MEASUREMENT TECHNIQUES FOR CHARACTERIZING
GRAPHENE, CARBON NANOTUBES, AND
NANO-MATERIALS AND DEVICES
LOW POWER, LOW VOLTAGE, LOW RESISTANCE

Avoiding Sources of Error When Measuring Low Power Materials and Devices

Noise: External Noise Sources • Low Frequency Noise • Johnson Noise

Use the Delta Mode Method to Eliminate Voltage Offsets and Noise

- External Noise Sources = interferences created by motors, computer screens, or other electrical equipment
- Control these External Noise Sources by:
  - Shielding and filtering
  - Remove or turn-off the noise source
  - Use DC instruments, integrate each measurement for an integer number of power line cycles. The line cycle noise will "average out" when the integration time is equal to an integer number of power line cycles.

Eliminate Thermoelectric Voltage Effects

Ways to Reduce Thermoelectric Voltages
- Construct test circuits using the same materials for interconnects.
- Minimize temperature gradients within the test circuit.
- Allow the test equipment to warm up.
- Use an offset compensation method.

Use Instrumentation with Sufficient Sensitivity

Use a Nanovoltmeter to Measure Voltage Drops

- When measuring the resistances of conductors or other low power materials, very small voltages are measured, typically in the microvolt and nanovolt range.
- To measure these very small voltage drops, use a sensitive voltmeter such as a nanovoltmeter.
- Verify the product specifications to make sure the measurement resolution and accuracy are sufficient to perform the sensitive measurement part of your application.

Use Appropriate Current Source

- Current source should be bipolar to perform current reversals to eliminate voltage offsets and reduce noise.
- Current source should be capable of accurately sourcing very low currents (pA to nA) for low level test devices and materials.
- The current source should have an adjustable voltage compliance to limit voltage to a safe level to avoid damage to the device.
- The current source should have constant output so user knows the exact value forced to the material – unlike using a voltage source of a variable resistance.