Measure range coupled to source range when simultaneously sourcing and measuring current.
**   As measured by precision digital multimeter. Use closest possible value, and modify reading limits if necessary.
*** The 100 nA and 10 nA ranges must be measured using the Keithley Model 6430.

DC current measurement accuracy

Follow the steps below to verify that Model 2450 current measurement accuracy is within specified limits. The procedure involves applying accurate currents from the Model 2450 current source and then verifying that Model 2450 current measurements are within required limits. The Agilent 3458A may be used for all Model 2450 current ranges EXCEPT 10 nA and 100 nA.

1. With the power off, connect the digital multimeter to the Model 2450 input/output rear jacks as shown in the following figure.

Figure 9: Current verification rear-panel connections

2. Select the multimeter DC current function and press the **HOME** key.
3. Press the **MENU** key.
4. Press the **QuickSet** on-screen button.
5. Press the **Function** on-screen button.
6. Press **Source Current and Measure Current**.
7. In the SOURCE area of the Home screen, set the source range to the lowest possible range for the value to be sourced by pressing the **Range** button and selecting the range.
8. While on the Home screen, select the exact source voltage by pressing the on-screen **Source** button and selecting a current.
9. The source value will be updated immediately after pressing the **OK** button on the Current Source Value window.
10. Press the **OUTPUT ON/OFF** button to turn on the output.

11. Verify measure current accuracy for each of the currents listed in the following table. For each measurement:

   ▪ Select the correct source range.
   ▪ Set the Model 2450 source output to the correct value as measured by the digital multimeter.
   ▪ Verify that the Model 2450 current reading is within the limits given in the table.

NOTE
It may not be possible to set the current source to the specified value. Use the closest possible setting and modify reading limits accordingly.

12. Repeat the procedure for negative calibrator currents with the same magnitudes as those listed in the following table.

Output current accuracy limits

Model 2450 source and measure range*	Source current**	Model 2450 current reading limits (1 year, 18 ºC to 28 ºC)
10 nA***	9.5000 nA***	9.49045 µA to 9.50955 µA
100 nA***	95.000 nA***	94.9429 µA to 95.0571 µA
1 µA	0.95000 µA	0.94946 µA to 0.95054 µA
10 µA	9.5000 µA	9.49693 µA to 9.50308 µA
100 µA	95.000 µA	94.9750 µA to 95.0250 µA
1 mA	0.95000 mA	0.94975 mA to 0.95025 mA
10 mA	9.5000 mA	9.49750 mA to 9.50250 mA
100 mA	95.000 mA	94.9703 mA to 95.0298 mA
1 A	0.95000 A	0.94922 A to 0.95079 A

*   Measure range coupled to source range when simultaneously sourcing and measuring current.
**   As measured by precision digital multimeter. Use closest possible value and modify reading limits if necessary.
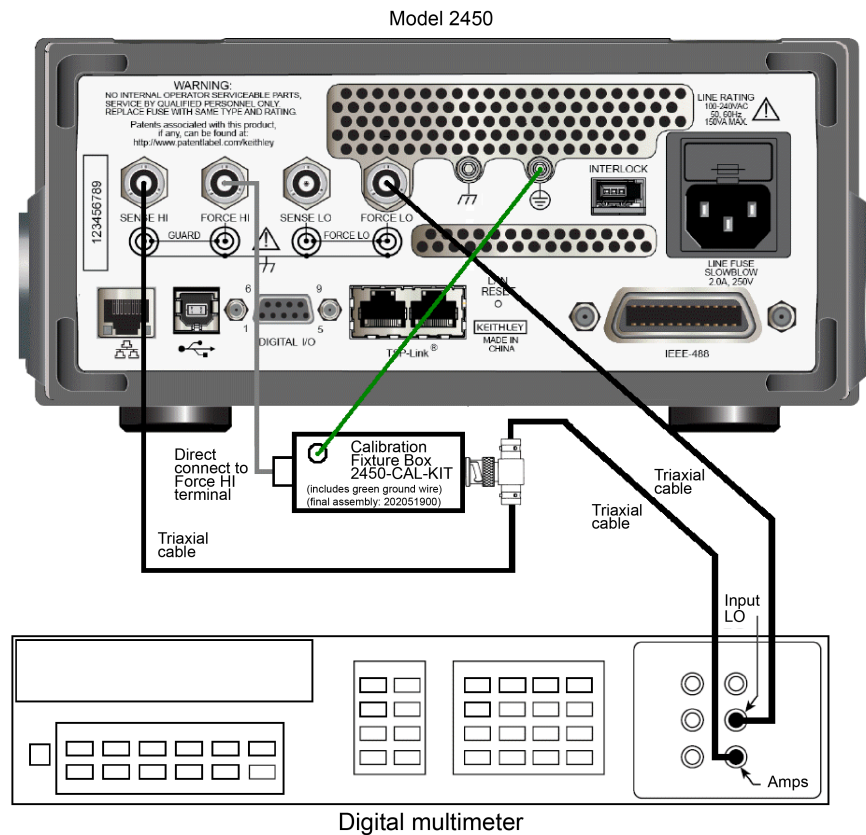***   The 100 nA and 10 nA ranges must be measured using the Keithley Model 6430 ONLY.

NOTE
For the 100 nA and 10 nA ranges, make connections according to the following figure and follow steps 1 through 13 for these two ranges ONLY.

13. Repeat the entire procedure using the front-panel input/output jacks. Be sure to select the front-panel jacks with the front-panel **TERMINALS FRONT/REAR** key.

Resistance measurement accuracy

Follow the steps below to verify that Model 2450 resistance measurement accuracy is within specified limits. This procedure involves applying accurate resistances from a resistance calibrator and then verifying that Model 2450 resistance measurements are within required limits.

1. With the power off, connect the resistance calibrator to the Model 2450 input/output triaxial jacks, as shown in the following figure. Be sure to use the four-wire connections as shown.

Figure 10: Resistance verification rear-panel connections
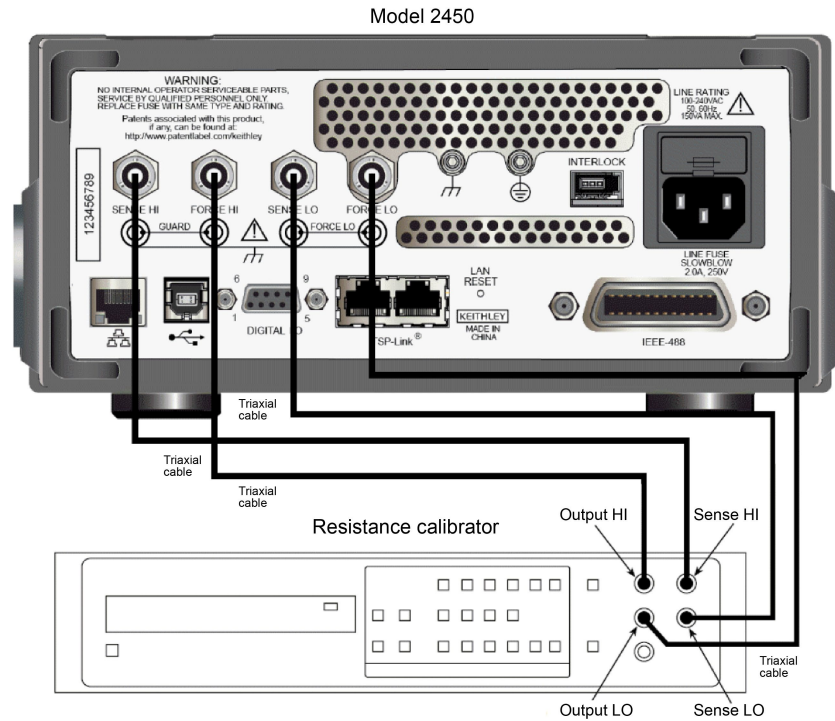
2. Select the resistance calibrator external sense mode.

3. Press the **MENU** key.

4. Press the **QuickSet** on-screen button.

5. Press the **Ohmmeter** Quick Setup button.

6. Press the **4-Wire Sense** button.

7. Press the **OUTPUT ON/OFF** button to turn output off.

8. Press the **TERMINALS FRONT/REAR** button to change to the rear terminals.

9. Press the **Output** button to turn output on.

10. Verify ohms measurement accuracy for each of the resistance values listed in the following table. For each measurement:

   ▪ Set the resistance calibrator output to the nominal resistance or closest available value.

   ▪ Press the **Measure Range** button on the Model 2450 and select the appropriate resistance range to be verified according to the following table.

NOTE

It may not be possible to set the resistance calibrator to the specified value. Use the closest possible setting and modify reading limits accordingly.

   ▪ Verify that the Model 2450 resistance reading is within the limits given in the following table.

Ohms measurement accuracy limits

Model 2450 range	Calibrator resistance*	Model 2450 resistance reading limits** (1 year, 18 ℃ to 28 ℃)
20 Ω	19 Ω	18.9784 Ω to 19.0216 Ω
200 Ω	190 Ω	189.824 Ω to 190.176 Ω
2 kΩ	1.9 kΩ	1.89845 kΩ to 1.90155 kΩ
20 kΩ	19 kΩ	18.9850 kΩ to 19.0150 kΩ
200 kΩ	190 kΩ	189.847 kΩ to 190.154 kΩ
2 MΩ	1.9 MΩ	1.89761 MΩ to 1.90239 MΩ
20 MΩ	19 MΩ	18.9781 MΩ to 19.0219 MΩ
200 MΩ	100 MΩ	99.3350 MΩ to 100.665 MΩ

* Nominal resistance value.
** Reading limits based on Model 2450 normal accuracy specifications and nominal resistance values. If actual resistance values differ from nominal values shown, recalculate reading limits using actual calibrator resistance values and Model 2450 normal accuracy specifications. See Verification limits (on page 1-3) for details.

11. Repeat the entire procedure using the front-panel input/output and 4-wire sense jacks. Be sure to select the front-panel jacks with the front-panel **TERMINALS FRONT/REAR** key. See the following figure for the resistance verification front-panel connections.

Figure 11: Resistance verification front-panel connections
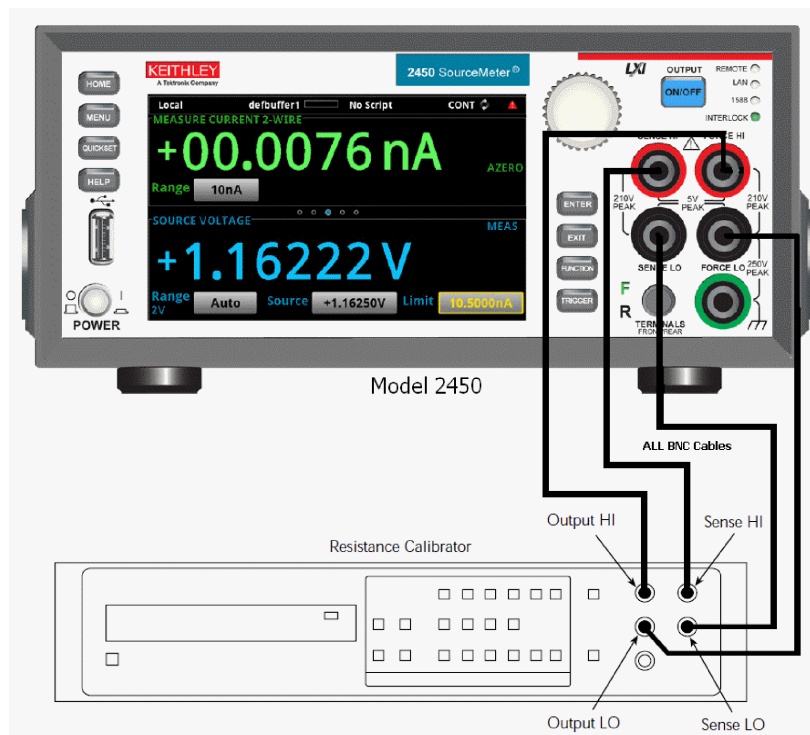
Calibration

In this section:

Introduction

Use the procedures in this section to calibrate the Model 2450. These procedures require accurate test equipment to measure precise DC voltages and currents. Calibration can be performed either from the front panel by running the Test Script Processor (TSP®) scripts documented in this manual or by sending SCPI calibration commands over the IEEE-488, USB, or ethernet port with the aid of a computer.

⚠ WARNING

The information in this section is intended for qualified service personnel only. Do not attempt these procedures unless you are qualified to do so. Some of these procedures may expose you to hazardous voltages.

Environmental conditions

Temperature and relative humidity

Conduct the calibration procedures in a test environment with:

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

Warm-up period

Allow the Model 2450 to warm up for at least one hour before conducting the calibration procedures.

If the instrument has been subjected to temperature extremes (those outside the ranges stated above), allow additional time for the instrument's internal temperature to stabilize. Typically, allow one extra hour to stabilize a unit that is 10 °C (18 °F) outside the specified temperature range.

Also, allow the test equipment to warm up for the minimum time specified by the manufacturer.

Line power

The Model 2450 requires a line voltage of 100 V to 240 V and a line frequency of 50 Hz or 60 Hz.

The instrument must be calibrated within this range.

Calibration considerations

When performing the calibration procedures:

*   Make sure that the test equipment is properly warmed up and connected to the Model 2450 rear-panel input/ output jacks. Also be certain that the rear-panel jacks are selected with the TERMINALS FRONT/REAR switch.
*   Always allow the source signal to settle before calibrating each point.
*   Do not connect test equipment to the Model 2450 through a scanner or other switching equipment.
*   If an error occurs during calibration, the Model 2450 will generate an appropriate error message. See Appendix B, Command reference (on page B-1) for more information.

⚠ WARNING

The maximum common-mode voltage (voltage between LO and chassis ground) is 250 V peak. Exceeding this value may cause a breakdown in insulation, creating a shock hazard.

The front and rear terminals of the Model 2450 are rated for connection to circuits rated Installation Category I only. Do not connect the Model 2450 terminals to CAT II, CAT III, or CAT IV circuits. Connection of the Model 2450 input/output terminals to circuits higher than CAT I can cause damage to the equipment or expose the operator to hazardous voltage.

Hazardous voltages may be present on the output and guard terminals. To prevent electrical shock that could cause injury or death, NEVER make or break connections to the Model 2450 while the unit is on. Power off the equipment from the front panel or disconnect the main power cord from the rear of the Model 2450 before handling cables connected to the outputs. Putting the equipment into standby mode does not guarantee the outputs are not powered if a hardware or software fault occurs.

⚠ CAUTION

The maximum voltage between input/output HI and LO or 4-wire sense HI and LO is 210 V peak. The maximum voltage between input/output HI and 4-wire sense HI or between input/output LO and 4-wire sense LO is 5 V. Exceeding these voltage values may result in instrument damage.

Calibration cycle

Perform calibration at least once a year to ensure the unit meets or exceeds its specifications.

NOTE

Calibration constants are stored in the nonvolatile memory of the Model 2450.

Calibration mode

Calibration must be performed in SCPI mode only. Calibration cannot be performed in 2400SCPI or in TSP modes. Additionally, on the Model 2450, calibration/adjustment should only be performed from the rear input/output terminals. Verification (no adjustment) can be performed on both the front and rear terminals, however, calibration/adjustment should only be performed from the rear input/output terminals.

Recommended calibration equipment

The following table lists the recommended equipment for the calibration procedures. You can use alternate equipment as long as that equipment has specifications at least as good as those listed in the table. When possible, test equipment specifications should be at least four times better than the corresponding Model 2450 specifications.

Recommended calibration equipment

Description	Manufacturer/Model	Accuracy*		
Digital multimeter	Hewlett Packard HP3458A	DC voltage	20 mV:	± 15 ppm
			200 mV:	± 15 ppm
			2 V:	± 6 ppm
			20 V:	± 9 ppm
			200 V:	± 7 ppm
		DC current	1 µA:	± 55 ppm
			10 µA:	± 25 ppm
			100 µA:	± 23 ppm
			1 mA:	± 20 ppm
			10 mA:	± 20 ppm
			100 mA:	± 35 ppm
			1 A:	± 110 ppm
Model 6430 Sub-Femtoamp Remote SourceMeter® (used for 100 nA and 10 nA ranges ONLY)	Keithley Instruments	DC current	10 nA:	± 110 ppm
			100 nA:	± 110 ppm
2450 Calibration Fixture (Model 2450-CAL-KIT)**	Keithley Instruments	n/a		

* 90-day specifications show accuracy at specified measurement point.
** Required accessory.

Unlocking calibration

Before performing calibration, you must first unlock calibration by entering or sending the calibration password as follows:

- Send the SCPI command `CALibration:UNLock 'KI002400'.`

- Calibration can now be executed.

- Calibration will be unlocked and assume the states summarized in the following table. Attempts to change any of the settings listed below with calibration unlocked will result in an error +510, "Not permitted with cal unlocked."

NOTE

With calibration unlocked, the sense function and range track the source function and range. That is, when `:SOUR:FUNC` is set to `VOLT`, the `:SENS:FUNC` setting will be `'VOLT:DC'`. When `:SOUR:FUNC` is set to `CURR`, the `:SENS:FUNC` setting will be `'CURR:DC'`. A similar command coupling exists for `:SOUR:VOLT:RANG` / `:SENS:VOLT:RANG` and `SOUR:CURR:RANG` / `:SENS:CURR:RANG`.

Calibration unlocked states

Mode	State	Equivalent remote command
Concurrent functions	Off	`:SENS:FUNC:CONC Off`
Sense function sense	Source	`:SENS:FUNC <source_function>`
Volts NPLC sense	1.0	`:SENS:VOLT:NPLC 1.0`
Volts range sense	Source V	`:SENS:VOLT:RANG <source_v_range>`
Current NPLC sense	1.0	`:SENS:CURR:NPLC 1.0`
Current range filter	Source I	`:SENS:CURR:RANG <source_i_range>`
Count	10	`:SENS:AVER:COUN 10`
Filter control	Repeat	`:SENS:AVER:TCON Repeat`
Filter averaging	On	`:SENS:AVER:STAT On`
Source V mode	Fixed	`:SOUR:VOLT:MODE Fixed`
Volts autorange	Off:sour	`:VOLT:RANG:AUTO Off`
Source I mode	Fixed	`:SOUR:CURR:MODE Fixed`
Current autorange	Off	`:SOUR:CURR:RANG:AUTO Off`
Autozero	On	`:SYST:AZERo On`
Trigger arm count	1	`:ARM:COUN 1`
Trigger arm source	Immediate	`:ARM:SOUR IMMediate`
Trigger count	1	`:TRIG:COUN 1`
Trigger source	Immediate	`:TRIG:SOUR IMMediate`

Changing the password

The default password may be changed from the front panel or via remote as discussed in the following paragraphs.

To change the calibration password, first send the present password, and then send the new password.

For example, the following command sequence changes the password from the `'KI002400'` remote default to `'KI_CAL'`:

    CALibration:PASSword 'newpswd'

You can use any combination of letters and numbers up to a maximum of eight characters.

Resetting the calibration password

The default Model 2450 calibration password is `KI002400`.

⚠ **CAUTION**

If you change the Model 2450 calibration password and forget it, you must return the Model 2450 to the local Keithley Worldwide Service Center to reset. There is no user-serviceable procedure to restore the default calibration password on the Model 2450.

Querying calibration dates and calibration count

To query the calibration and adjustment dates, send the following SCPI commands:

1. `CALibration:ADJust:DATE?`
2. `CALibration:ADJ:COUNt?`
3. `CALibration:VERify:DATE?`

Alternatively, the calibration dates and calibration count can be viewed by pressing the **MENU** key and selecting **System Information**.

Calibration errors

The Model 2450 checks for errors after each calibration step, minimizing the possibility that improper calibration may occur due to operator error.

Front-panel error reporting

If an error is detected during comprehensive calibration, the instrument will display an appropriate error message. Once the error is displayed, simply dismiss the error message and repeat the calibration step that caused the error with the corrected parameter or corrected command syntax.

Remote error reporting

You can detect errors while in remote by testing the state of the Error Available Bit (EAV) (bit 2) in the status byte (use the `*STB?` query to request the status byte). Query the instrument for the type of error by using the appropriate `:SYST:ERR?` query. The Model 2450 will respond with the error number and a text message describing the nature of the error.

Remote calibration

Use the following procedure to perform remote calibration by sending SCPI commands over the IEEE-488, USB, or ethernet bus. The remote commands and appropriate parameters are separately summarized for each step.

You can use the following tables to document each calibration value as the calibration/adjustment procedure is executed.

Voltage calibration data table

Source range	Source voltage	Multimeter voltage reading*
0.02 V	+20.000 mV	_____ mV
	+00.000 mV	_____ mV
	-20.000 mV	_____ mV
	-00.000 mV	_____ mV
0.2 V	+200.00 mV	_____ mV
	+000.00 mV	_____ mV
	-200.00 mV	_____ mV
	-000.00 mV	_____ mV
2 V	+2.0000 V	_____ V
	+0.0000 V	_____ V
	-2.0000 V	_____ V
	-0.0000 V	_____ V
20 V	+20.000 V	_____ V
	+00.000 V	_____ V
	-20.000 V	_____ V
	-00.000 V	_____ V
200 V	+200.00 V	_____ V
	+000.00 V	_____ V
	-200.00 V	_____ V
	-000.00 V	_____ V

*Multimeter reading used in corresponding calibration step. See procedure.

Current calibration data table

Source range	Source current	Multimeter current reading*
10 nA	+10.000 nA	_____ nA
	+00.000 nA	_____ nA
	-10.000 nA	_____ nA
	-00.000 nA	_____ nA
100 nA	+100.00 nA	_____ nA
	+000.00 nA	_____ nA
	-100.00 nA	_____ nA
	-000.00 nA	_____ nA
1 µA	+1.0000 µA	_____ µA
	+0.0000 µA	_____ µA
	-1.0000 µA	_____ µA
	-0.0000 µA	_____ µA
10 µA	+10.000 µA	_____ µA
	+00.000 µA	_____ µA
	-10.000 µA	_____ µA
	-00.000 µA	_____ µA
100 µA	+100.00 µA	_____ µA
	+000.00 µA	_____ µA
	-100.00 µA	_____ µA
	-000.00 µA	_____ µA
1 mA	+1.0000 mA	_____ mA
	+0.0000 mA	_____ mA
	-1.0000 mA	_____ mA
	-0.0000 mA	_____ mA
10 mA	+10.000 mA	_____ mA
	+00.000 mA	_____ mA
	-10.000 mA	_____ mA
	-00.000 mA	_____ mA
100 mA	+100.00 mA	_____ mA
	+00.000 mA	_____ mA
	-10.000 mA	_____ mA
	-00.000 mA	_____ mA
1 A	+100.00 mA	_____ A
	+000.00 mA	_____ A
	-100.00 mA	_____ A
	-000.00 mA	_____ A

* Multimeter reading used in corresponding calibration step. See procedure.

Remote calibration commands

The following three tables contain information you will need to calibrate the Model 2450 remotely.

- Remote calibration command summary table (on page 2-9). Summarizes remote calibration commands.
- CALibration:ADJust:SENSe parameter ranges table (on page 2-10). Contains command parameter limits. Note that each sense range requires three parameters: Zero, negative full scale, and positive full scale.
- CALibration:ADJust:SOURce parameter ranges table (on page 2-10). Each source range requires four parameters: Two zero parameters, a positive full-scale parameter, and a negative full-scale parameter.

For a more complete description of these commands, refer to Appendix B, Command reference (on page B-1).

Remote calibration command summary

2400 Legacy SCPI Command*	2450 SCPI Command**	Description
`:CALibration:PROTected:CODE`	`CALibration:PASSword <change code to unlock>`	**Unlock cal:** Changes password if cal is already unlocked. Default password:*** `KI002400`
`:CALibration:PROTected:COUNt?`	`CALibration:ADJust:COUNt?`	Query the number of times the Model 2450 calibration values have been adjusted. **Note:** The calibration adjust count is incremented automatically each time a customer adjustment is performed. The calibration adjust count can only be reset at the Keithley Instruments factory.
`:CALibration:PROTected:DATE and query`	`CALibration:ADJust:DATE and query`	Set or query the date the Model 2450 calibration values have been adjusted (year, month, day).
<not supported>	`CALibration:VERify:DATE and query`	Set or query the date the Model 2450 calibration values have been verified (year, month, day).
`:CALibration:PROT:LOCK and query`	`CALibration:LOCK and query`	Set or query whether or not the Model 2450 calibration constants are locked or unlocked.
<not supported>	`CALibration:UNLock <code to unlock>`	Unlock the Model 2450 calibration values.
`:CALibration:PROTected:NDUE and query`	<not supported>	No longer supported.
`:CALibration:PROTected:SAVE`	`CALibration:SAVE`	Save the updated calibration values to nonvolatile memory.
`:CALibration:PROTected:SENSe`	`CALibration:ADJust:SENSe`	Set the new calibration sense data value.
`:CALibration:PROTected:SENSe: DATA?`	`CALibration:ADJust:SENSe :DATA?`	Query the new calibration sense data.
`:CALibration:PROTected:SOURce`	`CALibration:ADJust:SOURce`	Set the new calibration source data value.
`:CALibration:PROTected:SOURce: DATA?`	`CALibration:ADJust:SOURce :DATA?`	Query the new calibration source data.

*   2400 Legacy commands shown for comparison only. These commands are NOT available on the Model 2450.
** Calibration data will not be saved if calibration was not unlocked with the `CALibration:UNLock <code>` command.
*** **CAUTION:** If you change the default calibration password and you forget the new password, you must return the unit to the Keithley Worldwide Service Center in order for the calibration password to be reset. This password is unique to calibration only and is NOT the same as the instrument password that is described in the Model 2450 Reference Manual.

CALibration:ADJust:SENSe parameter ranges

Sense range	First parameter (zero)	Second parameter (negative full scale)	Third parameter (positive full scale)
0.02 V	-0.0002 to +0.0002	-0.018 to -0.022	+0.018 to +0.022
0.2 V	-0.002 to +0.002	-0.18 to -0.22	+0.18 to +0.22
2 V	-0.02 to +0.02	-1.8 to -2.2	+1.8 to +2.2
20 V	-0.2 to +0.2	-18 to -22	+18 to +22
20 V	-2 to +2	-180 to -220	+180 to +220
10 nA	-1e10 to +1e-10	-9e-9 to -11e-9	+9e-9 to +11e-9
100 nA	-1e-9 to +1e-9	-90e-9 to -110e-9	+90e-9 to +110e-9
10 µA	-1e-7 to +1e-7	-9e-6 to -11e-6	+0.9e-6 to +1.1e-6
1 µA	-1e-8 to +1e-8	-0.9e-6 to -1.1e-6	+9e-6 to +11e-6
100 µA	1e-6 to +1e-6	-90e-6 to -110e-6	+90e-6 to +110e-6
1 mA	-1e-5 to +1e-5	-0.9e-3 to -1.1e-3	+0.9e-3 to +1.1e-3
10 mA	-1e-4 to +1e-4	-9e-3 to -11e-3	+9e-3 to +11e-3
100 mA	-1e-3 to +1e-3	-90e-3 to -110e-3	+90e-3 to +110e-3
1 A	-1e-2 to +1e-2	-0.9 to -1.1	+0.9 to +1.1

NOTE: Parameter steps for each range may be performed in any order, but all three parameter steps for each range must be completed.

CALibration:ADJust:SOURce parameter ranges

Source range	First parameter (negative full scale)	Second parameter (negative zero)	Third parameter (positive full scale)	Fourth parameter (positive zero)
0.02 V	-0.02 to -0.02	-0.0002 to +0.0002	+0.018 to +0.022	-0.0002 to +0.0002
0.2 V	-0.18 to -0.22	-0.002 to +0.002	+0.18 to +0.22	-0.002 to +0.002
2 V	-1.8 to -2.2	-0.02 to +0.02	+1.8 to +2.2	-0.02 to +0.02
20 V	-18 to -22	-0.2 to +0.2	+18 to +22	-0.2 to +0.2
200 V	-180 to -220	-2 to +2	+180 to +220	-2 to +2
10 nA	-9e-9 to -11e-9	-1e-10 to +1e-10	+9e-9 to +11e-9	-1e10 to +1e-10
100 nA	-90e-9 to -110e-9	-1e-9 to +1e-9	+90e-9 to +110e-9	-1e-9 to +1e-9
1 µA	-0.9e-6 to -1.1e-6	-1e-8 to +1e-8	+0.9e-6 to +1.1e-6	-1e-8 to +1e-8
10 µA	-9e-6 to -11e-6	-1e-7 to +1e-7	+9e-6 to +11e-6	-1e-7 to +1e-7
100 µA	-90e-6 to -110e-6	-1e-6 to +1e-6	+90e-6 to +110e-6	-1e-6 to +1e-6
1 mA	-0.9e-3 to -1.1e-3	-1e-5 to +1e-5	+0.9e-3 to +1.1e-3	-1e-5 to +1e-5
10 mA	-9e-3 to -11e-3	-1e-4 to +1e-4	+9e-3 to +11e-3	-1e-4 to +1e-4
100 mA	-90e-3 to -110e-3	-1e-3 to +1e-3	+90e-3 to +110e-3	-1e-3 to +1e-3
1 A	-0.9 to -1.1	-1e-2 to +1e-2	+0.9 to +1.1	-1e-2 to +1e-2

NOTE: Parameter steps for each range may be performed in any order, but all three parameter steps for each range must be completed.

Remote calibration procedure

Step 1. Prepare the Model 2450 for calibration

1. Connect the Model 2450 to the controller IEEE-488, USB, or ethernet interface using the appropriate shielded interface cable.

2. Turn on the Model 2450 and the test equipment, and allow them to warm up for at least one hour before performing calibration.

3. If you are using the IEEE-488 interface, make sure the primary address of the Model 2450 is the same as the address specified in the program you will be using to send commands (from the front panel, press the **MENU** key, and under System, select **Communication** to observe the current Model 2450 GPIB address).

Step 2. Voltage calibration

1. Connect the Keithley Model 2450 to the digital multimeter (see the following figure), and select the multimeter DC volts function.

Figure 12: Voltage calibration connections
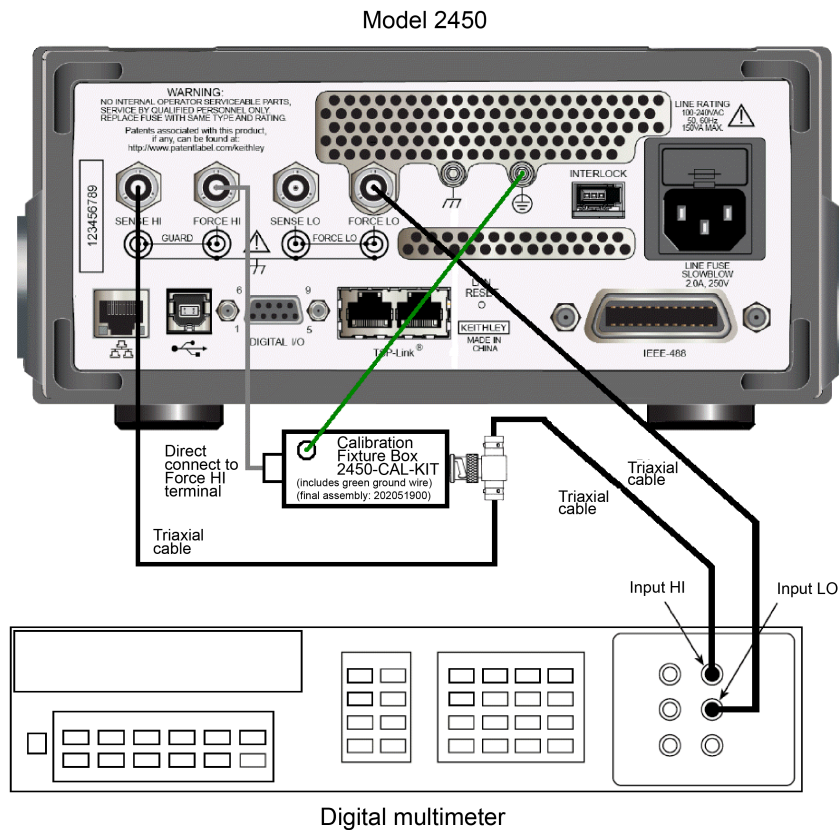
2. Send the commands summarized in the following table in the order listed to initialize voltage calibration (when the CAL:UNL command is sent, the instrument will assume the operating states listed in the "Calibration unlocked states" table in).

Voltage calibration initialization commands

Command	Description
`*RST`	Restore GPIB defaults.
`:SOUR:FUNC VOLT`	Activate voltage source.
`:SENS:CURR:RANG 0.1`	Make sure 1 A range is not active.
`:SOUR:VOLT:PROT:LEV NONE`	Maximum allowable source voltage.
`:SYST:RSEN OFF`	Disable remote sensing.*
`CAL:UNL 'KI002400'`	Unlock calibration.
`:ROUT:TERM REAR`	Route inputs/outputs to the rear terminals.
`:OUTP:STAT ON`	Turn source on.

* Remote sensing may be used if desired, but is not essential when using recommended digital multimeter.

3. Perform the range calibration steps listed in the following table for each range. For each range:
   - Send the `:SOUR:VOLT:RANG` command to select the source and sense range being calibrated. For example, for the 2 V range, the following command would be sent:
     `:SOUR:VOLT:RANG 2`
   - Program the source to output the negative full-range value using the `:SOUR:VOLT` command. For example:
     `:SOUR:VOLT –2`

   Note and record the multimeter reading in the "Voltage calibration data" table in Remote calibration (on page 2-6).

Voltage range calibration commands

Step	Command/procedure	Description
1	`:SOUR:VOLT:RANG <Range>`	Select source range.
2	`:SOUR:VOLT -<Range>`	Establish negative polarity.
3	Take DMM reading.**	Read actual output value.
4	`CAL:ADJ:SOUR <DMM_Reading>`	Calibrate source function negative full scale.
5	Check Model 2450 for errors.***	
6	`CAL:ADJ:SENS <DMM_Reading>`	Calibrate sense function negative full scale.
7	Check Model 2450 for errors.***	
8	`:SOUR:VOLT 0.0`	Set output to 0 V.
9	Take DMM reading.**	Read actual output value.
10	`CAL:ADJ:SOUR <DMM_Reading>`	Calibrate source function negative zero.
11	Check Model 2450 for errors.***	
12	`CAL:ADJ:SENS <DMM_Reading>`	Calibrate sense function negative zero.
13	Check Model 2450 for errors.***	
14	`:SOUR:VOLT +<Range>`	Establish positive polarity.
15	Take DMM reading.**	Read actual output value.
16	`CAL:ADJ:SOUR <DMM_Reading>`	Calibrate sense function positive full scale.
17	Check Model 2450 for errors.***	
18	`CAL:ADJ:SENS <DMM_Reading>`	Calibrate source function positive full scale.
19	Check Model 2450 for errors.***	
20	`:SOUR:VOLT 0.0`	Set output to 0 V.
21	Take DMM reading.**	Read actual output value.
22	`CAL:ADJ:SOUR <DMM_Reading>`	Calibrate source positive zero.
23	Check Model 2450 for errors.***	

*   Perform complete procedure for each range, where `<Range>` = 0.02, 0.2, 2, 20, and 200.
** `<DMM_Reading>` parameter is multimeter reading from previous step.
*** Use `:SYST:ERR?` query to check for errors.

- Use the multimeter reading as the parameter for the `CAL:ADJ:SOUR` and `CAL:ADJ:SENS` commands. For example, a typical value for the 2 V range would be:
  ```
  CAL:ADJ:SOUR -1.998
  CAL:ADJ:SENS -1.998
  ```
- Program the voltage source for 0 V output using the `:SOUR:VOLT 0.0` command.
- Note the multimeter reading.
- Send the source and sense calibration commands using the multimeter reading for the parameter. For example:
  ```
  CAL:ADJ:SOUR 0.001
  CAL:ADJ:SENS 0.001
  ```
- Set the source to the positive full-range value using the `:SOUR:VOLT` command. For example:
  ```
  :SOUR:VOLT 2
  ```
- Note and record the multimeter reading in the "Voltage calibration data" table in Remote calibration (on page 2-6).

- Send the source and sense commands using the multimeter reading as the parameter. For example:
  ```
  CAL:ADJ:SOUR 1.997
  CAL:ADJ:SENS 1.997
  ```

- Send the `:SOUR:VOLT 0.0` command to set the source voltage to 0 V.

- Note and record the multimeter reading in the "Voltage calibration data" table in Remote calibration (on page 2-6).

- Send the `CAL:ADJ:SOUR` command using the multimeter reading as the command parameter. For example:
  ```
  CAL:ADJ:SOUR -1.02e-3
  ```

Step 3. Current calibration

1. Connect the Model 2450 to the digital multimeter (see the following figures), and select the multimeter DC current function.

Figure 13: Current calibration connections
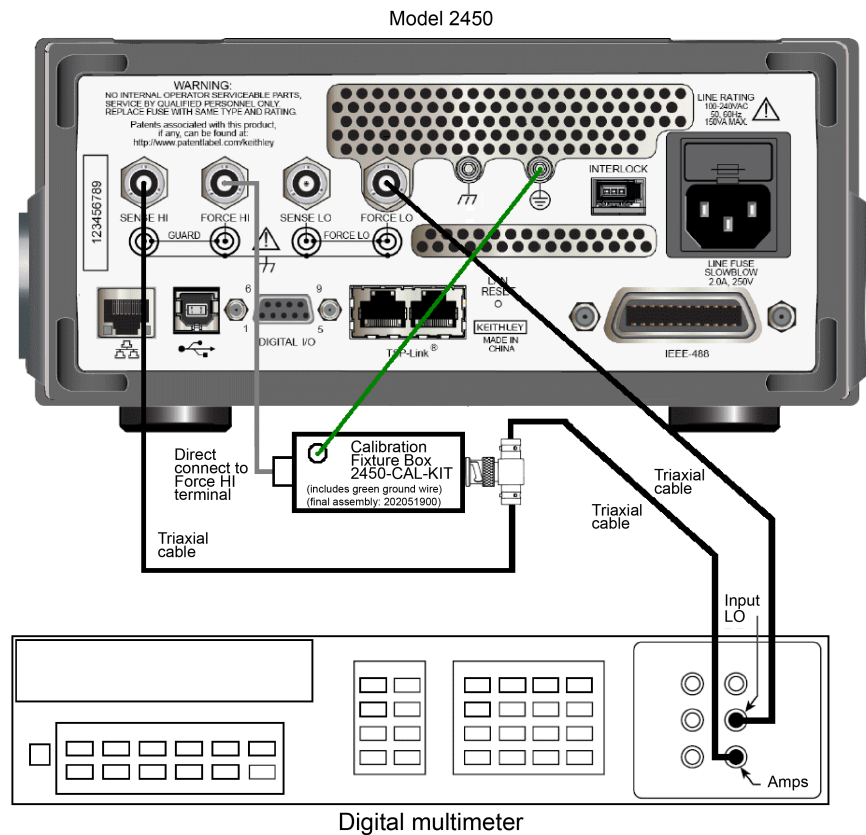
Figure 14: Current verification rear-panel connections for the 10 nA 100 nA ranges
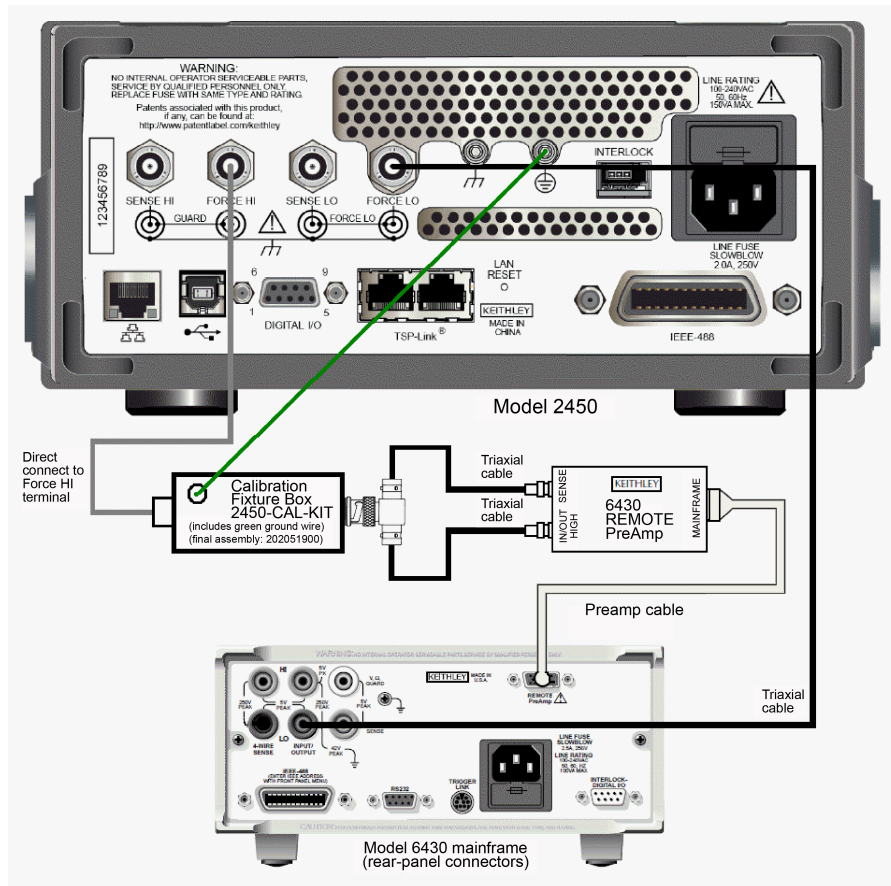
2. Send the commands summarized in the following table in the order listed to initialize current calibration.

Current calibration initialization commands

Command	Description
`*RST`	Restore GPIB defaults.
`:SOUR:FUNC CURR`	Select source current mode.
`:SENS:VOLT:RANG 20`	Make sure 200 V range is not active.
`CAL:UNL 'KI002400'`	Unlock cal.
`:ROUT:TERM REAR`	Route inputs/outputs to the rear terminals.
`:OUTP:STAT ON`	Turn source on.

3. Calibrate each current range using the procedure summarized in the following table. For each range:

   ▪ Send the `:SOUR:CURR:RANG` command to select the source and sense range being calibrated. For example, for the 1 mA range, the command is:

     `:SOUR:CURR:RANG 1e-3`

   ▪ Program the source to output the negative full-range value using the `:SOUR:CURR` command. For example:

     `:SOUR:CURR -1e-3`

   ▪ Note and record the multimeter reading in the "Current calibration data" table in <u>Remote calibration</u> (on page 2-6).

   ▪ Use the multimeter reading as the parameter for the `CAL:PROT:SOUR` and `CAL:PROT:SENS` commands. For example, a typical value for the 1mA range would be:

     `CAL:PROT:SOUR -1.025e-3`
     `CAL:PROT:SENS -1.025e-3`

   ▪ Program the current source for 0 A output using the `:SOUR:CURR 0.0` command.

   ▪ Note and record the multimeter reading in the "Current Calibration Data" table in <u>Remote calibration</u> (on page 2-6).

Current range calibration commands

Step	Command/procedure*	Description
1	`:SOUR:CURR:RANGE <Range>`	Select source range.
2	`:SOUR:CURR -<Range>`	Establish negative polarity.
3	Take DMM reading.**	Read actual output value.
4	`CAL:ADJ:SOUR <DMM_Reading>`	Calibrate source function negative full scale.
5	Check Model 2450 for errors.***	
6	`CAL:ADJ:SENS <DMM_Reading>`	Calibrate sense function negative full scale.
7	Check Model 2450 for errors.***	
8	`:SOUR:CURR 0.0`	Set output to 0 A.
9	Take DMM reading.**	Read actual output value.
10	`CAL:ADJ:SOUR <DMM_Reading>`	Calibrate source function negative zero.
11	Check Model 2450 for errors.***	
12	`CAL:ADJ:SENS <DMM_Reading>`	Calibrate sense function negative zero.
13	Check Model 2450 for errors.***	
14	`:SOUR:CURR +<Range>`	Establish positive polarity.
15	Take DMM reading.**	Read actual output value.
16	`CAL:ADJ:SOUR <DMM_Reading>`	Calibrate sense function positive full scale.
17	Check Model 2450 for errors.***	
18	`CAL:ADJ:SENS <DMM_Reading>`	Calibrate source function positive full scale.
19	Check Model 2450 for errors.***	
20	`:SOUR:CURR 0.0`	Set output to 0 A.
21	Take DMM reading.**	Read actual output value.
22	`CAL:ADJ:SOUR <DMM_Reading>`	Calibrate source positive zero.
23	Check Model 2450 for errors.***	

* Perform complete procedure for each range, where <Range> = 10e-9, 100e-9, 1e-6, 10e-6, 100e-6, 1e-3, 10e-3, 100e-3, or 1. The Keithley Model 6430 MUST BE USED for 100 nA and 10 nA ranges. See the figures above for connection details.

** `<DMM_Reading>` parameter is multimeter reading from previous step.

*** Use `:SYST:ERR?` query to check for errors.

- Send the source and sense calibration commands using the multimeter reading for the parameter. For example:

    `CAL:ADJ:SOUR 1e-6`
    `CAL:ADJ:SENS 1e-6`

- Set the source to the positive full-range value using the `:SOUR:CURR` command. For example, for the 1 mA range:

    `:SOUR:CURR 1e-3`

- Note and record the multimeter reading.
- Send the source and sense commands using the multimeter reading as the parameter. For example:

    `CAL:ADJ:SOUR 1.03e-3`
    `CAL:ADJ:SENS 1.03e-3`

- Send the `:SOUR:CURR 0.0` command to set the source current to 0 A.
- Note and record the multimeter reading in the "Current Calibration Data" table in Remote calibration (on page 2-6).
- Send the `CAL:PROT:SOUR` command using the multimeter reading as the command parameter. For example:

    `CAL:ADJ:SOUR -1.02e-3`

Step 4. Program calibration dates

Use the following commands to set the adjust date, adjust count, and calibration date.

`CAL:ADJ:DATE <year>, <month>, <day>` (adjust date)
`CAL:VER:DATE <year>, <month>, <day>` (calibration date)

Note that the year, month, and day must be separated by commas. The allowable range for the year is from 1995 to 2094, the month is from 1 to 12, and the day is from 1 to 31. The calibration date is the same as a calibration without adjustment, otherwise known as verification.

Finally, the Adjust Count is automatically incremented each time a customer calibration is executed and the Adjust Date is set with the commands above. Calling `CAL:ADJ:DATE` and `CAL:SAVE` in sequence will automatically increment the Adjust Count. The Model 2450 may need to be power cycled before the new dates will show on the display.

Step 5. Save calibration constants

Calibration is now complete, so you can store the calibration constants in nonvolatile memory by sending the following command:

`CAL:SAVE`

NOTE
Calibration will be temporary unless you send the `:SAVE` command. Also, calibration data will not be saved if (1) calibration is locked, (2) invalid data exists, or (3) all steps were not completed.

Step 6. Lock-out calibration

To lock out further calibration, send the following command after completing the calibration procedure:

`CAL:LOCK`

Single-range adjustment

Normally, the complete adjustment procedure should be performed to ensure that the entire instrument is properly calibrated. In some instances, however, you may want to adjust only certain ranges. To do so, complete the entire procedure only for the range or ranges to be adjusted. Keep in mind, however, that you must complete all parameter steps for each source or sense range. Also, be sure to set adjust and calibration dates and save calibration after adjusting the desired ranges.

Routine maintenance

In this appendix:

Introduction

The information in this section deals with routine maintenance that can be performed by the operator.

Line fuse replacement

A fuse located on the Model 2450 rear panel protects the power line input of the instrument.

> ⚠ **WARNING**
>
> *Disconnect the line cord at the rear panel and remove all test leads connected to the instrument before replacing the line fuse. Failure to do so could expose the operator to hazardous voltages that could result in personal injury or death.*

> ⚠ **CAUTION**
>
> To prevent instrument damage, use only the fuse type specified in the following table.

Power line fuse

Line voltage	Rating	Keithley part number
100 V to 240 V	250 V, 2 A, slow blow 5 × 20 mm	FU-81

To replace the fuse, you will need a small flat-bladed screwdriver.

Perform the following steps to replace the line fuse:

1. Power off the instrument.
2. Remove all test leads connected to the instrument.
3. Remove the line cord.
4. Locate the fuse drawer, which is above the AC receptacle, as shown in the figure below.

Figure 15: Model 2450 line fuse
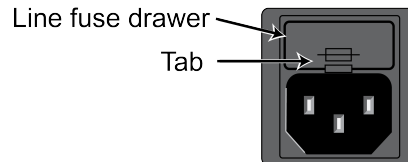
5. Use the screwdriver to lift the tab from the AC receptacle.
6. Slide the fuse drawer out. The fuse drawer does not pull completely out of the power module.
7. Snap the fuse out of the drawer.
8. Replace the fuse.
9. Push the fuse drawer back into the module.

If the power line fuse continues to get damaged, a circuit malfunction exists and must be corrected. Return the instrument to Keithley Instruments for repair.

Factory service

If the instrument is to be returned to Keithley Instruments for repair, perform the following:

- Call the Repair Department at 1-800-833-9200 or send an email to RMAREQUEST@tek.com for a Return Material Authorization (RMA) number.
- Carefully pack the instrument in the original packing carton.
- Write ATTENTION REPAIR DEPARTMENT and the RMA number on the shipping label.

Command reference

Introduction

This appendix contains detailed information on the various Model 2450 remote calibration commands, calibration error messages, and methods to detect the end of each calibration step.

See Calibration (on page 2-1) (Section 2 of this manual) for detailed calibration procedures.

Model 2450 calibration commands

Model 2450 calibration commands are those commands that perform such functions as saving calibration constants, locking out calibration, and programming date parameters.

:PASS

`(CALibration:PASSword)`

Purpose	To change the calibration password only. This command will not unlock calibration.
Format	`CAL:PASS '<password>'`
Parameter	Up to an 8-character string, including letters and numbers.
Description	The default remote password is `KI002400`.
Note	To change the code, first send the present code, then send the new code. The password parameter must be enclosed in single quotes.
Example	`CAL:PASS 'KI002400'` Send default code of KI002400.

:COUNT?

(`CALibration:ADJust:COUNt?`)

Purpose	To request the number of times the Model 2450 has been adjusted.
Format	`CAL:ADJ:COUN?`
Response	Number of times adjusted.
Description	The `:COUNT?` query may be used to determine the total number of times the Model 2450 has been adjusted.
Example	`CAL:ADJ:COUNt?` Request calibration count.

:LOCK

(`CALibration:LOCK`)

Purpose	To lock out calibration.
Format	`CAL:LOCK`
Query	`CAL:LOCK?`
Response	`0` Calibration unlocked `1` Calibration locked
Description	The `:LOCK` command lets you lock out comprehensive calibration after completing those procedures. Thus `:LOCK` performs the opposite of sending the password with the `:UNLock` command. The `:LOCK?` query returns calibration lock status.
Note	To unlock calibration, send the `:UNLock` command with the appropriate password.
Example	`CAL:LOCK` Lock out calibration

:SAVE

`(CALibration:SAVE)`

Purpose	To save calibration constants in nonvolatile memory after performing the calibration procedure.
Format	`CAL:SAVE`
Query	`CAL:SAVE?`
Description	The `:SAVE` command stores internally calculated calibration constants derived during the comprehensive calibration procedure into nonvolatile memory, and calibration constants will be retained indefinitely once saved. Generally, `:SAVE` is sent after all other calibration steps (except for `:LOCK`).
Note	Calibration will be only temporary unless the `:SAVE` command is sent to permanently store calibration constants. Calibration data will not be saved if: (1) calibration was not unlocked by sending the `:CODE` command, (2) invalid data exists (for example, cal step failed or was aborted), or (3) an incomplete number of cal steps were performed (for example, omitting a negative full-scale step).
Example	`CAL:SAVE` Save calibration constants

:ADJ:DATE

(CALibration:ADJust:DATE)

Purpose	To set the adjustment date.
Format	CAL:ADJ:DATE <year>, <month>, <day>
Parameter	<year> = 1995 to 2094 <month> = 1 to 12 <day> = 1 to 31
Query	CAL:ADJ:DATE?
Response	<year> , <month> , <day>
Description	The :ADJ:DATE command allows you to store the adjustment date in the instrument nonvolatile memory for future reference. You can read back the date from the instrument by using the :DATE? query or by pressing the **MENU** key on the Model 2450 front panel and then selecting the **Information** icon on the touch screen.
Note	The year, month, and day parameters must be delimited by commas.
Example	CAL:ADJ:DATE 2014,6,13 Send adjust date (06/13/2014).

:VER:DATE

(`CALibration:VERify:DATE`)

Purpose	To set the calibration date (also known as verification or cal without adjust date).
Format	`CAL:VER:DATE <year>, <month>, <day>`
Parameter	`<year>` = 1995 to 2094 `<month>` = 1 to 12 `<day>` = 1 to 31
Query	`CAL:VER:DATE?`
Response	<year>, <month>, <day>
Description	The `:VER:DATE` command allows you to store the calibration date in the instrument nonvolatile memory for future reference. You can read back the date from the instrument by using the `:DATE?` query or by pressing the **MENU** key on the Model 2450 front panel and then selecting the **Information** icon on the touch screen.
Note	The year, month, and day parameters must be delimited by commas.
Example	`CAL:VER:DATE 2014,6,13` Send cal date (06/13/2014).

:ADJ:SENSE

(`CALibration:ADJust:SENSe`)

Purpose	To calibrate the sense function.
Format	`CAL:ADJust:SENSe <dmm reading>`
Parameter	See the "CALibration:ADJust:SENSe parameter ranges" table in Step 1. Prepare the Model 2450 for calibration (on page 2-11).
Description	The `CAL:ADJ:SENS` command calibrates the Model 2450 sense function. To use this command, you must (1) program the source to the correct value, (2) select the range being calibrated, and (3) send the `CAL:ADJ:SENS` command for each parameter listed in the "CALibration:ADJust:SENSe parameter ranges" table in Step 1. Prepare the Model 2450 for calibration (on page 2-11).
Note	When the Model 2450 receives this command, it will attempt to place the parameter into one of the three parameter ranges summarized in the "CALibration:ADJust:SENSe parameter ranges" table in Step 1. Prepare the Model 2450 for calibration (on page 2-11), depending on the active `:SENS:FUNC` and range. If the parameter does not fit into any of the three allowed ranges, an error number -222, "Parameter data out of range" will be generated. Once the unit has successfully selected the appropriate parameter range, it will then check to see if autorange for the active `:SENS:FUNC` is enabled. If so, an error number -221, "Settings conflict" will be generated. If no error occurs, the active sense function/range point will be calibrated using the corresponding parameter.
	Note that parameters for a given sense function and range may be sent in any order. However, once one `CAL:ADJ:SENS` command executes, the other two must also be executed, or an error -200, "Execution error" will occur when the `CAL:SAVE` command is processed at the end of the calibration procedure.
Example	`CAL:ADJ:SENS +2.00003` Calibrate 2 V sense range.

:ADJ:SOURCE

`(CALibration:ADJust:SOURce)`

Purpose	To calibrate the source function.
Format	`CAL:ADJust:SOURce <dmm reading>`
Parameter	See the "CALibration:ADJust:SOURce parameter ranges" table in <u>Step 1. Prepare the Model 2450 for calibration</u> (on page 2-11).
Description	The `CAL:ADJ:SOUR` command calibrates the Model 2450 source function. To use this command, you must (1) program the source to the correct value, (2) select the range being calibrated, and (3) send the `CAL:ADJ:SOUR` command for each parameter listed in the "CALibration:ADJust:SOURce parameter ranges" table in <u>Step 1. Prepare the Model 2450 for calibration</u> (on page 2-11).
Note	When the Model 2450 receives this command, it will attempt to place the parameter into one of the four parameter ranges summarized in the "CALibration:ADJust:SOURce parameter ranges" table in <u>Step 1. Prepare the Model 2450 for calibration</u> (on page 2-11), depending on the active `:SOUR:FUNC` and range. If the parameter does not fit into any of the four allowed ranges, an error number -222, "Parameter data out of range" will be generated. Once the unit has successfully selected the appropriate parameter range, it will then check to see if the active source is programmed to a value within the selected parameter range and that `:OUTP:STAT` is `ON`. If the active source is not programmed to a value within the parameter range (or if the source is in autorange or in standby), an error number -221, "Settings conflict" will be generated. If no error occurs, the active source function/range point will be calibrated using the corresponding parameter.

Note that parameters for a given source function and range may be sent in any order. However, once one `CAL:ADJ:SOUR` command executes, the other three must also be executed, or an error number -200, "Execution error" will occur when the `CAL:SAVE` command is processed at the end of the calibration procedure.

Because the source is calibrated for both positive and negative values, two zero calibration points are required. The Model 2450 automatically uses the appropriate zero parameter based on whether the source polarity is positive or negative. |
| **Example** | `CAL:ADJ:SOUR +2.00003`   Calibrate 2 V source range. |

:DATA?

(CALibration:ADJust:SENSe:DATA?)
(CALibration:ADJust:SOURce:DATA?)

Purpose	To request the calibration constants for the active range.
Format	CAL:ADJ:SENS:DATA? CAL:ADJ:SOUR:DATA?
Parameter	Four comma-separated ASCII floating-point constants.
Description	The CAL:ADJ:SENS:DATA? and CAL:ADJ:SOUR:DATA? queries request the calibration constants for the active range of the sense and source functions, respectively. The four returned constants are in ASCII floating-point format delimited by commas.
Note	To request the appropriate constants, (1) select the source or sense function, (2) choose the desired range, and (3) send the desired :DATA? query.
Example	:SENS:FUNC 'VOLT:DC' Select DC sense function. :SENS:VOLT:DC:RANG 0.2 Choose 200 mV range. CAL:ADJ:SENS:DATA? Request cal constants.

Keithley Instruments, Inc.
Corporate Headquarters • 28775 Aurora Road • Cleveland, Ohio 44139 • 440-248-0400 • Fax: 440-248-6168 • 1-888-KEITHLEY • www.keithley.com

KEITHLEY

A Tektronix Company

A Greater Measure of Confidence

6/13