Keysight Technologies
1500 A and 10 kV High-Power MOSFET Characterization using the Keysight B1505A

Application Note
Introduction

The Keysight Technologies, Inc. B1505A Power Device Analyzer/Curve Tracer is a powerful tool for measuring and characterizing devices such as high-power MOSFETs. The B1505A's wide measurement range (1500 A and 10 kV) and advanced features combine to provide an efficient power device measurement solution.

The B1505A supports several new external modules that greatly improve its measurement range. These include: an ultra high current unit (UHCU) with a maximum output of 1500 A, a high voltage medium current unit (HVMCU) with a maximum output range of 2.5 A/2200 V and an ultra high voltage unit (UHVU) with a maximum output of 10 kV. These capabilities provide state of the art accuracy, flexibility and ease-of-use for characterizing power devices such as high-power MOSFETs.

With its improved measurement range, the B1505A can measure the majority of power devices as shown in Figure 1. This figure shows the voltage versus current output ranges of typical B1505A modules for high power applications.

Both the UHCU and HVMCU modules possess a 10 μs high-power pulsing capability that allows more precise measurements by eliminating device self heating effects.

The B1505A can also perform accurate capacitance versus voltage (CV) measurement at up to 3 kV of DC bias. The B1505A makes it easy to directly measure a power MOSFETs capacitance parameters.

Since the B1505A is a flexible and upgradable platform, users can start with a minimum configuration that meets their current power testing requirements. If their requirements grow or change in the future, then the user can upgrade their configuration by adding only the required module or modules. This minimizes both initial and future investments.

EasyEXPERT is a GUI-based software resident on the B1505A that supports interactive and real time sweep control in its Curve Tracer mode. EasyEXPERT supports the automatic extraction of power MOSFET parameters, which eliminates tedious manual post-measurement calculations.

These features make the B1505A a powerful replacement for traditional curve-tracers and provide the user with both improved test efficiency and measurement accuracy.

This application note explains how to use the B1505A to measure typical DC parameters of high-power MOSFETs.
Figure 1. B1505A output range.

* Decreases from the time zero value by the ratio of \( \exp(-\text{PW}/(0.22 \, \mu F \times (R_o + R \text{ load})) \) where, \( \text{PW} \): pulse width, \( R_o \): 600 \( \Omega \) or 2 \( k\Omega \).
**Typical High-Power MOSFET Parameters**

The DC and capacitance parameters listed in a typical power MOSFET data or specification sheet are summarized in Table 1. The right-most column indicates the B1505A's measurement range for each parameter.

Previously, these parameters could only be measured using either an expensive production power device tester or a collection of instruments that included a curve tracer, a CV meter and a DC bias source. However, with the introduction of the B1505A, all of these parameters can easily be measured by a single instrument.

### Table 1. Typical DC and capacitance parameters of power MOSFET and the compatibility of the B1505A.

<table>
<thead>
<tr>
<th>Typical power MOSFET parameter</th>
<th>Symbol</th>
<th>Unit</th>
<th>Measurement</th>
<th>Typical measurement module</th>
<th>Typical measurable range of B1505A</th>
</tr>
</thead>
<tbody>
<tr>
<td>Drain-to-source breakdown voltage</td>
<td>V(BR)DSS</td>
<td>V</td>
<td>Id-Vd</td>
<td>HVSMU</td>
<td>−3 kV to 3 kV&lt;sup&gt;2&lt;/sup&gt; (Minimum 200 µV resolution)</td>
</tr>
<tr>
<td>Drain current (DC)</td>
<td>ID</td>
<td>A</td>
<td>Id-Vd</td>
<td>HPSMU</td>
<td>−1 A to 1 A (Minimum 10 pA resolution)</td>
</tr>
<tr>
<td>Drain current (Pulse)</td>
<td>IDP, IDM</td>
<td>A</td>
<td>Id-Vd</td>
<td>UHCU</td>
<td>−1500 A to 1500 A&lt;sup&gt;3&lt;/sup&gt; (Minimum 2 mA resolution)</td>
</tr>
<tr>
<td>Drain-to-source leakage current</td>
<td>IDSS</td>
<td>A</td>
<td>Id-Vd</td>
<td>HVSMU</td>
<td>−8 mA to 8 mA&lt;sup&gt;4&lt;/sup&gt; (Minimum 10 fA resolution)</td>
</tr>
<tr>
<td>Gate-to-source voltage</td>
<td>VGSS</td>
<td>V</td>
<td>Ig-Vg</td>
<td>MCSMU</td>
<td>−30 V to 30 V&lt;sup&gt;5&lt;/sup&gt; (Minimum 0.2 µV resolution)</td>
</tr>
<tr>
<td>Gate-to-source leakage current</td>
<td>IGSS</td>
<td>A</td>
<td>Ig-Vg</td>
<td>MCSMU</td>
<td>−100 mA to 100 mA&lt;sup&gt;6&lt;/sup&gt; (Minimum 10 pA resolution)</td>
</tr>
<tr>
<td>Gate threshold voltage, or cutoff voltage</td>
<td>VGS(th)</td>
<td>V</td>
<td>Id-Vg (Vd=Vg)</td>
<td>SMUs</td>
<td>−30 V to 30 V&lt;sup&gt;7&lt;/sup&gt; (Minimum 0.2 µV resolution)</td>
</tr>
<tr>
<td>Forward transfer admittance, or Forward transconductance</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Static drain-to-source on-state resistance</td>
<td>RDS(on)</td>
<td>ohm</td>
<td>Vd-Vg @ Id</td>
<td>UHCU</td>
<td>Better than 100 µΩ&lt;sup&gt;9&lt;/sup&gt;</td>
</tr>
<tr>
<td>Diode forward voltage</td>
<td>VSD</td>
<td>V</td>
<td>Is-Vs</td>
<td>UHCU</td>
<td>−10 V to 10 V&lt;sup&gt;10&lt;/sup&gt; (Minimum 100 µV resolution)</td>
</tr>
<tr>
<td>Reverse drain current</td>
<td>ISD</td>
<td>A</td>
<td>Is-Vs</td>
<td>UHCU</td>
<td>~ 1500 A&lt;sup&gt;2&lt;/sup&gt;</td>
</tr>
<tr>
<td>Input capacitance</td>
<td>Ciss</td>
<td>pF</td>
<td>C-V</td>
<td>Yes</td>
<td>Better than 1% at C &lt; 10 nF&lt;sup&gt;11&lt;/sup&gt;</td>
</tr>
<tr>
<td>Output capacitance</td>
<td>Coss</td>
<td>pF</td>
<td>C-V</td>
<td>Yes</td>
<td>Better than 1% at C &lt; 10 nF&lt;sup&gt;11&lt;/sup&gt;</td>
</tr>
<tr>
<td>Reverse transfer capacitance</td>
<td>Crss</td>
<td>pF</td>
<td>C-V</td>
<td>Yes</td>
<td>Better than 1% at C &lt; 10 nF&lt;sup&gt;11&lt;/sup&gt;</td>
</tr>
</tbody>
</table>

<sup>1. Measurement used for extracting the parameter.</sup>

<sup>2. 4 mA/3 kV. Over 100 mA/2 kV by using HVMCU. Expandable to 10 kV with UHVU.</sup>

<sup>3. 1500 A-UHCU. 20 A-HCSMU, 2 A-HVMCU.</sup>

<sup>4. Maximum 4 mA at 3 kV. Over 100 mA/2 kV by using HVMCU.</sup>

<sup>5. 30 V-MCSMU. 200 V-HPSMU, 100 V-MPSMU.</sup>

<sup>6. 30 V-MCSMU.</sup>

<sup>7. Ic: 50 mA-MPSMU (Vc < 40 V). 1000 A-UHCU (Vc < 20 V).</sup>

<sup>8. Rule of thumb (Example: 1 mA/1 V − 1 A/1 mV).</sup>

<sup>9. Rule of thumb (Example: 1 mV/10 A).</sup>

<sup>10. Typical 10 V at Ic < 1250 A. 3 V at Ic < 1400 A, 1 V at Ic < 1500 A.</sup>

<sup>11. Max. 3 kV DC bias with high-voltage bias T adapter.</sup>
Measurement of Typical High-Power MOSFET Parameters

The B1500A can easily measure typical high-power MOSFET parameters. The following section illustrates how to measure some of the high-power MOSFET parameters listed in Table 1.

Multiple test modes available

The B1505A has four test modes available: Tracer Test, Application Test, Classic Test and Quick Test. Each test mode has unique capabilities as summarized in the following descriptions.

Tracer Test mode provides an interactive curve tracer interface that allows parameters to be modified in real time during a measurement using the B1505A’s front panel knob.

Tracer Test mode supports unique features not available on conventional curve tracers, such as the ability to place markers and lines exactly on a curve and to capture screen images in PC-compatible formats.

Application Test mode includes a library of pre-defined tests that eliminate the need to manually set up most instrument parameters for common device tests (such as Id-Vds measurements). The user can perform a measurement through an intuitive “fill in the blanks” process. Measurements are performed and parameters are automatically extracted with just a simple click of the measurement button.

Classic Test mode provides complete access to all of EasyEXPERT software’s measurement and analysis capabilities. Measurement setups created in Tracer Test mode can be imported into Classic Test mode and auto-analysis calculations can be added to them. The resulting Classic Test setups can then be used both interactively and for automated testing.

Quick Test mode provides a convenient means to automate test setups created in Tracer Test, Application Test or Classic Test modes without the need to do any programming. You can automate test sequences for both a test fixture and for on-wafer testing across an entire wafer using the wafer prober drivers furnished with EasyEXPERT.

Measurement Examples

The following examples illustrate high-power MOSFET parameter extraction using these different test modes.

1. Output characteristics: Id-Vds

Figure 2 shows a Tracer Test mode measurement of the Id-Vds output characteristics of a high-power MOSFET.

This example shows how Tracer Test mode’s knob sweep capability allows the user to interactively control the maximum drain voltage of the sweep in real time as the measurement is being made. Knob sweep is especially useful to determine the drain voltage and the current for the drain and the gate, since these parameters typically vary even for the same device type. Note that the measurement shown in Figure 2 was made with the power compliance set at 3.5 kW (shown in red line). This was done to avoid exceeding the maximum power rating (SOA limit) in pulsed mode of the device.

The two dotted white lines show the output voltage and current compliance limits (respectively). You can measure devices at high current and low voltage, but you also have to take into consideration the maximum voltage limit in the low current measurement region.

The current compliance ensures that you do not exceed the maximum current rating of the device.

Figure 2. Id-Vds Tracer Test example (UHCU).
2. High current characteristics: Id-Vds

Figure 3 shows an example of Id-Vds high-current characteristics of a typical high-power MOSFET.

The point at which the marker has been placed in this graph reads 2.52 V at 1,342 A.

The maximum UHCU output voltage has been set to 60 V. However, the actual voltage applied to the DUT is not the same as the set voltage. You need to take into account the voltage drop caused by the UHCU’s output resistance (40 mΩ typical). The voltage compliance (V Limit) has been set to 4.5 V to eliminate unnecessary measurements in the low current region.

3. ON characteristics: Rds-Vgs

The Rds-Vgs drain to source ON characteristics is an important parameter for switching applications. Figure 4 shows the Rds-Vgs ON characteristics for four constant drain current parameters from 50 A to 200 A with 50 A steps.

The Rds at which the marker has been placed in the graph reads 1.6 mΩ for all the Id at Vgs is 10 V.

The measurement was made using the UHCU as a constant current source attached to the drain. Applying a constant current is not possible using a traditional curve tracer, as it only has a voltage source mode. Previously, this measurement could only be performed using a very expensive production power device tester. However, the B1505A’s UHCU can easily perform this measurement.

Rds is calculated using EasyEXPERT’s arithmetic operation capabilities (supported in Rev. 5 and higher).
4. Near-breakdown characteristics of high-voltage MOSFET

Figure 5 shows an example of the near-breakdown characteristics of a high-voltage MOSFET measured using the HVMCU.

The yellow curve shows a measurement with the compliance set at 1.6 kV so as not to exceed the breakdown voltage of the test device. The blue curve is a reference trace that shows the real breakdown of this device. By setting the voltage compliance thusly, you can measure the near breakdown characteristics and avoid actual breakdown. There is a built-in output resistor (2 kΩ at 2200 V range) in the output of the HVMCU, and you can safely make breakdown measurements even in cases where the device breaks down suddenly.

The HVMCU’s medium current measurement capability in the high voltage region is also useful to test leakage currents at high temperature.

5. Id-Vgs transfer characteristics

An Id-Vgs measurement is typically made at fixed drain voltage.

Since curve tracers have an intrinsic output resistance, it is not possible using a curve tracer to supply constant voltage if the drain current is varying due to the output resistance IR voltage drop.

The standard B1505A EasyEXPERT library supplies an Id-Vgs application test that automatically compensates for the voltage drop caused by the output resistance (see Figure 6).

Note: In Figure 6 the window on the left shows the test parameter setup GUI, and the window on the right shows the measurement results.
6. Breakdown test

Figure 7 shows an example of a breakdown test using the HVSMU. The measurement is made by utilizing the test fixture’s built-in 100 kΩ resistor. The voltage drop caused by this resistor has been removed using a simple arithmetic operation function.

The yellow curve shows the true breakdown characteristics after removing the voltage drop due to the 100 kΩ series resistor from the blue reference trace.

Note: One advantage of utilizing the built-in 100 kΩ series resistor is that you can even measure breakdown characteristics that exhibit negative resistance or snap back.

If the HVSMU’s 3 kV is not sufficient, then you can increase the test voltage to 10 kV using the UHVU.

Other Features

Oscilloscope view

EasyEXPERT (Rev. 5 and higher) supports an Oscilloscope View (refer to Figure 8) on the B1505A that allows you to monitor pulse measurement waveforms with 2 µs resolution.

It has the following features:
- I/V curves and pulse waveforms are displayed simultaneously.
- Waveform measurement pulses can be monitored at any point.
- Both voltage and current can be read using the Marker line.
- The pulse measurement conditions can be changed during measurement and the resulted waveforms can be verified on the fly.

Large current signals applied to the drain can be distorted by parasitic components (such as the cable inductance of the test setup), and these parasitic components can lead to unexpected measurement results.

The Oscilloscope View helps to prevent this by providing the exact waveform shapes as well as the relative positions of the drain and gate signals. This allows you to adjust your timing parameters so as to achieve optimal measurement conditions.

The Oscilloscope View reduces debugging time while also improving...
Drain supply selector

High-power MOSFET measurements require wide voltage and current ranges be applied to the drain, which means that the test modules shown in Figure 9 have to be switched in and out.

Figure 9 shows a simplified block diagram of the N1265A UHC Expander/Fixture’s module selector. It eliminates the tedious task of reconnecting the cables for different types of measurement while removing any chance of human error.

EasyEXPERT software automatically selects the correct module depending on the test specified.

On wafer measurements

On wafer measurement is supported for over 200 A and up to 10 kV. The maximum current is limited by the wafer prober’s probe needles and not the B1505A.

The optional N1254A-524 ultra high current prober system cable can support over 500 A and 3 kV. Figure 10 illustrates a cable connection with a wafer prober by using this cable extension. The cable extension can also be used to make ultra high current measurements inside of a thermostatic chamber.

Note: To make measurements in the 3 kV to 10 kV range, the module selector must be bypassed and the UHVU needs to be connected directly to the DUT.
Conclusion

This application note explains how the B1505A can measure the typical DC parameters specified on a commercial high-power MOSFET data sheet.

The B1505A’s four test modes are: the Tracer Test mode, the Application Test mode, the Classic Test mode and the Quick Test mode. They provide the user with different options for device evaluation for maximum measurement flexibility.

The measurement range of the B1505A is up to 10 kV and 1500 A.

The N1265A’s Built-in Selector simplifies measurement module switching to the power MOSFET’s drain supply. On-wafer measurement is supported up to a maximum of 10 kV and more than 200 A.

The Oscilloscope View is a powerful feature that offers capabilities not available from an external oscilloscope. It is an invaluable tool for creating measurement setups and establishing parameters for reliable and accurate device measurement.

These capabilities combine with the B1505A’s many data analysis features to create a state-of-the-art tool for power MOSFET measurement that far surpasses the abilities of traditional curve tracers.
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