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Labs' Demands for Greater Measurement Flexibility Require Cabling Systems Capable of Accommodating Multiple Measurement Types

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Understanding a semiconductor device's electrical characteristics and the processes used to manufacture it requires a diverse array of measurements. I-V, C-V, and pulse-based measurements are the most common measurements made. All three of these measurement types are included as capabilities of leading SDC (Semiconductor Device Characterizers). These characterizers strive to integrate these measurements in order to reduce the time and effort required to make these measures. One of the most difficult problems associated with integrating these measurements is that the cabling required for each measurement type is fundamentally different. Although the cabling from the instrument to the probe station bulkhead and feed through is fairly straightforward, the cabling from the bulkhead to the probe tips can be confusing and difficult. The purpose of this paper is to explain the different cabling requirements and to describe a single multi-measurement cabling system that offers high performance and is easy to use.

Cabling Requirements for I-V Measurements

I-V measurements are made using four triaxial cables as shown in ***Figure 1***. Guarding is necessary to achieve low current I-V measurements, which makes the use of triaxial cables necessary for these measurements. The measurement signal is carried on the center conductor, the inner shield is driven as a guard for the signal, and the outer shield is used for safety to shield the user from high voltages that may be applied to the guard and signal conductors. Four cables are necessary in order to achieve a remote sense, or Kelvin, connection. Remote

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sense cables allow the instrument to sense the voltage at the device accurately. A two-terminal DUT is connected as shown in ***Figure 1***.

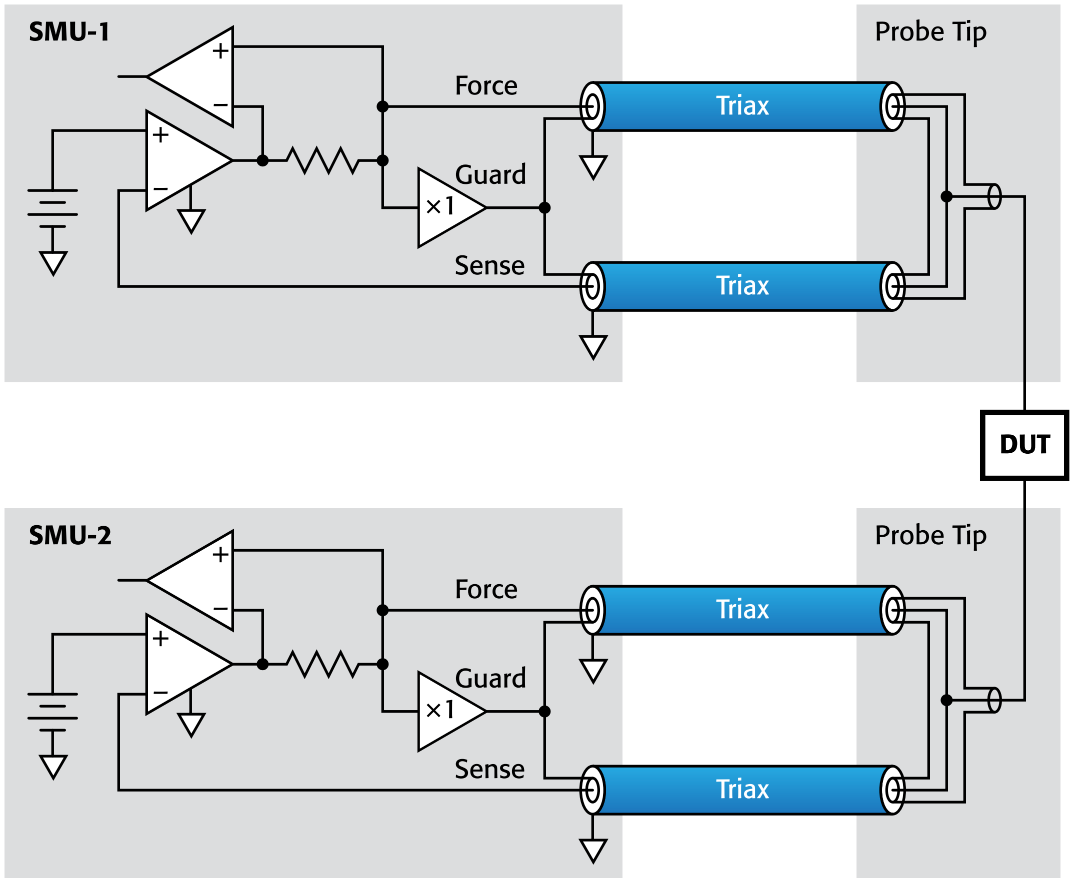

Figure 1: I-V measurement connection scheme for Kelvin connections.

Cable Requirements for C-V Measurements

C-V measurements are made using four coaxial cables as shown in ***Figure 2***. The outer shells are connected together to control the characteristic impedance the signals see. All four cables' outer shells must be inter-connected near the DUT.

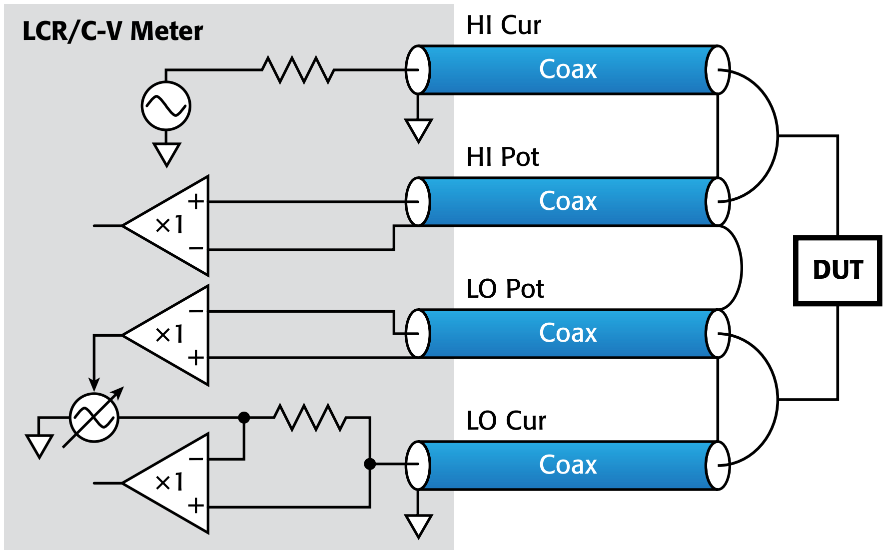

Figure 2: C-V measurement connection scheme for Kelvin connections.

Cable Requirements for Pulse Testing

Pulsed measurements require the highest bandwidth of the three measurement types, so the cable must have a characteristic impedance that matches the source impedance to prevent reflections off the DUT from reflecting off the source. Pulsing does not use a remote sense cable. ***Figure 3*** shows a typical connection to a two-terminal DUT. Pulsing is the only one of the three measurement types that connects the DUT to the outer shield of the cable.

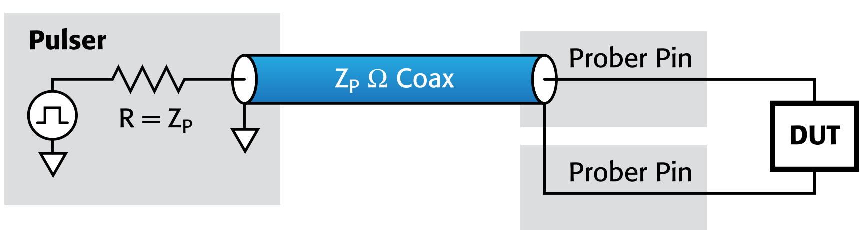

Figure 3: Pulse testing connection scheme for Kelvin connections.

Table 1. Summary of different cable requirements for I-V, C-V, and Pulsed I-V measurements.

DC I-V	• Triaxial cables • Kelvin connection • Isolated, driven guards
LCR/C-V	• Coaxial cables • Kelvin connection • Shields connected at the probe tips
Pulsed I-V	• Coaxial cables • Non-Kelvin connection (single cable) • Shields connected at the probe tips • Shield optionally connected to a probe tip

Transmission Line Theory

Given the challenges created by these differing cabling requirements for different measurement types, Keithley has developed a multi-measurement cabling system based on an understanding of two transmission concepts. The first concept is that if there are two parallel transmission lines, the characteristic impedance of the combined transmission line is the parallel combination of each transmission line's characteristic impedances, as shown in ***Figure 4***.

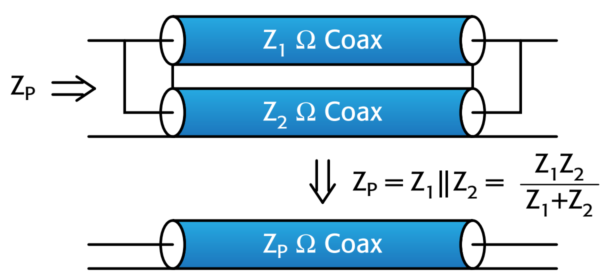

Figure 4: With two parallel transmission lines, the characteristic impedance of the combined transmission line is the parallel combination of each transmission line's characteristic impedances.

The second transmission line theory is that if there are two transmission lines connected in series, as shown in ***Figure 5***, the characteristic impedance of the combined transmission line is the sum of that of the two individual transmission lines.

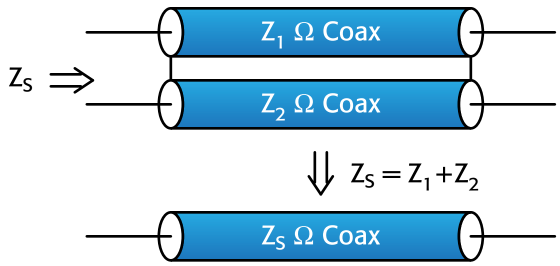

Figure 5: When two transmission lines are connected in series, the characteristic impedance of the combined transmission line is the sum of the two individual transmission lines.

This series arrangement can be observed in a triaxial cable, as shown in ***Figure 6***. A triaxial cable is actually two concentrically arranged transmission lines. The inner shield and the center conductor form one transmission line (Z_1) and the inner shield and the outer shield form a second transmission line (Z_2). The center conductor to outer shield interaction has a characteristic impedance (Z_S) equal to the sum of the two transmission lines that share the inner shield.

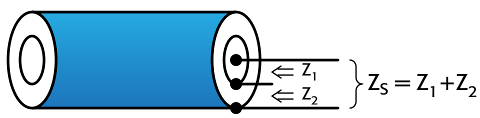

Figure 6: A triaxial cable.

With this understanding, Keithley has developed a cabling kit that can support I-V, C-V and pulsed I-V measurements, reducing the burden on the system operator, who would otherwise be forced to go through the laborious process of re-cabling the connections from the test instrumentation to the prober every time a new measurement type was required. Two versions of the cable kit are available—the Model 4210-MMPC-C for Cascade Microtech probers and the Model 4210-MMPC-S for use with SUSS MicroTec probers.

I-V and C-V Cabling System Overview

Starting from the I-V system illustrated in ***Figure 1***, the configuration in ***Figure 7*** shows how it can be connected to an LCR/C-V meter.

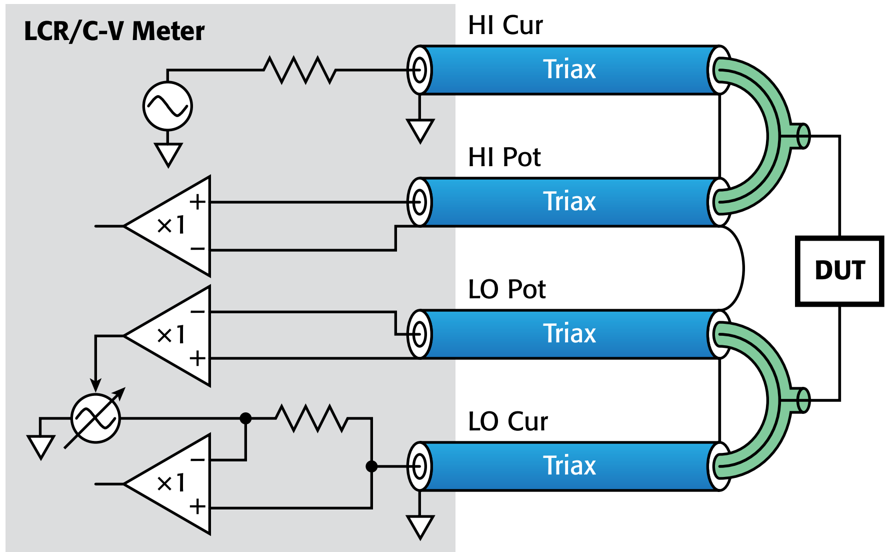

Figure 7: Connections between a DUT and an LCR/C-V meter.

Note the guard is allowed to float and the outer shields are all interconnected at the prober. (Interconnecting the outer shields does not adversely affect I-V measurements. It may even improve I-V measurement performance in some cases.) The triaxial cables replace the coaxial cables shown in ***Figure 2***. It's possible to switch between I-V and C-V measurements by re-connecting only the instrument end of the cable. The switch can even be performed without disconnecting the wafer from the prober.

Adding 50Ω Transmission Lines

Pulse testing (as well as other test types) requires 50Ω transmission lines to the DUT. If the triaxial cables are designed to have a characteristic impedance of 100Ω from their center connectors to their outer shields and two of these cables are connected in parallel, the combination has a characteristic impedance of 50Ω. In addition, pulsing usually requires one or more DUT pins to be connected to ground. The center connector can be connected to the outer shield by adding a jumper, as shown in ***Figure 8***, to make the ground connection.

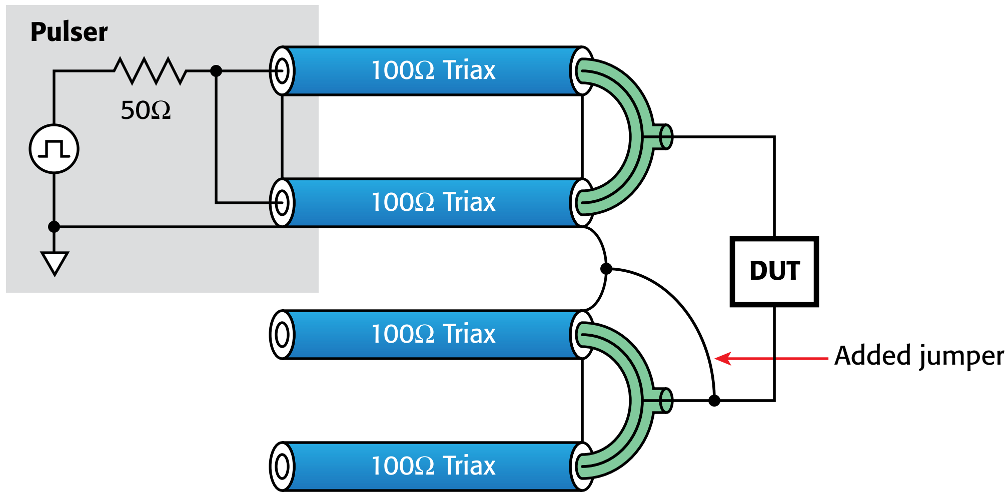

Figure 8: Pulse testing usually requires connecting one or more DUT pins to ground. A jumper can be used to tie the center connector to the outer shield to make this ground connection.

Attaching this jumper at the end of the probe arm would require disconnecting the probe needle from the wafer to protect the wafer; unfortunately, the probe needle area can be difficult to access. A simpler alternative would be to apply the ground connection at the end of a short cable; however, this will reduce the effective bandwidth of the ground. To obtain a clean 10ns rise time, the ground cable must have an electrical length that is less than 1.5ns (approximately 30cm), which would allow the ground to be applied at the mounting base of the probe manipulator. Adding connectors in the cables near the probe manipulator mounts allows inserting a shorting cap as shown in ***Figure 9***. The shorting cap can be added without disturbing the probe needle, making it possible to switch from I-V and/or C-V measurements to pulsed measurements without the need to re-probe a wafer site. Allowing operators to make quick, easy set-up changes while the probe needles are in contact with a wafer reduces pad damage and maintains the same contact impedance for all three types of measurements.

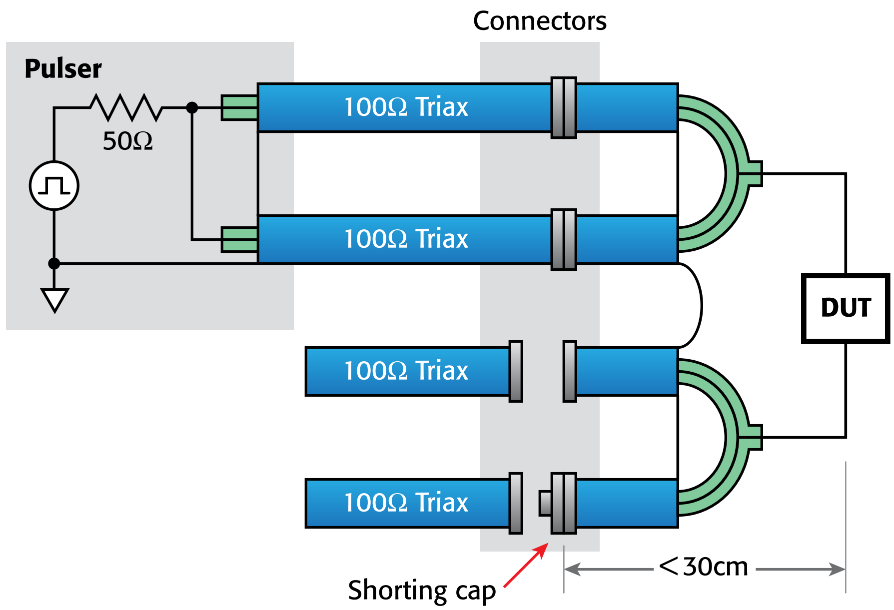

Figure 9: To insert a shorting cap, add connectors in the cables near the probe manipulator mounts.

In order to simplify switching from Kelvin to non-Kelvin measurements, it was necessary to allow the cables to be connected in parallel. This means that cables do not have to be added or removed when changing from one measurement type to another; they can simply be moved from one set of instrument connections to another. Given that most fast pulse instruments require a 50Ω pathway, the parallel combination of cables should yield 50Ω, so each cable must have a characteristic impedance of 100Ω. Most LCR/C-V meters are designed to function with 50Ω cables, but the Keithley Model 4200-CVU instrument for the Model 4200-SCS system is designed for use with 100Ω cables.

Conclusion

The main advantage of Keithley's new approach to connecting the instrumentation to the prober is that, no matter what type of measurement is being made, no changes to the probe manipulator cabling are required. This makes it much simpler to switch between I-V measurements, C-V measurements, and pulsed testing, simplifying the device characterization process. In addition, the setup changes can be made while the probe needles are in contact with a wafer, reducing pad damage and maintaining the same contact impedance for all three types of measurements.

Appendix – Four-Terminal Measurements

Many I-V and pulse measurements are made on devices with more than two terminals. The most common device type is a four-terminal MOSFET. ***Figure 10*** illustrates an I-V measurement setup for a four-terminal DUT.

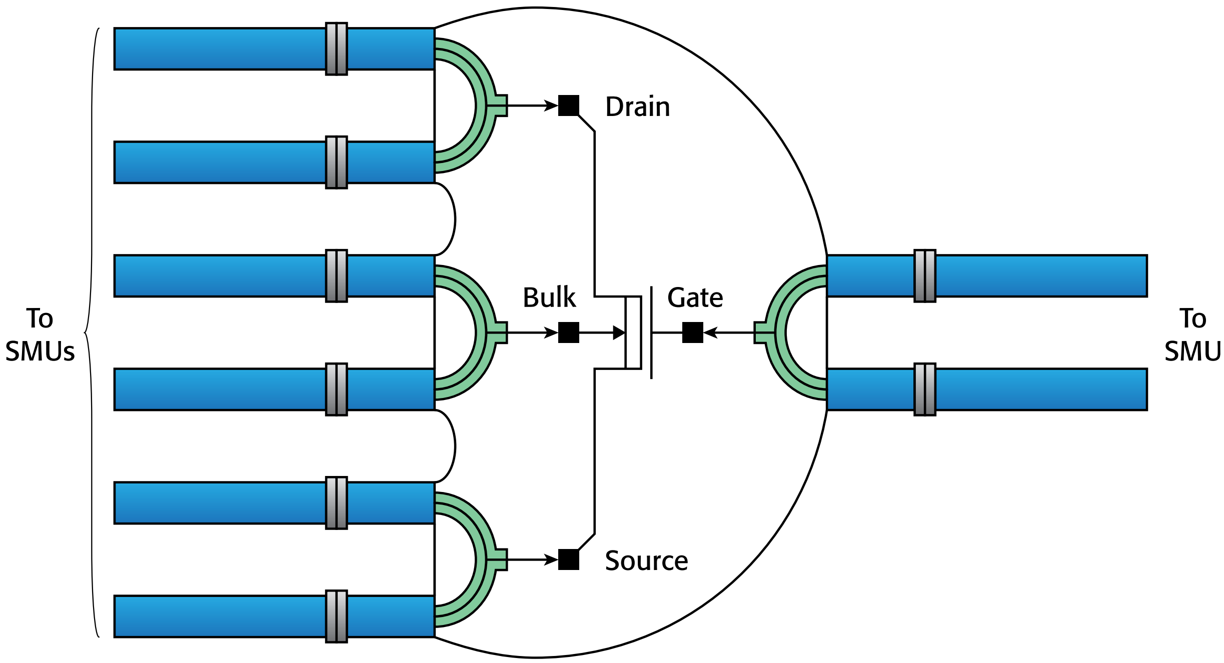

Figure 10: An I-V measurement setup for a four-terminal DUT.

The connectors can be disconnected and shorting caps inserted into the source and bulk cables to allow making a pulse measurement. ***Figure 11*** illustrates a pulsed I-V measurement setup.

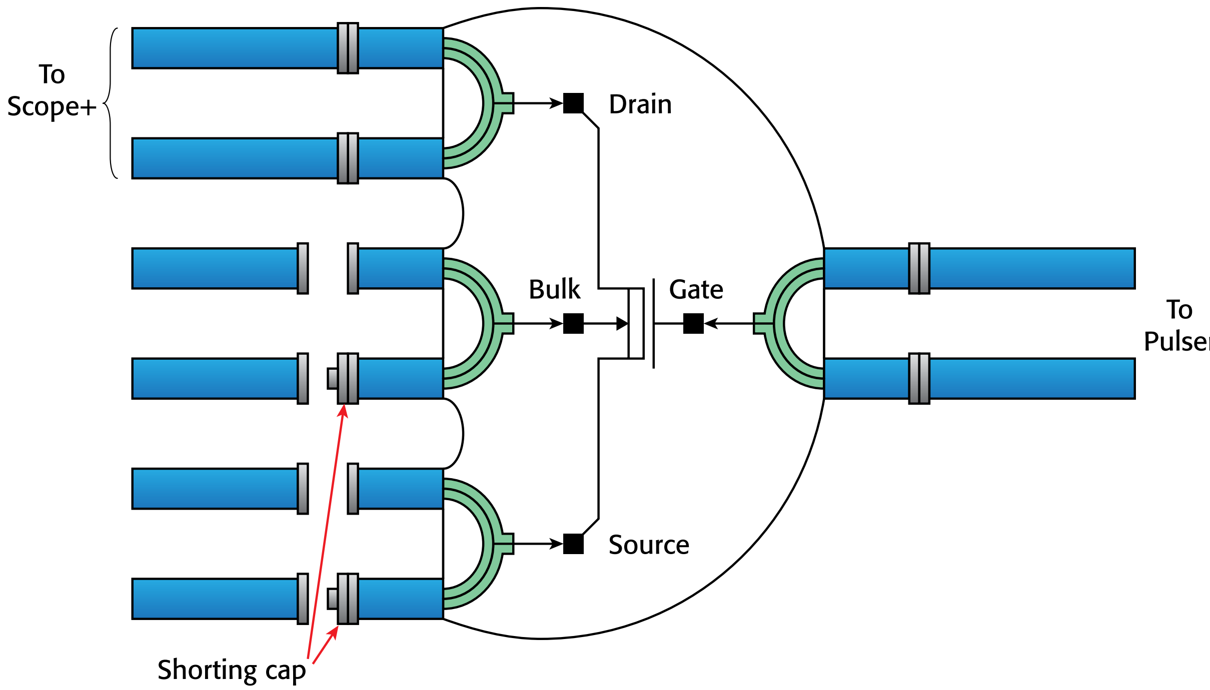

Figure 11: A pulsed I-V measurement setup.

An added benefit of having short cables near the DUT is that it's possible to short together the terminals of a DUT that function at frequencies up to or greater than 1MHz. ***Figure 12*** shows a four-terminal C-V measurement in which three of the four terminals are connected together to allow making a two-terminal C-V measurement. The frequency at which the C-V measurement can be made can be increased by connecting the three terminals together at the prober rather than at the LCR/C-V meter.

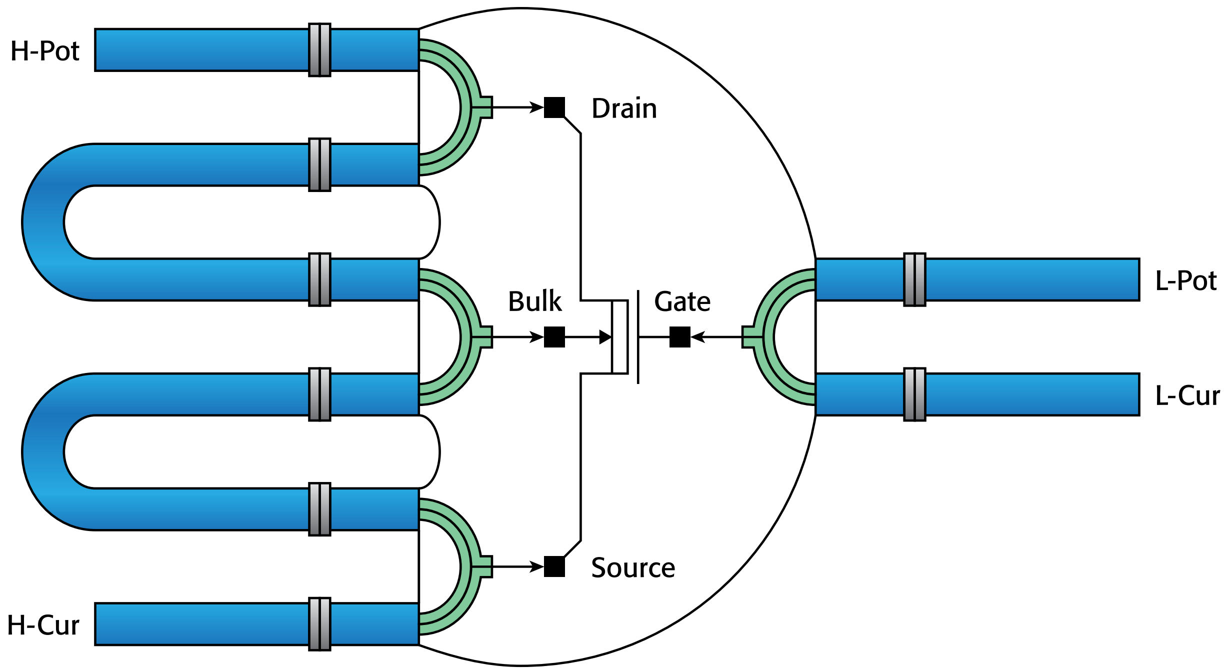

Figure 12: A four-terminal C-V measurement in which three of the four terminals are connected together for a two-terminal C-V measurement.

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