The need to reduce energy consumption as well as CO2 emissions is driving the growth of power electronics and power converters. These needs are driven by growth in the vehicle electrification and home energy management systems where renewable energy usage is becoming more prevalent. Two of the main power converter design drivers are increased conversion efficiency and better reliability. In green energy applications such as solar power, Levelized Cost of Energy (LCOE) is the main decider for what solar inverter a customer chooses for their solar installation. Both efficiency and reliability are two of the main variables in the LCOE algorithm that determines whether your inverter company gets the sale or not. In hybrid electric (HEV) and electric vehicles (EV) reliability is tied to an automotive manufacturer’s reputation and is also linked to safety and the preservation of human life. Hence comprehensive EV test for the various vehicle electrical subsystems at the design and test stages is vital.

The ceiling or limits of these design drivers was getting close for many power converter applications that used power devices based on silicon. The emergence of wide band gap (WBG) power devices based on silicon carbide (SiC) and gallium nitride (GaN) hold promises of raising the ceiling of these design drivers. With the ability to switch faster, handle higher voltages, and larger temperature ranges WBG devices can increase efficiency and reliability as well as reduce form factor in next generation power converter designs. But before power converter designs based on WBG power devices can become main stream there are design and test challenges that must be understood and overcome to utilize them to their full potential.

This is part one in a four part series that takes a look at each stage of the power converter design cycle. At each stage we will look at design and test challenges of next generation power converters and discuss hardware and software tools to help you overcome them. We will put an emphasis on improving the design drivers previously mentioned: increasing efficiency, improving reliability, and reducing form factor. We also consider the design and test challenges that WBG devices introduce into the power converter design cycle. Each of the four parts of this series will cover one of the following design cycles:

1. Power device and component evaluation
2. Design software simulation
3. Hardware design and debugging
4. Design validation and certification
Power Device and Component Evaluation

In this stage of the design cycle engineers want to evaluate the latest power devices (MOSFETs and IGBTs) to use in the next generation of their power converter designs to ensure they can deliver a competitive design that can win in the market. With the emergence of wide band gap (WBG) devices like Silicon Carbide (SiC) and Gallium Nitride (GaN) the task of power device evaluation has become much more challenging. WBG devices offer capabilities such as faster switching via faster slew rates, higher voltage handling capability, and increased temperature range compared to silicon. These capabilities lead to benefits such as increased efficiency and smaller form factors for power converter designs. But these same benefits make evaluating them and integrating them into future designs more challenging as we will discuss.

Understanding the performance specifications and reliability of power semiconductor devices is critical for the success of a design since their performance strongly dictates the efficiency and reliability of the entire power converter circuit. Unfortunately, power device manufacturer’s supplied datasheet information is often not sufficient to meet these needs. The datasheet conditions are often different 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. This is even truer for WBG devices since manufacturers differ on what specifications need to be on the data sheet and which ones they do not include.

Also the fast slew rates of WBG power devices create high frequency content that can excite resonant circuit conditions in the surrounding circuits causing the power engineer to have to think like an RF engineer. This means besides just evaluating the power devices, it also necessary to ensure the “supporting cast” of components and PCB designs around the new power devices can support the increased performance and capabilities of the WBG power devices. Once the evaluation has been completed it is critical to have an accurate picture of the power devices and supporting cast specifications and parameters to feed into the next stage of the design process to ensure accurate software models and power conversion circuit simulation.

In the following sections we will look at the tests necessary to evaluate WBG power devices. For simplicity sake we will divide power device tests into two main categories: static testing and dynamic or double pulse testing. In the third section we will take a look how to evaluate and characterize the supporting cast of WBG power device based designs.
Static testing:

Static tests of power devices that are done to understand a power device’s performance include parameters such as:

- IV parameters (Ron, BV, Leakage, Vth, Vsat, etc.)
- Input, output and reverse transfer capacitances (Ciss, Coss, Crss, Cies, Coes, Cres) and Rg

Measuring these parameters typically involves multiple instruments, such as a curve tracer and an LCR meter. But even with all the needed instruments accuracy is often less than ideal due to fixture challenges and often these parameters cannot be tested at their intended I or V operating levels. These challenges become even more complicated when you need to verify performance of the power device over a wide temperature operating range.

As a long time provider of power device precision test solutions to the semiconductor industry, Keysight Technologies, Inc. built a solution for characterizing power devices targeted at the end user or power converter designers and tuned its capabilities to meet the needs of WBG devices. The solution is the B1506A Power Device Analyzer. The B1506A provides the capability of a high precision IV curve tracer with the ability to make input, output and reverse transfer capacitance (Ciss, Coss, Crss, Cies, Coes, Cres) measurements. But it also provides the ability to make these measurements at the actual operating levels of the power device, covering a range of up to 1500A and 3kV.

Besides the static IV and capacitance measurements it can also measure gate charge as well as calculate and model power loss based on switching frequency, see Figure below.

The B1506A also provides optional temperature testing capability so you can verify the performance parameters of a power device over a wide temperature range. All of this comes in a single solution that is automated with an easy to use user interface and fixturing. If you already have an IV curve tracer and just want the capacitive measurement capabilities along with leakage and breakdown measurement capabilities there is the B1507A Power Device Capacitance Analyzer. For more information on Keysight’s Power Device Analyzers go to [http://www.keysight.com/find/B1506A](http://www.keysight.com/find/B1506A)
Dynamic testing:

Dynamic or double pulse testing of power devices typically involves sending high current pulses to one or more power devices and measuring the resulting voltage and current switching waveforms as well as the thermal characteristics of the power device. To generate the pulses, power converter designers either use a high power pulse generator or build a double pulse test circuit. Each approach has its own advantages and disadvantages. The appropriate choice often depends on the preferences of the engineers doing the test. The figure below shows a power device dynamic test setup with applicable Keysight instrumentation.

Figure 3. Power Device Dynamic or Double Pulse Test Setup

When doing dynamic testing one of the toughest test challenges engineers have today is to accurately characterizing the switching waveforms (voltage and current) of WBG power devices. If we first consider measuring the voltage waveform, one test challenge is to capture and measure peak-to-peak switching voltages that may range from 100's to perhaps 1000's of volts with slew rates sometimes exceeding 100V/1ns. With such fast slew rates, the bandwidth of the measurement instrument and any transducer must be considered. A good equation to calculate the bandwidth of a rising or falling edge is:

\[
\text{Bandwidth} = \frac{0.5}{\text{rise time} \ (10\% \ to \ 90\%)}
\]

Using the equation above, a switching waveform with a rise time of 10ns has a bandwidth of about 100MHz. Since the rated bandwidth of any applicable measurement instrument typically represents the 3 dB point of its bandwidth roll off, to accurately measure such a fast slew rate you would want to choose an instrument that has a rated bandwidth 2 to 3 times higher than the bandwidth of the switching waveform. For the 100MHz example mentioned earlier you would want to ensure your instrument has a bandwidth of at least 200MHz or above.

The dynamic range and measurement resolution of the instrument you are using is also important. For instance, accurately measuring device saturation voltage levels that may be in the range of 10's to 100's of millivolts in the presence of 100's of volts of switching can be a challenge.
To measure device switching currents, a traditional Hall-effect current probe can be used. But coaxial shunts or current transformers are the preferred method of measuring current when lower inductance and higher bandwidths are needed.

To accurately capture the voltage and current switching waveforms of WBG devices the measurement instrument typically used is an oscilloscope. Oscilloscopes are a good tool for measuring the switching characteristics of a power device because they offer wide measurement bandwidth, they have multiple channels (need current and voltage), and they can handle large voltage and current values with the right voltage and current probe and/or transducer. In the following sections we will look at some Keysight oscilloscopes that offer industry leading capabilities for dynamic testing of WBG devices.

InfiniiVision 3000, 4000, and 6000 X-Series Oscilloscopes

The InfiniiVision X-Series oscilloscopes provide unmatched performance in their class with an easy-to-use UI that includes a large touched-based display for viewing and analyzing switching waveforms. In addition, the InfiniiVision oscilloscopes have an optional built-in function/arbitrary waveform generator. This generator gives you the ability to control a double-pulse test circuit and measure the resulting switching waveforms from a single instrument. A scope and generator in one box can reduce the complexity of your test setup. The InfiniiVision X-Series oscilloscopes come standard with a broad range of advanced triggering capabilities, advanced waveform math, and automatic waveform characterization measurements. Also available is an optional power measurements application for analyzing power switching circuitry with automatic setups and measurements including switching loss and Rds(on). We will discuss how this power measurement app can help you optimize your power converter design as well as speed up the design process in part three of this series.

Infiniium S-Series Oscilloscopes

Keysight’s Infiniium S-Series oscilloscopes provide market leading measurement technology that delivers high resolution and dynamic range for measuring switching waveforms when evaluating power devices. The S-Series oscilloscope provides 10 bits of measurement resolution, very deep acquisition memory, and measurement bandwidths up to 8 GHz. Although there are scopes on the market that boast 12 bits of ADC resolution, this is mainly a marketing specification since they don’t have the measurement accuracy to actually take advantage of the high resolution. It is like selling a car with a speedometer that goes up to 120 MPH, but a drive train that only delivers 80 MPH. To achieve industry leading measurement performance the S-series not only employs a high-performance ADC, but it employs low-noise input signal conditioning and precision 20 GSa/s real-time sampling to take maximum advantage of the ADC’s 10-bit performance. The S-Series delivers the highest effective number of bits (ENOB) of resolution in its class, even more than the oscilloscopes that boast 12 bits of resolution.

Oscilloscope Probes

When measuring the dynamic switching waveforms the oscilloscope is just one piece of the puzzle. The other critical part is probing. Keysight offers a wide range of differential and single-ended probes with different voltage ranges and bandwidths. As an example, a single-ended probe that is a good fit for WBG voltage measurements is the 10076C, which can handle voltage levels up to 4kV with a bandwidth of 500MHz. This probe is low cost and provides plenty of voltage and bandwidth cushion in its ranges. For current measurements, many designers use coaxial shunts which can be measured with a high bandwidth single-ended or differential voltage probe, along with the math functions built into the Oscilloscopes. Keysight also offers a wide range of probing accessories ensure a good connection and reduce parasitics to deliver an accurate measurement. For more information about Keysight’s oscilloscope probing solutions, go [www.keysight.com/find/scopes-power](http://www.keysight.com/find/scopes-power), and then click on “View measurement options and probing solutions”.

www.keysight.com/find/scopes-power
Thermal Characterization of Power Devices

Characterizing the temperature profile of the WBG power device during test is also critical towards performance and long term reliability of future designs. Keysight provides multiple options to meet your specific needs. For making and logging direct multi-channel temperature measurements the 34970A 34972A DAQ Measurement Units are the proven high quality work horses of the power electronics industry. They offer a modular approach to doing multi-channel temperature measurements as well as other common measurements such as voltage and current. There is also free measurement logging software available for it, more on this in part four of this series.

Keysight also offers the U5855/6/7A family of Thermal Imagers for real time analysis and trend analysis of the power device’s thermal profile. The analysis software that is included adds reporting capability such as spot and line analysis, trend charting and changing color palette. This handy tool complements and speeds up the thermal characterization of the power devices.

For powering and controlling the double pulse circuit Keysight offers a wide range of DC power supplies and function / arbitrary waveform generators that provide functionality targeted at power electronic and power converter design. We will discuss this in more detail in part three, but you can find recommended model numbers in Figure 3.
Evaluating the supporting cast:

Besides just evaluating the power devices, you need to evaluate and characterize the “supporting cast,” which includes things like connectors, inductors, diodes, or even PCB designs. This is critical to verify performance over a range of conditions, ensure reliability, and to build more accurate software simulations to reduce cost and time when you start building hardware prototypes. The B1506A Power Device Analyzer that was discussed in detail in the static testing section is an ideal tool in this area as well for:

- For precision IV analysis over a wide voltage and current range
- Capacitive measurements up to high voltage levels
- Inductance DC resistance measurements with high current bias
- Verifying supporting cast’s performance over a wide temperature range

Keysight also provides a comprehensive family of LCR meters for making high accuracy impedance measurements on the supporting cast. Keysight LCR meters have been regarded as industry standard instruments with their best in class accuracy and repeatability over wide impedance measurement ranges.

Evaluating for near RF effects of WBG devices

As power conversion design become more and more complex with tighter control loops, faster switching speeds, and the introduction of WBG devices which generate high frequency components into circuits with their fast rise and fall slew rates, more complex impedance analysis tools are needed. No longer can a power electronics circuit be modeled with a simple lumped circuit and this lumped circuit is then applied to all conditions, but instead the circuit must be analyzed and modeled with a reliable power circuit simulator to understand how it impedance changes across a wide frequency range. Keysight can deliver this type of insight with two industry leading product lines:

- E4990A Impedance Analyzer
  - Frequency range: 20 Hz to 10/20/30/50/120 MHz
  - Z-range (10% accuracy): 25mOhm to 40MOhm

- E4991B Impedance Analyzer
  - Frequency ranges: 1MHz to 500 MHz/1 GHz/3 GHz
  - Z-range (10% accuracy : 120mOhm to 52kOhm

The E4990A series uses an Auto-balancing bridge method for impedance measurements and the E4991B series uses an RF I-V method for impedance measurements. The auto-balancing bridge and RF I-V methods are based on the linear relationship of the voltage-current ratio to impedance, as given by ohm’s law. Thus, the theoretical impedance measurement sensitivity is constant and, it achieves high accuracy over a wide impedance range compared to network analyzer based methods. The excellent measurement stability of the E4990A/E4991B impedance analyzer is achieved by the receiver section which is designed to minimize drift errors. This enables accurate characterization over a long period of time. Keysight also offers the E5061B ENA series network analyzer with option 3L5/005 supports network analysis,
impedance analysis, as well as gain/phase analysis. Although it cannot provide the impedance analysis accuracy or stability that the E4990A and E4991B provide, it gives the option of a real versatile analysis tool. Below is a chart that gives accuracy versus frequency comparison of the E4990A, E4991B, and the E5061B:

![Figure 6. 10% impedance accuracy range of the E4990A, E4991B, and E5061B](image)

For more information on Keysight's LCR meters and Impedance Analyzers use the following link: [http://www.keysight.com/find/impedance](http://www.keysight.com/find/impedance)

**Summary**

In this application note we look at the challenges power electronic engineers face trying to evaluate, characterize, and model wide band gap devices for their next generation power converter designs. We discussed how Keysight provides tools, solutions, and expertise to help you face some of the evaluation and design challenges that wide band gap devices present. For instance the B1506A power device analyzer provides a complete solution for characterizing IV, CV, and gate charge characteristics of a power device. Keysight’s family of industry leading impedance analyzers allow you to characterize the circuit elements surrounding the wide band gap devices over a wide frequency range so you can properly plan for the near RF effects of wide band gap devices.
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