Keysight Technologies
1500 A and 10 kV IGBT Characterization
Using the Keysight B1505A
Power Device Analyzer/Curve Tracer

Application Note

B1505A Power Device Analyzer/Curve Tracer
N1265A Ultra High Current Expander/Fixture N1266A HVSMU Current Expander
N1268A Ultra High Voltage Expander
The Keysight Technologies, Inc. B1505A Power Device Analyzer/Curve Tracer is a powerful tool for measuring and characterizing devices such as insulation gate bipolar transistors (IGBTs). 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 high power devices such as IGBTs.

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 an IGBT’s capacitance parameters.

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 IGBT 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 IGBTs.
Figure 1. B1505A output range.

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

The DC and capacitance parameters listed in a typical IGBT 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>
<thead>
<tr>
<th>Typical IGBT parameter</th>
<th>Symbol</th>
<th>Unit</th>
<th>Measurement</th>
<th>Typical measurement</th>
<th>Typical measurable range of B1505A</th>
</tr>
</thead>
<tbody>
<tr>
<td>Collector-to-emitter breakdown voltage</td>
<td>BVces</td>
<td>V</td>
<td>Ic-Vce</td>
<td>UHVU</td>
<td>-10 kV to 10 kV² (Minimum 10 mV resolution)</td>
</tr>
<tr>
<td>Gate-to-emitter voltage</td>
<td>VGES</td>
<td>V</td>
<td>Ig-Vge</td>
<td>MCSMU</td>
<td>-30 V to 30 V³ (Minimum 0.2 μV resolution)</td>
</tr>
<tr>
<td>Collector current (DC)</td>
<td>Ic</td>
<td>A</td>
<td>Ic-Vce</td>
<td>HPSMU</td>
<td>-1 A to 1 A (Minimum 10 pA resolution)</td>
</tr>
<tr>
<td>Collector current (Pulse)</td>
<td>Ic pulse</td>
<td>A</td>
<td>Ic-Vce</td>
<td>UHCU</td>
<td>-1500 A to 1500 A⁴ (Minimum 2 mA resolution)</td>
</tr>
<tr>
<td>Collector cut-off current</td>
<td>ICES</td>
<td>A</td>
<td>Ic-Vce</td>
<td>UHVU</td>
<td>-10 mA to 10 mA (at 10 kV)⁵ (Minimum 10 pA resolution)</td>
</tr>
<tr>
<td>Transfer characteristics</td>
<td>Ic</td>
<td>A</td>
<td>Ic-Vge</td>
<td>UHCU</td>
<td>-1500 A to 1500 A⁴ (Minimum 2 mA resolution)</td>
</tr>
<tr>
<td>Gate-to-emitter leakage current</td>
<td>IGES</td>
<td>A</td>
<td>Ig-Vge</td>
<td>MCSMU</td>
<td>-100 mA to 100 mA⁶ (Minimum 10 pA resolution)</td>
</tr>
<tr>
<td>Gate emitter threshold voltage</td>
<td>VGE(th)</td>
<td>V</td>
<td>Ic-Vce (Vc=Vg)</td>
<td>SMUs</td>
<td>-30 V to 30 V⁷ (Minimum 0.2 μV resolution)</td>
</tr>
<tr>
<td>Forward transfer admittance, or forward</td>
<td>yfs</td>
<td>S</td>
<td>Vce-Ic @ Vce</td>
<td>UHCU</td>
<td>1 mS ~ 1000 S⁸</td>
</tr>
<tr>
<td>transconductance</td>
<td>Gfs</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Collector-to-emitter saturation voltage</td>
<td>VCE(sat)</td>
<td>V</td>
<td>Vce-Vge( Vc=const.)</td>
<td>UHCU</td>
<td>-10 V to 10 V⁹ (Minimum 100 μV resolution)</td>
</tr>
<tr>
<td>Diode forward saturation voltage</td>
<td>VFM</td>
<td>V</td>
<td>Ie-Vec</td>
<td>UHCU</td>
<td>-10 V to 10 V⁹ (Minimum 100 μV resolution)</td>
</tr>
<tr>
<td>Input capacitance</td>
<td>Cies</td>
<td>pF</td>
<td>C-V (1 MHz)</td>
<td>MFCMU</td>
<td>Better than 1% at C &lt; 10 nF¹⁰</td>
</tr>
<tr>
<td>Output capacitance</td>
<td>Coes</td>
<td>pF</td>
<td>C-V (1 MHz)</td>
<td>MFCMU</td>
<td>Better than 1% at C &lt; 10 nF¹¹</td>
</tr>
<tr>
<td>Reverse transfer capacitance</td>
<td>Cres</td>
<td>pF</td>
<td>C-V (1 MHz)</td>
<td>MFCMU</td>
<td>Better than 1% at C &lt; 10 nF¹¹</td>
</tr>
</tbody>
</table>

1. Measurement used for extracting the parameter
2. 10 kV/20 mA-UHVU, 2.2 kV/1.1 A-HVSMU, 3 kV/4 mA-HVSMU
3. 30 V-MCSMU, 200 V-HPSMU, 100 V-MPSMU
4. 1500 A-UHCU, 20 A-HCSMU, 2 A-HVSMU
5. 10 kV-UHVU, 3 kV-HVSMU
6. 30 V-MCSMU
7. Ic: 50 mA-MPSMU (Vc < 40 V), 1000 A-UHCU (Vc < 20 V)
8. Rule of thumb (Example Ic/Vge: 1 mA/1 V ~ 100 A/100 mV)
9. Typical 10 V at Ic < 1250 A, 3 V at Ic < 1400 A, 1 V at Ic < 1500A
10. Drain and source is shorted by 1 μF capacitor
11. Max. 3000 V DC bias with high-voltage bias T adapter
Measurement of Typical IGBT Parameters

The B1505A can easily measure typical IGBT parameters. The following section illustrates how to measure some of the IGBT 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 abilities 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 Ic-Vce 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 IGBT parameter extraction using these different test modes.

1. Output characteristics: Ic-Vce

Figure 2 shows a Tracer Test mode measurement of the Ic-Vce output characteristics of an IGBT. This example shows how tracer test mode’s knob sweep capability allows the user to interactively control the maximum collector voltage of the sweep in real time as the measurement is being made. Knob sweep is especially useful to determine the correct voltages and currents for the collector and 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 by the 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. Ic-Vce tracer test example (UHCU).
2. IGBT ON characteristics: Ic-Vce

Figure 3 shows an example of the Ic-Vce ON characteristics of a typical IGBT. The point at which the marker has been placed in this graph reads 2.77 V at 1,511 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 5 V to eliminate unnecessary measurements in the low current region.

3. Saturation voltage: Vce-Vge

The Vce-Vge collector to emitter saturation voltage is an important parameter for switching applications. Figure 4 shows the Vce-Vge saturation characteristics for four constant collector current parameters from 50 A to 200 A with 50 A steps.

This measurement was made using the UHCU as a constant current source attached to the collector. 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.
4. IGBT near-breakdown characteristics

Figure 5 shows an example of the near-breakdown characteristics of an IGBT.

This measurement was made by connecting the HVMCU to the collector. The maximum HVMCU output voltage was set to 1500 V after taking into consideration the voltage drop due to the output resistance of the HVMCU (600 Ω in the example). The voltage compliance was set so as not to exceed the maximum collector voltage specification.

5. IGBT Ic-Vge transfer characteristics

An Ic-Vge measurement is typically made at fixed collector voltage. Since curve tracers have an intrinsic output resistance, it is not possible using a curve tracer to supply constant voltage if the collector current is varying due to the output resistance IR voltage drop.

The standard B1505A EasyEXPERT library supplies an Ic-Vge 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.

![Figure 5. IGBT near-breakdown characteristics (HVMCU).](image)

![Figure 6. Ic-Vge IGBT transfer characteristics using an application test.](image)
6. 10 kV breakdown test

The UHVU supports breakdown measurements up to 10 kV. Figure 7 shows an example of a breakdown test made using the UHVU. In this example the device breaks down at about 8 kV.

Other Features

Oscilloscope view

EasyEXPERT (Rev. 5 and higher) supports Oscilloscope View (see Figure 8) on the B1505A that allows you to monitor the 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 collector 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 collector and the 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 the quality of your measurement data.

Features

- I/V curves and pulse waveforms are displayed simultaneously
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- The pulse measurement conditions can be changed during measurement and the resulted waveforms can be verified on the fly
Collector supply selector

IGBT measurements require wide voltage and current ranges be applied to the collector, which means that the test modules shown in Figure 9 have to be switched out depending on the particular measurement desired. 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 500 A and up to 10 kV. The maximum current is actually limited by the wafer prober’s probe needles and not the B1505A.

The optional N1254A-524 ultra high current prober system cable can support up to 500 A and 3 kV. Figure 10 illustrates a prober connection 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 IGBT 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 IGBT's collector 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 IGBT measurement that far surpasses the abilities of traditional curve tracers.
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Published in USA, December 1, 2017
5991-0913EN
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