

Tips, Tools and Techniques that  
**Simplify I-V and C-V Characterization**

A GREATER MEASURE OF CONFIDENCE

**KEITHLEY**  
A Tektronix Company

# Tools, Tips, and Techniques that Simplify I-V and C-V Characterization



## Introduction

Semiconductor characterization presents a wide range of test challenges. This e-Guide offers an overview of advanced tools, tips, and techniques that you can use to simplify the I-V and C-V measurements that are essential to characterizing emerging semiconductor materials, devices, and processes.

## Table of Contents

Making Accurate I-V and C-V Measurements.....	3
Ensuring C-V Measurement Integrity .....	4-5
Preventing C-V Measurement Errors While Reducing Test Times.....	6
New C-V Measurement Techniques for High Impedance Devices.....	7
Measuring Sub-Picoamp Currents Accurately .....	8
Combining I-V, C-V, and Pulse I-V Measurements in One System .....	9

# Making Accurate I-V and C-V Measurements for Semiconductor Research, Design, Development, and Test

## I-V Measurements

Making low current measurements presents a variety of measurement challenges. Error sources such as leakage currents, noise, offset currents, piezoelectric currents, and environmental conditions can have a serious impact on measurement accuracy. Precision DC I-V measurements are the foundation of electrical characterization for cutting-edge devices, materials, and semiconductors. With proper measurement techniques and practices, these critical measurement challenges can be met.

## Ultra-Fast Pulsed I-V Measurements

Today, many parametric measurements require a fast, pulsed I-V measurement. Using pulsed I-V signals to characterize devices rather than DC signals makes it possible to study or reduce the effects of self-heating (joule heating) or to minimize current drift/degradation in measurements. Many applications require pulsed I-V along with C-V and DC I-V measurements. Learn how to combine all three measurement types into one test system while maintaining the measurement performance.

## Capacitance-Voltage (C-V) Measurements

Capacitance measurements have been used to determine a variety of semiconductor parameters on many different devices and structures. Three measurement techniques are used to derive critical parameters from a wide range of new materials, processes, devices. Multi-frequency capacitance provides capacitance vs. voltage (C-V), capacitance vs. frequency (C-f), and capacitance vs. time (C-t) measurements to evaluate at frequencies ranging from 10-MHz down to 1-kHz. Sometimes even lower frequency capacitance measurements are necessary to evaluate test parameters of thin film transistors, MEMS structures, and other high impedance devices. Called very low frequency (VLF) C-V, this newer technique performs C-V measurements in the range of 10-mHz to 10-Hz. To characterize slow trapping and de-trapping phenomenon in some materials, a capacitance measurement technique called quasistatic (or almost DC) measurements can be used.



**Want to learn more about Keithley's powerful characterization solutions?**  
Download our **Application Guides for DC I-V Testing, Pulsed I-V Testing, and C-V Testing.**

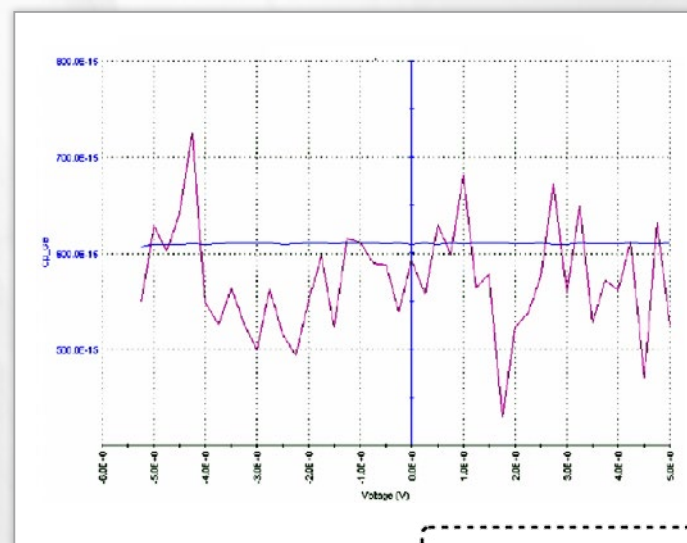
Get advice on optimizing your I-V/C-V characterization applications.

**Send us your question or join the discussion on our [application forum](#).**

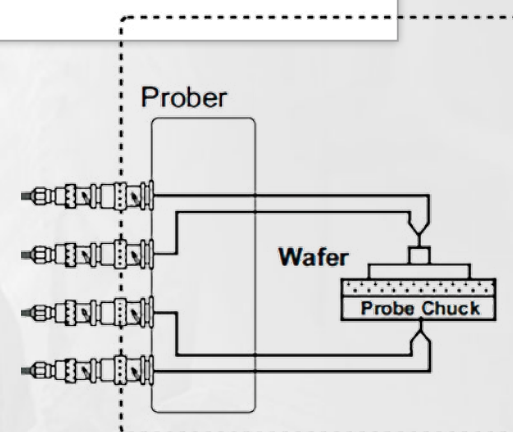
# Ensuring C-V Measurement Integrity

Capacitance measurements at the wafer level are often plagued by preventable measurement errors. Ensuring the accuracy of capacitance measurements can be challenging due to parasitic capacitance from cable, switch matrix, and fixturing combined with small capacitance values, often in the picofarad or femtofarad range. These values are typically far lower than most LCR meters can resolve. Additionally, measuring capacitance on a semiconductor wafer is very different from measuring a packaged device due to the effects of the probe station's chuck.

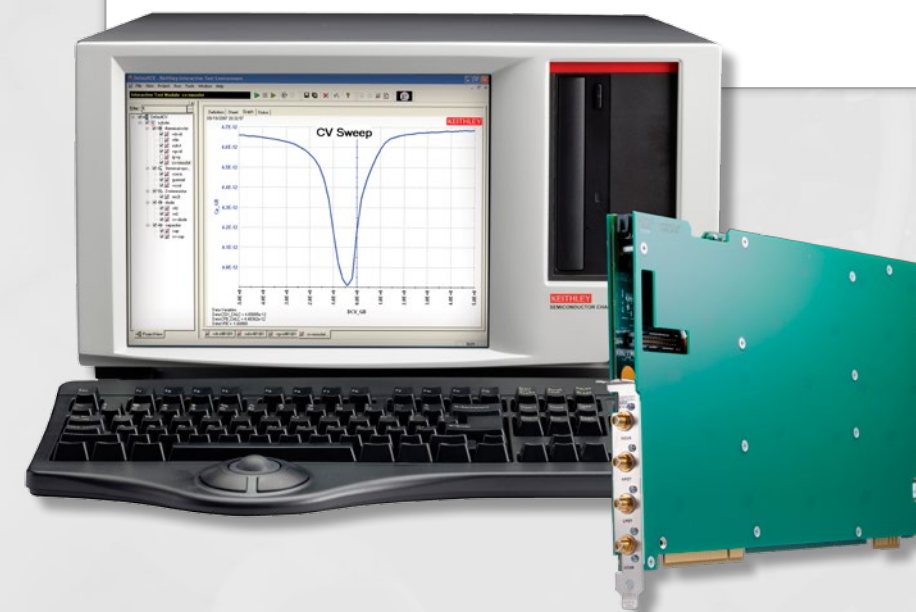
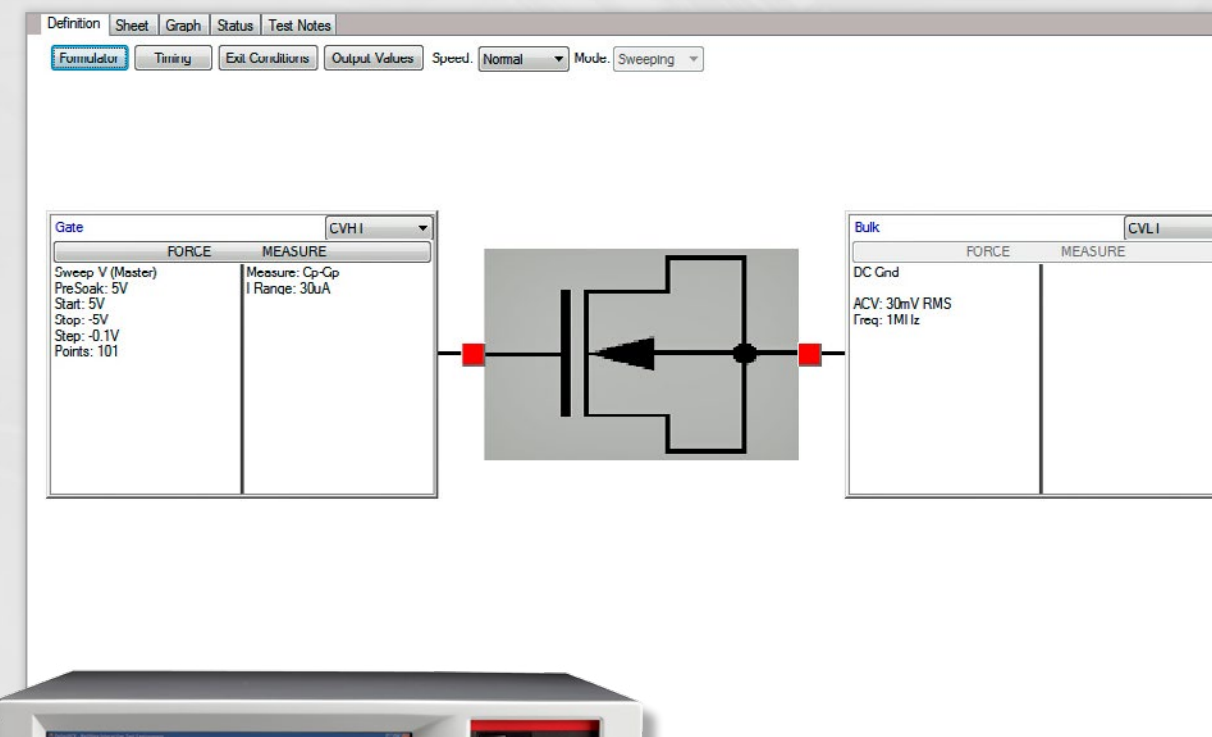
To ensure measurement integrity, it's important to understand how a capacitance measurement is made. A typical capacitance meter will apply a DC bias voltage across the device under test while measuring the AC signal at a frequency between 1-kHz to 10-MHz. For MOScap structures, the DC voltage is swept, which causes the device under test to pass through accumulation into the depletion region and then into the inversion region.



Interconnect Capacitance



Keithley's Model 4200-SCS Parameter Analyzer includes an extensive set of sample programs, test libraries, and built-in parameter extraction examples to simplify C-V measurements.



The optional Model 4210-CVU C-V Meter plugs directly into the Model 4200-SCS chassis for measuring capacitances from femtofarads to microfarads at frequencies from 1kHz to 10MHz. Users can quickly configure linear or custom C-V, C-f, and C-t sweeps with up to 4096 data points.

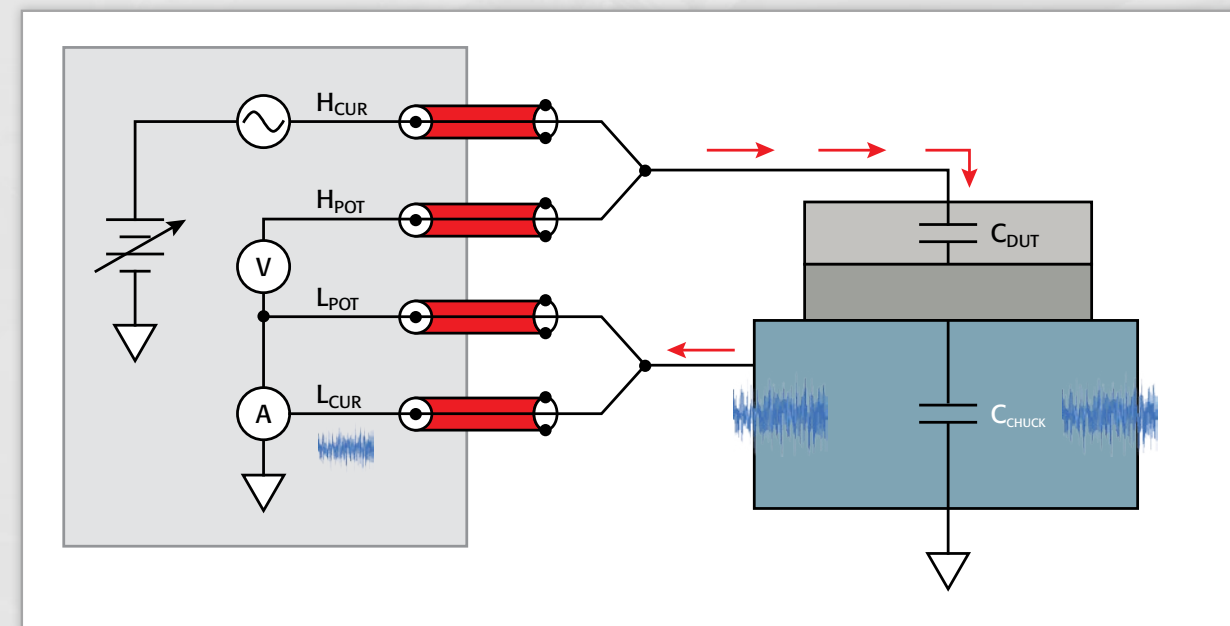
Get advice on optimizing your I-V/C-V characterization applications.

**Send us your question or join the discussion on our [application forum](#).**

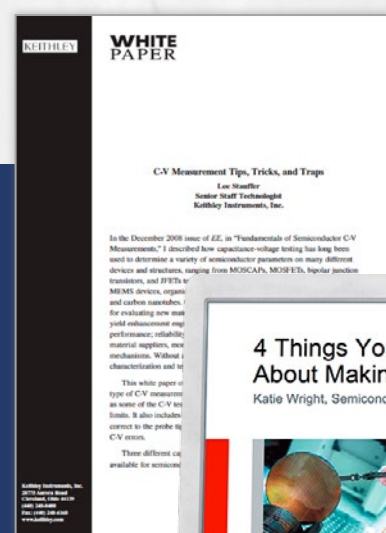
# Ensuring C-V Measurement Integrity

Most capacitance measurements are performed on a probe station, which is the source of many errors. A probe station's chuck can act as a large antenna that collects random noise. Since a wafer's substrate is connected electrically to the prober's noisy ground, the AC ammeter circuitry used in the capacitance meter can pick up this noise, which adds errors to measurements. Therefore, it's essential to connect the terminals of your meter to the DUT terminal with the least noise, which generally means the terminal with the least amount of capacitance to ground. Unfortunately, stopping a test and changing the setup to do this is time-consuming and increases the opportunity for reconnection errors. To ensure your C-V measurements, the Model 4200-SCS Parameter Analyzer software allows switching the AC ammeter with a simple mouse click, without the need to change the test setup.

The DC bias required to make a C-V measurement creates an electric field that pushes or pulls the mobile carriers closer to or farther away from the DUT's oxide layer. Precise control over that electrical field requires the ability to switch the DC bias from one device terminal to another. Similarly, the Model 4200-SCS Parameter Analyzer software makes switching the DC bias to the desired DUT terminal fast and easy. There's no need to change the test setup, which saves time and eliminates inadvertent misconnections, that can cause errors and require extra troubleshooting time.

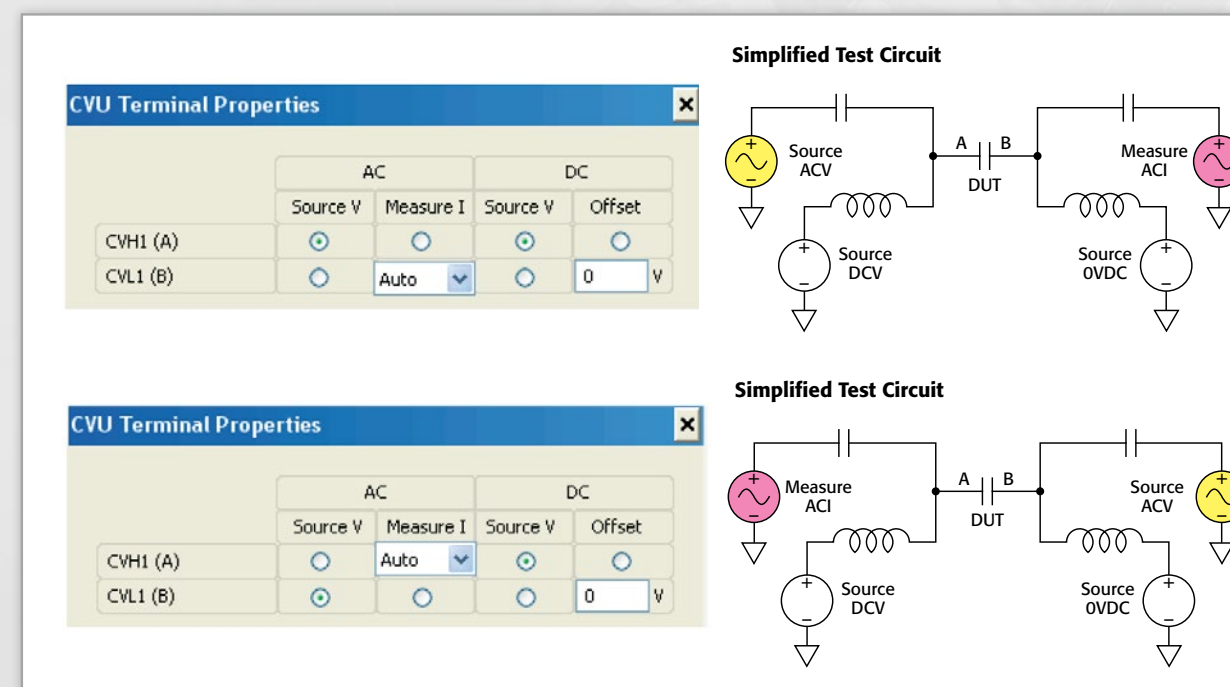


When measuring capacitance on a wafer and probe station, it is essential to connect AC ammeter circuitry to the least noisy DUT terminal.



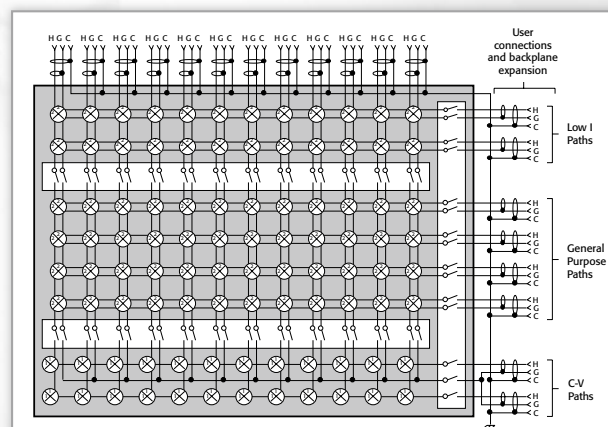
**4 Things You Might Not Know About Making C-V Measurements**  
Katie Wright, Semiconductor Product Line Manager

Want to learn more about increasing your C-V measurement accuracy? Watch our **"Four Things you Might Not Know about Making C-V Measurements"** webinar or download our **C-V Measurement Tips, Tricks, and Traps** white paper.



Model 4200-SCS Parameter Analyzer software enables easy AC ammeter and DC bias switching to DUT terminals.

# Preventing C-V Measurement Errors While Reducing Test Times

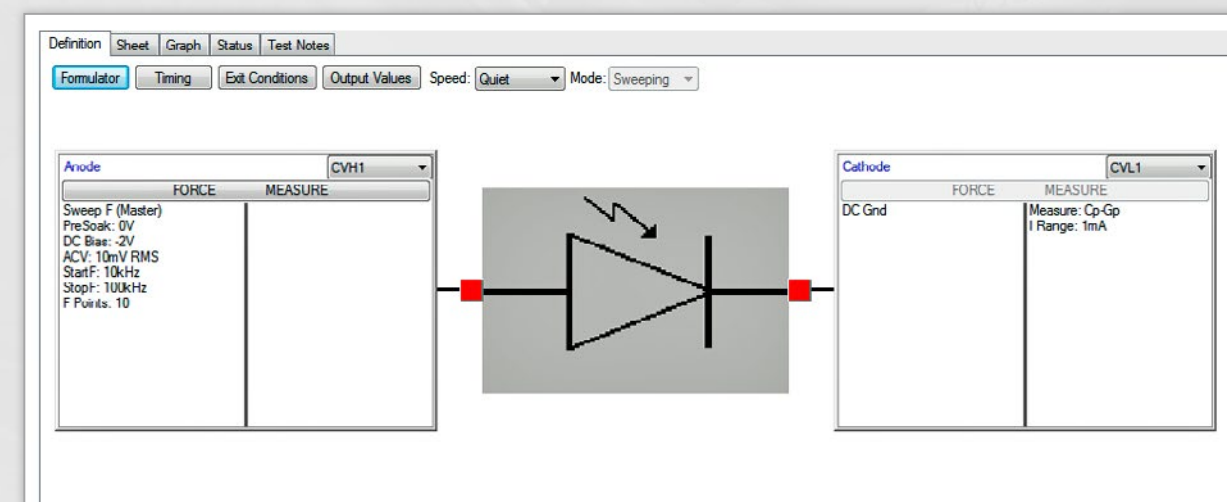


When making C-V measurements, it is important to minimize the effects of stray capacitance, including steps like the use of offset compensation and making the proper connections. C-V instruments are designed to be connected to the prober via interconnect cables and adaptors and may be routed through a switch matrix, which can add stray capacitance to the measurements.

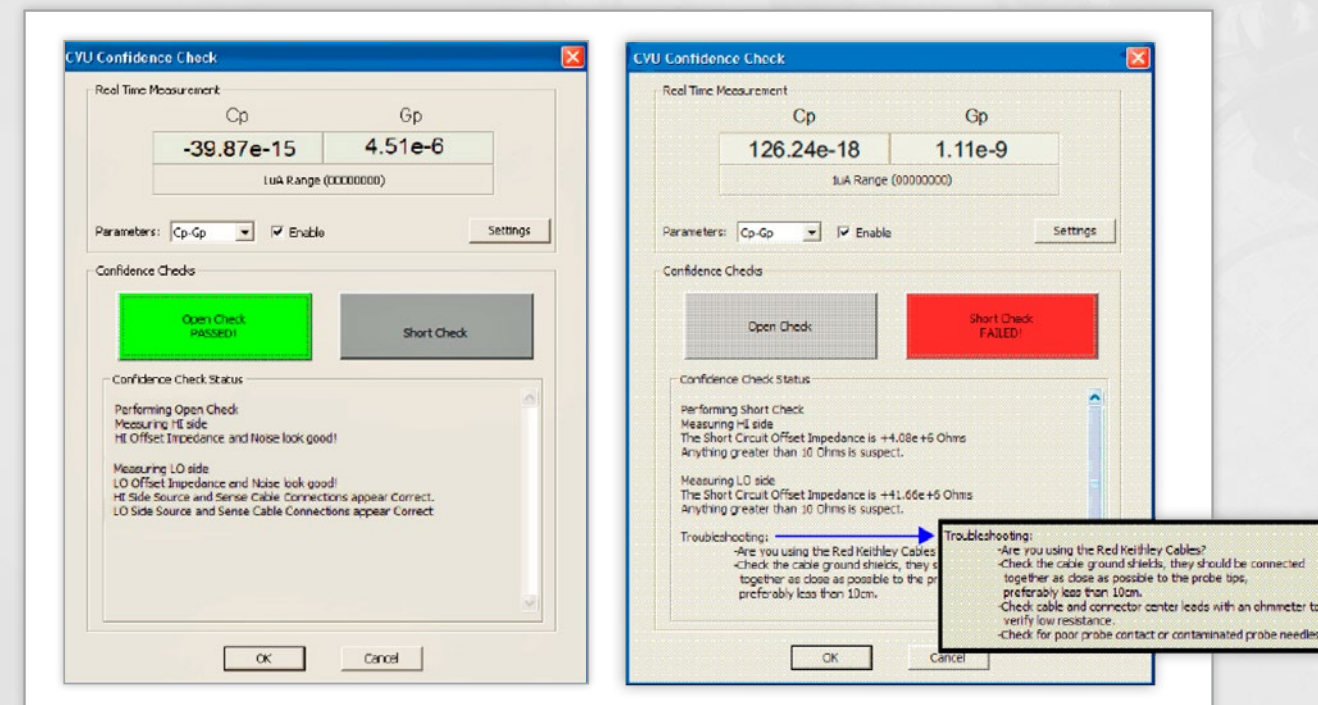
Keithley's Model 4200-SCS Parameter Analyzer incorporates Confidence Check, a unique diagnostic tool that simplifies checking the integrity of open and short connections and connections to a DUT.

When the Model 4210-CVU instrument is connected to the DUT, Confidence Check displays the measured readings in real time, so it can be used to perform quick and accurate C-V measurements without the need to run a pre-programmed test.

The Model 4210-CVU Confidence Check tool helps correct for stray capacitance that can interfere with test integrity when test signals are routed through a switching matrix such as those designed for use with Keithley's Model 707B Six-Slot Switch Mainframe or Model 708B Single-Slot Switch Mainframe. To verify switch matrix connections, perform real-time capacitance measurements using the Confidence Check tool. When the Model 4210-CVU is connected to a DUT, the Confidence Check tool displays the measured readings in real time.



Ready-to-use C-V application tests in the Model 4200-SCS Parameter Analyzer.



Keithley's Confidence Check confirms the integrity of the connections to your DUT.

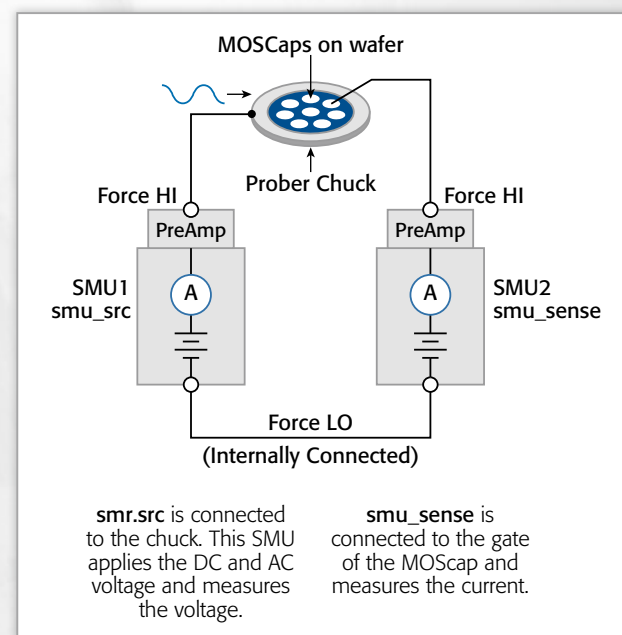


Want to learn more about how to ensure C-V measurement integrity? View our **"Tips, Tricks, and Traps of Semiconductor Capacitance-Voltage (C-V) Testing"** webinar or download the **Model 4200-SCS brochure**.

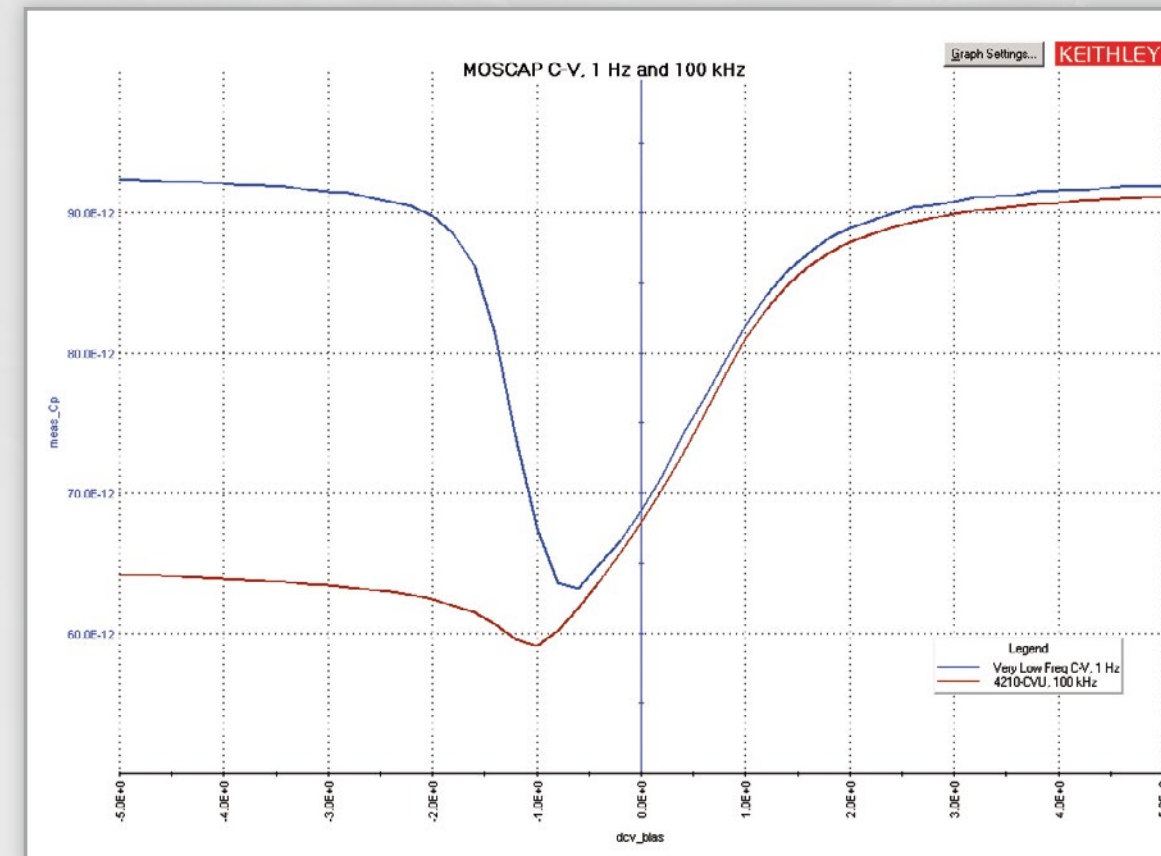
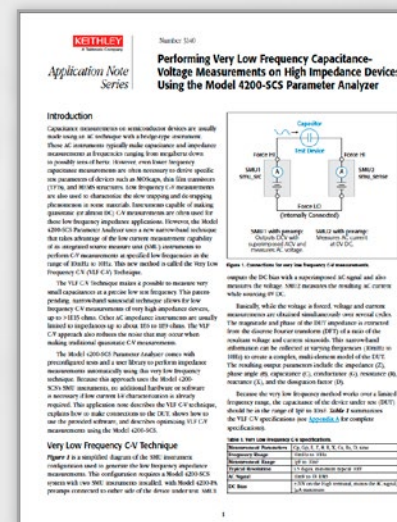
# New C-V Measurement Techniques for High Impedance Devices

C-V measurement instruments typically measure capacitance and impedance at frequencies ranging from megahertz down to tens of hertz. However, even lower frequency capacitance measurements are often necessary to derive specific test parameters of devices such as MOSCaps, thin film transistors, and MEMS structures. A low frequency C-V measurement is essential for characterizing the slow trapping and de-trapping phenomenon in some materials.

Keithley's Very Low Frequency (VLF) C-V technique allows measuring very small capacitances at a precise low test frequency. This patent-pending, narrow-band sinusoidal technique allows for low frequency C-V measurements of very high impedance devices, up to  $>1E15$  ohms. Other AC impedance instruments are usually limited to impedances up to about  $1E6$  to  $1E9$  ohms. The VLF C-V approach also reduces the noise that may occur when making traditional quasistatic C-V measurements.



The VLF C-V technique uses a Model 4200-SCS with two SMU instruments and two remote preamplifiers connected to either side of the device under test.



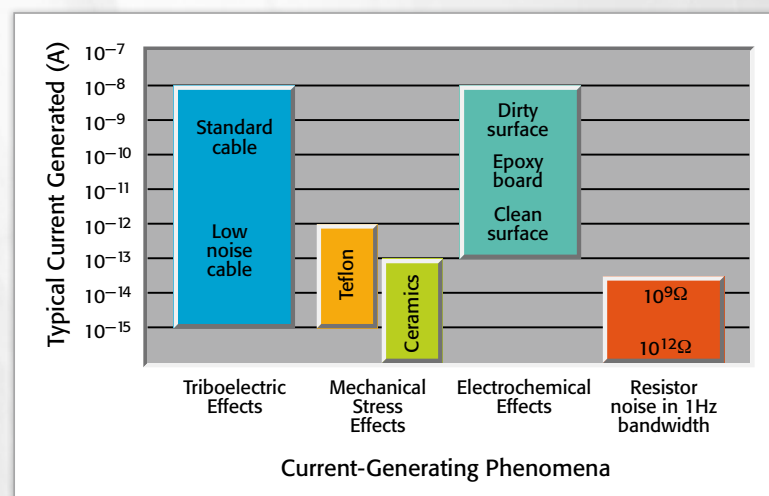
The VLF C-V technique is well-suited for both MOS device applications and emerging technologies like organic electronics, including organic LEDs, organic FETs, and organic photovoltaic cells, thin film transistors, and microelectromechanical systems.

**Want to learn more?**  
 Download our **Performing Very Low Frequency Capacitance-Voltage Measurements on High Impedance Devices** application note.

Get advice on optimizing your I-V/C-V characterization applications.  
**Send us your question or join the discussion on our application forum.**

# Measuring Sub-Picoamp Currents Accurately

Determining the gate leakage current of FETs, testing sensitive nanoelectronic devices, and measuring leakage current of insulators and capacitors demand the ability to measure currents of picoamps or less. And making accurate low current measurements like these depend not only on choosing a test system with a very sensitive ammeter, but on selecting the proper settings in the system's software, using low noise fixtures and cabling, allowing sufficient settling time, and using techniques that prevent unwanted currents from reducing measurement accuracy.



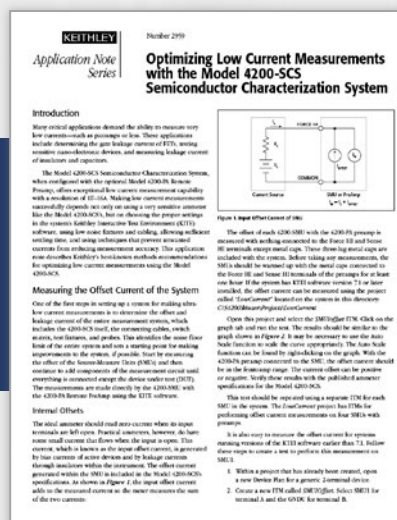
Unwanted currents in your test setup reduce measurement accuracy. Sources of error include triboelectric effects, piezoelectric effects, contamination, humidity, ground loops, light, and source impedance. These sources of measurement error can be reduced by using techniques such as shielding, guarding, proper grounding of instruments, and choosing the appropriate settings in the Model 4200-SCS Parameter Analyzer software.



The Model 4200-SCS's DC PreAmps can be mounted on the back of the parameter analyzer or on the probe station. By reducing the signal path between the DUT and the PreAmp, the Model 4200-SCS can reduce cable effects like parasitic capacitance and leakage currents, which provides for more accurate low-level measurements.

## Want to learn more?

Download our **Optimizing Low Current Measurements with the Model 4200-SCS Semiconductor Characterization System** application note.



Get advice on optimizing your I-V/C-V characterization applications.

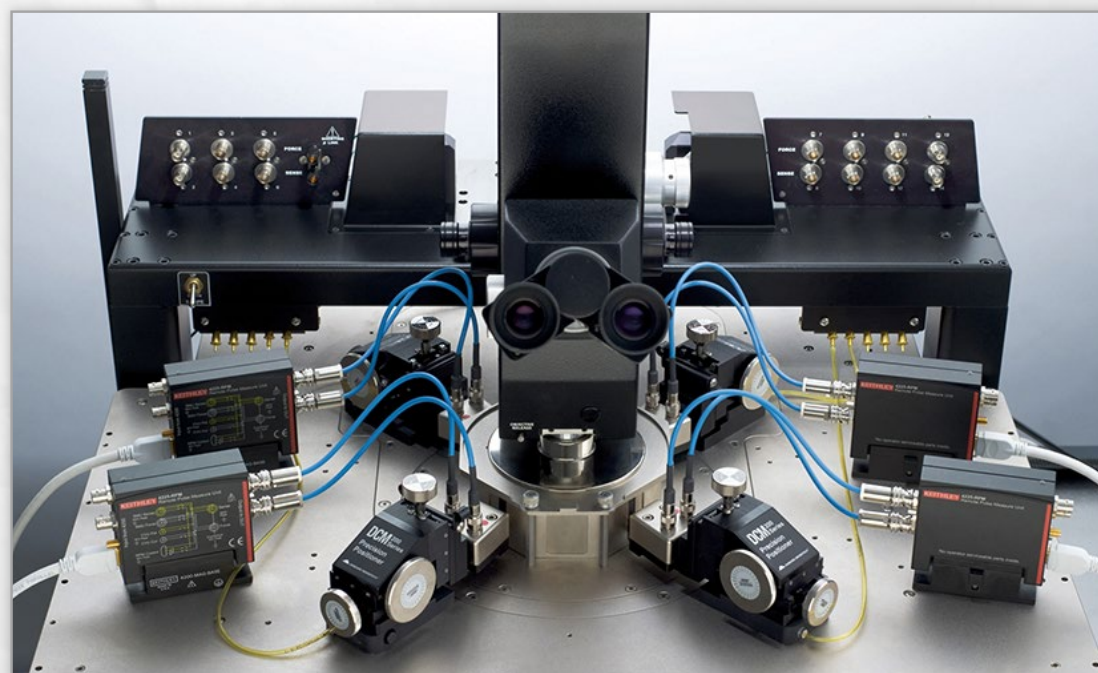
Send us your question or join the discussion on our [application forum](#).



# Combining I-V, C-V, and Pulse I-V Measurements in One System

Electrical characterization requires the ability to make three types of measurements: precision DC I-V measurements, AC impedance (capacitance) measurements, and ultra-fast I-V or transient I-V measurements. Since the cabling required for each measurement type is fundamentally different, combining all three measurement capabilities into a single test system is challenging. Poor-quality connections to the device under test can compromise the measurement integrity of even the most powerful and sophisticated test system. Matching cabling and grounding requirements for each measurement type enhances measurement integrity. However, changing cables for each measurement type is so time-consuming that many users simply tolerate the sub-optimal results.

To address these challenges, Keithley has developed the Model 4225-RPM Remote Amplifier Switch and the Model 4210-MMPC High-performance, Multi-measurement Cabling System. All three measurement types maintain their signal fidelity, cabling errors are reduced, and time is saved when integrated into the test setup with the remote amplifier switch and cabling kit.



Model 4225-RPM Remote Amplifier Switch with multi-measurement Performance Cabling System.



Want to learn more about integrating multiple measurement types in a single characterization system?

Download our White Papers:

- Labs' Demands for Greater Measurement Flexibility Require Cabling Systems Capable of Accommodating Multiple Measurement Types
- The Challenge of Integrating Three Critical Semiconductor Measurement Types into a Single Instrument Chassis

# Want to learn more?

Contact us by phone, fax, mail, or email:



Keithley Instruments hosts an online applications forum to encourage idea exchange, discussions among users. [Join the discussion today.](#)

## KEITHLEY CORPORATE HEADQUARTERS

Keithley Instruments  
28775 Aurora Road  
Cleveland, Ohio 44139  
Phone: 440-248-0400  
Toll-free: 800-552-1115  
Fax: 440-248-6168  
[info@keithley.com](mailto:info@keithley.com)

Consult with a Keithley applications engineer and learn how to get the most from your Keithley products

## WORLDWIDE HEADQUARTERS

Within the USA: 1-888-534-8453  
Outside the USA: +1-440-248-0400  
Email: [applications@keithley.com](mailto:applications@keithley.com)  
Additional contact information at [www.keithley.com](http://www.keithley.com)

## EUROPE

Germany: (+49) 89 849 307 40

## ASIA

China: (+86) 10 8447 5556  
Japan: (+81) 3 6714 30 70  
Korea: (+82) 2 574 7778  
Taiwan: (+886) 3 572 9077



Specifications are subject to change without notice. All Keithley trademarks and trade names are the property of Keithley Instruments, Inc. All other trademarks and trade names are the property of their respective companies. Tektronix and Keithley maintain a comprehensive, constantly expanding collection of application notes, technical briefs, and other resources to help engineers stay on the cutting edge of technology.

For further information, please visit [www.tektronix.com](http://www.tektronix.com) or [www.keithley.com](http://www.keithley.com)



KEITHLEY INSTRUMENTS ■ 28775 AURORA RD. ■ CLEVELAND, OH 44139-1891 ■ 440-248-0400 ■ Fax: 440-248-6168 ■ 1-888-KEITHLEY ■ [www.keithley.com](http://www.keithley.com)

**BENELUX**  
+31-40-267-5506  
[www.keithley.nl](http://www.keithley.nl)

**FRANCE**  
+33-01-69-86-83-60  
[www.keithley.fr](http://www.keithley.fr)

**ITALY**  
+39-049-762-3950  
[www.keithley.it](http://www.keithley.it)

**MALAYSIA**  
60-4-643-9679  
[www.keithley.com](http://www.keithley.com)

**SINGAPORE**  
01-800-8255-2835  
[www.keithley.com.sg](http://www.keithley.com.sg)

**BRAZIL**  
55-11-4058-0229  
[www.keithley.com](http://www.keithley.com)

**GERMANY**  
+49-89-84-93-07-40  
[www.keithley.de](http://www.keithley.de)

**JAPAN**  
81-120-441-046  
[www.keithley.jp](http://www.keithley.jp)

**MEXICO**  
52-55-5424-7907  
[www.keithley.com](http://www.keithley.com)

**TAIWAN**  
886-3-572-9077  
[www.keithley.com.tw](http://www.keithley.com.tw)

**CHINA**  
86-10-8447-5556  
[www.keithley.com.cn](http://www.keithley.com.cn)

**INDIA**  
080-30792600  
[www.keithley.in](http://www.keithley.in)

**KOREA**  
82-2-6917-5000  
[www.keithley.co.kr](http://www.keithley.co.kr)

**RUSSIA**  
+7-495-664-7564  
[www.keithley.ru](http://www.keithley.ru)

**UNITED KINGDOM**  
+44-1344-39-2450  
[www.keithley.co.uk](http://www.keithley.co.uk)

For further information on how to purchase or to locate a sales partner please visit [www.keithley.com/buy](http://www.keithley.com/buy)