

Model 4200A-SCS Source-Measure Unit (SMU)

User's Manual

4200A-SMU-900-01 Rev. A December 2020



4200A-SMU-900-01A

Model 4200A-SCS
Source-Measure Unit (SMU)
User's Manual

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The following safety precautions should be observed before using this product and any associated instrumentation. Although some instruments and accessories would normally be used with 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.

Keithley 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. 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.

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 Keithley. 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 Keithley to maintain accuracy and functionality of the product). If you are unsure about the applicability of a replacement component, call a Keithley office for information.

Unless otherwise noted in product-specific literature, Keithley instruments are designed to operate indoors only, 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.

Safety precaution revision as of June 2017.

Table of contents

Introduction	1-1
Introduction	1-1
Source-measure unit (SMU)	1-1
Preamplifier	1-2
Ground unit (GNDU)	1-2
Connections and configuration	2-1
Basic source-measure connections	2-1
SMU connections	2-2
Preamplifier local sense connections	2-11
Using the ground unit	2-12
Basic SMU circuit configuration	2-16
Test fixture and device under test (DUT) connections	2-20
Testing with less than ± 20 V with SMUs	2-20
Testing with more than ± 20 V	2-21
Recommended connecting cables	2-21
Setting up SMUs in Clarius	3-1
Introduction	3-1
Set up a simple project	3-1
Select project components	3-1
Add a device and test to the project	3-2
Configure a simple test	3-3
Set the key parameters	3-5
Set the test parameters	3-6
Run a simple test	3-8
Operation Mode (SMU)	3-9
Open operation mode - SMU	3-10
Voltage Bias operation mode	3-10
Voltage Linear Sweep operation mode - SMU	3-10
Voltage Segment Sweep operation mode	3-11
Voltage List Sweep operation mode	3-12
Voltage Log Sweep operation mode	3-12
Voltage Step operation mode	3-13
Current Bias operation mode	3-13
Current Linear Sweep operation mode - SMU	3-13
Current Segment Sweep operation mode - SMU	3-14
Current List Sweep operation mode - SMU	3-14
Current Log Sweep operation mode - SMU	3-15
Current Step operation mode	3-16
Common operation mode - SMU	3-16
SMU - all terminal parameters	3-16
Base Current	3-16
Base Voltage	3-16
Bias	3-16
Column Name (Measure Current)	3-17
Column Name (Measure Voltage)	3-17

Compliance	3-17
Dual Sweep	3-18
Force Range (Source Range)	3-19
List Values.....	3-19
Low Range	3-19
Measure Current	3-19
Off Time	3-19
On Time	3-20
Overvoltage protection	3-20
Points (list or segment sweep)	3-20
Points (log sweep).....	3-20
Points	3-21
Power On Delay	3-21
Pulse Mode	3-21
Range (Measure Current)	3-23
Report Status (SMU).....	3-24
Report Value (Measure Current or Report Current)	3-24
Report Value (Report Voltage or Measure Voltage).....	3-24
Segments	3-24
Start (step)	3-25
Start (sweep).....	3-25
Step (step).....	3-25
Step (voltage sweep)	3-26
Step (voltage sweep)	3-26
Stop (step).....	3-27
Stop (sweep).....	3-27
Voltage (Report Voltage).....	3-27
Voltage Range	3-27
SMU Test Settings	3-27
Speed.....	3-27
Report Timestamps.....	3-28
Delay Factor.....	3-29
Filter Factor	3-30
Auto A/D Aperture	3-31
A/D Aperture Time	3-31
Test Mode	3-31
Sweep Delay	3-32
Interval	3-32
Number of Samples	3-32
Hold Time - SMU.....	3-32
SMU Power On Sequence	3-32
Disable outputs at completion - SMU	3-33
Output Values	3-33
Compliance exit-condition options.....	3-34
Source-measure hardware	4-1
Source-measure units	4-1
Source-measure hardware overview	4-1
Basic SMU circuit configuration	4-2
SMU terminals and connectors	4-3
SENSE LO terminal	4-4
SENSE terminal	4-5
FORCE terminal.....	4-5
PA CNTRL connector.....	4-5
Source-measure unit (SMU) with 4200-PA overview	4-5
Basic SMU/preamplifier circuit configuration	4-6

Compliance limit for a SMU with a 4200-PA..... 4-6
 Using minimum compliance 4-7
 Operating boundaries..... 4-7
 Preamplifier terminals and connectors 4-8
 FORCE terminal..... 4-10
 SENSE terminal 4-11
 Preamplifier CONTROL connector 4-11
 SMU circuit COMMON connections 4-11

Ground unit (GNDU) overview 4-12
 Basic characteristics 4-12
 Ground unit connections 4-13
 Ground unit DUT connections 4-14
 Ground unit terminals and connectors 4-15
 FORCE terminal..... 4-15
 SENSE terminal 4-16
 COMMON terminal..... 4-16

Source-measure concepts 5-1

Source-measure concepts 5-1

Guarding 5-1
 Guard connections 5-2
 Guarding concepts 5-3
 Test fixture guarding 5-4

Local and remote sensing 5-5
 Local sensing 5-7
 Remote sensing 5-8

Source or sink 5-8
 4200-SMU and 4201-SMU source or sink..... 5-9
 4210-SMU or 4211-SMU source or sink 5-10
 4200-SMU and 4201-SMU sink boundaries 5-11
 4210-SMU and 4211-SMU sink boundaries 5-12

Source-measure considerations 5-12
 Source I, measure V or I 5-12
 Source V, measure I or V 5-13
 Measure only (V or I)..... 5-14
 I-Source operating boundaries 5-15
 I-Source operation examples 5-16
 V-Source operating boundaries..... 5-17
 V-Source operation examples 5-18
 Source I measure I and source V measure V 5-19

Sweep concepts 5-19
 Source-delay-measure cycle..... 5-20
 Sweep waveforms 5-20

Operation mode timing 5-22
 Sampling mode timing..... 5-23

Optimizing SMU measurements..... 6-1

Introduction 6-1

Making stable measurements with SMUs 6-1
 Single SMU stability considerations 6-1
 Multiple SMU stability considerations 6-2

Eliminating oscillations	6-3
Low-current measurements	6-4
Leakage currents	6-5
Generated currents	6-5
Voltage burden.....	6-8
Noise and source impedance.....	6-9
Cable capacitance.....	6-10
Test system performance.....	6-10
Interference	6-11
Electrostatic interference.....	6-11
Radio-frequency interference.....	6-11
Ground loops and other SMU grounding considerations.....	6-12
Make I-V measurements on a solar cell.....	7-1
Introduction	7-1
Equipment required.....	7-1
Device connections	7-2
Device connection schematic.....	7-2
Connect the 4200A-SCS to the DUT.....	7-3
Setting up measurements in the Clarius software	7-4
Create a new project.....	7-4
Search for and select a test.....	7-5
Configure the test.....	7-6
Run the test.....	7-8
Analyze the test results	7-9
Additional tests.....	7-10

In this section:

Introduction	1-1
Source-measure unit (SMU).....	1-1
Preamplifier	1-2
Ground unit (GNDU)	1-2

Introduction

This document provides information about the 4200-SMU, 4201-SMU, 4210-SMU, and 4211-SMU source-measure units and related instruments, including:

- [Connections and configuration](#) (on page 2-1): Basic information on connecting source-measure units (SMUs), the preamplifier, and the ground unit to devices under test (DUTs), making test equipment connections, and making control and data connections.
- [Setting up SMUs in Clarius](#) (on page 3-1): Describes the SMU operation modes, the options available for each mode, and the SMU test settings.
- [Source-measure hardware](#) (on page 4-1): Provides information about the SMUs and related instruments, including 4200-PAs and ground units, and provides information
- [Source-measure concepts](#) (on page 5-1): Provides information on guarding, remote sensing, sink operation, and sweep concepts.
- [Optimizing SMU measurements](#) (on page 6-1): Includes information on improving measurement stability, making low-current measurements, and reducing interference.

Source-measure unit (SMU)

The fundamental instrument module used by the 4200A-SCS is the source-measure unit (SMU). The basic function of a SMU is to perform one of the following source-measure operations:

- Source voltage and measure current or voltage
- Source current and measure voltage or current

The source of the SMU can be configured to sweep or step voltages or currents, or to output a constant bias voltage or current.

There are medium-power and high-power source-measure units available. The 2 W medium-power SMUs are models 4200-SMU and 4201-SMU. The 20 W high-power SMUs are models 4210-SMU and 4211-SMU. The following table lists the maximum limits of the SMUs.

Source-measure units

Model	Maximum voltage	Maximum current	Maximum power
4200-SMU 4201-SMU	210 V	105 mA	2.2 W
4210-SMU 4211-SMU	210 V	1.05 A	22 W

Preamplifier

A 4200-PA preamplifier adds five low-current source-measure ranges to a SMU. Without a preamplifier, the 100 nA range (100 fA resolution) is the lowest current source-measure range for a SMU. With a preamplifier installed, the 10 nA, 1 nA, 100 pA, 10 pA, and 1 pA source-measure ranges are added.

If preamplifiers are ordered, the 4200A-SCS is shipped from the factory with the preamplifiers installed on the rear panel of the mainframe.

Ground unit (GNDU)

The ground unit on the rear panel of the 4200A-SCS provides a convenient method of making ground connections. This eliminates the need to use a SMU for this purpose.

Connections and configuration

In this section:

Basic source-measure connections	2-1
Test fixture and device under test (DUT) connections	2-20

Basic source-measure connections

This section describes basic information on connecting source-measure units (SMUs), the preamplifier, and the ground unit to devices under test (DUTs).

WARNING

The 4200A-SCS is provided with an interlock circuit that must be positively activated for the high voltage output to be enabled. The interlock helps facilitate safe operation of the equipment in a test system. Bypassing the interlock could expose the operator to hazardous voltages that could result in personal injury or death.

WARNING

Asserting the interlock allows the SMU and preamplifier terminals to become hazardous, exposing the user to possible electrical shock that could result in personal injury or death. SMU and preamplifier terminals should be considered hazardous even if the outputs are programmed to be low voltage. Precautions must be taken to prevent a shock hazard by surrounding the test device and any unprotected leads (wiring) with double insulation that is rated for 250 V, Category O.

CAUTION

The maximum allowed voltage between circuit COMMON and chassis ground is ± 32 V dc. The maximum allowed voltages between the preamplifier signals are:

COMMON to chassis ground: 32 V_{PEAK}

GUARD to COMMON: 250 V_{PEAK}

SENSE or FORCE to GUARD: 40 V_{PEAK}

SMU connections

The following topics explain how to connect the source-measure units (SMUs) to the device under test (DUT).

The SMU can be connected directly to the device under test (DUT) with triaxial cables using either local or remote sensing, as described in the following topics. Remote sensing is typically used when currents exceed 1 mA and the FORCE path resistance is large (around 1 Ω). In this case, as much as 1 mV (= 1 mA \times 1 Ω) of measurement error is generated due to FORCE path resistance. Remote sensing eliminates these errors.

NOTE

When using more than one SMU, use the ground unit for circuit COMMON connections instead of the outer shield of the SMU terminals. Refer to [Using the ground unit](#) (on page 2-12).

WARNING

Do not touch test cables or connectors when powering up the 4200A-SCS. Hazardous voltage may be output momentarily, posing a safety hazard that could result in personal injury or death.

Do not turn on the 4200A-SCS until you have reviewed the safe power-up procedure in “Powering the 4200A-SCS” in *Model 4200A-SCS Setup and Maintenance*.

CAUTION

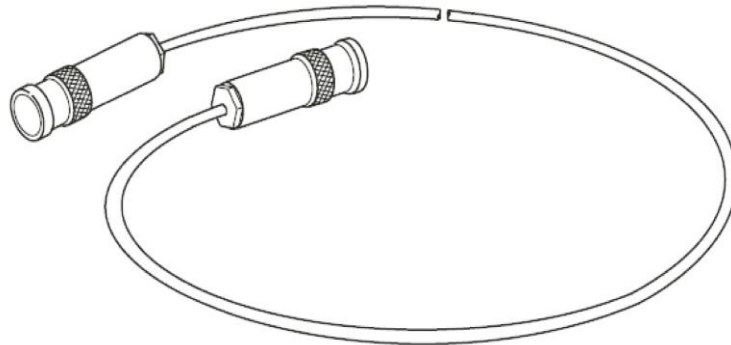
Do not connect the DUT to the 4200A-SCS before powering it up, because the hazardous voltage that may be output momentarily at power-up could damage the DUT.

If your 4200A-SCS includes preamplifiers, all tests should be performed using the preamplifiers, as the installed SMUs were optimized at the factory to use them.

Triaxial cables

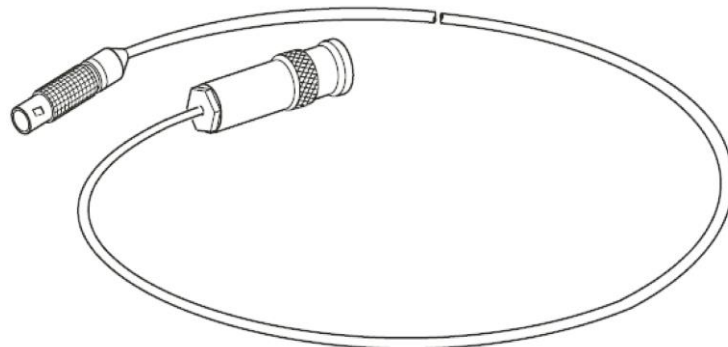
Triaxial cables are supplied to make connections to the DUT (device under test). With preamplifiers installed, use the low-noise triaxial cables, which are terminated with 3-slot triaxial connectors on both ends. One end of the cable connects to the preamplifier and the other end connects to the DUT test fixture or probe station.

Figure 1: Triaxial cable 4200-TRX-X



If your system does not have preamplifiers installed, use the cables that have a miniature triaxial connector on one end and a standard 3-slot triaxial connector on the other end. The cable end that is terminated with the miniature connector connects directly to the SMU, and the other end connects to the test fixture or probe station.

Figure 2: Triaxial cable 4200-MTRX-X



CAUTION

With preamplifiers installed, never make connections directly to any of the miniature triaxial connectors on the SMU modules. This may result in damage to the SMU or DUT or may produce corrupt data.

SMU local sense connections

The simplest method to connect SMUs to the device under test (DUT) is to use one SMU for each terminal of the device. When setting up a test, the FORCE terminal (center conductor) of the SMU is used to apply voltage or current to the device. The FORCE terminal or ground unit can also be used to connect the device terminal to the COMMON circuit.

The following figure shows typical SMU connections using local sensing. Use a triaxial cable such as the 4200-MTRX-X to make your connections as follows:

- Connect SMU FORCE (center conductor of FORCE terminal) to DUT HI.
- Connect circuit COMMON (outer shield of FORCE terminal) to DUT LO.

Figure 3: SMU local sense connections

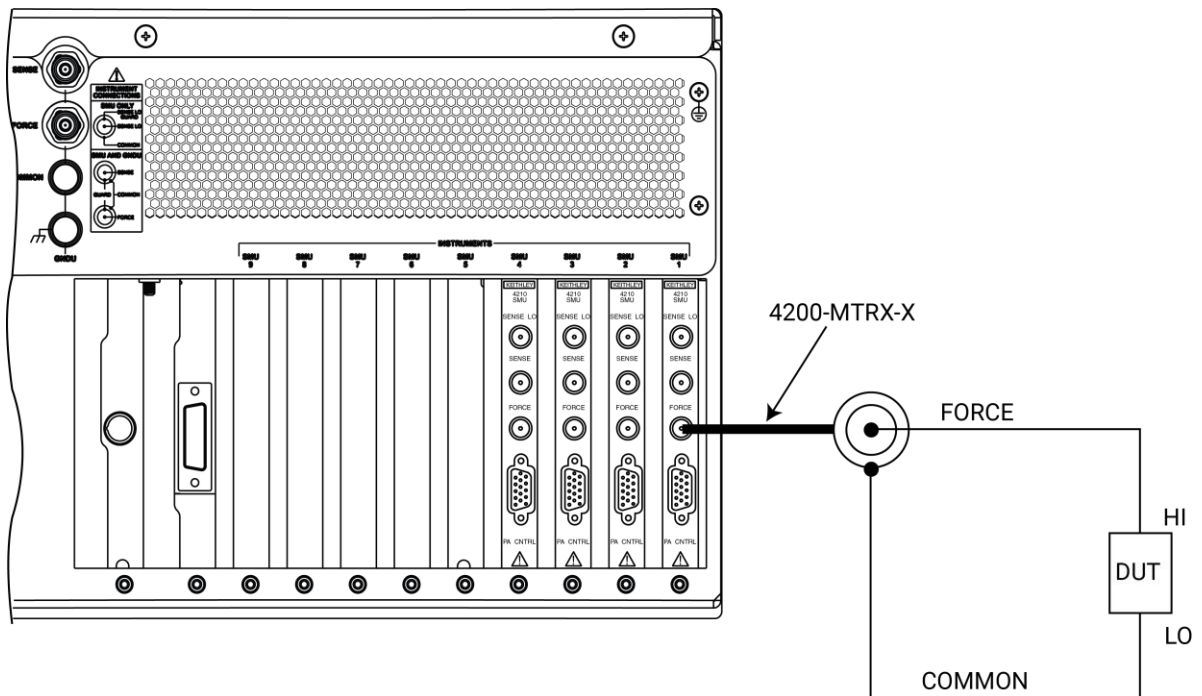
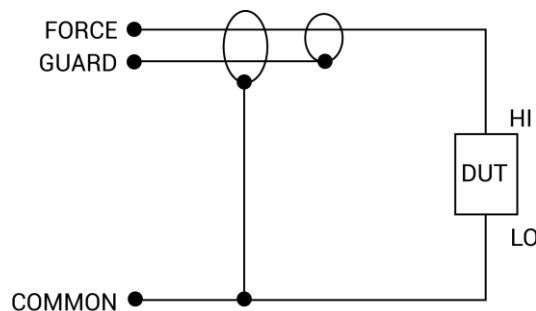


Figure 4: SMU local sense connections - equivalent circuit



Basic device connections for SMUs

The following figures show the basic connections to 2-terminal, 3-terminal, and 4-terminal devices. Notice that only the FORCE HI terminal of each SMU is connected to the device terminal. FORCE HI is the center conductor of the triaxial cable.

CAUTION

Connecting the SMU or ground unit SENSE terminal without the FORCE terminal may damage the instrument and return erroneous results.

Figure 5: Two-terminal device connections to SMUs and preamplifiers

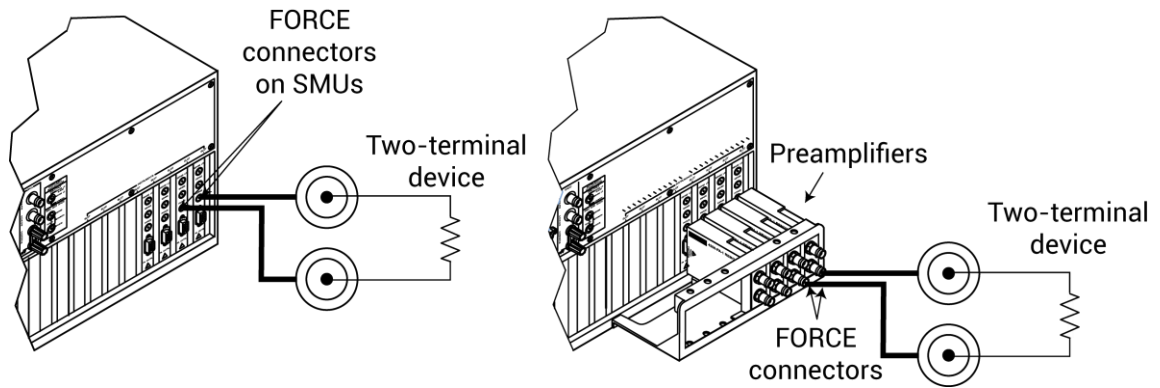


Figure 6: Three-terminal device connections to SMUs and preamplifiers

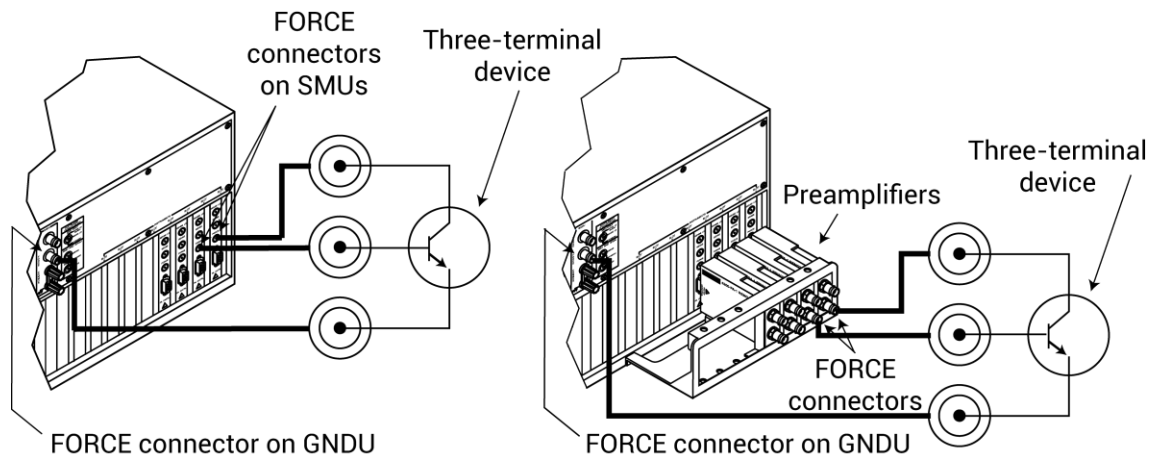
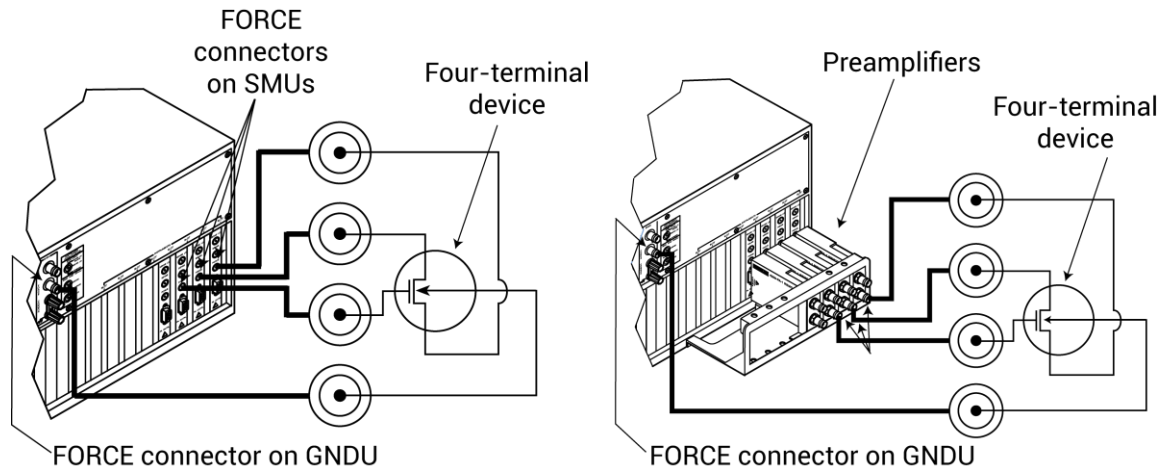


Figure 7: Four-terminal device connections to SMUs and preamplifiers

Shielding and guarding

Many test situations require that the device under test (DUT) be shielded or guarded (or both) to avoid detrimental effects caused by electrostatic interference, parasitic capacitance, system leakage currents, and so forth.

See [Guarding](#) (on page 5-1) for more information on the principles and advantages of guarding.

⚠ WARNING

A safety shield must be used whenever hazardous voltages (>30 V_{RMS}, 42 V_{PEAK}) will be present in the test circuit. To prevent electrical shock that could cause injury or death, never use the 4200A-SCS in a test circuit without a properly installed and configured safety shield.

To shield, but not guard, the device, connect the DUT shield to COMMON as shown in the following figure.

Figure 8: Device shielding

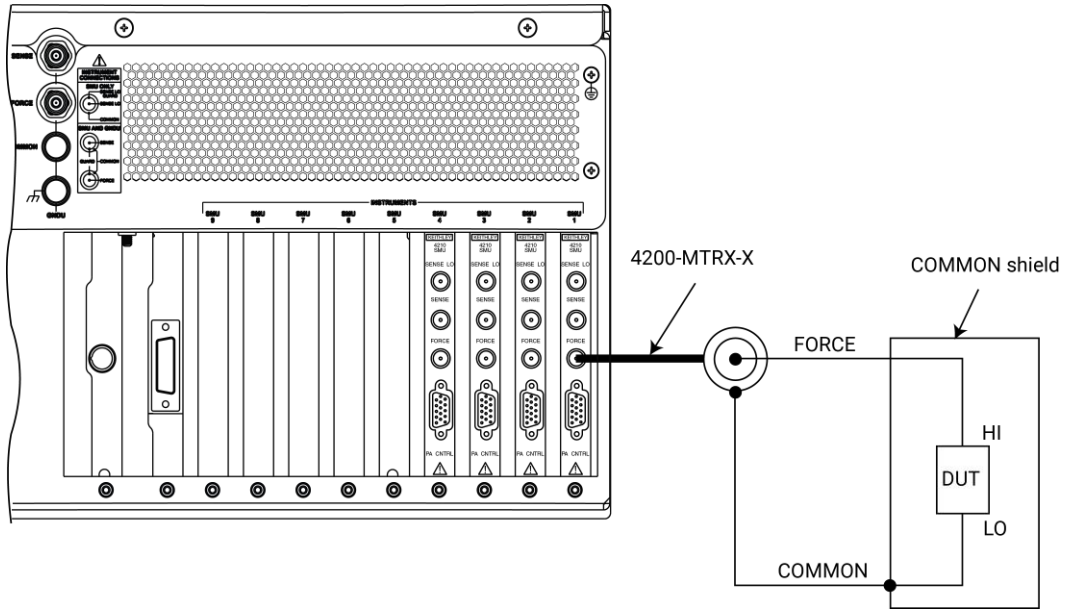
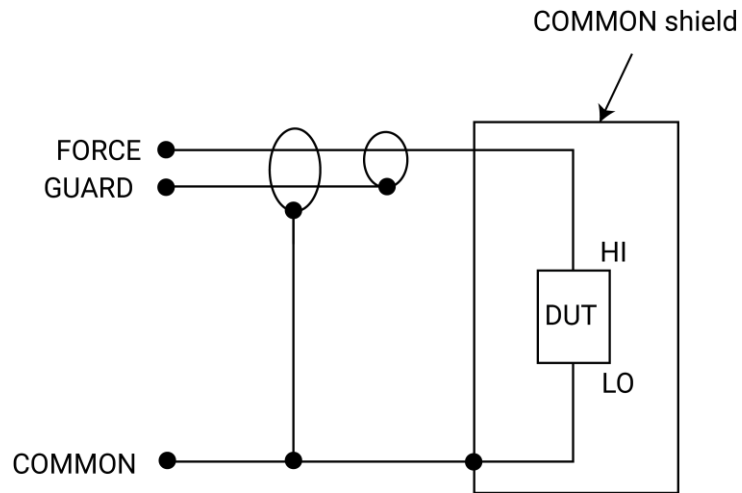


Figure 9: Device shielding basic circuit



To guard the device, connect the DUT shield to GUARD. GUARD is the inner shield of triaxial cable, as shown in the following figure.

Figure 10: Device guarding

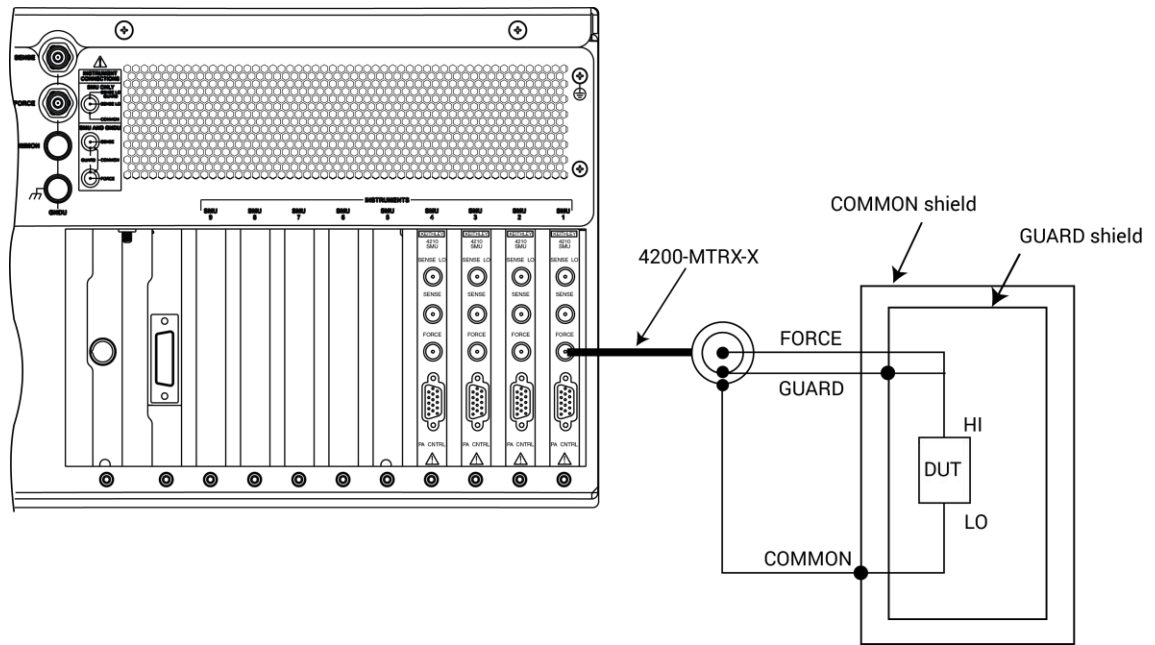
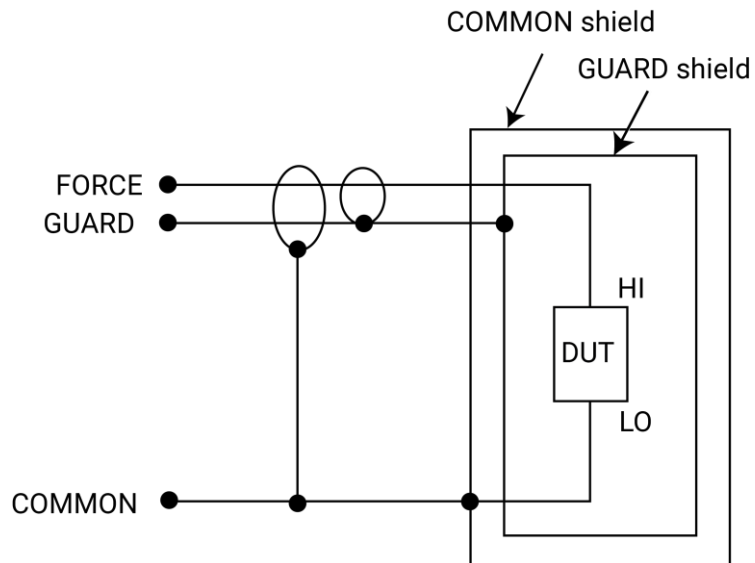


Figure 11: Device guarding basic circuit



Signal integrity

To maintain signal integrity, especially at low current levels, consider the following when making signal connections between the 4200A-SCS instrumentation and the device under test (DUT):

- Use only low-noise triaxial cables such as those provided with the SMU (4200-MTRX-X) and preamplifier (4200-TRX-X).
- Keep connecting cables as short as possible.
- Avoid flexing or vibrating connecting cables while making measurements.
- Do not touch connector insulators. Be sure to keep all connector insulators clean to minimize contamination-induced leakage currents.
- Avoid stresses in cables. Do not allow large portions to hang under their own weight. Place on a table or flat surface if possible. Avoid tight bends in the cables.

Refer to the “Maintenance” section of *Model 4200A-SCS Setup and Maintenance* or the *Keithley Instruments Low Level Measurements Handbook* for more information about measurement integrity.

Using the ground unit with more than two SMUs

Use the ground unit for circuit COMMON connections when using more than two SMUs. Make your connections using the same basic connections shown in the previous figures for the ground units. Be sure to connect all your DUT LO terminals to the GNDU FORCE terminal. If you are using remote sensing, also connect the DUT LO terminals to the SENSE terminal.

SMU circuit COMMON connections

Some tests require SMUs to be connected to each DUT terminal. In these tests, circuit COMMON is not hardwired to any of the DUT terminals. Each SMU must be able to internally connect circuit COMMON to its FORCE signal when the test requires a DUT terminal to be connected to COMMON.

The following figure shows typical SMU connections using three SMUs to test a transistor. You can use any one of the SMUs to provide access to circuit COMMON by programming the SMU accordingly. See the *Model 4200A-SCS Clarius User's Manual* for detailed instructions on configuring a SMU to provide a COMMON connection.

Figure 12: Typical SMU connections

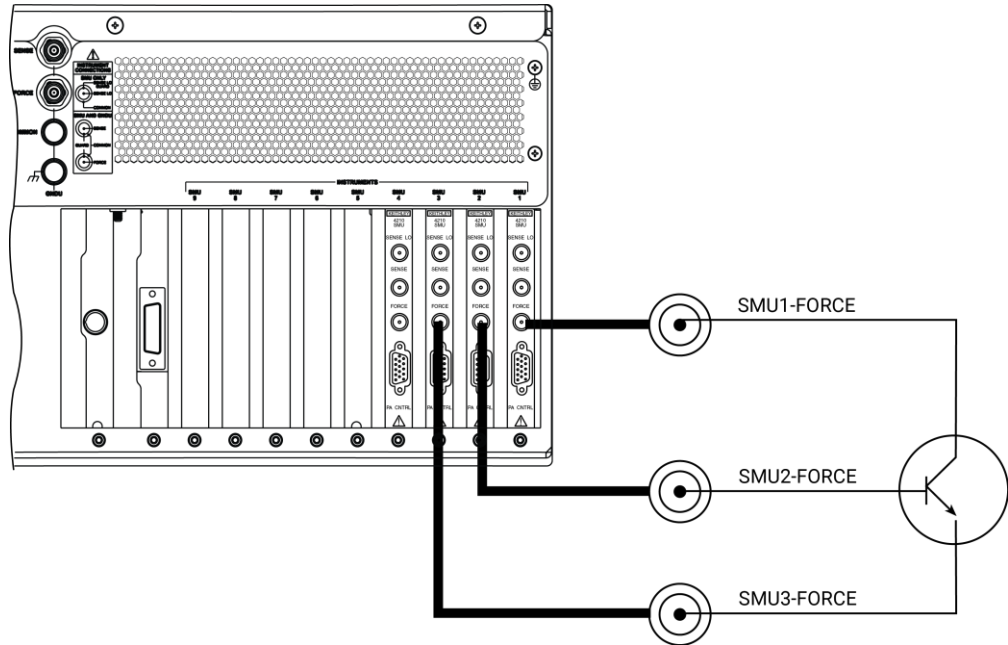
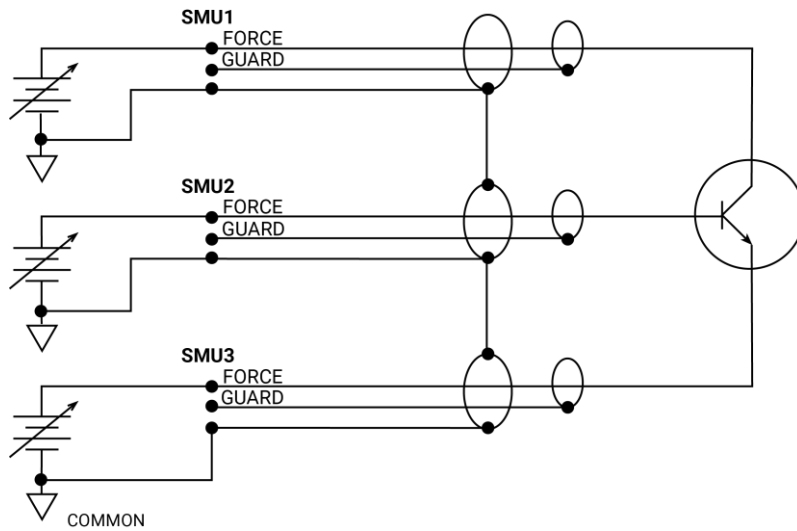


Figure 13: Typical SMU COMMON connections schematic



Preamplifier local sense connections

The following figures show typical preamplifier connections using local sensing. Use a triaxial cable to make your connections as follows:

- Connect preamplifier FORCE (center conductor of FORCE terminal) to DUT HI.
- Connect signal COMMON (outer shield of FORCE terminal) to DUT LO.

NOTE

When using more than one preamplifier, use the ground unit for circuit COMMON connections instead of the outer shield of the preamplifier terminals (see [Using the ground unit](#) (on page 2-12)).

Figure 14: Preamplifier local sense connections

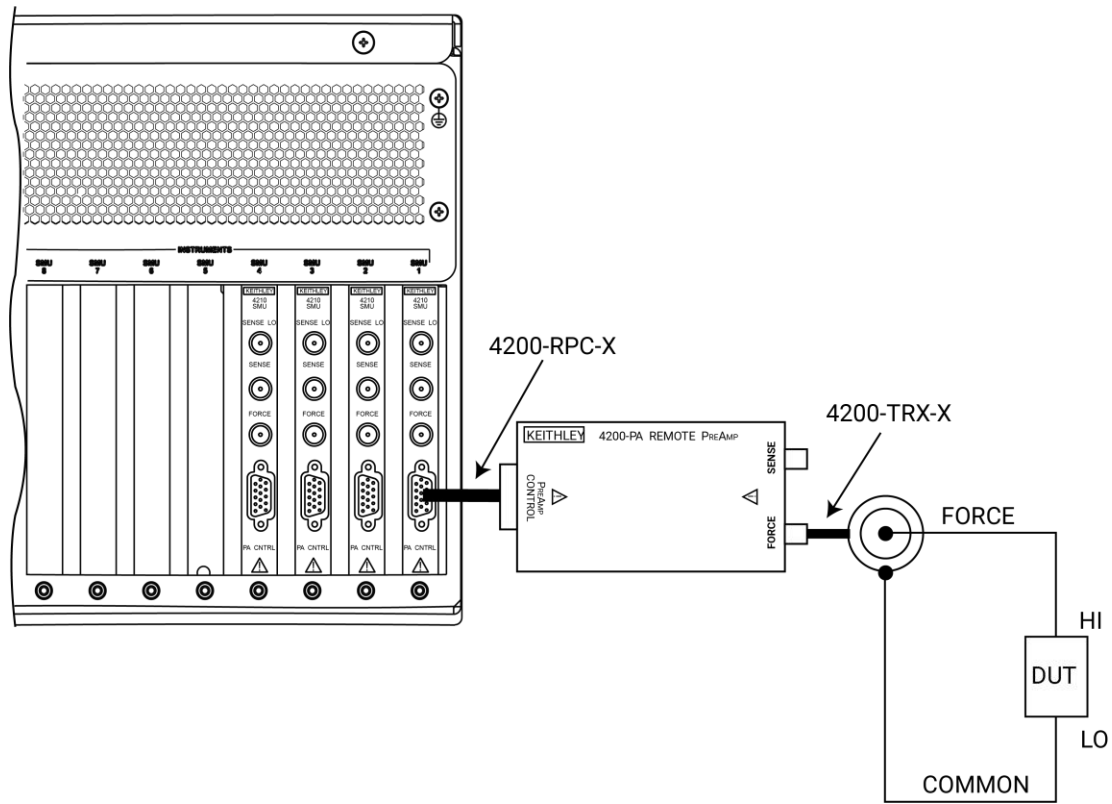
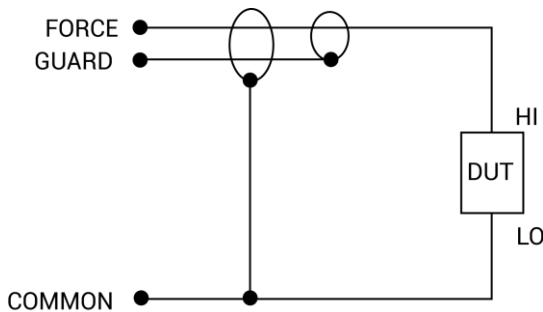


Figure 15: Basic preamplifier local sense connections



Using the ground unit

The ground unit (GNDU) provides convenient access to circuit COMMON through the GNDU FORCE terminal or the GNDU COMMON binding post terminal. The GNDU also has a SENSE terminal. The SENSE LO signal of each instrument installed in the 4200A-SCS is connected to the GNDU SENSE terminal. As a result, all SMU measurements are made relative to GNDU SENSE, which by default is connected to COMMON.

NOTE

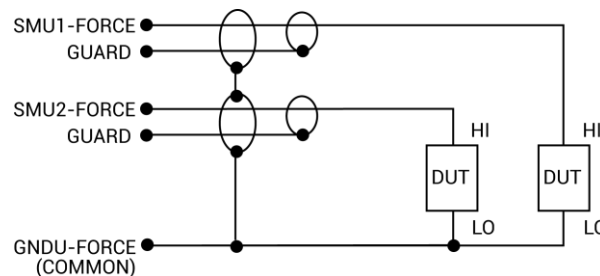
Although the ground unit is intended for circuit COMMON connections when using multiple SMUs, it can also be used for circuit COMMON connections when using only one SMU.

Ground unit and SMU local sense connections

The following figure shows typical local sense connections using two SMUs, two DUTs, and the ground unit. Make connections as follows:

- Connect the two SMU FORCE terminals to the two DUT HI terminals.
- Connect both DUT LO terminals together and connect GNDU FORCE to the common DUT LO connection point.

Figure 16: Ground unit and SMU local sense connections schematic

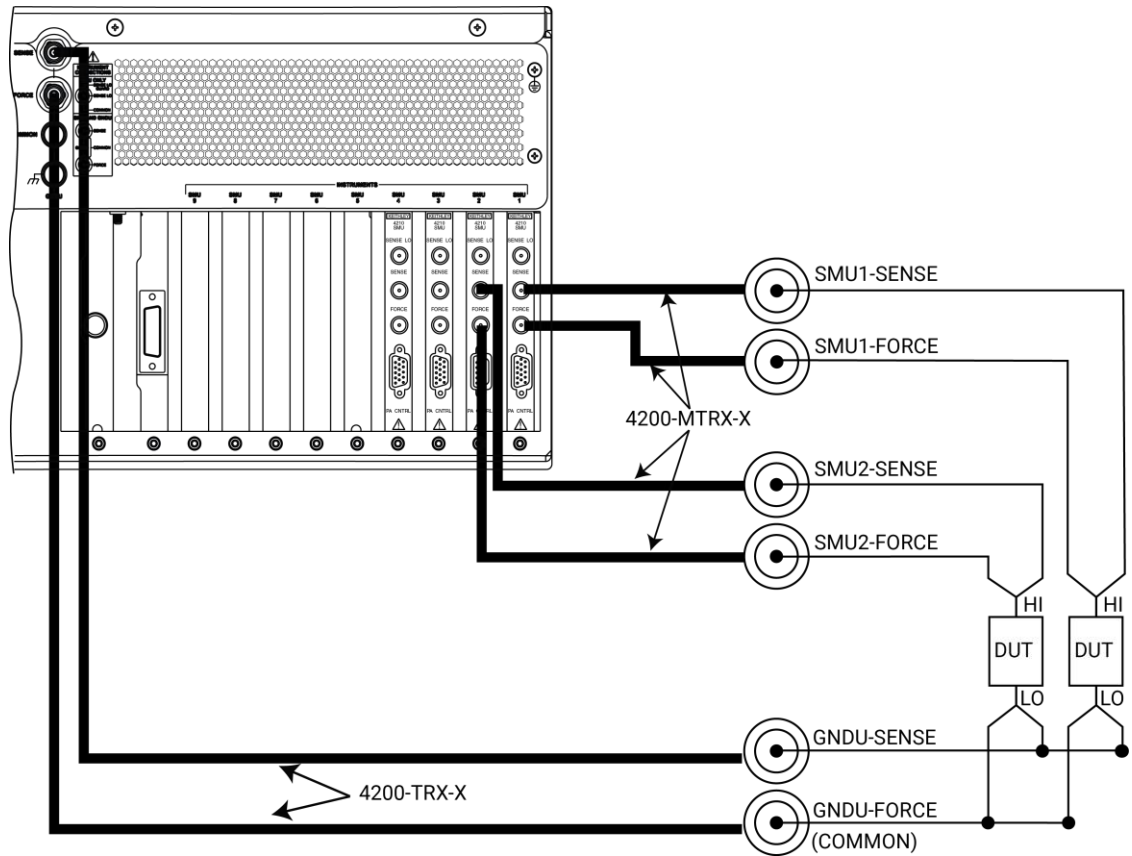


Ground unit and SMU remote sense connections

The following figure shows typical remote sense connections using two SMUs, two DUTs, and the ground unit. Make connections as follows:

- Connect the SMU FORCE and SENSE signals to the two DUT HI terminals.
- Connect both DUT LO terminals together, and connect GNDU SENSE and FORCE to the common DUT LO connection point.

Figure 17: Ground unit and SMU remote sense connections



Ground unit and preamplifier local sense connections

The following figure shows typical local sense connections using two preamplifiers, two DUTs, and the ground unit. Make connections as follows:

- Connect the two preamplifier FORCE signals to the two DUT HI terminals.
- Connect both DUT LO terminals together, and connect the GNDU FORCE signal to the common DUT LO connection point.

Figure 18: Ground unit and preamplifier local sense connections

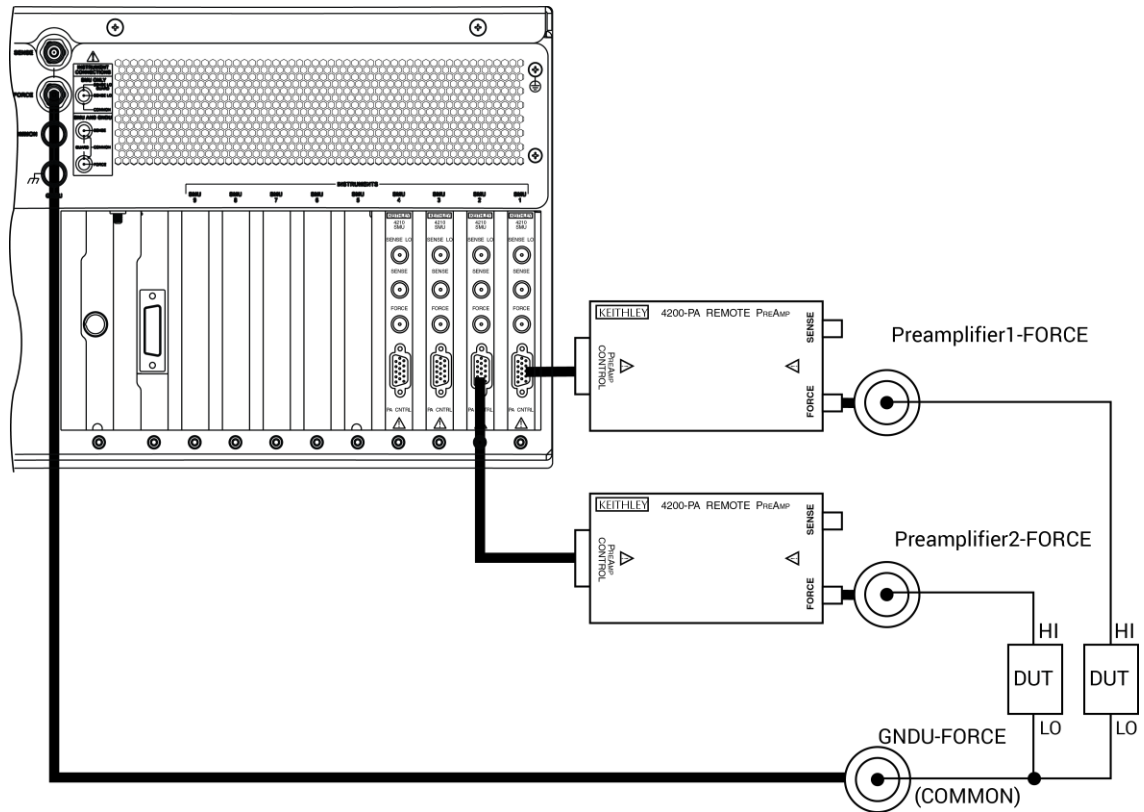
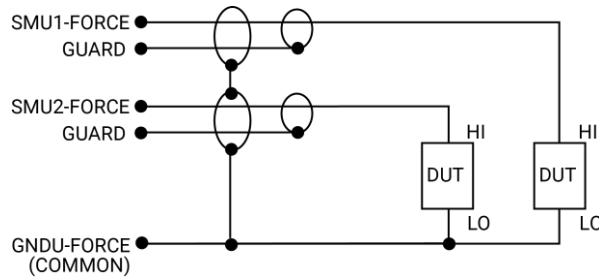


Figure 19: Ground unit and preamplifier local sense connections schematic



Ground unit and preamplifier remote sense connections

The following figure shows typical remote sense connections using two preamplifiers, two DUTs, and the ground unit. Make connections as follows:

- Connect the preamplifier FORCE and SENSE signals to the two DUT HI terminals.
- Connect both DUT LO terminals together, and connect the GNDU SENSE and FORCE signals to the common DUT LO connection point.

Figure 20: Ground unit and preamplifier remote sense connections

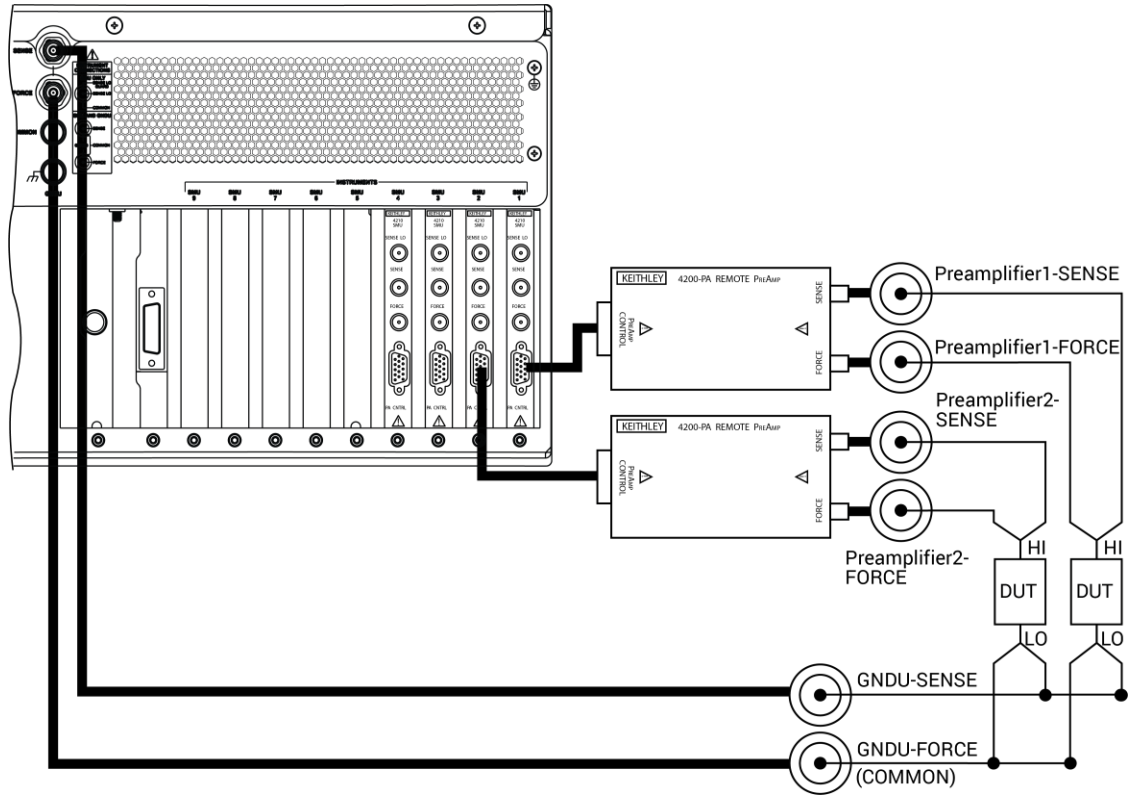
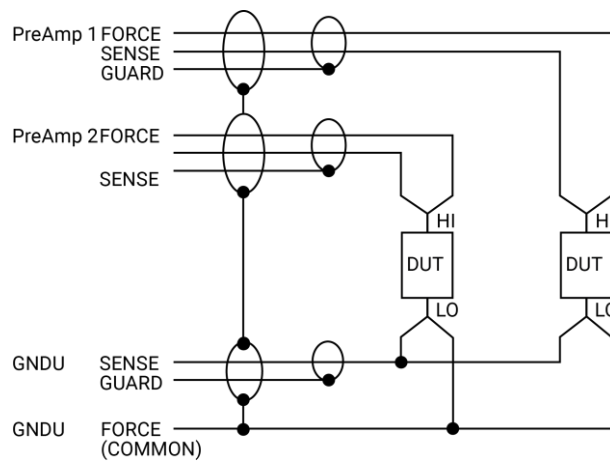


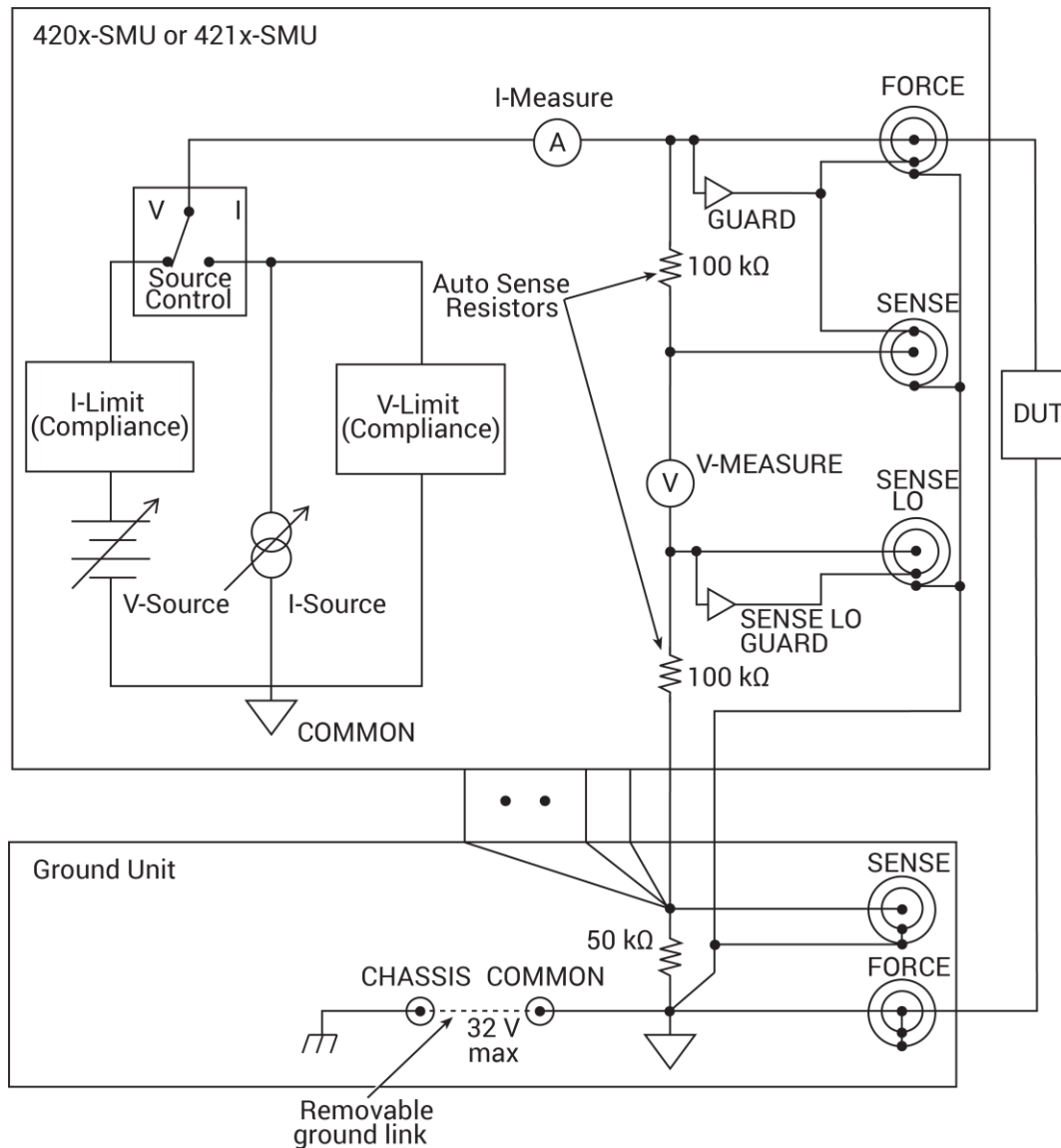
Figure 21: Ground unit and preamplifier remote sense connections schematic



Basic SMU circuit configuration

The basic SMU circuit configuration is shown in the following figure. The SMU is essentially a voltage or current source in series with a current meter, connected in parallel with a voltage meter. The voltage limit (V-limit) and current limit (I-limit) circuits limit the voltage or current to the programmed compliance value. In this example of local sensing, the SMU FORCE terminal is connected to DUT HI, while DUT LO is connected to COMMON. See [Basic source-measure connections](#) (on page 2-1) for more detailed information.

Figure 22: Basic SMU source-measure configuration



SMU terminals and connectors

The locations and configuration of the SMU terminals are shown in the following figure. Basic information about these terminals is summarized below.

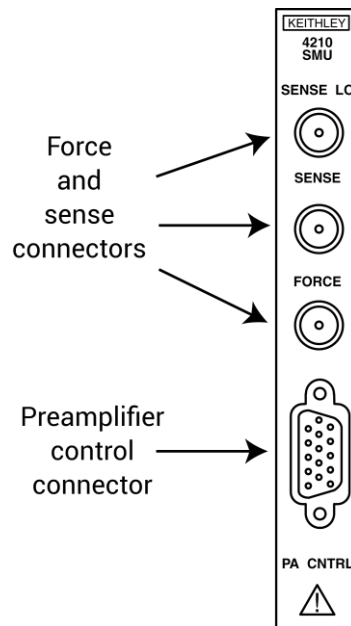
⚠ WARNING

Asserting the interlock allows the SMU and preamplifier terminals to become hazardous, exposing the user to possible electrical shock that could result in personal injury or death. SMU and preamplifier terminals should be considered hazardous even if the outputs are programmed to be low voltage. Precautions must be taken to prevent a shock hazard by surrounding the test device and any unprotected leads (wiring) with double insulation that is rated for 250 V, Category O.

CAUTION

The maximum allowed voltage between COMMON and chassis ground is ± 32 V dc.

Figure 23: 4200-SMU and 4210-SMU connectors



SENSE LO terminal

The SENSE LO terminal is a miniature triaxial connector used to apply the SMU SENSE LO signal to the DUT in a full-Kelvin (remote sense) application.

- The center pin is SENSE LO
- The inner shield is SENSE GUARD
- The outer shield is circuit COMMON

Nominal internal autosense resistance appears between SENSE LO GUARD and COMMON.

NOTE

Use the remote sense capability of the ground unit instead of the SENSE LO of a SMU. If it is necessary to use the SENSE LO terminal of a SMU, connect the SENSE LO terminals of all SMUs used in a single 4200A-SCS to the DUT.

SENSE terminal

The SENSE terminal is a miniature triaxial connector used to apply the SMU SENSE signal to the DUT in a remote-sense application when the preamplifier is not used.

- The center pin is SENSE
- The inner shield is GUARD
- The outer shield is circuit COMMON

Nominal internal autosense resistance appears between SENSE and FORCE.

NOTE

The SENSE terminal does not need to be connected to the DUT for the SMU to operate correctly. Remote sensing is automatic. If SENSE is connected to the DUT, errors due to voltage drops in the FORCE path between the SMU and the DUT are eliminated and the SMU senses locally.

FORCE terminal

The FORCE terminal is a miniature triaxial connector used to apply the SMU FORCE signal to the DUT when a preamplifier is not used.

- The center pin is FORCE
- The inner shield is GUARD
- The outer shield is circuit COMMON

PA CNTRL connector

The PA CNTRL (preamplifier control) terminal is a 15-pin D-sub connector that provides both power and signal connections to the 4200-PA Remote Preamplifier. The preamplifier can either be mounted and connected directly to the SMU, or it can be connected to the SMU using a cable (4200-RPC-X) when mounted remotely. Refer to the [Source-measure unit \(SMU\) with 4200-PA overview](#) (on page 4-5) for more information on the preamplifier.

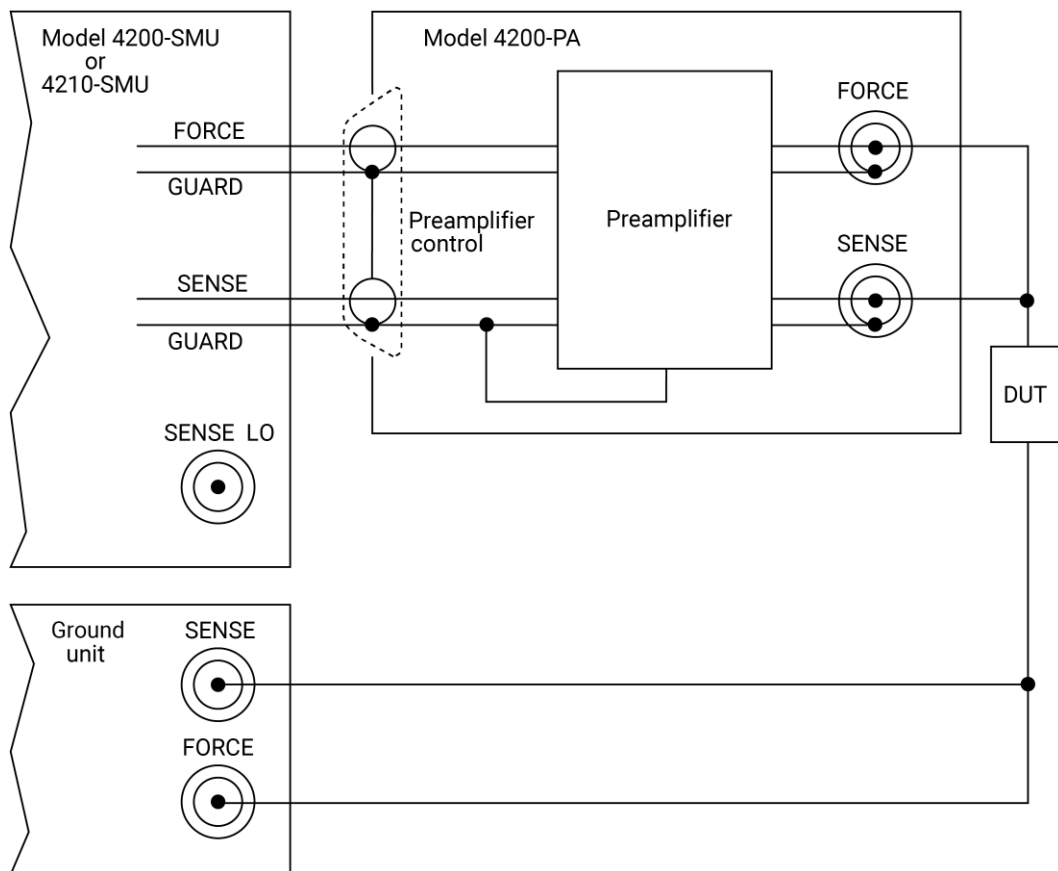
Basic SMU and preamplifier circuit configuration

A basic SMU and preamplifier circuit configuration is shown in the following figure.

NOTE

The preamplifier FORCE terminal is connected to DUT HI. DUT LO is connected to GROUND.

Figure 24: Basic SMU and preamplifier source-measure configuration



Test fixture and device under test (DUT) connections

The recommended Keithley Instruments test fixture to use with the 4200A-SCS is the Model 8101-PIV Test Fixture.

Test fixtures for the 4200A-SCS can be:

- Low-voltage fixtures (less than ± 20 V).
- High-voltage fixtures (greater than ± 20 V), which require extra precautions to ensure there are no dangerous shock hazards.

⚠ WARNING

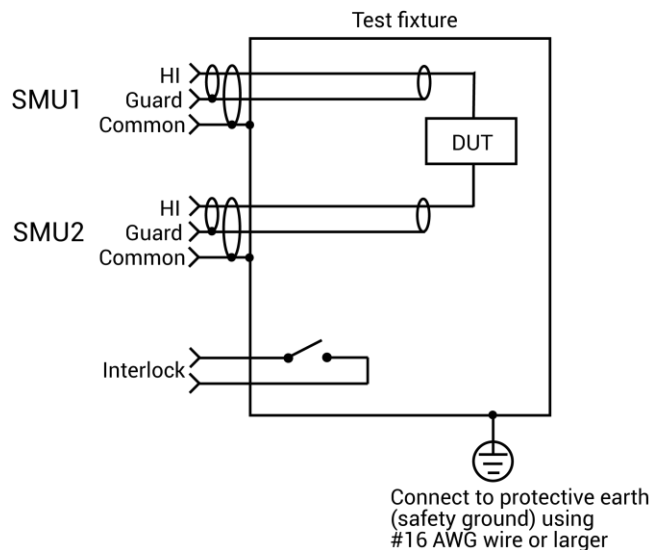
To avoid high voltage exposure that could result in personal injury or death, whenever the interlock of the 4200A-SCS is asserted, the FORCE and GUARD terminals of the SMUs and preamplifier should be considered to be at high voltage, even if they are programmed to a nonhazardous voltage current.

Testing with less than ± 20 V with SMUs

For testing discrete devices, you need a test fixture equipped with three-lug triaxial connectors. This allows the 4200A-SCS to be connected to the discrete device.

The following figure shows a basic test fixture to test a two-terminal device.

Figure 25: Typical test fixture



For best performance when testing with less than ± 20 V, follow these standard industry practices:

- Use a metal test fixture
- Connect the metal fixture to COMMON
- Mount the DUT on high-resistivity terminals (for example, Teflon™)
- Use guarding to reduce leakage and parasitic capacitance that degrades measurement quality

The Keithley Instruments *Low Level Measurements Handbook* provides an in-depth discussion on guarding and other techniques that are useful for building quality test fixtures. See the Learning Center on your 4200A-SCS for a copy of the *Handbook*.

NOTE

The 4200A-SCS functions on all current ranges and up to ± 20 V without the interlock being asserted.

Testing with more than ± 20 V

WARNING

Asserting the interlock allows the SMU and preamplifier terminals to become hazardous, exposing the user to possible electrical shock that could result in personal injury or death. SMU and preamplifier terminals should be considered hazardous even if the outputs are programmed to be low voltage. Precautions must be taken to prevent a shock hazard by surrounding the test device and any unprotected leads (wiring) with double insulation that is rated for 250 V, Category O.

If voltages greater than ± 20 V are required for testing, follow these practices:

- Add an interlock switch to the fixture to ensure that hazardous voltages are not present when the exterior enclosure of the test fixture is open.

NOTE

The 4200A-SCS voltage output is higher when the exterior enclosure of the test fixture is closed.

- Connect the exterior enclosure to COMMON or safety ground using #16 AWG wire or greater.
- Ensure that the wiring (FORCE, GUARD, and SENSE) within the fixture does not electrically contact the exterior enclosure.

Recommended connecting cables

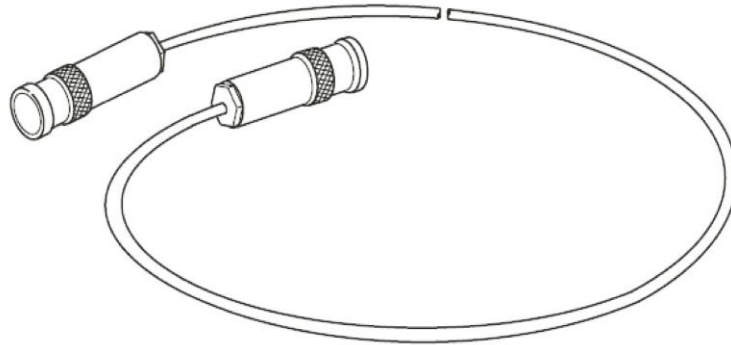
To ensure accurate, reliable connections, use only quality, low-noise triaxial cables such as those supplied with the SMU (4200-MTRX-X) and preamplifier (4200-TRX-X) for all source-measure signal connections.

NOTE

For optimum measurement accuracy, noise immunity, and settling time, keep cables as short as possible.

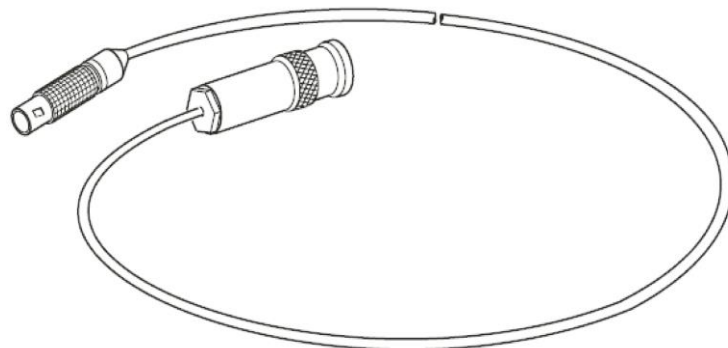
Triaxial cables are supplied to make connections to the device under test (DUT). With preamplifiers installed, use the low-noise triaxial cables, which are terminated with three-slot triaxial connectors on both ends. One end of the cable connects to the preamplifier and the other end connects to the DUT test fixture or probe station.

Figure 26: Triaxial cable 4200-TRX-X



If your system does not have preamplifiers installed, use the cables that have a miniature triaxial connector on one end and a standard 3-slot triaxial connector on the other end. The cable end that is terminated with the miniature connector connects directly to the SMU, and the other end connects to the test fixture or probe station.

Figure 27: Triaxial cable 4200-MTRX-X



CAUTION

With preamplifiers installed, never make connections directly to any of the miniature triaxial connectors on the SMU modules. This may result in damage to the SMU or DUT and may produce corrupt data.

Setting up SMUs in Clarius

In this section:

Introduction	3-1
Set up a simple project.....	3-1
Configure a simple test	3-3
Run a simple test	3-8
Operation Mode (SMU)	3-9
SMU - all terminal parameters.....	3-16
SMU Test Settings	3-27

Introduction

The following topics describe basic test and terminal setup of SMUs in Clarius. It also provides descriptions of the options available for SMUs.

For more detailed information about using Clarius, refer to the *Model 4200A-SCS Clarius User's Manual*.

Set up a simple project

To start testing, you can start with a new project or use an existing project. A project consists of items such as devices and tests.

The order of operations of a test is determined by the order and selection of items in the project tree.

The following topics describe how to set up and run a simple project using an existing project from the Project Library.

Select project components

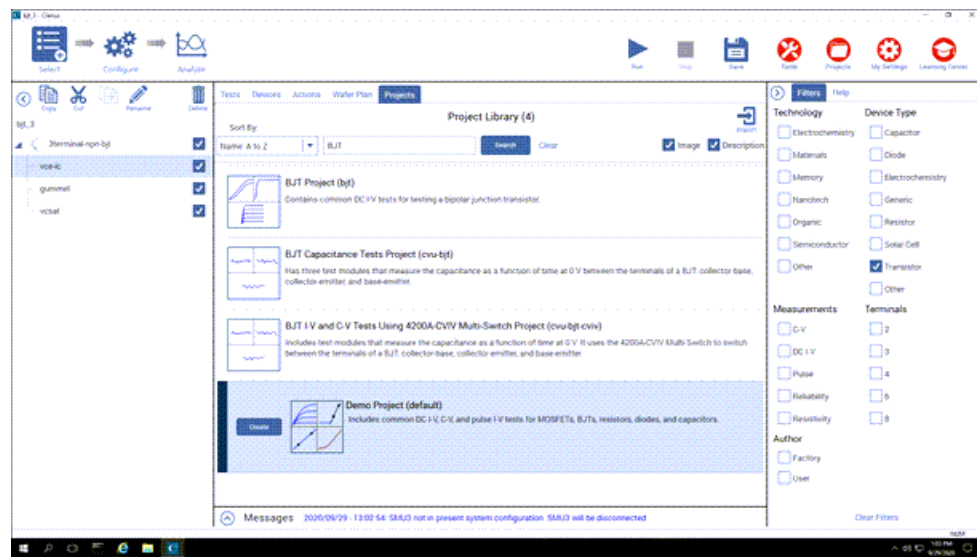
Use the Select pane to add items to the project tree. When Select is active, the center pane contains libraries for tests, devices, actions, wafer plans, and projects. You can use filters and search options to help you find the items you need for your test.

To clear filters, select **Clear Filters** at the bottom of the Filters pane. To clear the search, select **Clear** next to the Search button.

The following example shows you how to select tests for bipolar junction transistors (BJTs).

To set up a test of BJTs:

1. Select **Save** to save your existing project.
2. Choose **Select**.
3. Select the **Projects** tab.
4. In the Filters pane, select **Transistor**.
5. In the Search box, type **BJT** and select **Search**. The Project Library displays projects that are intended for BJT transistor testing.
6. Select **Create** for the project you want to open. The project replaces the previous project in the project tree.

Figure 28: Filter and search for the bjt project**Add a device and test to the project**

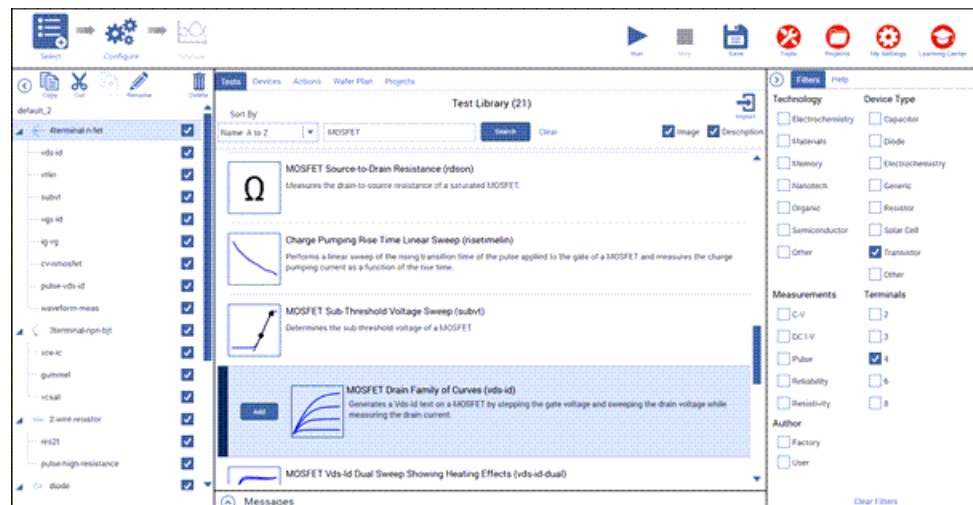
You can add additional items to a project. When you add a project from the library to the project tree, it is copied from the project in the library. Any changes you make do not affect the original project. The new project in the project tree is automatically stored in Projects.

This example shows you how to add a predefined test to the project. Predefined tests are configured with commonly used parameter settings and a set of typical data. Once they are in a project, you can change the parameters as needed. They can be an efficient way for you to add a test to your project.

You can use the basic procedure described here to find any items in the library.

To add a four-terminal MOSFET device and test to the project:

1. In the center pane, select **Tests**.
2. In the Filters pane, select **Transistor** and **4** Terminals.
3. In the search box, type **MOSFET** and select **Search**.
4. Scroll to the **MOSFET Drain Family of Curves (vds-id)** test.
5. Select **Add**. The selected test and the device are added to the project tree under the previous item that was highlighted.
6. To move the device and test, drag the device to a new location.
7. Select **Save**.

Figure 29: Add a MOSFET test and device to the project**NOTE**

If the device for a test is not in the project tree, Clarius adds the appropriate device when you add a test to the project tree. You can also add the device and test separately.

Configure a simple test

Use the Configure pane to set up your test. For interactive test modules (ITMs), the Configure pane displays a schematic of the test device. The schematic is connected to an object that shows the operation mode and the type of instrument that is connected to the terminal.

NOTE

The following topics discuss the Test Settings pane for interactive test modules (ITMs). For tests that are based on user modules (UTMs), you use the options in the Test Settings pane to select the User Library and User Module for the test. Refer to "Create a custom test" in the *Model 4200A-SCS Clarius User's Manual* for information on settings available for UTMs.

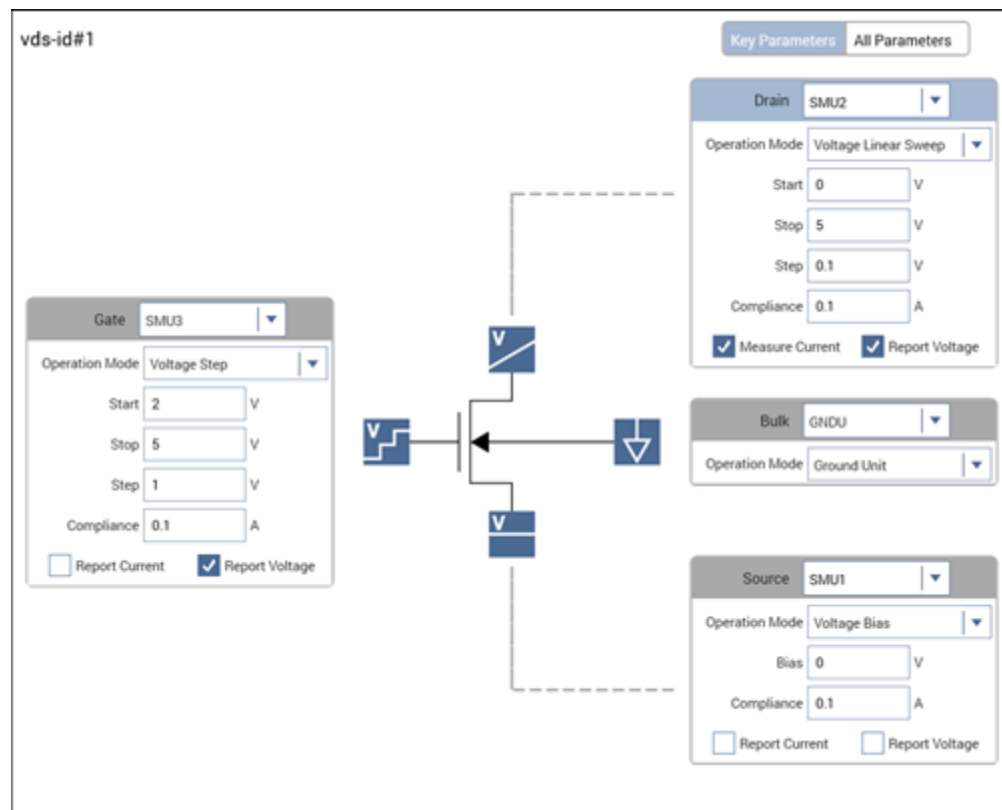
CAUTION

The connections selected in the Clarius software must accurately reflect the physical hardware connections when the test is executed. Incorrect terminal configurations can result in anomalous test results and device damage.

The key parameters for each terminal are displayed near the terminal. The key parameters include:

- The type of terminal, such as gate, drain, source, or collector.
- The instrument that is attached to the terminal. You assign the instrument, ground unit, or open circuit that is physically connected to the terminal during the test.
- The operation mode and basic settings for that mode. For example, the start and stop values are displayed if a sweep operation mode is selected.

Figure 30: Configure pane



NOTE

For user test modules (UTMs), the display depends on the settings of the user module that the UTM is based on.

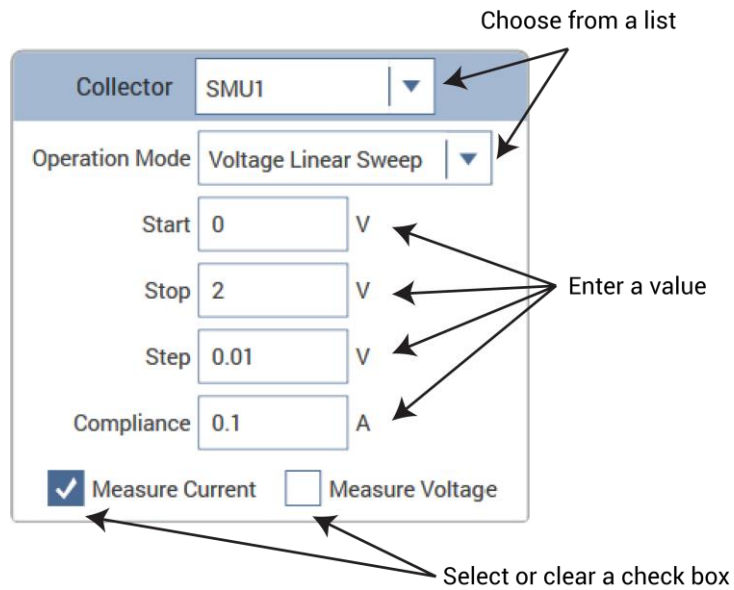
Set the key parameters

The Key Parameters are the most commonly used parameters for a terminal.

To set the Key Parameters:

1. Select the field that you want to change.
2. If there is a:
 - **Down arrow to the right of the field:** Select a value from the list.
 - **Field:** Type the value. Error messages are displayed if you type an out-of-range value.
 - **Check box:** Select or clear the check box to enable or disable an option.

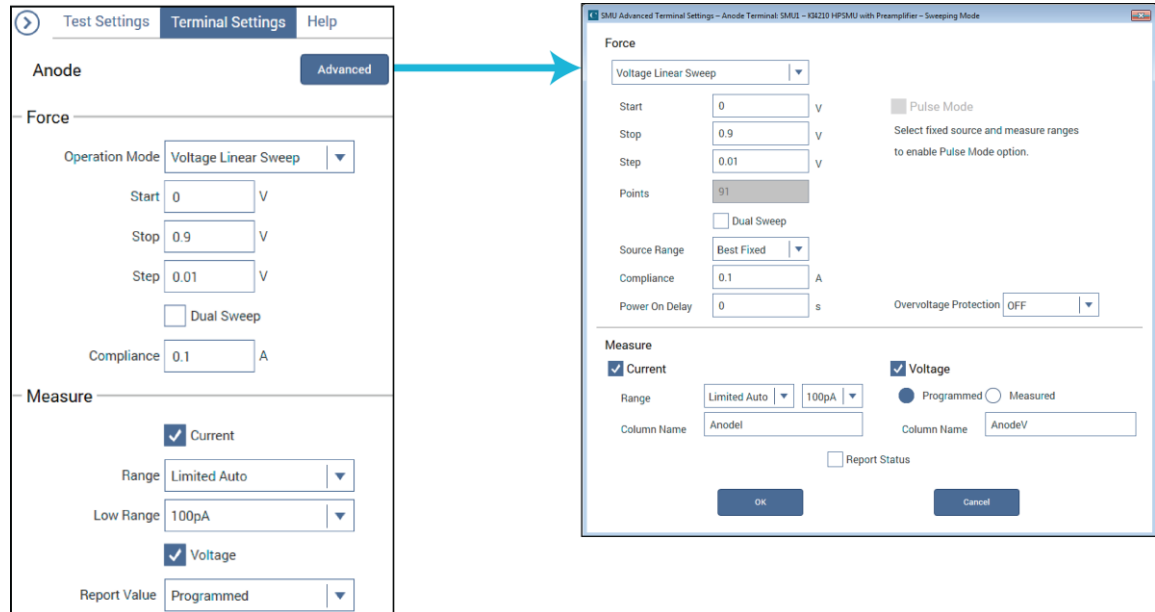
Figure 31: Clarius selection options



3. Select **Save**.

Additional terminal settings are available from the right pane Terminal Settings tab, shown in the following figure. Refer to [SMU - all terminal parameters](#) (on page 3-16) for descriptions of the options.

Figure 32: Terminal Settings tab and Terminal Settings Advanced dialog box



Set the test parameters

In the Test Settings pane, you can set items such as:

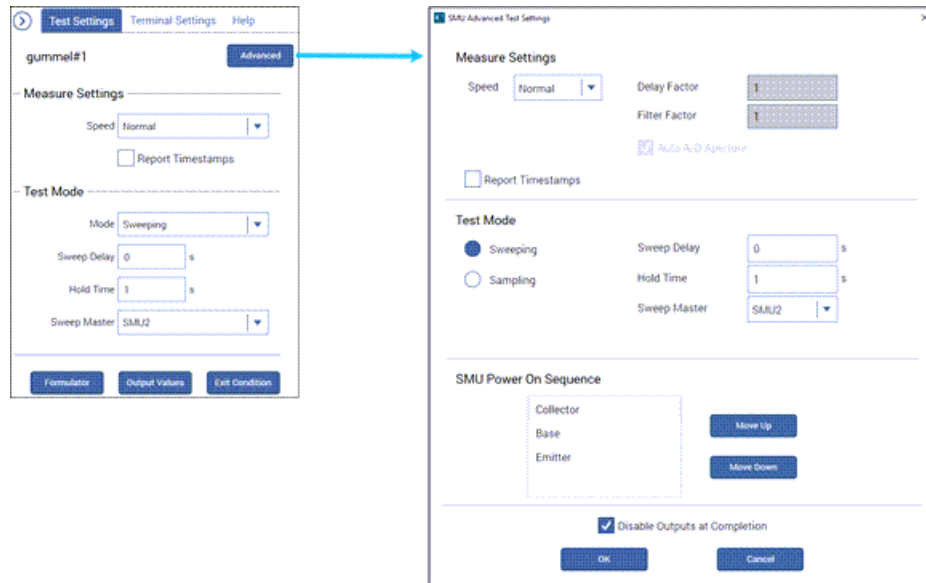
- Test speed.
- Timestamp reporting.
- Delays.
- Hold times.
- In-test and post-test data computations using the Formulator. Refer to “Formulator” in the *Model 4200A-SCS Clarius User's Manual* for detail on using the Formulator.
- Compliance exit condition.

NOTE

You can configure multiple measurement delays on the Test Settings tab. However, if you are using autoranging, these delays do not include autoranging delays, which can be substantial.

To set up test parameters:

1. In the project tree, select the test.
2. Select **Configure**.
3. Select **Test Settings** in the right pane.

Figure 33: Test Settings for a SMU test

4. Adjust settings as needed.
5. If needed, select **Advanced** to access additional settings.

For descriptions of the test options, refer to [SMU Test Settings](#) (on page 3-27).

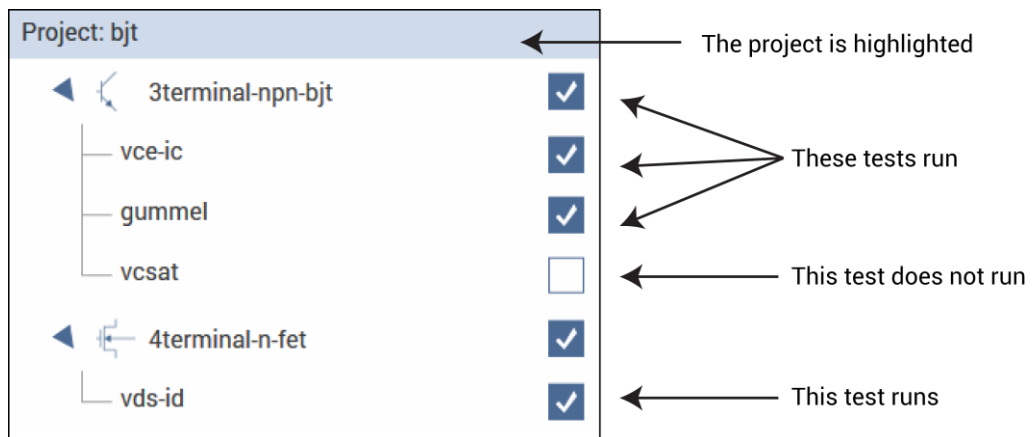
Run a simple test

When you select Run, selected tests and actions at a lower level than the highlighted item in the project tree are executed, from top to bottom in the project tree. If you want to run an entire project, make sure the project name is highlighted. Running a project saves the configuration settings and the existing run history of the project.

In the following example, when you select **Run**, the following occurs:

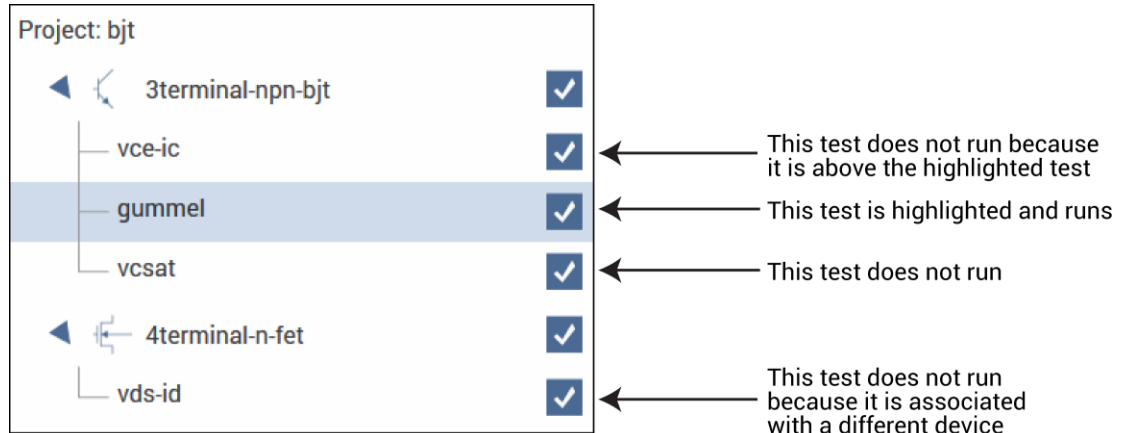
- The `vce-ic` test runs.
- The `gummel` test runs.
- The `vcsat` test is skipped.
- The `vds-id` test runs.

Figure 34: Run a test at the project level



In the following example, only the `gummel` test runs. Even though the other tests are selected, they are not below the `gummel` test in the hierarchy.

Figure 35: Run specific tests



To run a test in Clarius:

1. In the project tree, select that tests and actions that you want to run or execute.
2. Highlight the item where you want the test to start. For example, if you want to run the entire project, select the project.
3. Select **Run**.
4. Select **Analyze** to view the results.

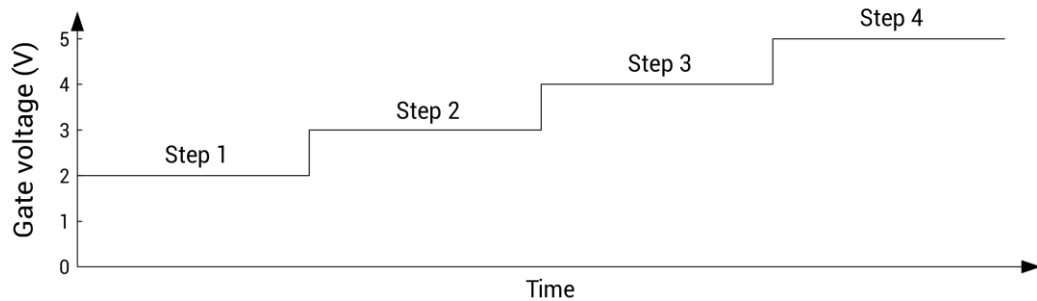
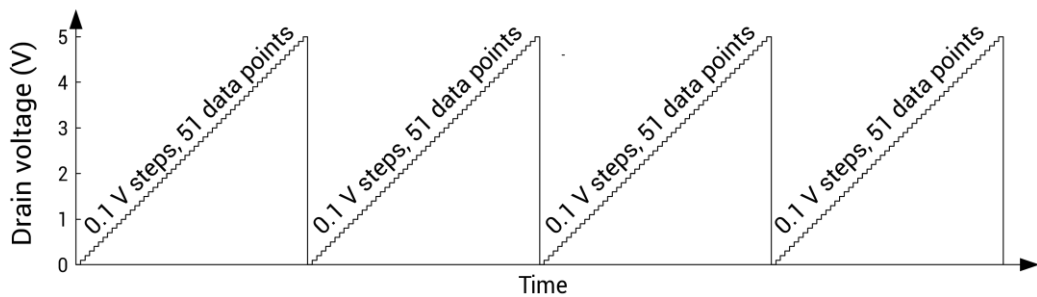
NOTE

To abort a test, select **Stop**. All test and action execution stops immediately.

Operation Mode (SMU)

The operation mode determines what type of test is run on the terminal. Selecting the appropriate mode sets the most common settings for that operation, which simplifies terminal and test configuration. The following topics describe the operation modes that are available when a SMU is selected as the instrument. For descriptions of the parameters that you can set for the operation modes, refer to [SMU - all terminal parameters](#) (on page 3-16).

Some of the operation modes allow sweeping or stepping. The figure below illustrates the difference between steps and sweeps.

Figure 36: Stepping and sweeping example**Stepping the gate voltage of a FET****Sweeping the drain voltage of a FET at each gate voltage****Open operation mode - SMU**

Open operation mode maintains a zero-current state at the terminal, subject to the maximum voltage compliance of the connected SMU.

You cannot set any parameters when the Open operation mode is selected.

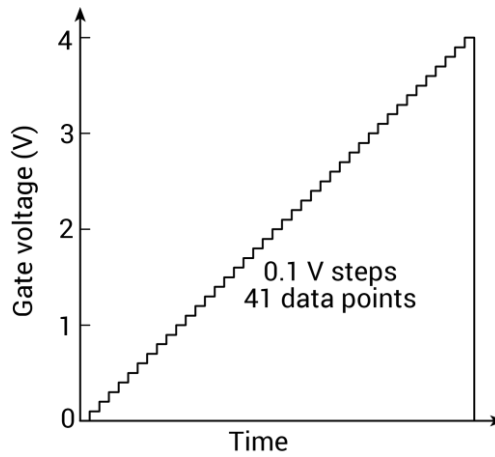
Voltage Bias operation mode

The Voltage Bias operation mode maintains a selected constant-voltage state at the terminal, subject to a user-specified current compliance of the connected SMU.

Voltage Linear Sweep operation mode - SMU

When you select the Voltage Linear Sweep operation mode, the test increments through a series of constant voltage steps. You define the start and stop voltages and the voltage size between each step. An example is shown in the next figure.

Figure 37: Example linear sweep



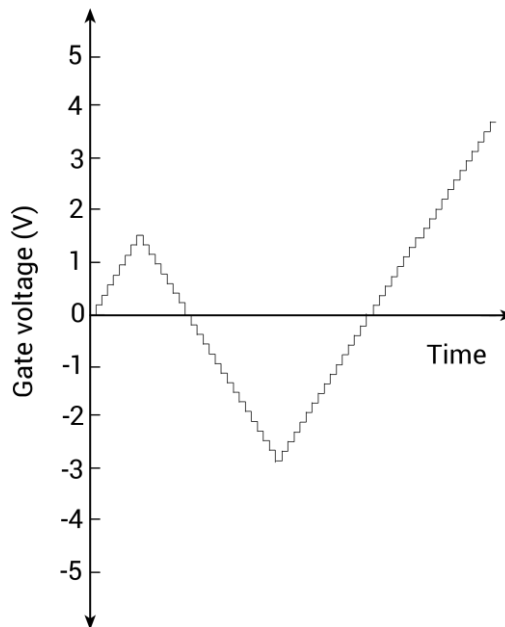
The voltage sweep generates parametric curve data that is recorded in the Analyze pane.

Voltage Segment Sweep operation mode

When you select the Voltage Segment Sweep operation mode, the test increments through a series of constant voltage steps. You can define the starting voltage and up to four stop voltage points and four step voltage points.

An example of a three-segment voltage sweep is shown in the following figure.

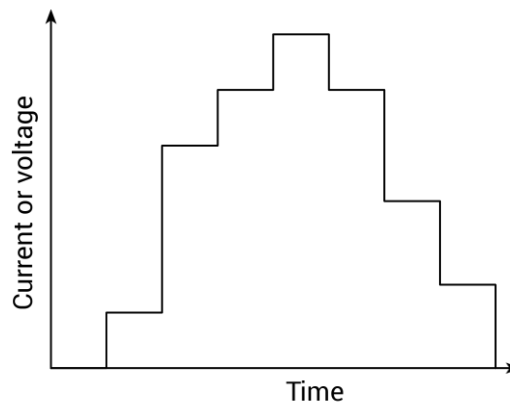
Figure 38: Example multi-segment voltage sweep



Voltage List Sweep operation mode

The Voltage List Sweep operation mode allows you to customize the voltage values for each step of the sweep. List sweeps allow you to make measurements only at selected forced voltages and currents. For example, they allow you to skip unimportant measurement points or to synthesize a custom sweep that is based on a special mathematical equation. You can also use list sweeps to make pulsed measurements to avoid overheating of sensitive devices. The following figure illustrates a possible list sweep.

Figure 39: Example list sweep



The voltage sweep generates parametric curve data that is recorded in the Analyze pane.

Voltage Log Sweep operation mode

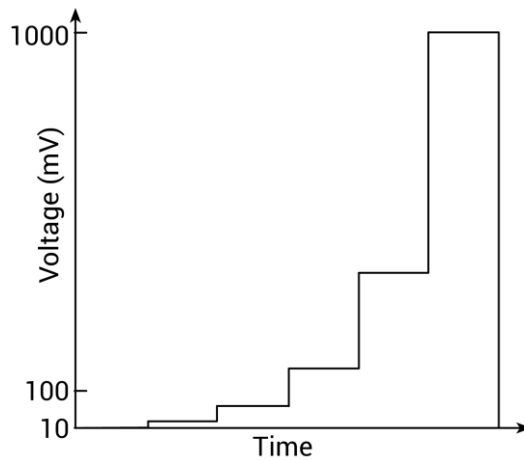
The Voltage Log Sweep operation mode allows you to sweep over a large range and plot the measurements on a logarithmic scale.

A linear sweep is typically unsatisfactory for such applications, because the first increment can miss several of the lower decades. For example, the first ~ 0.1 V step of a 101-point linear sweep from 0.001 V to 10 V misses the two decades between 0.001 V and 0.1 V.

By contrast, a log sweep varies the step size logarithmically over the specified range, so that all decades are characterized uniformly.

An example of a log sweep is shown in the following figure.

Figure 40: Example logarithmic sweep

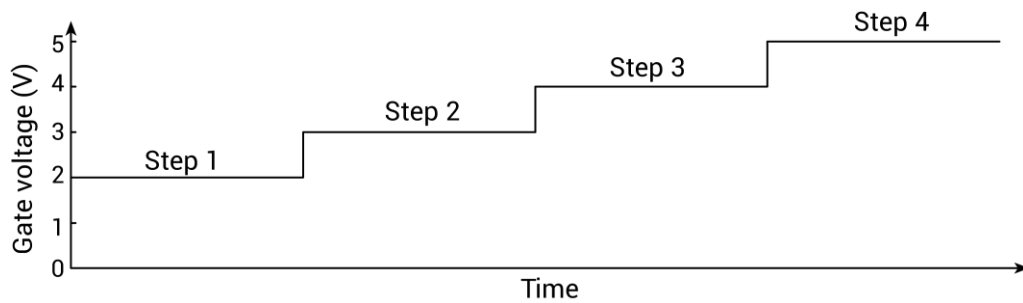


Voltage Step operation mode

The Voltage Step operation mode increments through evenly-spaced, constant voltage steps over a range that you specify. The time interval for each step is determined automatically by the time required to complete a sweep.

For each step, parametric curve data is generated. The data is recorded in the Analyze pane.

Figure 41: Stepping the gate voltage of a FET



Current Bias operation mode

Current Bias operation mode maintains a selected constant-current state at the terminal, subject to the maximum voltage compliance of the connected SMU.

Current Linear Sweep operation mode - SMU

When you select the Current Linear Sweep operation mode, the test increments through a series of constant current steps. You define the start and stop currents and the current size between each step.

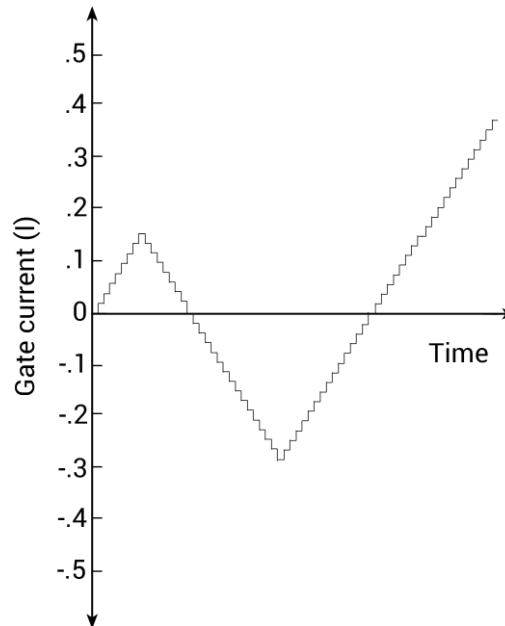
The current sweep generates parametric curve data that is recorded in the Analyze pane.

Current Segment Sweep operation mode - SMU

When you select the Current Segment Sweep operation mode, the test increments through a series of constant current steps. You can define the starting current and up to four stop-current points and four step-current points.

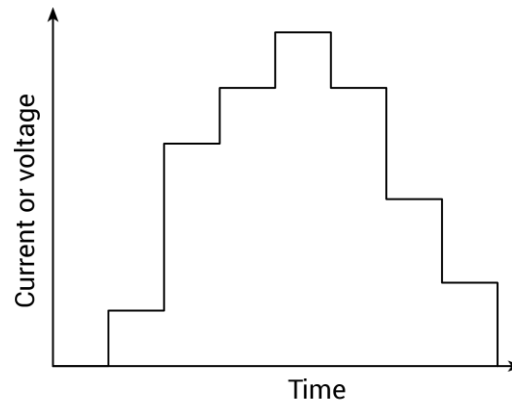
An example of a three-segment current sweep is shown in the following figure.

Figure 42: Example multisegment current sweep



Current List Sweep operation mode - SMU

The Current List Sweep operation mode allows you to customize the current values for each step of the sweep. List sweeps allow you to make measurements only at selected forced voltages and currents. For example, they allow you to skip unimportant measurement points or to synthesize a custom sweep that is based on a special mathematical equation. You can also use list sweeps to make pulsed measurements to avoid overheating of sensitive devices. The following figure illustrates a possible list sweep.

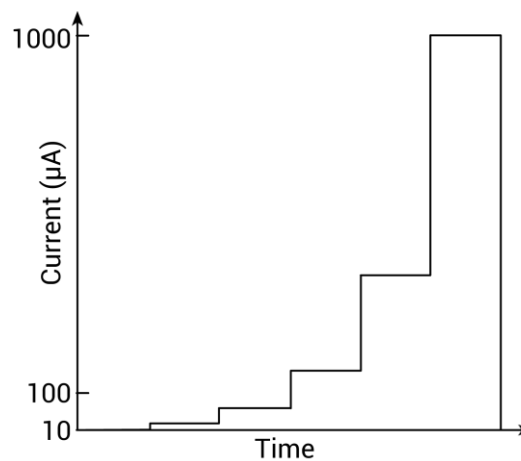
Figure 43: Example list sweep

The current sweep generates parametric curve data that is recorded in the Analyze pane.

Current Log Sweep operation mode - SMU

The Current Log Sweep operation mode allows you to sweep over a large range and plot the measurements on a logarithmic scale.

An example of a log sweep is shown in the following figure.

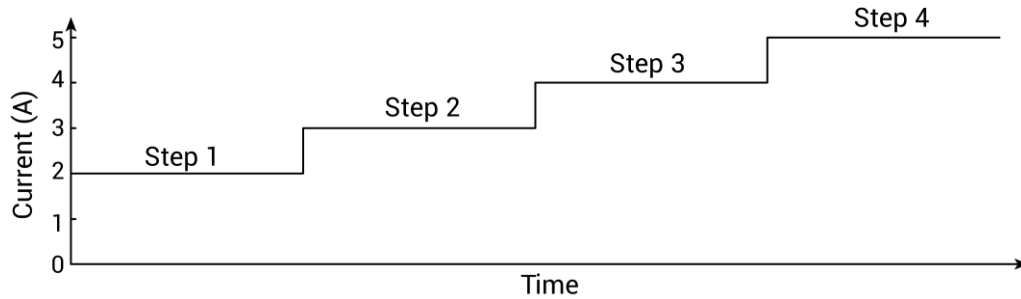
Figure 44: Example logarithmic sweep

The current log sweep generates parametric curve data that is recorded in the Analyze pane.

Current Step operation mode

The Current Step operation mode increments through evenly-spaced, constant current steps over a range that you specify. The time interval for each step is determined automatically by the time required to complete a sweep.

Figure 45: Stepping the diode current



For each step, parametric curve data is generated that is recorded in the Analyze pane.

Common operation mode - SMU

Common operation mode maintains a zero-voltage state at the terminal, subject to the maximum current compliance of the connected SMU. The 4200-SMU and 4201-SMU each have a compliance of 105 mA. The 4210-SMU and 4211-SMU each have a compliance of 1.05 A.

You cannot set any parameters for the Common operation mode.

SMU - all terminal parameters

When you select **All Parameters**, the Configure pane displays all available parameters for the terminals for the test that is selected in the project tree.

Parameter descriptions are provided in the following topics.

Base Current

Available when Pulse Mode is selected. The current level that the instrument sources when the pulse output is off. The level that you can set depends on the present source range.

Base Voltage

Available when Pulse Mode is selected. The voltage level that the instrument sources when the pulse output is off. The level that you can set depends on the present source range.

Bias

The bias is the amount of voltage or current to be forced.

Column Name (Measure Current)

The name of the current measurement. This is the name that Clarius displays in the Analyze spreadsheet column for that measurement.

If you do not define a name, Clarius assigns a name. The assigned name is a combination of the terminal label and I for current. For example, the Base terminal is assigned the name `BaseI`. This cannot be left blank. If it is left blank, Clarius uses the previous value.

The name is updated when the test is run. The results from earlier tests that are available through Run History are not changed to the new name.

Column Name (Measure Voltage)

The name of the voltage measurement. This is the name that Clarius displays in the Analyze spreadsheet column for that measurement.

If you do not define a name, Clarius assigns a name. The assigned name is a combination of the terminal label and V for voltage. For example, the Drain terminal is assigned the name `DrainV`. This cannot be left blank. If it is left blank, Clarius uses the previous value.

The name is updated when the test is run. The results from previous tests that are available through Run History are not changed to the new name.

Compliance

You can set a limit that stops a SMU from sourcing a current or voltage that is more than that limit. This limit is called compliance and helps prevent damage to the device under test (DUT). The SMU will not exceed the maximum limit set for compliance. When a SMU is acting as a current source, the voltage is clamped at the compliance value; conversely, the current is clamped at the compliance value when the SMU is acting as a voltage source.

When a SMU reaches compliance, it continues to make measurements. However, the measurement stays at the value it was at when compliance occurred. For example, if you are sourcing voltage and the compliance is set to 100 mA, it continues to measure 100 mA after compliance is reached. The voltage, however, is not at the programmed value.

You can stop the test if the source reaches compliance. Refer to [Compliance exit condition options](#) (on page 3-34) for detail.

If you set a specific measurement range, compliance can also be restricted by the range. Compliance must be more than 11% of the measurement range. If not, an event is generated and the compliance setting is automatically changed to the maximum compliance value for the selected range. For example, if compliance is set to 1 V and the measurement range is 200 mV, output voltage will clamp at 210 mV. If you attempt to change compliance to a value that is not appropriate for the selected range, compliance is not changed and a warning is generated. You must change the range before you can select the new compliance value. If you set the measurement range to be automatically selected, the measurement range does not affect compliance.

The lowest allowable compliance is based on the load and the source value. For example, if you are sourcing 1 V to a 1 k Ω resistor, the lowest allowable current compliance is 1 mA (1 V/1 k Ω = 1 mA). Setting a compliance lower than 1 mA limits the source.

For another example, assume the following conditions:

- Current compliance: 10 mA
- Voltage sourced by the instrument: 10 V
- DUT resistance: 10 Ω

With a source voltage of 10 V and a DUT resistance of 10 Ω , the current through the DUT should be 10 V / 10 Ω = 1 A. However, because compliance is set to 10 mA, the current cannot exceed 10 mA, and the voltage across the resistance is limited to 100 mV. In effect, the 10 V voltage source is transformed into a 10 mA current source.

In steady-state conditions, the set compliance value restricts the instrument output unless there are fast transient load conditions.

When measurement autorange is disabled, the maximum and minimum compliance values cannot be set below the minimum value. When autorange is enabled, the programmed compliance value cannot be set below 10 nA when sourcing voltage, or below 20 mV when sourcing current.

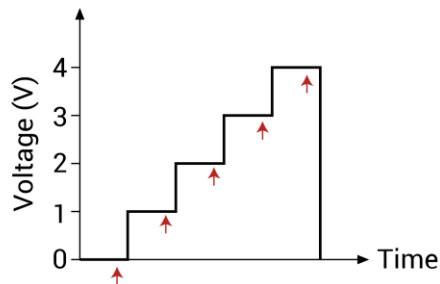
Dual Sweep

When you select Dual Sweep, the instrument sweeps from start to stop, then from stop to start. When you clear Dual Sweep, the instrument sweeps from start to stop only.

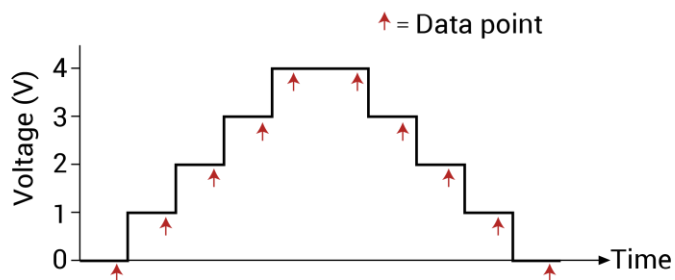
The following figure compares a single sweep to a dual sweep.

Figure 46: Single and dual sweep examples (linear voltage sweep; 0 V to 4 V in 1 V steps)

**Dual sweep disabled
(single sweep)**
Five data points



Dual sweep enabled
Ten data points



Force Range (Source Range)

The SMU range that is used when forcing the voltage or current.

You can select:

- **Best Fixed:** The instrument selects a single fixed source range that accommodates all the source levels in the test.
- **Auto:** The instrument selects the most sensitive source range for each source level in the test. This option provides the best resolution and control when sweeping or stepping several decades. However, the range changes can reduce speed.
- **Specific range:** Select a range. The source remains on the range that is set. If you are sweeping and a sweep point exceeds the source range capability, the source outputs the maximum level for that range. This range must be equal to or greater than the largest value in the sweep.

List Values

Select **Enter Values** to open a dialog box in which you can type the current or voltage level for each step of the sweep in the rows. You can type any valid instrument current or voltage.

You can select a value or multiple values in the list and copy, cut, or delete them. Use Paste to add values that you copied or cut to a new location in the list.

Note that you cannot have blank rows in between values.

You can use the Ctrl key plus mouse selections to pick selected rows, then use the buttons to copy, cut, or delete those rows. Note that when you paste the rows, any skipped rows are ignored (there will be no blank rows).

You can use the Shift key plus mouse selections to pick a range of rows. When you paste the rows, any blank rows are ignored.

Low Range

Available when the Measure Range is set to Limited Auto. This sets the minimum range that the instrument uses.

Measure Current

When Measure Current is selected, the instrument measures current. Current values are recorded in the Analyze sheet and shown in the graph.

Off Time

Available when Pulse Mode is selected. The amount of time that the pulse is off (5 ms to 20 s).

On Time

Available when Pulse Mode is selected. The amount of time that the pulse is on (5 ms to 20 s).

Overvoltage protection

Overvoltage protection restricts the maximum voltage level that the instrument can source. It is in effect when either current or voltage is sourced.

This protection is in effect for both positive and negative output voltages.

When this attribute is used in a test sequence, it should be set before turning the source on.

WARNING

Even with the overvoltage protection set to the lowest value, never touch anything connected to the terminals of the 4200A-SCS when the instrument is on. Always assume that a hazardous voltage (greater than 30 V_{RMS}) is present when the instrument is on. To prevent damage to the device under test or external circuitry, do not set the voltage source to levels that exceed the value that is set for overvoltage protection.

WARNING

Asserting the interlock allows the SMU and preamplifier terminals to become hazardous, exposing the user to possible electrical shock that could result in personal injury or death. SMU and preamplifier terminals should be considered hazardous even if the outputs are programmed to be low voltage. Precautions must be taken to prevent a shock hazard by surrounding the test device and any unprotected leads (wiring) with double insulation that is rated for 250 V, Category O.

Points (list or segment sweep)

The number of sweep points that were defined in the List Values or Segments list. This number is automatically generated.

Points (log sweep)

The number of points that the sweep generates. Clarius uses the start, stop, and number of points to calculate the step size and forcing values according to the following formulas:

$$\text{step size} = \frac{(\log_{10} |\text{stop}| - \log_{10} |\text{start}|)}{\text{data points} - 1}$$

$$\text{forcing value for data point } n = 10(\log_{10} |\text{start}| + (n-1)(\text{step size}))$$

Points

The number of points that are measured. This value is calculated by Clarius using the information entered for the Start, Stop, and Step parameters, using the following equation:

$$points = \frac{(stop - start)}{step} + 1$$

Power On Delay

When a test is run, the SMUs power on in a specific sequence. You can change the amount of time between when the SMUs power on in the sequence.

The first SMU in the sequence always powers on immediately. Subsequent SMUs power on in sequence after the delay.

For example, assume there are three SMUs in a test and the power-on sequence is SMU1, SMU2, and SMU3. The power-on delay for SMU1 is set to 50 ms and the delay for SMU2 is set to 100 ms. When the test is started, the power-on sequence for the SMUs is:

1. SMU1 powers on.
2. 50 ms delay.
3. SMU2 powers on.
4. 100 ms delay.
5. SMU3 powers on.

You can set the delay from 0 to 1.0 s.

For information on changing the sequence, refer to [SMU Power On Sequence](#) (on page 3-32).

Pulse Mode

Pulse Mode allows you to apply voltage or current to a device for brief periods at widely spaced intervals. This avoids device overheating in some tests. Pulse Mode is only available if the source range and measure ranges are set to a fixed range or the Best Fixed range. Select this option to enable Pulse Mode.

When Pulse Mode is selected, you can set the pulse on and off times and the pulse base voltage or current. The pulse output goes to the specified voltage or current level when the pulse is on. When the pulse is off, the pulse output returns to the specified base voltage or base current level.

The pulse on and off times determine the pulse period and pulse width as follows:

Pulse period = On Time + Off Time + cumulative measure time (if set to measure)

Pulse width = On Time

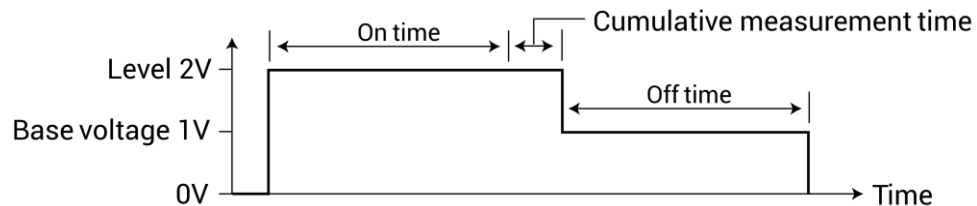
Pulse on and off times can be set from 5 ms to 20 s. The base voltage (or current) that can be set is dependent the present source range.

NOTE

More than one SMU in the test can be pulsing. If the pulse on or off times for the SMUs are different, the longer on and off times take precedence so that the SMUs operate synchronously and run at the same speed.

An example single-sweep pulse output for the Voltage Bias operation mode is shown in the following figure. The pulse output goes to the specified pulse level during the pulse on time. If the instrument is set to measure, the measurement occurs after the on time expires and before the transition to the off time. During pulse off time, the pulse output returns to the specified Base Voltage level. After the off time expires, the output returns to 0 V.

Figure 47: Pulse Mode example: Voltage bias with a 2 V level and 1 V base



When a measurement is made, it effectively increases the on time by the amount of time required to make the measurement.

To minimize this extra time:

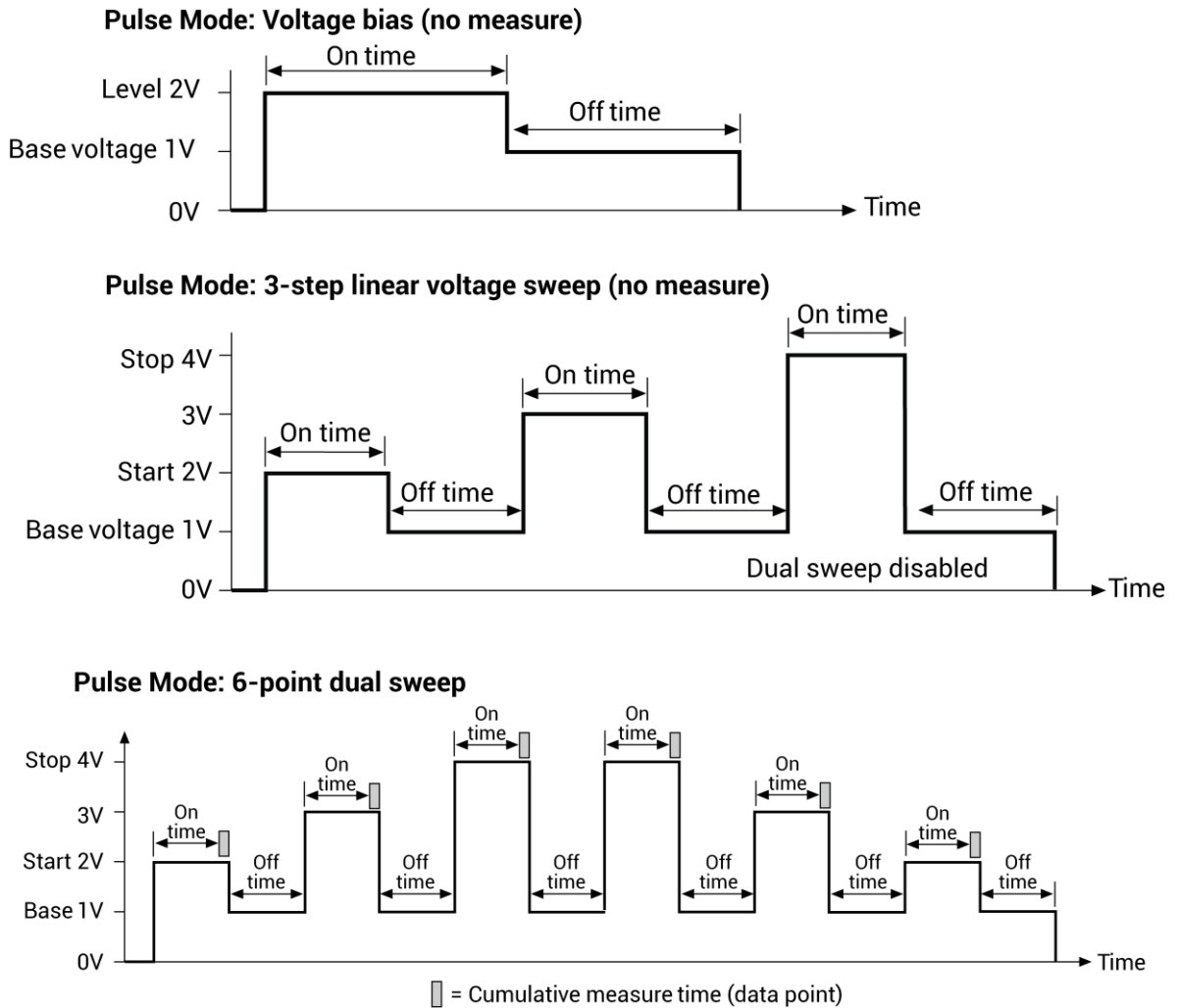
1. Select **Test Settings**.
2. Select **Advanced**.
3. For the Speed, select **Custom**.
4. Set the Delay Factor to **0**.
5. Set the Filter Factor to **0**.
6. Set the A/D aperture time to **0.01**.

This is the fastest measurement timing, but it reduces accuracy.

For a sweep operation mode, pulse output goes to the sweep step levels during the pulse on times. During the off times, pulse output goes to the specified Base Voltage (or Base Current) level. If set to measure, the measurement occurs after each on time expires and before the pulse transitions to the off time level.

The figure below shows some Pulse Mode examples.

Figure 48: Pulse Mode examples



Range (Measure Current)

The measure range determines the full-scale measurement span that is applied to the signal. It affects both the accuracy of the measurements and the maximum signal that can be measured.

The current range options are:

- **Auto:** The instrument automatically optimizes the measurement range as the test progresses. This option provides the best resolution when the measurements span several decades. However, time delays can occur with range changes that can limit the measurement speed.
- **Limited Auto:** A compromise between Auto and a fixed-range option. It allows you to specify the minimum range that the SMU uses when it automatically optimizes the current measurements. This option reduces test time when you do not need maximum resolution at minimum currents.
- **Best Fixed:** The instrument automatically selects a single measurement range based on the current or voltage compliance value.
- **Specific ranges:** You can select a fixed measurement range.

Report Status (SMU)

When this option is selected, Clarius records measurement status information when the test executes. A column of the Analyze spreadsheet displays this information. Hover over a cell to review the information. An example of the status information is displayed in the following figure.

Figure 49: SMU Report Status column in the Analyze sheet

	A	B	C	D
1	Time	AV	SMU1_S	SMU2_S
2	174.6265E-3	173.5735E-3	00240251	009000B0
3	215.1949E-3	180.1555E-3	00240251	009000B0
4	256.2046E-3	186.7446E-3	Status:	009000B0
5	297.2239E-3	193.3215E-3	Source Current	009000B0
6	338.2374E-3	199.8583E-3	Measure Voltage	009000B0
7	379.2452E-3	206.4212E-3	100nA Current Range	009000B0
8	420.2530E-3	213.0085E-3	20V Voltage Range	009000B0
9	461.2608E-3	219.5958E-3	Interlock open	009000B0

Report Value (Measure Current or Report Current)

The Report Value setting determines which current values are recorded in the Analyze spreadsheet. You can select:

- **Programmed:** Requested current values are recorded. For example, if you specified a current of 10 mA, the reported value is 10 mA, even if the measured value is 9.9982 mA.
- **Measured:** Recorded voltage values are actual measured values. For example, if you specified a current of 10 mA, the actual measured value, such as 9.9982 mA, is recorded. The Measured mode increases the measurement time because it requires an additional analog-to-digital (A/D) conversion.

Report Value (Report Voltage or Measure Voltage)

If Voltage is selected, Report Value determines which voltage values are recorded in the Analyze spreadsheet. You can select:

- **Programmed:** Requested voltage values are recorded. For example, if you specified a voltage of 2.5 V, the reported value is 2.5 V, even if the measured value is 2.4997 V.
- **Measured:** Recorded voltage values are actual measured values. For example, if you specified a voltage of 2.5 V, the actual measured value, such as 2.4997 V, is recorded. The measured mode increases the measurement time because it requires an additional analog-to-digital (A/D) conversion.

Segments

The number of source sweeps in Segment Sweep operation mode. You can define up to four segments with distinct Start, Stop, and Step points.

Start (step)

The Start parameter is the current or voltage that is forced for the first step value.

Start (sweep)

The current or voltage source level at which the sweep starts. For a log sweep, the start value cannot be 0.

Step (step)

Specifies the current or voltage increments of the steps.

Clarius never steps the force voltage beyond the value specified by the stop parameter, even if you specify a step value that is larger than the stop value.

Use a step value that does not result in a fractional number of points. If the point is fractional, the step value is forced to a value that results in a whole number of points. To calculate the points:

$$points = \frac{(stop - start)}{step} + 1$$

The points are rounded to the nearest value.

For example, if Start = 0 V, Stop = 5 V, and Step = 0.6 V:

$$points = \frac{(5 - 0)}{0.6} + 1$$

In this case, the Step value is forced to 0.625 V, which results in a point value of 9.333, which is rounded to 9. The instrument forces nine voltages at 0 V, 0.625 V, 1.25 V, 1.875 V, 2.5 V, 3.125 V, 3.75 V, 4.375 V, and 5 V.

If Start = 0 A, Stop = 0.005 A, and Step = 0.0015 A:

$$points = \frac{(0.005 - 0)}{0.0015} + 1$$

This results in a value of 4.333, which is rounded to 4. The instrument forces four values at 0 A, 0.001666 A, 0.0033326 A, and 0.0049992 A.

Step (voltage sweep)

The current size of each step of the sweep. The current level changes in equal steps of this size from the start level to the stop level. A measurement is made at each source step (including the start and stop levels).

Clarius never steps the force current beyond the value specified by the stop parameter, even if you specify a step value that is larger than the stop value.

Use a step value that does not result in a fractional number of data points. If the data point is fractional, the step value is forced to a value that results in a whole number of data points. To calculate the data points:

$$points = \frac{(stop - start)}{step} + 1$$

For example, if Start = 0 A, Stop = 0.005 A, and Step = 0.0015 A:

$$points = \frac{(0.005 - 0)}{0.0015} + 1$$

This results in a data point value of 4.333. In this case, the Step value is forced to 0.001 A, which results in four data points at 0 A, 0.0015 A, 0.0030 A, and 0.0045 A.

Step (voltage sweep)

The voltage size of each step of the sweep. The source level changes in equal steps of this size from the start level to the stop level. A measurement is made at each source step (including the start and stop levels).

Clarius never steps the force voltage beyond the value specified by the stop parameter, even if you specify a step value that is larger than the stop value.

Use a step value that does not result in a fractional number of points. If the point is fractional, the step value is forced to a value that results in a whole number of points. To calculate the points:

$$points = \frac{(stop - start)}{step} + 1$$

The points are rounded to the nearest value.

For example, if Start = 0 V, Stop = 5 V, and Step = 0.6 V:

$$points = \frac{(5 - 0)}{0.6} + 1$$

In this case, the Step value is forced to 0.625 V, which results in a point value of 9.333, which is rounded to 9. The instrument forces nine voltages at 0 V, 0.625 V, 1.25 V, 1.875 V, 2.5 V, 3.125 V, 3.75 V, 4.375 V, and 5 V.

Stop (step)

The current or voltage that is forced for the last step value.

Stop (sweep)

The voltage or current source level at which the sweep stops. For a log sweep, the stop value cannot be 0 or the opposite polarity of the start value.

Voltage (Report Voltage)

When this box is selected, the instrument measures voltage. Voltage is recorded in the Analyze sheet and shown in the graph.

Voltage Range

The measure range determines the full-scale measurement span that is applied to the signal. It affects both the accuracy of the measurements and the maximum signal that can be measured.

The measurement range options are:

- **Auto:** The instrument automatically optimizes the measurement range as the test progresses. This option provides the best resolution when the measurements span several decades. However, range-change time delays limit the measurement speed.
- **Best Fixed:** The instrument automatically selects a single measurement range based on the current or voltage compliance value.
- **Specific ranges:** You can select a fixed measurement range from a list.

SMU Test Settings

The settings that are available for SMU tests are described in the following topics.

Speed

The SMU automatically takes into account both settling time and noise issues. It provides measurement speeds that allow you to select a compromise between speed and noise. You can select:

- **Fast:** Optimizes the SMU for speed at the expense of noise performance. It is a good choice for measurements where noise and settling time are not concerns.
- **Normal:** The default and most commonly used setting. It provides a good combination of speed and low noise and is the best setting for most cases.
- **Quiet:** Optimizes the SMU for low-noise measurements at the expense of speed. If speed is not a critical consideration, it is a good choice when you need the lowest noise and most accurate measurements.
- **Custom:** Allows you to fine-tune the timing parameters. With Custom, you can configure the A/D aperture time and individual delay and filtering factors to produce a composite setting that is faster than the Fast setting, quieter than the Quiet setting, or anything in between.

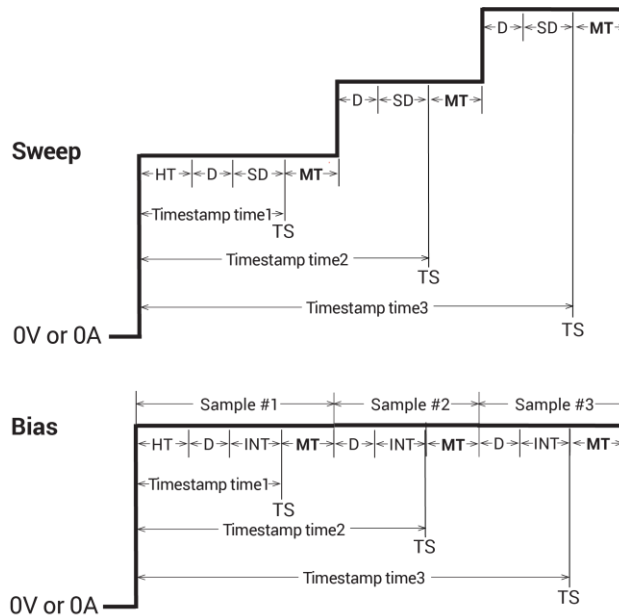
Report Timestamps

When this option is selected, every measurement in the Analyze sheet includes a timestamp. When this option is cleared, the timestamp is not included.

The timestamp records the elapsed time for each measurement. Each elapsed time value is placed in the Analyze sheet in the same row as the measurement.

Each elapsed time is measured relative to the beginning of the test when voltage or current is first applied to the device. If Clarius requires only one reading for each measurement, Clarius records the timestamp at the beginning of this reading, as shown in the following figure.

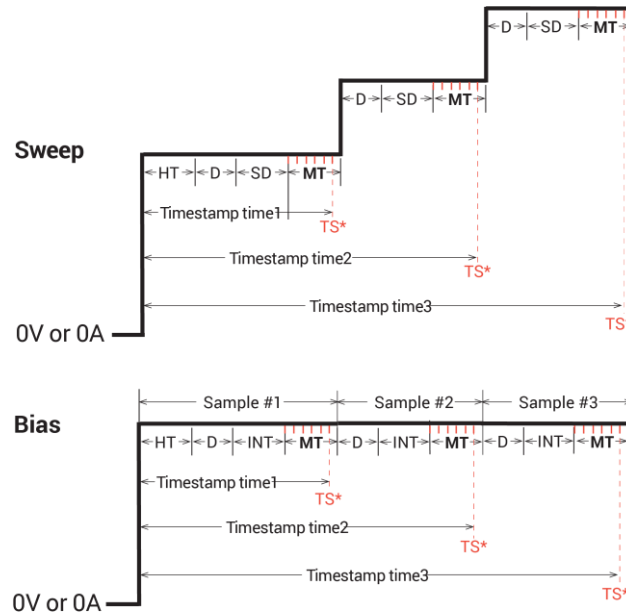
Figure 50: Timestamps when Clarius requires only one reading for a measurement



- TS = Timestamp at the start of the reading when one reading is made
- HT = Hold Time - applies presoak voltage
- D = Delay (default delay x delay factor)
- SD = Sweep Delay
- INT = Interval
- MT = Measure Time

If Clarius makes and averages multiple readings for a measurement, then Clarius records the timestamp at the last of these readings, as shown in the following figure.

Figure 51: Timestamps when Clarius requires multiple readings for a measurement



- = Measurement consisting of multiple readings that are averaged
- TS* = Timestamp at the beginning of the last reading of multiple readings
- HT = Hold Time - applies presoak voltage
- D = Delay (default delay x delay factor)
- SD = Sweep Delay
- INT = Interval
- MT = Measure Time

You can enable the timestamp for any of the measurement speeds.

Delay Factor

After applying a voltage or current, the instrument waits for a delay time before making a measurement. The delay time allows for source settling. The Delay Factor adjusts the delay time for the selected speed. It is fixed for Fast, Normal, and Quiet speeds. If you select Custom Speed, you can enter a factor from 0 to 100.

The applied delay time is a multiple of the default delay time. The Delay Factor specifies this multiple. That is:

$$\text{Applied delay time} = (\text{Default delay time}) \times (\text{Delay Factor})$$

For example, if the default delay time is 1 ms and the Delay Factor is 0.7, the actual applied delay time is 0.7 ms (1 ms × 0.7).

The following table summarizes the Delay Factor settings.

Speed Mode	Delay Factor
Fast	0.7
Normal	1.0
Quiet	1.3
Custom	0 to 100

When entering a custom Delay Factor setting, consider the following:

- A Delay Factor of 1 allows for settling before the analog-to-digital (A/D) converter is triggered to make a measurement.
- Each doubling of the Delay Factor doubles the time allowed for settling.
- A delay factor of 0 multiplies the default delay by zero, resulting in no delay.

NOTE

If you set the Filter Factor and Delay Factor to 0, the internal preprogrammed values are ignored.

In general, cables and matrices increase the settling time. You may need to experiment to find the ideal time. However, for a good quality switch, such as the Keithley 7174A High Speed Low Leakage Current Matrix, you should not need to increase the Delay Factor by more than two times.

Filter Factor

To reduce measurement noise, each 4200A-SCS applies filtering, which averages multiple readings to make one measurement. The Filter Factor is fixed for Fast, Normal, and Quiet speeds. If you select the Custom Speed mode, you can enter a Filter Factor of 0 to 100. The default Filter Factor settings are listed in the following table.

Speed Mode	Filter Factor
Fast	0.2
Normal	1
Quiet	3
Custom	0 to 100

When entering a custom Filter Factor, consider the following:

- A Filter Factor of 1 provides filtering that is appropriate for most applications.
- Increase the Filter Factor to average multiple readings for reduced noise. As a general rule, doubling the Filter Factor halves the measurement noise.
- Measurement time is increased by the square of the Filter Factor.
- A Filter Factor of 0 nullifies the internal filtering.

NOTE

When the Filter Factor and Delay Factor are set to 0, the preprogrammed values are ignored.

Auto A/D Aperture

When Speed is set to Custom and Auto A/D Aperture is selected, the instrument picks the optimum analog-to-digital (A/D) conversion time for most normal measurements.

A/D Aperture Time

If Custom Speed is selected and Auto A/D Aperture is cleared, you can specify the analog-to-digital (A/D) converter integration time that is used to measure a signal. Each measured reading is the result of one or more A/D conversions. A short integration time for each A/D conversion results in a relatively fast measurement speed with increased noise. A long integration time results in a relatively low-noise reading at a relatively low speed.

The integration time setting is based on the number of power line cycles (NPLCs). For 60 Hz line power, 1.0 PLC = 16.67 ms (1/60). For 50 Hz line power, 1.0 PLC = 20 ms (1/50).

The applied A/D conversion time also depends on the Filter Factor setting:

- If the Filter Factor is not 0, the SMU applies an optimum A/D converter time that is based on the Filter Factor setting. The applied A/D converter time value is never less than the specified A/D Aperture Time.
- If the Filter Factor setting is zero, the SMU applies a fixed A/D converter time that equals the specified A/D Aperture Time.

The Auto A/D Aperture and A/D Aperture Time settings for each Speed Mode are shown in the following table.

Speed Mode	A/D Aperture Time
Fast	Auto
Normal	Auto
Quiet	Auto
Custom	0.01 to 10 PLC

Test Mode

You can set a test to the sweeping or sampling test mode.

Sweeping test mode is used for tests in which the voltage, current, or frequency varies with time.

Sampling Mode allows you to measure voltages or currents as a function of time while forcing constant voltages or currents. The sampling test mode is used for tests in which the forced voltage and frequency are static, with measurements made at timed intervals. For example, you could use sampling mode to profile a capacitor charging voltage while forcing a constant current. Time is measured relative to when the instruments apply the forced voltage or current ($t = 0$ at the step change from 0.0 V or 0.0 A to the applied voltage or current).

When Sampling Mode is selected, all device terminals are set to a static operation mode, such as Open or Voltage Bias.

Refer to [Operation mode timing diagrams](#) (on page 5-22) for additional detail.

Sweep Delay

If you are using a sweep operation mode and need extra settling time before each measurement, you can specify an additional delay with the Sweep Delay setting. Sweep Delay is independent of the [Delay Factor](#) (on page 3-29). You can specify a Sweep Delay value from 0 s to 999 s. The default Sweep Delay value is 0 s.

Interval

Sampling mode only. The time between measurements (points). The interval can be set from 0 s to 1000 s.

Number of Samples

Specifies the number of points to be acquired. Set the number of samples to a value from 1 to 4096.

Hold Time - SMU

The starting voltages or currents of a sweep may be substantially larger than the voltage or current increments of the sweep. This means that the source settling time required to reach the starting voltages or currents of a sweep may be substantially larger than the settling times required to increment the sweep. To compensate, you can specify a Hold Time, which applies a delay at the beginning of each sweep. You can specify a Hold Time of 0 s to 1000 s.

SMU Power On Sequence

When you run a test, the SMUs for the given test power on in a specific sequence. You can adjust this sequence.

To adjust the power-on sequence for the SMUs:

1. Select the test.
2. Select **Configure**.
3. In the right pane, select the **Test Settings** tab.
4. Select **Advanced**.
5. Under SMU Power On Sequence, use the **Move Up** and **Move Down** buttons to change the sequence.
6. Select **OK**.

Disable outputs at completion - SMU

WARNING

If "Disable Outputs at Completion" is cleared, the SMU outputs remain at their last programmed levels when the test is completed. To prevent electrical shock that could cause injury or death, never make or break connections to the 4200A-SCS while the output is on.

When a test is complete, you can disable the outputs or leave them enabled. If you enable the outputs, the SMU starts the next test from its state at the end of the previous test. If the next test does not use the SMU, the SMU remains in that state.

To set the output action on completion:

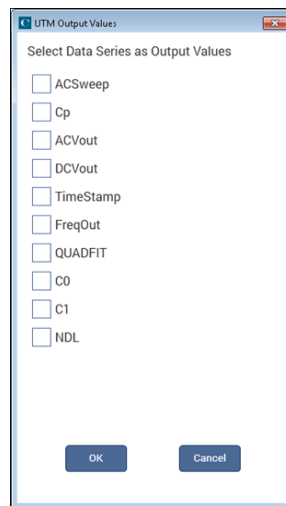
1. Select the test.
2. Select **Configure**.
3. In the right pane, select the **Test Settings** tab.
4. Select **Advanced**.
5. Select or clear **Disable Outputs at Completion**.

Output Values

If you are using subsites, each time a subsite is cycled, the measurements for the enabled Output Values are placed in the Analyze sheet for the subsite. For example, if the subsite is cycled five times, there will be five measured readings (Output Values) for the test. For details, see "Subsite cycling" in the *Model 4200A-SCS Clarius User's Manual*.

To select output values:

1. In the project tree, select the test.
2. Select **Configure**.
3. In the right pane, select **Test Settings**.
4. Select **Output Values**. The Output Values dialog box is displayed.
5. Select the data series that you want to send to the Analyze sheet.
6. Select **OK**.

Figure 52: Select Output Values

Compliance exit-condition options

The compliance exit-condition options are available from the Test Settings pane when you select **Exit Condition**.

When the source goes into compliance, you can choose the action that the system takes.

You can select one of the following exit-condition options:

- **None:** The run continues. This is the default setting.
- **Test:** The 4200A-SCS exits the test that is presently being run. If there are additional tests, operation continues to the next test.
- **Device:** The 4200A-SCS exits the device that is presently being run. If there are additional devices, operation continues to the next device.
- **Subsite:** The 4200A-SCS exits the subsite presently being run. If there are additional subsites, operation continues to the next subsite.
- **Site:** The 4200A-SCS exits the site. If there are multiple sites, operation continues to the next site.
- **Project:** The 4200A-SCS exits the project. All testing stops.

To set the Exit Condition when compliance occurs:

1. Select the test in the project tree.
2. Select **Configure**.
3. Select **Test Settings**.
4. Select **Exit Condition**.
5. Select the option for your test.
6. Select **OK**.

Source-measure hardware

In this section:

Source-measure units	4-1
Source-measure hardware overview.....	4-1
Basic SMU circuit configuration.....	4-2
SMU terminals and connectors	4-3
Source-measure unit (SMU) with 4200-PA overview	4-5
Ground unit (GNDU) overview	4-12

Source-measure units

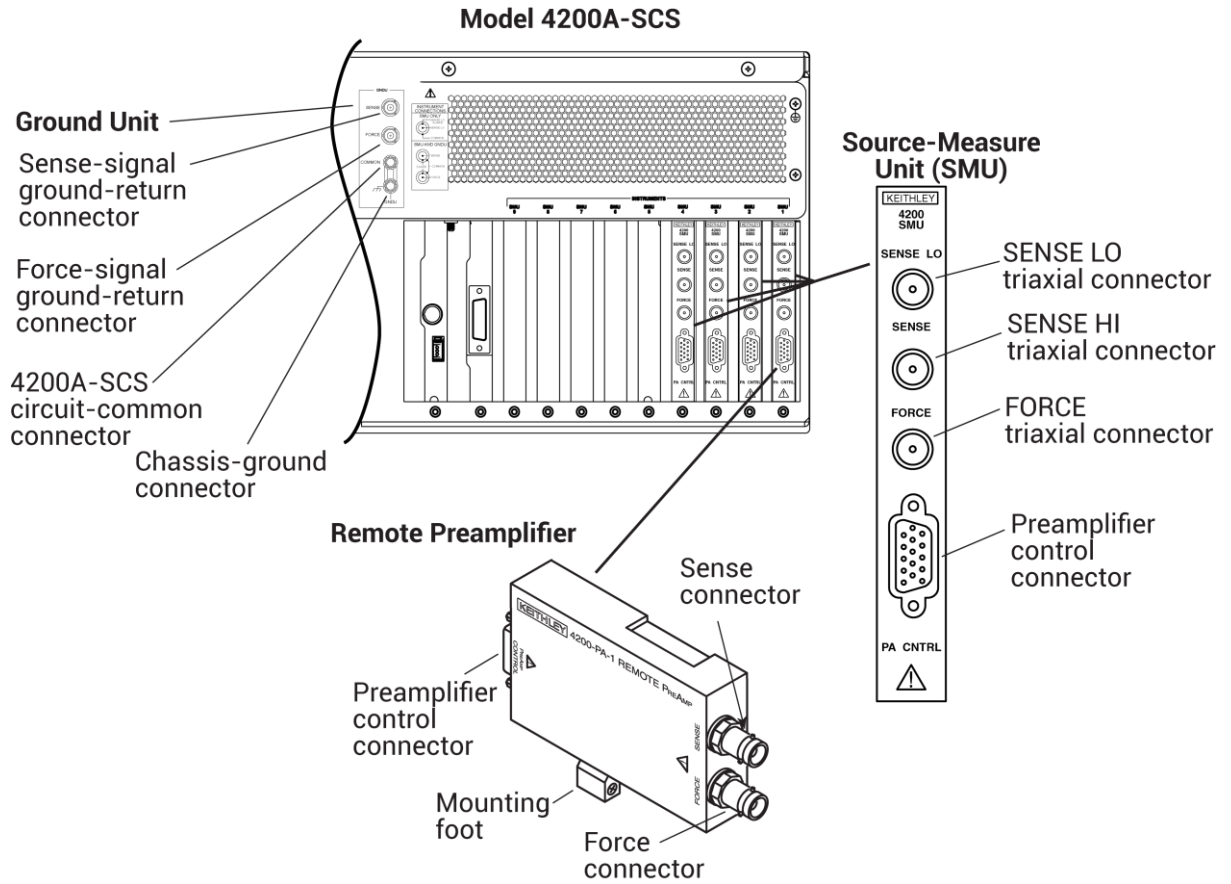
This section provides information about the hardware and connections for the 4200-SMU, 4201-SMU, 4210-SMU, and 4211-SMU source-measure units and related instruments, including:

- [Source-measure hardware overview](#) (on page 4-1): Discusses basic circuit configurations for SMUs, operating boundaries, and connectors.
- [Source-measure unit \(SMU\) with 4200-PA overview](#) (on page 4-5): Details how the 4200-PA extends the dynamic range of the SMUs. Also describes basic circuit configurations, operating boundaries, and connectors.
- [Ground unit \(GNDU\) overview](#) (on page 4-12): Provides basic information about using the ground unit.

Source-measure hardware overview

The 4200A-SCS mainframe accepts up to eight SMUs, each of which may be used with or without preamplifiers. Four of the SMUs may be high-power 4210-SMU or 4211-SMU models.

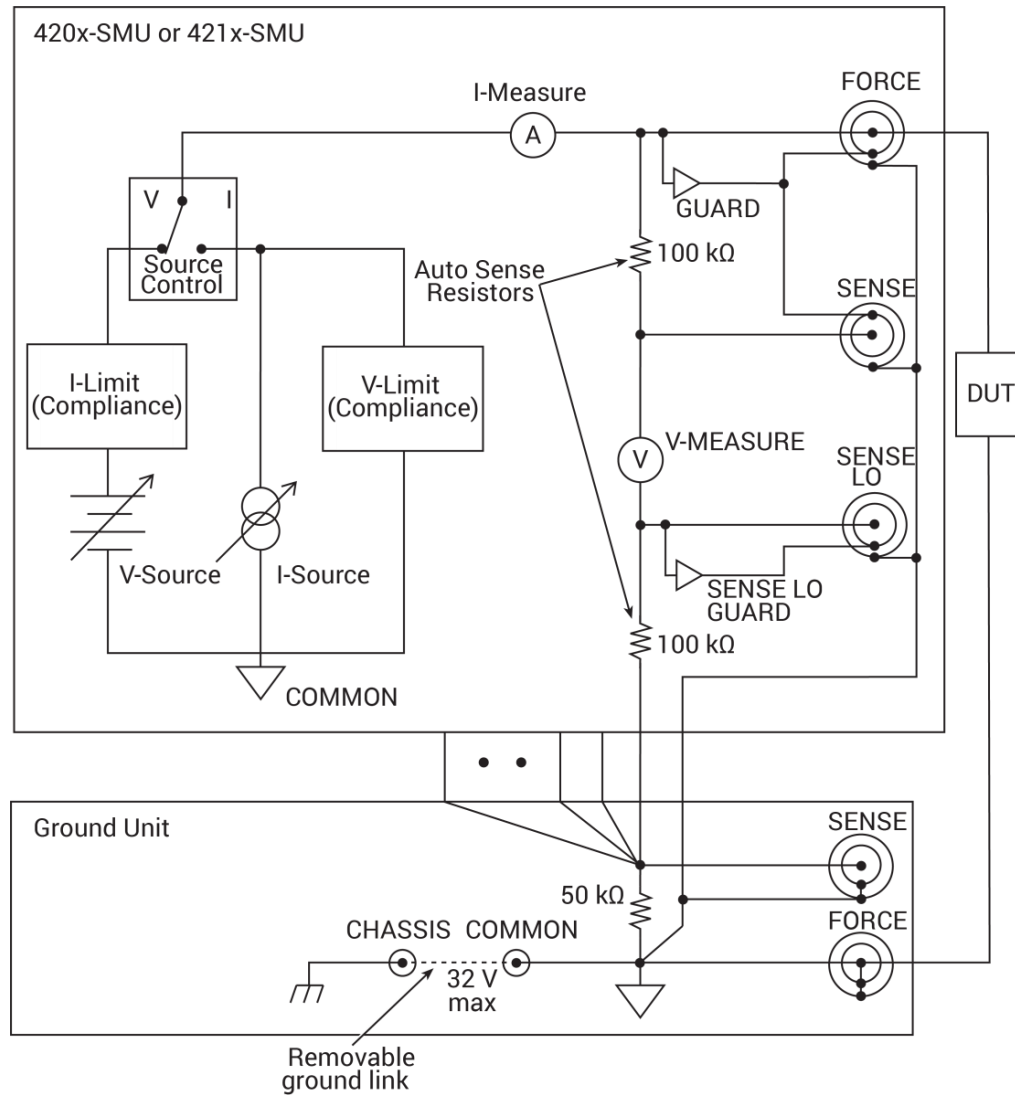
Figure 53: Source-measure hardware overview



Basic SMU circuit configuration

The basic SMU circuit configuration is shown in the following figure. The SMU is essentially a voltage or current source in series with a current meter, connected in parallel with a voltage meter. The voltage limit (V-limit) and current limit (I-limit) circuits limit the voltage or current to the programmed compliance value. In this example of local sensing, the SMU FORCE terminal is connected to DUT HI, while DUT LO is connected to COMMON. See [Basic source-measure connections](#) (on page 2-1) for more detailed information.

Figure 54: Basic SMU source-measure configuration



SMU terminals and connectors

The locations and configuration of the SMU terminals are shown in the following figure. Basic information about these terminals is summarized below.

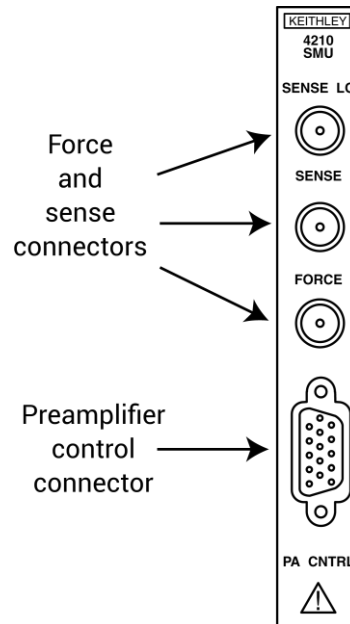
⚠ WARNING

Asserting the interlock allows the SMU and preamplifier terminals to become hazardous, exposing the user to possible electrical shock that could result in personal injury or death. SMU and preamplifier terminals should be considered hazardous even if the outputs are programmed to be low voltage. Precautions must be taken to prevent a shock hazard by surrounding the test device and any unprotected leads (wiring) with double insulation that is rated for 250 V, Category 0.

CAUTION

The maximum allowed voltage between COMMON and chassis ground is ± 32 V dc.

Figure 55: 4200-SMU and 4210-SMU connectors



SENSE LO terminal

The SENSE LO terminal is a miniature triaxial connector used to apply the SMU SENSE LO signal to the DUT in a full-Kelvin (remote sense) application.

- The center pin is SENSE LO
- The inner shield is SENSE GUARD
- The outer shield is circuit COMMON

Nominal internal autosense resistance appears between SENSE LO GUARD and COMMON.

NOTE

Use the remote sense capability of the ground unit instead of the SENSE LO of a SMU. If it is necessary to use the SENSE LO terminal of a SMU, connect the SENSE LO terminals of all SMUs used in a single 4200A-SCS to the DUT.

SENSE terminal

The SENSE terminal is a miniature triaxial connector used to apply the SMU SENSE signal to the DUT in a remote-sense application when the preamplifier is not used.

- The center pin is SENSE
- The inner shield is GUARD
- The outer shield is circuit COMMON

Nominal internal autosense resistance appears between SENSE and FORCE.

NOTE

The SENSE terminal does not need to be connected to the DUT for the SMU to operate correctly. Remote sensing is automatic. If SENSE is connected to the DUT, errors due to voltage drops in the FORCE path between the SMU and the DUT are eliminated and the SMU senses locally.

FORCE terminal

The FORCE terminal is a miniature triaxial connector used to apply the SMU FORCE signal to the DUT when a preamplifier is not used.

- The center pin is FORCE
- The inner shield is GUARD
- The outer shield is circuit COMMON

PA CNTRL connector

The PA CNTRL (preamplifier control) terminal is a 15-pin D-sub connector that provides both power and signal connections to the 4200-PA Remote Preamplifier. The preamplifier can either be mounted and connected directly to the SMU, or it can be connected to the SMU using a cable (4200-RPC-X) when mounted remotely. Refer to the [Source-measure unit \(SMU\) with 4200-PA overview](#) (on page 4-5) for more information on the preamplifier.

Source-measure unit (SMU) with 4200-PA overview

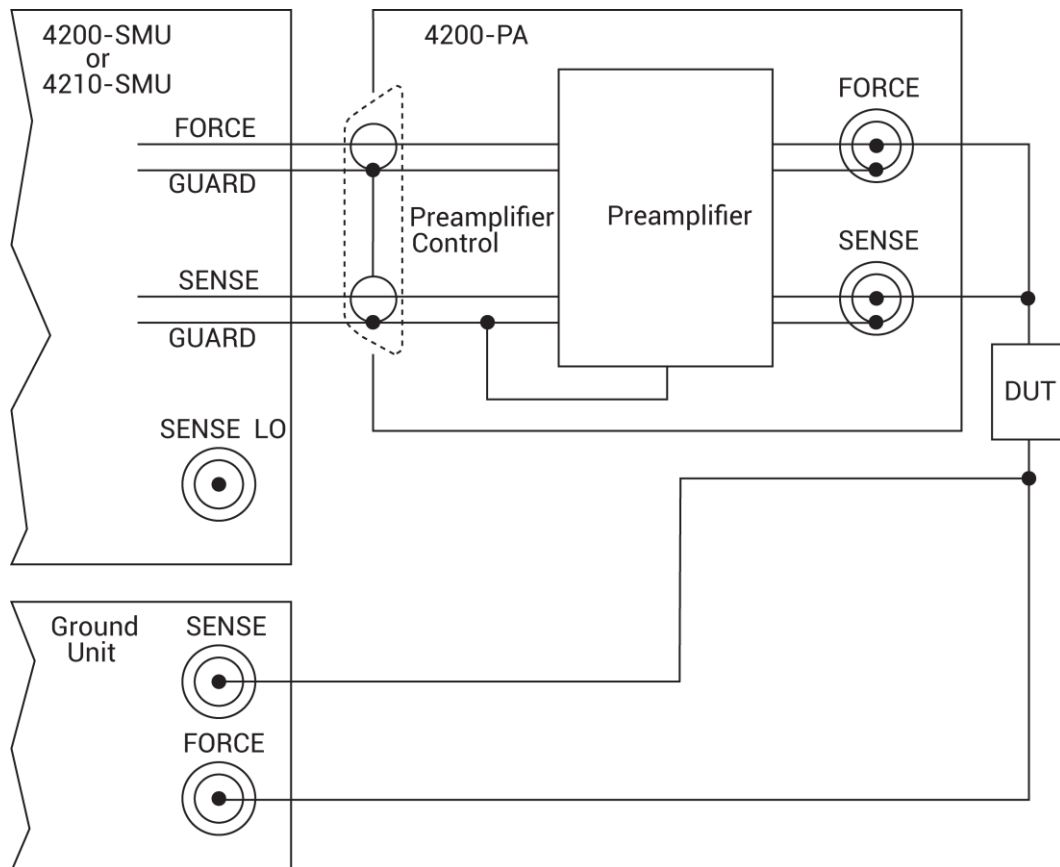
The following paragraphs discuss these aspects of the 4200-PA remote preamplifier:

- Basic circuit configuration
- Compliance limit
- Operating boundaries
- Connectors
- Preamplifier mounting

Basic SMU/preamplifier circuit configuration

The basic SMU and preamplifier circuit configuration is shown in the following figure. This configuration is similar to the SMU configuration discussed earlier, with the exception of the preamplifier, which adds low-current source-measure capabilities. The preamplifier FORCE terminal is connected to DUT HI and DUT LO is connected to COMMON. See [Basic source-measure connections](#) (on page 2-1) for more detailed information.

Figure 56: Basic SMU and preamplifier source-measure configuration



Compliance limit for a SMU with a 4200-PA

A current limit can be programmed for a SMU with a 4200-PA when it is sourcing voltage. However, a voltage limit can be programmed when sourcing current. The compliance limit characteristics are the same for a SMU with a 4200-PA as for a SMU alone. Refer to [Compliance limits](#) (on page 3-17).

Using minimum compliance

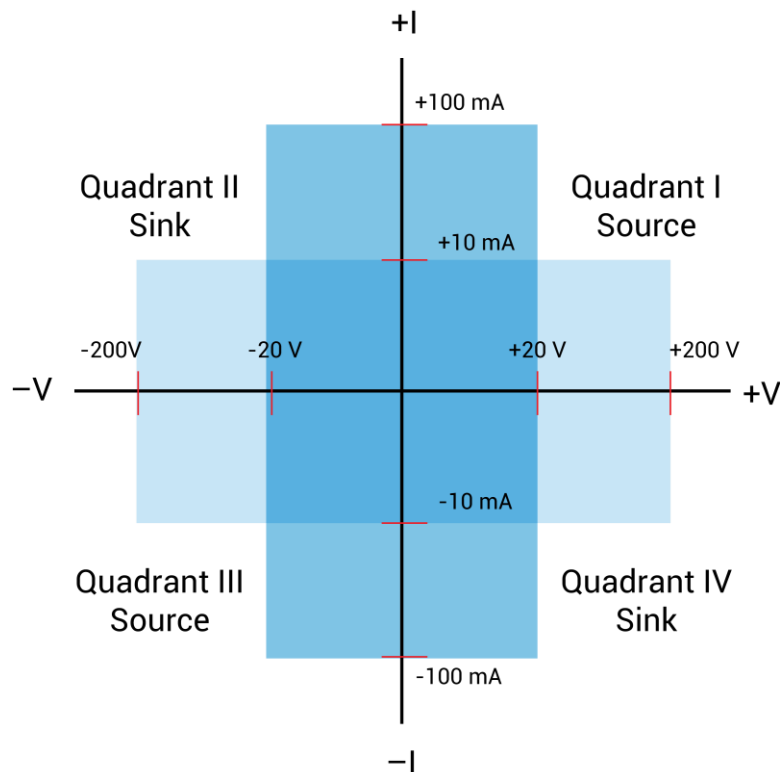
The minimum compliance value is particularly applicable when measurement autorange is disabled. When measurement autorange is disabled, the compliance value cannot be set below the minimum value that is specified in the previous tables indicating 4200-PA compliance limits. When autorange is enabled, the programmed compliance value cannot be set below 100 fA when sourcing voltage, or below 20 mV when sourcing current.

Operating boundaries

The four quadrants of operation for the 4200-PA with a SMU are shown in the following figures.

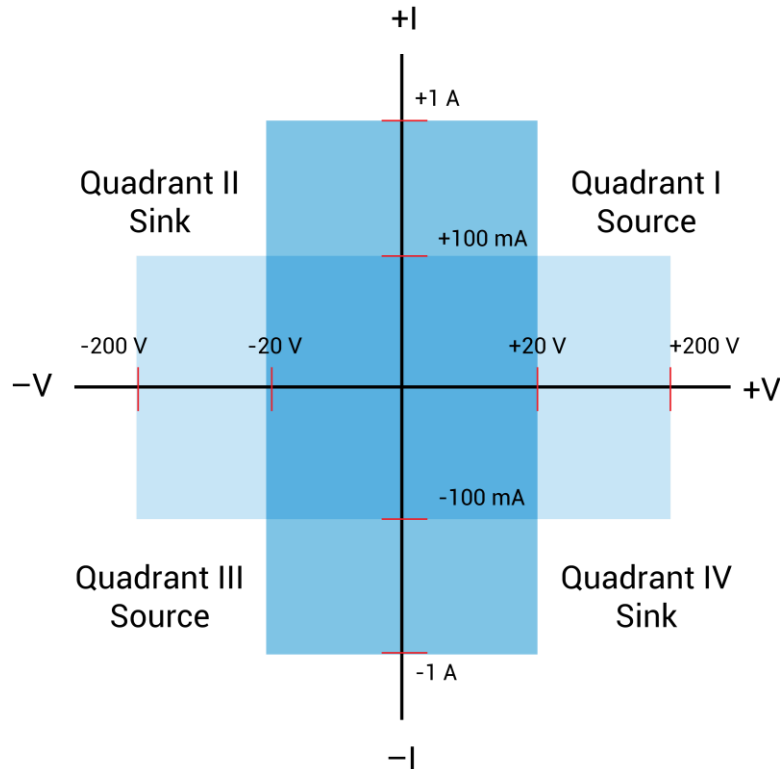
4200-SMU or 4201-SMU with 4200-PA: In the general operating boundaries in the following figure, the 100 mA, 20 V and 10 mA, 200 V magnitudes are nominal values. The actual maximum output magnitudes of the 4200-SMU or 4201-SMU and 4200-PA are 105 mA, 21 V and 10.5 mA, 210 V. Note that the boundaries are not drawn to scale.

Figure 57: 4200-SMU or 4201-SMU with a 4200-PA operating boundaries



4210-SMU or 4211-SMU with 4200-PA: In the following figure, the 1 A, 20 V and 100 mA, 200 V magnitudes are nominal values. The actual maximum output magnitudes of the 4210-SMU or 4211-SMU and 4200-PA are 1.05 A, 21 V and 105 mA, 210 V. Note that the boundaries are not drawn to scale.

Figure 58: 4210-SMU or 4211-SMU with a 4200-PA operating boundaries



Preamplifier terminals and connectors

The locations and configuration of the 4200-PA terminals are shown in the following figure. Basic information about these terminals is summarized below. Refer to the [Basic source-measure connections](#) (on page 2-1) for additional information regarding making preamplifier signal connections.

⚠ WARNING

Exposure to electrical shock could result in personal injury or death. Precautions must be taken to prevent a shock hazard by surrounding the test device and any unprotected leads (wiring) with double insulation that is rated for 250 V, Category O. See IEC 61010-1 safety standards for details. When connecting to the 4200A-SCS SMU outputs, make sure to use devices and cables that have ratings for the sourced voltages. Cables with incorrect ratings will not properly insulate the external connections to the instrument and may pose a shock hazard. SMU and preamplifier terminals should be considered hazardous even if the outputs are programmed to be low voltage.

CAUTION

Turn off the system and disconnect the power cord before connecting or disconnecting the preamplifier. Failure to do so may result in SMU or preamplifier damage, possibly voiding the warranty.

CAUTION

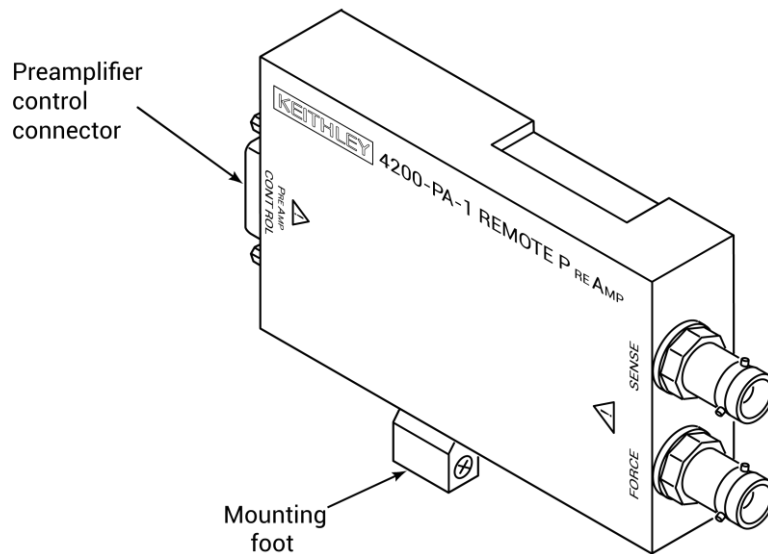
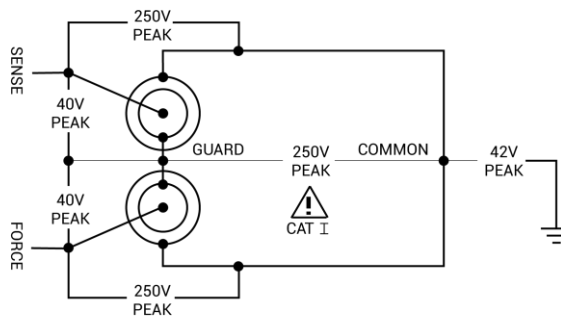
The maximum allowed voltages between the various preamplifier signals are as follows:

COMMON to chassis ground: 32 V_{PEAK}

GUARD to COMMON: 250 V_{PEAK}

SENSE or FORCE to GUARD: 40 V_{PEAK}

Figure 59: 4200-PA connectors



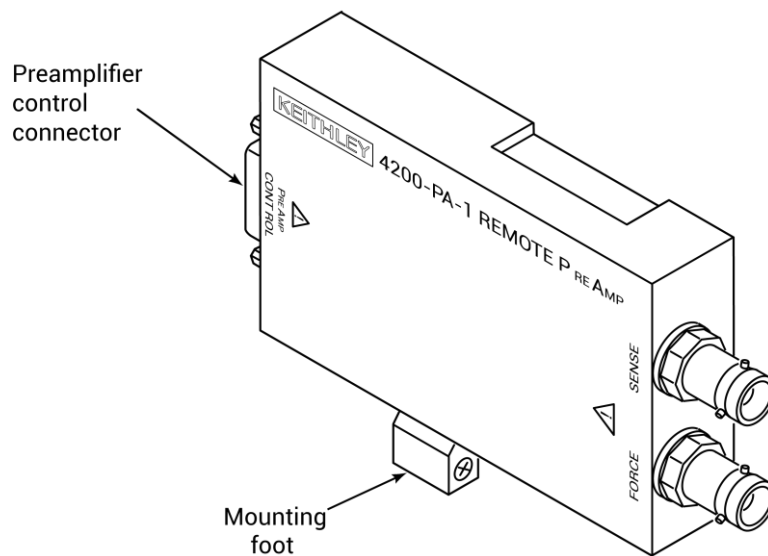
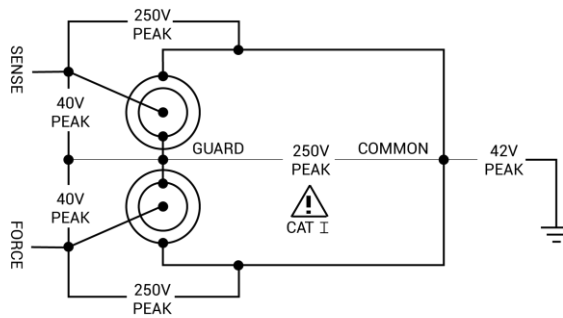
FORCE terminal

The FORCE terminal is a standard triaxial connector used as a return path for the SMU or preamplifier FORCE current. The center pin is FORCE, the inner shield is GUARD, and the outer shield is circuit COMMON.

NOTE

The ground unit FORCE and GUARD signal terminals are connected to circuit COMMON.

Figure 60: 4200-PA connectors



SENSE terminal

The SENSE terminal is a standard triaxial connector used to apply the ground unit SENSE signal to the DUT in a remote sense application. The center pin is SENSE, the inner shield is GUARD, and the outer shield is circuit COMMON. When the ground unit SENSE signal is connected to a DUT, all SMU/preamplifier measurements are made relative to this DUT connection.

NOTE

The SENSE terminal does not need to be connected to the DUT for the SMU to operate correctly. Remote sensing is automatic. If SENSE is connected to the DUT, errors due to voltage drops in the FORCE path between the SMU and the DUT are eliminated; otherwise, the SMU will sense locally.

Preamplifier CONTROL connector

The preamplifier CONTROL connector connects to the SMU PA CNTRL connector and provides both power and signal connections from the SMU to the 4200-PA preamplifier.

SMU circuit COMMON connections

Some tests require SMUs to be connected to each DUT terminal. In these tests, circuit COMMON is not hardwired to any of the DUT terminals. Each SMU must be able to internally connect circuit COMMON to its FORCE signal when the test requires a DUT terminal to be connected to COMMON.

The following figure shows typical SMU connections using three SMUs to test a transistor. You can use any one of the SMUs to provide access to circuit COMMON by programming the SMU accordingly. See the *Model 4200A-SCS Clarius User's Manual* for detailed instructions on configuring a SMU to provide a COMMON connection.

Figure 61: Typical SMU connections

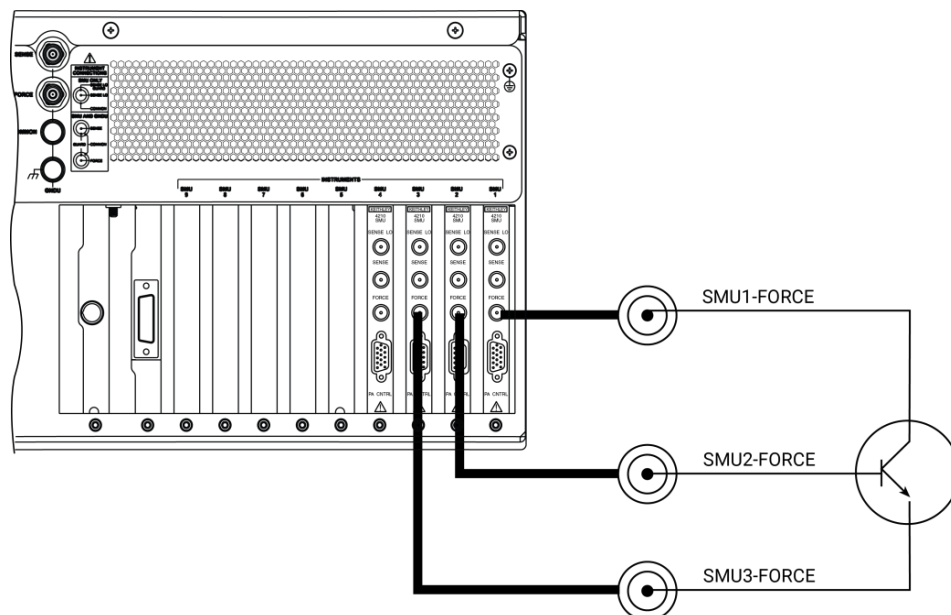
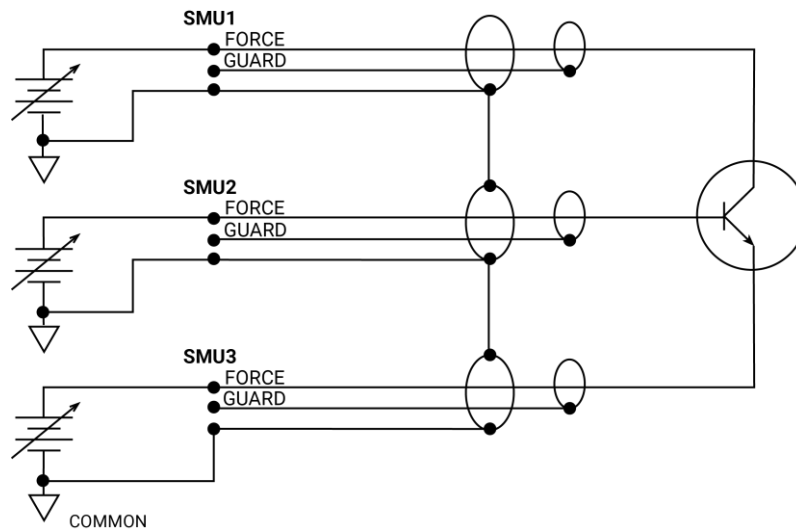


Figure 62: Typical SMU COMMON connections schematic



Ground unit (GNDU) overview

The following topics describe:

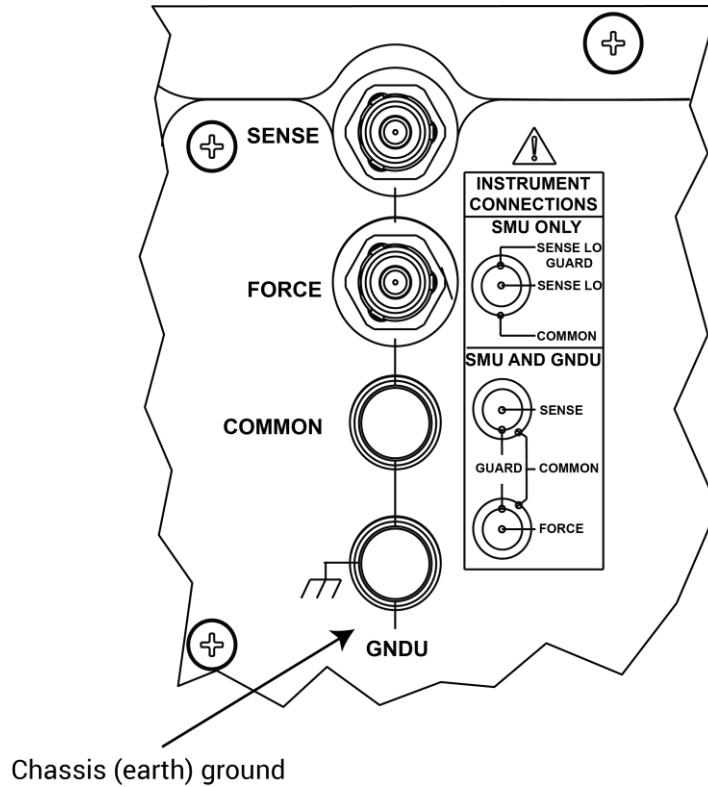
- Basic circuit configurations
- Connectors

Basic characteristics

The ground unit, shown in the following figure, provides convenient access to circuit COMMON, which is the measurement ground signal shared by all installed 4200A-SCS instrumentation. COMMON provides a convenient connection point to system chassis ground for shielding a test fixture.

The GNDU SENSE terminal provides access to the SMU SENSE LO signals

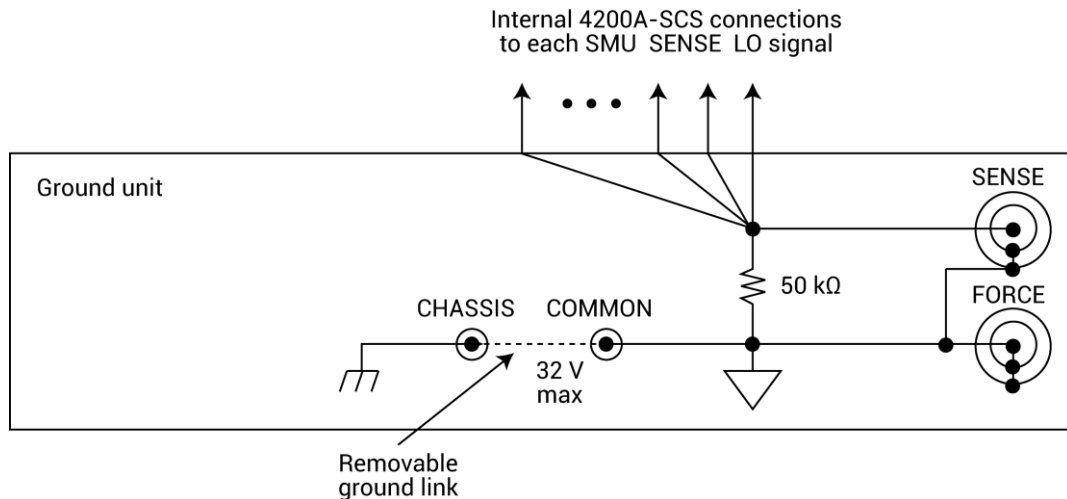
Figure 63: Ground unit (GNDU) connectors



Ground unit connections

The following figure shows how the various GNDU signals are related to the SMU signals. The GNDU FORCE signal is circuit COMMON. The GNDU SENSE terminal is connected to each SMU SENSE LO signal through an autosense resistor. When the GNDU SENSE signal is connected to a DUT, all measurements are made relative to this DUT connection.

Figure 64: Ground unit connections



Ground unit DUT connections

The following figure shows the connections necessary to use the GNDU with a SMU to make full-Kelvin remote sense measurements. Similarly, the following figure includes the preamplifier. As shown in these figures, the GNDU FORCE signal provides the return path for SMU or preamplifier FORCE current. See [Basic source-measure connections](#) (on page 2-1) for detailed information on the ground unit, SMU, and preamplifier connections.

Figure 65: Full-Kelvin SMU to ground unit connections

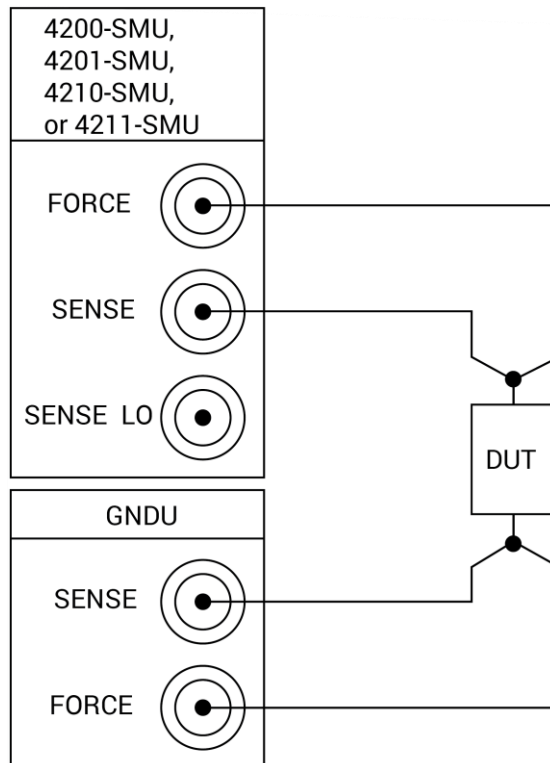
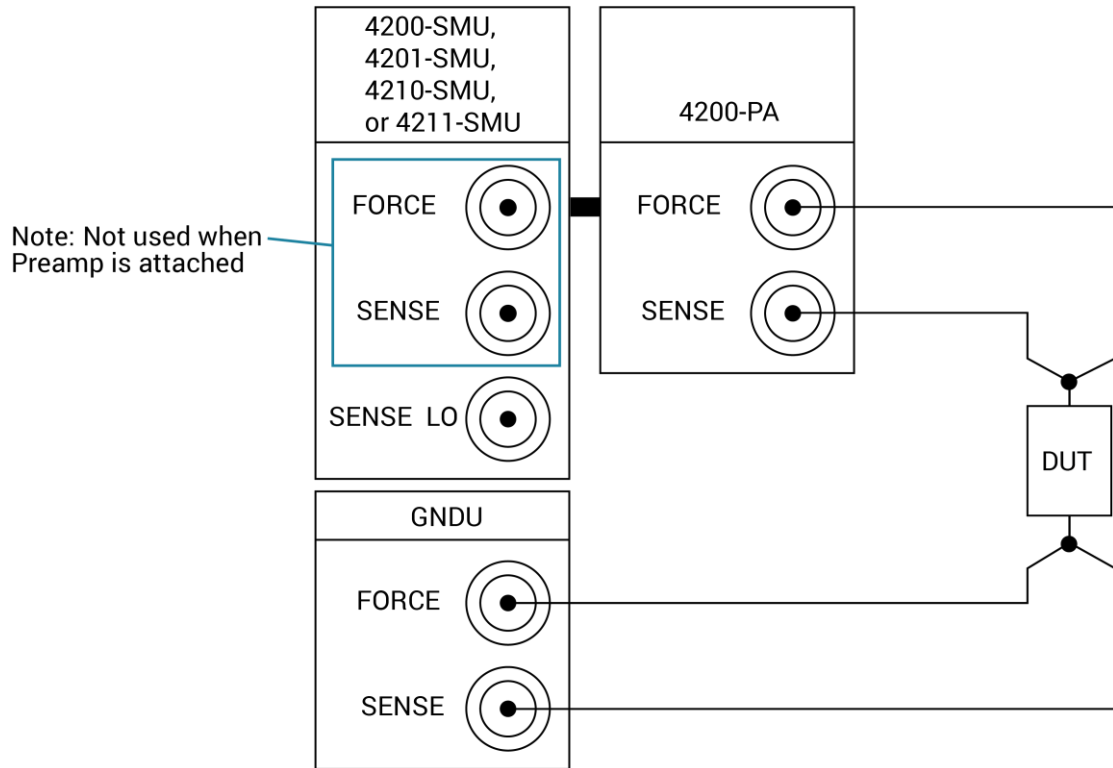


Figure 66: Full-Kelvin preamplifier to ground unit connections



Ground unit terminals and connectors

Refer to [Using the ground unit](#) (on page 2-12) for the locations and configuration of the GNDU terminals. Basic information about these connectors is summarized below. Refer to [Basic source-measure connections](#) (on page 2-1) for additional information about signal connections for ground units.

CAUTION

The maximum allowed voltage between circuit COMMON and chassis ground is ± 32 V dc.

FORCE terminal

The FORCE terminal is a standard triaxial connector used as a return path for the SMU or preamplifier FORCE current. The center pin is FORCE, the inner shield is GUARD, and the outer shield is circuit COMMON.

NOTE

The ground unit FORCE and GUARD signal terminals are connected to circuit COMMON.

SENSE terminal

The SENSE terminal is a standard triaxial connector used to apply the ground unit SENSE signal to the DUT in a remote sense application. The center pin is SENSE, the inner shield is GUARD, and the outer shield is circuit COMMON. When the ground unit SENSE signal is connected to a DUT, all SMU/preamplifier measurements are made relative to this DUT connection.

COMMON terminal

The COMMON terminal is a binding post that provides access to circuit COMMON.

NOTE

Normally, a link is connected between ground unit COMMON and chassis ground, but it may be necessary to remove the link to avoid measurement problems caused by ground loops or electrical interference. Refer to [Interference](#) (on page 6-11) for details.

Source-measure concepts

In this section:

Source-measure concepts	5-1
Guarding	5-1
Local and remote sensing	5-5
Source or sink	5-8
Source-measure considerations.....	5-12
Sweep concepts.....	5-19
Operation mode timing.....	5-22

Source-measure concepts

- [Guarding](#) (on page 5-1): An overview of guarding, guarding concepts, guard connections, and test fixture guarding.
- [Local and remote sensing](#) (on page 5-5): Describes sensing, sensing concepts, and sense selection.
- [Source or sink](#) (on page 5-8): Describes source and sink operations and summarizes the operating boundaries.
- [Source-measure considerations](#) (on page 5-12): Details various source-measure circuit configurations, including Source V, Measure V, and measure-only.
- [Sweep concepts](#) (on page 5-19): Covers the source-delay-measure cycle and provides an overview of sweep waveforms.

Guarding

The purpose of guarding is to eliminate the effects of leakage current (and capacitance) that can exist between FORCE and COMMON, or between SENSE and COMMON. The driven GUARD is always enabled and provides a buffered voltage that is at the same level as the FORCE or SENSE HI voltage (GUARD for both SOURCE and SENSE are the same signal that is referenced in FORCE). In the absence of a driven guard, leakage in the external test circuit could be high enough to adversely affect the performance of the SMU or preamplifier.

Leakage current can occur through parasitic or nonparasitic leakage paths. An example of parasitic resistance is the leakage path across the insulation in a triaxial cable. An example of nonparasitic resistance is the leakage path through a resistor that is connected in parallel to the device-under-test (DUT).

⚠ WARNING

To avoid high voltage exposure that could result in personal injury or death, whenever the interlock of the 4200A-SCS is asserted, the FORCE and GUARD terminals of the SMUs and preamplifier should be considered to be at high voltage, even if they are programmed to a nonhazardous voltage current.

Guard connections

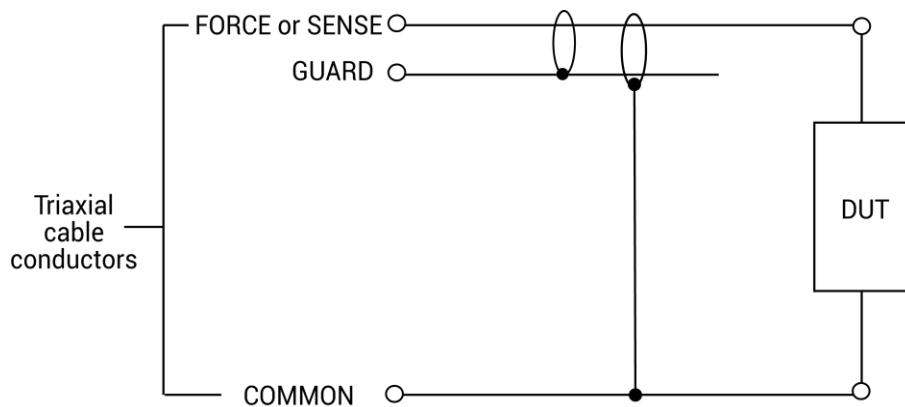
GUARD is available at the inner shield of the FORCE and SENSE triaxial connectors for both the SMU and the preamplifier, as shown in the following figure.

Figure 67: SMU and preamplifier triaxial connectors



The following figure shows the triaxial cable connections to the device under test (DUT). GUARD is not connected in this example, but it can be routed internally to a test fixture, as described in [Test fixture guarding](#) (on page 5-4).

Figure 68: GUARD connections

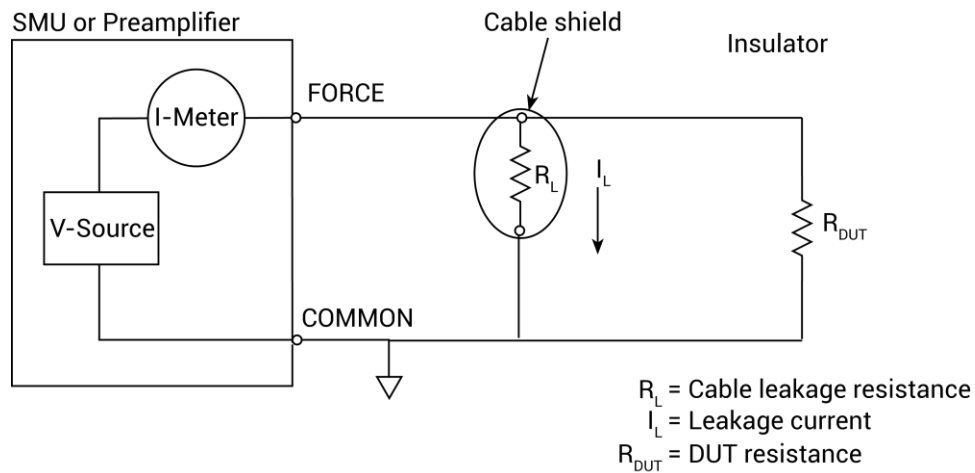


Guarding concepts

Guarding is especially important with high-impedance circuits. Consider the comparison of the unguarded and guarded circuits shown in the following figures. In both cases, FORCE is connected to DUT HI and COMMON is connected to DUT LO.

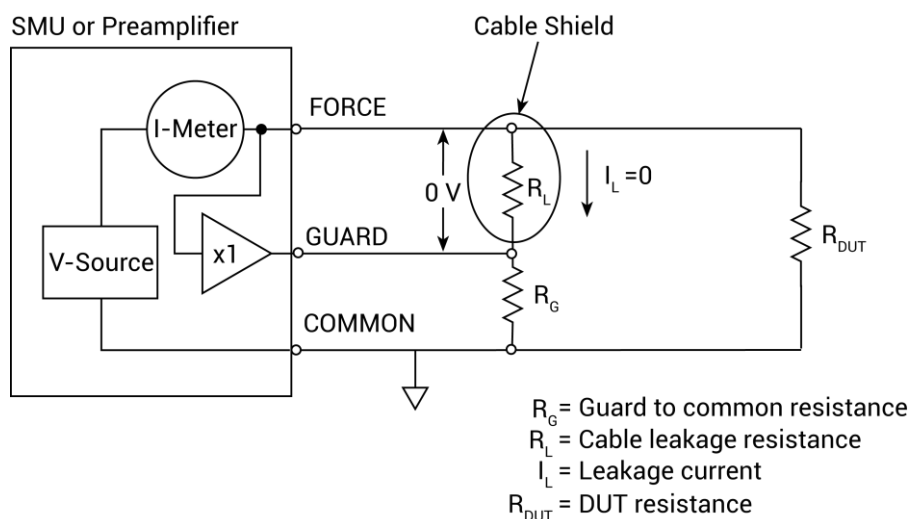
In the unguarded circuit in the following figure, the cable leakage resistance, R_L , is effectively in parallel with the DUT, creating an unwanted leakage current, I_L . This leakage current may seriously affect readings, particularly at low current levels.

Figure 69: Unguarded circuit



In the guarded circuit of the following figure, the cable shield is driven by a unity-gain, low-impedance amplifier (GUARD). Since the voltage across R_L is nearly 0 V, the leakage current is effectively eliminated. Current through any leakage resistance (R_G) between the shield and COMMON may be considerable, but it is of little consequence because it is supplied by the unity-gain amplifier rather than the FORCE terminal of the SMU or preamplifier.

Figure 70: Guarded circuit



Test fixture guarding

GUARD used to drive the inner shields of triaxial connecting cables can be routed within test fixtures. Inside the test fixture, a triaxial cable can be used to extend the guard near to the DUT, and the guard can be connected to a guard plate or shield that surrounds the DUT. The center conductor of the cable is used for FORCE or SENSE, the inner shield is used for GUARD, and the outer shield is COMMON.

⚠ WARNING

To provide protection from shock hazards, an enclosure should be provided that surrounds all live parts.

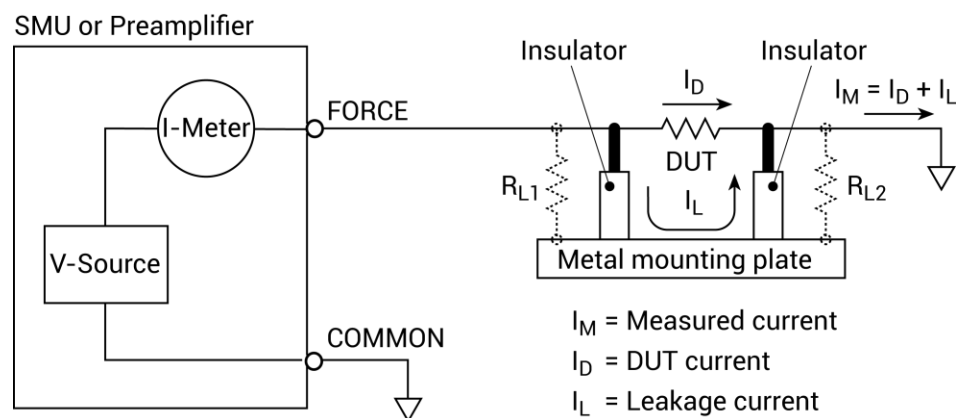
Nonconductive enclosures must be constructed of materials that are suitably rated for flammability and the voltage and temperature requirements of the test circuit. Connect the enclosure of all metal test fixtures to protective earth (safety ground). See your specific test fixture for information. Nonconductive test fixtures must be rated to double the maximum capability of the test equipment in the system.

For metallic enclosures, the test fixture chassis must be properly connected to protective earth (safety ground). A grounding wire (16 AWG or larger) must be attached securely to the test fixture at a screw terminal designed for safety grounding. The other end of the ground wire must be attached to a known protective earth (safety ground).

The following figures show how guard can eliminate leakage current through the insulators in a test fixture.

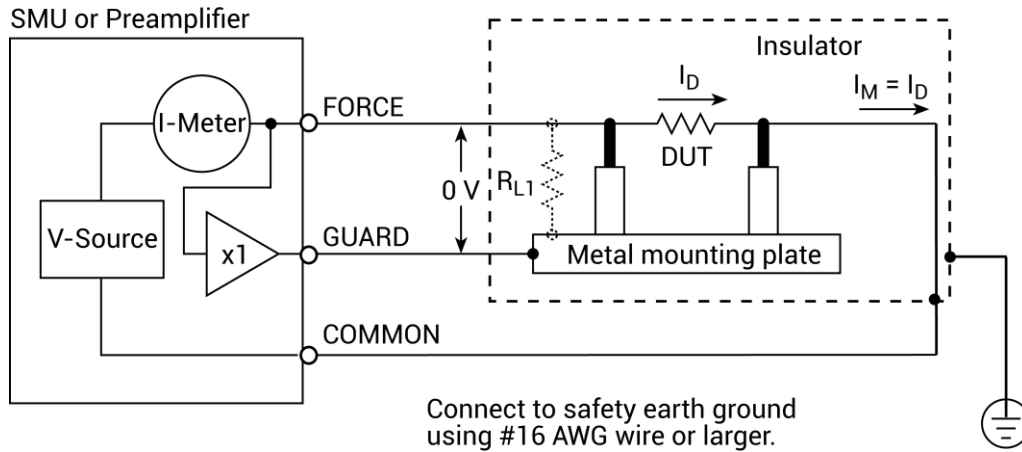
In the following figure, leakage current (I_L) flows through the insulators (R_{L1} and R_{L2}) to COMMON, adversely affecting the low-current (or high-resistance) measurement of the DUT.

Figure 71: Test fixture - unguarded



In the following figure, the driven GUARD is connected to the metal guard plate for the insulators. Since the voltage on either end of R_{L1} is the same (0 V drop), no current can flow through the leakage resistance path. As a result, the SMU or preamplifier measures only the current through the DUT.

Figure 72: Test fixture - guarded



NOTE

The guard signal has an output impedance of 100 k Ω , which is effective only when connected to high-impedance loads.

Local and remote sensing

The type of sensing, local or remote, is automatically selected depending on the connections.

Local sensing is adequate for many test and measurement situations. However, you should use remote sensing for maximum accuracy for the following source-measure conditions:

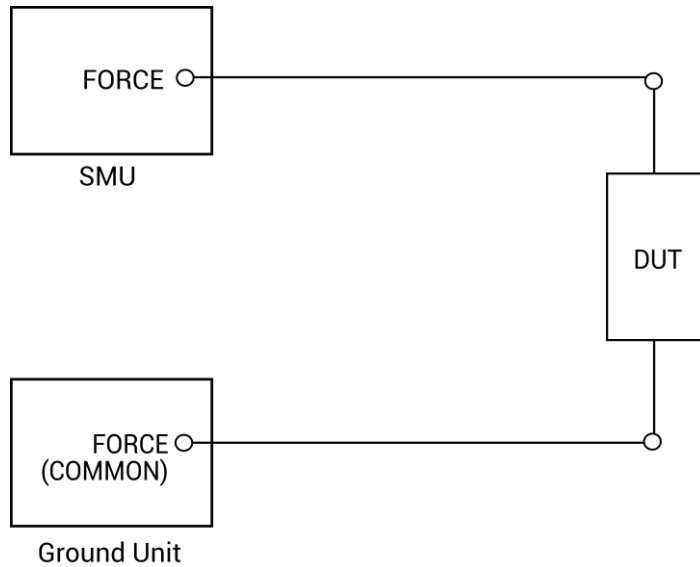
- Test circuit impedance <1 k Ω
- Maximum voltage source or voltage measurement accuracy are required

NOTE

Specified accuracies for both source and measure are achieved using remote sensing.

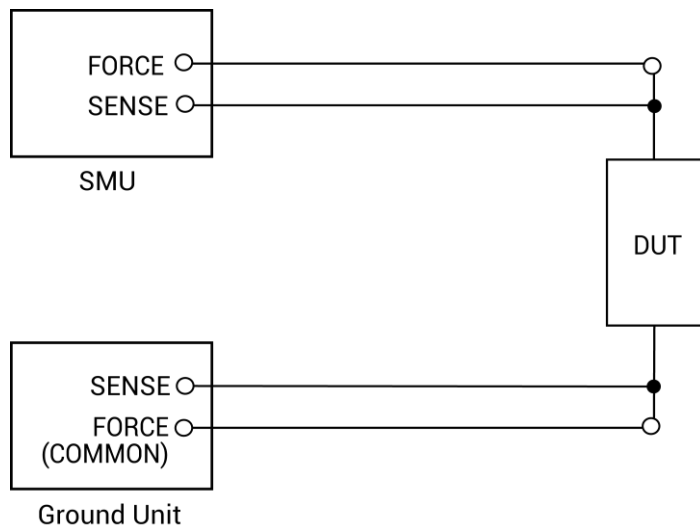
To use local sensing, connect only SMU FORCE and ground unit FORCE (COMMON) to the DUT, as shown in the following figure.

Figure 73: Local sensing overview



To use remote sensing, connect both SENSE and both FORCE terminals to the DUT as shown in the following figure.

Figure 74: Remote sensing overview



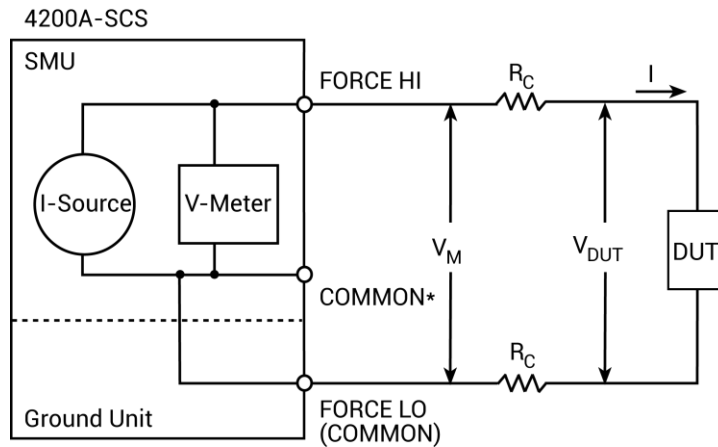
NOTE

See [Basic source-measure connections](#) (on page 2-1) for detailed information on various connection methods. To simplify the figures, Guard connections are not shown.

Local sensing

Measurements made on devices with impedances above approximately 1 kΩ are generally made using the local sensing method, as shown in the following figure. The SMU test current is forced through the test leads and the DUT being measured, developing a voltage across the device (V_{DUT}). The SMU then measures the voltage across the DUT (V_M) through the same set of test leads.

Figure 75: Local sensing



* Common terminal on the SMU is the outside shield of the triaxial connector.

R_C = Cable resistance

I = Test current through DUT

V_M = Measured voltage

V_{DUT} = Voltage across DUT

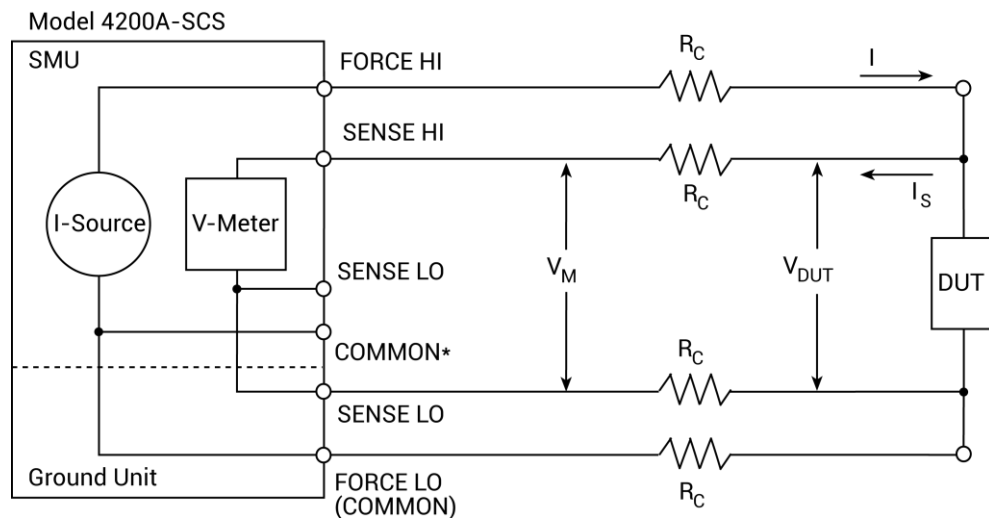
$V_{DUT} < V_M$ because of I through R_C

If you are measuring low-impedance DUTs, the local sensing method may give inaccurate results. The cable resistance (R_C) and the connection resistance (such as matrix crosspoint resistance or prober-to-IC pad resistance) can be as high as 1 Ω. Since the test current (I) causes a small but significant voltage drop across the cable resistance, the voltage measured by the SMU (V_M) will not be exactly the same as the voltage directly across the DUT (V_{DUT}) and considerable error can result. Typical cable resistances lie in the range of 1 mΩ to 100 mΩ, so it may be difficult to get accurate local sensing measurements with DUT resistances below 100 Ω to 1 kΩ, depending on the magnitudes of the cable resistance and contact resistance. In these cases, you may need to use remote sensing.

Remote sensing

The remote sensing method shown in the following figure is generally preferred for measurements on low-impedance DUTs. With this configuration, the test current I is forced through the DUT through one set of test cables, while the voltage across the DUT is measured through a second set of sense cables. Although some small current (I_S) may flow through these sense cables, it is usually negligible (typically pA or less) and can generally be ignored. Since the voltage drop across the sense cables is negligible, the voltage actually measured by the SMU (V_M) is essentially the same as the voltage across the DUT (V_{DUT}).

Figure 76: Remote sensing



* Common terminal on the SMU is the outside shield of the triaxial connector.

R_C = Cable resistance

I = Test current through DUT

I_S = Sense current (negligible)

V_M = Measured voltage

V_{DUT} = Voltage across DUT

$V_{DUT} = V_M$ because of negligible I_S

Source or sink

Depending on how they are programmed and what is connected to the output (load or source), the SMUs can operate in any of the four quadrant of operation, as shown in the following figures. When operating in the first (I) or third (III) quadrant, the SMUs are operating as a source (voltage and current have the same polarity). As a source, the SMUs are delivering power to a load.

When operating in the second (II) or fourth (IV) quadrant, the SMUs are operating as a sink (voltage and current have opposite polarity). As a sink, they dissipate power rather than sourcing it. An external source (such as another SMU) or an energy storage device (such as a capacitor) can force operation into the sink region.

For example, if a second SMU that is sourcing +12 V is connected to the first SMU that is programmed for +10 V, sink operation for the first SMU occurs in the second quadrant (source +V and measure -I).

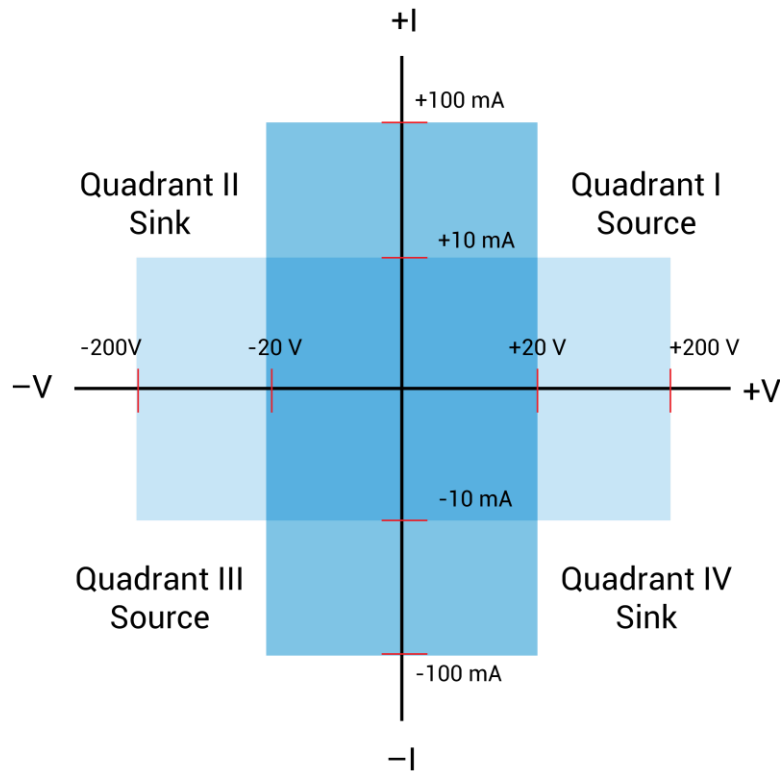
CAUTION

When using the current source as a sink, always set the voltage compliance to a level that is higher than the external voltage level. Failure to do so could damage the SMU or preamplifier due to excessive current that will flow into the unit.

4200-SMU and 4201-SMU source or sink

In the general operating boundaries in the following figure, the 100 mA, 20 V and 10 mA, 200 V magnitudes are nominal values. The actual maximum output magnitudes of the 4200-SMU and 4201-SMU are 105 mA, 21 V and 10.5 mA, 210 V. Note that the boundaries are not drawn to scale.

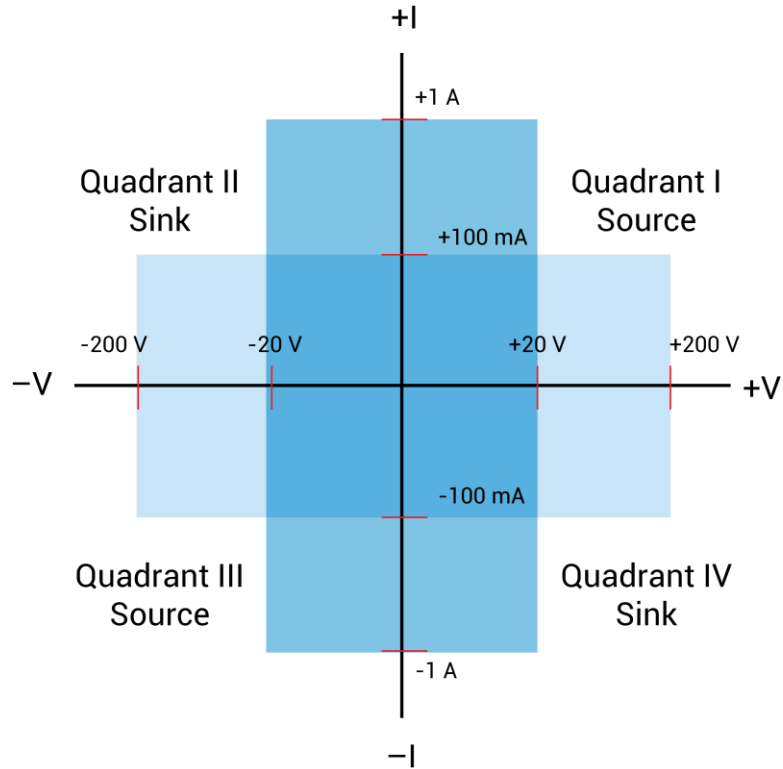
Figure 77: 4200-SMU or 4201-SMU with a 4200-PA operating boundaries



4210-SMU or 4211-SMU source or sink

In the following figure, the 1A, 20 V and 100 mA, 200 V magnitudes are nominal values. The actual maximum output magnitudes of the 4210-SMU and 4211-SMU are 1.05 A, 21 V and 105 mA, 210 V. The boundaries are not drawn to scale.

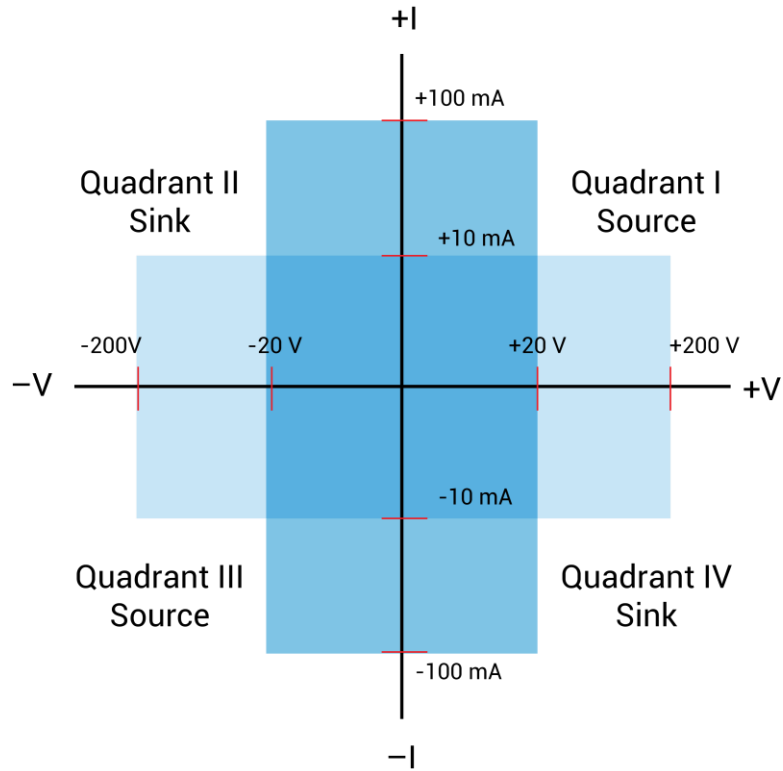
Figure 78: 4210-SMU or 4211-SMU with a 4200-PA operating boundaries



4200-SMU and 4201-SMU sink boundaries

Nominal 4200-SMU and 4201-SMU boundaries are shown in the following figure. Note that actual boundaries are 210 V at 10.5 mA or 21 V at 105 mA.

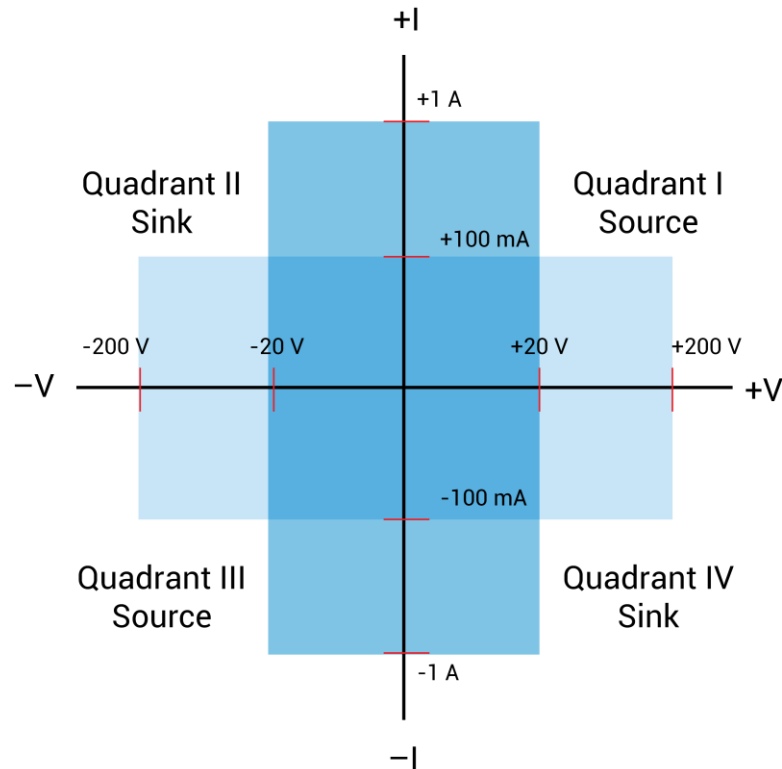
Figure 79: 4200-SMU or 4201-SMU with a 4200-PA operating boundaries



4210-SMU and 4211-SMU sink boundaries

Nominal 4210-SMU and 4211-SMU sink boundaries are shown in the following figure. Actual boundaries are 210 V at 105 mA or 21 V at 1.05 A.

Figure 80: 4210-SMU or 4211-SMU with a 4200-PA operating boundaries



Source-measure considerations

When configured to source current (I-Source), the SMU functions as a high-impedance current source with voltage limit capability that can measure current (I-Meter) or voltage (V-Meter). The compliance circuit limits the output voltage to the programmed value.

Source I, measure V or I

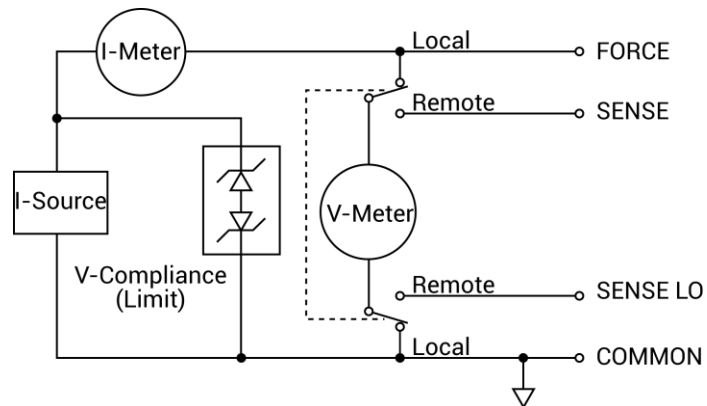
For voltage measurements, the SENSE selection (local or remote) determines where the measurement is made. In local SENSE, voltage is measured at the FORCE and COMMON terminals.

In remote SENSE, voltage can be measured directly at the DUT using the SENSE and SENSE LO terminals. This method eliminates any voltage drops that may be in the test cables or connections between the SMU or preamplifier and the DUT.

NOTE

The current source does not require or use the SENSE leads to enhance current source accuracy.

Figure 81: Source I, measure V configuration

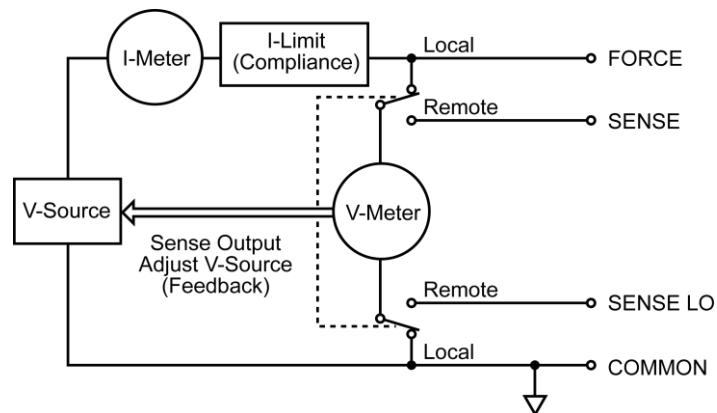


Source V, measure I or V

When configured to source voltage (V-Source) as shown in the following figure, the SMU functions as a low-impedance voltage source with current limit capability and can measure current (I-Meter) or voltage (V-Meter). The compliance circuit limits the current to the programmed value.

Sense circuitry is used to continuously monitor the output voltage and adjust the V-Source as needed. The V-Meter senses the voltage at the FORCE and COMMON terminals (local SENSE) or at the DUT (remote SENSE using the SENSE and SENSE LO terminals) and compares it to the programmed voltage level. If the sensed level and the programmed value are not the same, the V-Source is adjusted accordingly. Remote SENSE eliminates the effect of voltage drops in the test cables, ensuring that the exact programmed voltage appears at the DUT.

Figure 82: Source V, measure I configuration



Measure only (V or I)

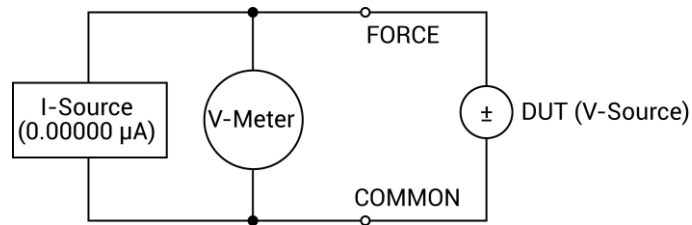
The next figures show the configurations for using the SMU exclusively as a voltmeter or ammeter. For both of these configurations, use local sensing.

CAUTION

For measure V, set the voltage compliance higher than the measured voltage. For measure I, set the current compliance higher than the measured current.

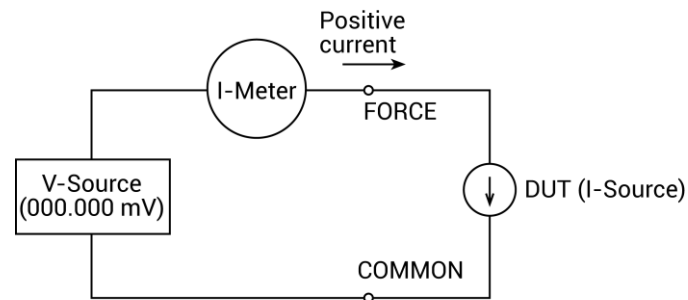
In the following figure, the SMU is configured to measure voltage only by setting it to source 0 A and measure voltage.

Figure 83: Measure voltage only



In the following figure, the SMU is configured to measure current only by setting it to source 0 V and measure current. Note that to get positive (+) readings, conventional current must flow from FORCE to COMMON.

Figure 84: Measure current only



NOTE: Positive current flowing out of FORCE results in positive (+) measurements.

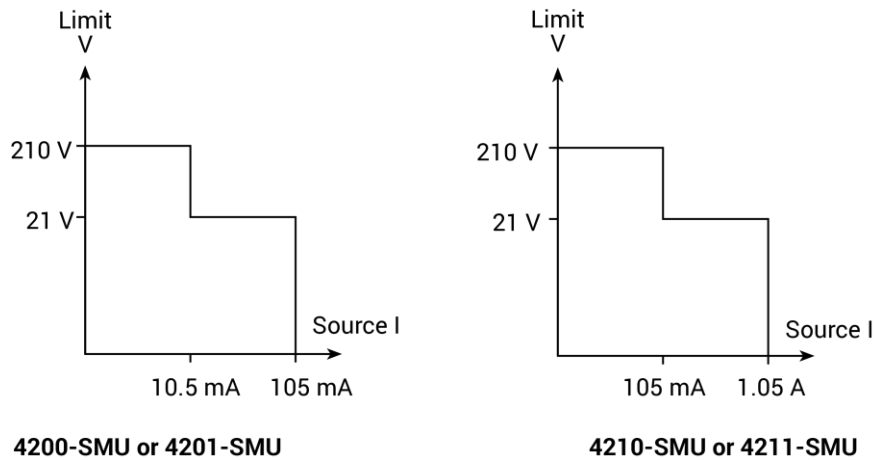
I-Source operating boundaries

Limit lines are boundaries that represent the operating limits of the SMU for a certain quadrant of operation. The operating point can be anywhere inside (or on) these limit lines. The limit line boundaries for the other quadrants are similar.

The following two figures show the operating boundaries for the I-Source. Only the first quadrant of operation is covered; operation in the other three quadrants is similar.

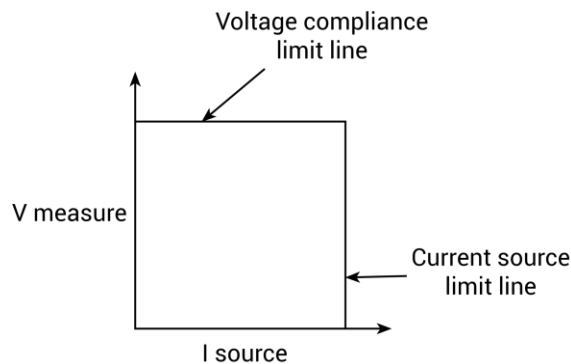
As shown in the following figure, the 4200-SMU or 4201-SMU can output up to 105 mA at 21 V, or 10.5 mA at 210 V. The 4210-SMU or 4211-SMU can output up to 1.05 A at 21 V, or 105 mA at 210 V.

Figure 85: SMU current source output characteristics



The following figure shows the limit lines for the I-source. The current source limit line represents the maximum source value possible for the selected current source range. For example, the current source limit line is at 105 mA on the 100 mA current source range. The voltage compliance limit line represents the actual compliance that is in effect.

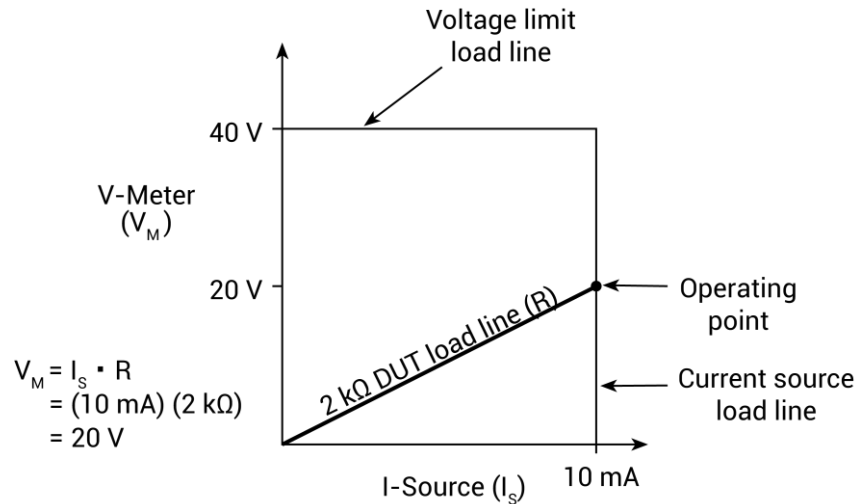
Figure 86: SMU current source limit lines



I-Source operation examples

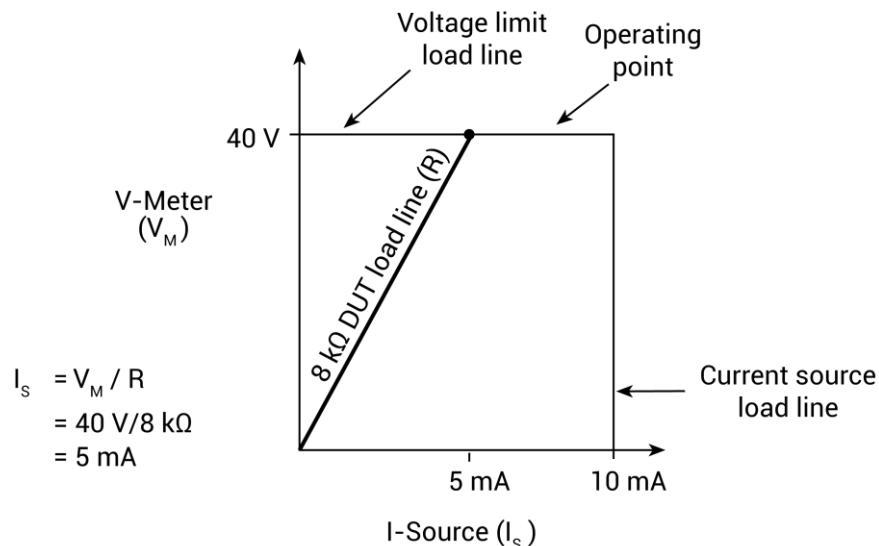
The following figures show operation examples for resistive loads that are 2 kΩ and 8 kΩ, respectively. For these examples, the SMU is programmed to source 10 mA and limit (compliance) 40 V. The SMU is sourcing 10 mA to the 2 kΩ load, and subsequently measures 20 V. As shown, the load line for 2 kΩ intersects the 10 mA current source line at 20 V, which is below the programmed voltage limit.

Figure 87: Current source normal operation



The following figure shows what happens if the resistance of the load is increased to 8 kΩ. The DUT load line for 8 kΩ intersects the 40 V voltage compliance limit line, placing the SMU in compliance. In compliance, the SMU cannot source its programmed current (10 mA). For the 8 kΩ DUT, the SMU only outputs 5 mA (at the 40 V limit).

Figure 88: Current source in compliance



Notice that as resistance increases, the slope of the DUT load line increases. As resistance approaches infinity (open output), the SMU sources virtually 0 mA at 40 V. However, as resistance decreases, the slope of the DUT load line decreases. At zero resistance (shorted output), the SMU sources 10 mA at virtually 0 V.

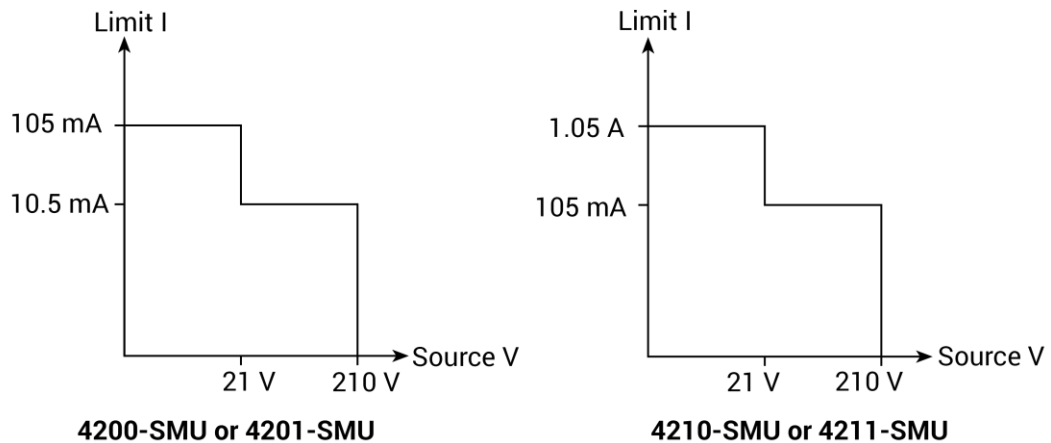
Regardless of the load, voltage will never exceed the programmed compliance of 40 V.

V-Source operating boundaries

The following figures show the operating boundaries for the voltage source. Only the first quadrant of operation is covered; operation in the other three quadrants is similar.

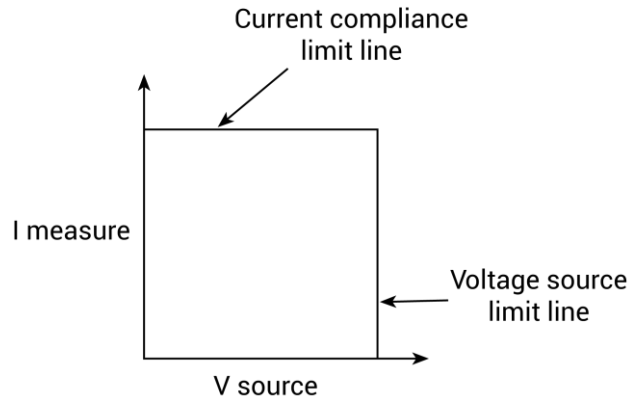
As shown in the following figure, the 4200-SMU or 4201-SMU can output up to 21 V at 105 mA, or 210 V at 10.5 mA. The 4210-SMU or 4211-SMU can output up to 21 V at 1.05 mA, or 210 V at 1.5 mA.

Figure 89: V-Source operating boundaries



The following figure shows the limit lines for the voltage source. The voltage source limit line represents the maximum source value possible for the selected voltage source range. For example, the voltage source limit line is at 21 V for the 20 V source range. The current compliance limit line represents the actual compliance in effect. These limit lines are boundaries that represent the operating limits of the SMU for this quadrant of operation. The operating point can be anywhere inside (or on) these limit lines. The limit line boundaries for the other quadrants are similar.

Figure 90: SMU voltage source limit lines

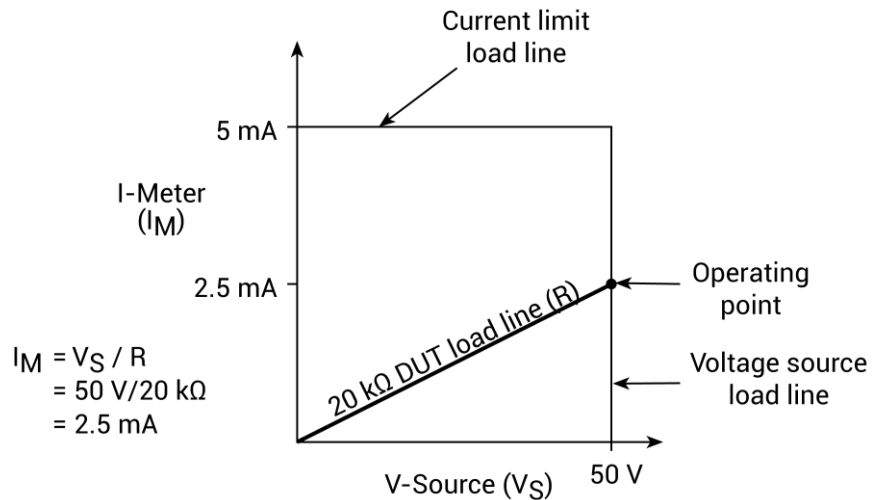


V-Source operation examples

The following figures show operation examples for resistive loads that are 20 kΩ and 8 kΩ, respectively. For these examples, the SMU is programmed to source 50 V and limit 5 mA. The SMU is sourcing 50 V to the 20 kΩ load and subsequently measures 2.5 mA, which is within the 5 mA programmed current limit.

As shown in the following figure, the load line for 20 kΩ intersects the 50 V voltage source line at 2.5 mA.

Figure 91: Normal voltage source operation

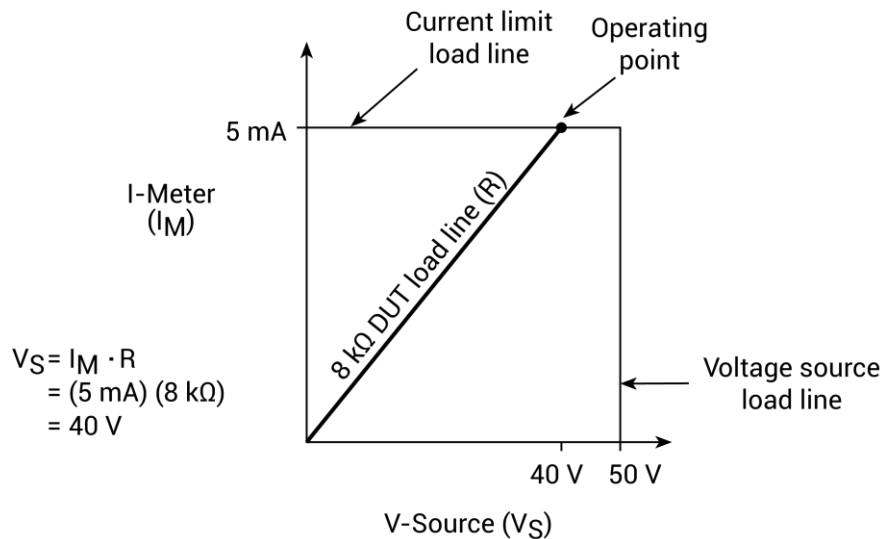


The following figure shows what happens if the resistance of the load is decreased to 8 kΩ. The DUT load line for 8 kΩ intersects the current compliance limit line, which places the SMU in compliance. In compliance, the SMU cannot source its programmed voltage (50 V). For the 8 kΩ DUT, the SMU will only output 40 V (at the 5 mA limit).

Notice that as resistance decreases, the slope of the DUT load line increases. As resistance approaches infinity (open output), the SMU will source about 50 V at 0 mA. However, as resistance decreases, the slope of the DUT load line increases. At zero resistance (shorted output), the SMU will source virtually 0 V at 5 mA.

Regardless of the load, current never exceeds the programmed compliance of 5 mA.

Figure 92: Voltage source in compliance



Source I measure I and source V measure V

The SMU can measure the function it is sourcing. When sourcing a voltage, you can also measure voltage. However, if you are sourcing current, you can also measure the output current. For these measure source operations, the measure range is always the same as the source range.

This feature is valuable when operating with the source in compliance, or when additional overall accuracy is desired. When in compliance, the programmed source value is not reached. Thus, measuring the source lets you measure the actual output voltage.

Sweep concepts

Although the SMU can be used for static source or measure operation, SMU operation usually consists of a series of source-delay-measure (SDM) cycles (see the following figure) as part of a sweep (refer to [Sweep waveforms](#) (on page 5-20)).

Source-delay-measure cycle

During each source-delay-measure cycle, the following occurs:

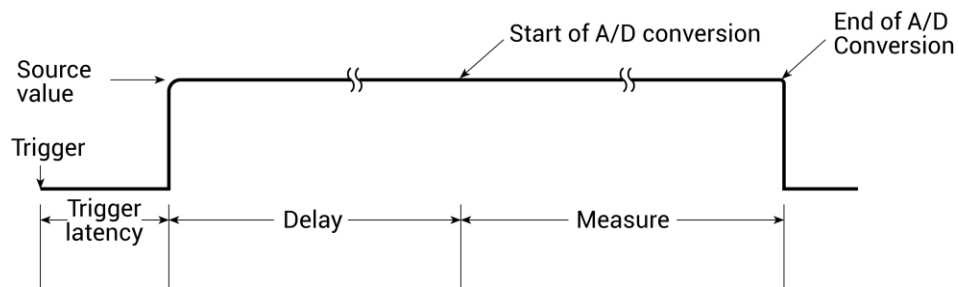
1. The source output level is set.
2. There is a wait for the source delay.
3. The measurement is made.

The delay phase of the cycle, which is programmed by software, allows the source and external circuitry to settle before the measurement is made. Although the source settles quickly if unit is not in compliance, external voltage or current settling may take longer due to interaction between the DUT and the SMU.

When there is more capacitance at the output, more settling time is required for the source signal. The actual delay that is needed can be calculated or determined by trial and error. For purely resistive loads and at higher current levels, the sweep delay can be set to a minimum.

The measure time depends on the selected integration period and it can be extended by autorange.

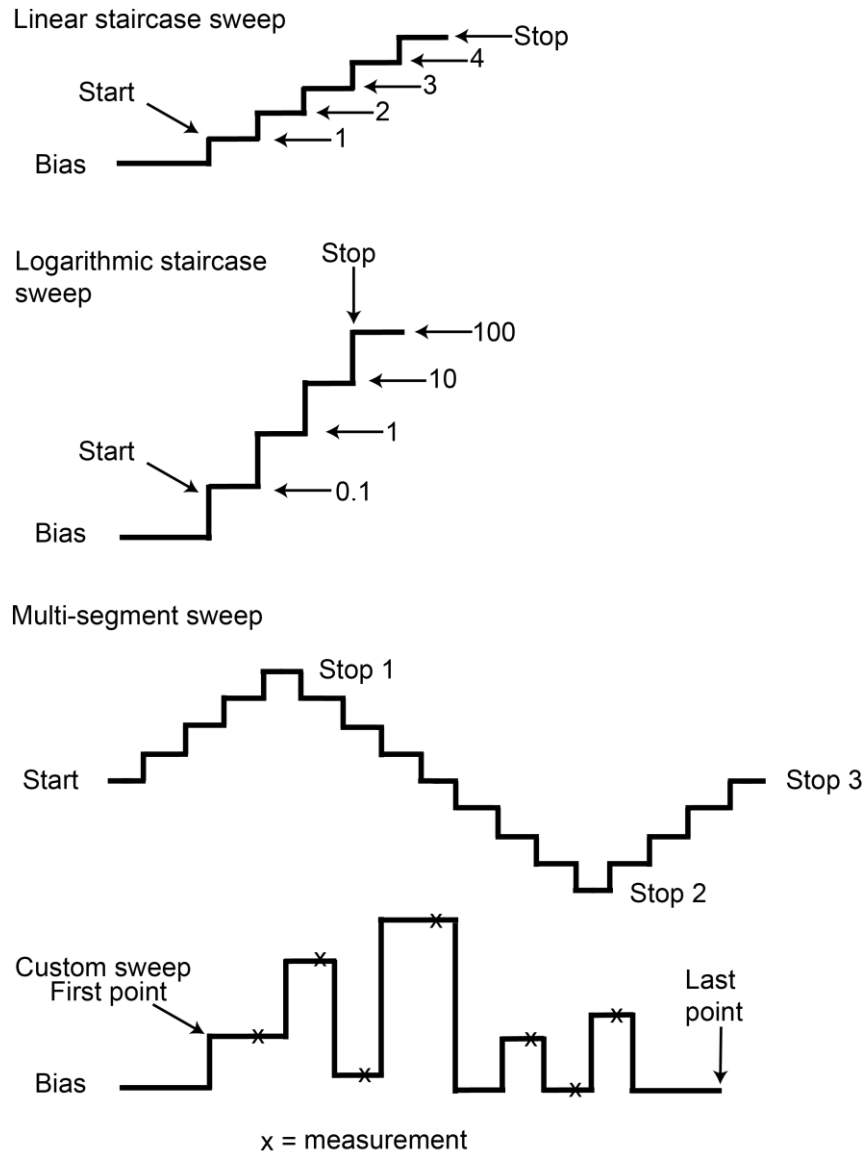
Figure 93: Source-measure-delay cycle



Sweep waveforms

The general sweep types are linear staircase, logarithmic staircase, multi-segment, and custom, as shown in the following figure. The linear staircase sweep goes from the start level to the stop level in equal linear steps. The logarithmic staircase sweep is similar, except it is done on a logarithmic scale with a specified number of steps per decade. The multisegment sweep increments through a series of segments with variable voltage or current steps. The custom sweep lets you construct your own sweep by specifying the number of measure points and the source level at each point.

Figure 94: Sweep waveforms



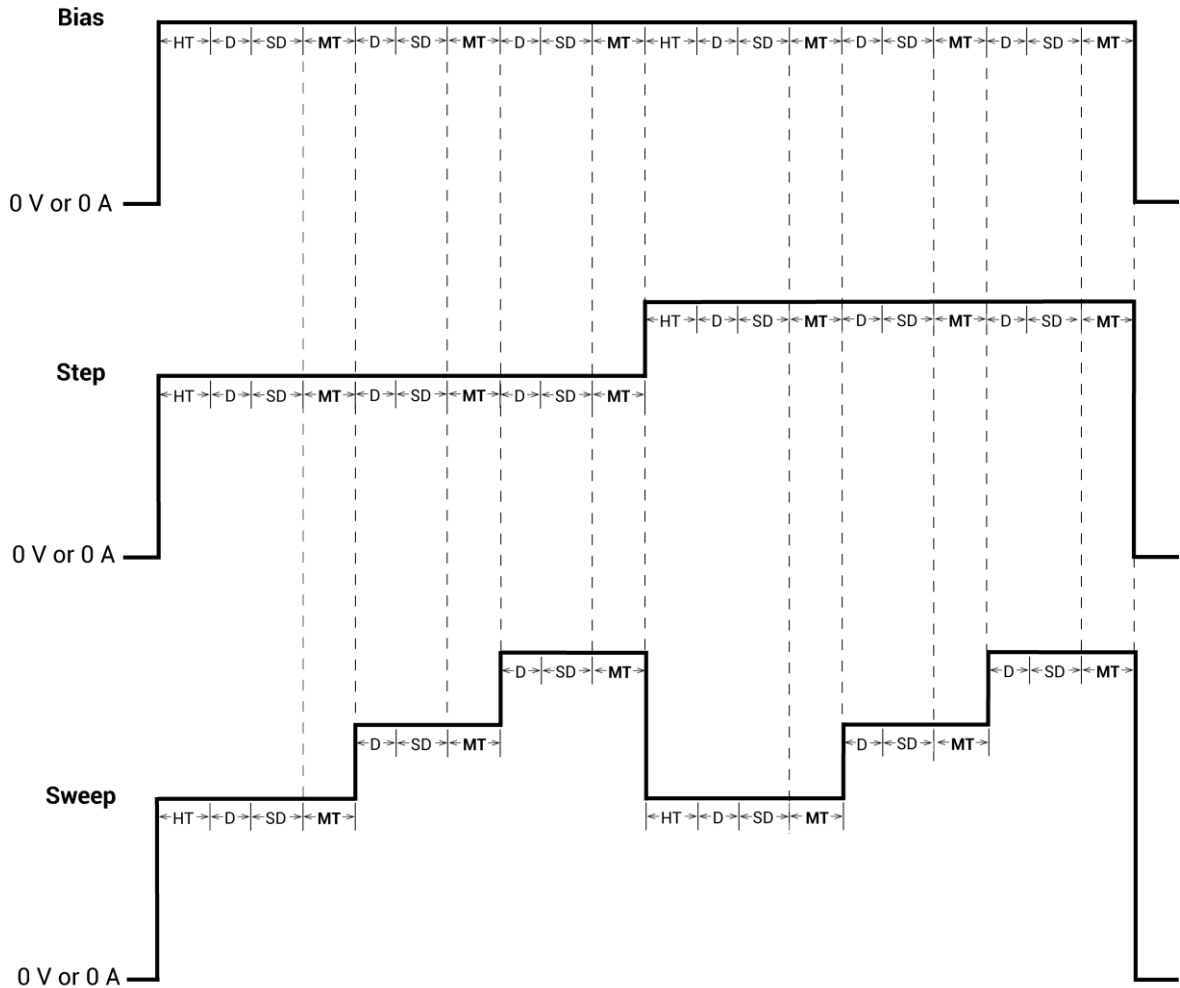
A source-delay-measure cycle is performed on each step (or point) of the sweep. One measurement is made at each step. The time spent at each step depends on how the source-delay-measure cycle is configured, such as the sweep delay setting.

Typical applications for staircase sweeps include I-V curves for two-terminal and three-terminal semiconductor devices, characterization of leakage versus voltage, and semiconductor breakdown.

Operation mode timing

The following figure shows source-measure timing for a test system using three SMUs. It shows basic timing between the sweep, step, and bias operation modes.

Figure 95: Sweeping Mode timing diagram



HT = Hold time
 D = Delay (default delay x delay factor)
 SD = Sweep delay
 MT = Measure time

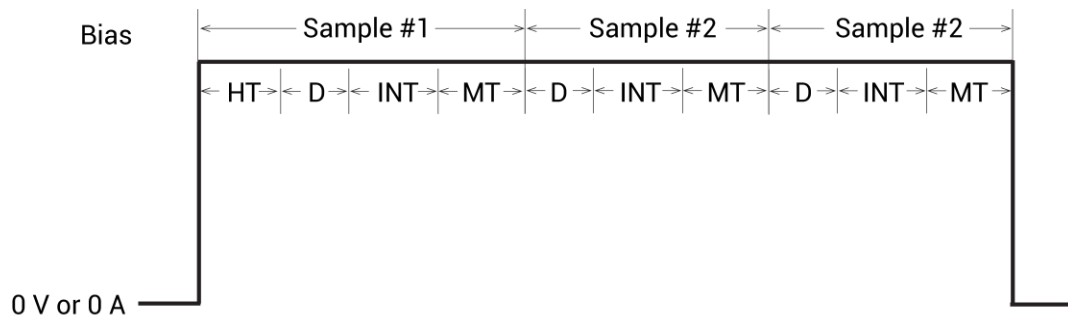
The timing elements act as follows:

- **Hold Time (HT):** The sweep graph shows two sweeps that correspond to the two steps shown directly above in the step graph. There is a hold time at the start of each sweep. The hold time is a global setting, so it is the same for all SMUs in the test system.
- **Delay (D):** The delay time allows the source to settle and is dependent on the measurement range. All SMUs in the test system are synchronized, so the delay time applied by the most delayed SMU is the delay time applied by all SMUs.
- **Sweep Delay (SD):** The sweep delay provides additional settling time for each step in the sweep. It is a global setting that is applied identically to all SMUs in the test system.
- **Measure Time (MT):** The measure time is determined by the filter factor and the A/D aperture time. All SMUs in the test system are synchronized, so the measure time for the SMU that requires the longest measure time is the same for all SMUs in the test system.

Sampling mode timing

The following figure shows a timing diagram for the Sampling test mode.

Figure 96: Sampling test mode timing diagram



HT = Hold time
 D = Delay (default delay x delay factor)
 INT = Interval
 MT = Measure time

A range-dependent delay (D) is automatically applied by a SMU before each measurement to allow for source settling. All SMUs in the test system are synchronized. Therefore, the delay time applied by the most-delayed SMU is the delay time applied by all SMUs.

In sampling mode, all device terminals are set to a static operation mode (Open, Common, Voltage Bias, or Current Bias). The range-dependent delay may not be needed because a source settling time is not needed after the initial application of current or voltage. You can set the Delay Factor to 0.

The Measure Time (MT) is determined by the Filter Factor and the A/D Aperture Time. All SMUs in the test system are synchronized, so the measure time for the SMU that requires the longest measure time is the same for all SMUs in the test system.

Optimizing SMU measurements

In this section:

Introduction	6-1
Making stable measurements with SMUs	6-1
Low-current measurements.....	6-4
Interference	6-11

Introduction

This section includes information on improving measurement stability, making low-current measurements, and reducing interference.

Making stable measurements with SMUs

The following topics discuss various considerations when making stable measurements, including single-SMU stability, multiple-SMU stability, and avoiding oscillation.

Single SMU stability considerations

Driving inductive loads can cause current source instability. Current source instability almost never occurs in semiconductor applications.

A SMU that is sourcing voltage is stable when driving capacitive loads up to 10 nF. However, at the lower current measurement ranges, large capacitive loads may increase settling time and may cause overshoot and ringing. To reduce this effect, you can add a small resistor in series with the capacitive load. Choose a resistor that provides an R_C time constant of 1 ms to 10 ms. You can increase the measurement delay factor to reduce this effect.

To increase the measurement delay factor:

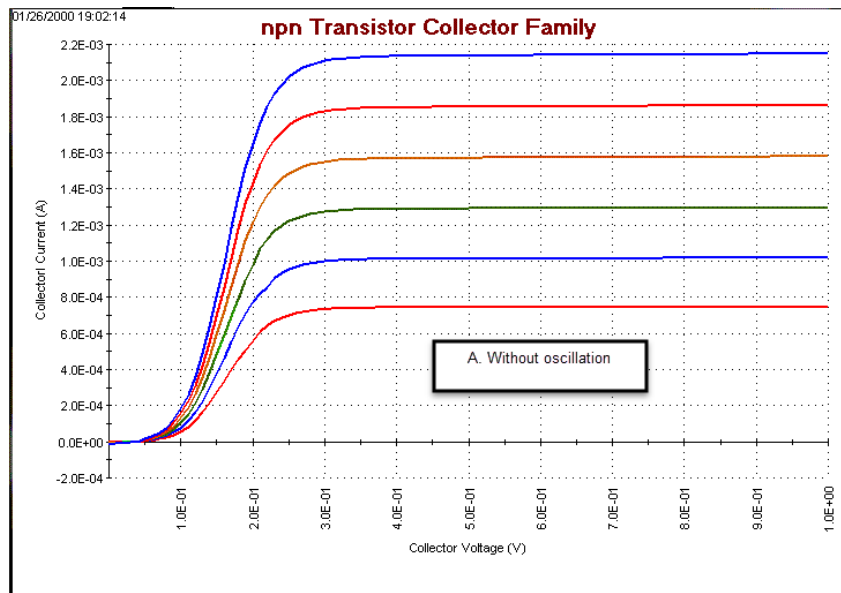
1. In Clarius, select the test.
2. Select **Configure**.
3. In the right pane, select **Test Settings**.
4. Select **Advanced**.
5. Set the Speed to **Custom**.
6. Increase the **Delay Factor**.

Refer to [Delay Factor](#) (on page 3-29) for additional information.

Multiple SMU stability considerations

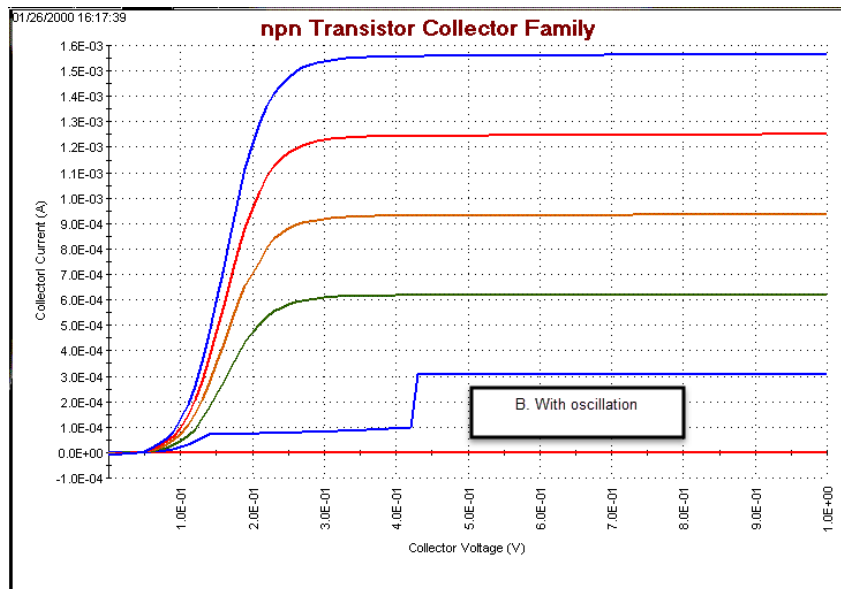
Using two or more SMUs to test an active device, such as a field-effect transistor (FET) or bipolar junction transistor (BJT), can increase system instability. The following figure shows an example of BJT characterization curves measured under stable conditions.

Figure 97: Effects of oscillation on test data: Without oscillation



The next figure shows an example of what can happen to a BJT characterization curve when the system oscillates.

Figure 98: Effects of oscillation on test data: With oscillation



Eliminating oscillations

In general, oscillations can be classified as high-frequency (100 kHz through 200 MHz) or low frequency (below 100 kHz). The measures needed to eliminate oscillations depend on which type of the oscillation is occurring.

Eliminating high-frequency oscillations

One or more of the following remedies may help to eliminate high-frequency oscillations; the remedies are listed in order of preference:

- Mount the preamplifiers as close to the DUT as possible.
- Connect the COMMONs (outer shields) of all cables together at the DUT.
- Use lossy ferrite beads or 100 Ω resistors in series with the DUT leads.
- Disconnect the ground link between GNDU COMMON and chassis ground on the rear panel of the mainframe. Connect the cable shields to the proper chassis.
- Add a high-quality capacitor between the base and emitter of a bipolar junction transistor (BJT) or between the gate and source of a field-effect transistor (FET). Use a 100 pF to 1000 pF capacitor.

Eliminating low-frequency oscillations

Oscillations at low frequencies (dc to 100 kHz) occur when the gain of a transistor under test interacts with the output impedances of the connected SMUs. The following ratios of impedance (Z) determine the gains of the transistors:

- **For a FET:** $Z_{\text{Drain SMU}} / Z_{\text{Source SMU}}$
- **For a BJT:** $Z_{\text{Collector SMU}} / Z_{\text{Emitter SMU}}$

A SMU measures current through the voltage drop across a resistance, which is in series with the DUT. This series resistance is high for low-current ranges and low for high-current ranges. A large current-range difference, or oscillation, occurs when two SMUs are connected to the BJT collector and emitter terminals or FET source and drain terminals. This oscillation results in:

- A large series-resistance difference
- A large impedance ratio between the two series resistances connected to the transistor
- A large circuit gain (potentially, the maximum, intrinsic transistor gain)
- A potentially unstable circuit

To avoid oscillations for a FET, try the following actions:

- Set (Drain SMU current measure range) = (Source SMU current measure range)
- If necessary, set both SMUs to autorange.
- Configure the source SMU for the Voltage Bias Operation Mode and set it to 0 V. This allows you to configure the current measurement range.

For the source SMU, do not select the Common Operation Mode. This mode prevents you from configuring a current measurement range for the source SMU. This results in a lower impedance than at the drain SMU, a potentially high gain, and an increased likelihood of low-frequency oscillation.

To avoid oscillations for a BJT, try the following actions:

- Set (Collector SMU current measure range) = (Emitter SMU current measure range)
- If necessary, set both SMUs to autorange.
- Configure the emitter SMU for the Voltage Bias Operation Mode and set it to 0 V. This allows you to configure the current measurement range.

For the emitter SMU, do not select the Common Operation Mode. This mode prevents you from configuring a current measurement range for the emitter SMU. This results in a lower impedance than at the collector SMU, a potentially high gain, and an increased likelihood of low-frequency oscillation.

NOTE

Both the Drain/Collector and Source/Emitter (SMU) must be set to measure current if they are set to autorange.

Low-current measurements

Low-current measurements made with a SMU or preamplifier are subject to error sources that can have a serious impact on measurement accuracy. The following topics discuss low-current measurement considerations, including leakage currents, generated currents, noise and source impedance, and voltage burden. Refer to the Keithley Instruments *Low Level Measurements Handbook* for more information. The *Handbook* is available in the Learning Center.

Leakage currents

Leakage currents are generated by high-resistance paths between the measurement circuit and nearby voltage sources. These currents can considerably degrade the accuracy of low-current measurements.

Cable leakage currents are a common source of leakage. Typically, insulation resistance between conductors in the type of triaxial cables supplied with the SMUs and preamplifiers is approximately $1 \text{ P}\Omega$ ($10^{15} \Omega$). If the cables were used in an unguarded configuration, leakage current would flow through the cable insulation, affecting the measurement. Properly connecting the triaxial cables to the SMU or preamplifier automatically drives the inner cable shield at guard potential, minimizing the effects of cable leakage currents. See [Guarding](#) (on page 5-1) for details.

Methods to reduce leakage currents include:

- Use good quality insulators, such as Teflon or polyethylene, in the test fixture.
- Reduce the humidity of the test environment. Insulators and the test circuit may absorb water, causing spurious currents to be generated.
- Use guarding in the test fixture to isolate the high-impedance nodes from leakage current due to voltage sources. See [Test fixture guarding](#) (on page 5-4) for details.

Generated currents

Any extraneous generated currents in the test system add to the expected current, which can cause errors. Currents can be internally generated, as in the case of preamplifier input offset current, or they can come from external sources such as insulators and cables. The following paragraphs discuss the various types of generated currents. The following table summarizes the typical ranges of a number of generated currents.

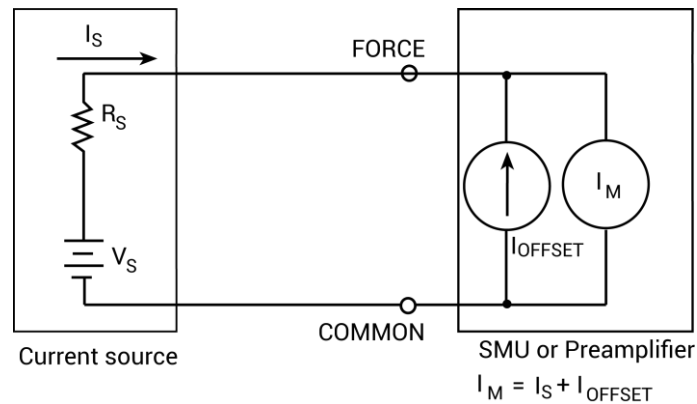
Typical generated currents

Effect	Generated current range
Triboelectric	1 fA to 10 nA
Mechanical stress (Teflon)	1 fA to 1 pA
Mechanical stress (ceramics)	100 aA to 100 fA
Clean epoxy circuit board	100 fA
Dirty epoxy circuit board	100 pA

Offset currents

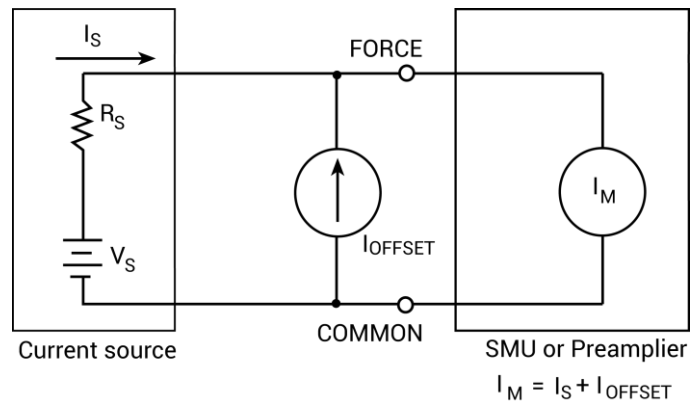
The preamplifier has a small current, known as the input offset current, that flows at all times. As shown in the figure below, the input offset current adds to the measured current so that the SMU measures the sum of the two currents. Note that input offset current can be brought to within specifications by calibrating the system. Refer to “Calibrate the system” in *Model 4200A-SCS Setup and Maintenance*.

Figure 99: Input offset currents



Offset currents can also be generated externally from such sources as [triboelectric](#) (on page 6-7) and [piezoelectric effects](#) (on page 6-7). As shown in the next figure, the external offset current also adds to the source current, and the SMU again measures the sum of the two. These external offset currents can be suppressed manually by subtracting them using the Formulator. For more information, refer to “The Formulator” and “Analyze data using the Run tab” in the *Model 4200A-SCS Clarius User's Manual*.

Figure 100: External offset current



Triboelectric effects

Triboelectric currents are generated by charges created by friction between a conductor and an insulator. Free electrons rub off the conductor and create a charge imbalance that causes the current flow.

The triaxial cables supplied with the SMU and preamplifier greatly reduce this effect by using graphite-impregnated insulation underneath the outer shield. The graphite provides lubrication and a conducting cylinder to equalize and minimize charges generated by frictional effects of cable movement. However, even this type of triaxial cable creates some noise when subjected to vibration and expansion or contraction. Therefore, all connections should be kept short, away from temperature changes (which can create thermal expansion forces), and supported by taping or wiring the cable to a surface that does not vibrate such as a wall, bench, or rigid structure.

Other solutions to movement and vibration problems include:

- Remove or mechanically decouple vibration sources such as motors, pumps, and other electromechanical devices.
- Securely mount or tie down electronic components, wires, and cables.
- Mount the preamplifier as close as possible to the DUT.

NOTE

A temporary triboelectric current is generated when a triaxial cable is first connected. This current is typically tens or hundreds of femtoamperes and can last as long as 5 to 10 minutes.

Piezoelectric and stored charge effects

Piezoelectric currents are generated when mechanical stress is applied to certain crystalline materials used for insulated terminals and interconnecting hardware. In some plastics, pockets of stored charge cause the material to behave in a manner similar to piezoelectric materials.

To minimize the current due to this effect, remove mechanical stresses from the insulator. Also use insulating materials such as polyethylene that have minimal piezoelectric and stored charge effects.

CAUTION

To prevent piezoelectric currents and stored charge effects, do not bend cables to make tight corners and do not let long cables hang. Lay all cables on a flat surface.

Contamination and humidity

Error currents can arise from electrochemical effects when ionic chemicals create weak batteries between two conductors on a circuit board. For example, if epoxy-printed circuit boards are not thoroughly cleaned of etching solution, flux, or other contamination, the contamination can generate currents of a few nanoamps between conductors.

High humidity and ionic contamination can dramatically reduce insulation resistance. High-humidity conditions occur with condensation or water absorption. Ionic contamination may be the result of body oils, salts, or solder flux.

To avoid the effects of contamination and humidity, select insulators that resist water absorption (such as Teflon), and keep relative humidity to less than 50 percent. Also be sure that all insulators are kept clean and free of contamination. If insulators become contaminated, clean them thoroughly with a pure solvent such as methanol. To clean ionic contamination, use a deionized (DI) water wash.

Dielectric absorption

Dielectric absorption in an insulator can occur when a voltage across that insulator causes positive and negative charges within the insulator to polarize. When the voltage is removed, the separated charges generate a decaying current through circuits connected to the insulator as they recombine.

To minimize the effects of dielectric absorption on current measurements, avoid applying voltages greater than a few volts to insulators that are used for sensitive current measurements. In cases where this practice is unavoidable, it may take minutes or even hours for the current caused by dielectric absorption to dissipate.

Voltage burden

As shown in the next figure, the SMU or preamplifier ammeter may be represented by an ideal ammeter (I_M), with zero internal resistance, in series with a resistance (R_M). When a current source is connected to the input of the ammeter, the current is reduced from what it would be with the ideal resistance meter ($R_M = 0 \Omega$). This reduction is caused by R_M , which creates an additional voltage drop called the voltage burden (V_{BURDEN}), which reduces the measured current from its theoretical value as follows:

$$I_M = \frac{V_S - V_{BURDEN}}{R_S}$$

The percent error (E) in the measured reading due to voltage burden is:

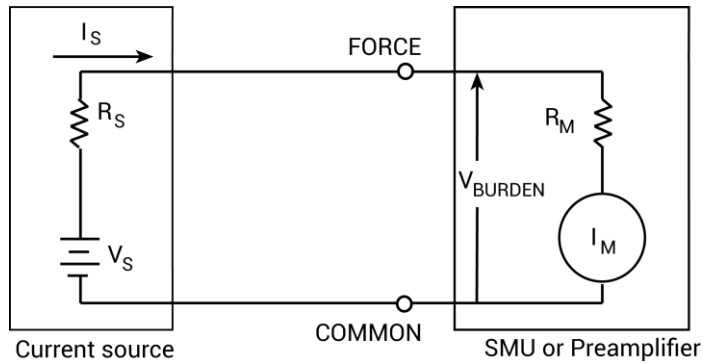
$$E = \frac{V_{BURDEN}}{R_S} \times 100$$

If the voltage burden is 0 V, the percent error is zero.

NOTE

Voltage burden for the SMUs is less than or equal to the offset specifications of the source voltage.

Figure 101: Effects of voltage burden



Noise and source impedance

Noise can seriously affect sensitive current measurements. The following paragraphs discuss how source resistance and source capacitance affect noise performance.

Source resistance

The source resistance of the DUT affects the noise performance of the SMU or preamplifier. As the source resistance decreases, the current noise increases. Because decreasing the source resistance can have a detrimental effect on noise performance, there are usually minimum recommended source resistance values based on measurement range. The following table summarizes minimum recommended source resistance values for various measurement ranges.

Minimum recommended source resistance values

Range	Minimum recommended source resistance
1 pA to 100 pA	1 GΩ to 100 GΩ
1 nA to 100 nA	1 MΩ to 100 MΩ
1 μA to 100 μA	1 kΩ to 100 kΩ
1 mA to 100 mA	1 Ω to 100 Ω

Source capacitance

DUT source capacitance also affects the noise performance of the preamplifier. In general, as source capacitance increases, the noise gain also increases. Although there is a limit to the maximum source capacitance value, you can usually measure at higher source capacitance values by connecting a resistor in series with the source. However, this increases the voltage burden. For example, the source resistance values listed in the previous table result in a voltage burden between 1 mV and 1 V.

Cable capacitance

Without guarding, the effects of cable capacitance would adversely affect the settling time when sourcing current. The rise time of the source depends on the total shunt capacitance at its output. For a high-impedance load, even a small amount of cable capacitance can result in long rise times. For example, cable capacitance of 100 pF and a load resistance of 1 G Ω results in an R_c time constant of approximately 100 ms. Guarding drastically reduces cable capacitance, resulting in much faster rise times. With FORCE and GUARD at virtually the same potential, the cable capacitance cannot charge, and rise time is not affected (refer to [Guarding](#) (on page 5-1)).

When sourcing voltage, the rise time due to cable capacitance is usually insignificant. Because the voltage source is low impedance ($<1 \Omega$), the R_c time constant of 10^{-10} seconds $1 \Omega \times 100 \text{ pF}$ is negligible.

Test system performance

When making a semiconductor I-V measurement, there is always a compromise between speed and noise. Even with a fixed set of measurement settings, changes to the system configuration (such as cable length or adding a switch matrix) change the measurement results. The 4200A-SCS has settings to allow optimal I-V measurements. The settings fast, normal, and quiet are fixed. You can also set a custom value.

To achieve a low-noise measurement, the quiet setting is recommended. The compromise is that measurement speed is slower in comparison to the fast and normal settings. To make a fast measurement, the fast setting can be selected, though the noise will be higher. Typically, the normal setting is used to balance the speed and low-noise requirements. To further fine-tune the measurement, the custom setting can be used.

The fixed settings are tuned to the 4200A-SCS for standard cable lengths connected to the DUT. In general, this should be sufficient to make good measurements. However, when extra-long cables or a switch matrix are used in the system, these settings may not be adequate. A typical phenomenon is the appearance of a glitch or offset error. The magnitude of the error increases if the fast setting is used to make the measurement. This is caused by insufficient settling time for the system. With added load or capacitance (cables or matrix relays), it takes longer for transient effects to settle. If you only use the measurement parameters optimized for short cables, you may generate erroneous measurements.

The best way to minimize this effect is to allow extra settling time. The normal or quiet settings should improve the measurement result. You can also use custom settings to fine-tune the measurement settings. It may be a trial and error process. Various combinations of parameters can be used to achieve the best results. In general, longer cables or slower settling of switch relays require a larger delay factor.

Interference

Forms of interference that can degrade measurement integrity include electrostatic interference, radio-frequency interference, and ground loops.

Electrostatic interference

Electrostatic interference occurs when an electrically charged object is brought near an uncharged object, thus inducing a charge on the previously uncharged object. Usually the effects of such electrostatic action are not noticeable because low impedance levels allow the induced charge to dissipate quickly. However, the high impedance levels of many SMU or preamplifier measurements do not allow these charges to dissipate rapidly, and erroneous or unstable readings may be caused in the following ways:

- Undetected errors or noise in the reading can be caused by dc electrostatic fields.
- Errors can be caused by ac electrostatic fields that drive the amplifier into saturation, or through rectification that produces dc errors.

Electrostatic interference is first recognizable when hand or body movements near the DUT cause fluctuations in the reading. Pick-up from ac fields can also be detected by observing the output on an oscilloscope.

To minimize electrostatic interference, you can use:

- **Shielding:** Possibilities include a shielded room, a shielded booth, shielding the sensitive circuit (test fixture), and using shielded cable. The shield should usually be connected to a solid connector that is connected to signal COMMON. Shielding can increase capacitance, possibly slowing down response time unless guarding is used within the test fixture.
- **Reduction of electrostatic fields:** Moving power lines or other sources away from the DUT reduces the amount of electrostatic interference induced into the test circuit.

Radio-frequency interference

Radio-frequency interference (RFI) is a general term frequently used to describe electromagnetic interference over a wide range of frequencies across the spectrum. RFI can be especially troublesome at low signal levels, but it may also affect higher level measurements in extreme cases.

RFI can be caused by steady-state sources such as television or radio broadcast signals. It can also result from impulse sources, as in the case of arcing in high-voltage environments. In either case, the effect on measurement performance can be considerable if enough of the unwanted signal is present. The effects of RFI can often be seen as an unusually large offset, or, in the case of impulse sources, sudden, erratic variations in readings.

To minimize the effects of RFI:

- Keep the DUT as far away from the RFI source as possible.
- Shield the test equipment, DUT, and test cables.
- In extreme cases, use a specially-constructed screen room to attenuate the troublesome signal.

Ground loops and other SMU grounding considerations

Ground loops, which occur when more than one point in a test system is connected to safety (earth) ground, can create error signals that cause erratic or erroneous performance. The configuration shown in the following figure shows a ground loop that is created by connecting 4200A-SCS signal COMMON and DUT LO to safety (earth) ground. A large ground current flowing in the loop will encounter small resistances, either in the conductors or at the connecting points. This small resistance results in voltage drops that can affect performance.

To prevent ground loops, connect the test system to ground at a single point. If it is not possible to remove the DUT ground, remove the ground link between the GNDU COMMON terminal and chassis ground, as shown in the following figure.

NOTE

Removing the COMMON-to-chassis link may result in oscillations (refer to [Making stable measurements](#) (on page 6-1)).

Figure 102: Ground loops

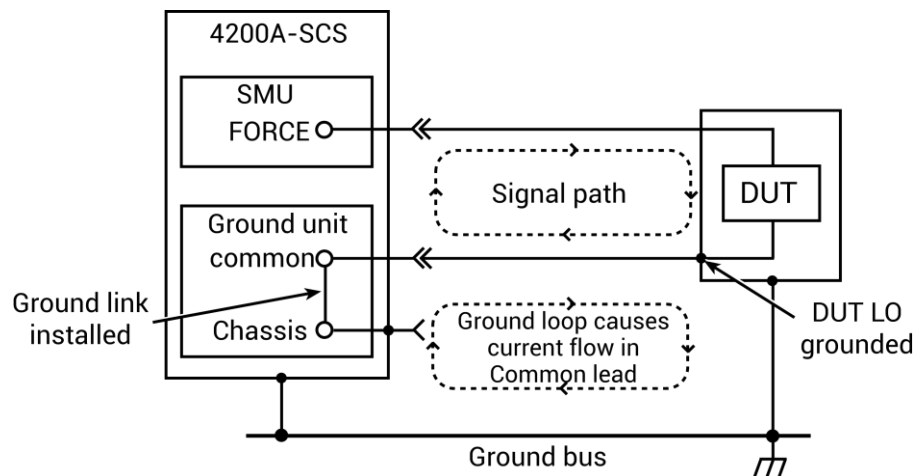
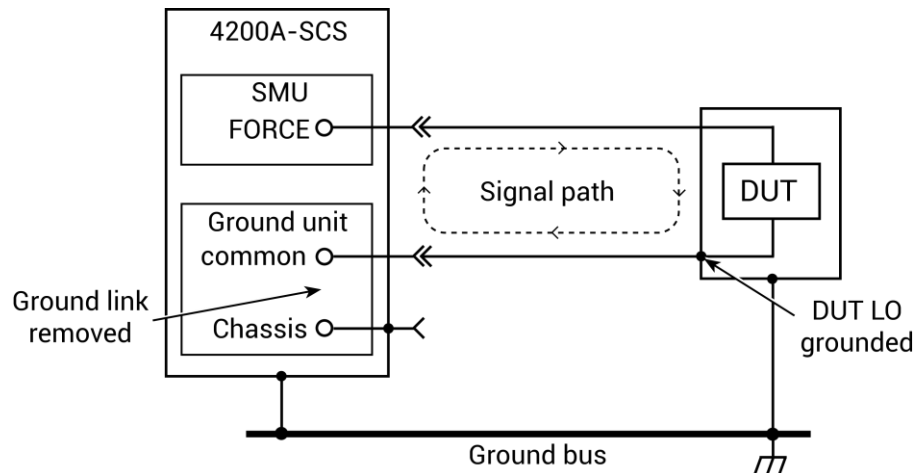


Figure 103: Eliminating ground loops



Make I-V measurements on a solar cell

In this section:

Introduction	7-1
Equipment required.....	7-1
Device connections	7-2
Setting up measurements in the Clarius software	7-4

Introduction

This example shows how to use a 4200-SMU, 4201-SMU, 4210-SMU, or 4211-SMU instrument to perform a forward-biased voltage sweep on a solar cell in a 4-wire configuration. Current is measured on each step of the sweep and an I-V graph is generated from the collected data. The Formulator calculates common electrical characteristics of the cell.

These instructions show you how to make connections from the SMU to the solar cell and how to add the forward bias I-V test into a new project and automate the measurements.

From the I-V characteristics measured by the 4200A-SCS, you can determine important parameters about the solar cell, including:

- Maximum current (I_{MAX}) and voltage (V_{MAX})
- Maximum power (P_{MAX})
- Open-circuit voltage (V_{OC})
- Short-circuit current (I_{SC})

Equipment required

- One 4200A-SCS with one 4200-SMU, 4201-SMU, 4210-SMU, or 4211-SMU
- Four triaxial cables (4200-TRX-2 or 4200-MTRX-2)
- One solar cell
- One light source

Device connections

Connect your preamplifier or SMU output terminals to the solar cell in a 4-wire configuration. This provides the best measurement accuracy and eliminates the effects of the resistance of the test leads and unwanted voltage drops.

⚠ WARNING

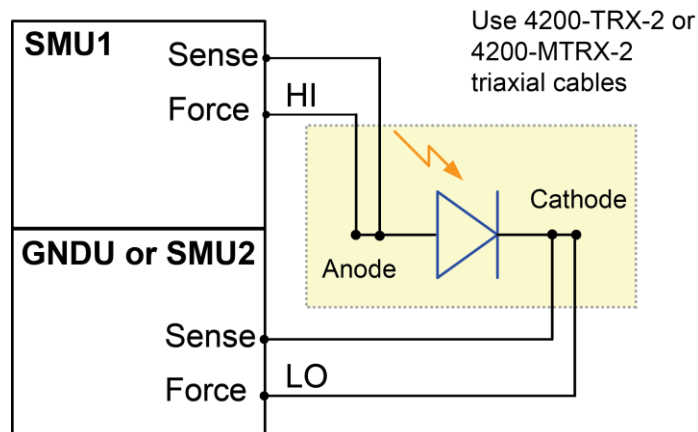
Hazardous voltages may be present on all output and guard terminals. To prevent electrical shock that could cause injury or death, never connect or disconnect from the 4200A-SCS while the output is on.

To prevent electric shock, test connections must be configured such that the user cannot come in contact with test leads, conductors, or any device under test (DUT) that is in contact with the conductors. It is good practice to disconnect DUTs from the instrument before powering up the instrument. Safe installation requires proper shields, barriers, and grounding to prevent contact with test leads and conductors.

Device connection schematic

Connections to the solar cell can be made using two SMUs or one SMU and the Ground Unit (GNDU). The following figure shows the connection schematic for the application.

Figure 104: Solar cell device connection schematic



Connect the 4200A-SCS to the DUT

The following figures show the 4200A-SCS rear-panel connections for the methods mentioned in the [Device connection schematic](#) (on page 7-2) topic. You can make the connections shown in the following figures using four 4200-TRX-2 or 4200-MTRX-2 triaxial cables.

Figure 105: Rear-panel connections using two SMUs

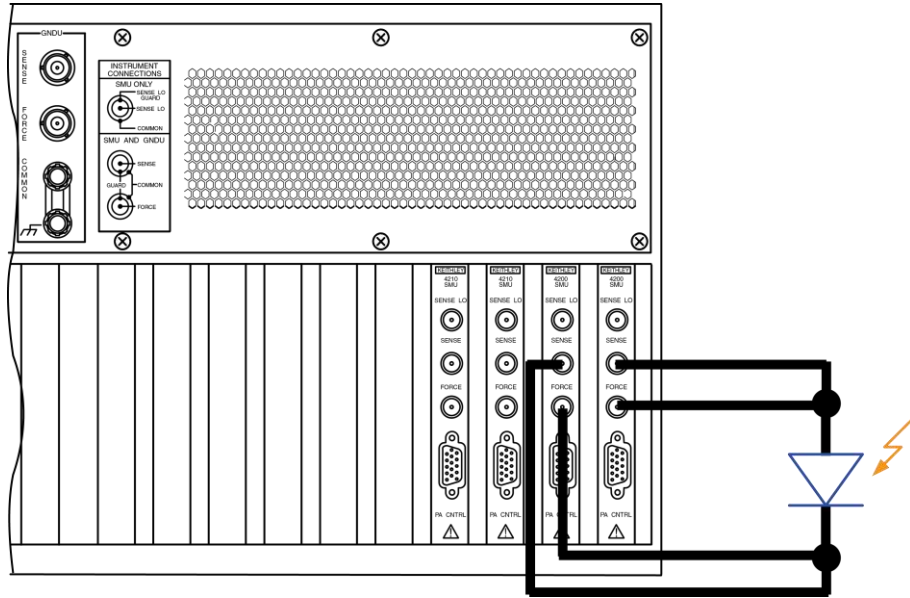
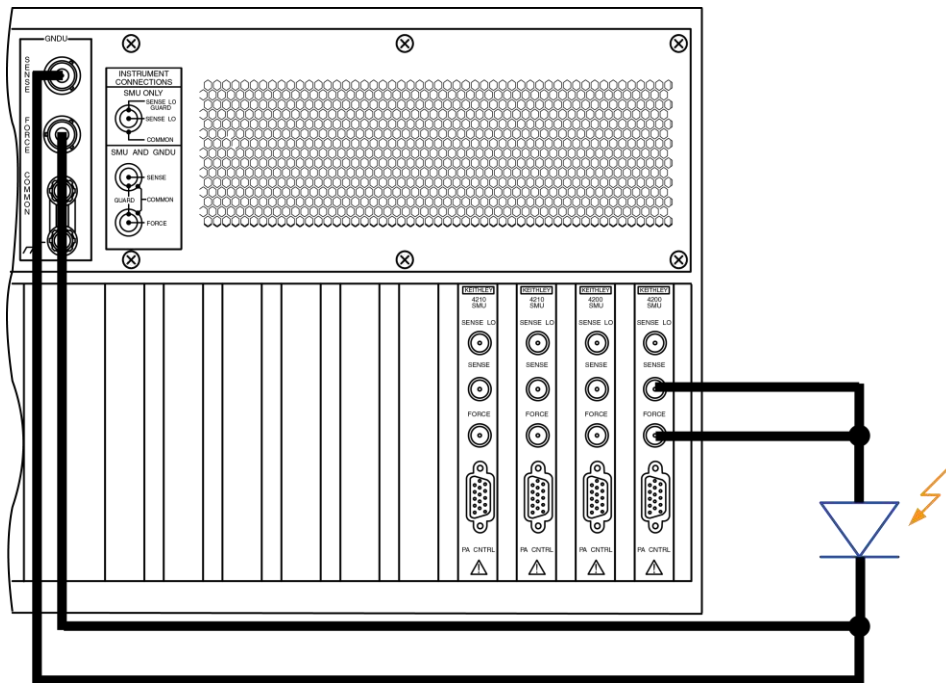


Figure 106: Rear-panel connections using one SMU and GNDU



Setting up measurements in the Clarius software

This section demonstrates how to set up the 4200A-SCS to perform an I-V sweep on a solar cell. The `fwd-ivswEEP` test measures current at each step of a user-configured voltage sweep. An I-V curve is generated from the acquired data and device parameters are calculated in the Formulator.

For this example, use the Clarius application to to:

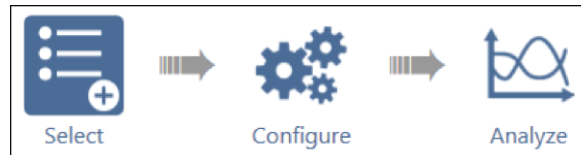
- Create a new project
- Search for and select a test
- Configure the test
- Run the test
- View and analyze the test results

Create a new project

To create a new project:

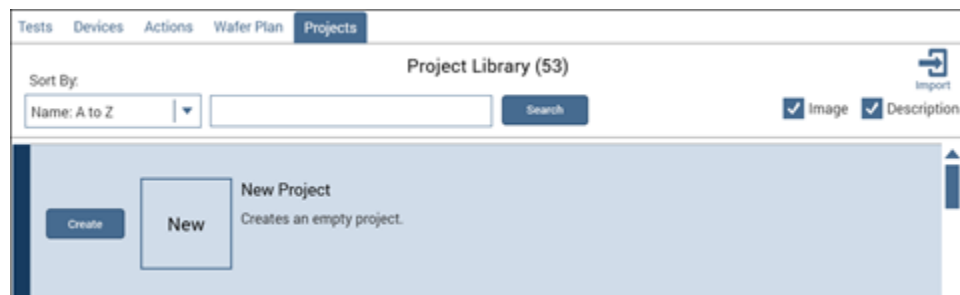
1. Choose **Select**.

Figure 107: Select highlighted



2. In the Library, select **Projects**.
3. Select **New Project**.
4. Select **Create**.

Figure 108: Select a New Project from the Project Library



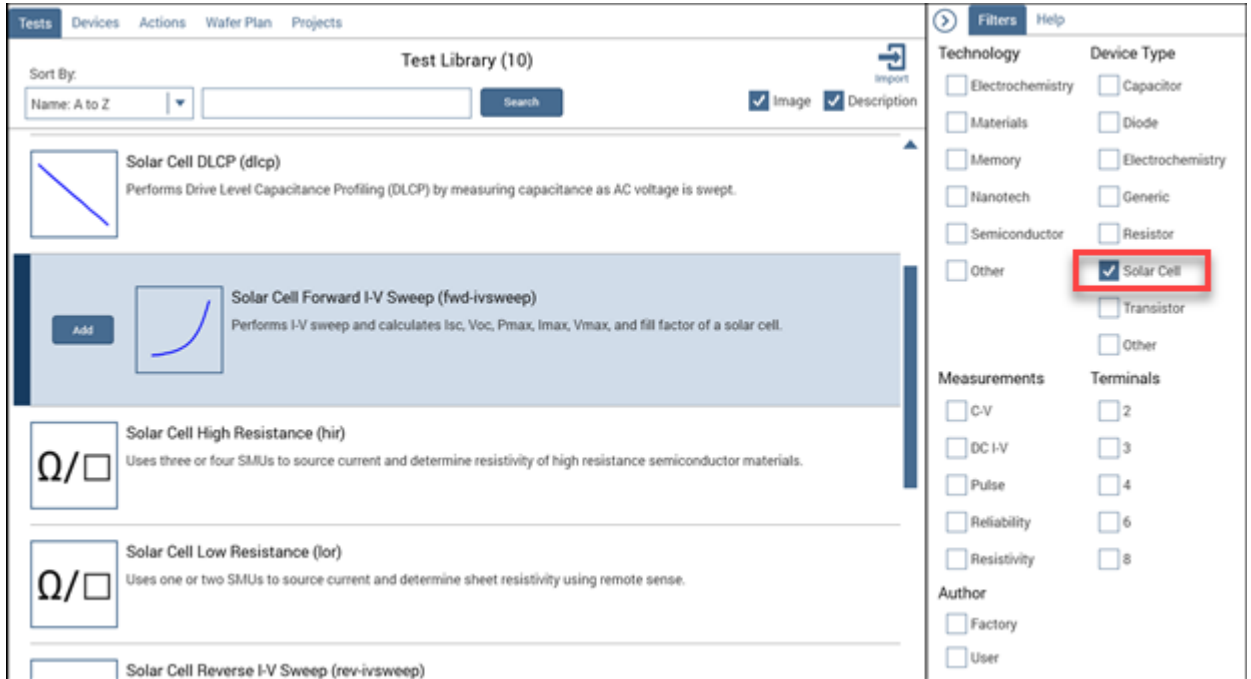
5. Select **Yes** when prompted to replace the existing project.

Search for and select a test

To search for and select the test:

1. Select **Tests**.
2. In the Filters pane, select **Solar Cell**.

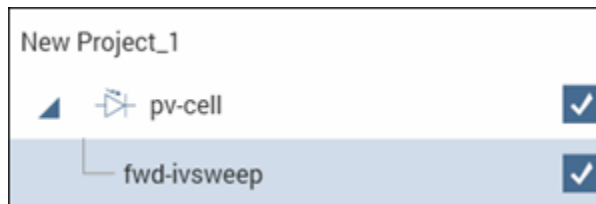
Figure 109: Use filters to select the fwd-ivsweep test



3. Select the **Solar Cell Forward I-V Sweep (fwd-ivsweep)** test.
4. Select **Add**.

The test is displayed in the project tree.

Figure 110: Test added to the project tree

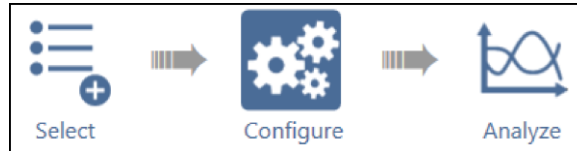


Configure the test

To configure the test:

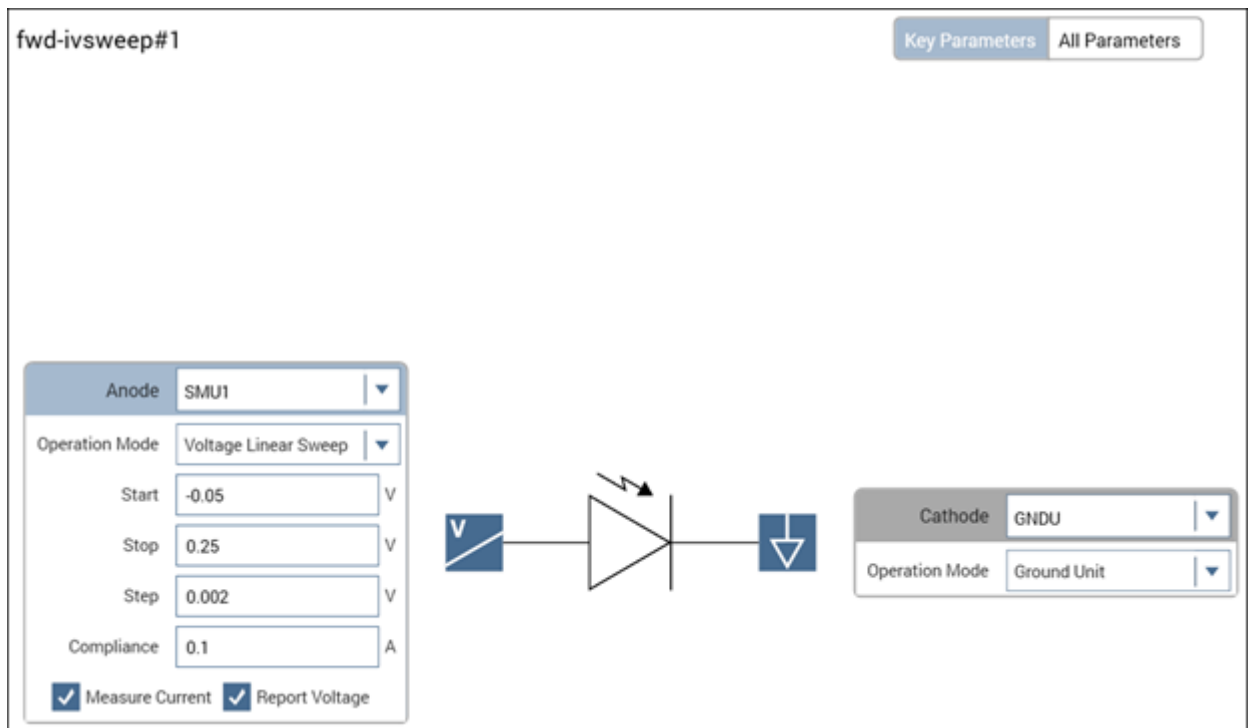
1. In the project tree, select the **fwd-ivsweep** solar cell I-V test in the project tree.
2. Select **Configure** .

Figure 111: Configure highlighted



3. Adjust the Anode settings as needed.

Figure 112: Key Parameters pane for the I-V sweep of a solar cell



4. In the Test Settings pane, adjust the Measure Settings and Test Mode as needed.

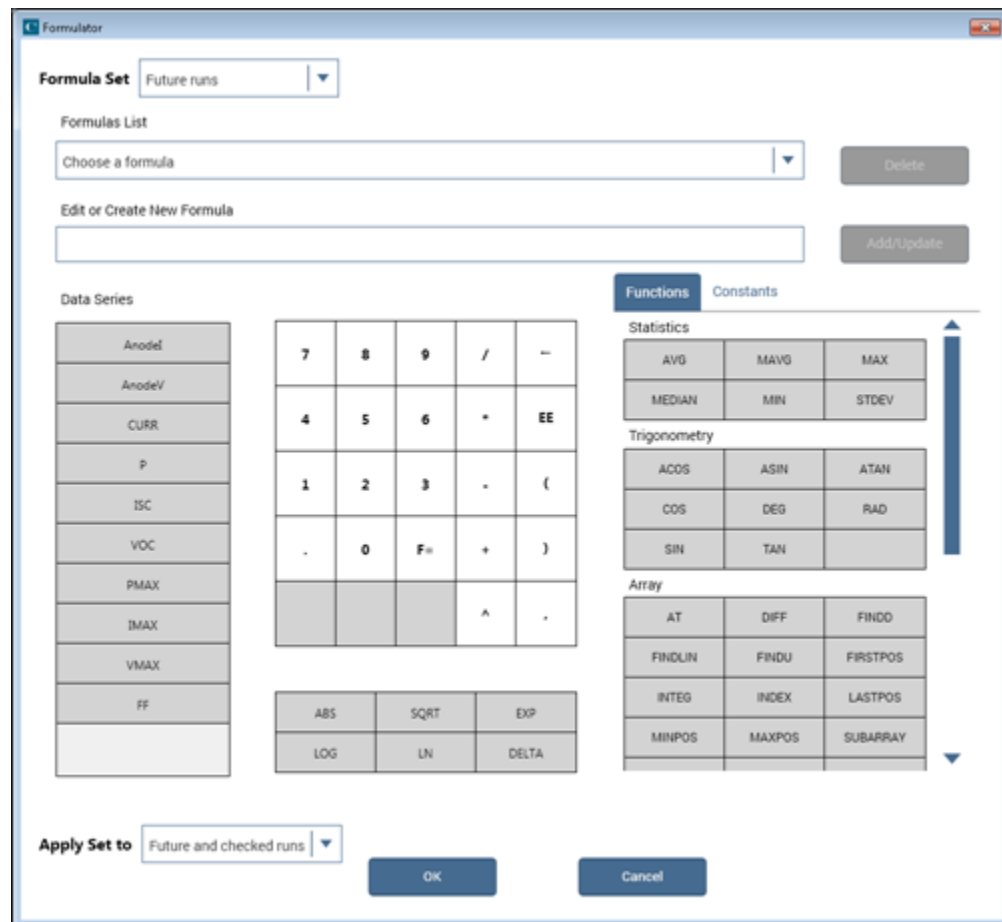
Figure 113: Test Settings pane

The screenshot shows the 'Test Settings' pane of the SMU software. At the top, there are three tabs: 'Test Settings' (selected), 'Terminal Settings', and 'Help'. Below the tabs, the test name 'fwd-iv-sweep#1' is displayed next to an 'Advanced' button. The pane is divided into two main sections: 'Measure Settings' and 'Test Mode'. In the 'Measure Settings' section, there is a 'Speed' dropdown menu set to 'Normal' and a checkbox for 'Report Timestamps' which is currently unchecked. In the 'Test Mode' section, there is a 'Mode' dropdown menu set to 'Sweeping', a 'Sweep Delay' input field with the value '0.1' and a unit 's', and a 'Hold Time' input field with the value '0' and a unit 's'. At the bottom of the pane, there are three buttons: 'Formulator', 'Output Values', and 'Exit Condition'.

NOTE

The Formulator is also in the Test Settings pane. If you select the Formulator in the Test Settings pane, the Formulator dialog box appears as shown in the figure below.

Figure 114: Formulator dialog box



This test calculates V_{oc} , I_{sc} , P_{max} , and other device parameters. See the *Electrical Characterization of Photovoltaic Materials and Solar Cells with the 4200A-SCS Parameter Analyzer* application note for details on Formulator calculations. You can also add new formulas or edit existing formulas. See “Formulator” in the *Model 4200A-SCS Clarius User's Manual*.

Run the test

1. Highlight the `fwd-ivswEEP` test in the project tree.
2. Select **Run** to execute the test.

Figure 115: Run



Analyze the test results

You can select **Analyze** when you run the project to view test results in real time.

Figure 116: Analyze highlighted



You can also use the View icons in the upper-right of the center pane to display the sheet, graph, or sheet and graph. The sheet-only view is shown in the following figure.

Figure 117: Analyze sheet

fwd-ivsweep#1

View:

Run1 Formulas List

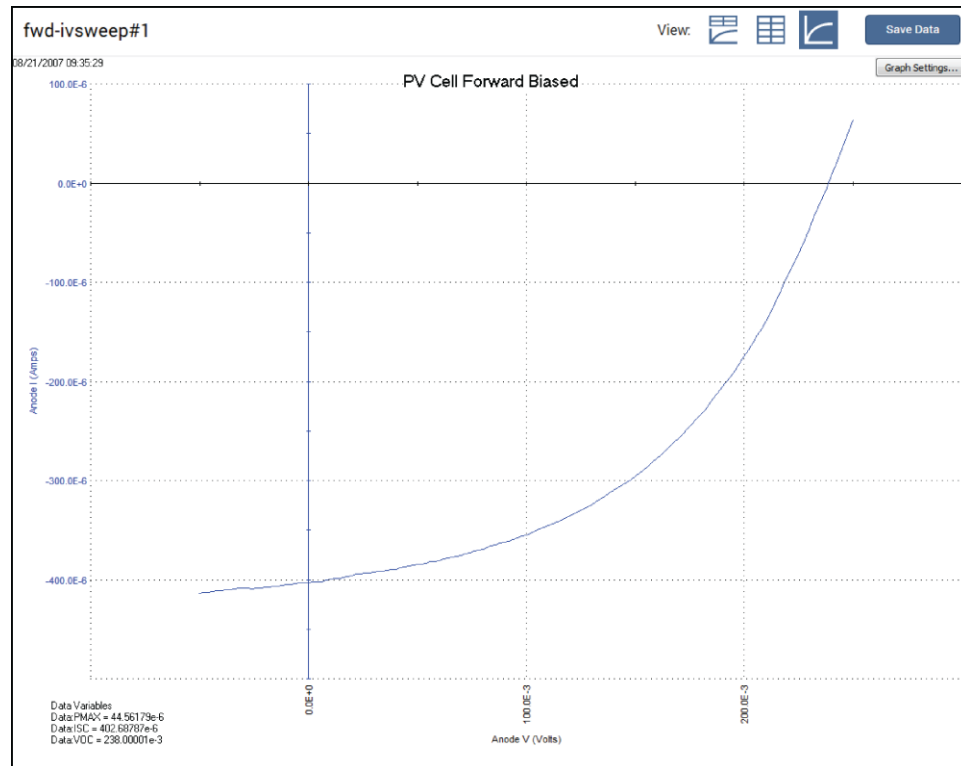
	AnodeI	AnodeV	CURR	P	ISC	VOC	PMAX	IMAX	VMAX	FF
1	-413.3802E-6	-50.0000E-3	413.3802E-6	-20.6690E-6	402.6879E-6	238.0000E-3	44.5617E-6	289.3623E-6	154.0000E-3	464.9616E-3
2	-412.7658E-6	-48.0000E-3	412.7658E-6	-19.8127E-6						
3	-412.6070E-6	-46.0000E-3	412.6070E-6	-18.9799E-6						
4	-412.0101E-6	-44.0000E-3	412.0101E-6	-18.1284E-6						
5	-411.1007E-6	-42.0000E-3	411.1007E-6	-17.2662E-6						
6	-410.6701E-6	-40.0000E-3	410.6701E-6	-16.4268E-6						
7	-409.9707E-6	-38.0000E-3	409.9707E-6	-15.5788E-6						
8	-409.8355E-6	-36.0000E-3	409.8355E-6	-14.7540E-6						
9	-409.3015E-6	-34.0000E-3	409.3015E-6	-13.9162E-6						
10	-408.8281E-6	-32.0000E-3	408.8281E-6	-13.0825E-6						
11	-408.1941E-6	-30.0000E-3	408.1941E-6	-12.2458E-6						
12	-408.7257E-6	-28.0000E-3	408.7257E-6	-11.4443E-6						
13	-409.3095E-6	-26.0000E-3	409.3095E-6	-10.6420E-6						
14	-408.6217E-6	-24.0000E-3	408.6217E-6	-9.8069E-6						
15	-408.2313E-6	-22.0000E-3	408.2313E-6	-8.9810E-6						
16	-407.6464E-6	-20.0000E-3	407.6464E-6	-8.1529E-6						
17	-407.6886E-6	-18.0000E-3	407.6886E-6	-7.3383E-6						
18	-407.0621E-6	-16.0000E-3	407.0621E-6	-6.5129E-6						
19	-406.6541E-6	-14.0000E-3	406.6541E-6	-5.6931E-6						
20	-406.1934E-6	-12.0000E-3	406.1934E-6	-4.8743E-6						
21	-404.7976E-6	-10.0000E-3	404.7976E-6	-4.0479E-6						
22	-405.2458E-6	-8.0000E-3	405.2458E-6	-3.2419E-6						
23	-404.3831E-6	-6.0000E-3	404.3831E-6	-2.4262E-6						

Run1 Run Settings

The sheet displays the results with the voltage and current data labeled AnodeV and AnodeI, respectively. The formulas calculated in the Formulator are shown in the right-most columns. They include the maximum power (P_{MAX}), open circuit voltage (VOC), short circuit current (ISC), and fill factor (FF). For more information about the Formulator, refer to “Formulator” in the *Model 4200A-SCS Clarius User's Manual*.

To see an expanded view of the graphed test results, select the graph view. The following graph shows the sweep of an illuminated silicon photovoltaic (PV) cell generated by the SMU.

Figure 118: Test results showing I-V graph of an illuminated solar cell



Because the system SMUs can sink current, the curve can pass through the fourth quadrant and allow power to be extracted from the device (I^- , V^+). If you want to have the data displayed in the first quadrant, use the Formulator to multiply the current by -1 and plot this calculated result instead.

You can also show previous test runs in the graph window by selecting them under the Run History tab. Select the check box next to the test you want to display, and the test curves are displayed in the graph window. If you select multiple run histories, the graphs are overlaid.

Additional tests

You can add other solar cell tests to the project. Search for **solar cell** in the Tests library to find additional tests.

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