Welcome!

Device Characterization with the Keithley Model 4200-SCS Characterization System

Low Current and High Resistance Measurement Techniques

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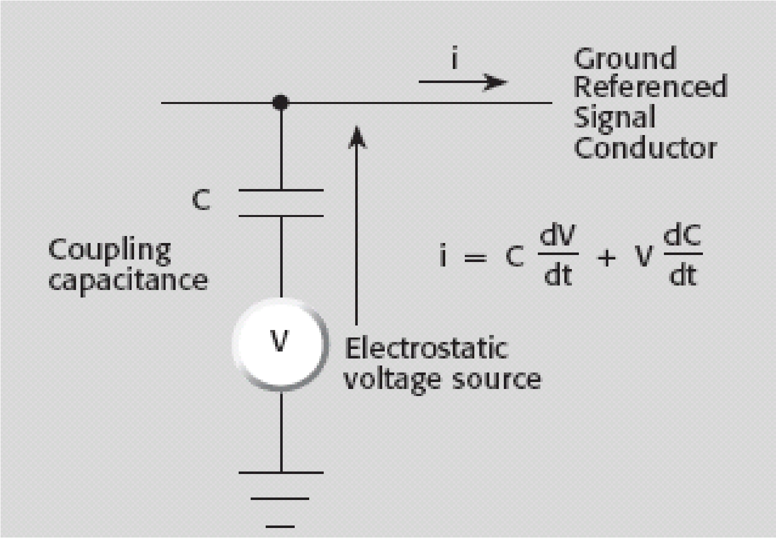
Low Current and High Resistance Measurements

Sources of Measurement Error:

- **Electrostatic Interference**
- **Leakage Current**
- **Generated Currents:**
  - Offset Currents: Internal and External
  - Triboelectric Effects
  - Piezoelectric Effects
  - Contamination and Humidity
- **Source Impedance:**
  - Source Resistance
  - Source Capacitance

Electrostatic Interference

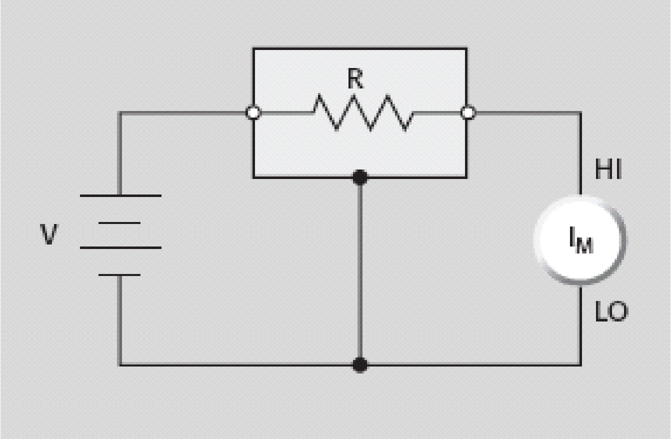


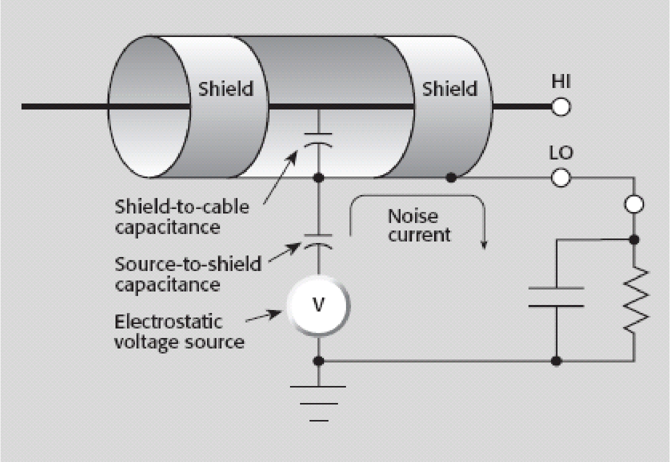
- An electrostatic voltage source in the vicinity of a conductor, such as a cable or trace on a PC board, generates a current proportional to the rate of change of the voltage and of the coupling capacitance.
- Typically an issue when measuring currents $\leq$ 1nA and resistances $\geq$ 1GΩ

To reduce electrostatic interference effects:

- Build a shield to enclose the circuit or device being measured
- Shield can be just a simple metal box or meshed screen that encloses the test circuit
- Shield should be connected to measurement circuit LO, which is not necessarily earth ground

Electrostatic Interference: More on Shielding





- Connect shield Force LO (or common) terminal of SMU
- If circuit LO is floating above ground, add grounded safety shield around the electrostatic shield
- Shield cabling between Force HI terminal and the DUT
- With cable shield in place, noise current generated by the electrostatic voltage source and the coupling capacitance flows through the shield to ground rather than through the signal conductors

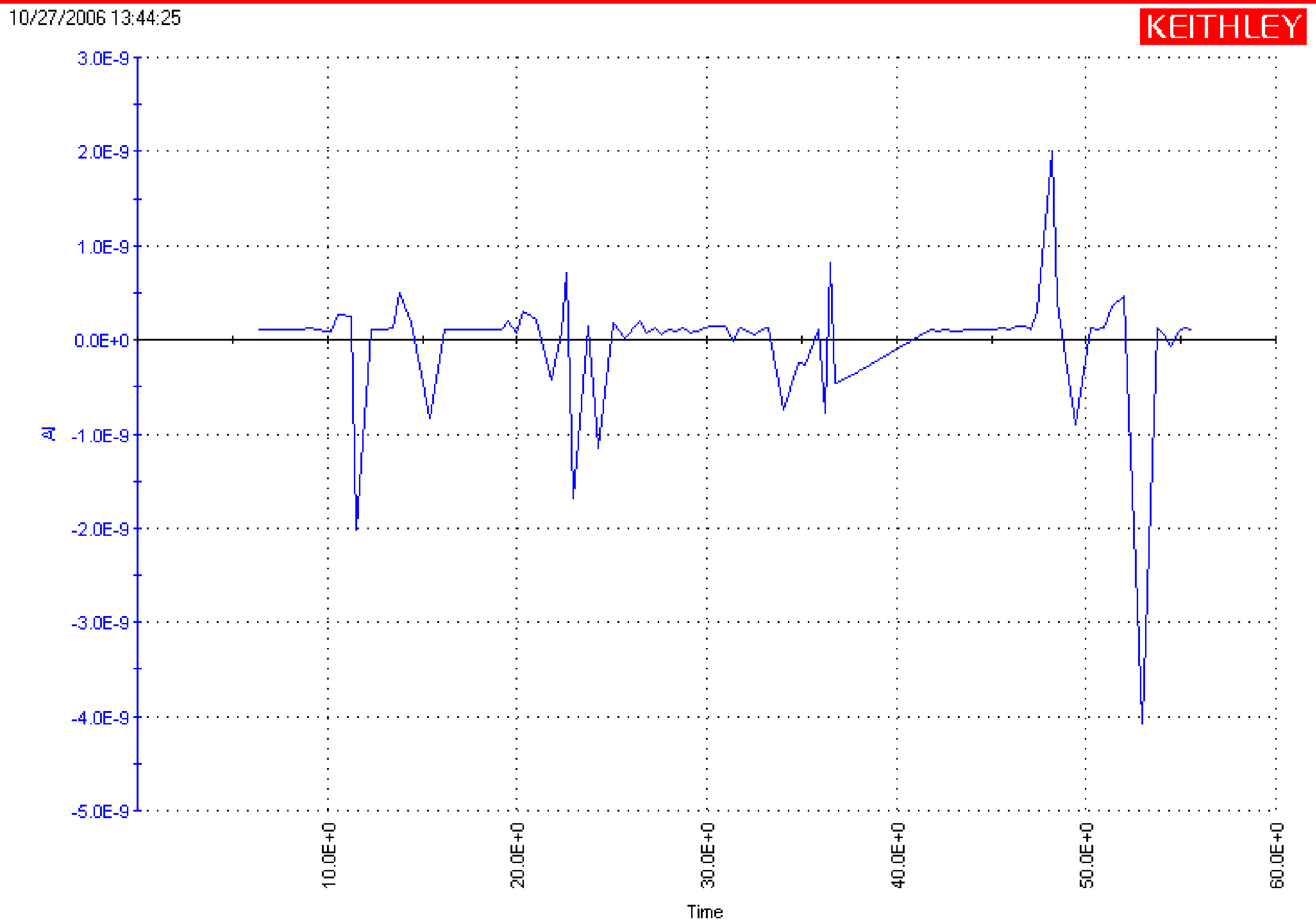
To minimize error currents due to electrostatic coupling:

- Keep all charged objects (including people) and conductors away from sensitive areas of test circuit
- Avoid movement and vibration near the test area
- Shield device-under-test and connect the enclosure electrically to the test circuit common terminal

Lab 8

Minimizing Electrostatic Interference by Using Shielding

Unshielded



10/27/2006 13:44:25
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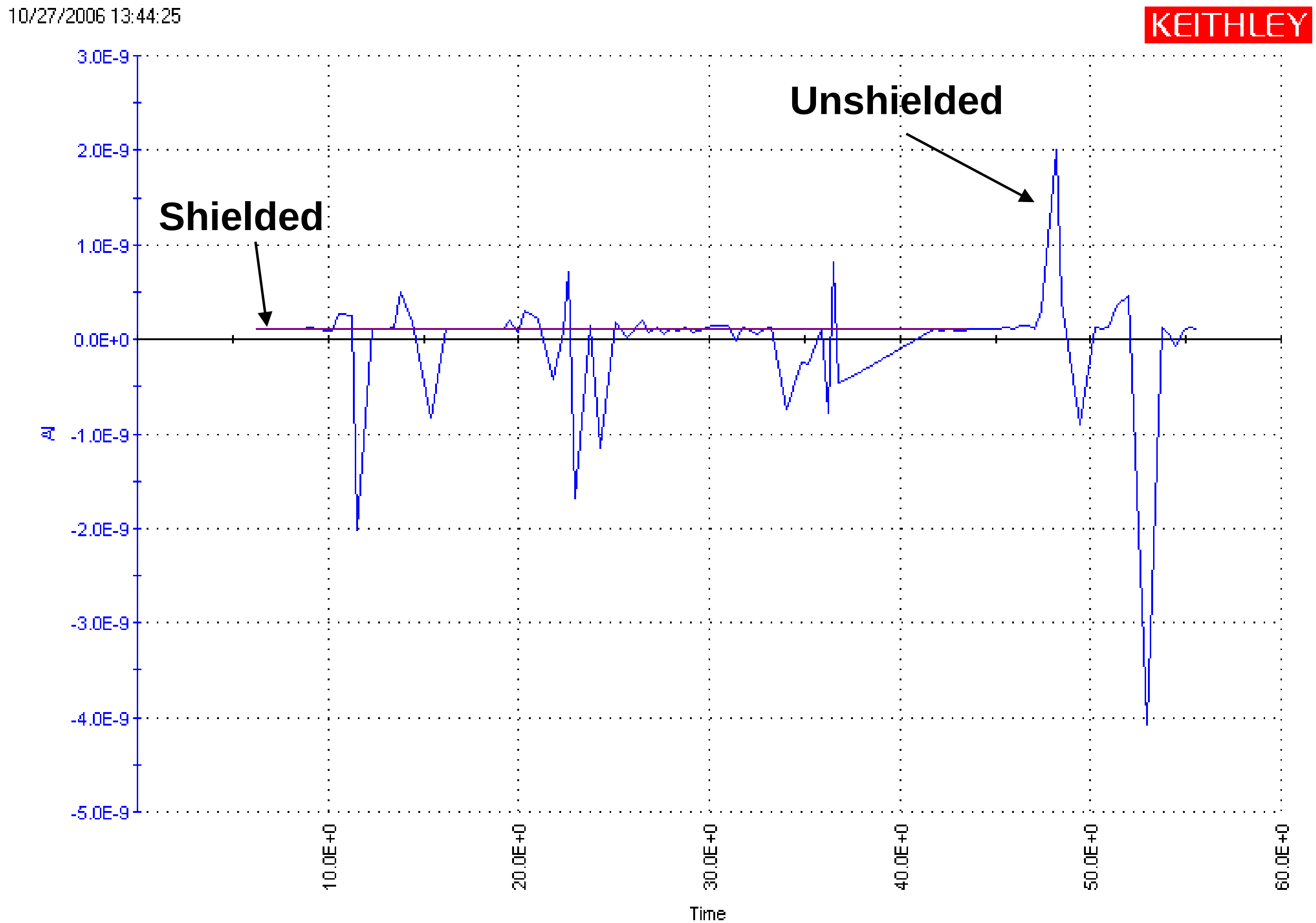
3.0E-9
2.0E-9
1.0E-9
0.0E+0
-1.0E-9
-2.0E-9
-3.0E-9
-4.0E-9
-5.0E-9
A
10.0E+0
20.0E+0
30.0E+0
40.0E+0
50.0E+0
60.0E+0
Time

Shielded



10/27/2006 13:44:25
KEITHLEY
Unshielded
Shielded
3.0E-9
2.0E-9
1.0E-9
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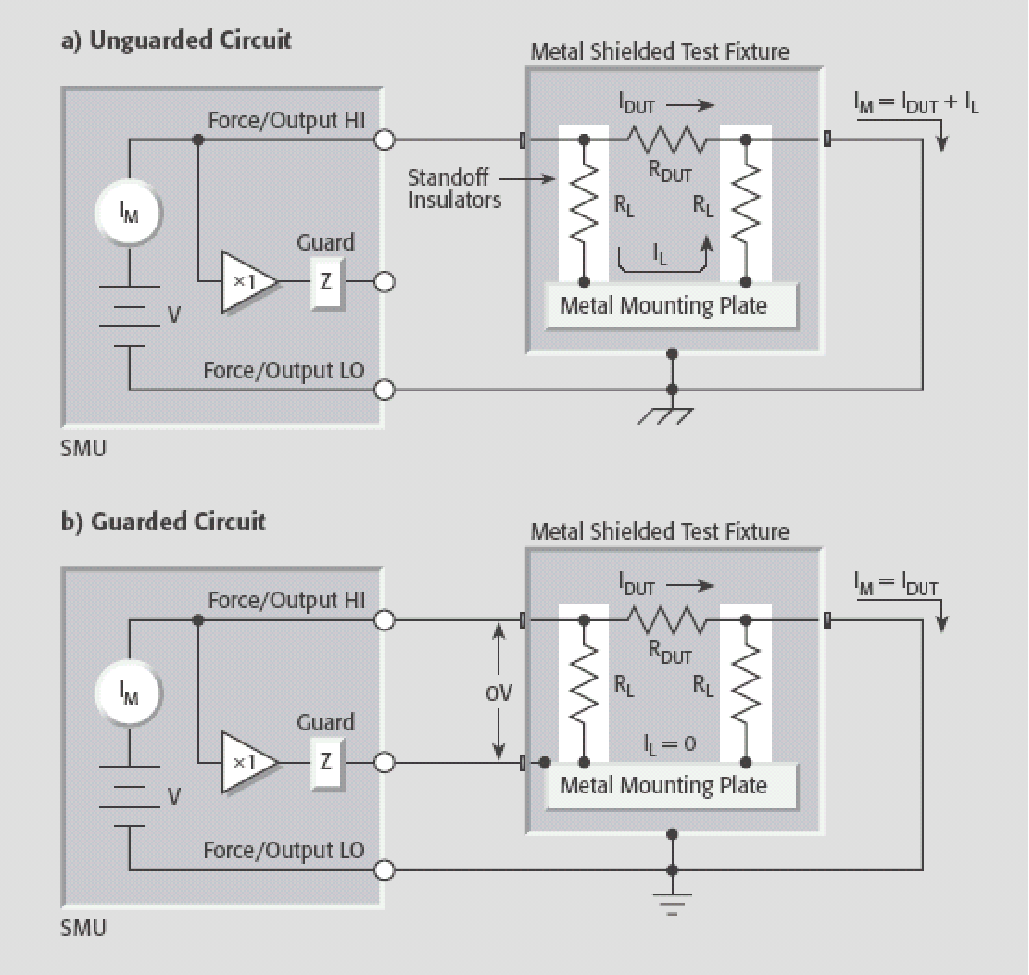
-4.0E-9
-5.0E-9
A
10.0E+0
20.0E+0
30.0E+0
40.0E+0
50.0E+0
60.0E+0
Time

Leakage Current

- **Error current that flows (leaks) through insulation resistance when a voltage is applied**
- **Generally an issue when the impedance of the device-under-test is comparable to that of the insulators in the test circuit**
- **To reduce leakage currents:**
  - ➢ Use good quality insulators in the test circuit (e.g. Teflon®, polyethylene)
  - ➢ Reduce humidity in the test lab
  - ➢ Use guarding

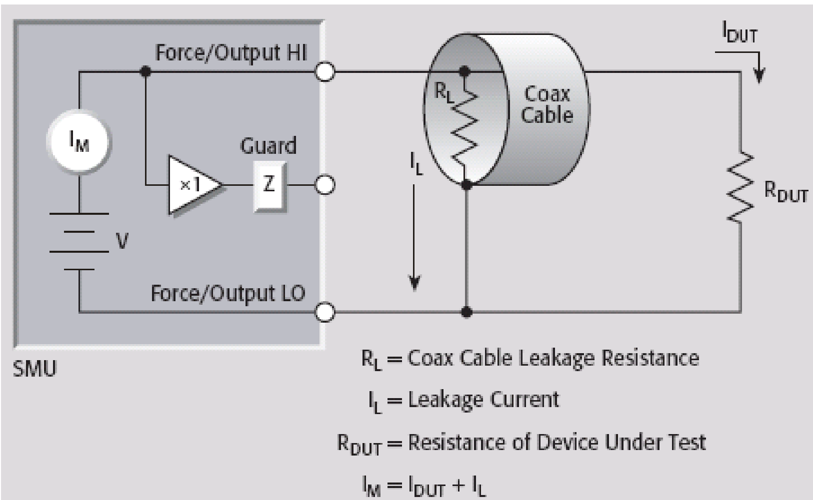
Using Guard to Reduce Leakage
In a Test Fixture



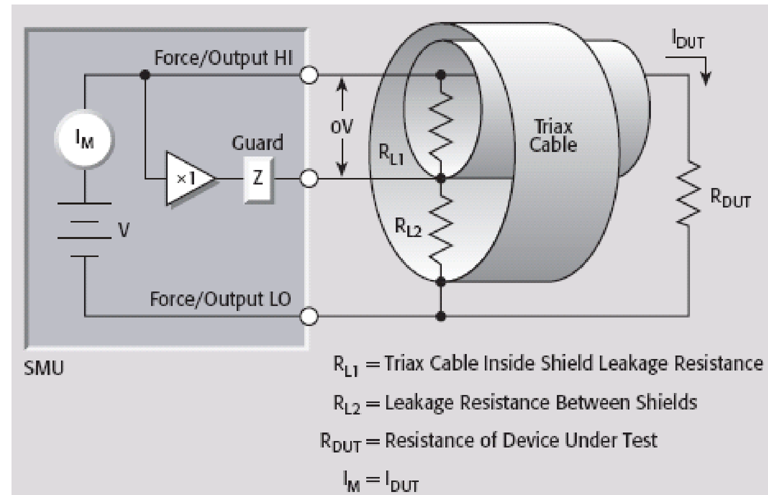
- **Guard – A conductor driven by low impedance source whose output is at or near the same potential as the high impedance terminal**
- **The guard terminal (inside shield of the triax cable) is used to guard test fixture and cable insulation resistance and capacitance.**

Use Guard to Reduce Leakage Currents
In Cabling

Unguarded Configuration



Guarded Configuration

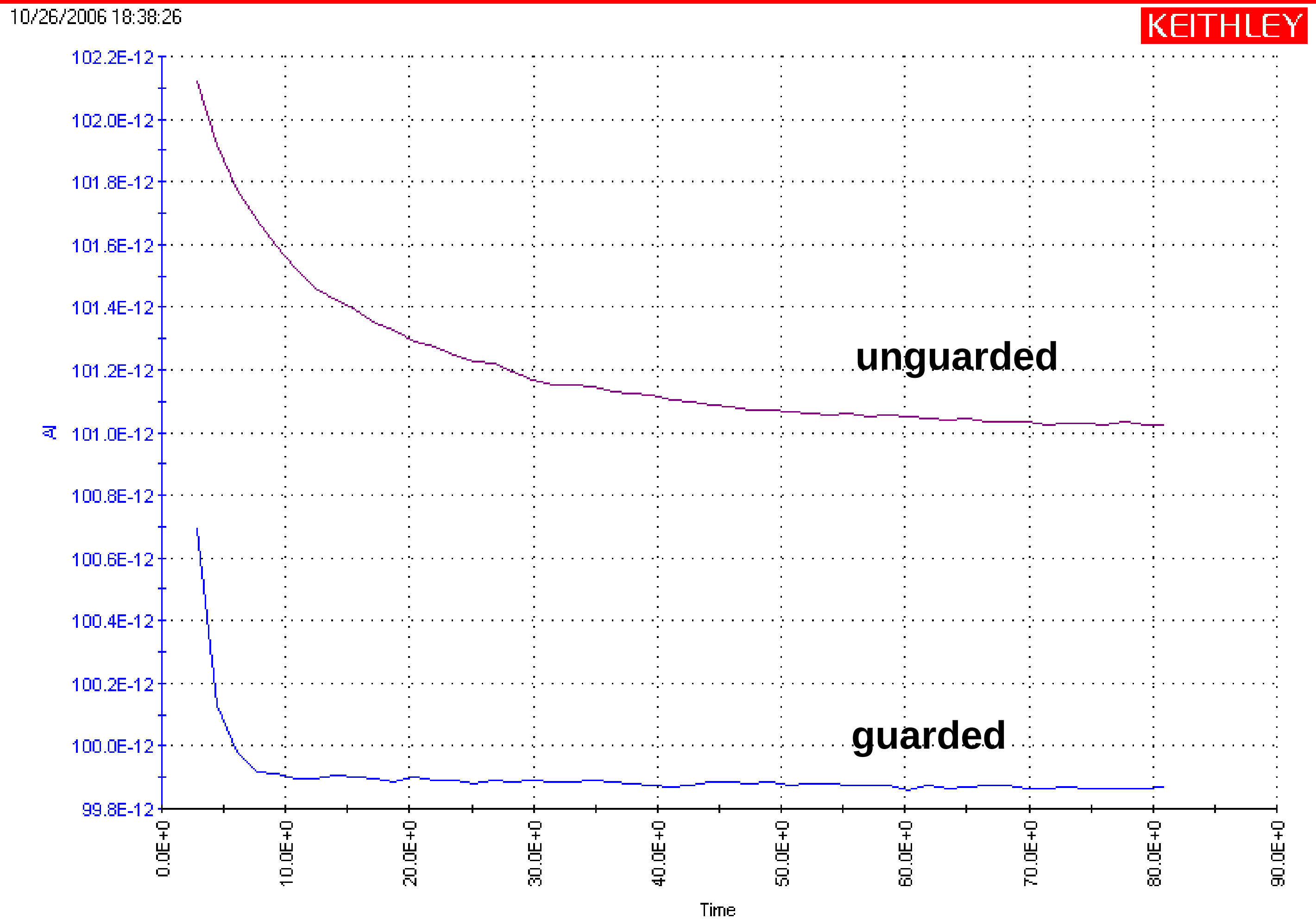


- **Use SMU to source 10V, and measure resulting current, I_M, to determine R_{DUT}**
  - If R_{DUT} = 100MΩ and R_L = 10GΩ, then I_M = 101nA and measured value for R_{DUT} will be 99.01MΩ → a 0.99% Error!
- **Guarding eliminates leakage current in R_{L1}; measured value for R_{DUT} is 100MΩ**
  - Current flowing in R_{L2} is supplied by guard source and does not affect I_{DUT}
- **Guarding also reduces capacitance, which decreases response time of circuit.**

Lab 9

Guarding the Leakage Resistance of a Cable

Lab 9 Results



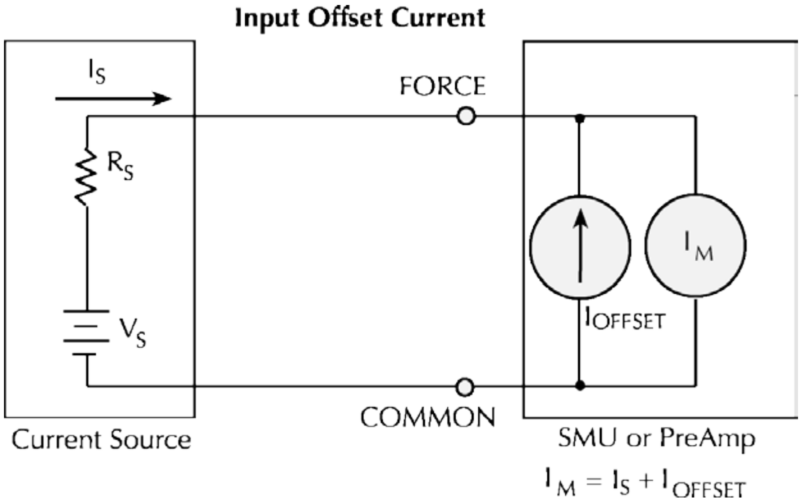
Generated Currents

- **Any extraneous generated currents in the test system will add to the desired current, causing errors.**
- **Offset Currents**
  - **Internal Offsets: Input offset current of ammeter**
  - **External Offsets: Insulators and cables:**
    - Triboelectric Effects
    - Piezoelectric and Stored Charge Effects
    - Contamination and Humidity

Typical Generated Currents

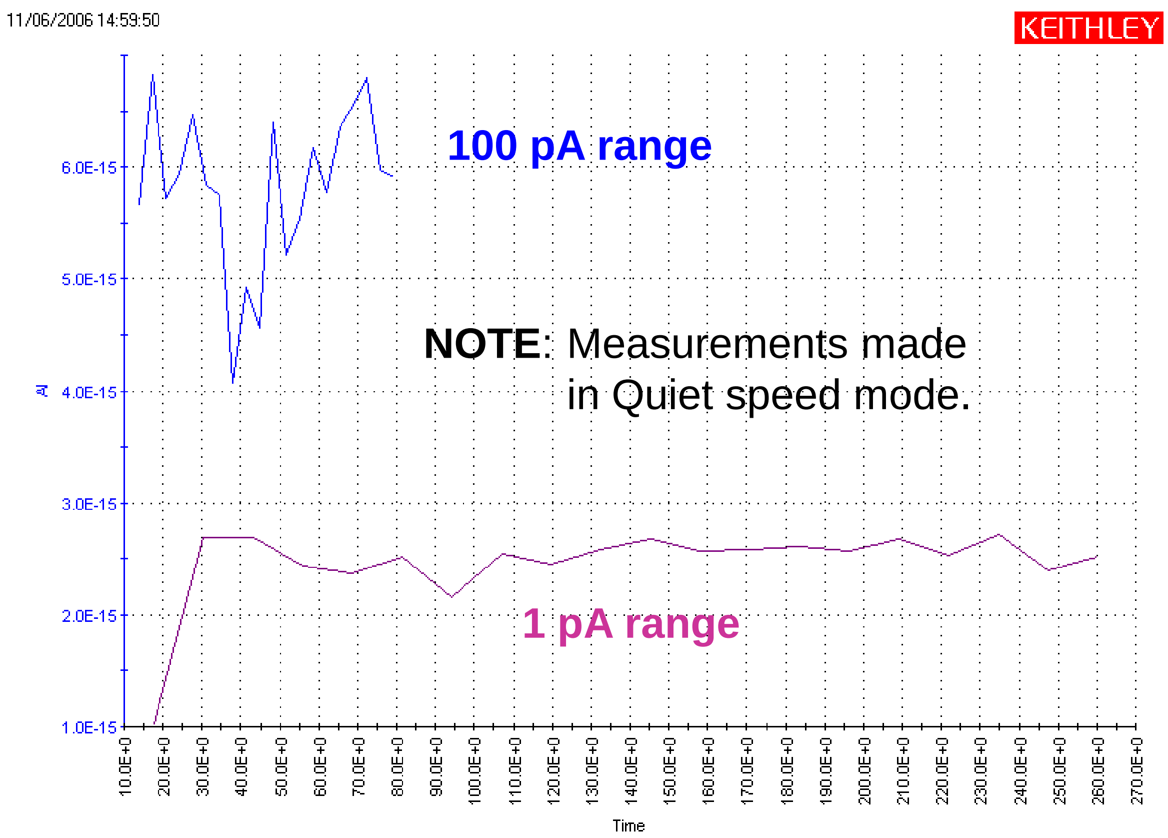
Effect	Generated Current Range
Triboelectric	1fA to 10nA
Mechanical stress (Teflon)	1fA to 1pA
Mechanical stress (Ceramics)	100aA to 100fA
Clean epoxy circuit board	100fA
Dirty epoxy circuit board	100pA

Offset Currents
Internal Offsets



- Input Offset Current is a small current that flows from the ammeter.
- This current is caused by bias currents of active devices and leakage currents through insulators within the instrument.
- Input offset current can be brought down to within spec by performing a system calibration.
- To perform a system calibration, go to the KITE Tools menu and click on Auto Calibration.

Offset Currents
Internal Offsets



- **The offset current of the 4200-SCS can be displayed by measuring and graphing the current vs. time of a particular SMU with no cables connected.**
- **To measure the offset of the entire system, repeat (or append) the graph of current vs. time with cables connected and probes in the “up” position.**

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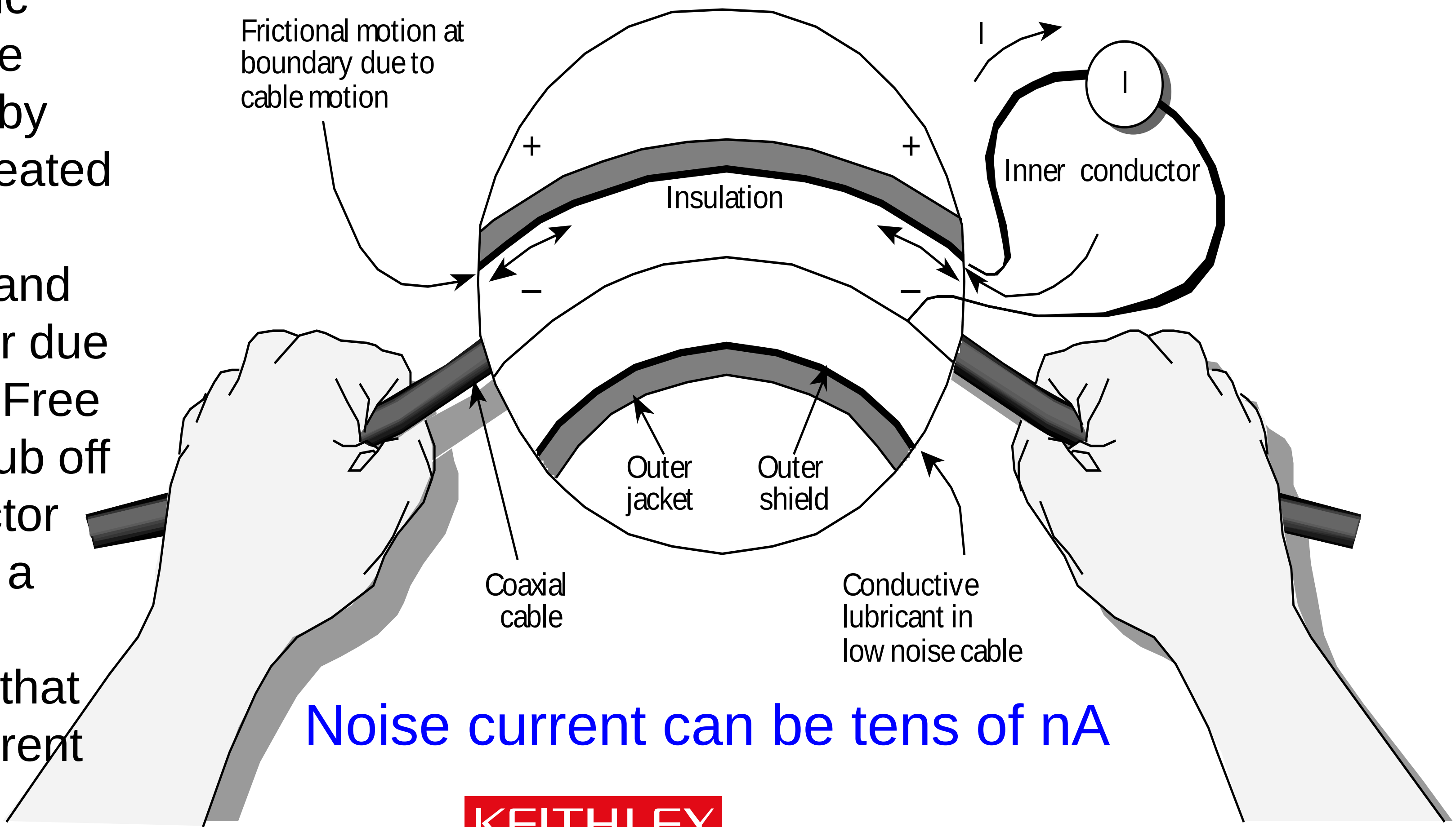
Offset Currents
Triboelectric Effect

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



Noise current can be tens of nA

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Offset Currents
Triboelectric Effect

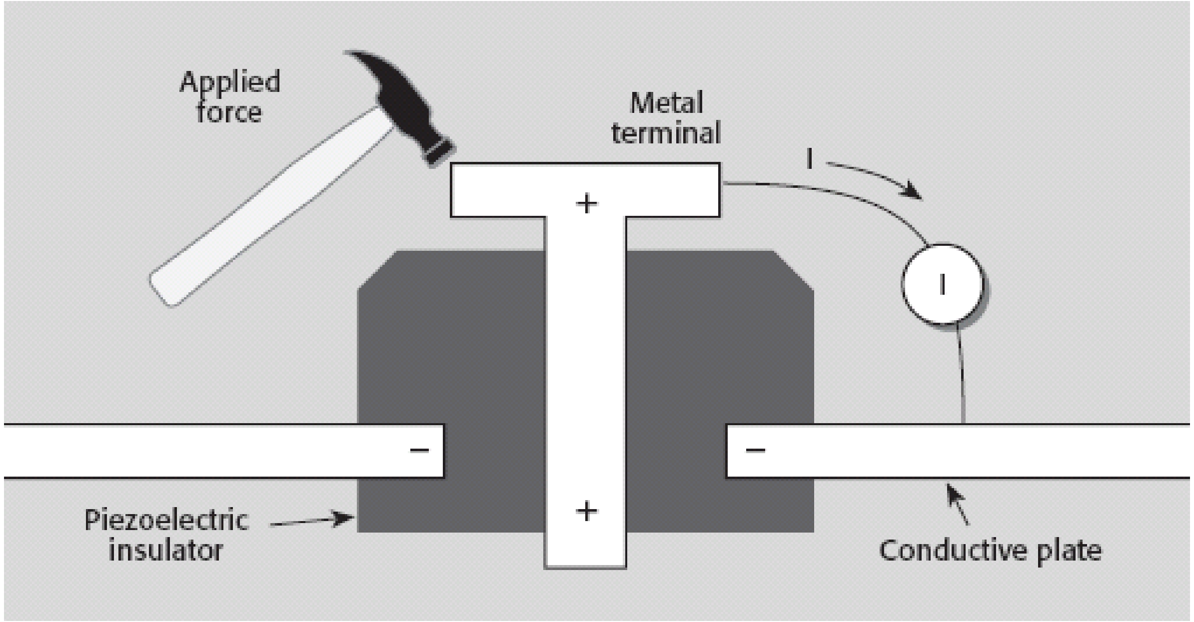
Triboelectric effects can be reduced by:

- Use low noise, triax cables that are supplied with the 4200-SCS.
- Keep all connections away from temperature changes.
- 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 preamps as close as possible to the DUT.

Offset Currents
Piezoelectric and Stored Charge Effects

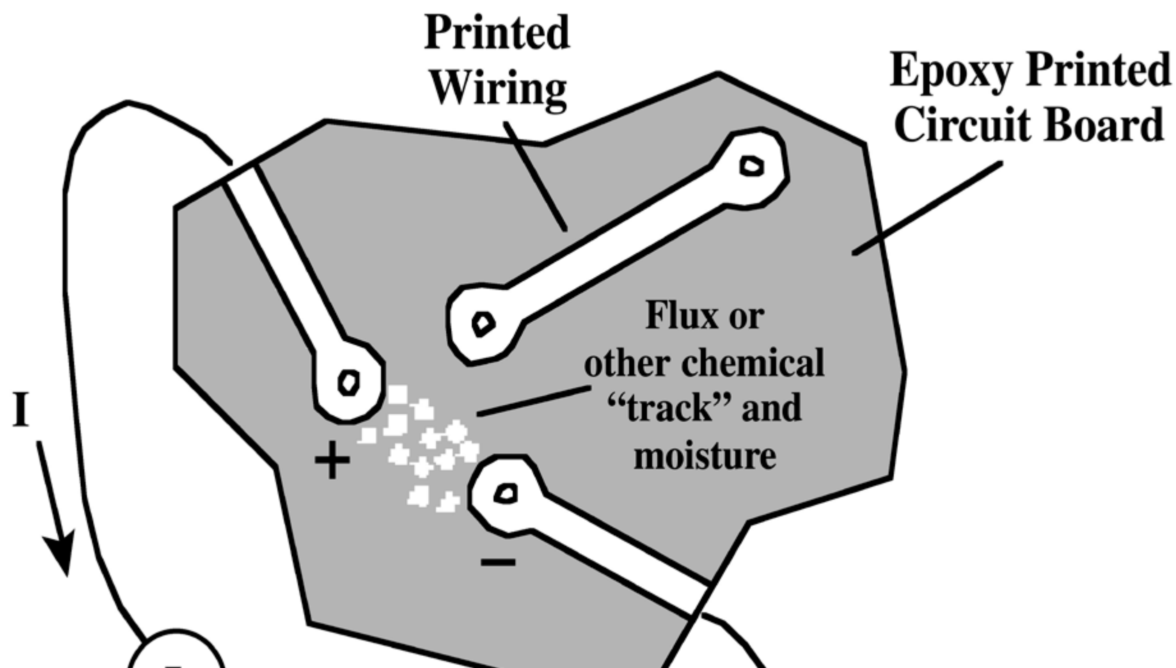
- Piezoelectric currents are generated when mechanical stress is applied to certain crystalline materials when used for insulated terminals and interconnecting hardware. In some plastics, pockets of stored charge cause the material to behave in a manner similar to piezoelectric materials.
- To minimize these effects, remove mechanical stresses from the insulators and use insulating materials with minimal piezoelectric and stored charge.

Piezoelectric Effect



Offset Currents
Contamination and Humidity Effects

- Insulation can be drastically reduced by high humidity or ionic contamination.
- High humidity conditions occur with condensation or water absorption.
- Ionic contamination may be the result of body oils, salts, or solder flux.
- To avoid these effects:
  - Keep humidity to moderate levels.
  - Keep all insulators clean.
  - Select insulators that resist water absorption.



Noise current can be tens of nA

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Offset Currents
Properties of Various Insulating Materials

Properties of Various Insulating Materials:

		PROPERTY			
Material	Volume Resistivity (Ohm-cm)	Resistance to Water Absorption	Minimal Piezoelectric Effects[1]	Minimal Triboelectric Effects	Minimal Dielectric Absorption
Sapphire	$>10^{18}$	+	+	0	+
Teflon® PTFE	$>10^{18}$	+	–	–	+
Polyethylene	10^{16}	0	+	0	+
Polystyrene	$>10^{16}$	0	0	–	+
Kel-F®	$>10^{18}$	+	0	–	0
Ceramic	10^{14}–10^{15}	–	0	+	+
Nylon	10^{13}–10^{14}	–	0	–	–
Glass Epoxy	10^{13}	–	0	–	–
PVC	5×10^{13}	+	0	0	–

KEY: + Material very good in regard to the property.
0 Material moderately good in regard to the property.
– Material weak in regard to the property.

[1] Stored charge effects in non-piezoelectric insulators.

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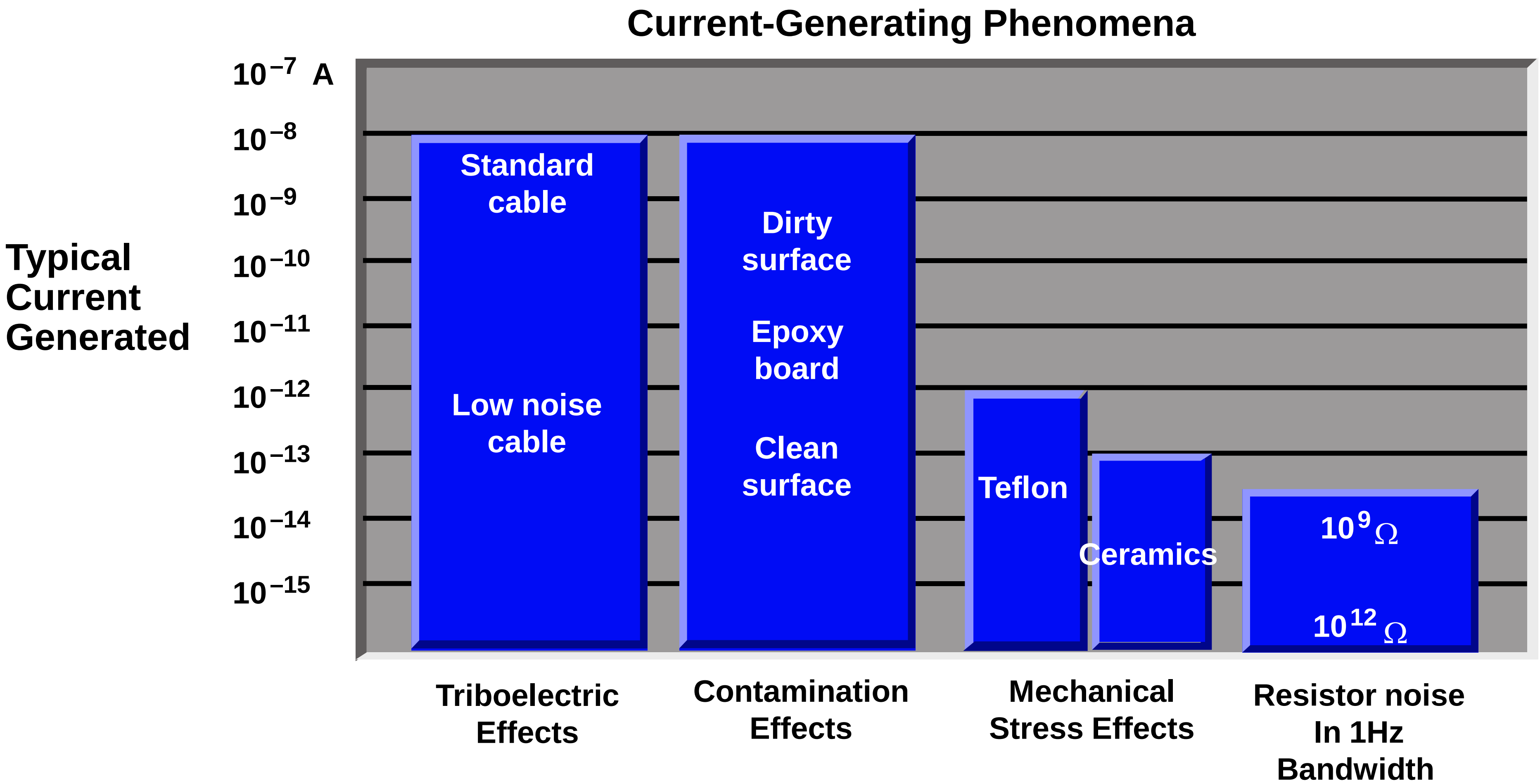
Offset Currents
Typical Magnitudes of Generated Currents



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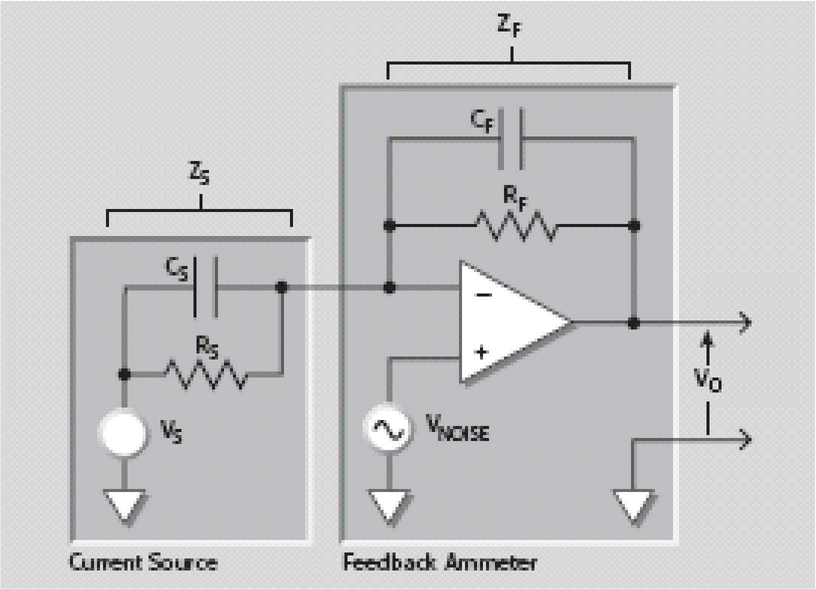
Noise and Source Impedance
Source Resistance

Simplified Model of a Feedback Ammeter



The noise gain of the circuit can be given by the following equation:

Output V_{NOISE} = Input V_{NOISE} $(1 + R_F/R_S)$

- **The source resistance of the DUT will effect the noise performance of the SMU or preamp.**
- **As the source resistance decreases, the current noise increases.**
- **Minimum recommended source resistance based on measurement range.**

Minimum recommended source resistance values

Range	Minimum Recommended Source Resistance
1pA to 100pA	1GΩ to 100GΩ
1nA to 100mA	1MΩ to 100MΩ
1µA to 100µA	1kΩ to 100kΩ
1mA to 100mA	1Ω to 100Ω

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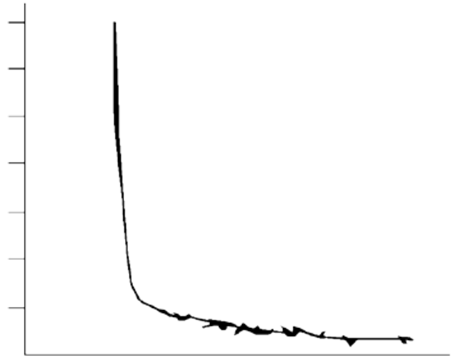
Noise and Source Impedance
Source Resistance

- **Never short the input of the SMU as an ammeter !!**
- **With a short-circuited input, the ammeter will have no negative feedback. Therefore, the readings are meaningless.**
- **An ammeter has low impedance. If you want to check it for zero, then test it with an open circuit.**

Noise and Source Impedance
Source Capacitance

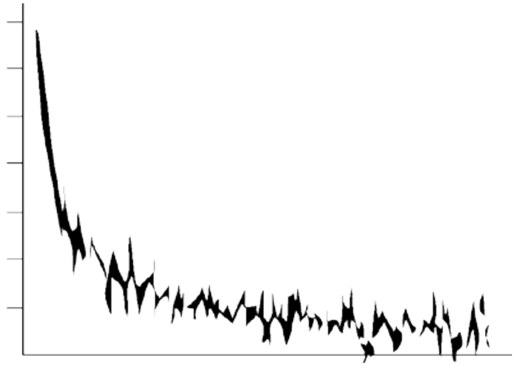
- **The source capacitance of the DUT will also affect the noise performance of the SMU.**
- **As source capacitance increases, the noise gain also increases.**
- **To increase the source resistance, add a forward-biased diode in series with the DUT. The diode acts like a variable resistance, low when the charging current to the source capacitance is high, then increasing in value as the current decreases with time.**

With Series Resistance



10pA/div. vs. Time
68MΩ and 8nF

Without Series Resistance



10pA/div. vs. Time
10MΩ and 8nF

Typical Response Curves

Low I and High R Measurements
Summary

More information about making successful low level measurements:

- **4200-SCS Reference Manual, Section 5**
- **Low Level Measurements Handbook, 6th Edition**
- **Applications Notes and White Papers – can be found at www.keithley.com**

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