What is an SMU Instrument, and How Do You Decide Which One is Right for Your Application?

Bona, Oh
SMU Instrument Basics
SourceMeter® SMU Instruments

- SMUs are precision instruments which are used for sourcing current or voltage and simultaneously measuring current, voltage and/or resistance with high speed and accuracy.
Basic SMU Topology
SMUs compared to Power Supplies

<table>
<thead>
<tr>
<th>2602A SourceMeter Instrument</th>
<th>Typical Power Supply</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Speed</strong></td>
<td></td>
</tr>
<tr>
<td><img src="Graph.png" alt="Graph of Speed Comparison" /></td>
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<td><strong>Source/Measure Precision</strong></td>
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</tr>
<tr>
<td>10μA measurement uncertainty = 5nA</td>
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</tr>
<tr>
<td><strong>Voltage and Current Resolution</strong></td>
<td></td>
</tr>
<tr>
<td>Voltage</td>
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</tr>
<tr>
<td>1μV - 40V</td>
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</tr>
<tr>
<td>Current</td>
<td>Current</td>
</tr>
<tr>
<td>1pA - 3A</td>
<td>1pA - 3A</td>
</tr>
<tr>
<td><strong>4 Quadrant Operation</strong></td>
<td></td>
</tr>
<tr>
<td><img src="Diag.png" alt="4 Quadrant Operation Diagram" /></td>
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*KEITHLEY*
A Tektronix Company

*Tektronix®*
SMUs compared to Power Supplies

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</tr>
<tr>
<td>40V</td>
<td>1mV</td>
</tr>
<tr>
<td>Current</td>
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</tr>
<tr>
<td>1pA</td>
<td>1mA</td>
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</table>
Built-in Sweeps

**DC**
- **Fixed Level**
- **Linear Stair**
- **Logarithmic Stair**

**Pulse**
- **Pulse**
- **Linear Stair Pulse**
- **Logarithmic Stair Pulse**

**Custom**
- **Arbitrary**
- **Sine Wave**
SMUs compared to DMMs

**Voltmeter Configuration**

- Source I = 0A, Measure V
- HI
- V meter
- LO
- I = 0A
- I_{leakage}

**Ammeter Configuration**

- Source V = 0V, Measure I
- HI
- I meter
- V = 0V
- V_{burden}
- LO

**Ohmmeter Configuration**

- I = \text{test current}
- HI
- Sense HI
- V meter
- Sense LO
- LO

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Measurement Terminology
Measurement Terminology

- Accuracy
- Repeatability
- Resolution
- Sensitivity
- A/D Converter Integration Time (NPLC)
Measurement Terminology

Accuracy

The closeness of agreement between the result of a measurement and its true value or accepted *standard value*.

Repeatability

The closeness of agreement between *successive* measurements carried out under the same conditions.
Measurement Terminology

Resolution

The smallest portion of the signal that can be observed.

Sensitivity

The smallest change in the signal that can be detected.
A/D Converter Integration Time (NPLC)
Key Considerations for Selecting a SMU Instrument
Key Considerations for Selecting a SMU Instrument

- System-level Speed / Throughput
- Source Resolution vs. Stability
- Measure Settling Time, Offset Error, Noise
- Cabling and Connections
System-level Speed / Throughput

Example: Diode / LED Test

- Three Measurements
  - $V_f$ – Forward Voltage
  - $V_R$ – Reverse Breakdown Voltage
  - $I_L$ – Reverse Leakage Current

- Measurements are compared against upper and lower limits for each parameter.
System-level Throughput Considerations

- Must consider and optimize all elements of speed:
  - Trigger In Time
  - Range Change Time
  - Function Change Time
  - Source Settling Time
  - A/D Converter (NPLC)
  - Measurement Speed
  - Trigger Out Time
  - Program Execution Time
Test Throughput: Actual Parts per Second

(more is better!)

<table>
<thead>
<tr>
<th></th>
<th>1 NPLC</th>
<th>0.1 NPLC</th>
<th>0.01 NPLC</th>
<th>0.001 NPLC</th>
<th>0.00048 NPLC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Non-Keithley SMU instrument</td>
<td>6.1</td>
<td>8.1</td>
<td>8.2</td>
<td>8.2</td>
<td>8.2</td>
</tr>
<tr>
<td>Keithley 2600A Series</td>
<td>13.3</td>
<td>33.2</td>
<td>37.8</td>
<td>38.2</td>
<td>N/A</td>
</tr>
</tbody>
</table>

A SourceMeter running at 0.1 NPLC A/D conversion time is 4x faster and much more accurate than a SMU instrument running at 0.00048 NPLC.
Keithley TSP® Technology

- The SourceMeter® SMU Instrument has embedded intelligence!

Example TSP script:

```plaintext
for Voltage = 1,10 do
    smua.source.levelv = Voltage
delay(1)
    Current = smua.measure.i()
    Resistance = Voltage / Current
    print("Resistance=",Resistance)
End
```

Keithley Model 2600A Series SourceMeter
## Source Programming Resolution vs. Stability

### Spec sheet (Programming Resolution):

<table>
<thead>
<tr>
<th></th>
<th>Programming Resolution 20 V range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Non-Keithley 6.5 Digit SMU instrument</td>
<td>10 uV</td>
</tr>
<tr>
<td>Keithley Model 2400</td>
<td>500 uV</td>
</tr>
</tbody>
</table>

### Actual Output (Stability):

<table>
<thead>
<tr>
<th>Source Value = 10.001V</th>
<th>Source Readback Displayed Value (pk-pk variation)</th>
<th>Actual Measured Value of Source Output (pk-pk variation)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Non-Keithley 6.5 Digit SMU instrument</td>
<td>0.0 uV</td>
<td>438.7 uV</td>
</tr>
<tr>
<td>Keithley Model 2400</td>
<td>30.0 uV</td>
<td>42.9 uV</td>
</tr>
</tbody>
</table>
Actual Source Performance:
Programming Resolution vs. Stability

Non-Keithley 6.5 Digit SMU Instrument

Keithley Model 2400

500 uV Programming Resolution

Programmed Voltage
Readback Voltage
Actual Measured Voltage
The Non-Keithley 6.5 Digit SMU has over 0.2 nA error when the 2636A is already settled to its’ 120 fA spec.

The Non-Keithley 6.5 Digit SMU takes almost 4 seconds to reach its’ 50pA offset spec.
Comparing Specifications and Performance

Spec table:

<table>
<thead>
<tr>
<th>SMU</th>
<th>Lowest range</th>
<th>Total accuracy*</th>
<th>Resolution</th>
</tr>
</thead>
<tbody>
<tr>
<td>Non-Keithley 10nA</td>
<td>10nA</td>
<td>±(0.10% + 50pA)</td>
<td>10fA</td>
</tr>
<tr>
<td>Keithley 2636A 100pA</td>
<td>100pA</td>
<td>±(0.15% + 120fA)</td>
<td>1fA</td>
</tr>
</tbody>
</table>

*Total accuracy = Gain accuracy (%) + Offset accuracy
Cable and Connection Considerations

Coax Cable

\[ R_L = \text{Coax Cable Leakage Resistance} \]
\[ I_L = \text{Leakage Current} \]
\[ R_{\text{OUT}} = \text{Resistance of Device Under Test} \]
\[ I_M = I_{\text{OUT}} + I_L \]

Triax Cable

\[ R_{L1} = \text{Triax Cable Inside Shield Leakage Resistance} \]
\[ R_{L2} = \text{Leakage Resistance Between Shields} \]
\[ R_{\text{OUT}} = \text{Resistance of Device Under Test} \]
\[ I_M = I_{\text{OUT}} \]
Cable and Connection Considerations

Coax Cable

Triax Cable

$R_L = \text{Coax Cable Leakage Resistance}$

$I_L = \text{Leakage Current}$

$R_{DUT} = \text{Resistance of Device Under Test}$

$I_M = I_{DUT} + I_L$

$R_{L1} = \text{Triax Cable Inside Shield Leakage Resistance}$

$R_{L2} = \text{Leakage Resistance Between Shields}$

$R_{DUT} = \text{Resistance of Device Under Test}$

$I_M = I_{DUT}$

Triax cables are included in the price of the 2635A and 2636A SourceMeter SMU Instruments
## SourceMeter® Source Measurement Unit (SMU) Instruments

Industry Leading I-V Characterization & Test Tools

<table>
<thead>
<tr>
<th>Feature</th>
<th>High Power SourceMeter Instruments (2651A, 2657A)</th>
<th>Low Current SourceMeter Instruments (2635B/36B, 6430)</th>
<th>Series 2600B System SourceMeter Instruments</th>
<th>Series 2400 Bench SourceMeter Instruments</th>
</tr>
</thead>
<tbody>
<tr>
<td># of Channels</td>
<td>1 (Optional Expansion to 32)</td>
<td>1 – 2 (Optional Expansion to 64)</td>
<td>1 – 2 (Optional Expansion to 64)</td>
<td>1</td>
</tr>
<tr>
<td>Current Max/Min</td>
<td>2651A: 50A pulse / 100mA</td>
<td>10A pulse / 10aA</td>
<td>10A pulse / 100aA</td>
<td>5A / 10pA</td>
</tr>
<tr>
<td></td>
<td>2657A: 120mA / 1fA</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Voltage Max/Min</td>
<td>2651A: 40V / 100nV</td>
<td>200V / 100nV</td>
<td>200V / 100nV</td>
<td>1100V / 1uV</td>
</tr>
<tr>
<td></td>
<td>2657A: 3000V / 100nV</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>DC Power</td>
<td>2651A: 200W (DC), 2000W (pulse)</td>
<td>2 - 30W per channel</td>
<td>30 – 40W per channel</td>
<td>20 – 110W</td>
</tr>
<tr>
<td></td>
<td>2657A: 180W (DC or Pulse)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Max readings/sec</td>
<td>38,500</td>
<td>20,000</td>
<td>20,000</td>
<td>2,000</td>
</tr>
<tr>
<td></td>
<td>1uSec / pt., 18-bit Digitizer</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Connectors</td>
<td>2651A: Screw Terminal, Banana</td>
<td>Triax</td>
<td>Screw Terminal, Adaptors for Banana or Triax</td>
<td>Banana</td>
</tr>
<tr>
<td></td>
<td>2657A: HV Triax, SHV</td>
<td></td>
<td></td>
<td></td>
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Keithley is the Leader in SMU Instruments

- 20 patents issued for SMU-specific technology
- Numerous industry awards, including R&D100, Test of Time, Best in Test, Best Electronic Design, and more
- Thousands and thousands of customers
- Serving Semiconductor, Electronic Components, Optoelectronics, Automotive, Mil/Aero, Medical, Research & Education, and many more industries

Series 2400 SourceMeter Instruments
Series 2600A System SourceMeter Instruments
Model 237 High-Voltage SMU
Model 4200-SCS Semiconductor Characterization System
S500 and S530 Parametric Test Systems
Choosing the Optimal Source Measurement Unit (SMU) Instrument for Your Test and Measurement Application

Rapidly Expanding Array of Test Applications Continues to Drive Source Measurement Unit Instrument Technology

Precision Sourcing and Measurement Techniques for Applications from Semiconductor Research and Development to High Throughput Component Test

Low Level Measurements Handbook: Precision DC Current, Voltage, and Resistance Measurements (Sixth Edition)
Thank You!