Semi Device Measurement Integrity Starts with Making the Right Connections

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Poor-quality electrical connections to the device under test (DUT) can compromise the measurement integrity of even the most powerful and sophisticated semiconductor test system. For high speed pulse measurements, interconnect quality typically determines maximum bandwidth; for low current measurements, it often affects measurement speed and accuracy. This article outlines the problems poor connections can create. Although it specifically addresses MOSFET measurements, the techniques and results discussed also apply to many other devices.

V_{DS}–I_{DS} curves

The most straightforward way to assess a MOSFET's overall performance is to take V_{DS}–I_{DS} curves for a set of gate voltages because these curves define the operating regions of the device. Pulsed I-V characterization, wherein voltages and currents are applied for a very short time and at a limited duty cycle, is a common way to measure these curves. Pulsed I-V measurements can reduce test times and allow characterizing a device without exceeding its safe operating area or causing device self-heating and the associated parameter shifts.

Two pulsed I-V channels are typically used to measure these curves on a MOSFET, with one connected to the gate and the other to the drain. The ground of each channel is connected to the MOSFET source pin.

To construct the transistor curves, the gate channel first applies voltage to the gate, then the drain channel sweeps V_{DS} through a range of values, measuring the resulting current at each point. Next, the gate channel applies a different voltage to the gate and the process repeats, constructing the next transistor curve in the set.

Modern pulse instruments can produce very short voltage pulses (100ns or less) with rise times as fast as 20ns, so wide bandwidth is critical to obtaining good measurements. For optimal performance, both pulse generator channels should be connected with coaxial cables matched to the generator's 50W output impedance. However, it is impossible to maintain 50Ω impedance all the way to a device on a wafer in practice; at some point, the ground must be connected to one pin and the signal to another, breaking 50Ω characteristic impedance (***Figure 1***). Minimizing the length of these non-coaxial ground and signal connections is crucial.

Figures 2A and ***2B*** illustrate how inadequate grounding and coaxial cabling can produce erroneous data when characterizing a MOSFET using pulses with 20ns rise times, 20ns fall times, and a width of 200ns. ***Figure 2A*** shows data taken with 100Ω impedance triaxial cables and 1–2 ft. ground connections. ***Figure 2B*** shows data taken with 50Ω impedance coaxial cables and ground connections just a few inches long. The difference is striking: the data from an improperly cabled system are compressed (***Figure 2A***), measuring about half the level expected,

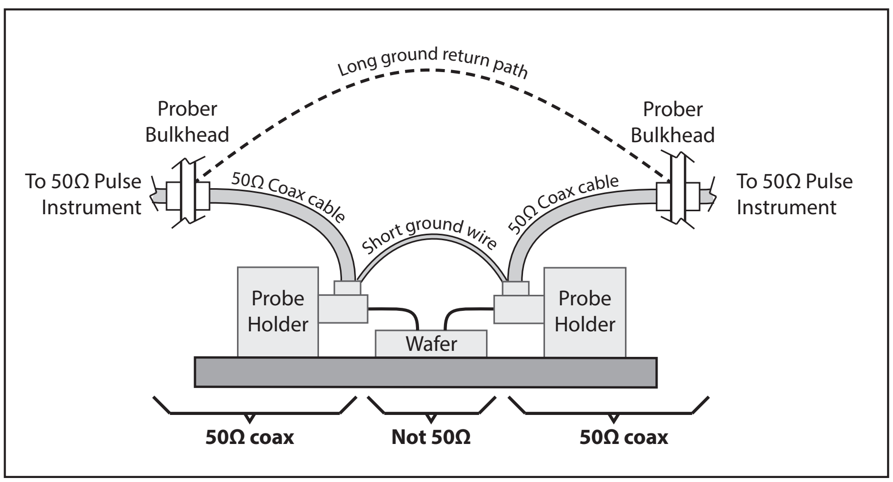

Figure 1. Prober hookups usually do not maintain 50Ω all the way to the DUT. If the short ground wire is not used, the much longer ground return path will limit bandwidth.

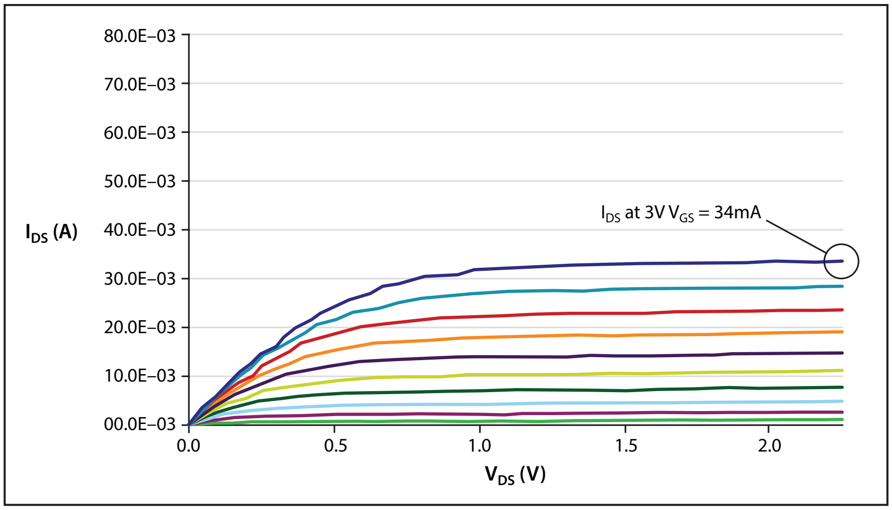

Figure 2A. MOSFET curves with poor cabling and grounding. I_{DS} at a V_{GS} of 3V is measured as 34mA.

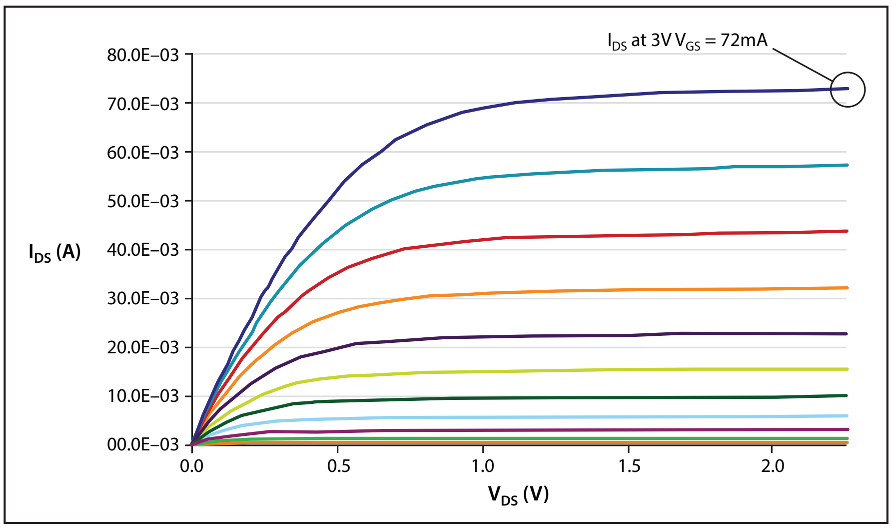

Figure 2B. MOSFET curves with optimal cabling and grounding. I_{DS} at a V_{GS} of 3V is measured as 72mA.

while the data from the correctly cabled system (***Figure 2B***) match conventionally measured data.

Maximum g_m and V_{TH}

Transconductance (g_m) is a critical parameter widely used to determine the threshold voltage (V_{TH}) of MOSFETs [1]. Pulsed I-V testing is ideal for this application because these parameters can be determined without violating safe operating area (SOA) limits or damaging the device.

For a small signal analysis about a given gate and drain bias point, g_m is defined as:

$$g_m = \frac{\partial i_{DS}}{\partial V_{GS}} \quad g_m = \frac{\partial i_{DS}}{\partial V_{GS}} \tag{1}$$

When measuring g_m, the same connection scheme used to obtain the data in ***Figures 2A*** and ***2B*** is used, but this time a DC voltage is applied to the drain while the gate voltage (V_{GS}) is swept over the voltage range that transitions the device from off to on. Because the connections and pulsing speeds are the same, the earlier bandwidth discussion applies to g_m and V_{TH} testing as well.

Figures 3A and ***3B*** show the results of another example of g_m and V_{TH} measurement, with the data shown in each taken with the same pulse rise and fall times, pulse widths, connections, and grounding. As Eq. 1 states, calculating g_m requires computing the first derivative of the drain current with respect to the gate voltage. The blue curve is the drain current and the red curve is its calculated derivative.

Just as with the V_{DS}–I_{DS} curves, the difference is significant. The results produced using the improperly cabled setup would mislead the user to think the DUT's g_m is half its actual value and its V_{TH} roughly 200mV higher than it actually is.

Capacitance-Voltage Testing

Capacitance-voltage (C-V) measurements are often used to characterize a MOSFET's gate oxide thickness, oxide defect density, doping profiles, etc. In this measurement, as the gate voltage varies, the capacitance of the gate to the drain and source changes. The Model 4210-CVU option allows Keithley's Model 4200-SCS Semiconductor Characterization System to make 1kHz–10MHz C-V measurements. It has four terminals wired to two device connections: CVU high and CVU low. In a standard C-V measurement, the source, bulk, and drain of a MOSFET are connected together and tied to CVU low; the gate is connected to CVU high. The Model 4210-CVU applies a DC bias and a small AC voltage to bias the transistor and simultaneously measure its capacitance, returning capacitance values for a wide range of bias voltages.

C-V measurements can be made at many frequencies (sometimes greater than 1MHz), depending on the parameters to be extracted. At higher frequencies, transmission line effects and cable length can impact measurement integrity significantly. For optimal C-V measurements, DUTs must be connected to the instrumentation using coaxial cables of the proper length and impedance level; for example, the Model 4210-CVU uses 1.5-meter, 100Ω cables.

Although using cables longer than those provided with the instrument will cause large changes in data at high frequencies, a feature known as cable length compensation can mitigate this problem. Using cables of different characteristic impedances, such as when coaxial cables are improperly adapted to triaxial cables, will also produce increased measurement error at high frequencies.

Off-State Leakage

Characterizing off-state leakage is critical to understanding quiescent power dissipation and transistor quality for

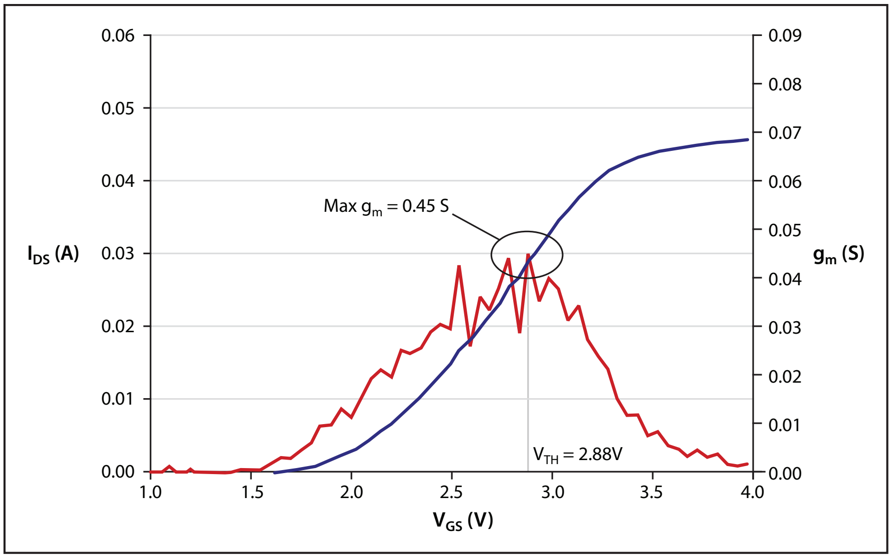

Figure 3A. g_m test with poor cabling and grounding.

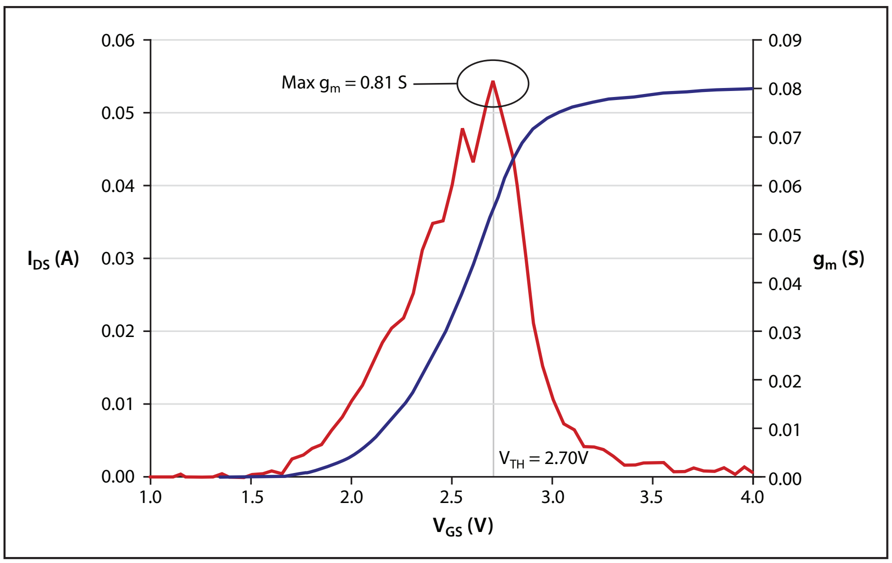

Figure 3B. g_m test with optimal cabling and grounding. From this measurement, g_m is 0.81 S and V_{TH} is 2.70V.

small-scale parameter transistors. A source measurement unit (SMU) capable of measuring picoamp-level (1E–12A) currents is essential.

As with any low current measurement, properly guarded triaxial cables are essential. Using coaxial cables will produce erroneous results due to high cable capacitance (50Ω coaxial cables typically have 30pF of capacitance per foot). This capacitance must be charged with high currents before small currents flowing in the DUT can be measured, extending settling times substantially.

Triaxial cables alleviate this problem by providing a third conductor between the center pin and shell, called the guard, driven at the same potential as the center pin. The guard conductor drastically reduces the effective capacitance and reduces settling times. Never use poor-quality triaxial cables, which can introduce problematic dielectric absorption, triboelectric effects, or high noise. Unguarded cable segments should be minimized. For best performance, triaxial cables should be run as close to the DUT as possible.

Match the Cable to the Measurement

As these examples illustrate, matching cabling and grounding to the measurement type enhances measurement integrity. However, changing cables for each measurement type is so time-consuming many users simply tolerate the sub-optimal results. Moreover, whenever cables are rearranged, users run the risk of reconnecting them improperly, thereby causing errors and demanding extra troubleshooting time. Worse still, these errors may go unnoticed for a long time.

One alternative is to use a remote switch capable of handling I-V, C-V and pulsed I-V signals, such as Keithley's Model 4225-RPM Remote Amplifier/Switch. When combined with a multi-measurement performance cable kit, such as Keithley's 4210-MMPC kit, it can often eliminate the need to recable between tests. This kit delivers the correct impedance and cable type, allowing low current, high speed pulse, and C-V measurements with no manipulator reconnection, eliminating the need to reprobe wafers.

Given the importance of characterizing semiconductor devices quickly and accurately, the value that the latest cable solutions can provide to device researchers is obvious. ■

References

[1] X. Zhou, K. Y. Lim, and D. Lim. A Simple and Unambiguous Definition of Threshold Voltage and Its Implications in Deep-Submicron MOS Device Modeling. IEEE Transactions on Electron Devices, Vol 46, No. 4, p. 807. April 1999.

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