# Next generation semiconductor devices and applications

## (차세대 반도체 소자 및 응용)

장소: 공과대학 6호관 510호

시간: 화 (6-A, 6-B, 7-A, 7-B, 8-A, 8-B)

# 3. Semiconductor parameter analyzer

## SMU - all terminal parameters

Parameter descriptions are provided in the following topics

### Compliance

- One 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
- 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.

One can stop the test if the source reaches compliance

# 3. Semiconductor parameter analyzer

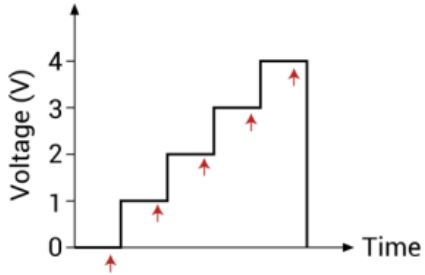
## SMU - all terminal parameters

Parameter descriptions are provided in the following topics

### Dual Sweep

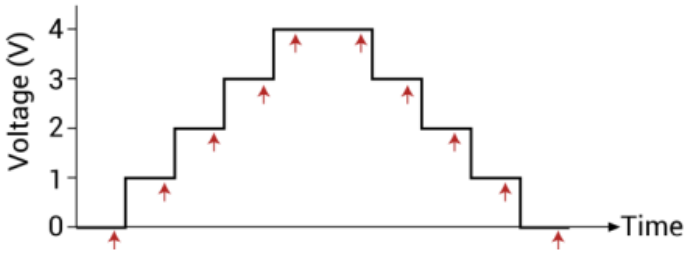
- When you select Dual Sweep, the instrument sweeps from start to stop, then from stop to start. When you clear Dual Sweep, the instrument sweeps from start to stop only.

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





**Dual sweep enabled**
Ten data points




# 3. Semiconductor parameter analyzer

## SMU - all terminal parameters

Parameter descriptions are provided in the following topics

### Force Range (Source Range)

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

- **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.

# 3. Semiconductor parameter analyzer

## SMU - all terminal parameters

Parameter descriptions are provided in the following topics

### 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

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

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

# 3. Semiconductor parameter analyzer

## SMU - all terminal parameters

Parameter descriptions are provided in the following topics

### Points (Linear sweep)

- 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:

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

# 3. Semiconductor parameter analyzer

## SMU - all terminal parameters

Parameter descriptions are provided in the following topics

### 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.

# 3. Semiconductor parameter analyzer

## SMU - all terminal parameters

Parameter descriptions are provided in the following topics

### Pulse Mode (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.

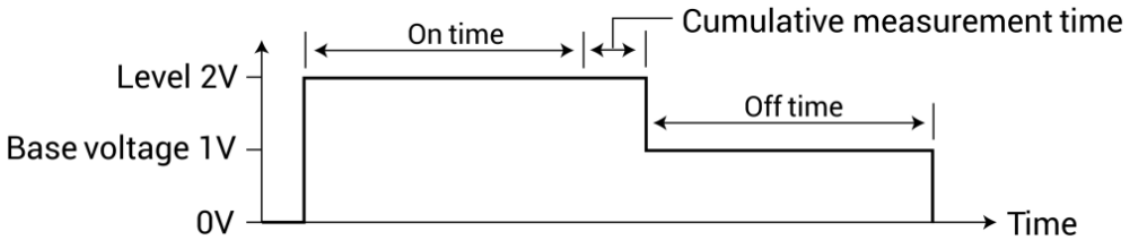



**Figure 47: Pulse Mode example: Voltage bias with a 2 V level and 1 V base**

# 3. Semiconductor parameter analyzer

## SMU - all terminal parameters

Parameter descriptions are provided in the following topics

### Pulse Mode (Example)

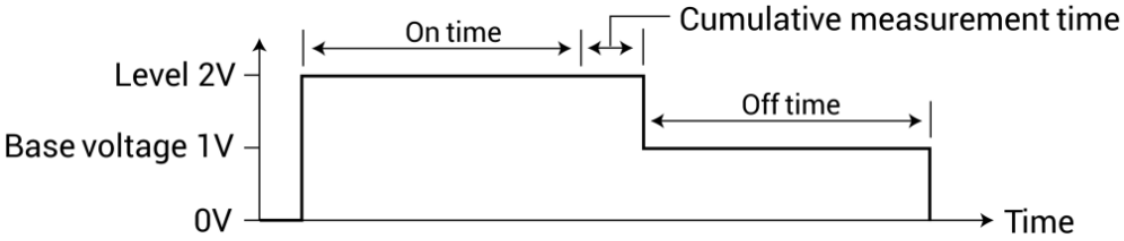



**Figure 47: Pulse Mode example: Voltage bias with a 2 V level and 1 V base**

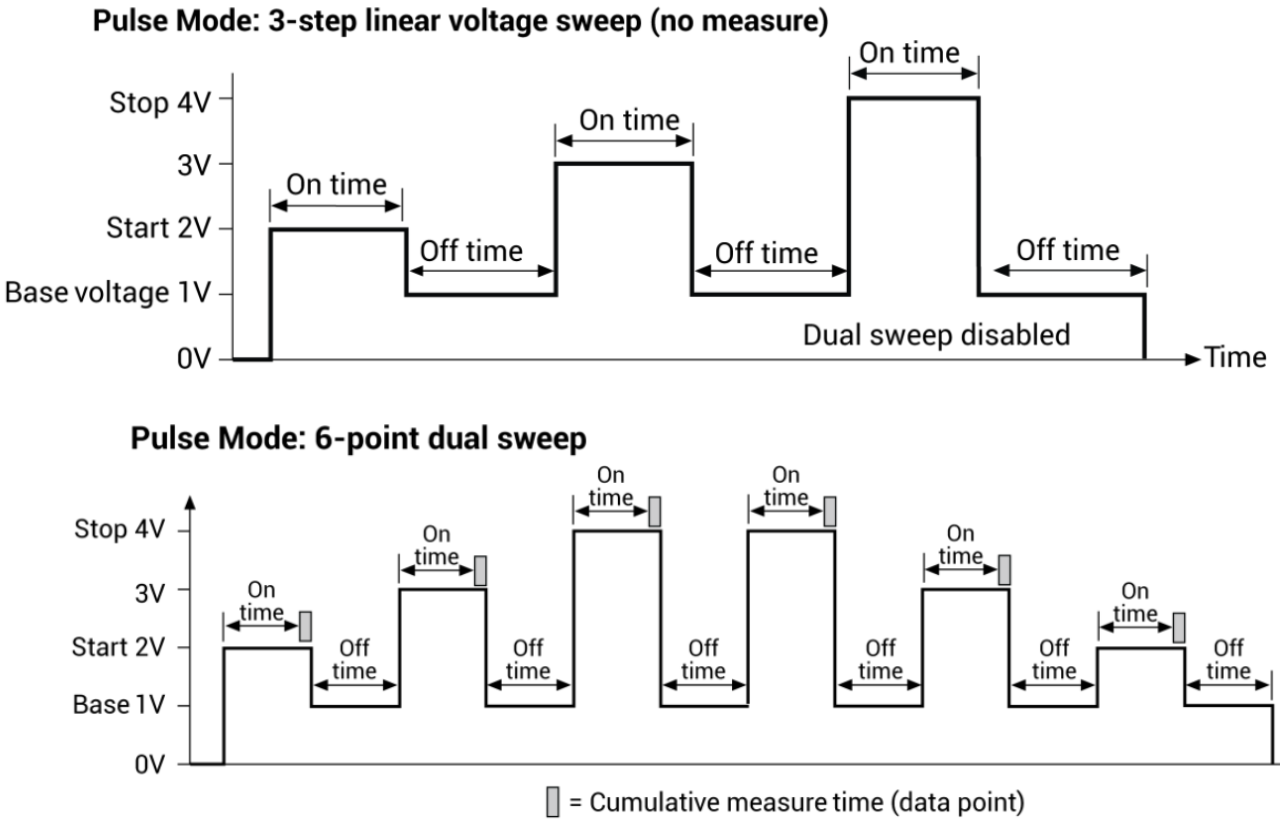
- For a sweep operation mode, pulse output goes to the sweep step levels during the pulse on times.
- During the off times, pulse output goes to the specified Base Voltage (or Base Current) level.
- If set to measure, the measurement occurs after each on time expires and before the pulse transitions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

# 3. Semiconductor parameter analyzer

## SMU - all terminal parameters

Parameter descriptions are provided in the following topics

### Pulse Mode (Example)



# 3. Semiconductor parameter analyzer

## SMU - all terminal parameters

Parameter descriptions are provided in the following topics

### 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.

# 3. Semiconductor parameter analyzer

## SMU - all terminal parameters

Parameter descriptions are provided in the following topics

### 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 | | 009000B0 |
| 5 | 297.2239E-3 | 193.3215E-3 | | 009000B0 |
| 6 | 338.2374E-3 | 199.8583E-3 | | 009000B0 |
| 7 | 379.2452E-3 | 206.4212E-3 | | 009000B0 |

Status:
Source Current
Measure Voltage
100nA Current Range
20V Voltage Range
Interlock open

# 3. Semiconductor parameter analyzer

## SMU - all terminal parameters

Parameter descriptions are provided in the following topics

### Report Value (Measure Current or Report Current)

- The Report Value setting determines which current values are recorded in the Analyze spreadsheet.

- **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.

# 3. Semiconductor parameter analyzer

## SMU - all terminal parameters

Parameter descriptions are provided in the following topics

### Report Value (Report Voltage or Measure Voltage)

- The Report Value setting determines which voltage values are recorded in the Analyze spreadsheet.

- **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.

# 3. Semiconductor parameter analyzer

## SMU - all terminal parameters

Parameter descriptions are provided in the following topics

### Report Value (Report Voltage or Measure Voltage)

- The Report Value setting determines which voltage values are recorded in the Analyze spreadsheet.

- **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.

# 3. Semiconductor parameter analyzer

## SMU - all terminal parameters

Parameter descriptions are provided in the following topics

### 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(Zero).

# 3. Semiconductor parameter analyzer

## SMU - all terminal parameters

Parameter descriptions are provided in the following topics

### Start (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.
- To calculate the points: $points = \frac{(stop - start)}{step} + 1$

(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

# 3. Semiconductor parameter analyzer

## SMU - all terminal parameters

Parameter descriptions are provided in the following topics

### 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.

### Sweep Delay

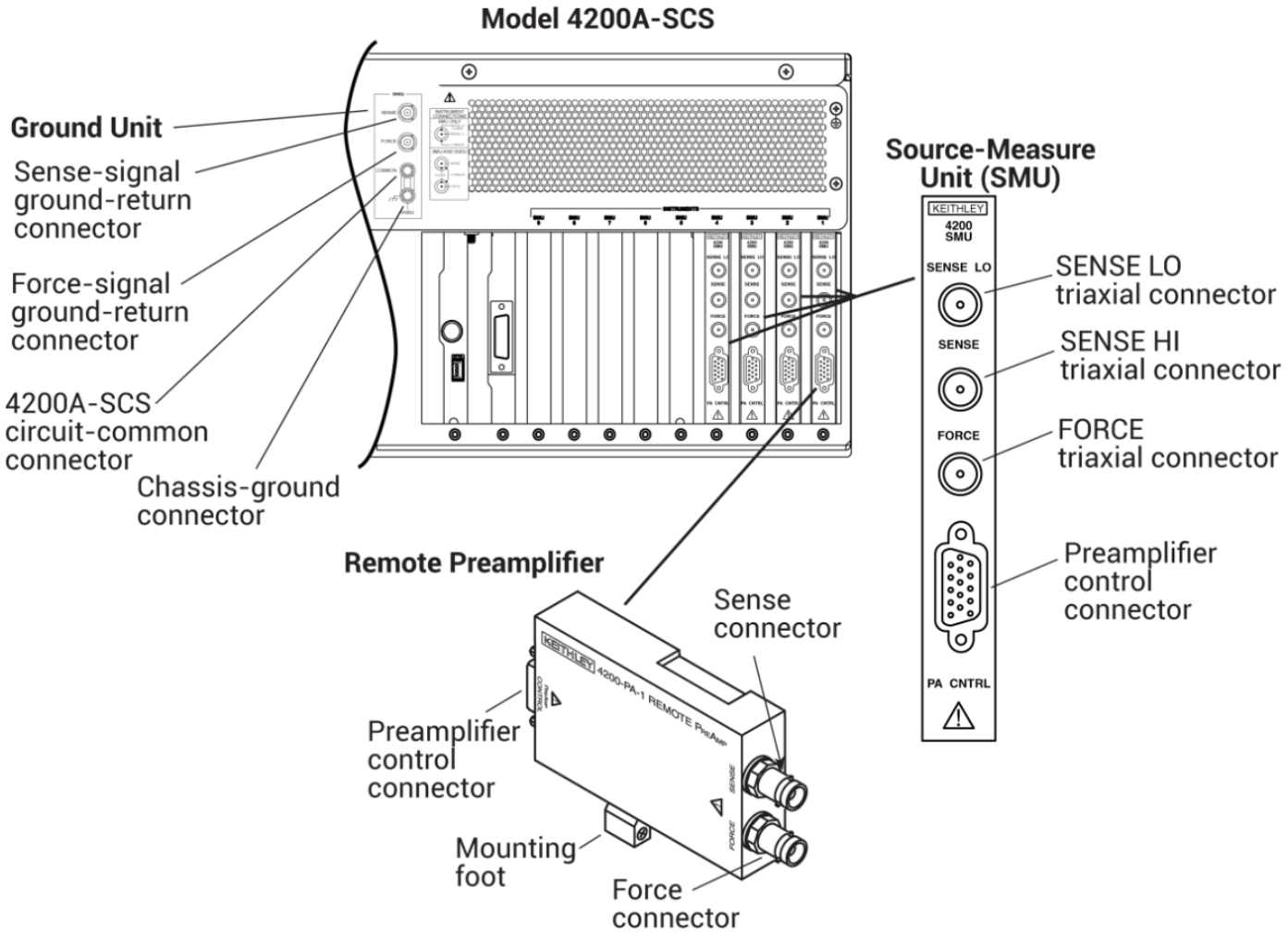
- If you are using a sweep operation mode and need extra settling time before each measurement, you can specify an additional delay with the Sweep Delay setting.

- Sweep Delay value from 0 s to 999 s. The default Sweep Delay value is 0 s

# 3. Semiconductor parameter analyzer

## Source-measure hardware

**Figure 53: Source-measure hardware overview**

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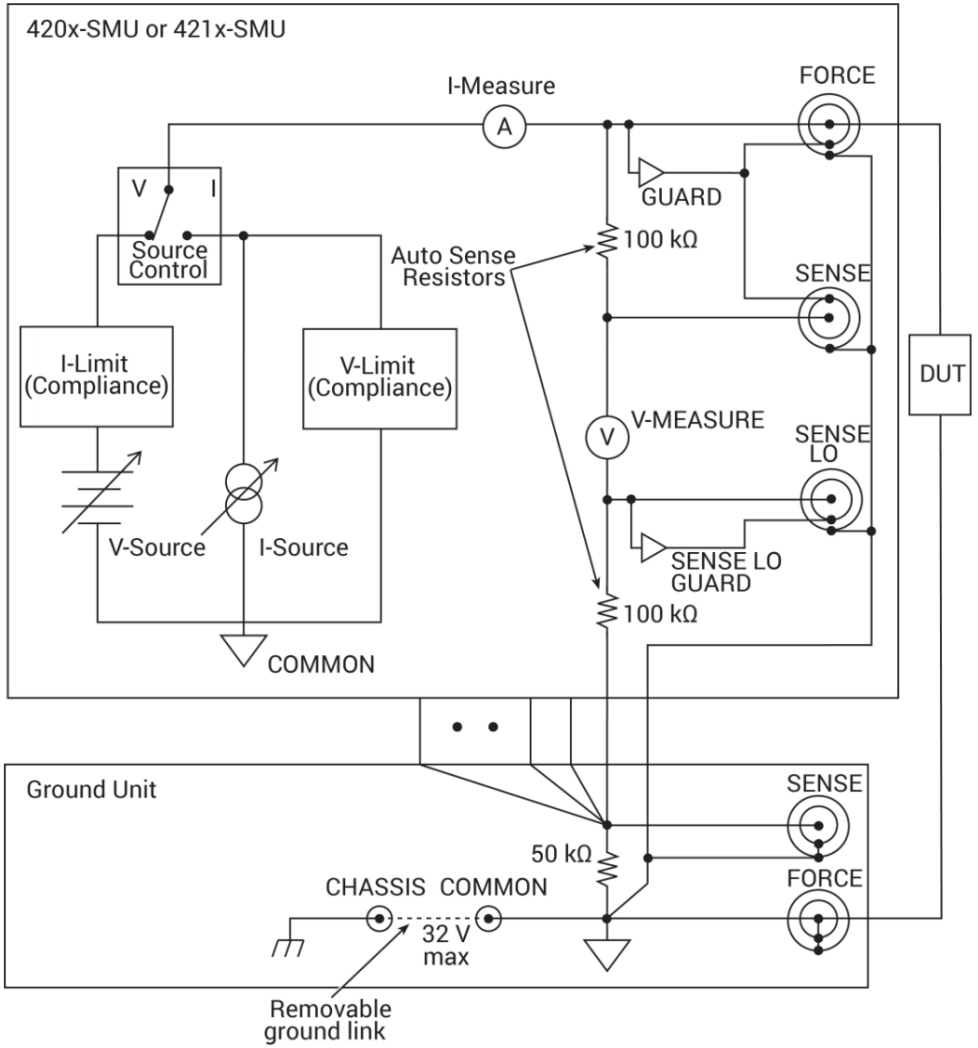
# 3. Semiconductor parameter analyzer

## Source-measure hardware

### Basic SMU circuit configuration

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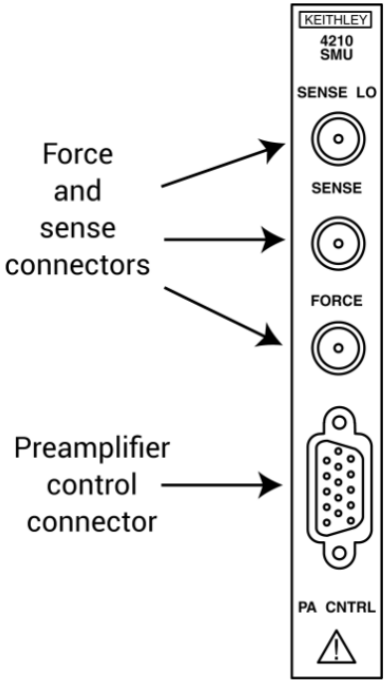
# 3. Semiconductor parameter analyzer

## Source-measure hardware

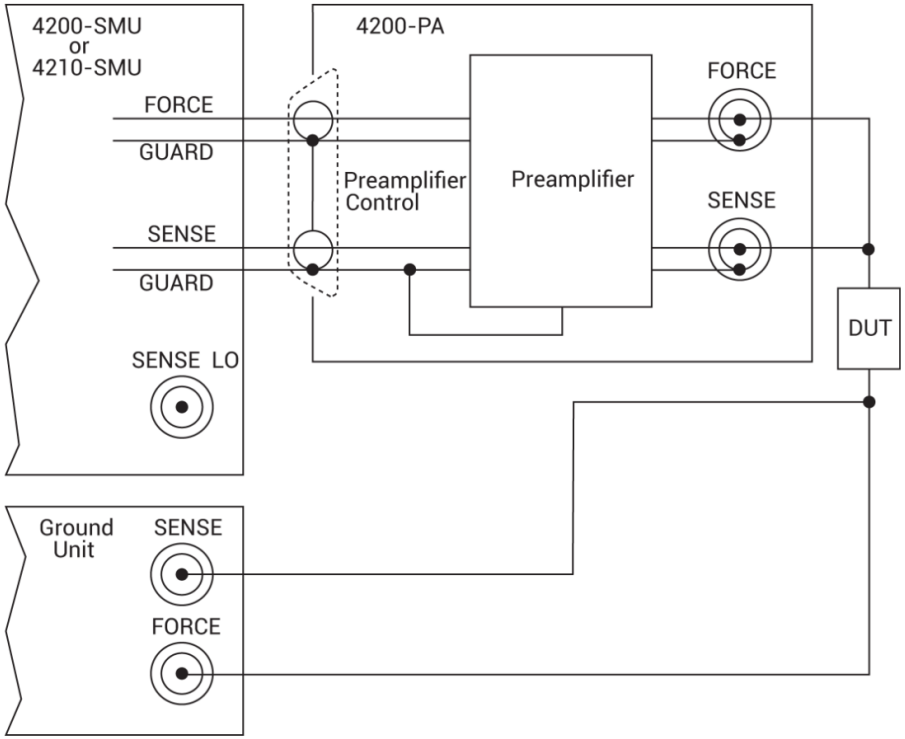
### SMU terminals and connectors

**Figure 55: 4200-SMU and 4210-SMU connectors**




### Basic SMU/preamplifier circuit configuration

**Figure 56: Basic SMU and preamplifier source-measure configuration**

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# 3. Semiconductor parameter analyzer

## Source-measure hardware

### 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.

**Figure 61: Typical SMU connections**

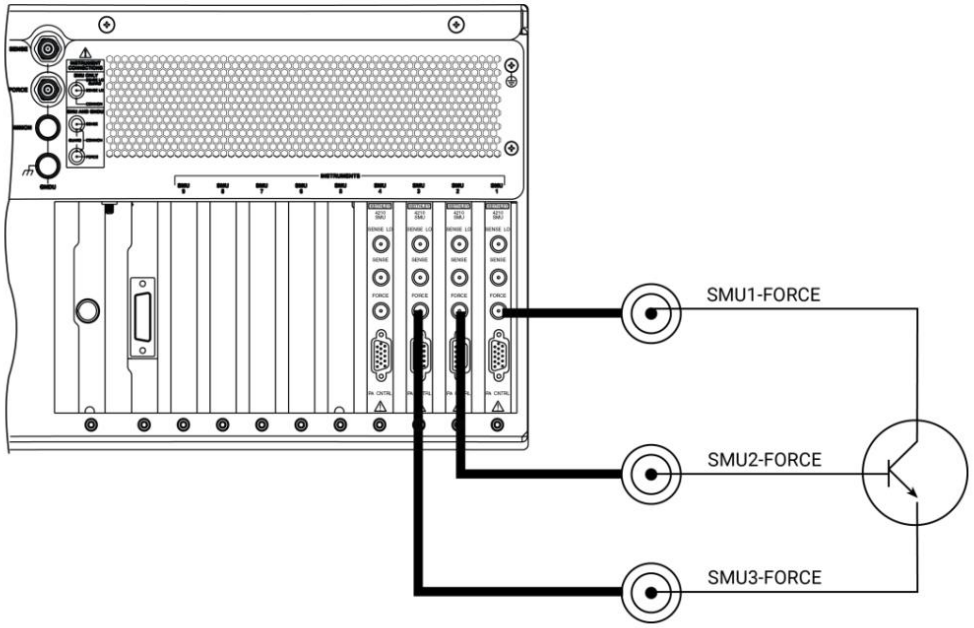
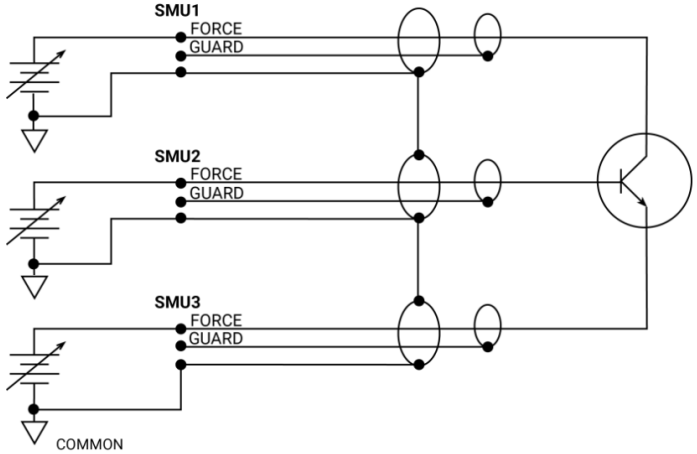



**Figure 62: Typical SMU COMMON connections schematic**

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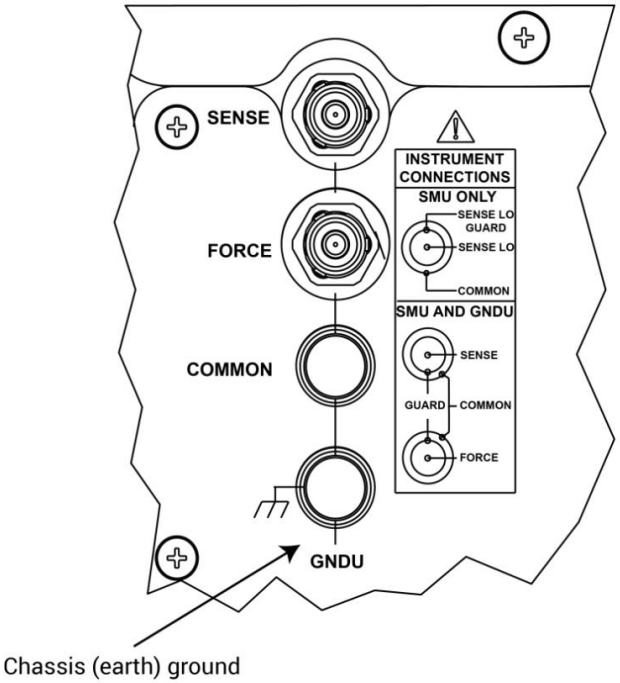
# 3. Semiconductor parameter analyzer

## Source-measure hardware

### Ground unit (GNDU) overview

- 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.

**Figure 63: Ground unit (GNDU) connectors**



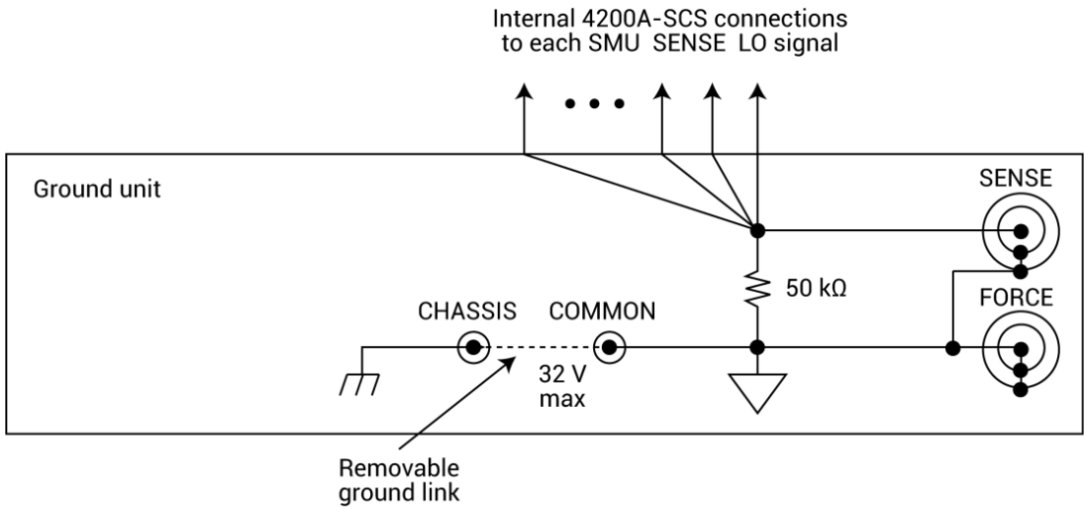
# 3. Semiconductor parameter analyzer

## Source-measure hardware

### 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**



# 3. Semiconductor parameter analyzer

## Source-measure hardware

### 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

**Figure 65: Full-Kelvin SMU to ground unit connections**

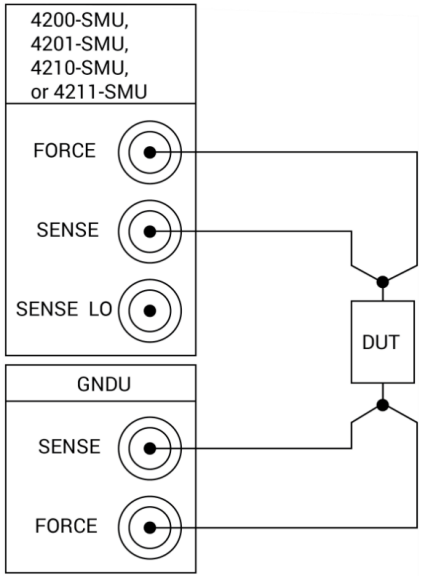
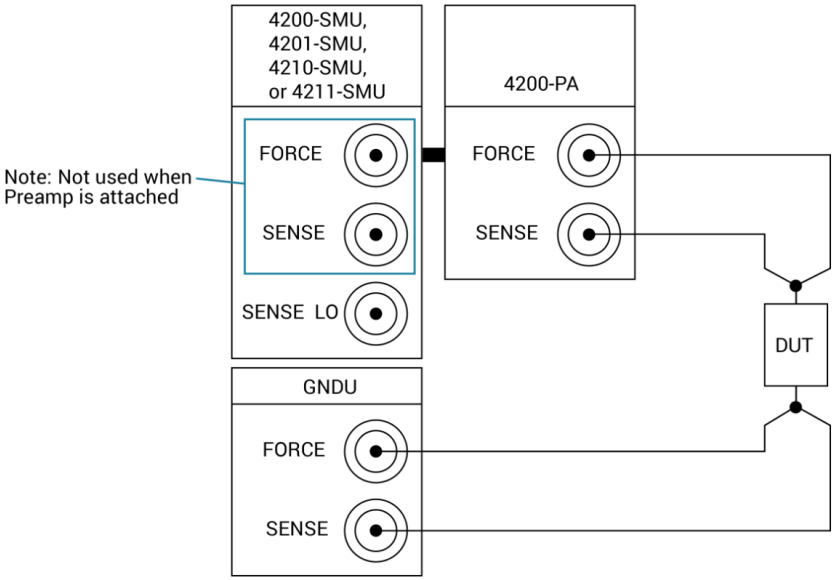



**Figure 66: Full-Kelvin preamplifier to ground unit connections**



# 3. Semiconductor parameter analyzer

## Source-measure concepts

### 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.

# 3. Semiconductor parameter analyzer

## Source-measure concepts

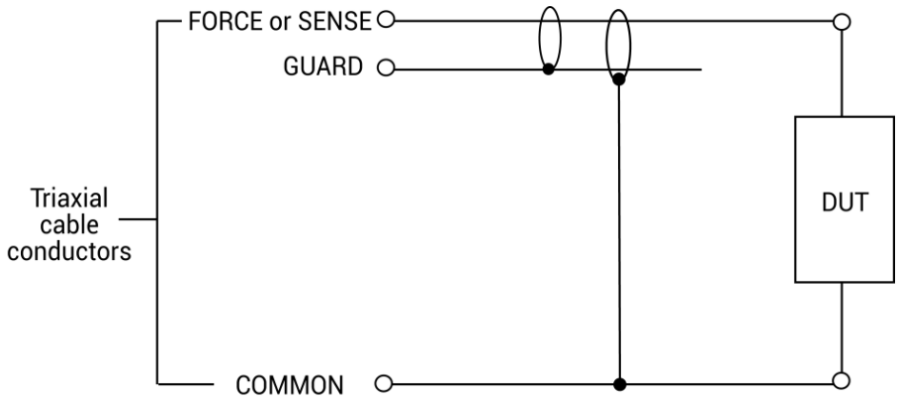
### Guard connections

- 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 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.

**Figure 68: GUARD connections**

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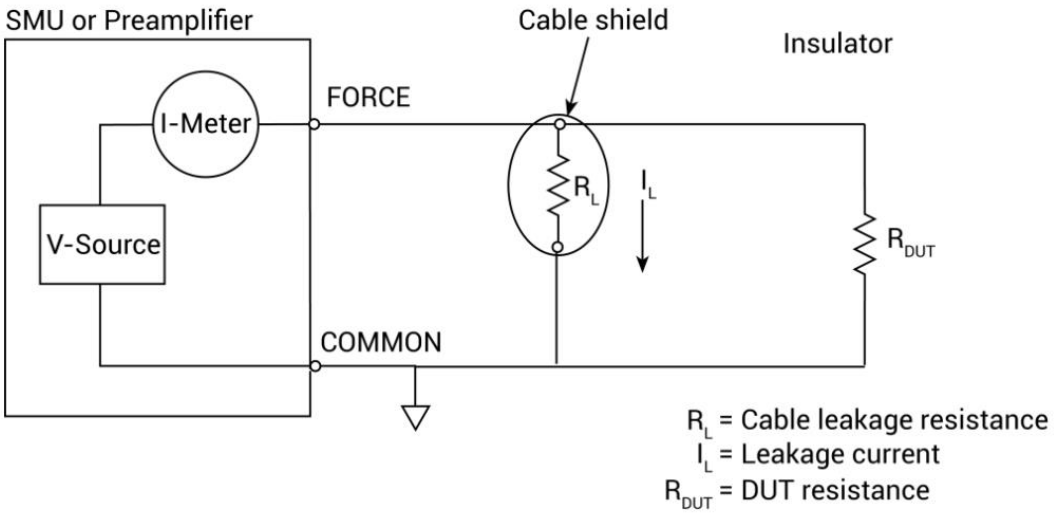
# 3. Semiconductor parameter analyzer

## Source-measure concepts

### 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**



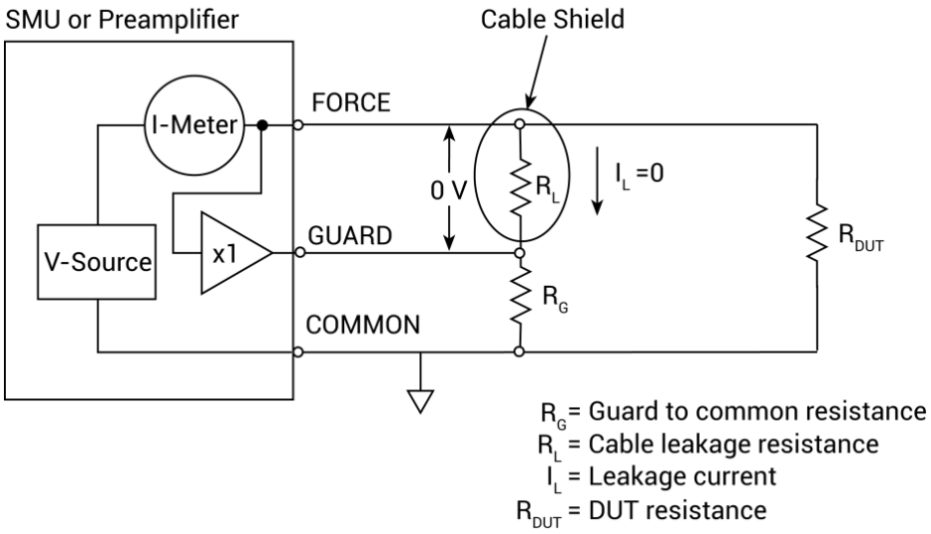
# 3. Semiconductor parameter analyzer

## Source-measure concepts

### Guarding concepts

- 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**



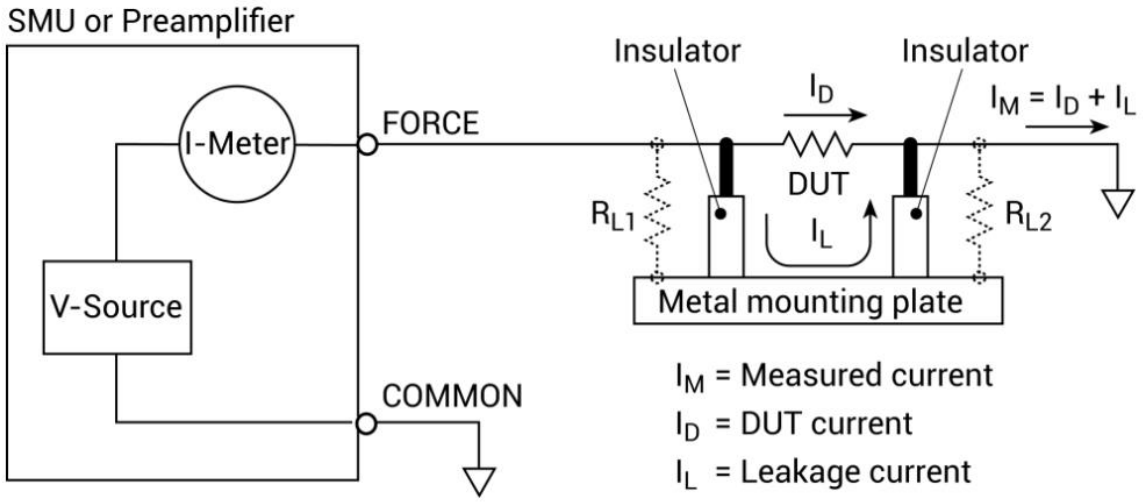
# 3. Semiconductor parameter analyzer

## Source-measure concepts

### Test fixture guarding

- 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**



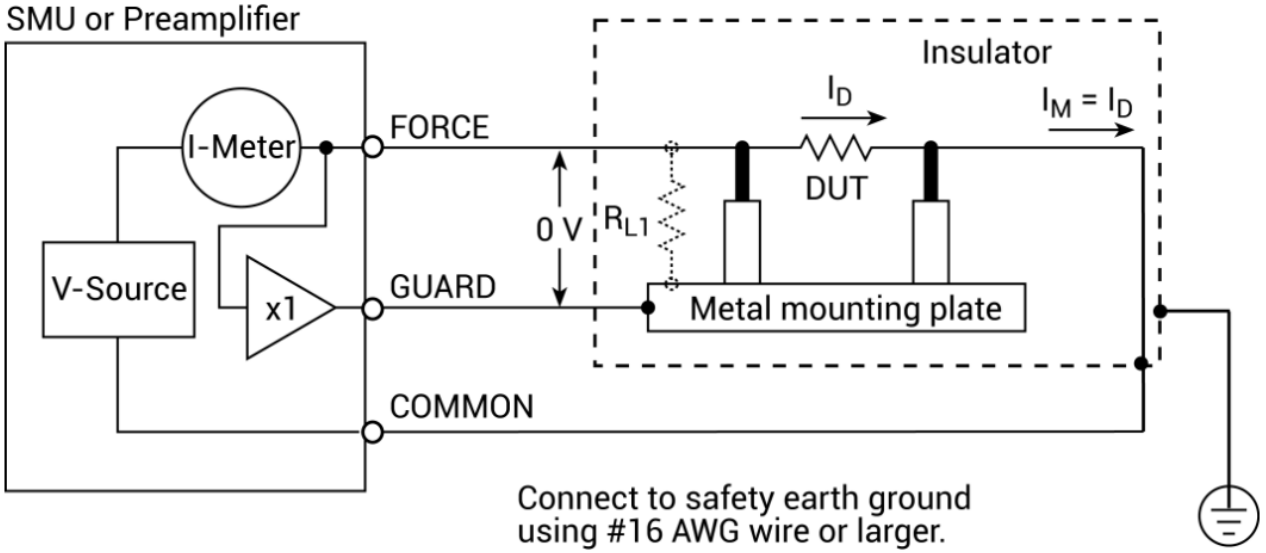
# 3. Semiconductor parameter analyzer

## Source-measure concepts

### Test fixture guarding

- 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**



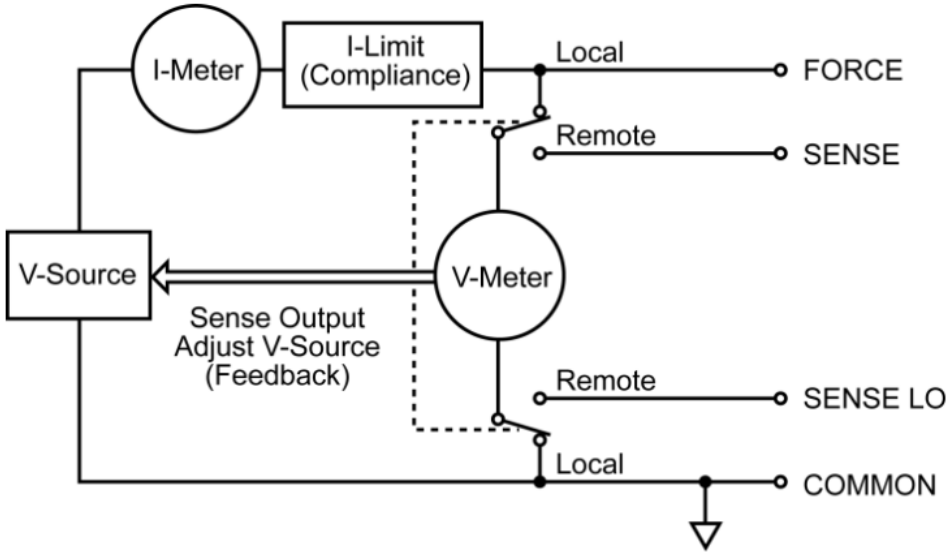
# 3. Semiconductor parameter analyzer

## Source-measure considerations

### 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

**Figure 82: Source V, measure I configuration**



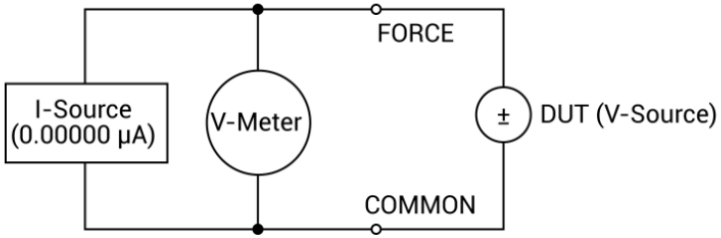
# 3. Semiconductor parameter analyzer

## Source-measure considerations

### Measure only (V or I)

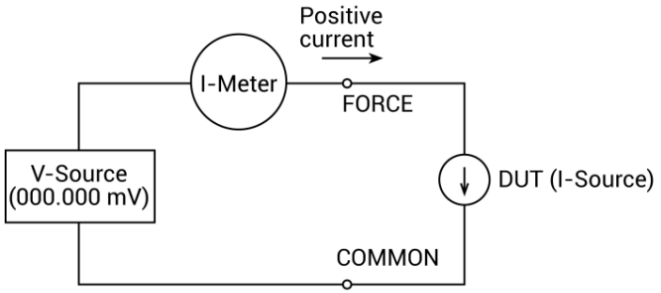
- In the following figure, the SMU is configured to measure voltage only by setting it to source 0 A and measure voltage.

**Figure 83: Measure voltage only**




- 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**



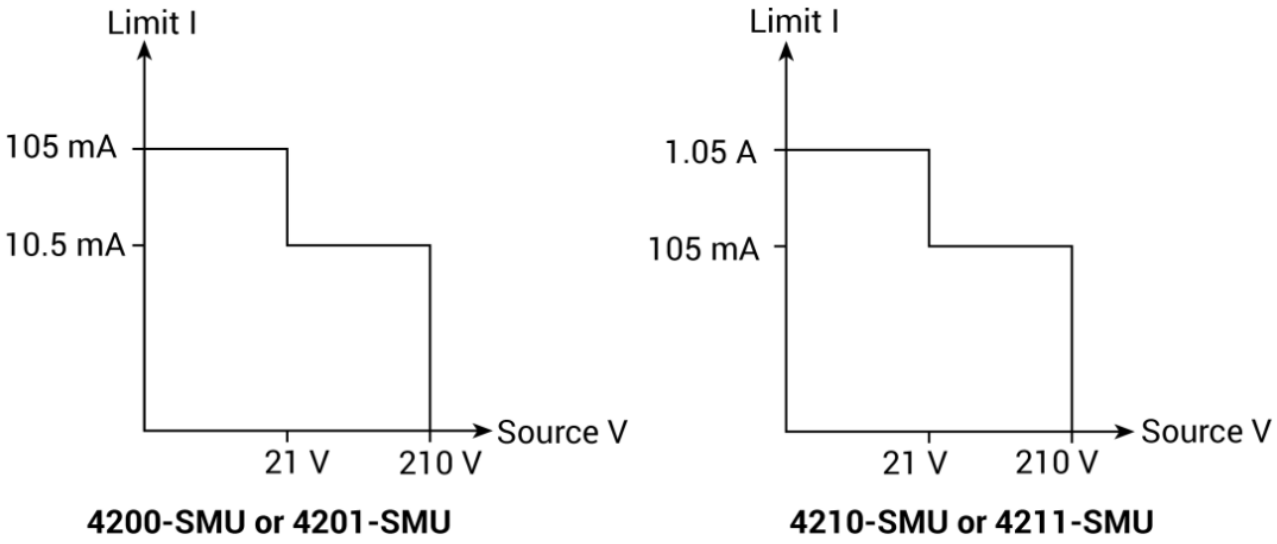

NOTE: Positive current flowing out of FORCE results in positive (+) measurements.

# 3. Semiconductor parameter analyzer

## Source-measure considerations

### V-Source operating boundaries

**Figure 89: V-Source operating boundaries**




- 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.

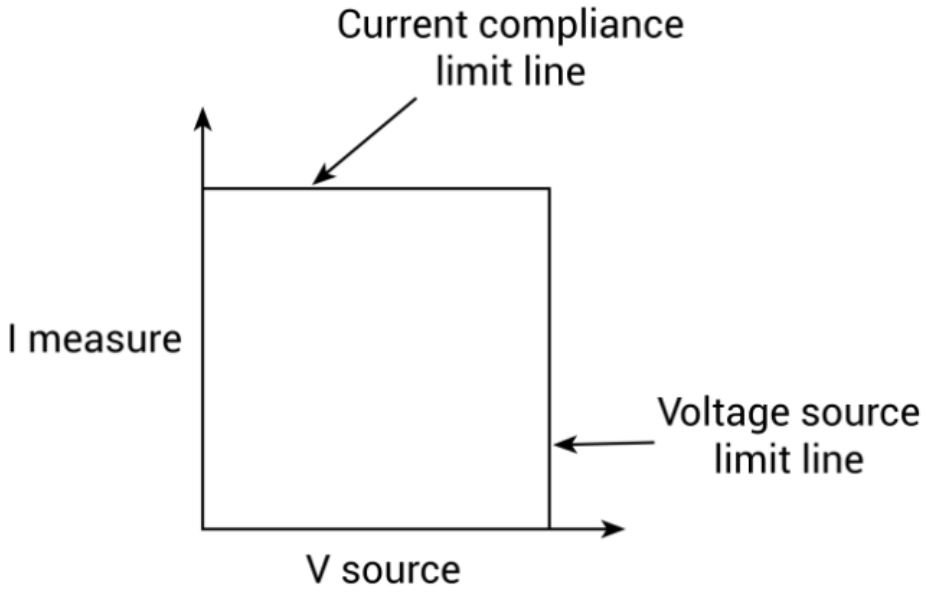
# 3. Semiconductor parameter analyzer

## Source-measure considerations

### V-Source operating boundaries

- 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.

**Figure 90: SMU voltage source limit lines**



# 3. Semiconductor parameter analyzer

## Source-measure considerations

### V-Source operation 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.

**Figure 91: Normal voltage source operation**

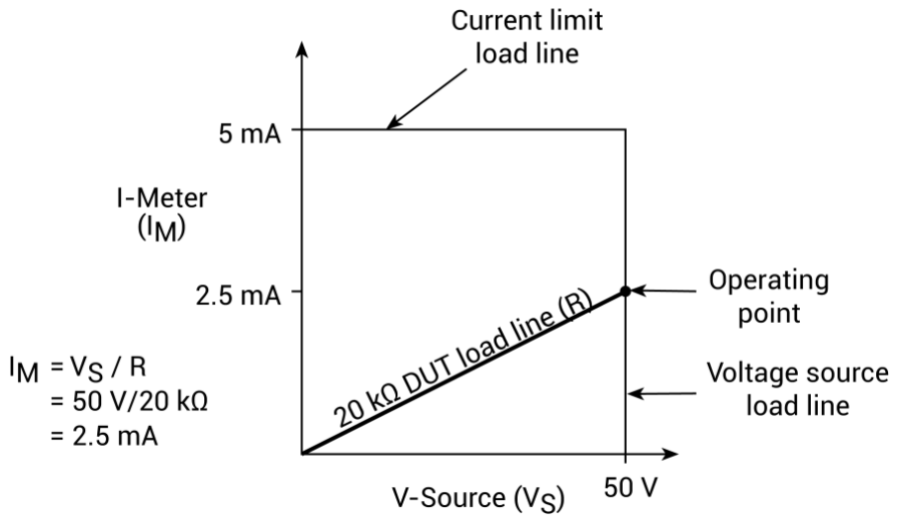
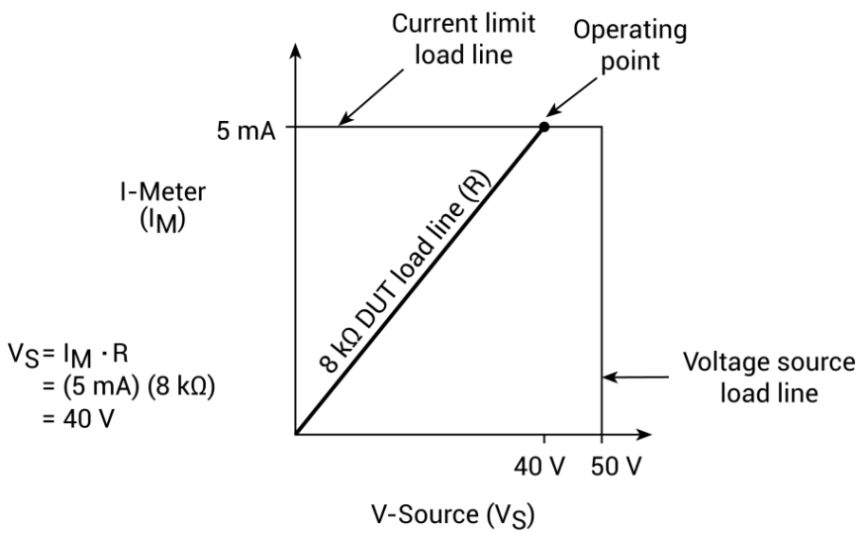



**Figure 92: Voltage source in compliance**




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

# 3. Semiconductor parameter analyzer

## Source-measure considerations

### 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**

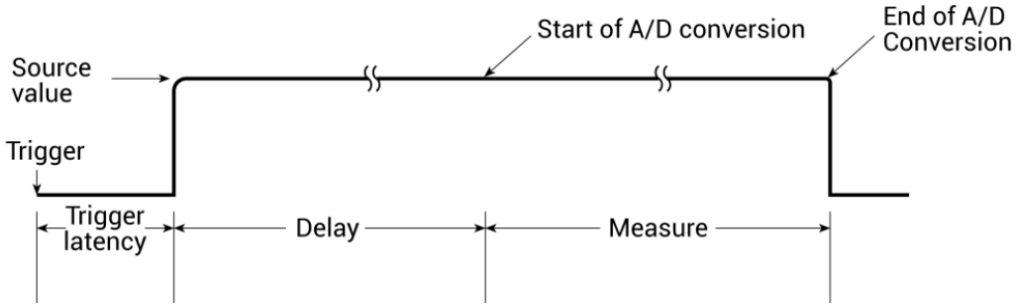
### Source-delay-measure(SDM) cycle

- 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**

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.

**Figure 93: Source-measure-delay cycle**

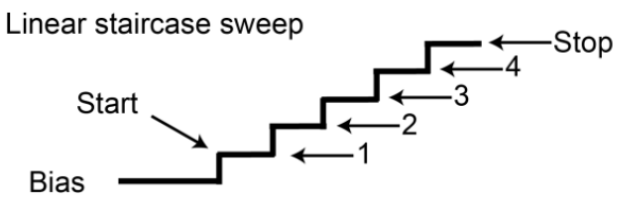


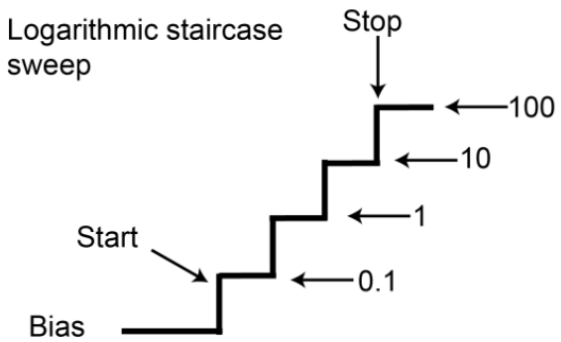
# 3. Semiconductor parameter analyzer

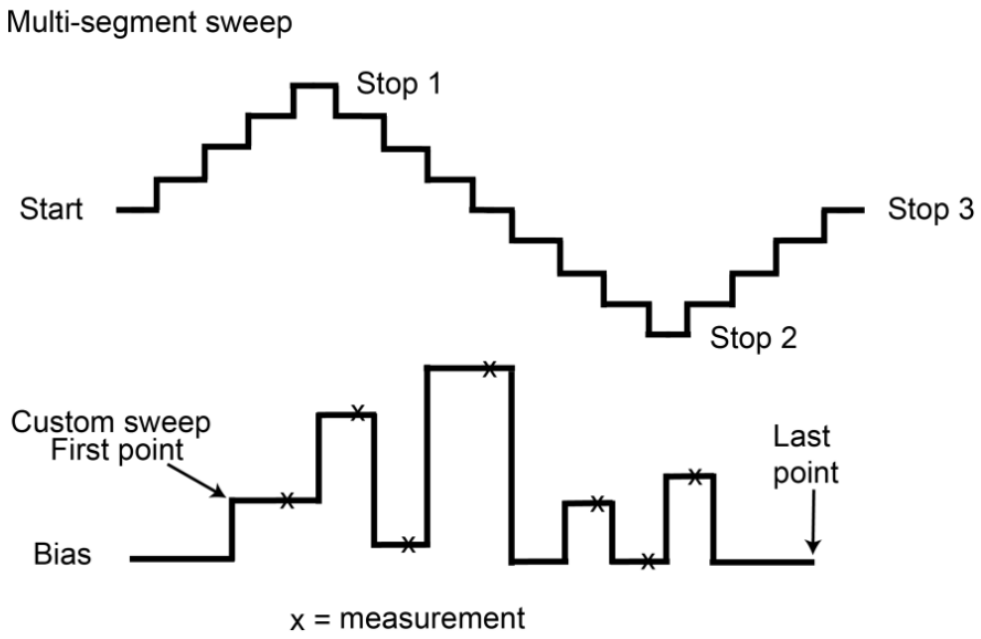
## Source-measure considerations

### Sweep waveforms

- The general sweep types are linear staircase, logarithmic staircase, multi-segment, and custom.




- 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.

# 3. Semiconductor parameter analyzer

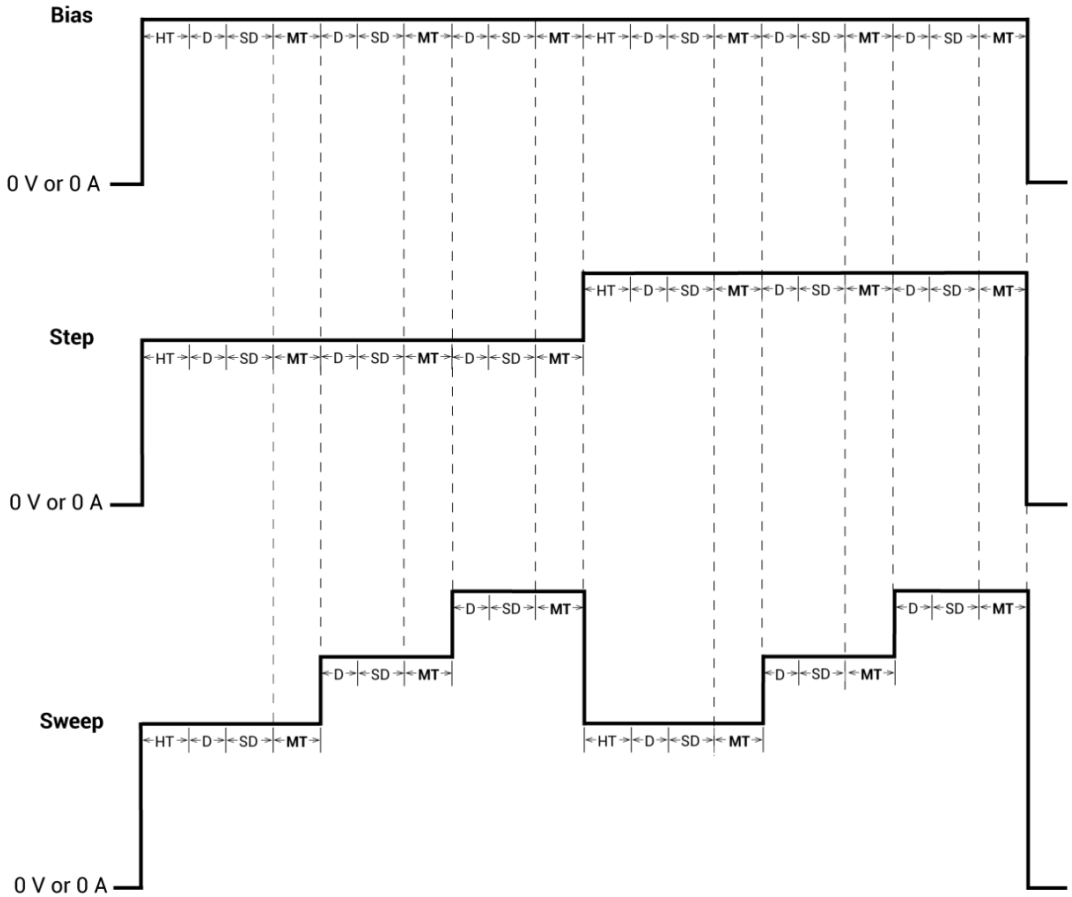
## Source-measure considerations

### Operation mode timing

- Basic timing between the sweep, step, and bias operation modes.

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

**Figure 95: Sweeping Mode timing diagram**



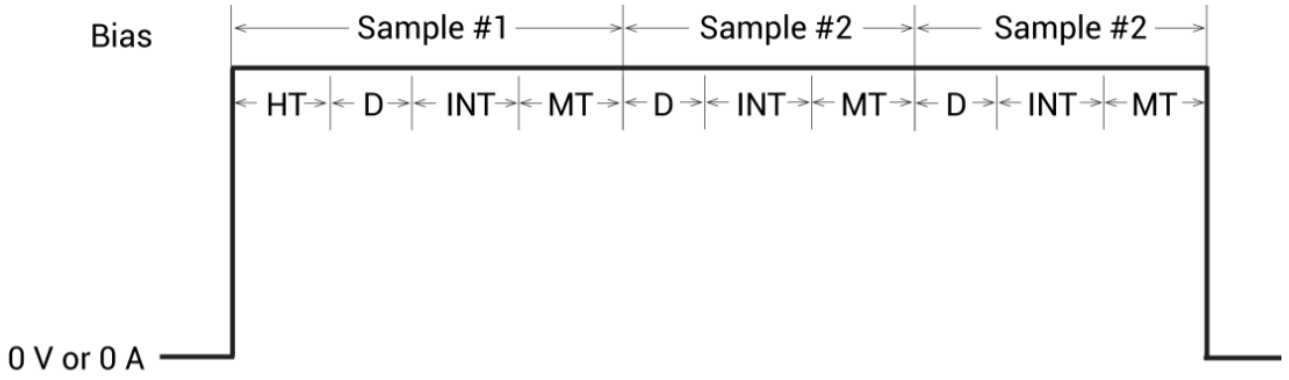
# 3. Semiconductor parameter analyzer

## Source-measure considerations

### Sampling mode timing

- 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.

**Figure 96: Sampling test mode timing diagram**




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

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