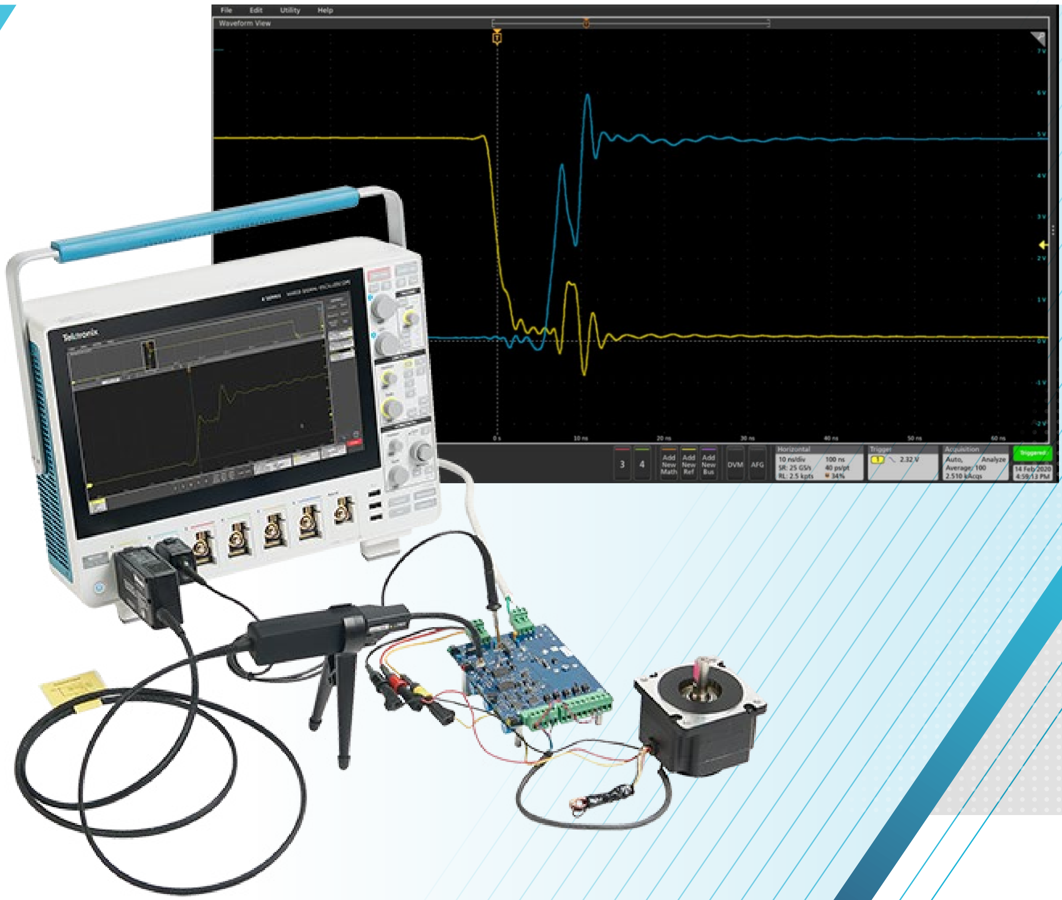
NEW

IsoVu™ Gen 2—An Improvement in Accuracy, Sensitivity, Accessibility, and Convenience

WHITE PAPER



Tektronix®

Introduction

This white paper describes how an optically isolated measurement system architecture offers complete galvanic isolation and is the industry's first measurement solution capable of accurately resolving high bandwidth, high voltage differential signals in the presence of large common mode voltages. The system is labeled IsoVu, and, in its second generation, provides improved technical characteristics compared to the first IsoVu generation in the form of:

- Easier accessibility with a size reduction of 80% compared to IsoVu first generation;
- Better accuracy with an improved gain accuracy;
- Superior sensitivity with less noise;
- Greater convenience with fewer tips needed and an optimization for use on Tektronix 4/5/6 Series MSOs.

This white paper will provide information on the IsoVu Gen 2 isolated measurement system theory of operation and performance capabilities.

Theory of Operation

IsoVu Gen 2 utilizes an electro-optic sensor to convert the input signal to optical modulation, which electrically isolates the device-under-test from the oscilloscope. IsoVu Gen 2 incorporates four separate lasers, an optical sensor, four optical fibers, and sophisticated feedback and control techniques. The sensor head, which connects to the test point, has complete electrical isolation and is powered over one of the optical fibers. **Figure 1** shows the block diagram.

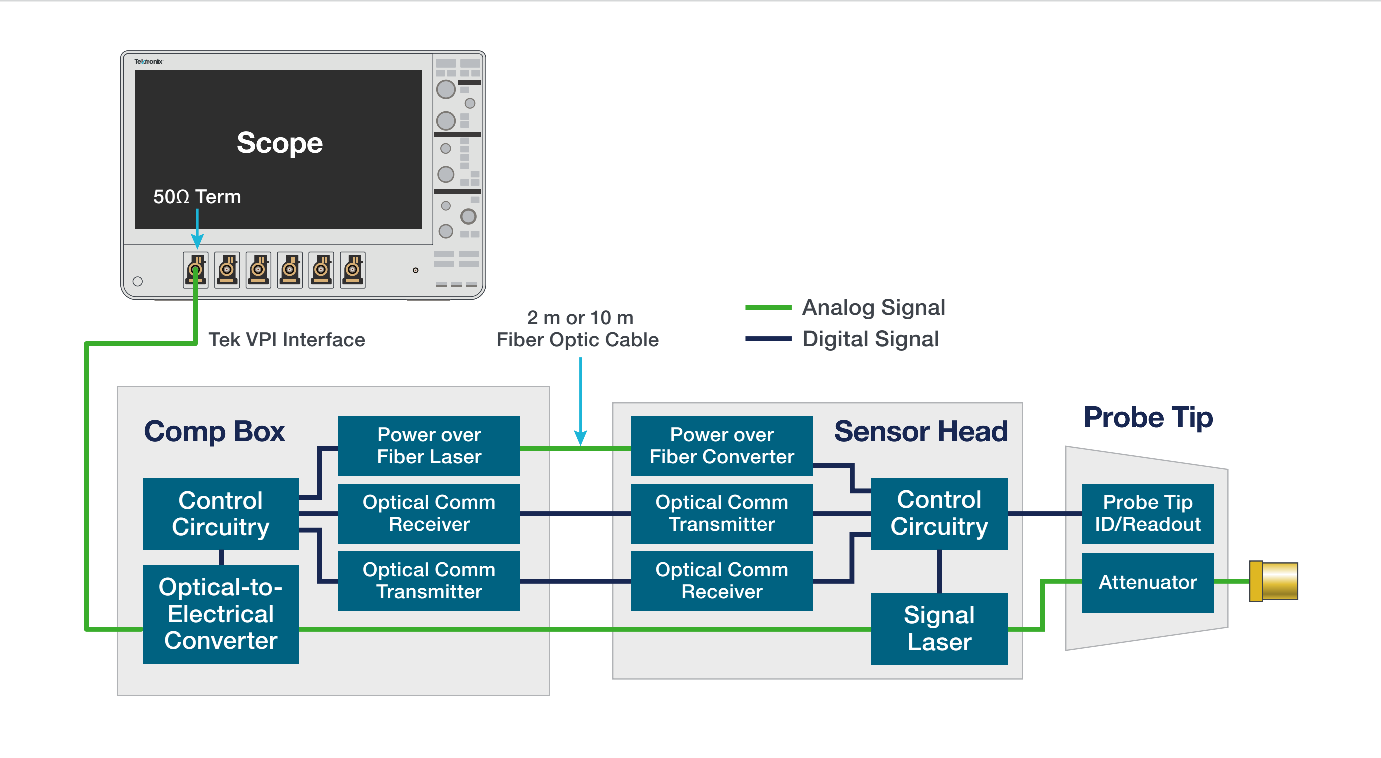


Figure 1: IsoVu block diagram.

Differential and Common Mode Signals Background

Differential measurements are typically made with a differential probe. Differential probes are based on difference amplifiers that measure the potential difference between two test points. If the voltage at one input is 2 V and the voltage at the other input is 1 V, the output is the difference between the two inputs, which is, as shown in **Figure 2**, 2 – 1 or 1 V. However, there is typically a common mode component that must be considered.

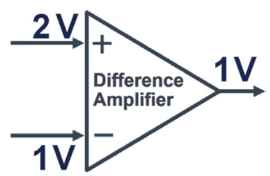


Figure 2: Differential measurement.

So, if the inputs to the amplifier are connected to the same source signal, what would you expect the output to look like? If this is an ideal amplifier, you would expect the output to be a completely flat line or 0 V because the amplifier should subtract the signals at both inputs. This signal that is "common" to both the non-inverting input and the inverting input is referred to as the common mode signal. An ideal difference amplifier would reject 100% of the common mode signal. For example (see **Figure 3**), if there is 100 V on both the non-inverting input and 100 V on the inverting input, an ideal differential probe would have an output of 100 – 100 = 0 V.

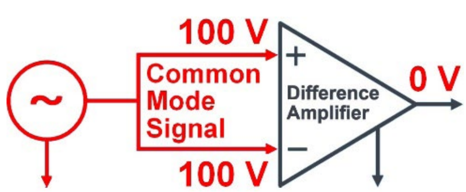


Figure 3: Common mode rejection.

When you're making a differential measurement, the only thing you want to see is the difference between the two signals you're trying to measure. You shouldn't see the effects of the common mode voltage at the output of the amplifier. The ability to reject the common mode signal is the amplifier's common mode rejection ratio (CMRR). Ideally, an amplifier would have an infinite CMRR. The higher an amplifier's CMRR, the less impact the common-mode input voltage has on the differential measurement. Because it's impossible to perfectly match the two inputs of a differential probe, every differential measurement will include some common mode error; it is only a question of how much. It's important to note that an amplifier's common mode rejection ratio is frequency dependent. Differential probes typically have higher CMRR at DC and low frequencies but the CMRR degrades as the frequency increases.

Consider the simplified half bridge circuit shown in **Figure 4**. The differential voltage between the gate and source at the high-side transistor is 5 V. When there is 100 V of common mode voltage, the measurement system needs to display the difference between 105 V and 100 V. The measurement system's ability to accurately resolve the 5 V differential signal is dependent on the amplifier's common mode rejection capability.

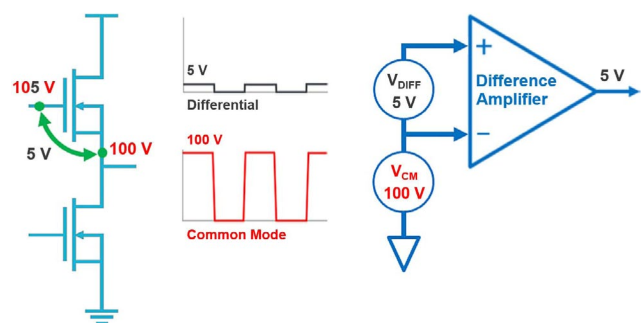


Figure 4: Simplified half-bridge circuit.

How Common Mode Rejection is Specified

Because of the frequency dependence of CMRR, most differential probes only list the CMRR values at DC and low frequencies on the datasheet. Let's examine the datasheet of a high voltage differential probe shown in **Figure 5**. It's a 100 MHz probe, but when we zoom in on the numbers in the datasheet, it only specifies values at DC, 60 Hz, 1 kHz, and 1 MHz. It seems strange that the datasheet doesn't include the CMRR value for 100 MHz since that's the listed bandwidth of the probe. When you look at the CMRR plot in the manual in **Figure 6**, it becomes clear why the CMRR values at higher bandwidths are omitted. At 100 MHz, this probe only has ~27 dB CMRR which is about 22:1, using the dB = $20\log(V_{IN}/V_{OUT})$ equation.

Product	
Bandwidth (-3dB)	≥100 MHz probe bandwidth
DC CMRR	–70 dB at 500 VDC
AC CMRR	–80 dB at 50/60 Hz –50 dB at 1 kHz –50 dB at 1 MHz

Figure 5: High voltage differential probe datasheet.

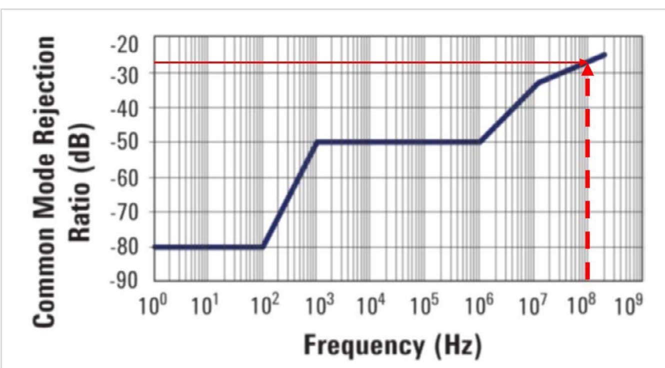


Figure 6: High voltage differential probe CMRR plot.

Going back to the example of 100 V common mode voltage in **Figure 4**, the common mode error would be calculated as 100 V divided by 22, which is approximately 4.5 V of common mode error. With this amount of common mode error, it wouldn't be possible to resolve a 5 V differential signal in the presence of 4.5 V of common mode error. Given IsoVu Gen 2's 10,000 to 1 rejection ratio at much higher bandwidth, the common mode error using an IsoVu probe would be calculated as 100 V divided by 10,000. That's about 10 mV of error. Those results are summarized in the **Table 1** below:

	High Voltage Differential Probe	IsoVu Gen 2 Probe
Maximum Bandwidth	100 MHz	1 GHz
CMRR at the probe's Maximum Bandwidth	–27 dB (22:1)	–90 dB (10,000:1)
Estimated Error	4.5 V (too much)	3.2 mV

Table 1: Measuring a differential voltage of 5 V.

In practice, a CMRR of at least 80 dB (10,000:1) will result in usable measurements. Most differential probes can easily obtain a CMRR of 80 dB or higher at DC and low frequencies where it's possible to tune the components accurately. As the frequency of the measurement increases, a differential probe's CMRR degrades because the mismatches become increasingly difficult to control. At 100 MHz, the CMRR capability of most measurement systems is 20 dB or less. **Table 2** compares the CMRR specifications of the isolated measurement system IsoVu Gen 2 versus a traditional high voltage differential probe.

	Bandwidth	CMRR (DC)	CMRR (1 MHz)	CMRR (100 MHz)	CMRR (1 GHz)
Tektronix **IsoVu Gen 2**	1 GHz	160 dB (100 million:1)	145 dB (10 million:1)	100 dB (100,000:1)	90 dB (10,000:1)
Traditional High Voltage Differential	200 MHz	> 80 dB (10,000:1)	50 dB (316:1)	Not listed in the data sheet. ~27 dB from the manual's CMRR plot	N/A

Table 2: Common mode rejection ratio comparison.

A user may fall into the trap of thinking the 1 MHz specification is "fast enough" for their application. However, it's important to remember that while the repetition rate may not be fast, the rise time of the signal you're measuring may be quite fast, in the ones or tens of ns.

If the differential signal you're measuring is in the presence of 500 V common mode voltage, how much error should you expect? Again, it depends on the signal's rise time. **Table 3** describes how much common mode error the user should expect in the presence of 500 V common mode voltage across bandwidth.

	Common Mode Error for 500 V Common Mode Voltage across Bandwidth			
	DC	1 MHz (35 ns rise time)	100 MHz (3.5 ns rise time)	1 GHz (≤ 1 ns rise time)
Tektronix **IsoVu Gen 2**	5 µV	28 µV	5 mV	15.8 mV
Traditional High Voltage Differential	50 mV	1.6 V	22.3 V	N/A

Table 3: Error due to insufficient common mode rejection rate.

Characterize the Entire Switching Circuit

When evaluating signals such as VDS or VGS at the high-side transistor where the switch node voltage is rapidly switching between "ground" and the input supply voltage, a measurement solution with the following characteristics is required:

- High bandwidth: > 500 MHz
- Large common mode voltage: > the input supply voltage
- Large common mode rejection ratio: > 60 dB at 100 MHz
- Large input impedance: > 10 MΩ || < 2 pF

Tektronix launched the TIVM Series products squarely aimed at measurements such as the high-side VGS where the measurement system needed high performance, high common mode voltage, and large common mode rejection ratio across bandwidth. Tektronix followed the TIVM Series with the TIVH Series products that significantly increased the differential voltage range and input impedance, allowing measurements such as high-side VDS to be possible. With the new IsoVu Gen 2 TIVP, Tektronix offers differential probes that improve gain accuracy, flatter frequency response, and emit less noise when compared to the IsoVu first generation (TIVM/H).

KEY SPECIFICATIONS COMPARISON			
	Tektronix TIVP (with TIVPMX50X tip†) IsoVu Gen 2	Tektronix TIVH (with MMCX250X tip†) IsoVu first generation	Tektronix THDP0200 Differential Probe
Applications	High Side V_{GS}, Wide Bandgap (GaN and SiC) characterization, SMPS optimization, Temperature Testing (with SMA cable)	High Side V_{GS}, Wide Bandgap (GaN and SiC) characterization, SMPS optimization	General Purpose, Si and IGBT-based power electronics
Bandwidth	200 MHz, 500 MHz, **1 GHz**	200 MHz, 500 MHz, 800 MHz	160 MHz, 200 MHz
Risetime	2 ns, 850 ps, **450 ps**	2 ns, 850 ps, **450 ps**	1.75 ns
CMRR @DC	**160 dB**	**160 dB**	80 dB
CMRR @100 MHz	85 dB	85 dB	26 dB
Diff. Voltage Range	250 V†	250 V†	150 V, 1500 V
CM. Voltage Range	**±60 kV**	**±60 kV**	±1500 V
Offset Voltage Range	**±250 V**	**±250 V**	50X Scope Input Offset Range ±50V typ.
Noise (200mV to 3 V measurements)	41.8 mV_{pp}	79.8 mV_{pp}	110 mV_{pp}
DC Gain Accuracy	0.6% typ.	3%	2%
Input Impedance	10 MΩ || 3 pF	10 MΩ || 2 pF	
Operating Temperature Range	0°C to 50°C (probe head) 0°C to 85°C (probe tip cable)	0°C to 70°C (probe head) 0°C to 85°C (probe tip cable)	0°C to 40°C
Oscilloscope Compatibility	4/5/6 Series MSO only	**All TekVPI Oscilloscopes (incl 4/5/6 Series MSO)**	**All TekVPI Oscilloscopes (incl 4/5/6 Series MSO)**

† Closest value to THDP0200 selected for comparison purposes.

Table 4: Tektronix TIVP and TIVH Series specifications compared to traditional differential probes (dependent upon the probe tip cable).

IsoVu Gen 2 Makes Hidden Signals Visible

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 **Figure 7**.

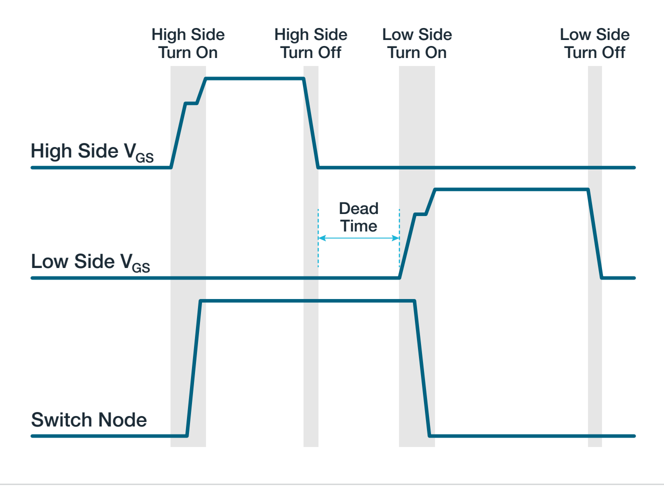


Figure 7: Example ideal half-bridge switching waveforms.

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 **Figure 8**.

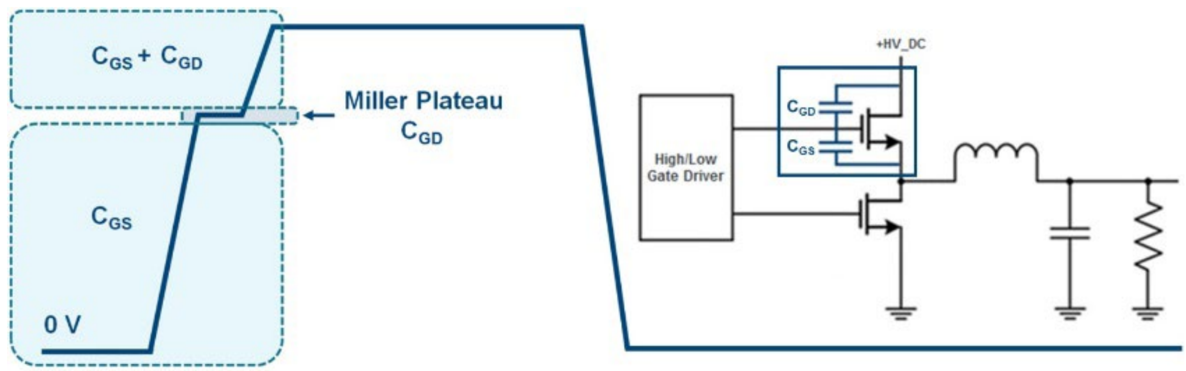


Figure 8: High side turn on characteristics.

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.

Comparing this actual output to the ideal transition, it's difficult to extract any meaningful details regarding what is happening in each of the regions referenced above and make design decisions based on this measurement. It's worth noting that the waveform shown below in **Figure 9** changes dramatically based upon position of the probe's input leads making a repeatable measurement impossible.

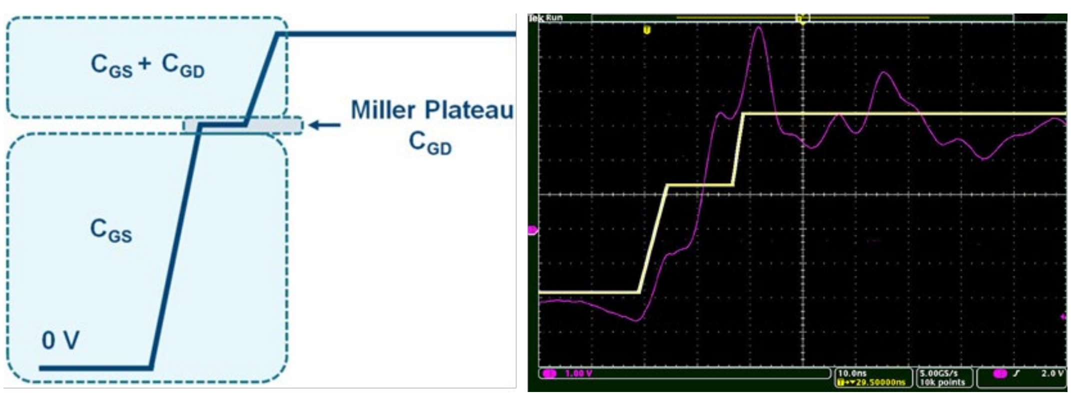


Figure 9: VGS Measurement using a probe with inadequate CMRR.

Until now, a traditional high voltage differential probe 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. After all, it does seem to show some of the expected characteristics. However, the IsoVu Gen 2 system shows a very different story. **Figure 10** 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 severely mistune their design. The capture on the left represents the results when measuring with IsoVu first generation (see yellow waveform). The capture on the right reveals how the performance of IsoVu Gen 2 is greatly improved over those of IsoVu first generation (see yellow waveform). IsoVu Gen 2 provides more detailed, accurate, and sensitive results.

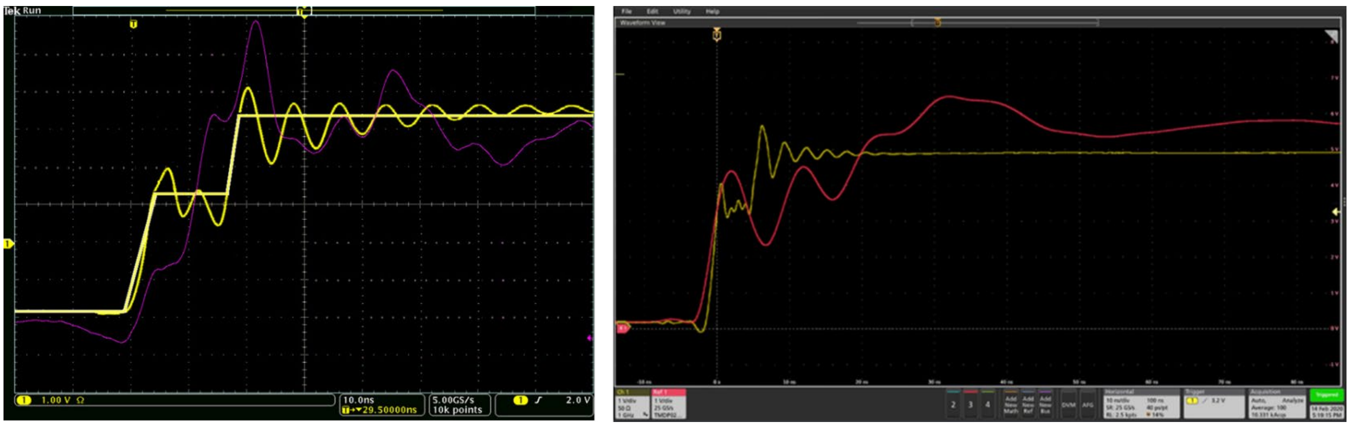


Figure 10: High side turn on characteristics – Comparison between IsoVu first generation (left) and IsoVu Gen 2 (right).

Although the low side switch is supposed to be "ground" referenced, it's also interesting to see the actual waveform and how it may affect the high side performance. **Figure 11** shows the low side switch has ringing due to parasitic coupling between the low side switch, the high side gate, and the switch node. Again, the results of IsoVu first generation (on the left), are compared with the results of IsoVu Gen 2. The capture on the right reveals how the performance of IsoVu Gen 2 is greatly improved over those of IsoVu first generation. IsoVu Gen 2 provides more detailed, accurate, and sensitive results.

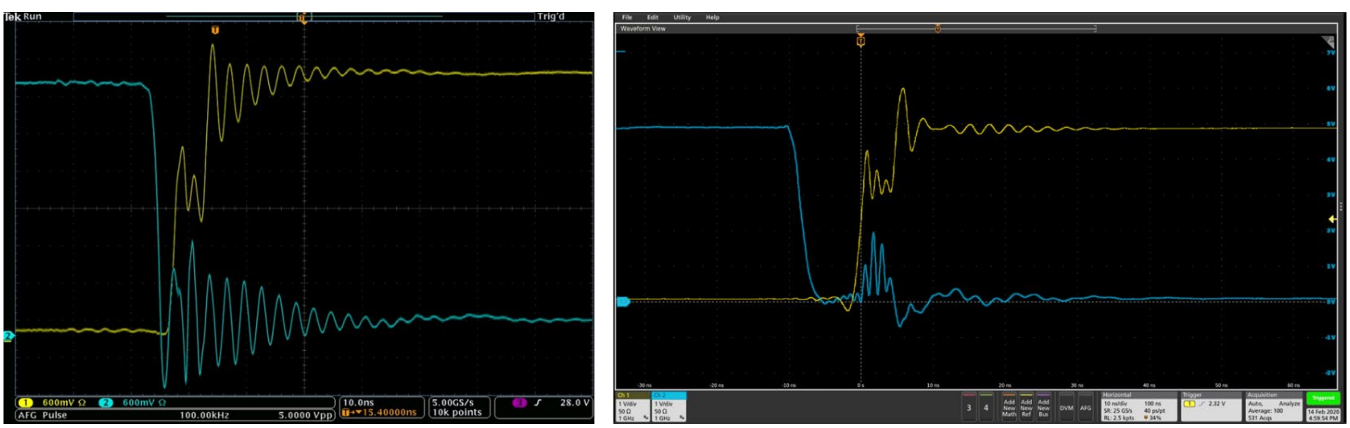


Figure 11: Interaction of the high side and low side switches - Comparison between IsoVu first generation (left) and IsoVu Gen 2 (right).

Many of the same characteristics are apparent during the high-side turn off/low side turn on transitions. As shown in **Figure 12**, 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, and the IsoVu Gen 2 measurement system has more than adequate bandwidth to measure the dead time.

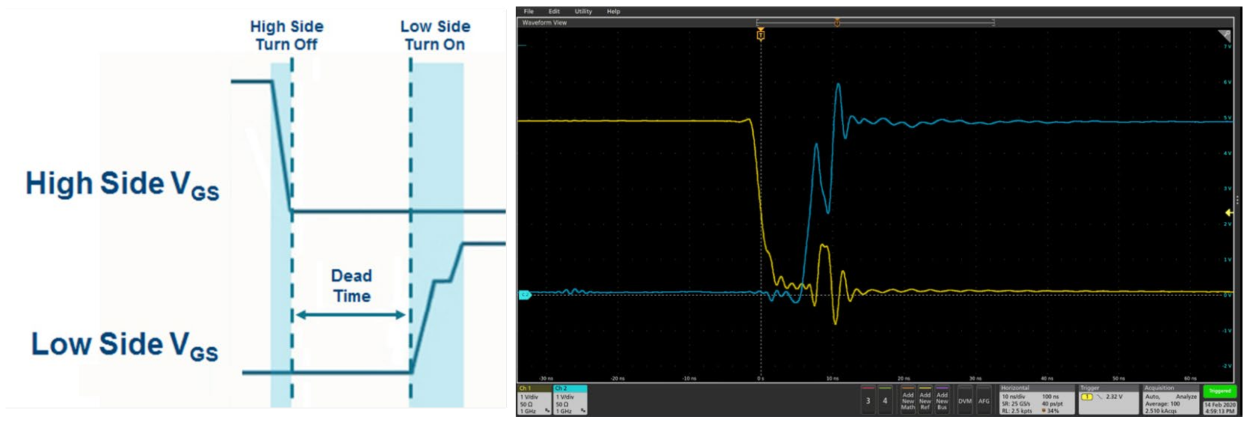


Figure 12: High side turn off, low side turn on, and dead time.

With the IsoVu Gen 2 (TIVP Series), TIVM Series and TIVH Series of products, the entire circuit can be completely characterized as shown in **Figure 13**. IsoVu Gen 2 is able to:

- Characterize the gate voltages, V_{DS} and I_S
- Characterize the time alignment of high and low side events
- Optimize and tune switching characteristics (edge rates, overshoot, ringing, and dead time)

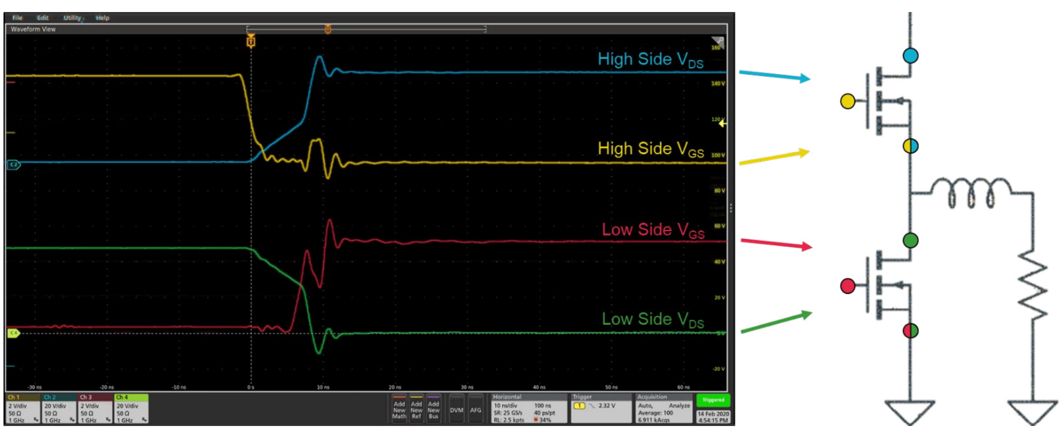


Figure 13: High side turn off, low side turn on, and dead time.

Different Tip Connectors

Designed for Optimal Performance and Convenience

MMCX Style Sensor Tip Cables (high performance up to 250 V applications)

The best performance from IsoVu Gen 2 measurement system is achieved when an MMCX connector is inserted close to the test points. MMCX connectors are an industry standard and are available from many electronic component distributors. These connectors offer high signal fidelity. The solid metal body and gold contacts provide a well-shielded signal path. The mating MMCX interface offers a Snap-On connection with a positive retention force for a stable, hands-free connection. The disengage force provides a safe, stable connection for high voltage applications. MMCX connectors are available in many configurations as shown below and can be adapted to many designs, even if the connector was not designed into the board. Information for soldering these connectors into your design can be found at tek.com/isolated-measurement-systems.

Figure 14: MMCX connectors.

Square Pin to MMCX Adapters

When an MMCX connector cannot be used, the tip cable can be adapted to fit onto industry standard square pins. Tektronix provides probe tip adapters to connect the sensor tip cables to square pins on the circuit board. Two adapters with different pitches are available, MMCX-to-0.1-inch (2.54 mm) and MMCX-to-0.062-inch (1.57 mm).

The adapters have an MMCX socket for connection to an IsoVu tip cable. The other end of the adapter has a center pin socket and four common (shield) sockets around the outside of the adapter. Notches on the adapters can be used to locate the shield sockets. The best electrical performance is achieved when the probe tip adapter is close to the circuit board.

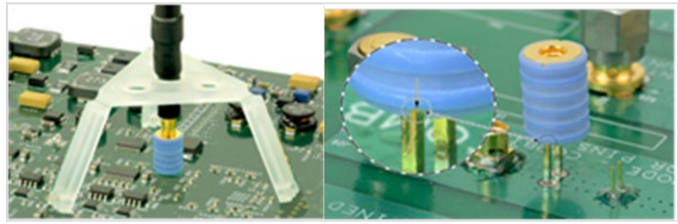


Figure 15: MMCX to square pin adapter.

Square Pin Style Sensor Tip Cables

The TIVP Series (IsoVu Gen 2) products also include square pin style sensor tip cables to achieve higher input differential voltage capability. These tip interfaces offer both ease of connectivity and a secure connection for safe, hands free operation in high voltage environments. The square pin style sensor tip cables are available in both 0.100 in (2.54 mm) pitch that can be used in applications up to 600 V and 0.200 in (5.08 mm) pitch that can be used in applications up to 2500 V.

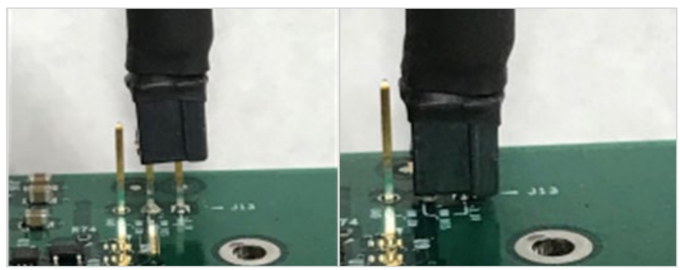


Figure 16: Square pin style sensor tip cables.

Conclusion

Accurate differential measurements rely on a measurement system's bandwidth, rise time, common mode voltage range, common mode rejection capability, and the ability to connect to smaller test points to characterize devices that are shrinking in size and increasing in performance. While differential voltage probes have had modest performance gains in bandwidth, these probes have failed to make any substantial improvements in common mode rejection and connectivity. The IsoVu Gen 2 measurement system is a leap forward in technology and is the only solution with the required combination of high bandwidth, high common mode voltage, and high common mode rejection to enable modern differential measurements.

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