Welcome!

Device Characterization with the Keithley Model 4200-SCS Characterization System

Safety Precautions

Working with Electricity

- Before starting, check cables for cracks or wear. Get new cables if needed.
- Do not touch any connection. Only touch insulation.
- Even when a unit appears off, it may still be outputting voltage.
- If you need to touch a conductor, turn the main power off and unplug the unit.
- Do not remove the chassis cover unless instructed to do so.
- These products are typically rated as safety category I (signal level only) – do NOT connect signal lines to mains.
- **Keithley products are NEVER to be connected to a human. A single fault in the system can expose a person to lethal voltage.**

Schedule – Day 1

8:00-9:00AM

- Introduction to device characterization
- System Overview: System Architecture, Hardware Features, and Software Features
- Precision DC I-V Source-Measure Features and Concepts

9:00-9:15AM Break

9:15-11:00AM

- Basics of Keithley Interactive Test Environment (KITE)

11:00-12:30 Lunch

12:30-1:30PM

- More KITE Setup and features
- Speed, Timing and Noise settings

1:30-1:45PM Break

1:45-3:00PM

- General Shielding, noise and guarding
- Low Current and High Resistance Measurement Techniques

3:00-3:15PM Break

3:30-5:00PM

- Troubleshooting instruments and results
- Measurement Tools and considerations

Schedule – Day 2

8:00-9:00AM

- **Keithley CONfiguration Utility (KCON) Overview**
- **Basic KULT (Low level programming)**
- **Basic KXCI (External command interface)**

9:00-9:15 AM Break and Refreshments

9:30-11:00AM

- **AC Impedance – CVU overview**
- **CV tips, tricks and traps**

11:00-12:30 Lunch

12:30-1:30PM

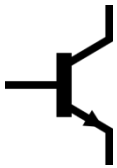
- **Ultra-Fast I-V – Pulse and Transient I-V testing**

1:30-5:00PM

- **Projects, Applications, Hands on session**

Introduction to device characterization

Electrical Characterization is usually performed on the four basic device types

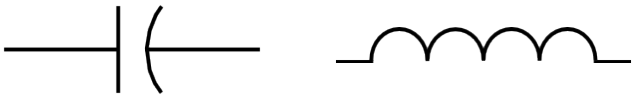


Transistors

-BJT, MOS, IGBT etc.

Diodes

-PN, Schottky, Gated etc.



Reactive elements

-Capacitors and Inductors

Resistors

-Linear, van der Pauw etc.

What about Memristors? Are they a new fundamental element type?
For our purposes, the answer is YES, since we characterize them also !

Introduction to device characterization

Four Main Types of Electrical Characterization:

1) Precision DC Current-Voltage (I-V)
2) AC Impedance or Capacitance-Voltage (C-V)
3) Pulse or Transient Current-Voltage (Ultra-fast I-V)
4) Radio Frequency (RF)

For this seminar, we will focus on DC and CV, and introduce Ultra-fast I-V.
RF demands it's own seminar and will not be discussed here.

Introduction to device characterization

Where is Electrical Characterization used?

1) Characterizing new materials or devices
2) Device Modeling
3) Process development
4) Device Reliability
5) Process Control

Keithley Model 4200-SCS

The 4200 is a complete system that integrates everything together in an easy to use system

Hardware Features and Capabilities

- Nine module slots – Allows a variety of measurement modules to be installed or added to the system
- Display – Built-in 12.1 inch flat panel display with external high resolution monitor supported. The 4200-SCS/F can drive both the FPD and an external CRT/monitor simultaneously.
- Integrated Controller – Pentium Cor2Duo microprocessor running Microsoft Windows XP Professional, 1TB HDD.
- IEEE-488 Interface – Allows the Model 4200-SCS to control GPIB equipped devices or to be controlled by an external GPIB controller.

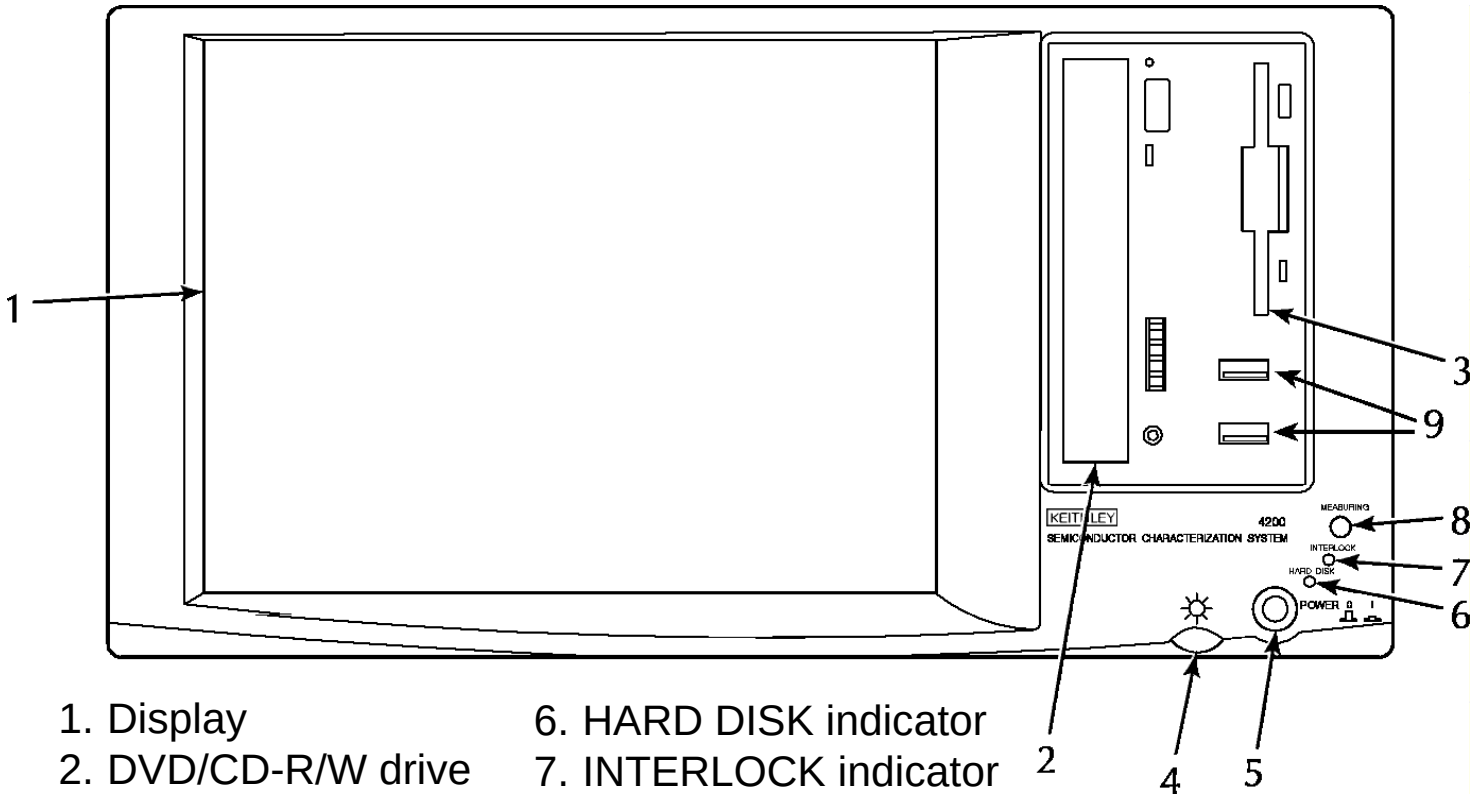
Hardware Features and Capabilities

- USB, RS-232 and Parallel Ports – Interfaces the unit to peripherals such as a printer, plotter, memory stick, or prober.
- Interlock Connector – Interfaces to a test fixture or prober interlock circuit to ensure the instrumentation is controlled in a safe manner.
- LAN Connection – Built-in Ethernet interface for connections to a local area network, allows external computers to control 4200 through Ethernet

Instrument Module Options

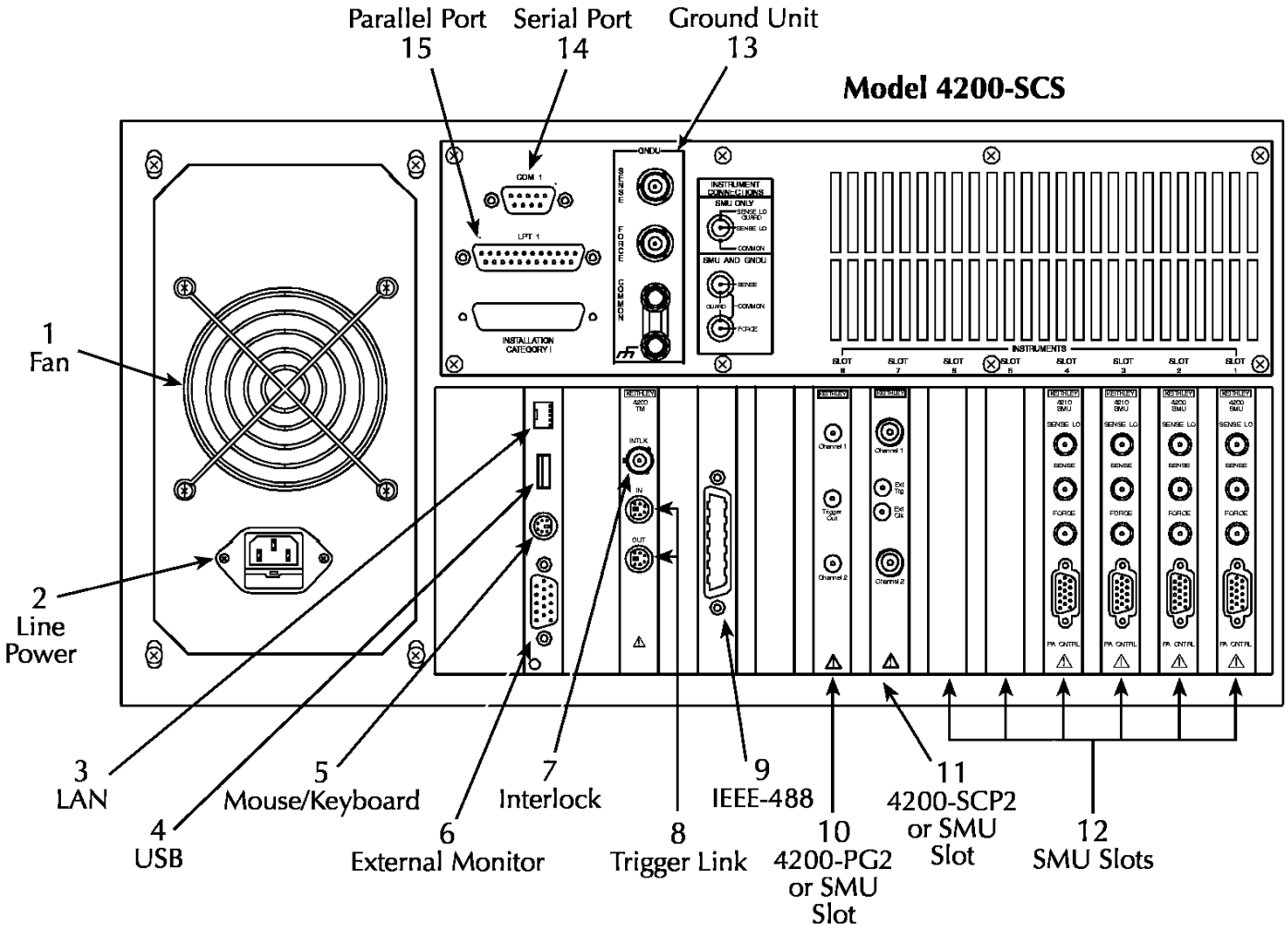
- 4200-SMU: Medium power SMU, 1pA-100mA, 1uV-210V
- 4210-SMU: High power SMU, 1pA-1A, 1uV-210V
- 4200-PA: DC PreAmp, extends any SMU to 0.1fA resolution
- 4210-CVU: Multi-frequency AC Impedance meter, 1KHz-10MHz, 20aF-1uF
- 4225-PMU: dual channel Ultra-fast I-V module, 10ns rise time, digitize both voltage and current simultaneously, 100nA-1A, 1mV-40V
- 4225-RPM: Remote Amplifier Switch, extends 4225-PMU current ranges down to 50pA, acts as a switch matrix
- 4255-PGU: Dual channel pulse generator, 20ns pw, 40V max
- 4200-SCP2: Dual channel digital oscilloscope
- 707B/708B Series: Switch Matrices and matrix cards

4200-SCS
Front Panel



1. Display
2. DVD/CD-R/W drive
3. Floppy deleted
4. Display brightness
5. POWER switch
6. HARD DISK indicator
7. INTERLOCK indicator
8. **MEASURING indicator**
9. Two USB 2.0 Ports

4200-SCS
Rear Panel



Overview

System Overview

Power Up and Log On

- Power-up – Disconnect DUTs, stay clear of SMU output connectors/probes
- Log-on – KIUSER (no password) or KIADMIN (password: KIADMIN1)
- Keithley Interactive Test Environment will load by default. You are ready to test.

Software Features – 4200 Desktop

Complete Reference contains manuals, white papers, applications notes, release notes and other related literature

KITE – Keithley Interactive Test Environment

KULT – Keithley User Library Tool

KCON – Keithley Configuration Utility

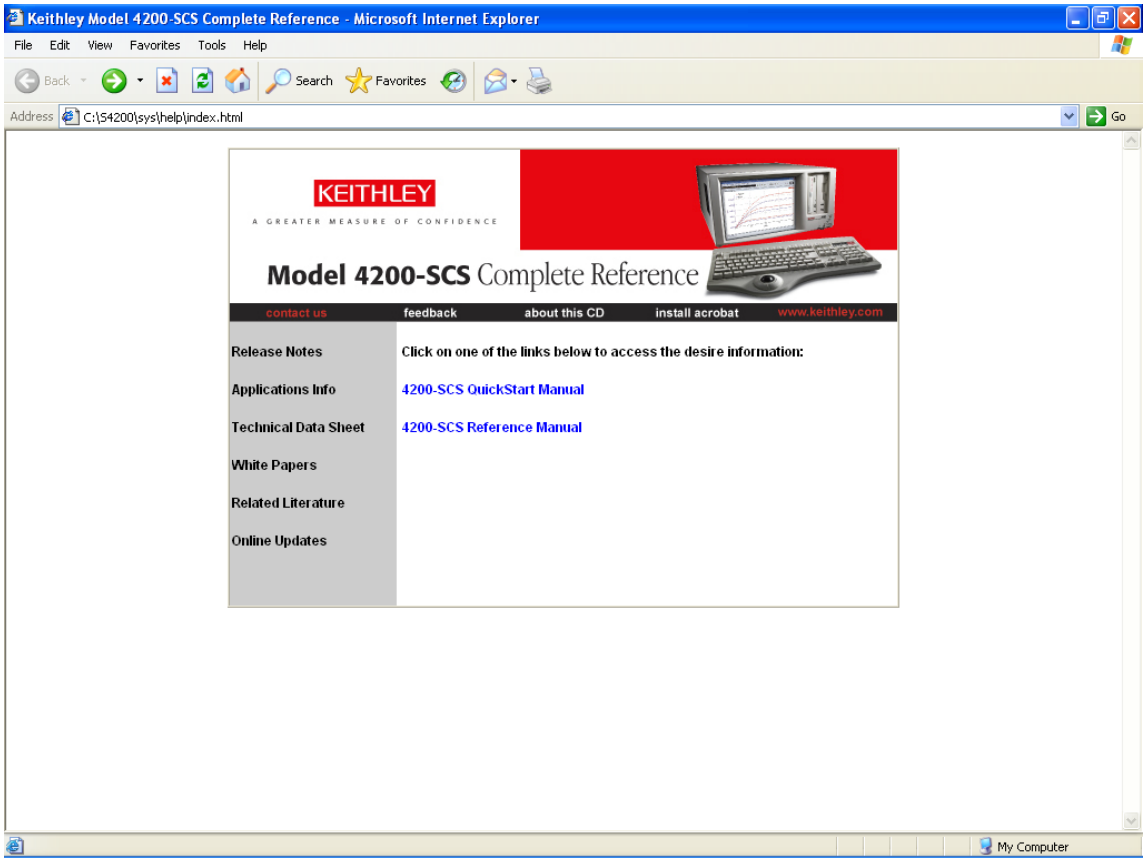
KXCI – Keithley External Control Interface

KPulse – Keithley Virtual Front Panel for Pulse Generator Card

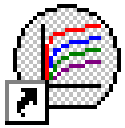
KScope – Keithley Virtual Front Panel for Scope Card

Complete Reference

Action Click on the Complete Reference icon on the desktop.



Software Features
KITE, KULT and KCON



- **KITE** — Keithley Interactive Test Environment (*KITE*) is the main Model 4200-SCS device characterization application. *KITE* is a versatile tool that facilitates both interactive characterization of an individual device or automated testing of an entire semiconductor wafer. Tests are organized into individual projects which are managed and executed by *KITE*.

- **KULT** — The Keithley User Library Tool (*KULT*) allows test engineers to integrate custom algorithms (user modules) into *KITE*. Internal 4200-SCS instrumentation and external instrumentation can be controlled via user modules written using the C programming language. *KULT* is used to create and manage libraries of user modules.

- **KCON** — The Keithley CONfiguration (*KCON*) utility allows test engineers to define the configuration of external GPIB instruments, switch matrices, and analytical probers connected to the 4200-SCS. *KCON* also provides basic diagnostic and troubleshooting functions.

Software Features
KXCI, KPulse and KScope

- **KXCI** — The Keithley External Control Interface (KXCI) allows you to use an external computer to remotely control the SMUs of the Model 4200-SCS over the GPIB (IEEE-488) bus using an Agilent 4145B style command set. You can do this in either of two modes: the 4145 emulation mode or the more full-featured 4200 extended mode, which provides access to all 4200-SCS SMU commands and ranges.

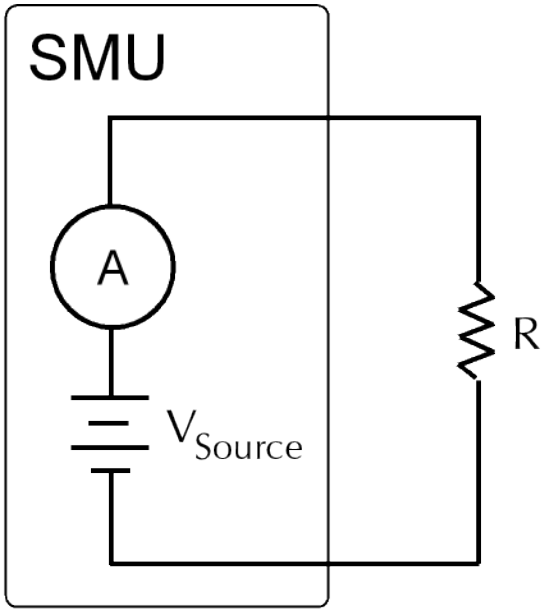
- **KPulse** — *KPulse* is the Keithley virtual front panel application for the 4200-PG2 dual channel pulse card. This is a stand-alone application that allows direct access to the 4200-PGU.

- **KScope** — *KScope* is the Keithley virtual front panel application for the 4200-SCP2 dual channel digital storage oscilloscope. This is a stand-alone application that allows direct access to the 4200-SCP2.

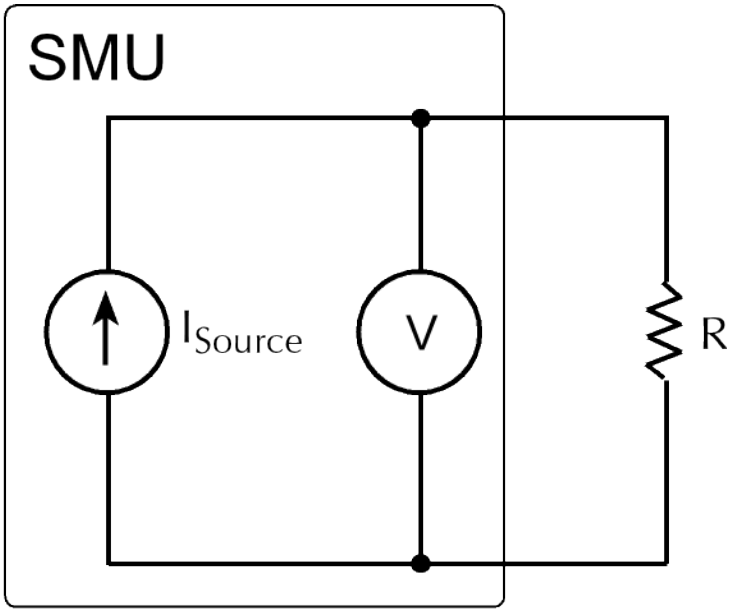
Basic Source-Measure Features and Concepts

Precision DC Source-Measure Units

SMU stands for Source Measure Unit. An SMU is a single unit that can source and measure both current and voltage.



Source V, Measure I



Source I, Measure V

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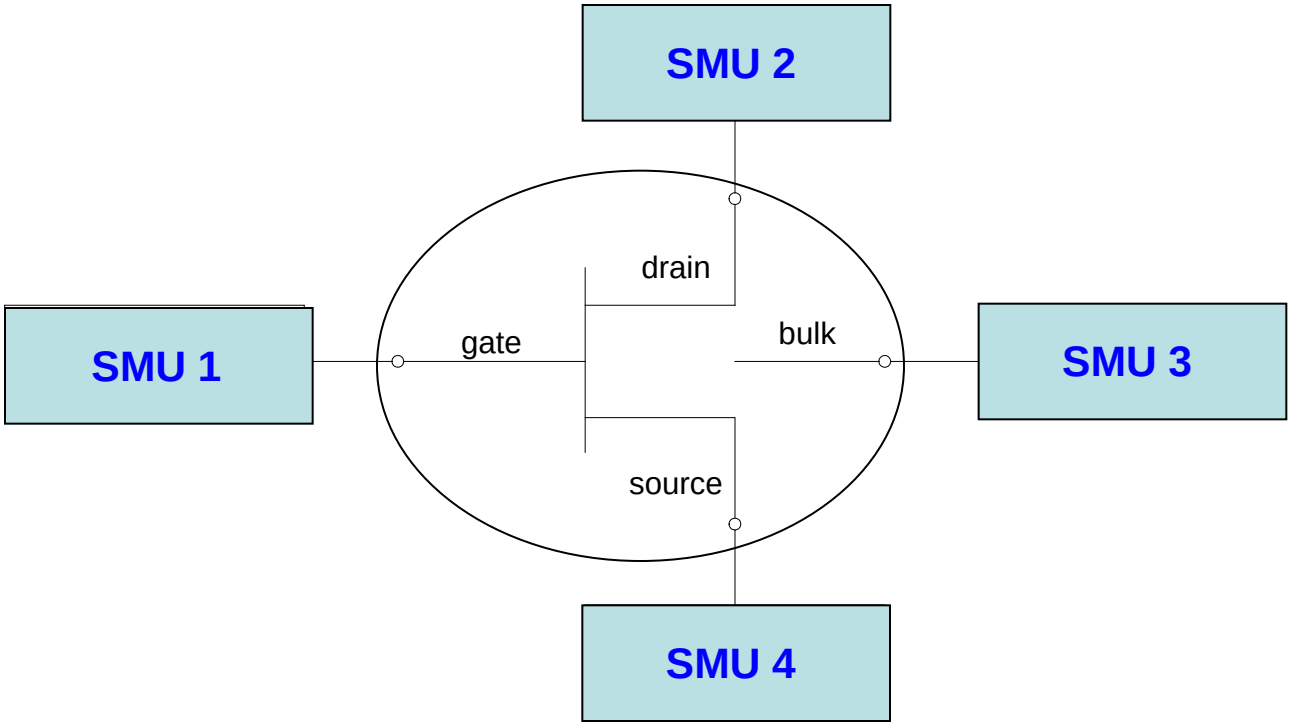
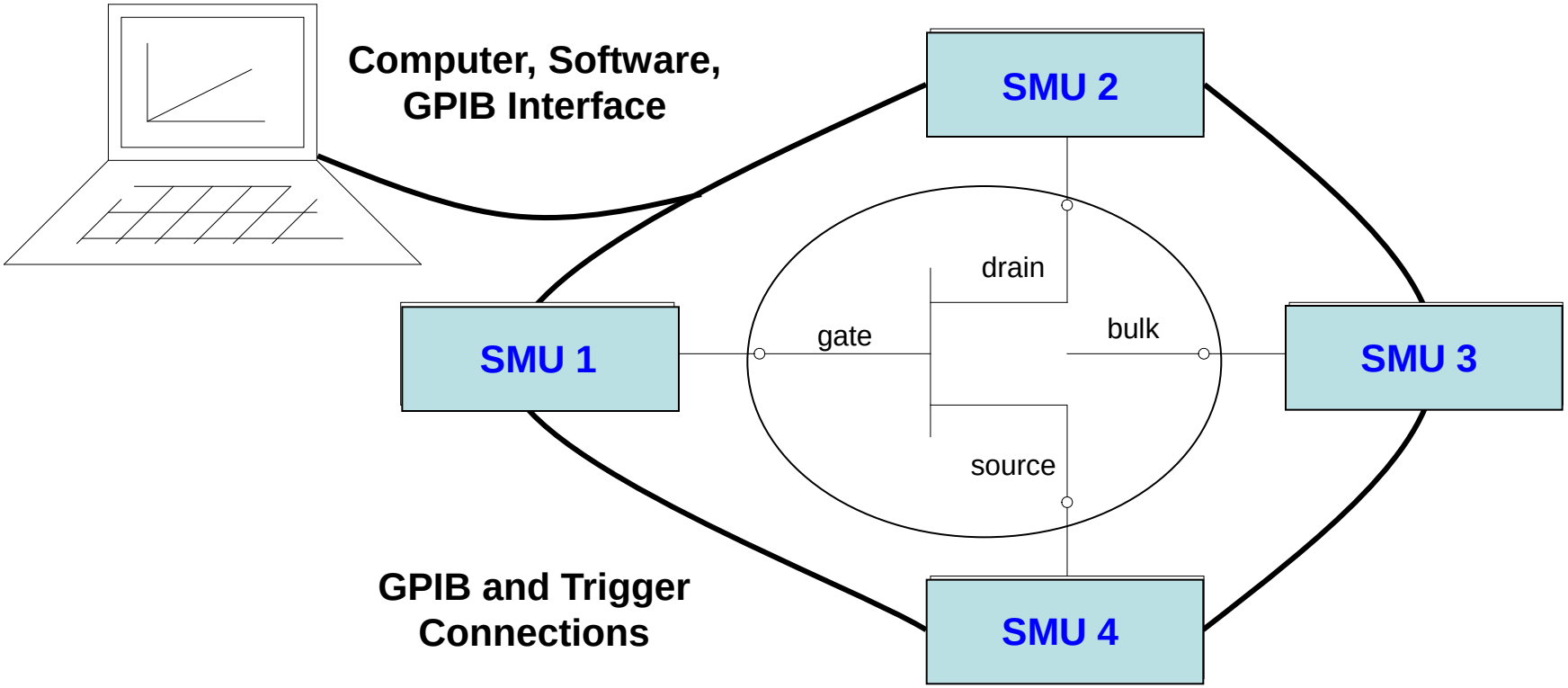
Multiple SMUs



Devices with multiple terminals usually required several SMUs for IV characterization of the device. In this example, the 4-terminal MOSFET requires 3 or 4 SMUs for complete testing.

Automating Multiple SMUs

Automating and testing of multi-terminal devices requires the user to create a highly complex system involving programming of multiple instruments, precise triggering, graphics, analysis, etc.



SMU Basic Specs

4200-SMU Medium Power Source Measure Unit (2.1watts max)
4210-SMU High Power Source Measure Unit (21 watts max)

Maximum Number of units per chassis: 9
Voltage Range: +/-200V, 4 ranges from 200mv to 200v full scale
Basic Voltage Accuracy: 0.01% measure, 0.02% source
Voltage resolution: 0.1uV to 100uV
Current Range: +/- 100ma, 7 ranges from 100nA to 100mA full scale (1A for 4210)
Basic Current Accuracy: 0.03% measure, 0.04% source
Current Resolution: 0.1pA to 100pA

With optional 4200-PA: adds 5 low current ranges with resolution down to 0.1fA

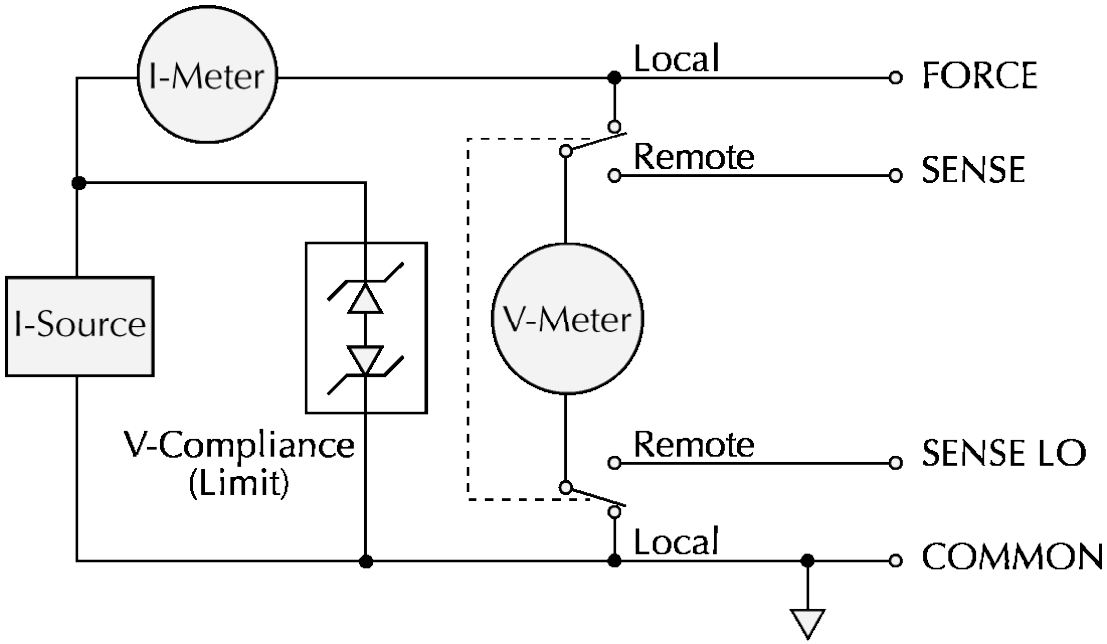
Interpreting an SMU spec

Range	MaxV	Measure Resolution	Measure Accuracy	Source Resolution	Source Accuracy
1 nA	210 V	3 fA	0.050% + 100 fA	50 fA	0.060% + 300 fA
200mV	1A	1uV	.012%+100uV	5uV	.02%+150uV

Measure Resolution: 1.000003 nA is almost 7 digits, about 24 bits
Measure Offset: 100fA, we never know absolutely better than that
Source Resolution: 1.000005 nA is about 5.5 digits
Source offset: this much current could flow, even when set to zero

SMU Configuration
Source I, Measure V

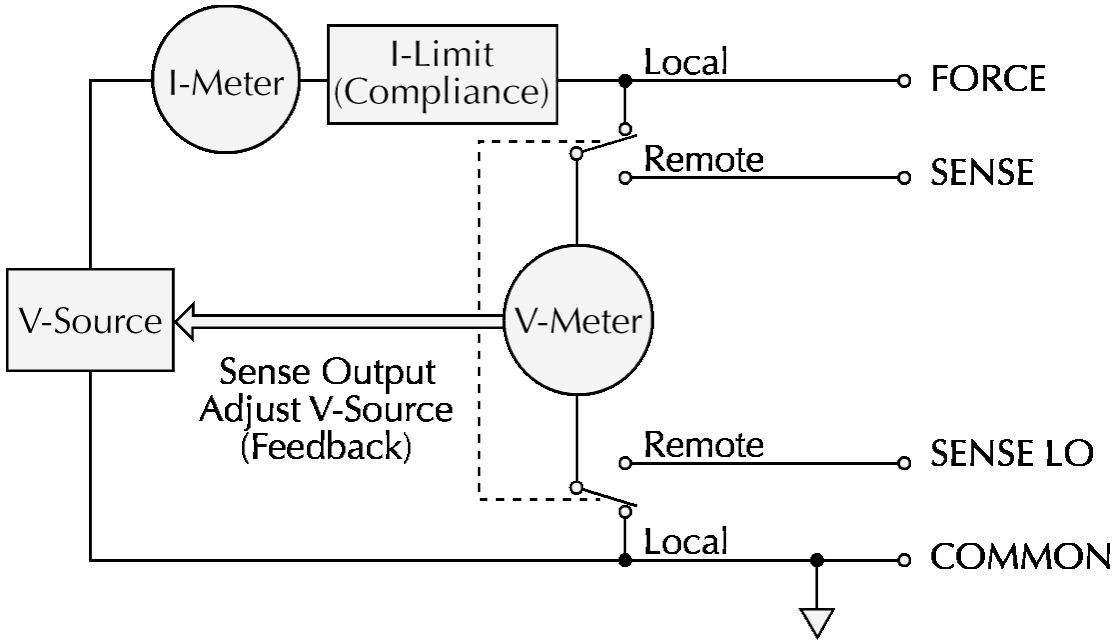
SMU is a fixed combination of a current source with a voltmeter in parallel.



- **Source I, Measure V turns SMU into a high-impedance current source.**
- **If I = 0, SMU becomes a voltmeter.**

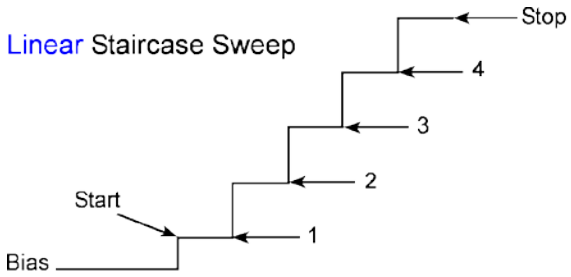
SMU Configuration
Source V, Measure I

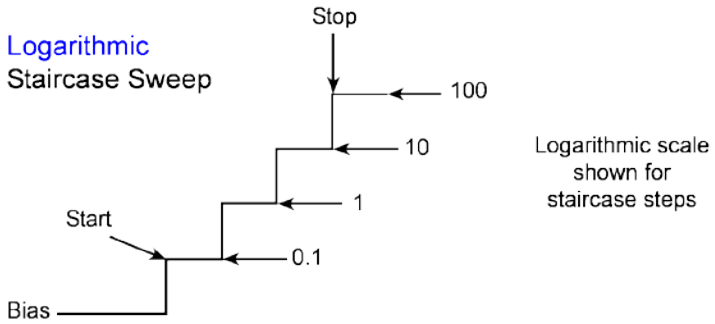
SMU is a fixed combination of a voltage source with an ammeter in series.

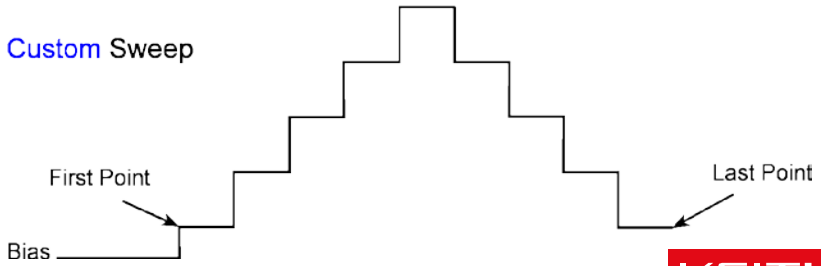


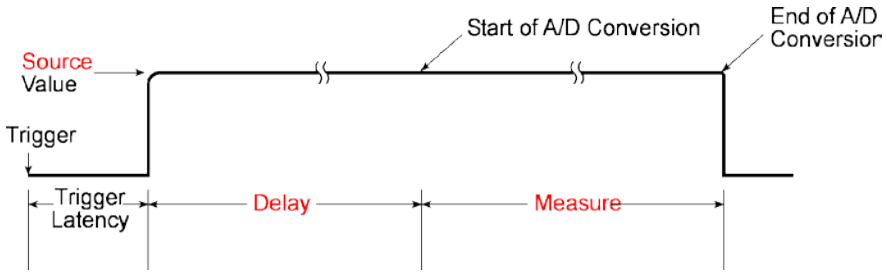
- **Source V, Measure I turns SMU into a low-impedance voltage source.**
- **If V = 0, SMU becomes an ammeter only.**

Understanding Sweep Basics









- SDM (**Source**-**Delay**-**Measure**) cycle:
  1. Set source output level
  2. Wait for the source delay
  3. Make the measurement
- Delay and Measure times can be controlled from KITE
- Four sweep types – **Linear**, **Logarithmic, Dual** and **Custom**
- Each step (sweep point) is an SDM cycle
- Additional timing variable in sweep – Hold Time (initial delay before sweep starts)

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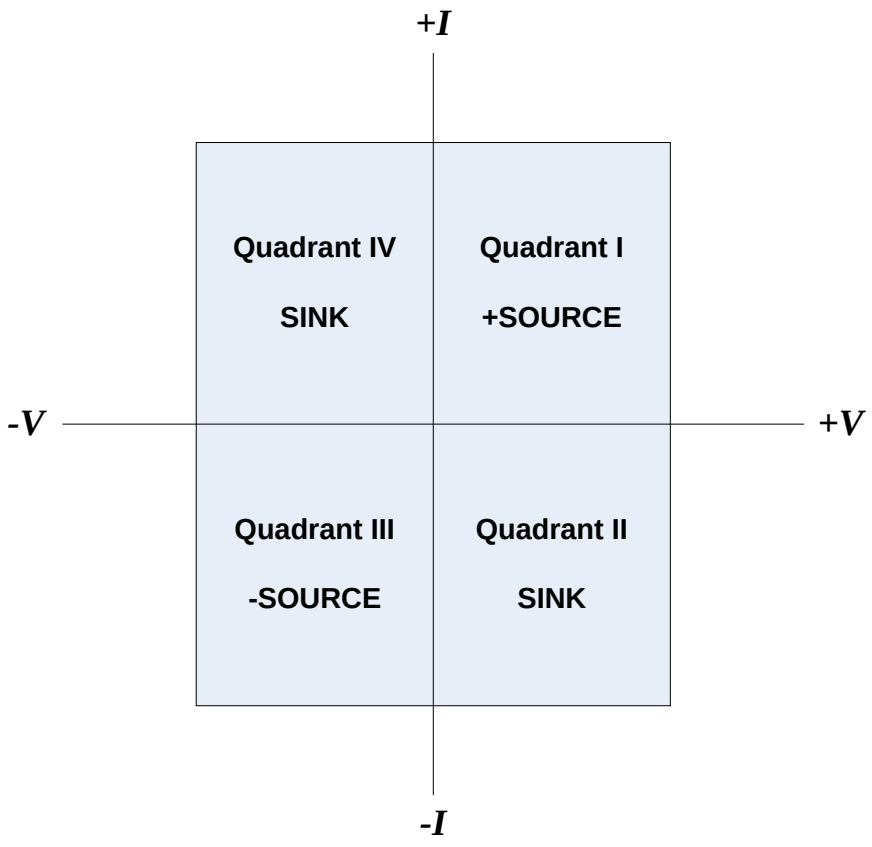
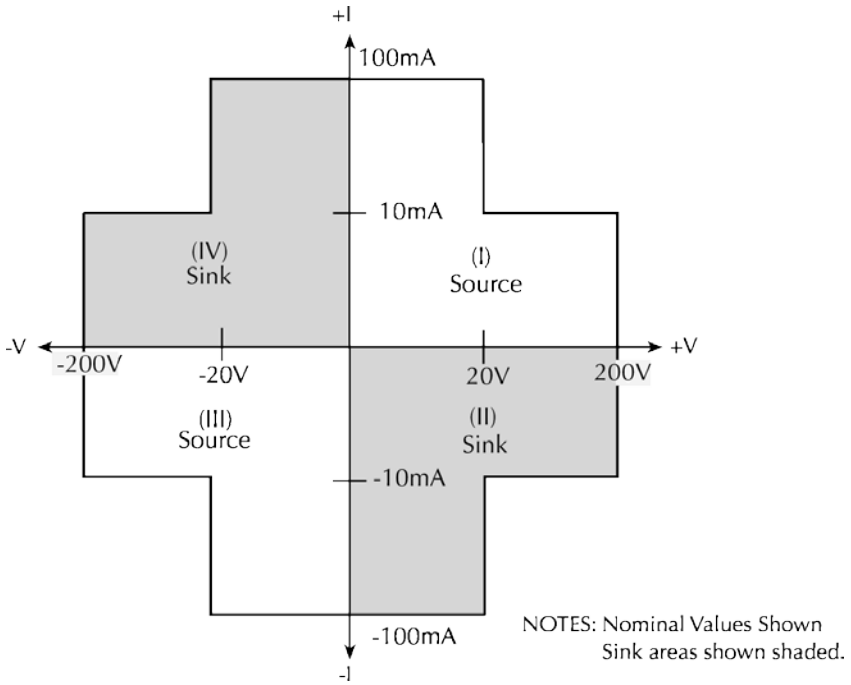
Four Quadrant Operation



- SMUs can operate in one of four quadrants.
- Quadrants I and III are sourcing (I and V have same polarity):
  - Sourcing SMUs deliver power to load.
- Quadrants II and IV are sinking (I and V have different polarity):
  - Sinking SMUs dissipate power.

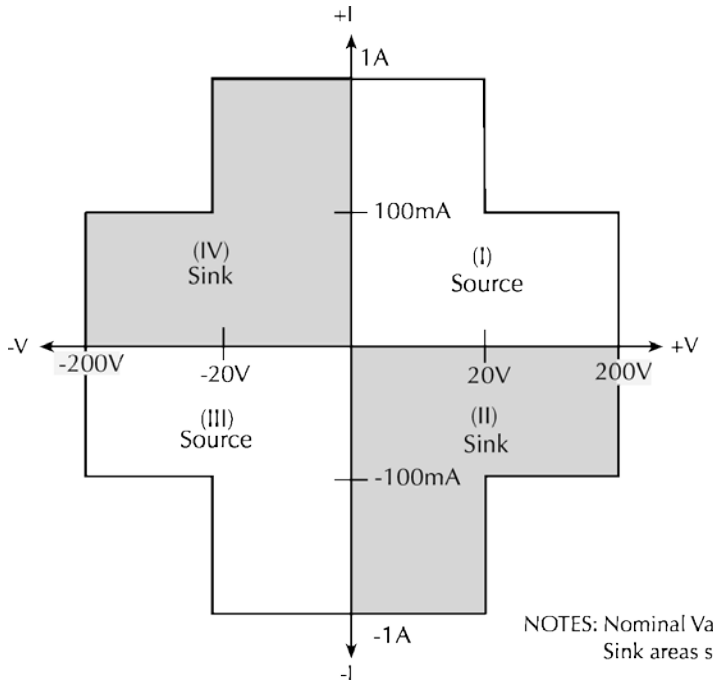
Operating Boundaries

4200-SMU: 105mA, 21V
10.5mA, 210V



NOTES: Nominal Values Shown
Sink areas shown shaded.

4210-SMU: 1.05A, 21V
105mA, 210V



NOTES: Nominal Values Shown
Sink areas shown shaded.

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Compliance

Built-in mechanism that limits current or voltage depending on whether the SMU is configured as a V-Source or I-Source.

SMU as V-Source

- Compliance limits the maximum current that may be output to the device.
- When compliance is reached, the SMU effectively becomes a constant current source

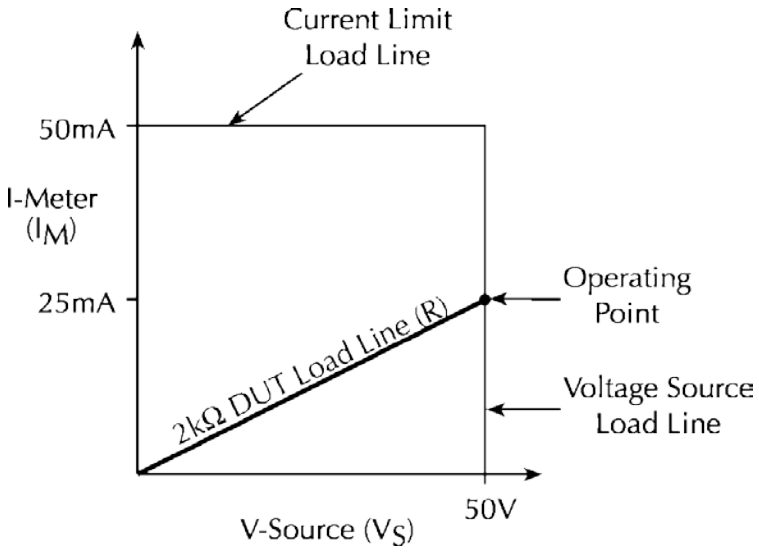
SMU as I-Source

- Compliance limits the maximum voltage that appears across the output terminals (Local sense) or across the device (Remote sense).
- When compliance is reached, the SMU effectively becomes a constant voltage source.

Understanding Compliance

Set Voltage to 50V and Compliance to 50mA

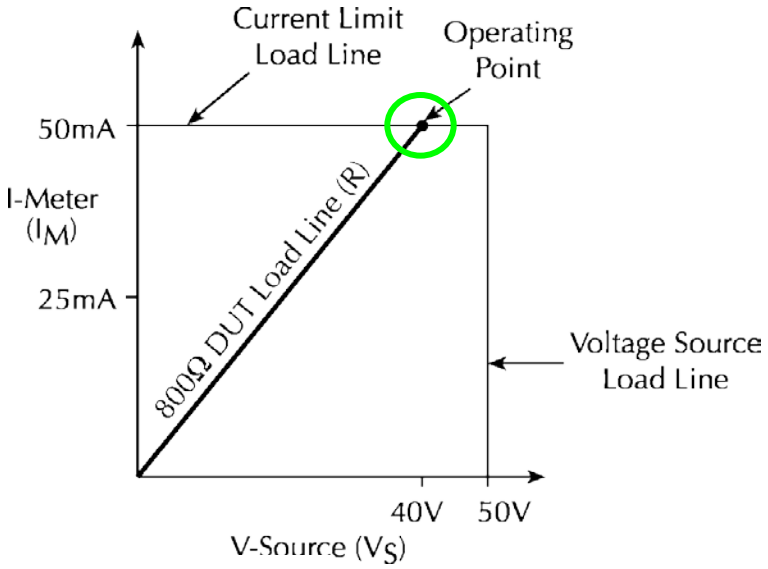
Normal V-Source Operation



$R = 2k\Omega$

$I_M = V_S / R$
$= (50V) / (2000\Omega)$
$= 25mA$

V-Source in compliance



$R = 800\Omega$

$I_M = V_S / R$
$= (50V) / (800\Omega)$
$= 62.5mA$

No !
I-Limit is 50mA !!

$R = 800\Omega$

$V_S = I_M \cdot R$
$= (50mA) \cdot (800\Omega)$
$= 40V$

SMU has become a current source!

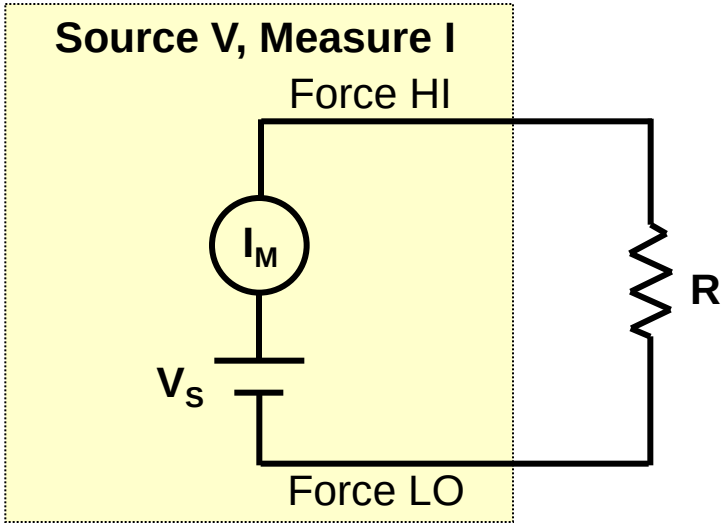
Local vs. Remote Sensing

Local Sense

(2-wire measure)

Use when lead resistance is negligible compared to DUT resistance. Examples:

- Measuring resistance of insulators
- Measuring low current

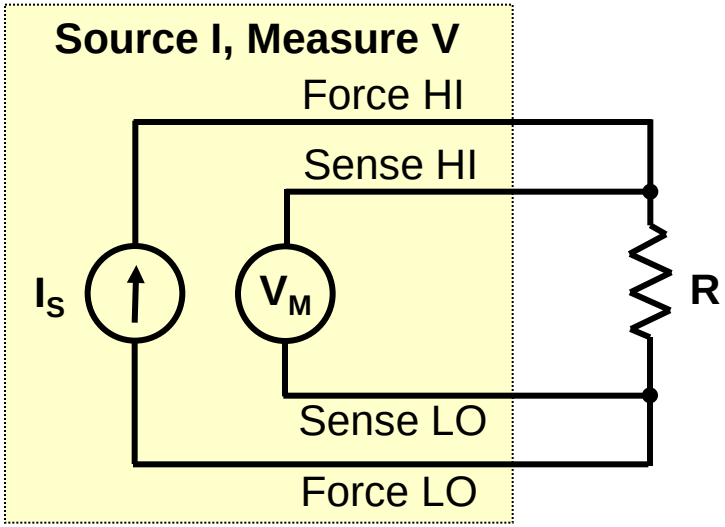


Remote Sense

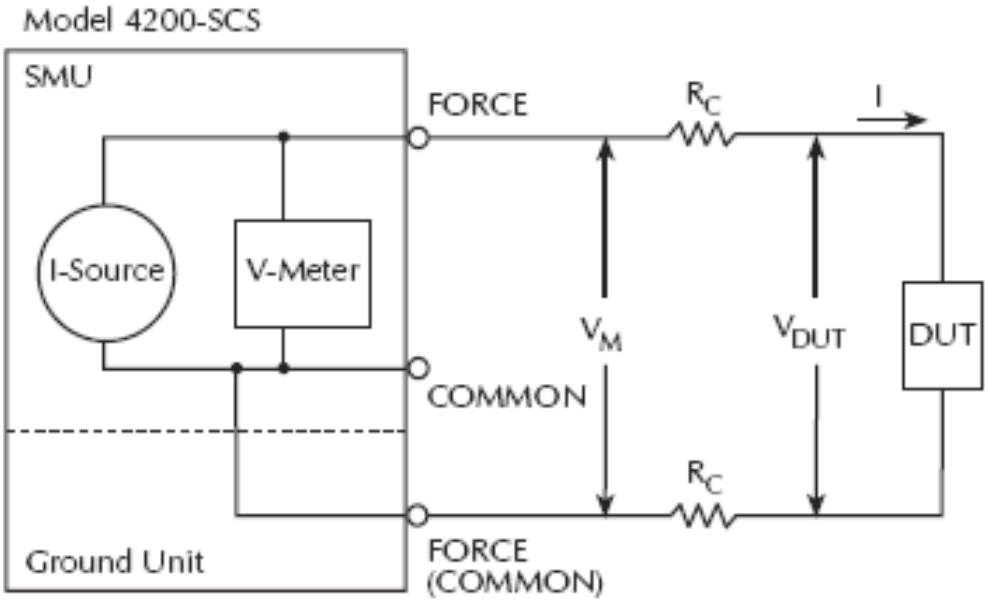
(4-wire measure)

Use to eliminate lead and contact resistance from affecting measure accuracy. Examples:

- Measuring low resistance (<10Ω)
- Sourcing voltage at a high current



Local Sensing



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 RC

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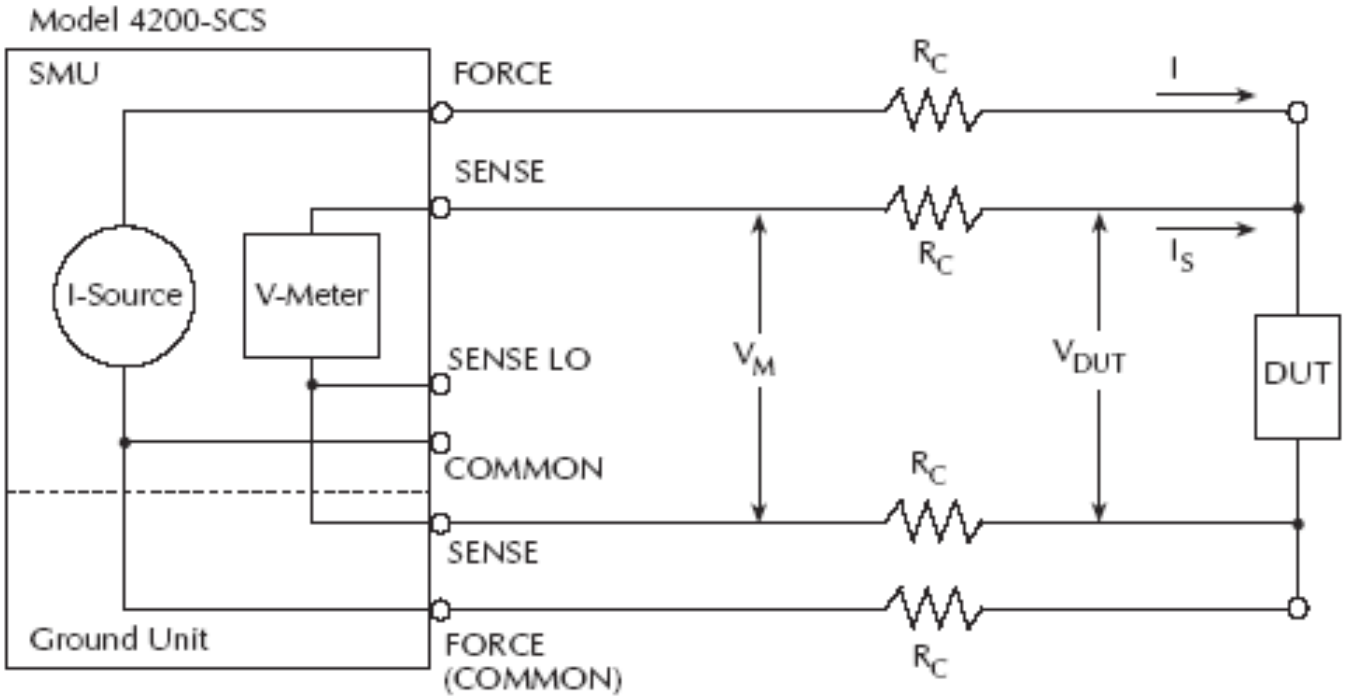
Remote Sensing



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

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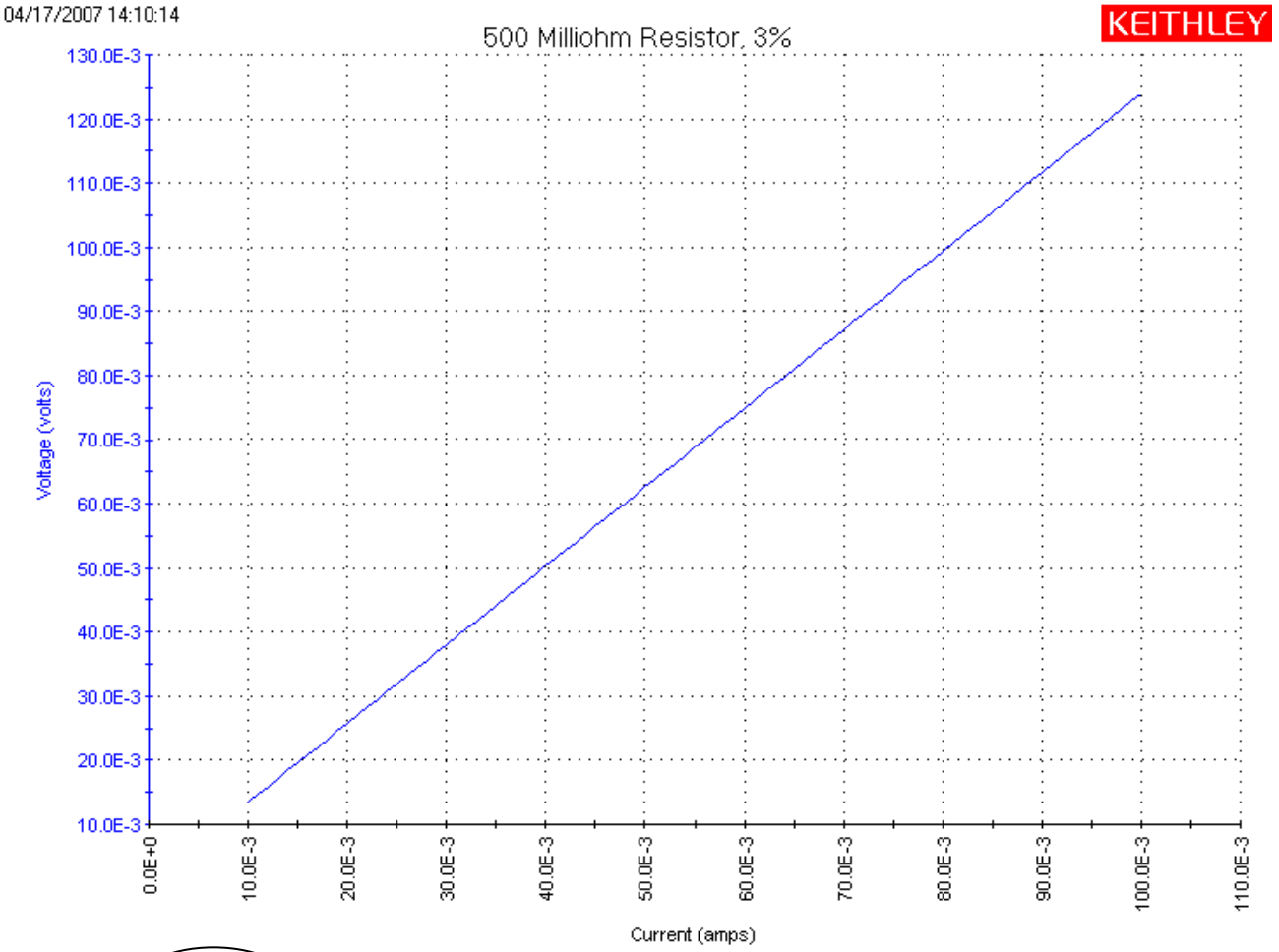
Lab 1

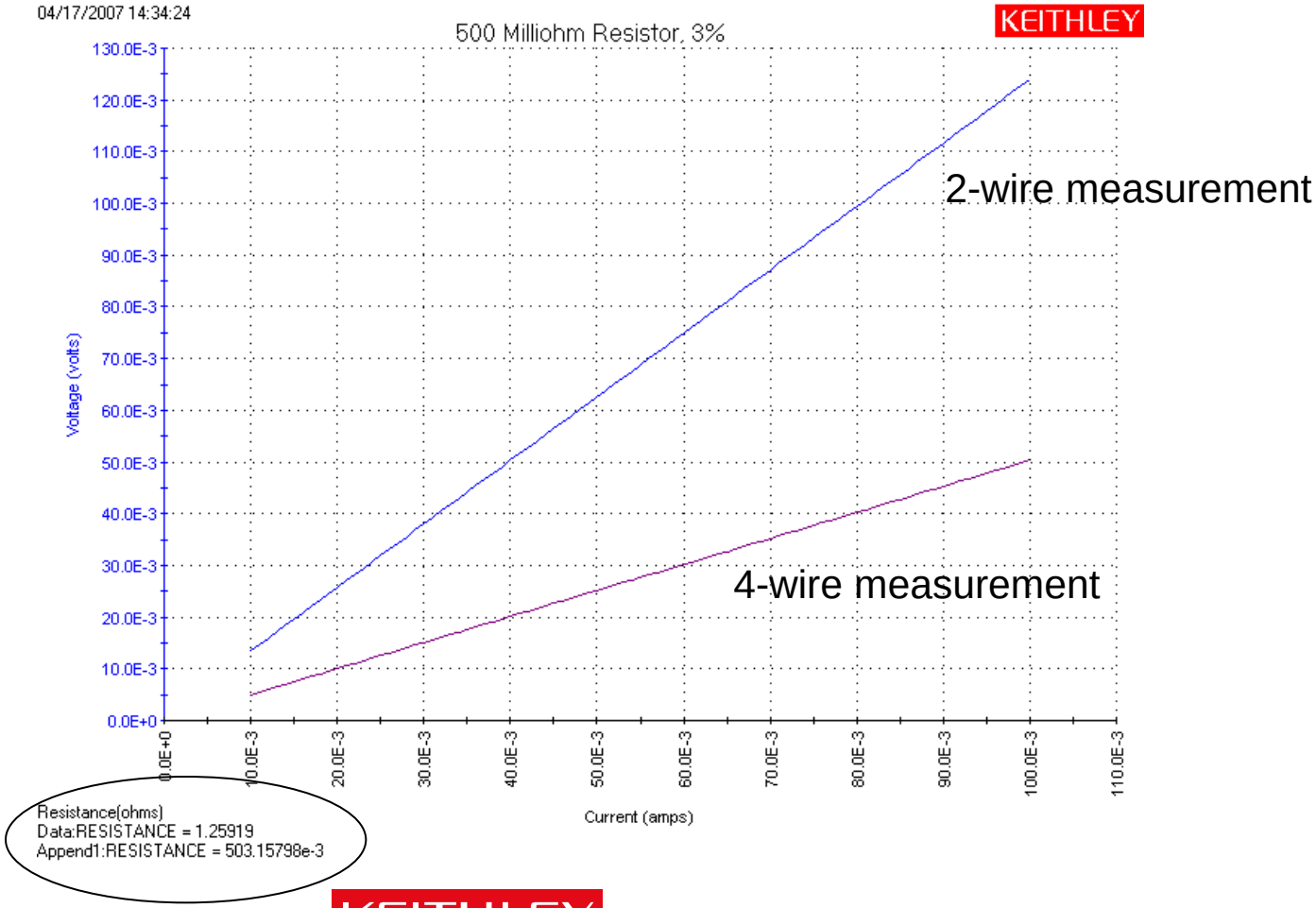
Measuring a Low Resistance Using Remote Sense

Lab 1 Results



Resistance(ohms)
Data:RESISTANCE = 1.25919

Lab 1 Results



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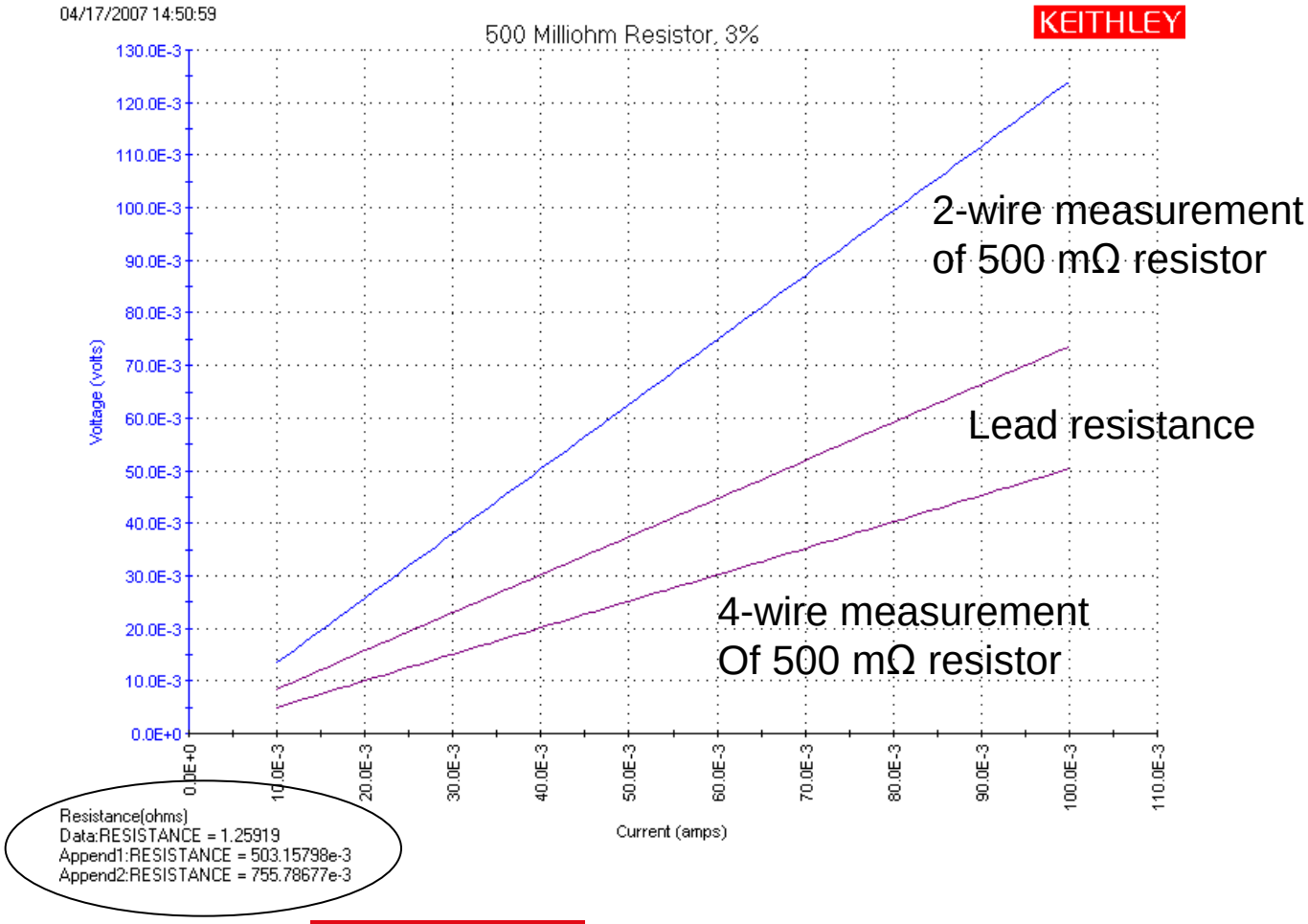
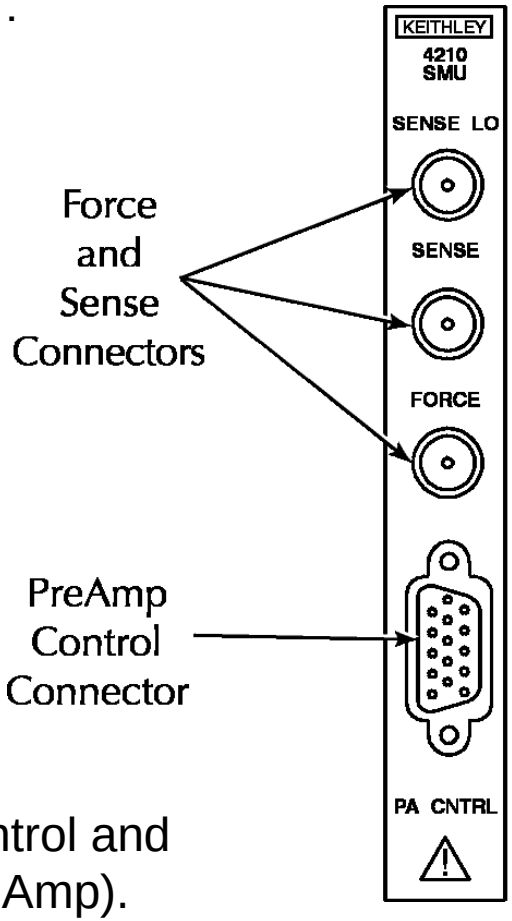
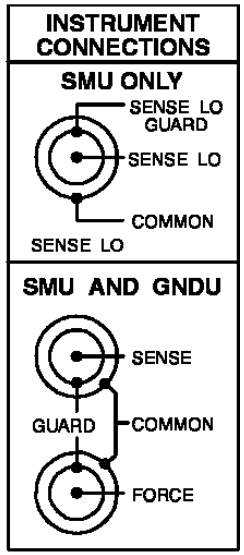
Lab 1 Results



4200-SMU Connectors

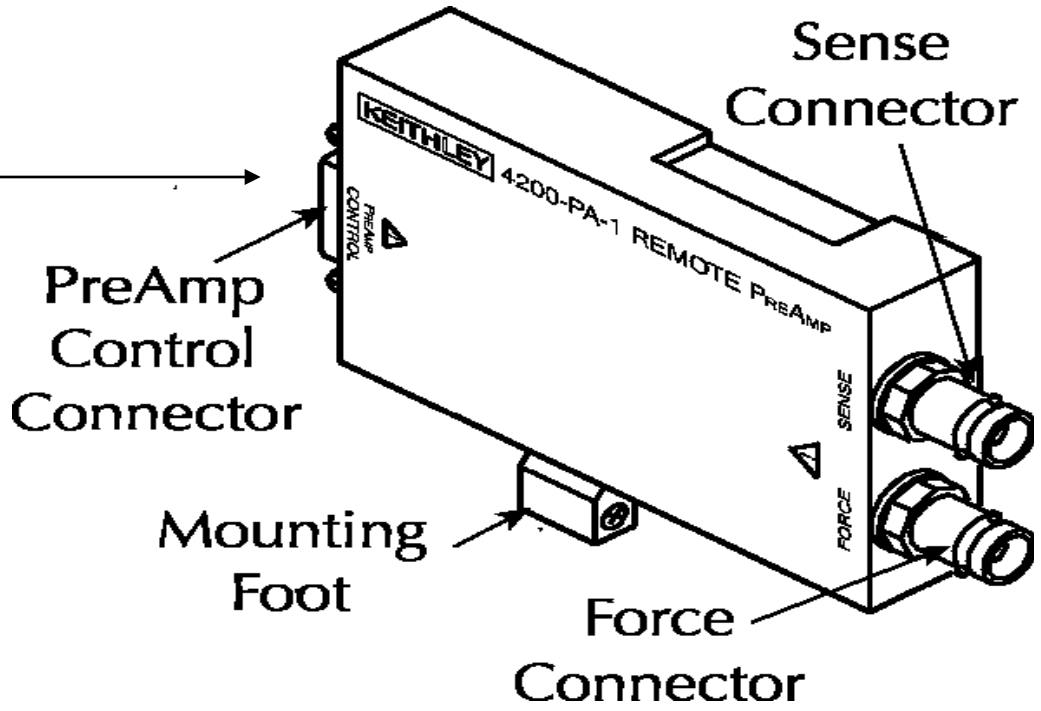
- **SENSE LO** miniature triaxial connector:
  - Sense Lo – Center pin
  - Sense Lo Guard – Inner shield
  - Common – Outer shield
- **SENSE** miniature triaxial connector:
  - Sense – Center pin
  - Guard – Inner shield
  - Common – Outer shield
- **FORCE** miniature triaxial connector:
  - Force – Center pin
  - Guard – Inner shield
  - Common – Outer shield
- **PA CNTRL** – D connector provides control and signal connections to the 4200-PA (PreAmp).





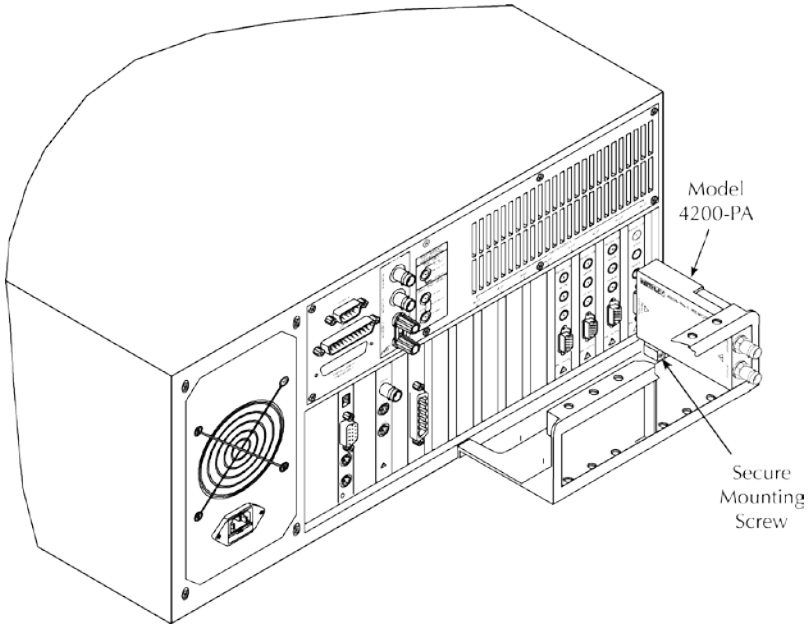
4200-PA
DC PreAmp

Connects to PreAmp control connector of 4200-SMU

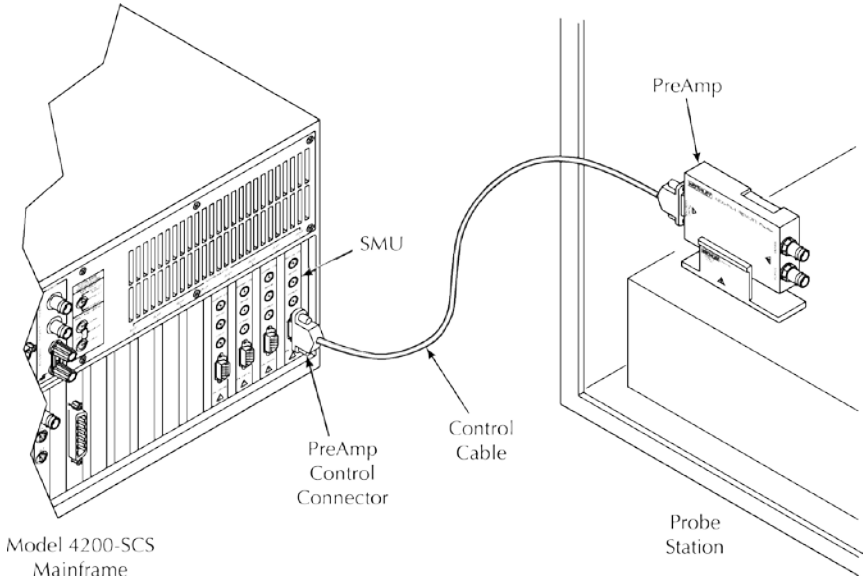


Preamp Mounting

Rear Panel Mounting



Remote Mounting



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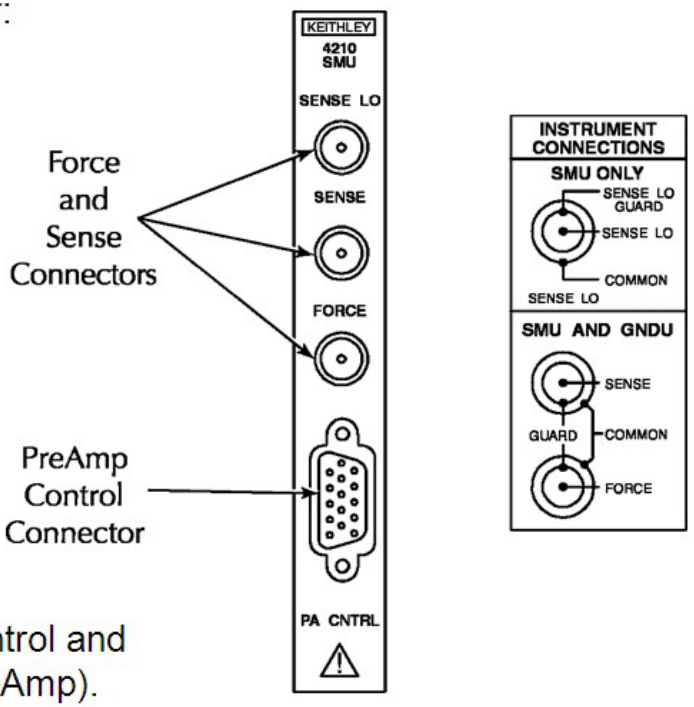
Operation

4200-SMU Connectors

- **SENSE LO** miniature triaxial connector:
  - Sense Lo – Center pin
  - Sense Lo Guard – Inner shield
  - Common – Outer shield
- **SENSE** miniature triaxial connector:
  - Sense – Center pin
  - Guard – Inner shield
  - Common – Outer shield
- **FORCE** miniature triaxial connector:
  - Force – Center pin
  - Guard – Inner shield
  - Common – Outer shield
- **PA CNTRL** – D connector provides control and signal connections to the 4200-PA (PreAmp).



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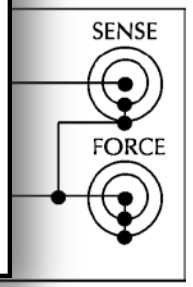
A GREATER MEASURE OF CONFIDENCE

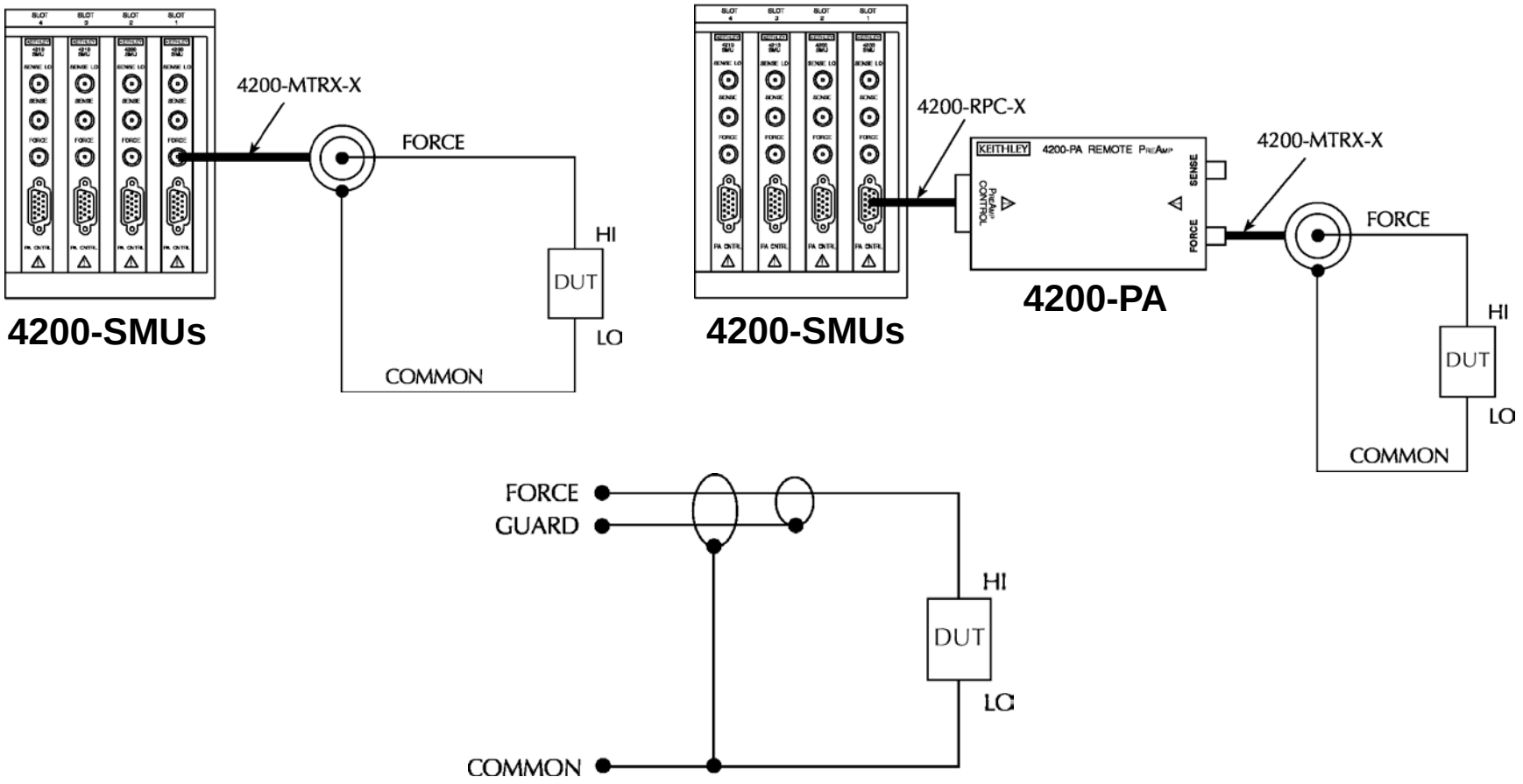
40



Removable Ground Link

Ground Unit Circuitry

Local Sense Connections
(2-Wire)



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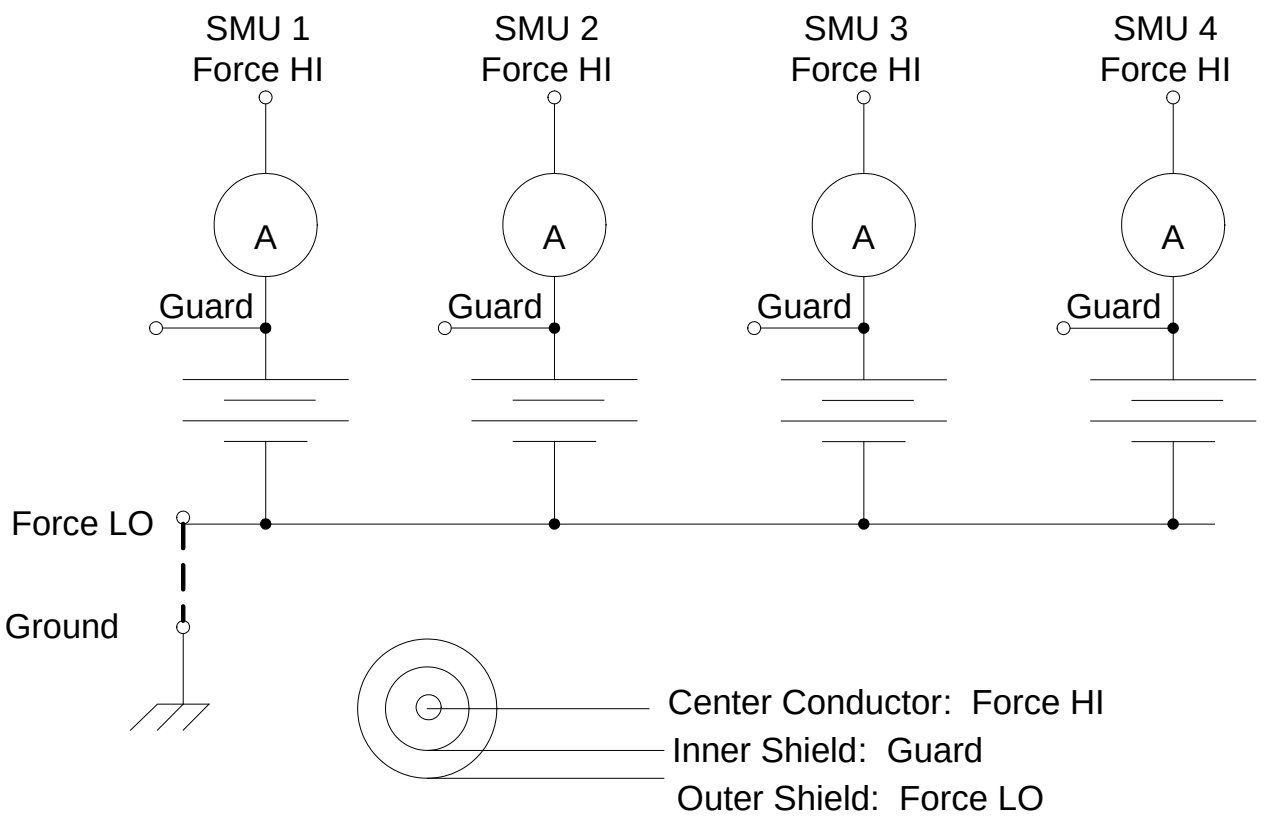
Common Connection of SMUs

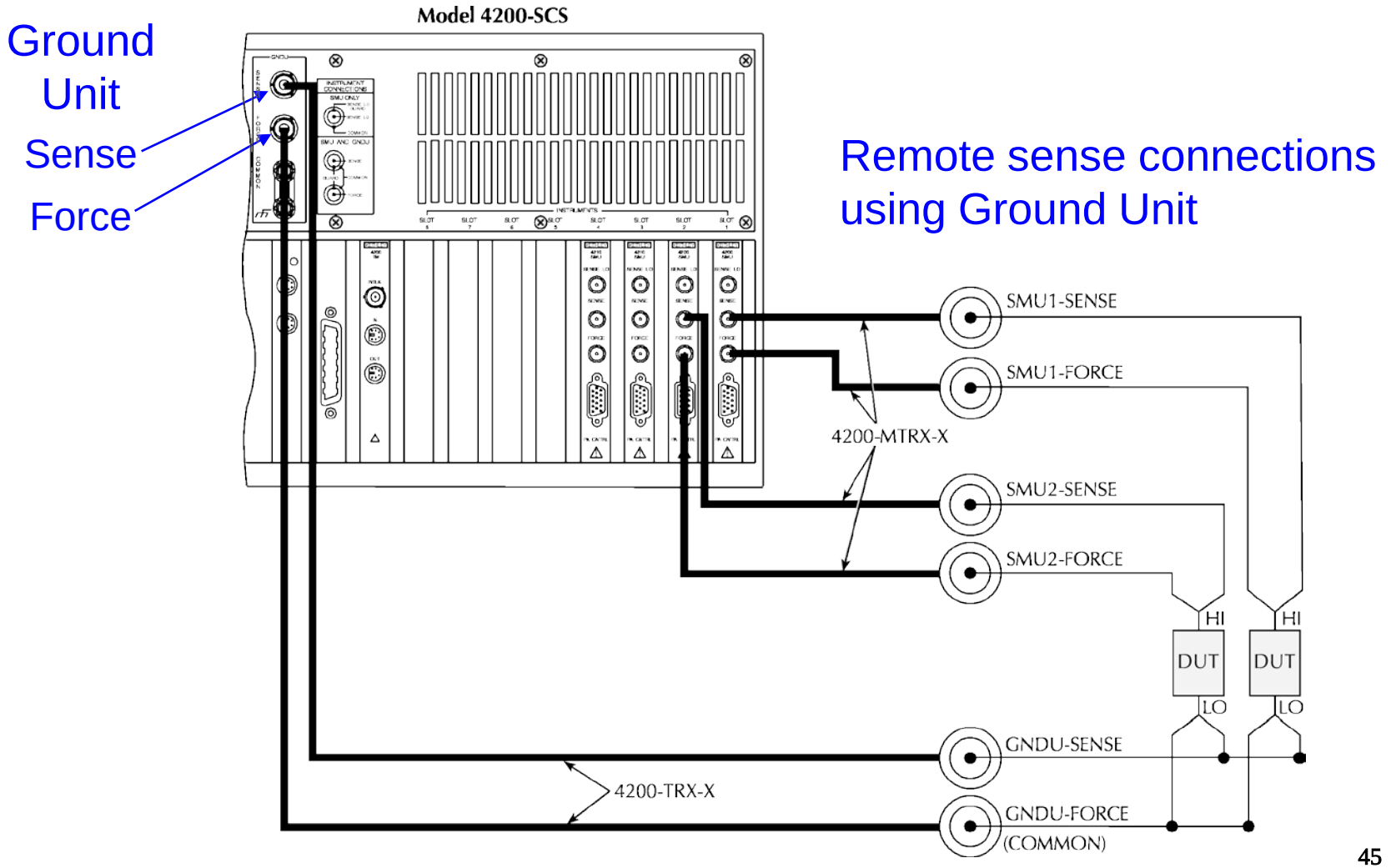
Force Hi Terminal
Center pin of triax cable of each SMU.

Force LO terminal
1. Outside shell of SMU triax connector.
2. Center pin of Force terminal on GNDU.

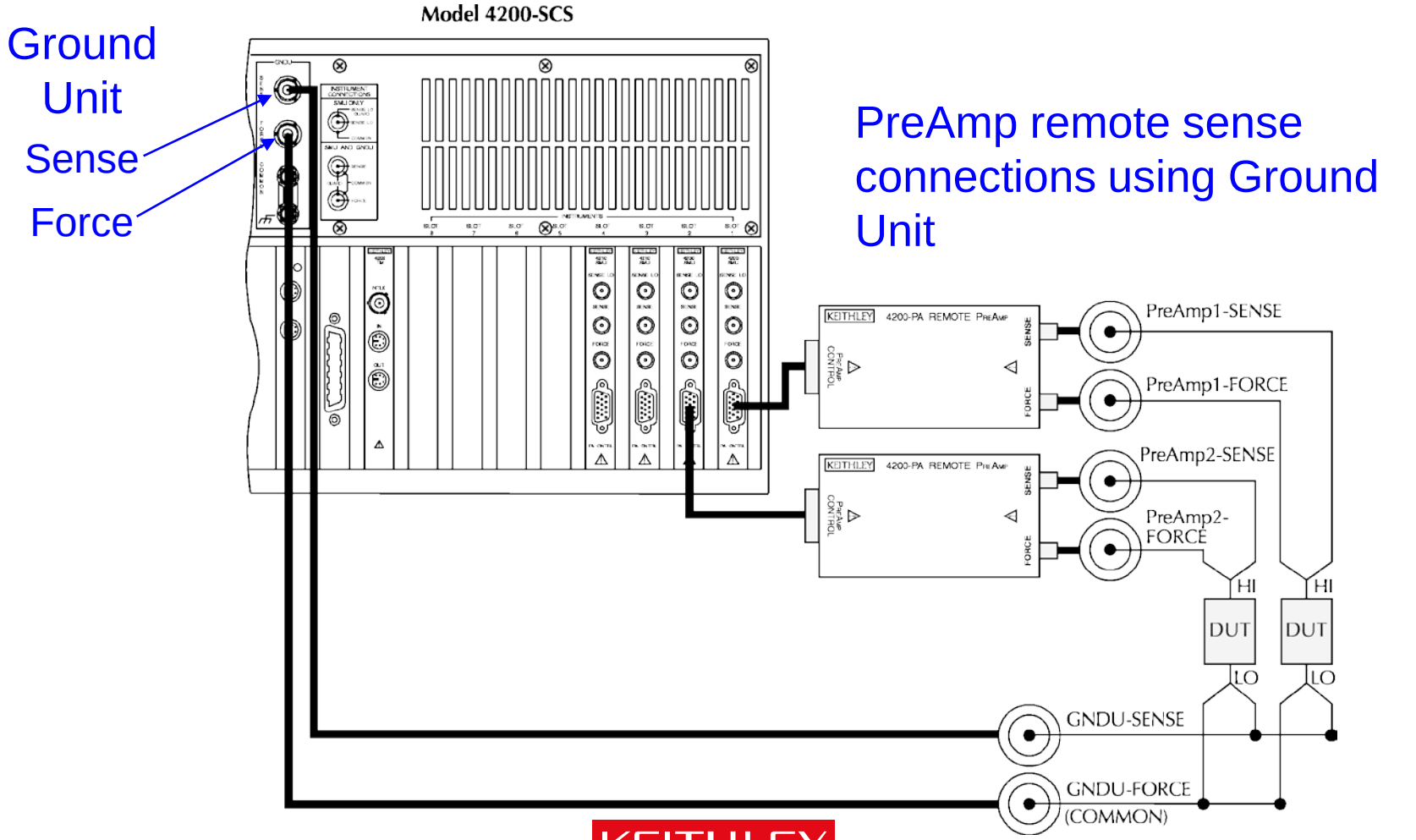
Guard
Inside shield of SMU triax connector.



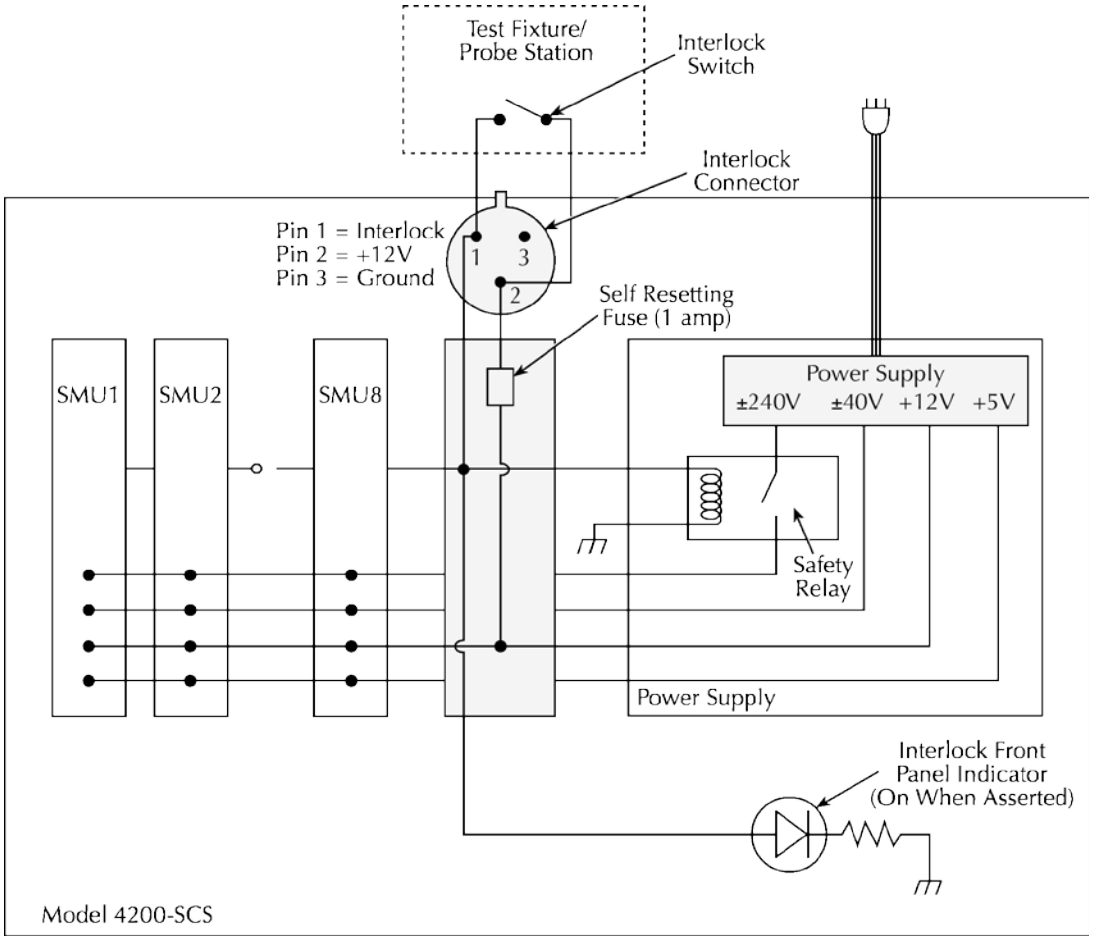
Remote Sense Connections
(4-Wire)



PreAmp Remote Sense Connections (4-Wire)



Interlock Connections



- Without interlock, SMU output is limited to ±20V, **or 35V if software override**
- Interlock will engage the 200V range
- Use supplied interlock cable to connect to safety switch on test fixture or probe station dark box
- Safety switch closes circuit between pins 1 and 2 of the interlock cable
- Green Interlock LED on 4200-SCS front panel will be lit when interlock is engaged
- DO NOT SHORT PIN 3 TO OTHER PINS!

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