Optimize Half-Bridge Circuit Designs Through Accurate V_{GS} Measurements

by Tom Neville, Tektronix, Beaverton, Ore.

This article looks at the use of an innovative new galvanically isolated measurement system for improving the accuracy of high-side gate-source voltage (V_{GS}) measurements, which in turn opens up new opportunities to optimize half-bridge circuit designs. The IsoVu measurement system developed by Tektronix was demonstrated for the first time at APEC 2016[1,2] and will become commercially available later this year. The standout feature of IsoVu is its best in class common-mode rejection across its entire bandwidth.

The measurements described in this article are shown on a half-bridge configuration with eGaN FETs on both the high-side and low-side switch. While high-side gate measurements are the focus of this article, the low-side gate will also be examined. In addition, examples of how these measurements can be used to gain insights never possible before will be discussed. This article addresses measurements during high-side turn-on as well as during high-side turn-off and low-side turn-on.

Half-Bridge Testing Challenges

Components used in topologies such as the half bridge have greatly evolved leading to advancements in efficiencies, densities, and reliability. An example half-bridge configuration is shown in Fig. 1.

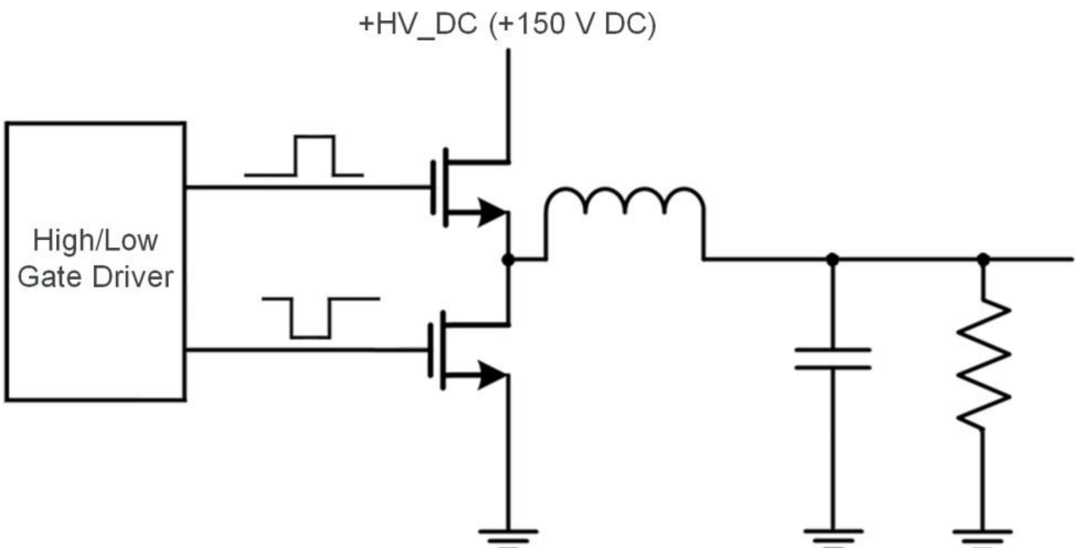

Fig. 1. Half-bridge configuration.

The advancement of power conversion components and more stringent design requirements have far outpaced the ability to accurately measure and characterize these designs. At present, there is no test and measurement equipment capable of accurately making measurements such as the high-side gate-source voltage in the presence of high common-mode voltage. In fact, most differential signals in the presence of today's higher-frequency common-mode voltages cannot be measured accurately.

To make sense of what is happening in these environments, designers have been forced to use alternative methods such as extensive simulation, measuring the low-side ("ground" referenced) switch and inferring the results to the high-side switch, examining thermal characteristics, EMI proximity probing, or trial and error methods.

The benefits of a design such as a half-bridge circuit can only be achieved when the half-bridge circuit, the gate-drive circuit, and layout, are all properly designed and optimized. It's impossible to tune and optimize this circuit if you cannot measure it. Completing this design requirement involves characterizing the waveforms shown in the ideal case in Fig. 2.

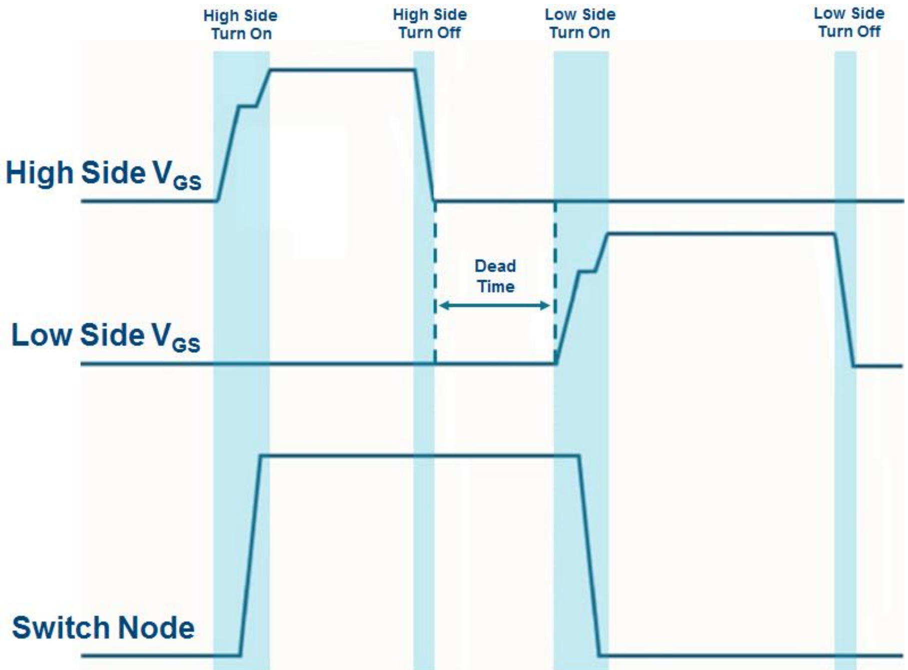

Fig. 2. Example of ideal half-bridge switching waveforms.

High-Side Turn-On Characteristics

In general, there are three characteristic regions of the turn-on waveform that are of interest. The first region is the C_{GS} charge time. This is followed by the Miller plateau, which is the time required to charge the gate-drain Miller capacitance (C_{GD}), and is V_{DS} dependent. This charge time increases as V_{DS} increases. Once the channel is in conduction, the gate will charge up to its final value. The ideal representation of these regions is shown in Fig. 3.

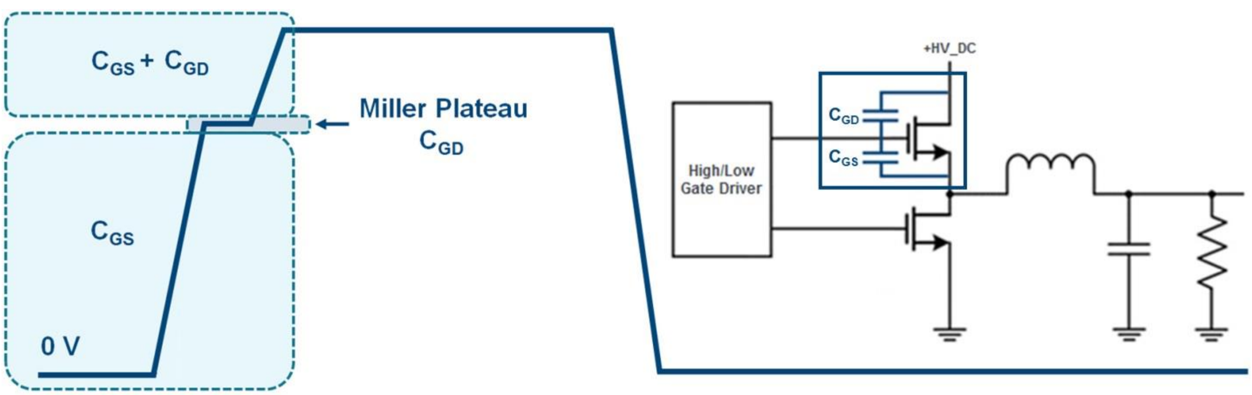

Fig. 3. High-side turn-on characteristics.

The high-side V_{GS} is riding on top of the switch-node voltage, which is switching between "ground" and the input supply voltage. Because of this rapidly changing common-mode voltage, the gate-source voltage is impossible to measure without adequate common-mode rejection.

Attempting to make the high-side V_{GS} measurement invariably results in a waveform similar to the output shown in Fig. 4. The Teledyne LeCroy DA1855A is considered to have a best-in-class amplifier and was selected for this measurement along with a Teledyne LeCroy scope. The DA1855A's common-mode rejection ratio (CMRR) is relatively good and exceeds 80 dB at low frequencies up to a few megahertz. However, this amplifier derates as frequencies increase. For example, at 100 MHz it offers CMRR of 20 dB.

Comparing this actual output to the ideal transition, it's difficult to extract meaningful details regarding what is happening in each of the regions referenced above and make design decisions based on this measurement. It's important to note that the waveform shown in Fig. 4 changes dramatically based upon position of the probe's input leads making repeatable measurements impossible.

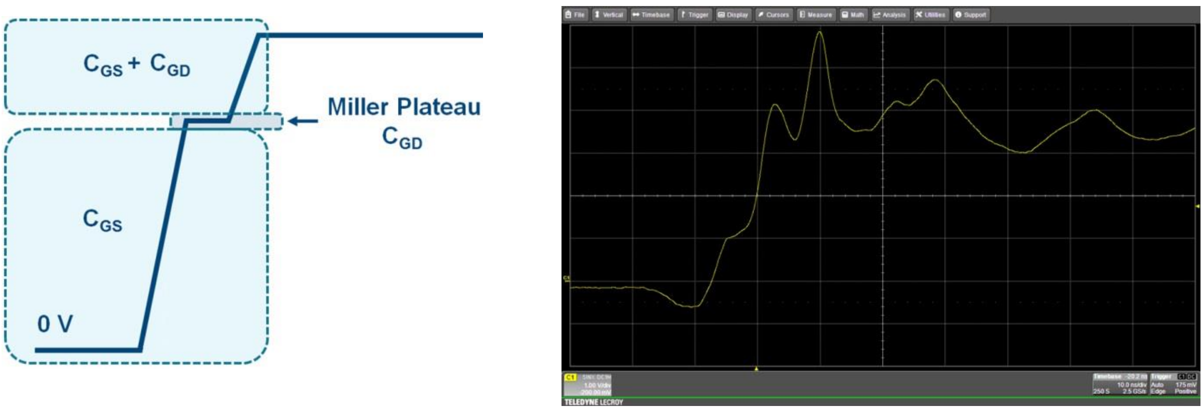

Fig. 4. Comparison of LeCroy's DA1855A high side V_{GS} output to ideal.

The IsoVu Solution To The Common-Mode Problem

When the best amplifier available fails to deliver repeatable results, it's clear that traditional probe architectures are no longer viable for this application—advancing technology has exceeded the capability of the measurement system. This points to the need to address the root of the problem: the electrical connection to the scope.

Unlike all other commercially available probes, IsoVu uses an electro-optic sensor to convert the input signal to optical modulation, which electrically isolates the device-under-test from the oscilloscope. IsoVu incorporates four separate lasers, an optical sensor, five optical fibers, and sophisticated feedback and control techniques (Fig. 5.)

IsoVu architecture with galvanic isolation provides common-mode withstand voltages of >2000 Vpeak across its frequency range with no derating. The electrical limitation for an optically isolated solution such as IsoVu is many thousands of volts. Because IsoVu achieves galvanic isolation through its fiber optic connection, the only limitation in its common-mode voltage rating is due to safety certification standards.

Fig. 5. IsoVu measurement system.

The sensor head, which connects to the test point, has complete electrical isolation and is powered over one of the optical fibers as shown in the block diagram in Fig. 6. The sensor head also contains a DC/LF feedback loop that measures the DUT signal and sends it to the controller for analysis. This allows the system to correct for a variety of drifts and offset errors in the system.

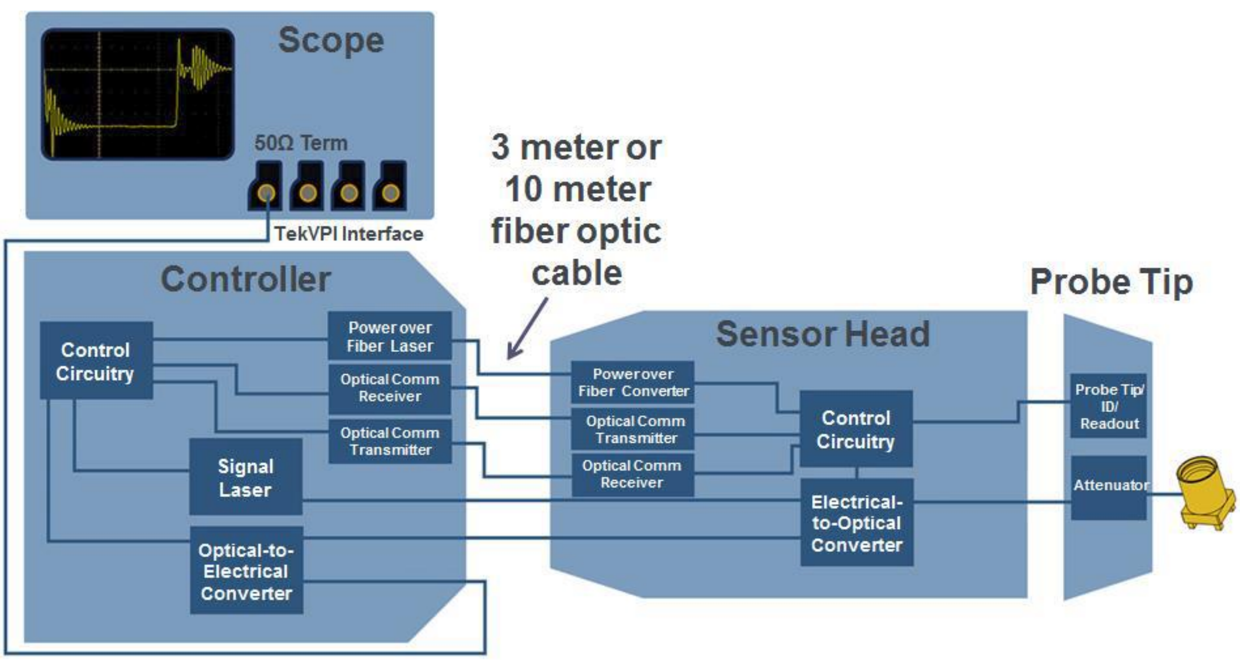

Fig. 6. IsoVu block diagram.

The connection from the DUT to the sensor head is through tip cables, which can have different attenuations to allow optimization for the signal being measured. The tip cable connects to the sensor head via an SMA connector and includes readout encoding so the sensor head can communicate the attenuation factor to the scope to display the correct vertical scale factor.

Based on this design, IsoVu is well-suited for differential measurements where complete galvanic isolation is required such as when there is high common-mode voltage and high-frequency common-mode interference. The use of an optical connection also makes it useful for performing measurements in high EMI environments as well as for EMI compliance testing and ESD testing. Remote measurements up to 10 meters away from the device under test are also possible without loss in measurement performance.

IsoVu offers superior banner specifications[3] including:

- Ability to resolve <50-V high-speed differential voltages in the presence of large common-mode voltages (up to 2 kVpeak)
- Bandwidth from dc to 1 GHz
- Common-mode rejection of 120 dB from dc to 100 MHz and 80 dB at 1 GHz
- Ability to resolve a 10-mV signal in 1X mode with a 1X tip and down to 5 mV using high-res mode or averaging.

New Signal Details Uncovered

As shown in Fig. 7, IsoVu can uncover details of what is occurring in the design. Moreover, the measurement is stable and repeatable. The resulting waveform shows previously hidden resonances and signal details. This measurement is made on an actual reference design.

Fig. 7. Comparison of high-side V_{GS} output as measured using the IsoVu isolated high-voltage measurement system to the ideal.

Until now, the Teledyne LeCroy DA1855A with a 12-bit oscilloscope has offered the most insight into these kinds of measurements. With this measurement system, the user may have been tempted to optimize their design based on the waveform information since it does seem to show some of the expected characteristics.

However, partial or incomplete information can often be misleading, and that is in fact the case here. Fig. 8 shows a comparison of these two measurement systems and reveals how optimizing based on a measurement system with limited CMRR and bandwidth can cause users to mistune their design.

Fig. 8. Comparison of waveforms highlight the pitfalls of attempting to make design decisions based on partial or incomplete information.

An isolated high-voltage measurement system offers the resolution and repeatability required to optimize the performance of designs. As visible in Fig. *9*, there is clear correlation between the Miller plateau and the switch-node transition.

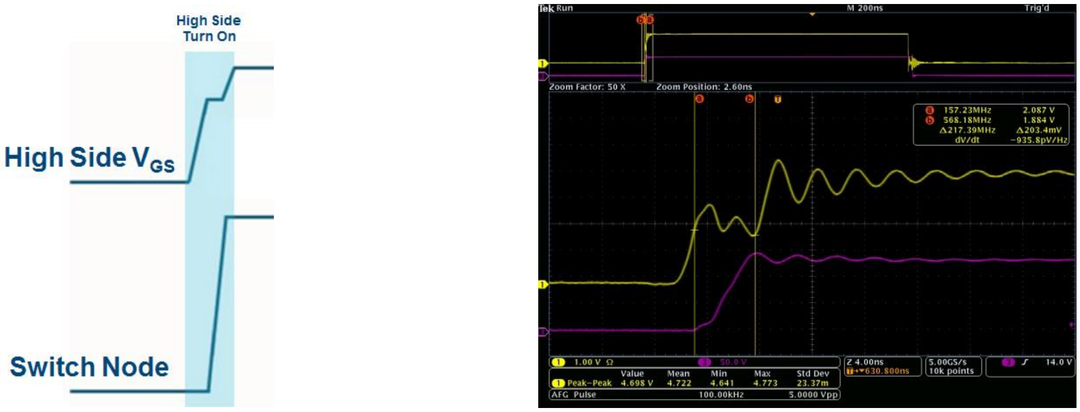

Fig. 9. High-side V_{GS} turn-on and switch node compared to the ideal.

Although the low-side switch is supposed to be "ground" referenced, it's informative to see the actual waveform and how it may affect the high-side performance. Fig. 10 shows the low-side switch has ringing due to parasitic coupling between the low-side switch, the high-side gate and the switch node.

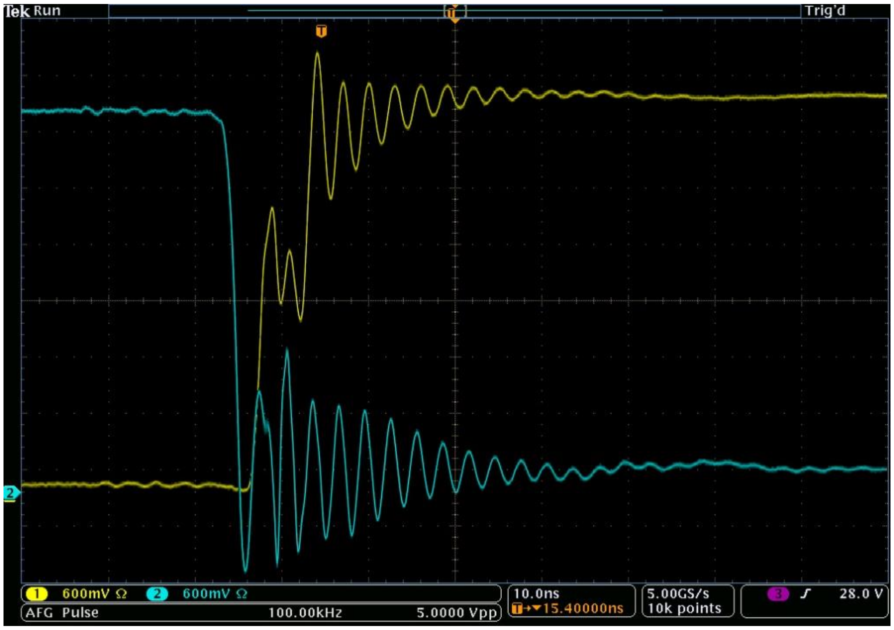

Fig. 10. Interaction of the high-side and low-side switches.

High-Side Turn-Off, Low-Side Turn-On Characteristics

Many of the same characteristics are apparent during the high-side turn-off/low-side turn-on transitions. As shown in Fig. 11, the Miller plateau on the low-side V_{GS} is clearly visible. The coupling due to parasitics between the switch node and the high- and low-side FETs is apparent. Additionally, the isolated high-voltage measurement system demonstrates sufficient bandwidth to measure the dead time.

Accurate measurement of the time-aligned high-side and low-side events is critical to avoid simultaneous conduction of the two FETs, which can lead to excess switch loss, loss of efficiency and device degradation.

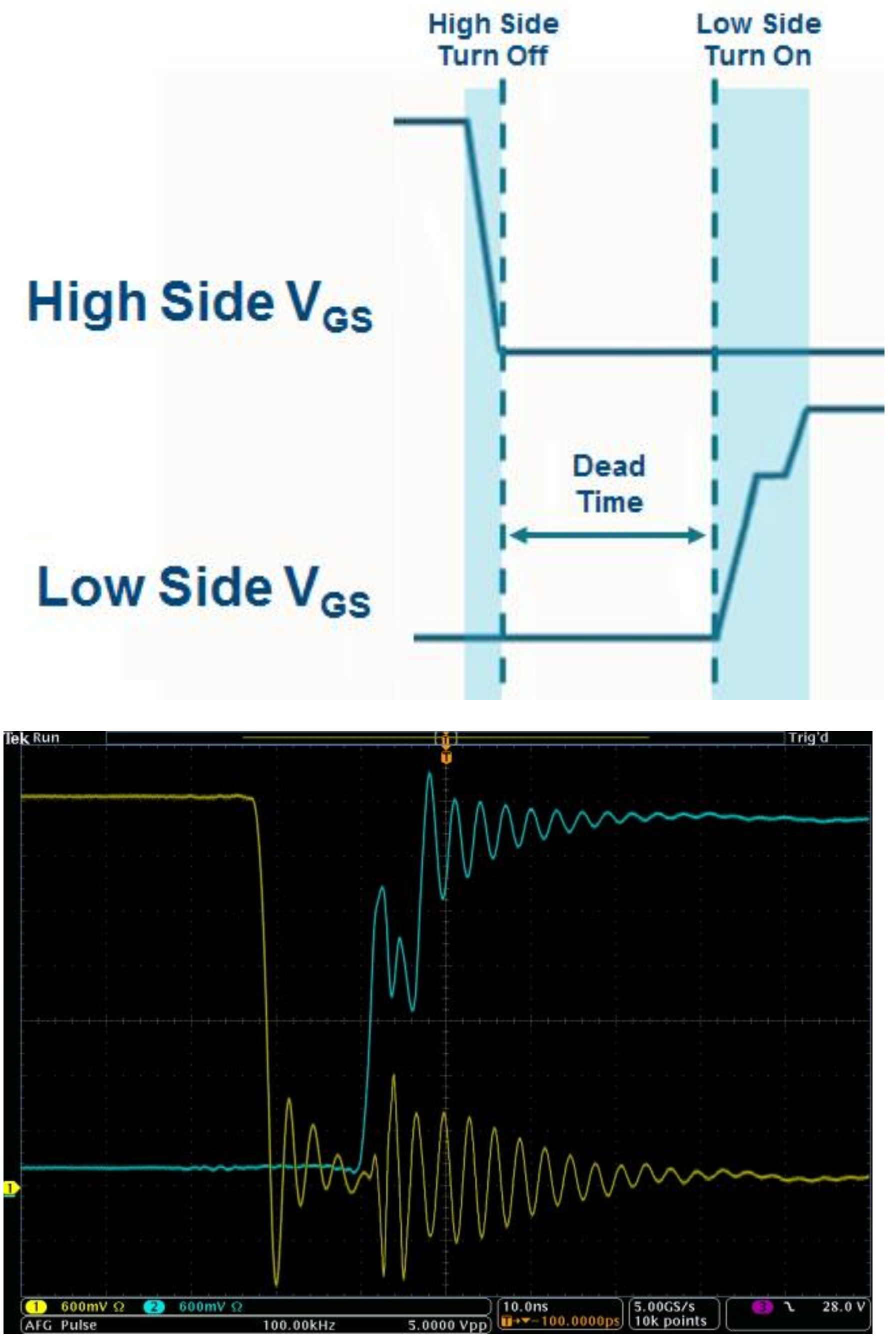

Fig. 11. High-side turn-off, low-side turn-on, and dead time. Ideal waveforms versus actual measurement using IsoVu.

Conclusion

To accurately and reliably measure half-bridge circuits, particularly at higher frequencies and higher voltages, a measurement system must have sufficient bandwidth, excellent CMRR, and superior common-mode voltage range. Traditional measurement systems fail to meet these requirements, particularly as they derate as frequencies increase.

As has been demonstrated in this article, the IsoVu measurement system, which employs an optical connection to the oscilloscope, effectively eliminates the common-mode signal from the differential signal, making repeatable, accurate measurements in the presence of large common-mode voltage routine. This in turn gives designers the insights needed to properly design and optimize half-bridge circuits, gate-drive circuits and layouts.

References

1. Tektronix Previews 1 GHz Optically Isolated Measurement System at APEC 2016.
2. "1-GHz Optically Isolated Measurement System Offers 120 dB CMRR Up To 100 MHz," How2Power Today, April 2016 issue.
3. Tektronix IsoVu Measurement System White Paper.

About The Author

Tom Neville is a product planner and product marketing manager in Tektronix's Time Domain Business Unit. He has an MSEE from Portland State University and a BS degree from the United States Military Academy. Tom has worked at Tektronix for the past nine years with a focus on measurement solutions for power applications.

For further reading on test and measurement techniques relating to power conversion, see the How2Power Design Guide, select the Advanced Search option, and select "Test and Measurement" in the "Design Area" category.