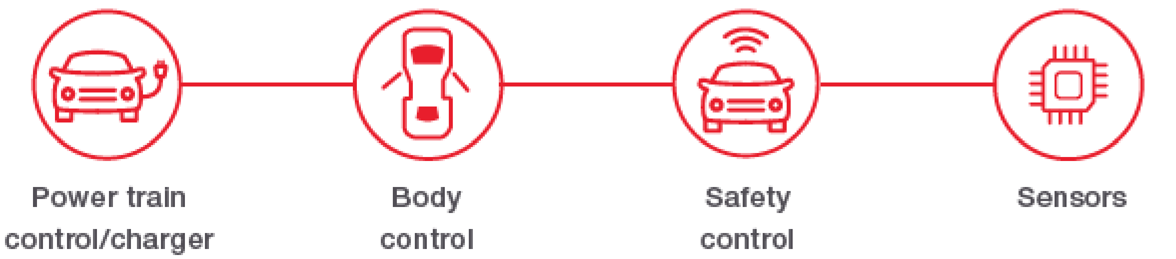
Challenges and Solutions for Power Testing in Automotive Applications

Introduction

Each year, vehicle electrification continues to increase, with all signs pointing to this trend accelerating in the future. Some of the factors contributing to this development are the increasing use of hybrid and fully electric vehicles to meet “green energy” and e-mobility goals, the desire for the greater reliability that electronic components generally provide, and the need to reduce automotive recalls (which are largely due to mechanical rather than electrical failures). In addition, globalization has created fierce competition in the automotive and automotive component industries as everyone strives to develop automotive functions at a lower cost without sacrificing energy efficiency, safety, and reliability.

This technical overview provides a synopsis of automotive electronic systems, their challenges, and what tools automotive electronics engineers need to meet them. It concludes with a discussion of Keysight’s solutions to these challenges.



Automotive Functions Undergoing Electrification

Power train control/charger

- EV
- HEV
- Onboard charger
- Charging station

Body Control

- Power door/window
- HID lighting system

Safety Control

- Electrical power steering
- Brake system

Sensors

- Pressure sensors
- Accelerometer
- Current sensor
- Photo sensor

Challenges Facing Vehicle Electrification

Many automotive functions are now controlled electronically. Figure 1 shows block diagrams of some typical automotive electronic applications.

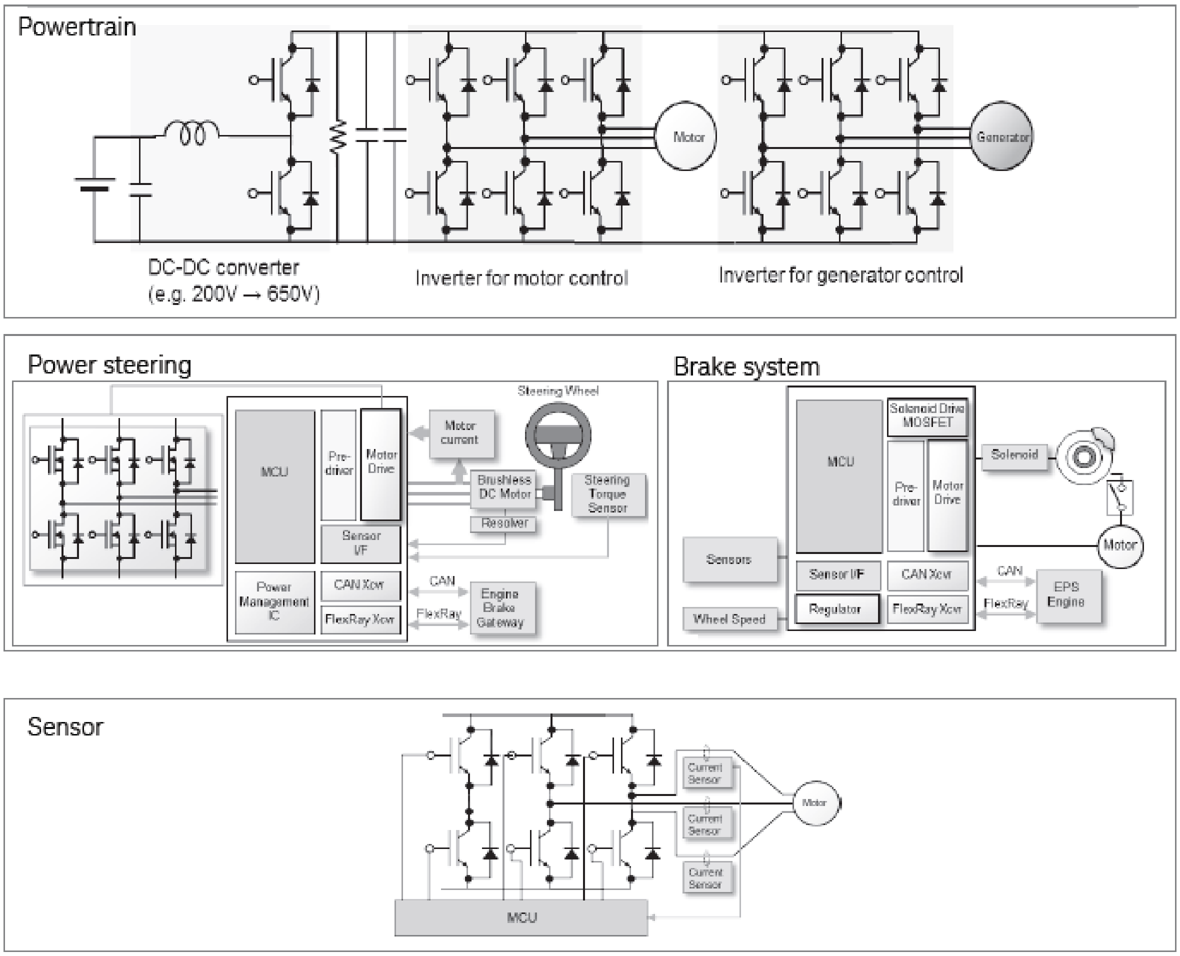


Figure 1. Block diagram examples of electrified automotive functions

Hybrid electric vehicle (HEV) and electric vehicle (EV) technologies can significantly improve automotive fuel efficiency (and even eliminate entirely the need for liquid fuels). At the core of these vehicle electrification technologies is the electrified power train, which consists of a converter to boost voltage and an inverter to drive the motor. Because it is at the heart of all HEV/EV systems, the power train has to be extremely reliable. Among the challenges the power train faces are EV tests for the need to withstand high voltages and currents (up to 650 V and 200 A) as well as the ability to function in harsh temperatures (-40 to 40 °C) and high humidity. Power devices (such as IGBTs or diodes) used in the powertrain can end up operating at more than 100 °C due to dissipating energy. Nevertheless, the powertrain has to work reliably even under these extreme conditions.

The performance of the diodes and IGBTS used in the powertrain's circuitry is crucial to achieving high fuel efficiency. Using devices with low conduction loss and low switching loss is very important to meet this goal. In addition, increasing the converter/inverter operating frequency allows the surrounding capacitors and inductors to be smaller in size, reducing weight and increasing fuel efficiency. Devices fabricated from new materials such as SiC and GaN offer higher operating frequencies and more robust temperature performance, making them attractive as components in future power automotive systems.

Of course, even vehicles with no electrical powertrain have many critical electrical systems. DC-DC converters and rectifiers are used in onboard chargers and charging systems, and these circuits have requirements similar to those of the powertrain. Electrical power steering, brake, and lighting systems are obviously all crucial for automotive safety, and their operation needs to be as reliable as possible. Therefore, all of the components used in these systems (MOSFETs, diodes, capacitors, inductors, etc.) must maintain stable behavior under various conditions. Electrical sensors used in automobiles provide critical information about motion control, operating efficiency, and safety, making their performance and reliability very important. For this reason, many automotive and automotive component manufacturers are actively developing improved versions of these sensors.

Key challenges facing vehicle electrification systems:

- Must be reliable under a wide range of conditions
- Employ large operating currents and voltages (e.g. 200 A, 650 V)
- Must function over a wide temperature range (e.g. -40 to +150°C)
- Need high conversion efficiencies
- Need high operating frequencies to reduce module size and weight
- Need reliable sensors to provide critical safety information
- Must utilize SiC/GaN devices to increase efficiency and functional temperature range

What Challenges Do Automotive Electrical Circuit Designers Face?

Since electrical engineers working in the automotive industry must develop highly efficient, safe, and reliable electric circuits, evaluating final circuit characteristics is very important. This makes evaluating the efficiency of the entire circuit, including verifying current and voltage waveforms at each node of the circuit, a necessary process. For this to be possible, a detailed understanding of the power devices, components, and sensors used in a circuit is mandatory. This is especially true for power devices used in the circuit (such as IGBTs and MOSFETs) since their performance often dictates the efficiency, safety, and reliability of the entire circuit. Unfortunately, device manufacturer-supplied datasheet information is often insufficient to meet these needs. The datasheet conditions often differ from actual use conditions, and the supplied information often has large margins with no information on device variations. This makes it hard to design reliable and efficient circuits using only the information supplied by device and component manufacturers.

The following sections describe in more detail the critical factors necessary for component-level testing and explain EV test and power circuit simulator solutions that Keysight has created for the automotive industry to meet these challenges.

Summary of Component-Level Automotive Test Challenges

Figure 2 summarizes the major considerations when performing component-level tests for automotive applications; all of these relate to the previously discussed challenges facing vehicle electrification systems. Of course, underlying these issues is the need for improved safety, reliability, and efficiency. Meeting these concerns requires that automotive electrical engineers test component parameters such as on-resistance (Ron), saturation voltage (Vsat), breakdown (BVdss), and input/output capacitances (Ciss, Coss). Moreover, these tests must be performed under operating conditions (such as 400 A or 1200 V) and across a wide temperature range. In addition, to minimize power loss, a thorough understanding of parameters such as Crss, gate charge (Qg) and gate resistance (Rg) is necessary. Verifying the performance of automotive sensors (especially capacitive MEMS sensors) is also important, and the DC test (IV and CV) is the first step in this process.

Besides technical concerns, there are competitive forces driving the testing of semiconductor components used in automotive applications. Tantamount among these is the need for automotive engineers to adopt new technologies (such as SiC and GaN) to reduce costs. In addition, the prevalence of counterfeit or substandard power devices means that automotive companies need to perform some screening of devices before using them in mass production.

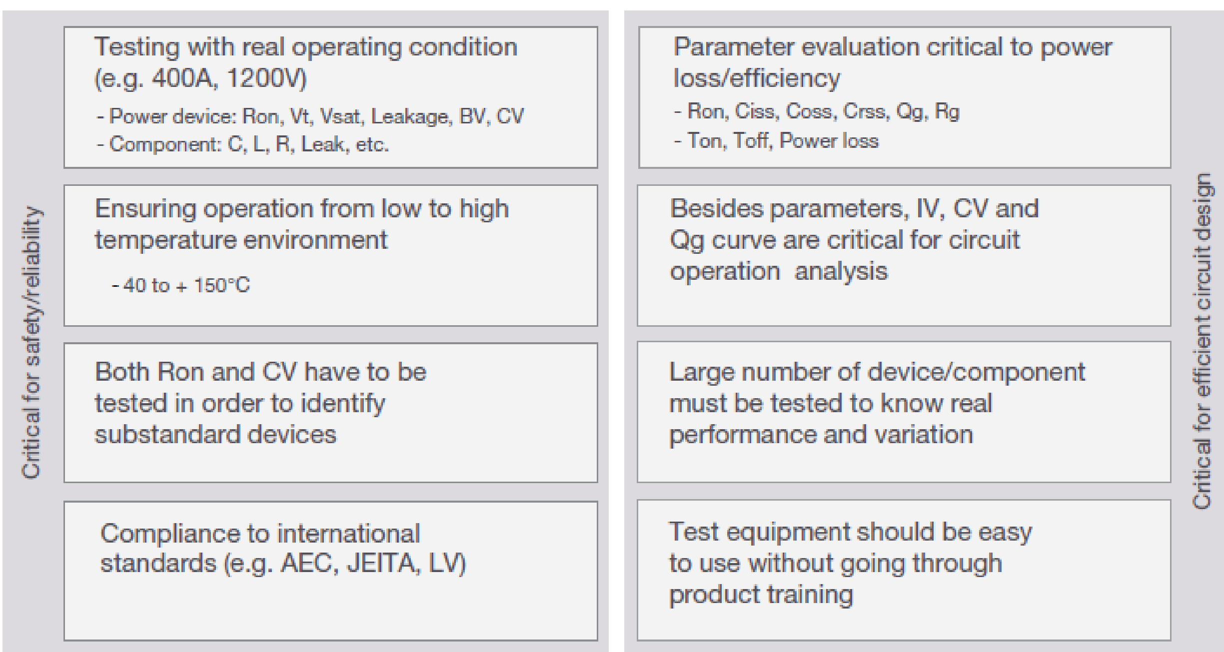


Figure 2. Summary of component level automotive test challenges

Keysight Solutions for Component Level Test

Keysight Technologies provides an overview of our solutions for component-level testing. Figure 3 has many solution portfolios for component-level testing.

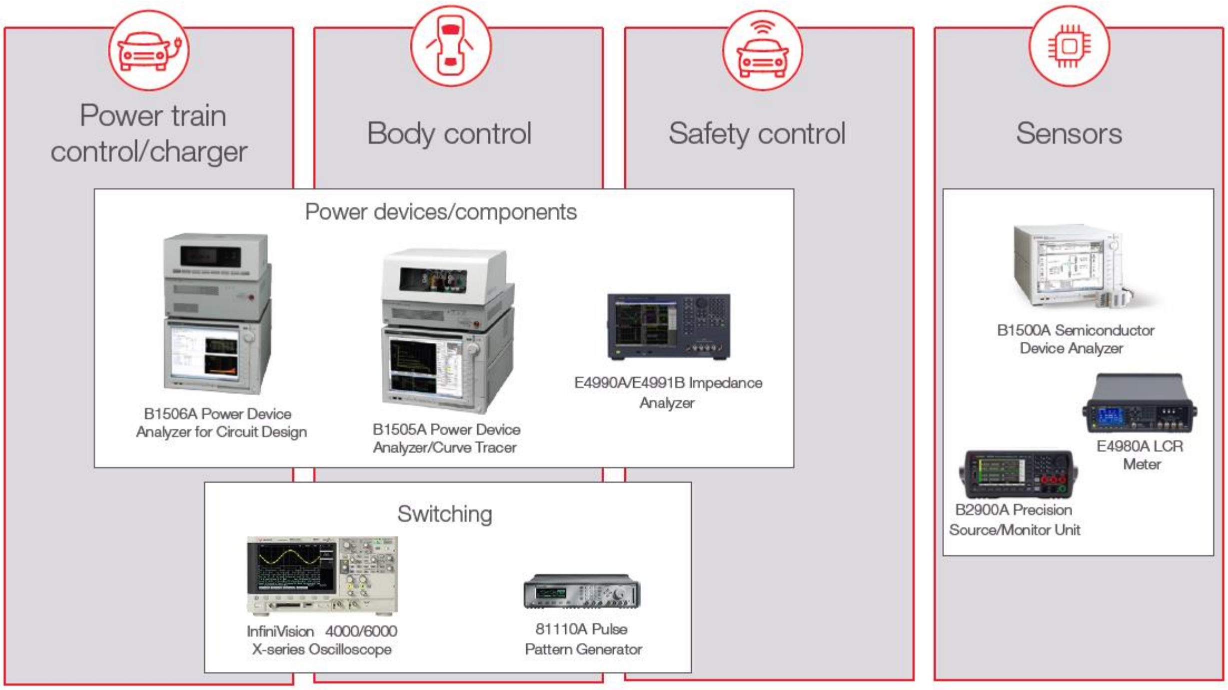


Figure 3. Keysight solution portfolio for automotive component level testing

The next section describes each solution in detail and gives additional information on Keysight Power Device Analyzers, which are all-in-one solutions for power device and component testing.

B1506A Power Device Analyzer for Circuit Design

The B1506A Power Device Analyzer for Circuit Design is a complete solution that can help automotive electronic circuit designers maximize the efficiency, safety and reliability of automotive electrical systems. It can evaluate all relevant device and component parameters under a wide range of operating conditions, including IV parameters such as breakdown voltage and on-resistance, as well as three-terminal FET capacitances, gate resistance, gate charge and power loss.

B1506

- Turnkey solution for power semiconductor and component test
- Automatic IV/CV test
- Automatic thermal test
- CV (Ciss, Crss, Coss, Cgs, Cds, Cgd) up to 3kV
- Power loss calculation

Dynamic tester oscilloscope/PG

- Switching parameter, power loss (Tr, Tf, E, P)

LCR meter

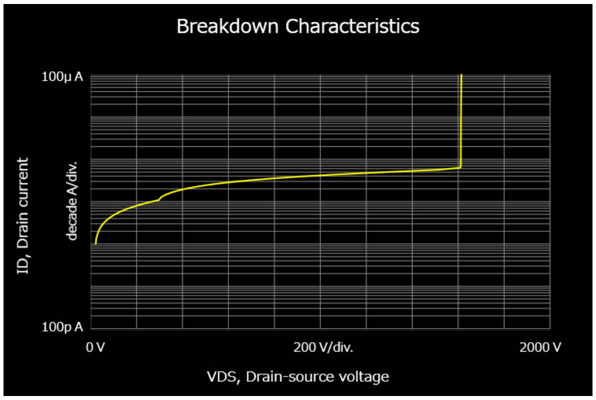
- Capacitance measurement (low voltage)

Curve tracer

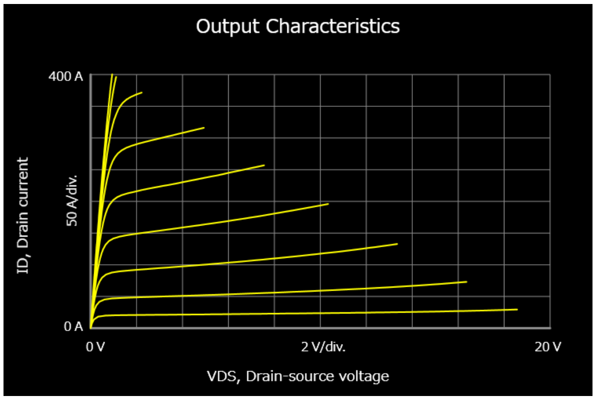
- IV curve

Characterizing Devices Under Actual Operating Conditions

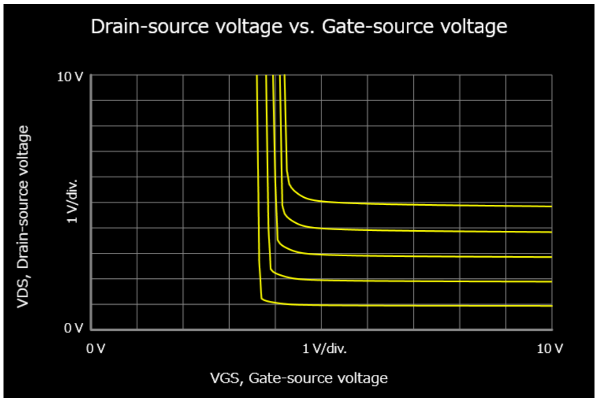
The B1506A covers a wide range of current and voltage, from sub-nA to 1500 A and microvolts to 3 kV. This supports the evaluation of the vast majority of devices and components used in automotive electronic circuits. The B1506A's 10 μs pulse width measurement capability limits self-heating effects and provides more accurate device characteristics. Moreover, the B1506A can also evaluate device capacitance, gate resistance and gate charge characteristics – all key parameters for determining device power loss. Figure 4 shows some typical device parameters obtained using the B1506A.



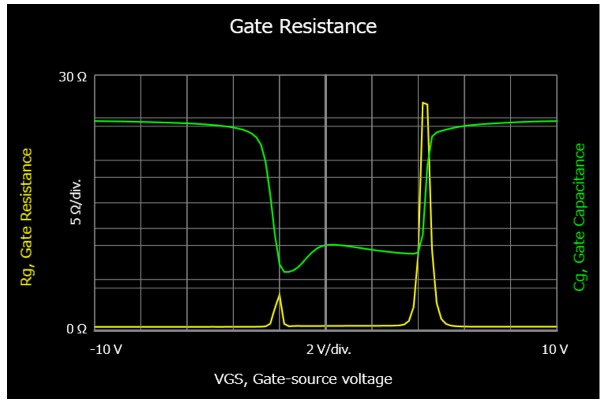
BV and Leakage up to 3 kV



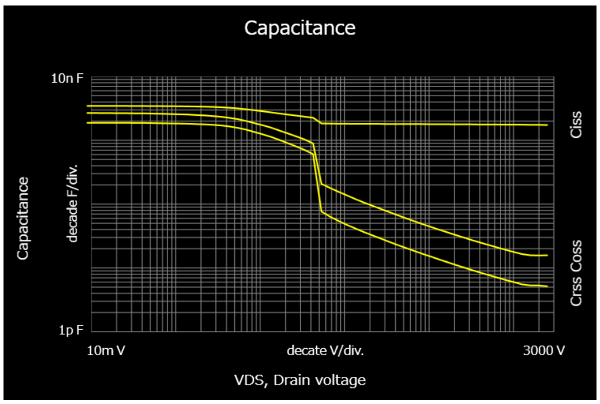
Id-Vds up to 1500 A



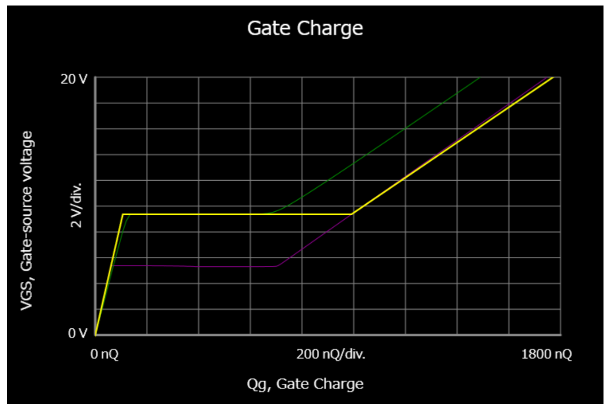
Vsat taken with I sourcing



Rg and Ciss versus Vgs



Up to 3 kV Ciss, Coss, Crss



Gate charge (Qg)

Figure 4. Typical characteristics measured by the B1506A

Verifying Device Operation Across Temperature

Characterizing device behavior across temperature is important for automotive applications, but it is not easy to do. Temperature test chambers can be slow to stabilize, and the long cables from the test equipment to the chamber introduce resistance and inductance that can cause oscillation issues. In contrast, the B1506A provides automated, easy to use and accurate temperature dependent measurement across a wide range of temperature (from -50 to +250°C). Two solutions are available. One solution supports industry-standard inTEST Thermostream temperature systems, while the other solution is a thermal plate (also available from inTEST) that resides inside the B1506A's test fixture (see Figure 5). With these solutions, thermal testing that used to take an entire day can be done in less than one hour (refer to Figure 6).

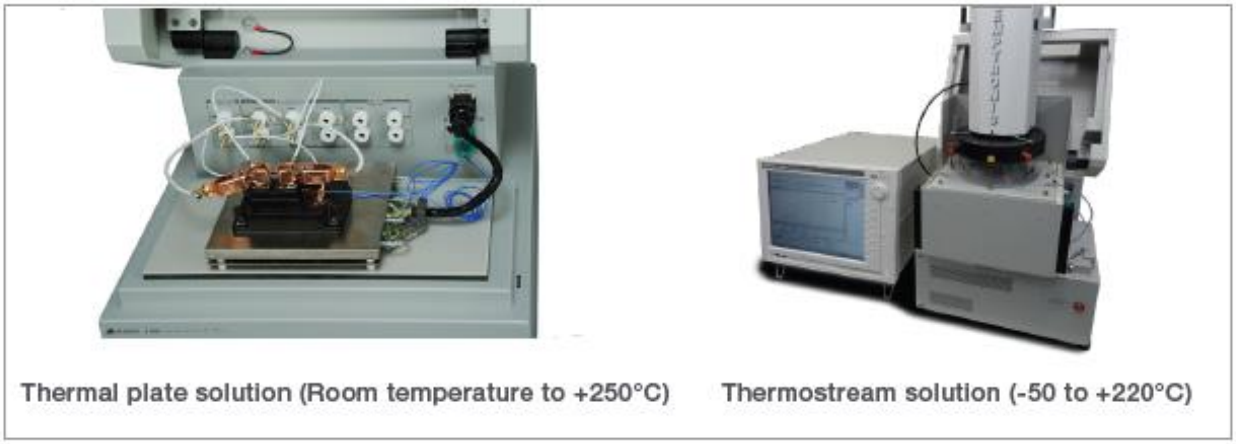


Figure 5. Temperature testing solutions supported by the B1506A.

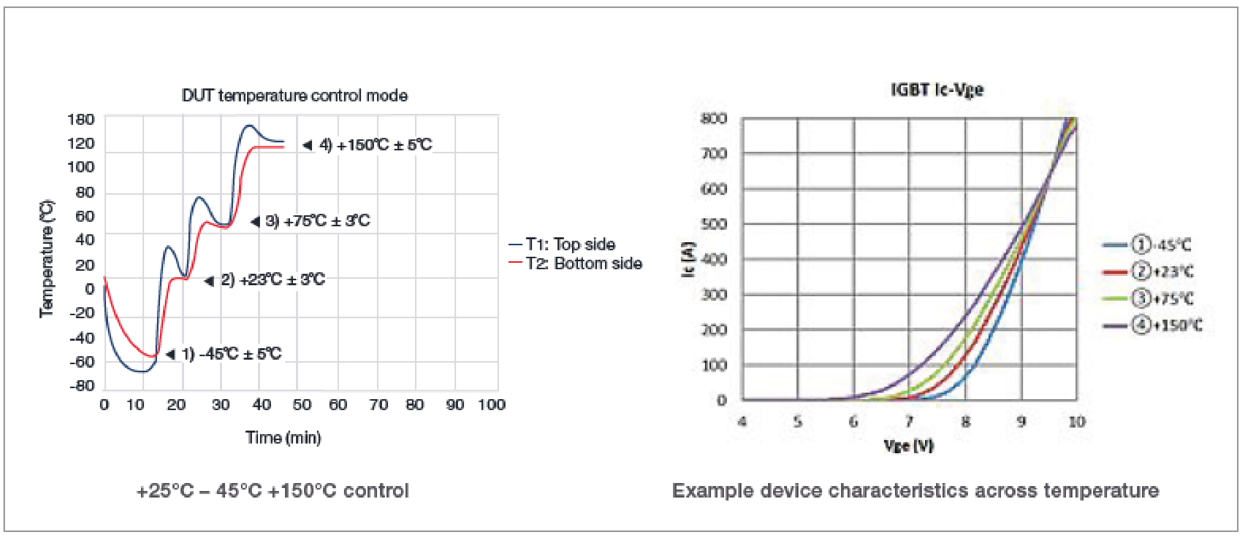


Figure 6. Examples of temperature dependent measurements made using the B1506A.

Maximizing Circuit Efficiency Through Optimal Device Selection

Maximizing circuit performance and efficiency requires more data than conventional curve tracers can supply. In particular, as switching frequencies increase switching loss and drive loss begin to dominate device power loss. This makes characterization of device capacitances, gate resistance and gate charge extremely important. However, since these parameters are difficult to measure, many automotive engineers do not attempt them. The B1506A solves this issue with its ability to not only automatically measure all of these parameters, but also with its capability to use the extracted parameters to perform power loss calculations.

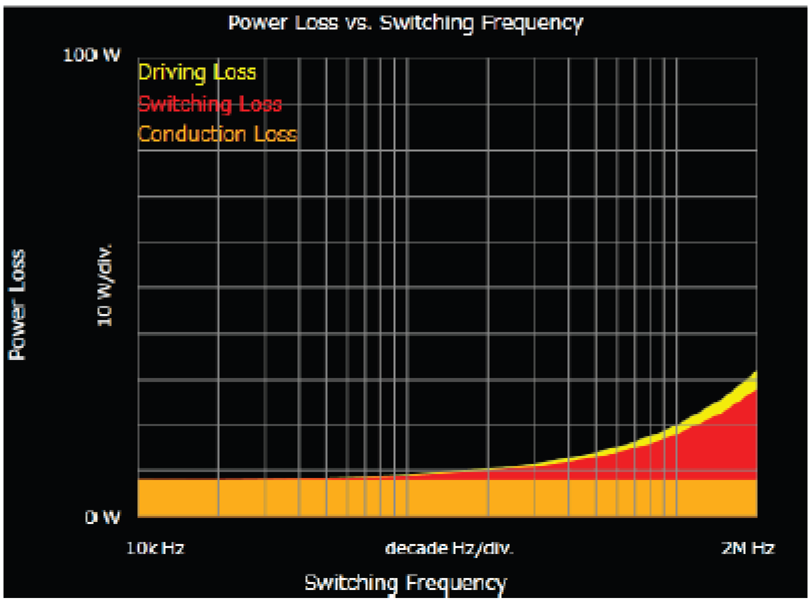


Figure 7. Calculated power loss vs. frequency made using the B1506A

Intuitive and automated datasheet characterization

The B1506A's datasheet characterization mode enables anyone to automatically measure key device parameters without any specialized training. All characteristics can be printed out in datasheet format, making it easy to compare the performance of different components.

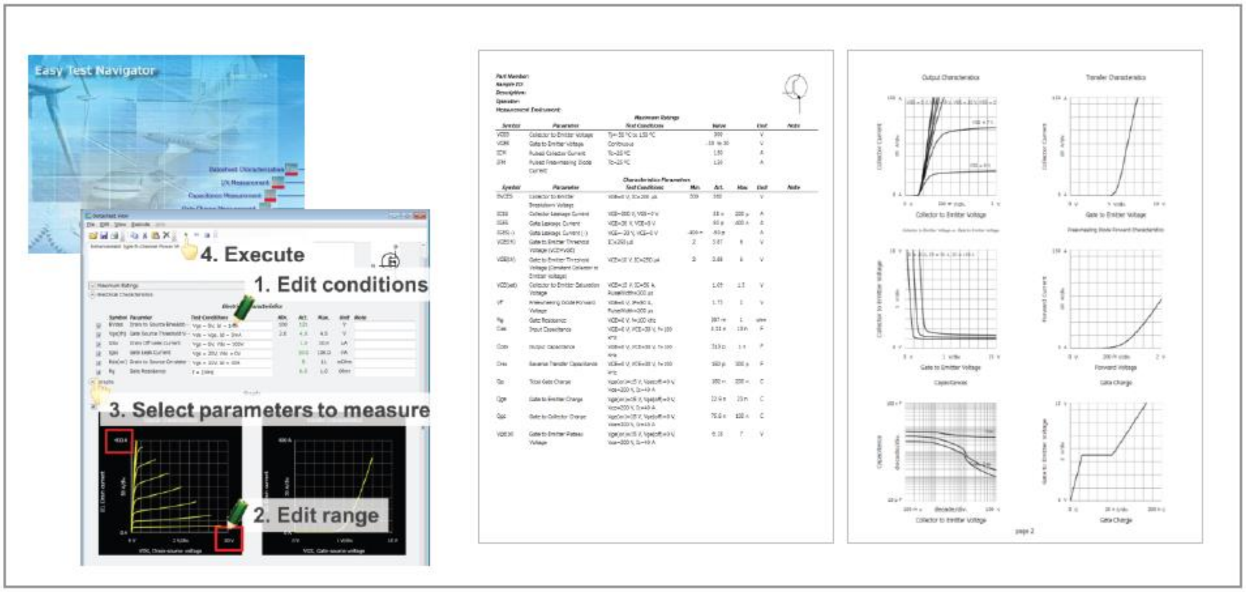
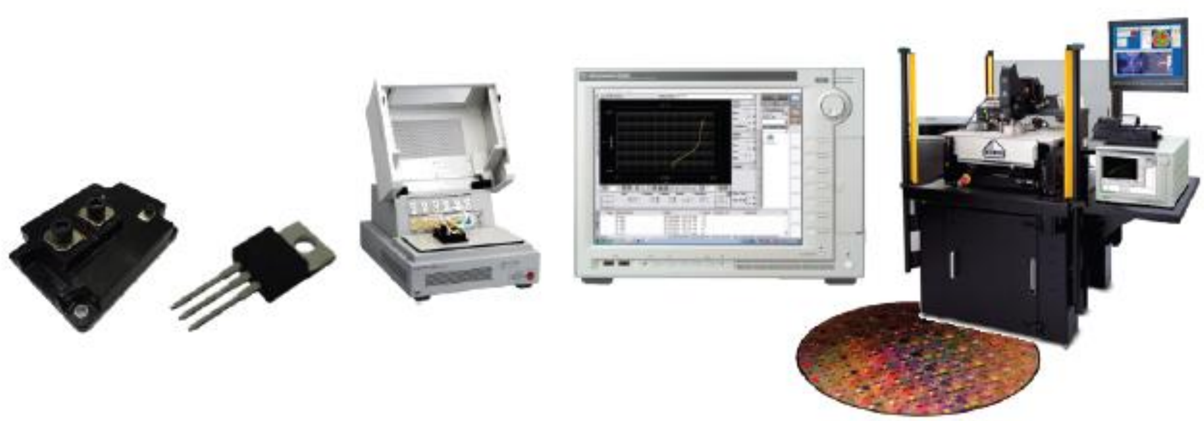


Figure 8. Easy Test Navigator software provides intuitive and automated device and component testing with datasheet generation capabilities.

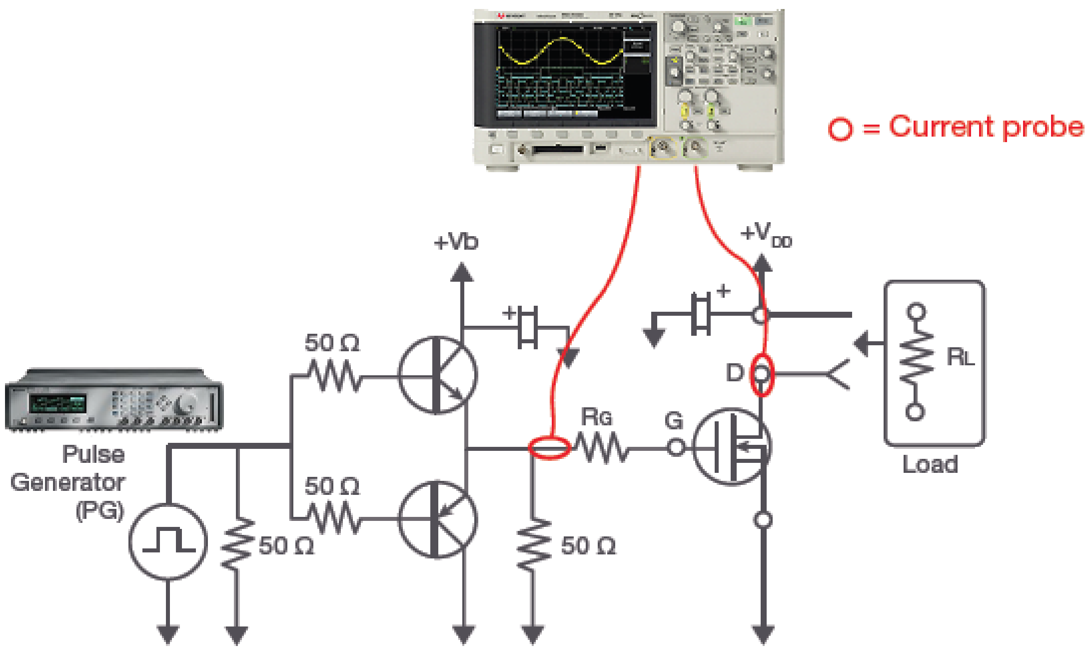
B1505A Power Device Analyzer/Curve Tracer

The B1505A is a more flexible alternative to the B1506A that offers wider current and voltage ranges, better low-current measurement accuracy, high voltage with medium current measurement (e.g. 500 mA at 1.2 kV) capability, a GaN current collapse testing option and the ability to measure more than three pins simultaneously. In addition, the B1505A can measure both on-wafer and packaged devices. Besides being widely used by power device manufacturers, the B1505A is valuable for automotive electronics engineers utilizing GaN power devices, measuring the sense emitter current of 4-terminal IGBTs, and characterizing HVICs for gate driver circuits.



Keysight Oscilloscopes and Pulse Generators

Switching characteristics are an important part of component level test, and Keysight has both oscilloscopes and pulse generators that can help evaluate these parameters. The InfiniiVision 4000 X series oscilloscopes provide sufficient bandwidth and resolution at a reasonable cost, and they can be used with a current probe if necessary. The 81110A pulse generator is also able to provide voltage pulses fast and large enough to characterize automotive components.



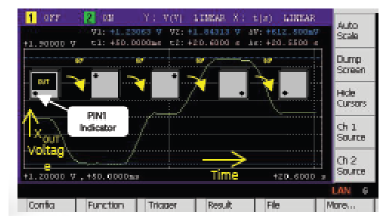
Sensor Characterization Solutions

Easy characterization of DC MEMS performance using B1500A and B2900B SMUs

With the ability to both source and measure current and voltage, SMUs are convenient tools to characterize the IV performance of automotive sensors. For example, both the B1500A and the B2900B series have SMUs that can perform DC current and voltage characterization on MEMs devices (such as accelerometers). As shown in the graph below, an SMU can measure output voltage as the MEMS device is manually rotated 360 degrees.

B2900B Source Measure Unit

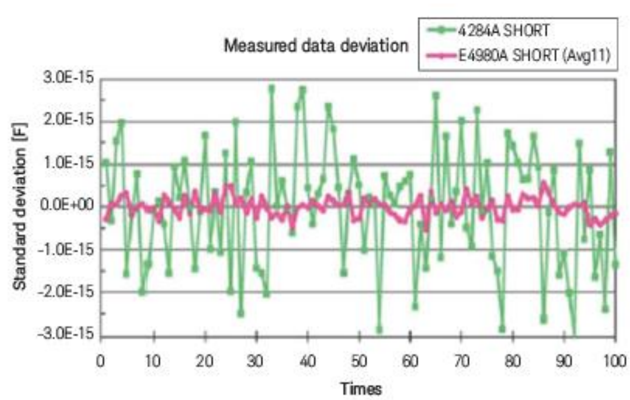
B1500A Semiconductor Device Analyzer



MEMS accelerometer output voltage measurement

MEMS evaluation using the E4980A LCR Meter

MEMS capacitive sensors (such as pressure sensors or accelerometers) detect mechanical displacement through capacitance change. To test the functionality of these devices, electrostatic force (rather than physical stimulus) is usually used as it results in greater test efficiency. However, since the capacitive change in the actuator is very small, test equipment with the ability to measure capacitance with sub-femto farad resolution is necessary. The E4980A is ideal tool for this as it can measure capacitance with atto-farad repeatability (σ < 1 fF).



E4980A LCR Meter

Enhancing Circuit Designs for Faster Time to Market

In addition to the comprehensive suite of hardware for your automotive power testing needs, Keysight offers the Advanced Design System (ADS) to support HEV/ EV electronics engineers in the circuit design validation phase with its power circuit simulation capabilities. With its ease of use and powerful capabilities, Keysight's ADS has garnered a global share of over 70% among high frequency circuit designers, enabling design of power circuit simulation tests that match actual measurements.

More information is available at: www.keysight.com/find/ads

Summary

The ongoing trend of ever-increasing automotive electrical content creates many challenges for electronic circuit designers and the need for better power circuit simulator solutions. The goals of improved operating efficiency and better safety mandate that the components used in these circuits undergo much more extensive testing than in the past. For semiconductor devices and components, IV, CV, Qg, and gate resistance must be characterized to meet these requirements. MEMS sensors require low-level IV characterization as well as extremely precise CV measurements. Keysight Technologies can provide complete solutions that meet all of these testing needs.