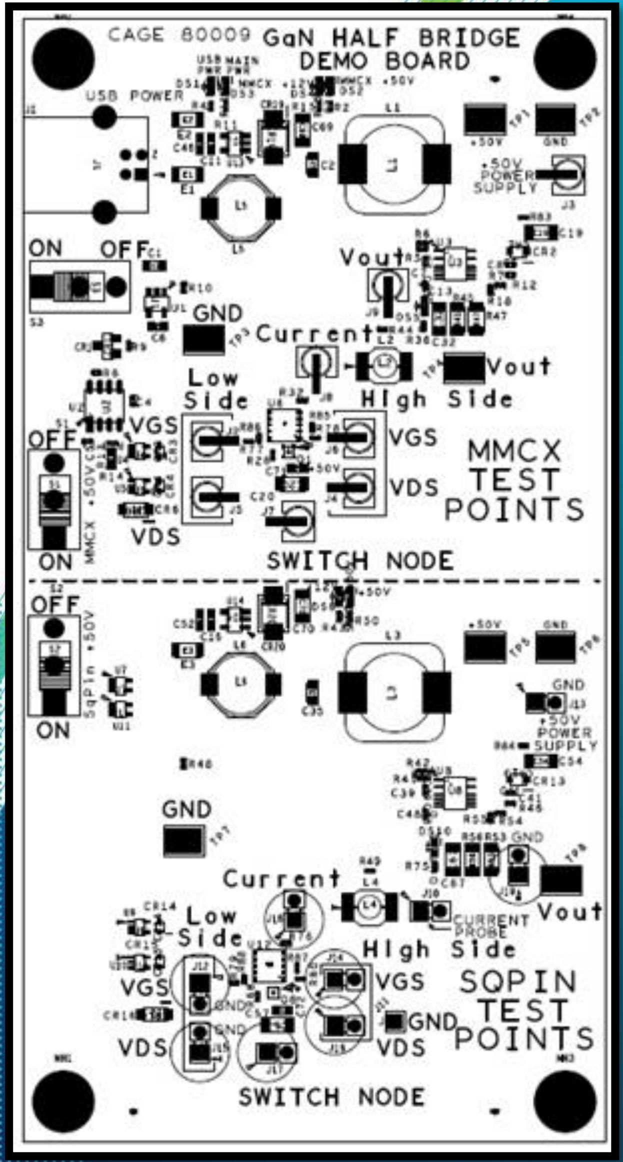
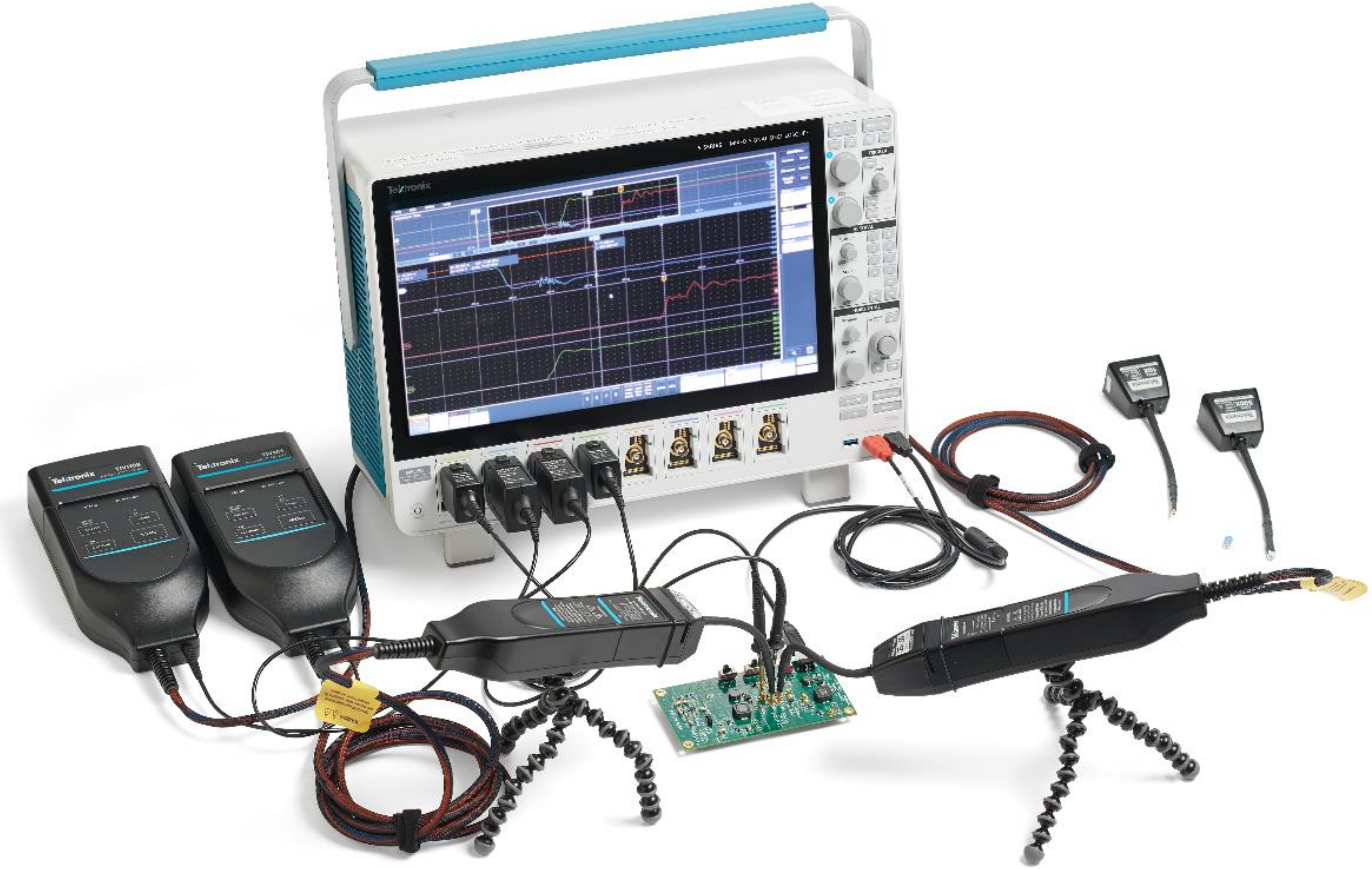
Tektronix

# SiC and GaN Power Converter Analysis Kit

## Instruction Guide





# SIC AND GAN POWER CONVERTER ANALYSIS KIT

1. **5 Series MSO:** (1 GHz) Oscilloscope
2. **5-PWR Software:** Power analysis software
3. **TIVH08:** (2.5 kV, 800 MHz) High voltage isolated differential probes
4. **TIVH05 (Optional):** (2.5 kV, 500 MHz) High voltage isolated differential probes
5. **TIVM1 (Optional):** (50 V, 1 GHz) High BW Isolated differential probes
6. **TPP1000 (Free):** (1 GHz) High BW passive probe. Comes standard with scope. One per channel.
7. **MMCX Tip for TPP1000 (Optional):** Passive probe MMCX Tip for high BW performance.
8. **GaN Half-bridge Demo Board Guide:** Instruction Guide for getting started.

* All products come standard with their own accessories.

# Index

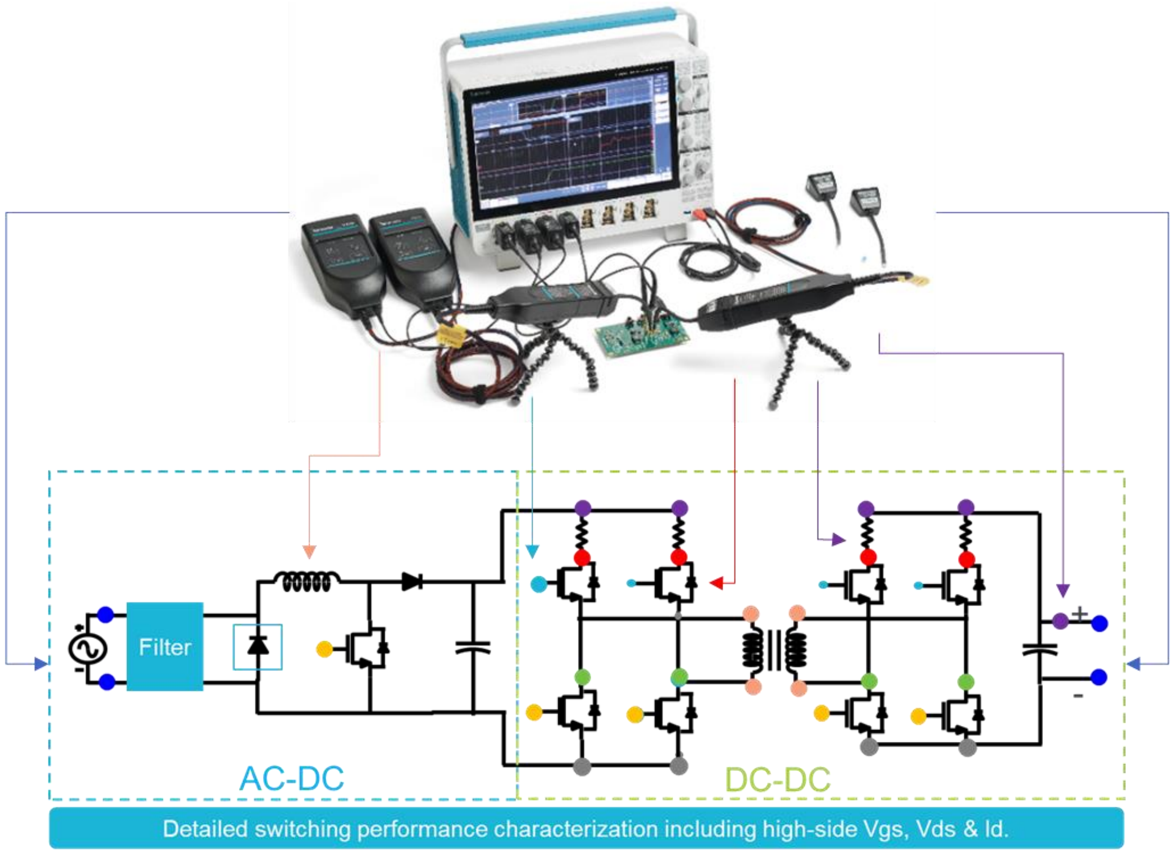
## SIC AND GAN POWER CONVERTER SWITCHING ANALYSIS

# Introduction

The SiC and GaN Switching Power Converter Analysis Kit is the ONLY solution in the market that can accurately characterize most of the critical parameters for optimizing Power Electronics topologies that use ultra-fast, power semiconductor switching technology such as SiC, GaN and even some silicon-based MOSFET and IGBTs.

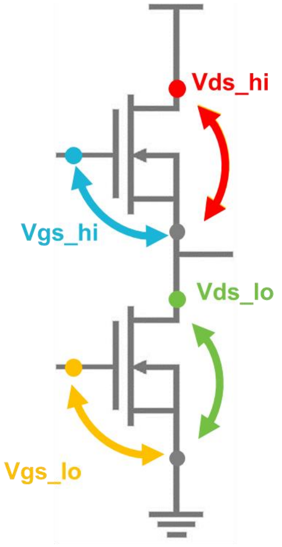
Characterize:

- $V_{GS}$, $V_{DS}$ and $I_D$ measurements on high-side and low-side switches.
- Dead time optimization, including accurate turn-on, turn-off and gate-drive timing analysis.
- Switching and conduction loss measurements.
- Magnetic performance, losses and system efficiency.



# GaN Half-bridge Evaluation Board Connections

2X

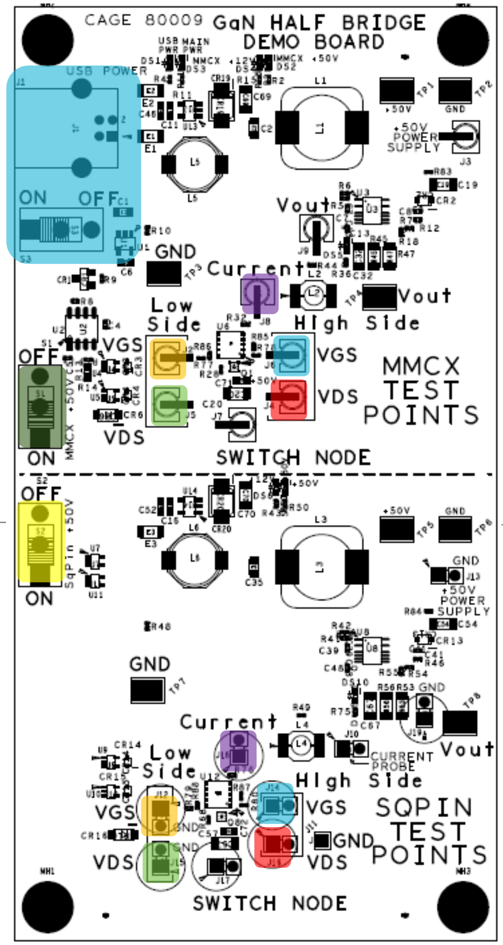



USB Power

Main Power Switch (S3)

MMCX Board Power Switch (S1)

Square Pin Board Power Switch (S2)




VGS_High Side (MMCX)

VDS_High Side (MMCX)

VGS_Low Side (MMCX)

VDS_Low Side (MMCX)

Shunt Current (MMCX)

VGS_High Side (Square Pin)

VDS_High Side (Square Pin)

VGS_Low Side (Square Pin)

VDS_Low Side (Square Pin)

Shunt Current (Square Pin)

- Two independent GaN-based half-bridge circuits.
- Choose between MMCX connectors (top half) or the Square pin connectors (bottom half) for your evaluation.
- DC Bus Voltage 50 V; Gate Voltage 5 V
- USB Powered *

*Use both ports of the provided dual-input USB cable. Using any other cable can cause serious damage to the oscilloscope's USB port.

# Selecting the Right Sensor Tip for TIVM

**For this Demo, TIVM1 probe system is used to measure floating, high dv/dt Gate-Source ($V_{GS}$) signal:**

- Maximum dv/dt: 5 V/1 nS = 5 V/ns
- Maximum differential voltage at the test points: **7 $V_{pk\text{-}pk}$**
- Minimum differential loading (input impedance) that the circuit can tolerate : **1 KΩ**
- Required measurement sensitivity (V/div) **<50 mV/div**
- **Sensor tip selected: IVTIP25X:** ±25 V; 1.25 kΩ // <1 pF; 25 mV/div

| ISOVU TIVH SERIES | | | | | | |
|---|---|---|---|---|---|---|
| **Sensor Tip Cable** | Connection to DUT | Differential Voltage Range | Offset Range | Input Impedance | Most Sensitive V/div Setting | Attenuation |
| **SMA Input** | MMCX | | | | | |
| **IVTIP1X** | MMCX | ± 1 V | ± 2 V | 50 Ω // <1 pF | 1 mV/div | 1X |
| **IVTIP5X (Standard)** | MMCX | ± 5 V | ± 10 V | 250 Ω // <1 pF | 5 mV/div | 5X |
| **IVTIP10X** | MMCX | ± 10 V | ± 20 V | 500 Ω // <1 pF | 10 mV/div | 10X |
| **IVTIP25X (Standard)** | MMCX | ± 25 V | ± 50 V | 1.25 kΩ // <1 pF | 25 mV/div | 25X |
| **IVTIP50X (Standard)** | MMCX | ± 50 V | ± 100 V | 2.5 kΩ // <1 pF | 50 mV/div | 50X |

*Note: Specifications are dependent on the probe tip cable.*

# Selecting the Right Sensor Tip for TIVH

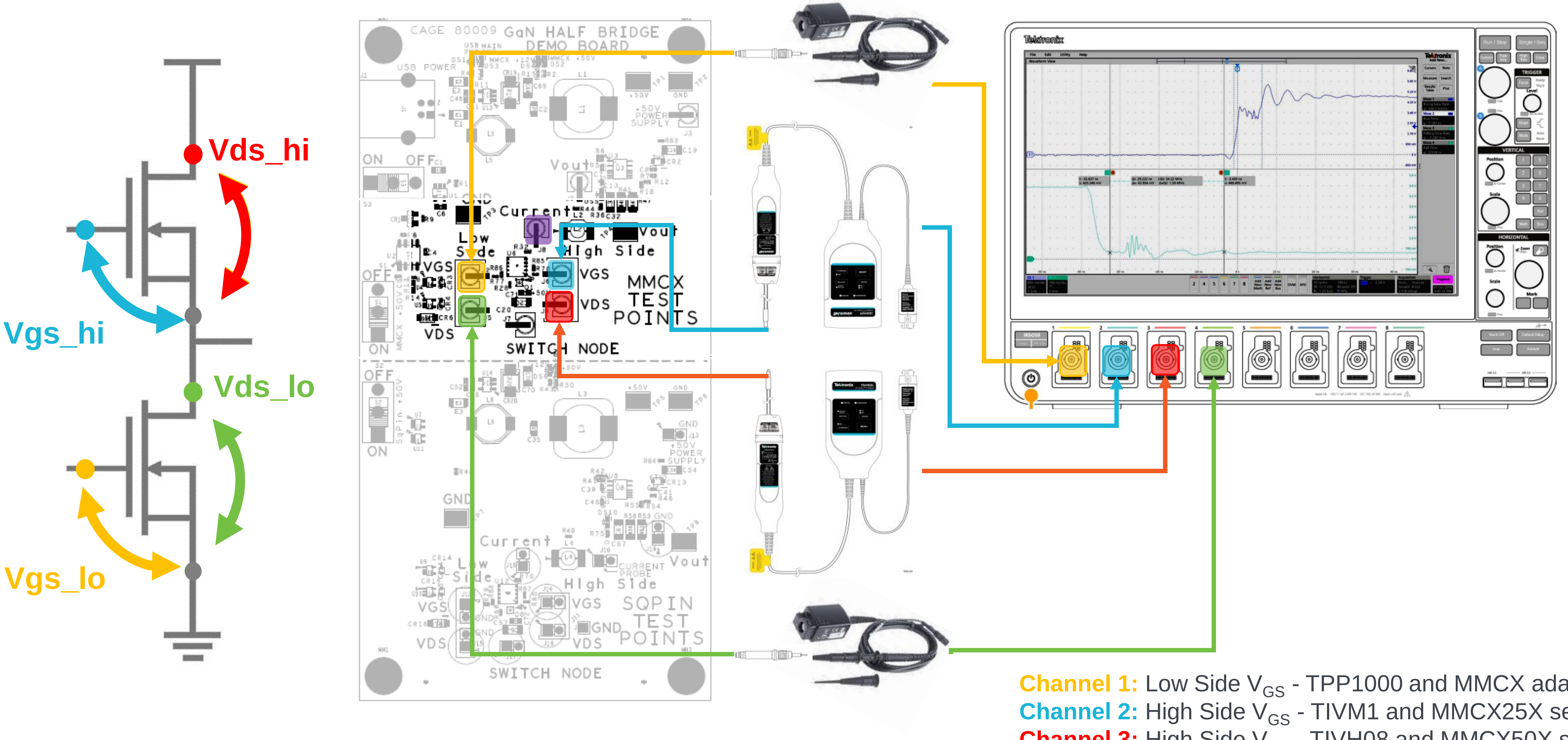
**For this Demo, TIVH probe system is used to measure floating, high dv/dt Drain-Source ($V_{DS}$) signal:**

- Maximum dv/dt: 50 V/5ns = 10 V/ns
- Maximum differential voltage at the test points: **50 $V_{pk-pk}$**
- Minimum differential loading (input impedance) that the circuit can tolerate: 10 kΩ
- Required measurement sensitivity (V/div): 10 V/div
- **Sensor tip selected: MMCX50X:** ±50 V; 10 MΩ // <3 pF; 50 mV/div

| ISOVU TIVH SERIES | | | | | | |
|---|---|---|---|---|---|---|
| **Sensor Tip Cable** | Connection to DUT | Differential Voltage Range | Offset Range | Input Impedance | Most Sensitive V/div Setting | Attenuation |
| **Direct Connection into SMA Input of the Sensor Head** | | | | | | |
| **SMA Input** | MMCX | ± 1 V | ± 25 V | 1 MΩ // 20 pF | | 1X |
| **Requires MMCX Style female connectors on the DUT** | | | | | | |
| **MMCX10X** | MMCX | ± 10 V | ± 250 V | 10 MΩ // 6 pF | 10mV | 10X |
| **MMCX50X (Standard)** | MMCX | ± 50 V | ± 250 V | 10 MΩ // 3 pF | 50mV | 50X |
| **MMCX250X** | MMCX | ± 250 V | ± 250 V | 10 MΩ // 2 pF | 250mV | 250X |
| **Requires 0.100” Pitch (2.54 mm) Square Pins on the DUT** | | | | | | |
| **SQPIN100X** | Square pin | ± 100 V | ± 600 V | 10 MΩ // 3.5 pF | 100mV | 100X |
| **SQPIN500X (Standard)** | Square pin | ± 500 V | ± 600 V | 10 MΩ // 3.5 pF | 500mV | 500X |
| **Requires 0.200” Pitch (5.08 mm) Square Pins on the DUT** | | | | | | |
| **WSQPIN1000X** | Square pin | ± 1000 V | ± 1000 V | 40 MΩ // 3 pF | 1.0V | 1000X |
| **WSQPIN2500X** | Square pin | ± 2500 V | ± 1000 V | 40 MΩ // 3 pF | 2.5V | 2500X |

*Note: Specifications are dependent on the probe tip cable*

# Make Connections – $V_{DS}$ and $V_{GS}$ Measurements

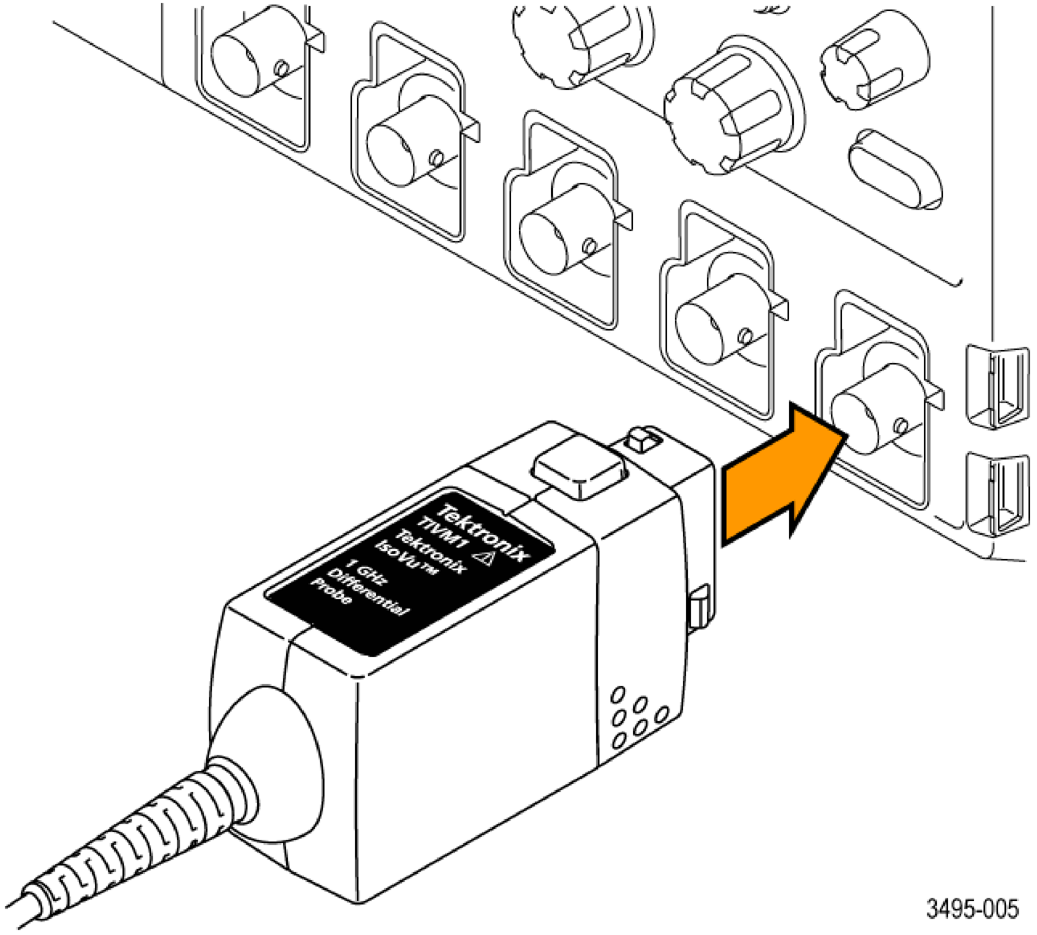



**Channel 1:** Low Side $V_{GS}$ - TPP1000 and MMCX adapter tip.
**Channel 2:** High Side $V_{GS}$ - TIVM1 and MMCX25X sensor tip.
**Channel 3:** High Side $V_{DS}$ - TIVH08 and MMCX50X sensor tip.
**Channel 4:** Low Side $V_{GS}$ - TPP1000 and MMCX adapter tip.

***Do not use TPP1000 passive probe for any high-side, floating measurements. This can cause serious damage to the oscilloscope input.**

# Before Making Measurements

1. Once all the connections are made, turn on the oscilloscope by pushing the power button in the lower left corner of the front panel.
2. Press ‘Default Setup’ button on the oscilloscope.
3. Turn on Ch1, Ch2, Ch3, Ch4 on the oscilloscope by double-clicking on the respective channels’ badges on the bottom ribbon.
4. **Before** turning the GaN evaluation board ON or making any measurements, run following settings on **all active channels**. (Details on the following pages):
   - Self Calibration (IsoVu only)
   - Auto Zero (IsoVu only)
   - Deskew
   - Probe Compensation (passive probes only)



# Self Calibration for IsoVu Probes

The SELF CAL sequence should always be run on an IsoVu probe after it is first powered on and has **warmed up for 20 minutes**.

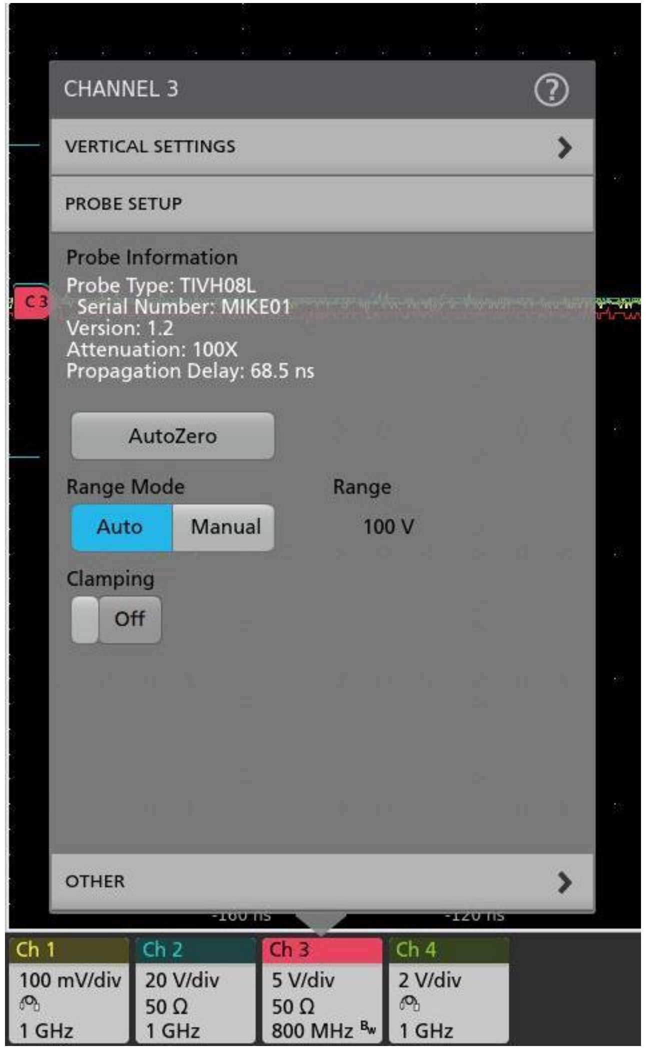
1. Make sure there is no differential signal present at the sensor tip cable.
2. Press the SELF CAL button on the controller to adjust the operating point of the measurement system.
3. The indicator blinks orange during the self calibration process; it turns solid green when the operation completes or solid red when the operation fails.

- Always run Self Calibration in following situations:
  - The measurement system is first attached to the oscilloscope.
  - Changes are made to the range (1X|2X), internal compensation or clamp (ON|OFF) setting.
  - The temperature in the sensor head changes more than 10°C.
  - The sensor tip cable is changed.

# Auto Zero for IsoVu Probes

Run Autozero on start or when the displayed waveform is not centered correctly (for example, due to a small DC offset error).

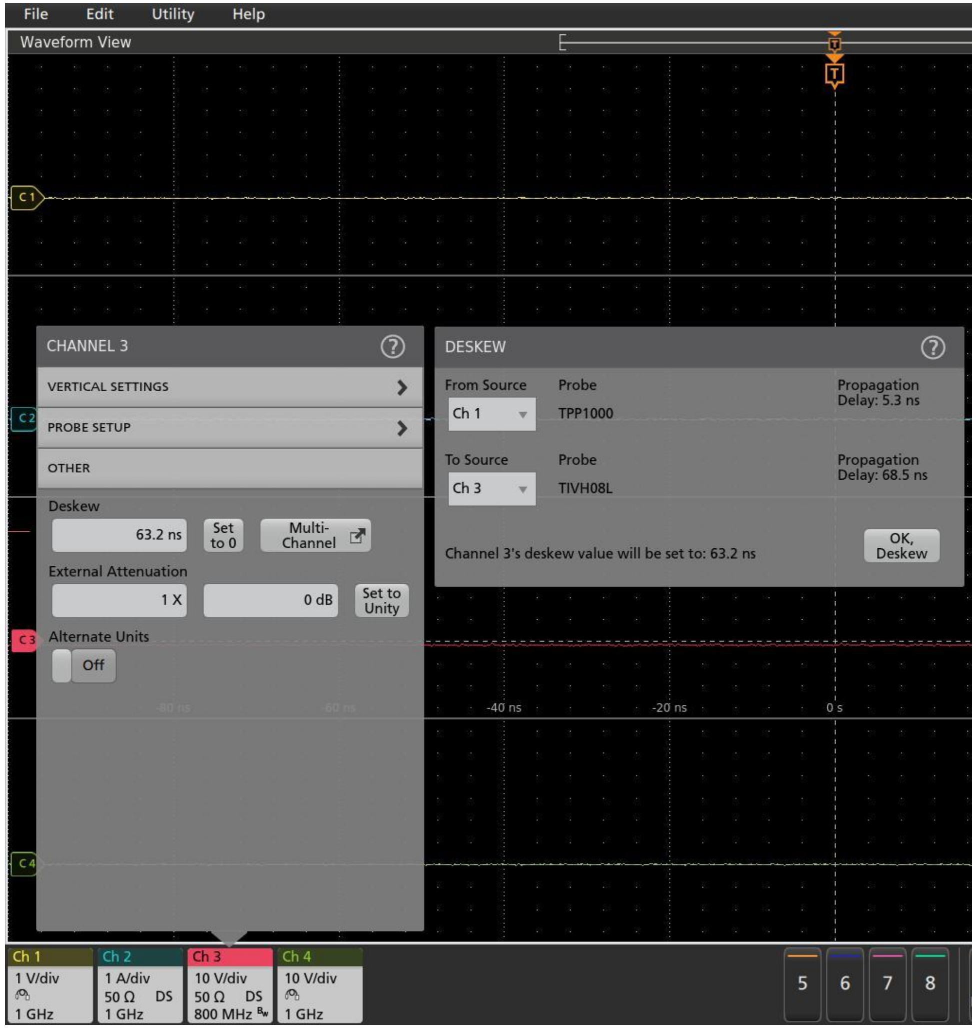
1. Make sure there is no differential signal present at the sensor tip cable.
2. Press the MENU button on the IsoVu controller to view the Probe Setup menu* on the oscilloscope.
3. Press the Autozero button in the Probe Setup menu of the oscilloscope.
4. Repeat this for all the connected IsoVu probes.



# Deskew All Probe Channels

Running Deskew is very important to get accurate delays between the signals. Double-tap the Ch1 badge and go to ‘Other’ Menu.

1. Set the Ch1 Deskew to 0 by pressing ‘Set to 0’ soft button.
2. To set other channels’ Deskew, press the ‘Multi Channel’ soft button. This will open an Deskew setting popup.
3. Select ‘From Source’ as Ch1, ‘To Source’ as Ch2, and press the ‘OK, Deskew’ button.
4. This will deskew the second channel using the default propagation delay for each probe.
5. Repeat this step for all channels and deskew them with respect to Ch1.



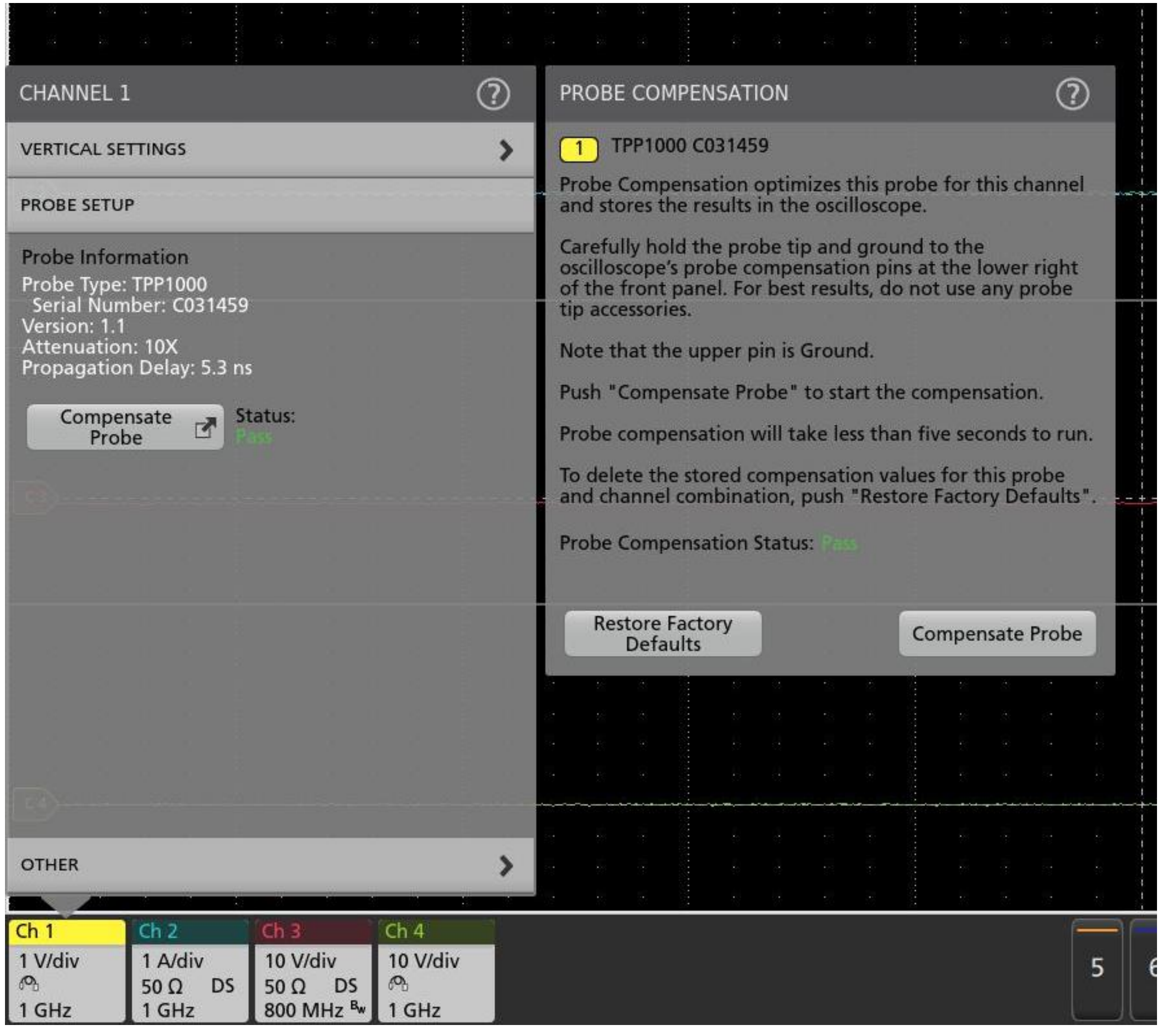
# Probe Compensation for Passive Probes

Probe compensation optimizes probes to a specific channel and stores the results to the oscilloscope.

IsoVu probes are compensated at the factory and do not need any additional compensation.

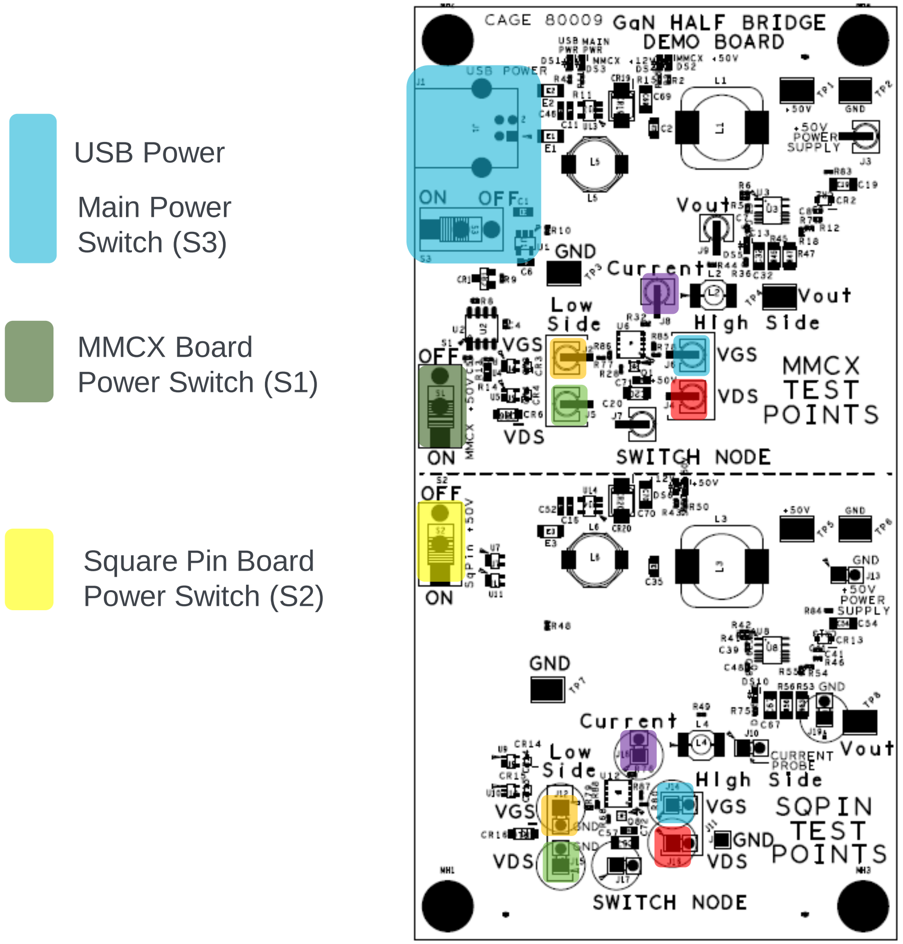
For all other passive probes, run the probe compensation under the Probe Setup menu by double-tapping the respective channel badges.

Follow the instructions under the ‘Probe Compensation’ popup.



# Powering on the GaN Half-bridge Evaluation Board

1. Once all the pre-requisite settings are applied, connect the supplied dual-input USB cable to two of the oscilloscope USB ports *before* connecting the cable to the USB Power input on the demo board. Using any other cable can cause serious damage to the oscilloscope's USB port due to high inrush current on the board.
2. Now, connect the GaN Half-bridge **board power (USB power)** to the USB cable.
3. The green LED labeled 'USB PWR' on the board will turn on and remain steady when the USB cable is connected.
4. Turn **Switch S3**, next to the USB input, to the ON position to turn on the main board power.
5. Next, turn ON **Switch S1** to power the upper half of the board with MMCX test points.
6. Now, you are ready to make the measurements.




GaN Half-bridge Evaluation Board

***Use both ports of the provided dual-input USB cable. Using any other cable can cause serious damage to the oscilloscope's USB port.**

# Test 1:

## Gate-charge Characterization and Effective Dead Time Analysis

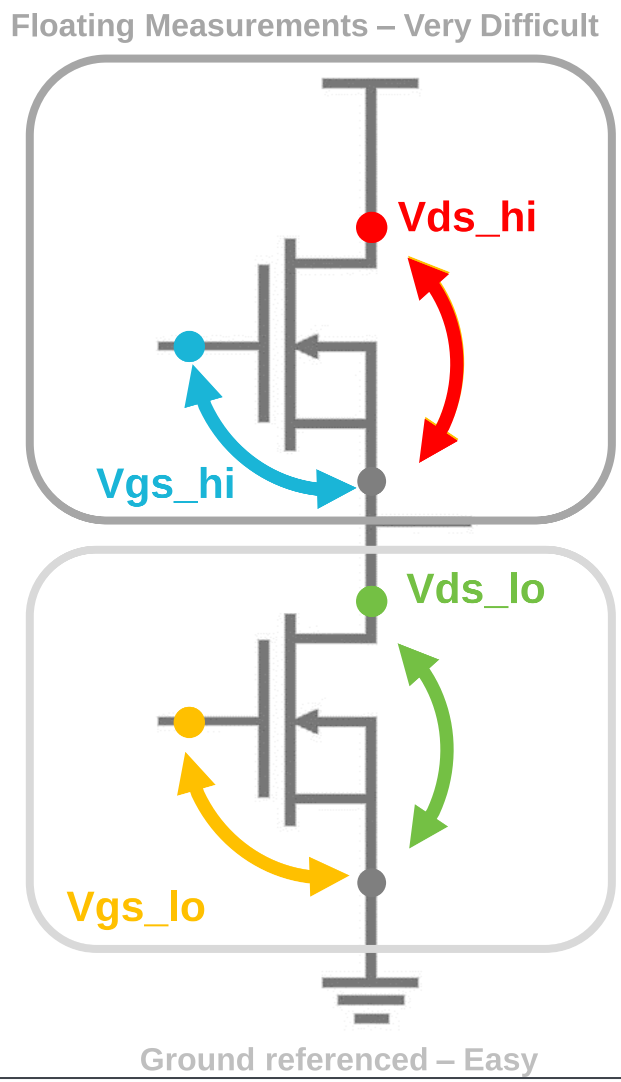
- Measuring high-side $V_{GS}$ and low-side $V_{GS}$ simultaneously
- Measuring high-side $V_{DS}$ and low-side $V_{DS}$ simultaneously

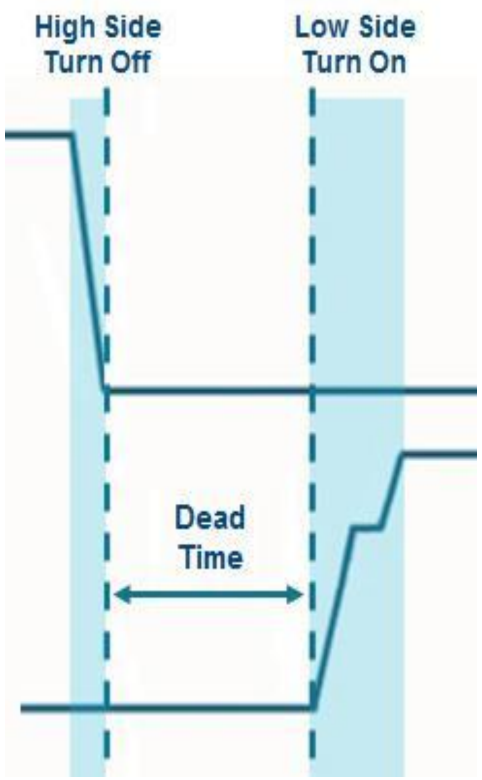
# Gate-charge Characterization and Effective Dead Time Analysis

Getting the best performance out of a SiC- or GaN-based power converter topology requires optimizing dead time and gate charge characteristics. This requires accurate measurement of all high-side and low-side gate-source ($V_{GS}$) and drain-source ($V_{DS}$) voltages.

Measuring the signals on the low-side, ground referenced switch is possible with a passive probe setup, but ground return currents and the ground lead inductance of a traditional passive probe can degrade the measurement. The high-side, high frequency, floating measurements are almost impossible to measure using traditional differential measurement systems due to the presence of high common-mode voltage.

The following section will demonstrate how to make all gate-source ($V_{GS}$) and ($V_{DS}$) measurements accurately.



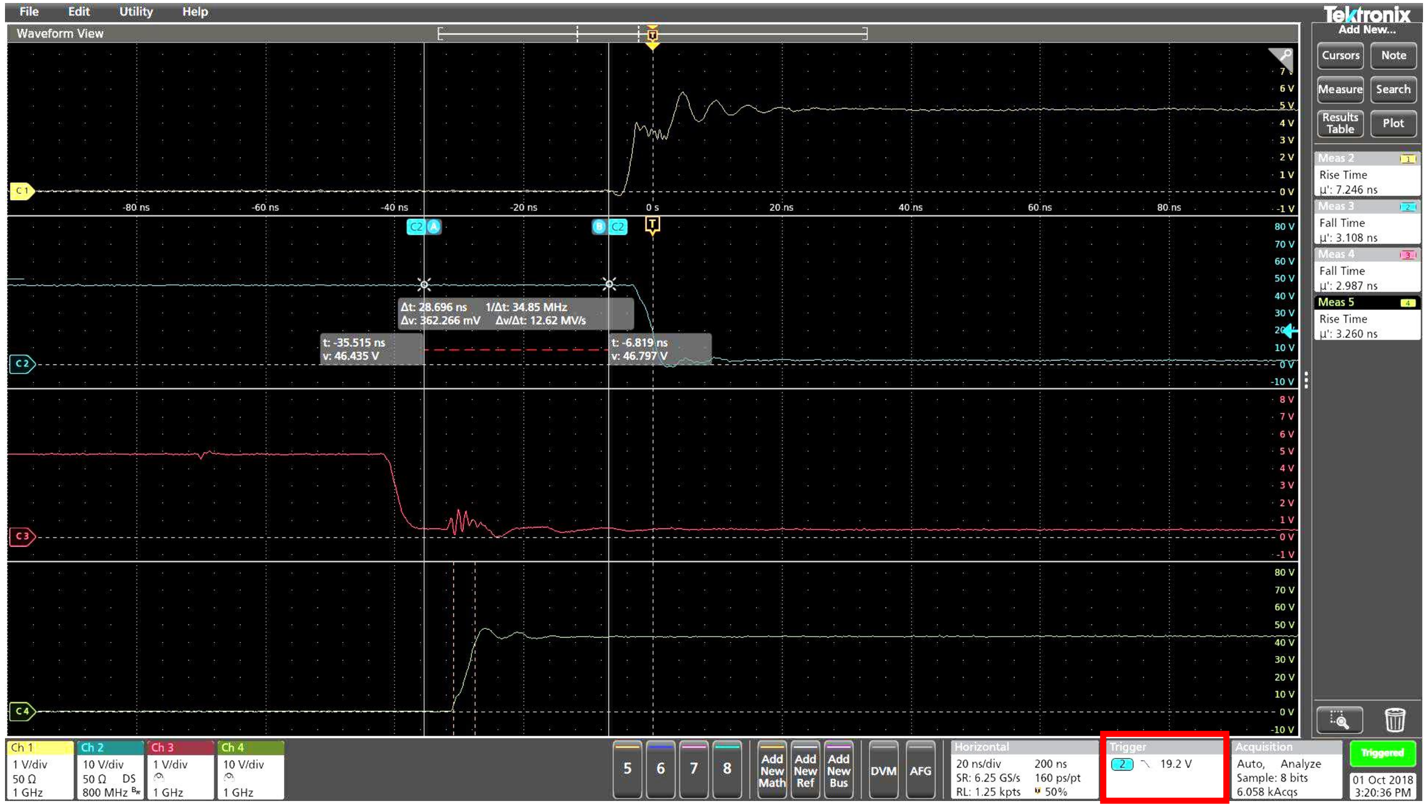
# On-Screen Setup – All Measurements

1. Start by pressing the ‘Autoset’ button on the front panel. This will adjust the screen to show all the waveforms simultaneously.

2. Press trigger badge and set the trigger on Ch2 (Vgs_High Side) rising edge and set trigger to 50%.

3. For the most accurate measurements, the probe’s offset function should be used to center the signals on the display; for instance, the 0-50 V $V_{DS}$ signals should be offset 25 V).

4. Enable cursors to analyze dead time and switch characteristics.



# High-Side and Low-Side $V_{GS}$ Measurements

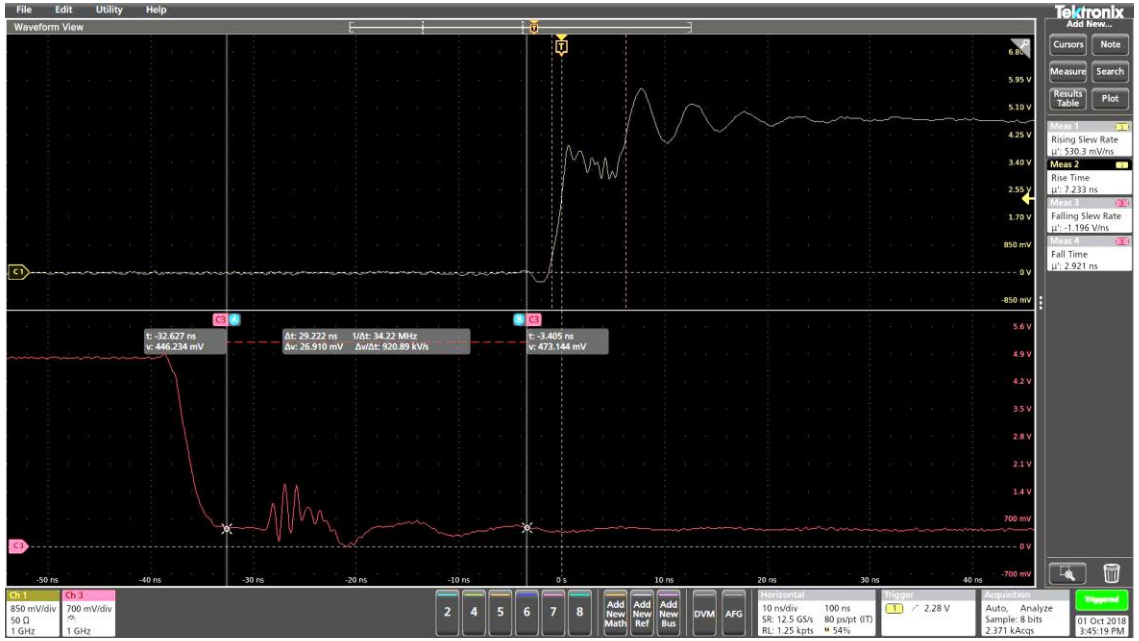
1. Turn off Ch3 and Ch4 by double-tapping the respective channel badges and tapping the display button to OFF. This will give a clear view of gate-source ($V_{GS}$) signals on the low side and high side.

2. Set trigger on Ch2 and adjust the horizontal scale to 10 nS/div to fill the screen with the turn-on (rise) sequence on Ch2 (Vgs_hi).

3. Adjust the vertical scale on Ch2 and Ch1 to 1 V/div. Alternatively, use pinch and zoom to view the gate-charge response on the gate signals.

4. Miller plateau and dead time should be clearly visible for analysis. Use cursors for further evaluation.

5. Use the Measure button on the right soft panel to enable Rise Time, Fall Time, Slew rates and other critical measurements for each channel. Note that the rise time measurement might include the time to charge the Miller capacitance, depending on where the reference level is set.



# High-Side and Low-Side $V_{DS}$ Measurements

1. Turn on Ch3 (Vds_hi) and Ch4 (Vds_lo) and turn off Ch1(Vgs_lo) and Ch2(Vgs_hi) to get a clear view of drain-source ($V_{DS}$) signals on the high side and low side.

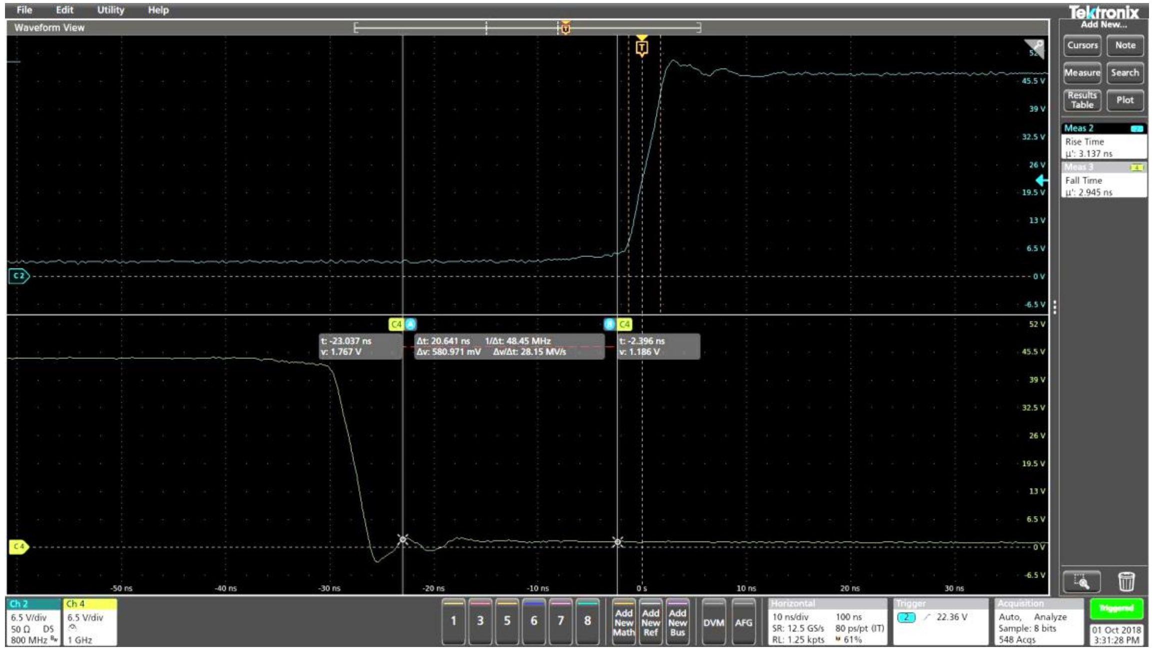
2. Set the trigger on Ch3 (Vds_hi) falling edge.

3. Adjust the horizontal scale to 200 ns/div to view the dead time between the (Ch3) Vds_hi falling edge and Ch4 (Vds_lo) rising edge.

4. Adjust the vertical scale on Ch3 and Ch4 to 10 V/div. Alternatively, use pinch and zoom to view the drain-source response on the full screen.

5. Dead time should be clearly visible. Use cursors to evaluate dead time and rise-fall time characteristics.

6. Use the Measure button on the right soft panel to enable Rise Time, Fall Time, Slew rates and other critical measurements for each channel.




*Note: Turn on Ch2 (Vgs_hi) and Ch3 (Vds_hi) to view $V_{GS}$, Miller charge time and $V_{DS}$ turn-on correlation (not demonstrated).*

# Test 2:

Fast-Switching Load Current or Drain Current Analysis

- Measuring high di/dt switching, drain/load current using a shunt

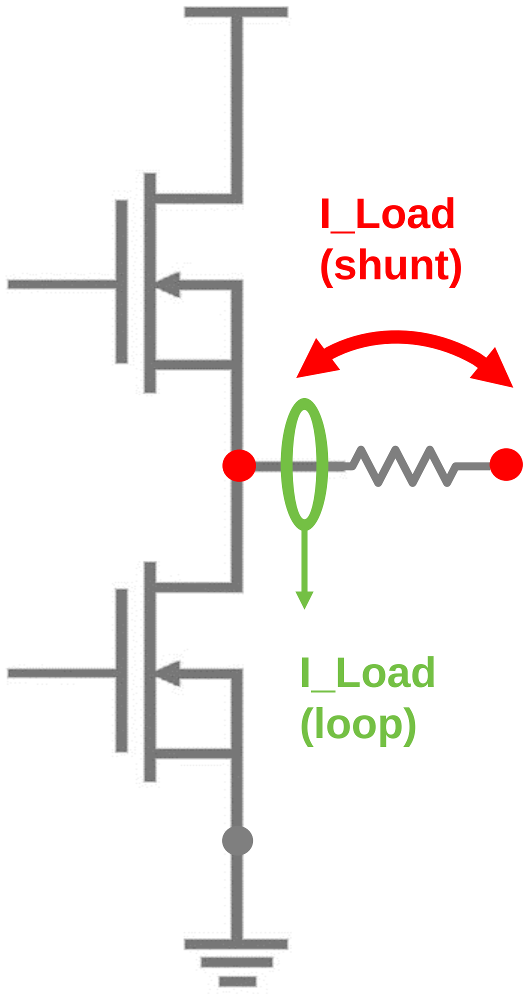
# Fast-Switching Load Current or Drain Current Analysis

Testing high di/dt load and drain current is critical for optimizing power converter performance. The most common methods of measuring these currents involves inserting either a wire loop for a current probe or a resistive current shunt at the test point.

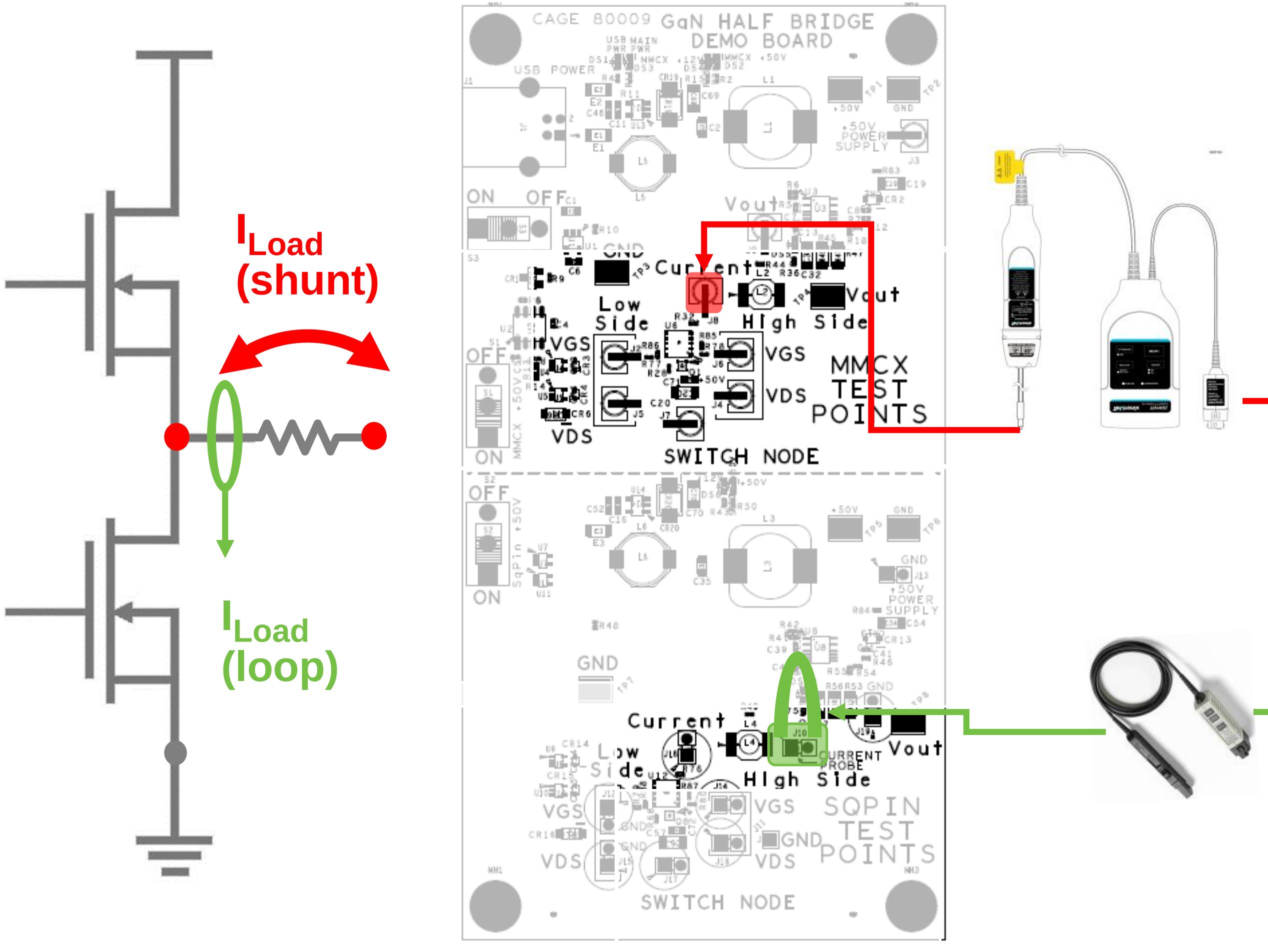
The added inductance of a wire loop for a current probe can have a negative impact on the performance of the circuit. Using a low-inductance resistive current shunt can be a better choice in many applications.

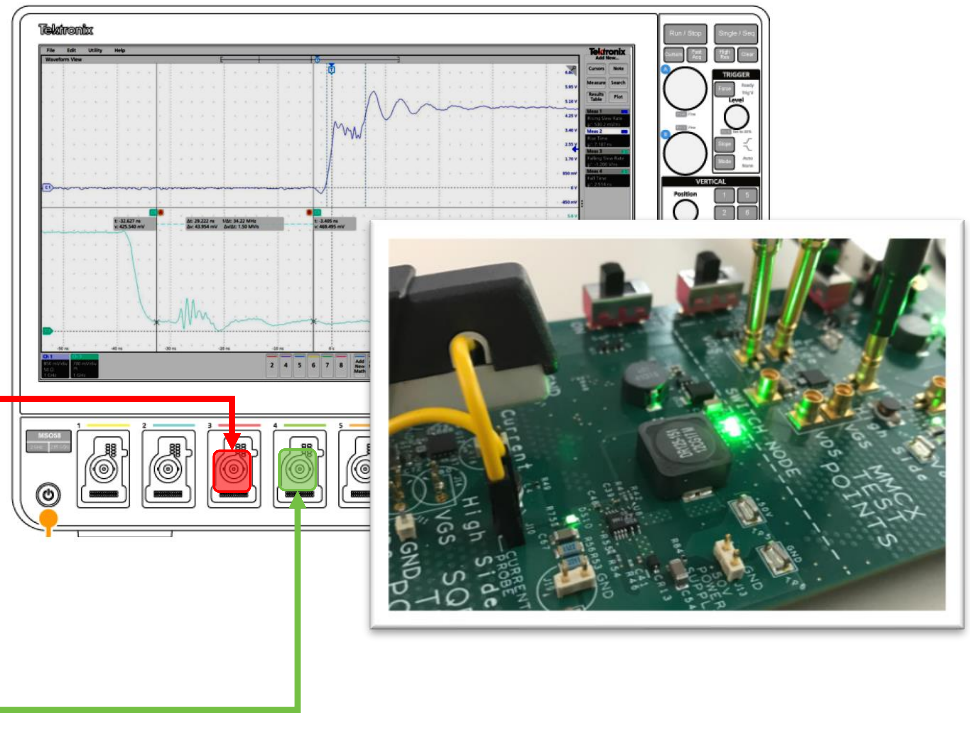
The following section will demonstrate how to make fast-switching load current measurements on a floating shunt using the IsoVu probe.

NOTE: The GaN Evaluation board is not designed to carry any significant current, so use the following steps as representative test only.



# Make Connections – Current Measurements Shunt vs. Loop



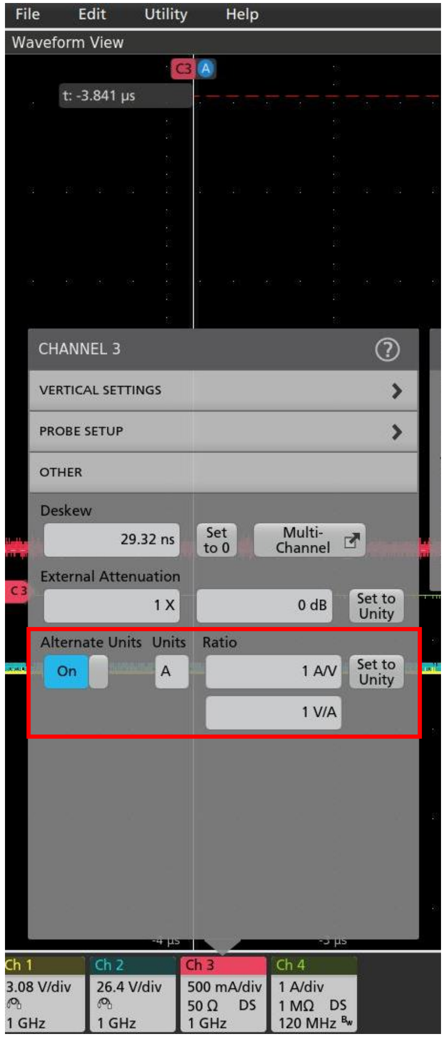




Channel 3: Load current ($I_L$) using a shunt – TIVM1 and MMCX25X sensor tip.
Channel 4: Load current ($I_L$) using a loop – TCP0300A current probe.

* The GaN Evaluation board is not designed to carry any significant current, so use the following steps as representative tests only.

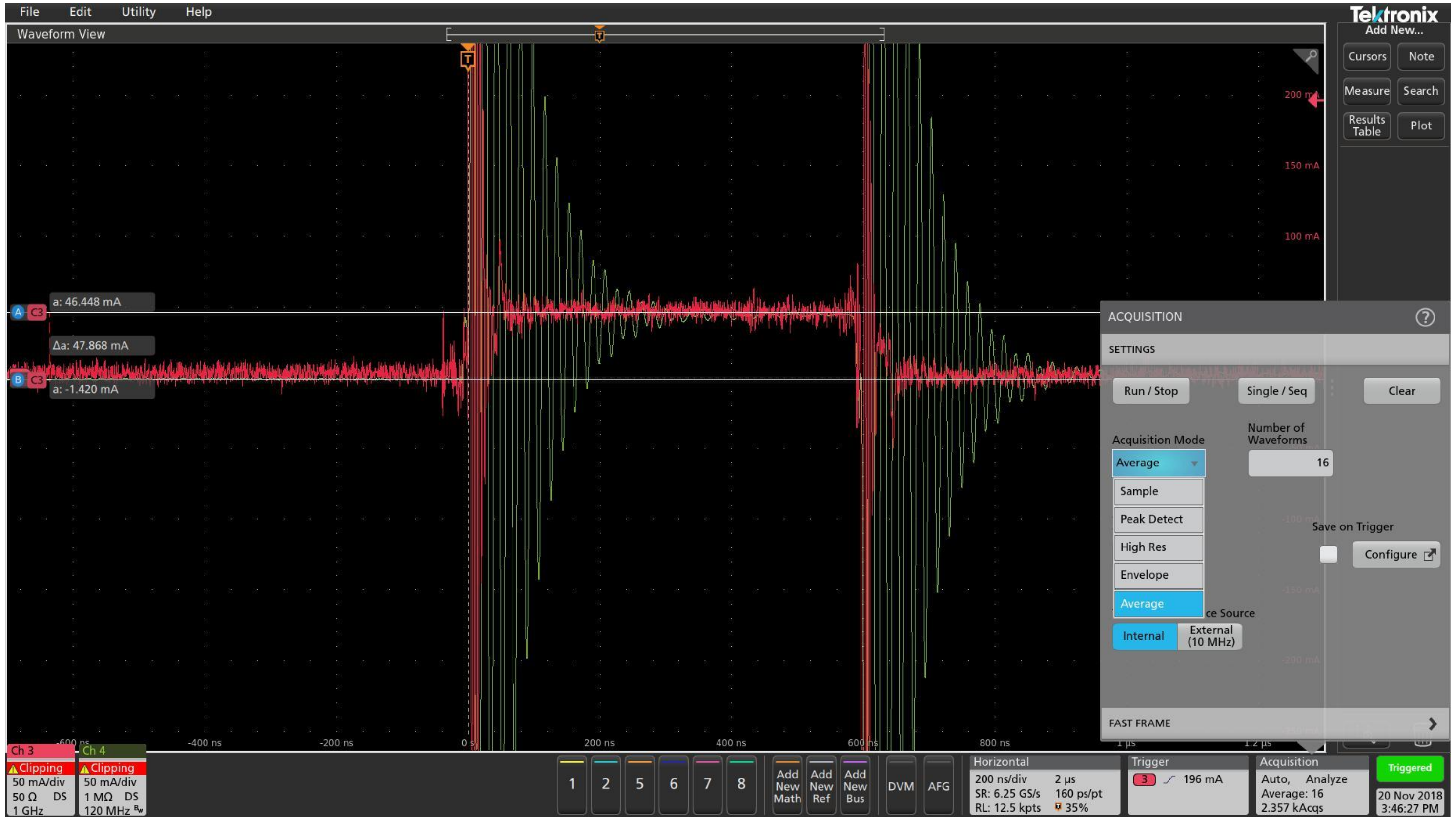
# Fast-Switching Load Current or Drain Current Analysis

- Make sure the Ch3 and Ch4 are deskewed using the steps noted in the Deskew section.
- Because Ch3 -TIVM1 (IsoVu) probe is testing current through a floating shunt, change the measurement unit to current: ‘A’.
- Double-tap the Ch3 badge and under ‘OTHER,’ toggle the ‘Alternate Units’ switch On and set the Ratio to 1 A/V. (Current shunt value on the board is 1 Ω).
- To compare the traditional loop-based measurement with the shunt-based measurement, add current loop using a standard square pin lead on the ‘Current probe’ test-point of the lower GaN Half-bridge circuit.
- Use a high BW current probe (TCP0030A) to measure load current through the loop. Degauss the probe before making the measurement.



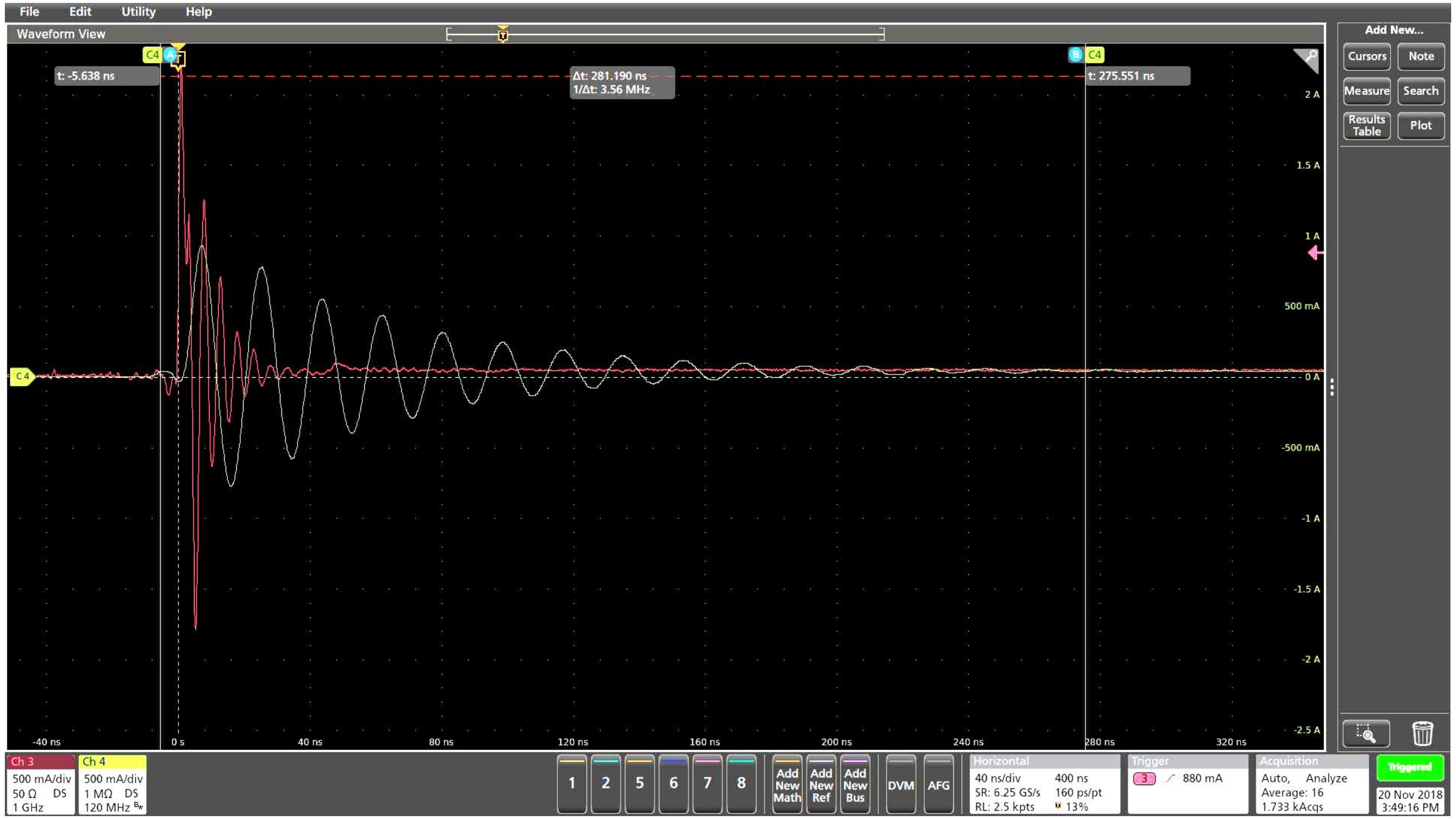
# Measuring Fast-Switching Load Current

- Average current through the shunt in on-state is quite low (~50 mA). The parasitic elements on output circuit causes ringing as high as 4 $A_{pk\text{-}pk}$, which makes it difficult to measure the on-state current.
- To see the on-state current, switch to averaging mode by tapping the Acquisition badge and selecting Average from Acquisition mode.
- The vertical scale might have to be extended beyond the clipping range to view the average current.



# Current Measurement – Shunt vs. Loop

- It can be clearly seen from the waveform that adding a loop adds quite a lot of ringing and settling time (~275 ns) vs. (~50 ns) on the shunt-based measurement.
- The effects of lower bandwidth on Hall effect-based current probe are also visible on the low frequency ringing on the loop-based (Ch4) waveform.
- Adding a loop can also affect the performance of gate drive, along with other timing characteristics and can be seen in $V_{GS}$ and $V_{DS}$ measurements.



# Test 3:

## Testing Switching/Conduction Losses and Magnetic Properties

(This test does not use the GaN Evaluation Board)

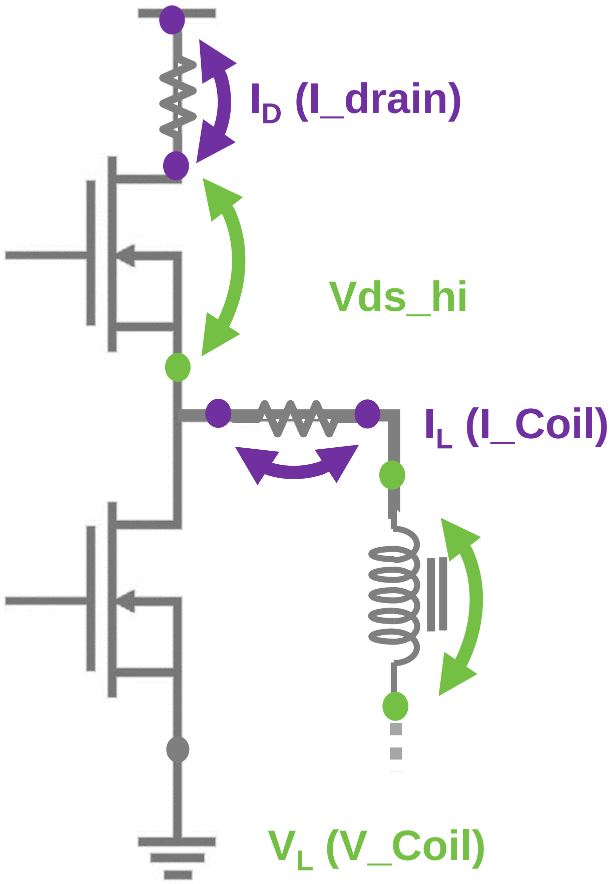
# Switching/Conduction Loss and Magnetic Measurements

Getting the best efficiency and power density out of any power converter requires accurate measurements of switching, conduction and magnetic losses.

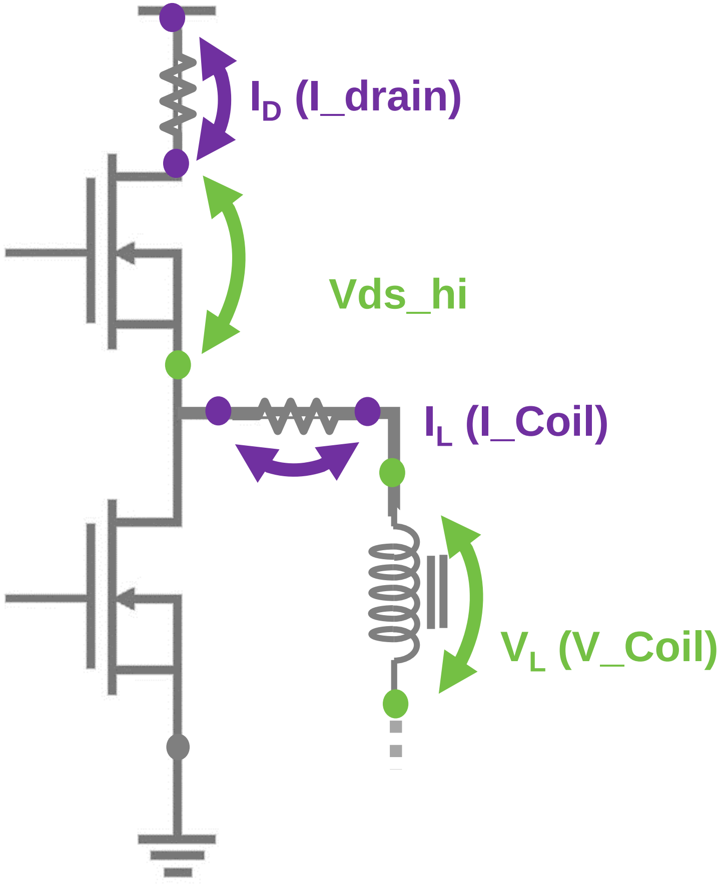
To measure switching and conduction losses, measure the drain-source voltage ($V_{DS}$) and drain current ($I_D$) across the power switch using appropriate probes, as shown in the connection diagram on the next page. For magnetic properties, measure voltage ($V_L$) across the coil and current ($I_L$) through the coil.

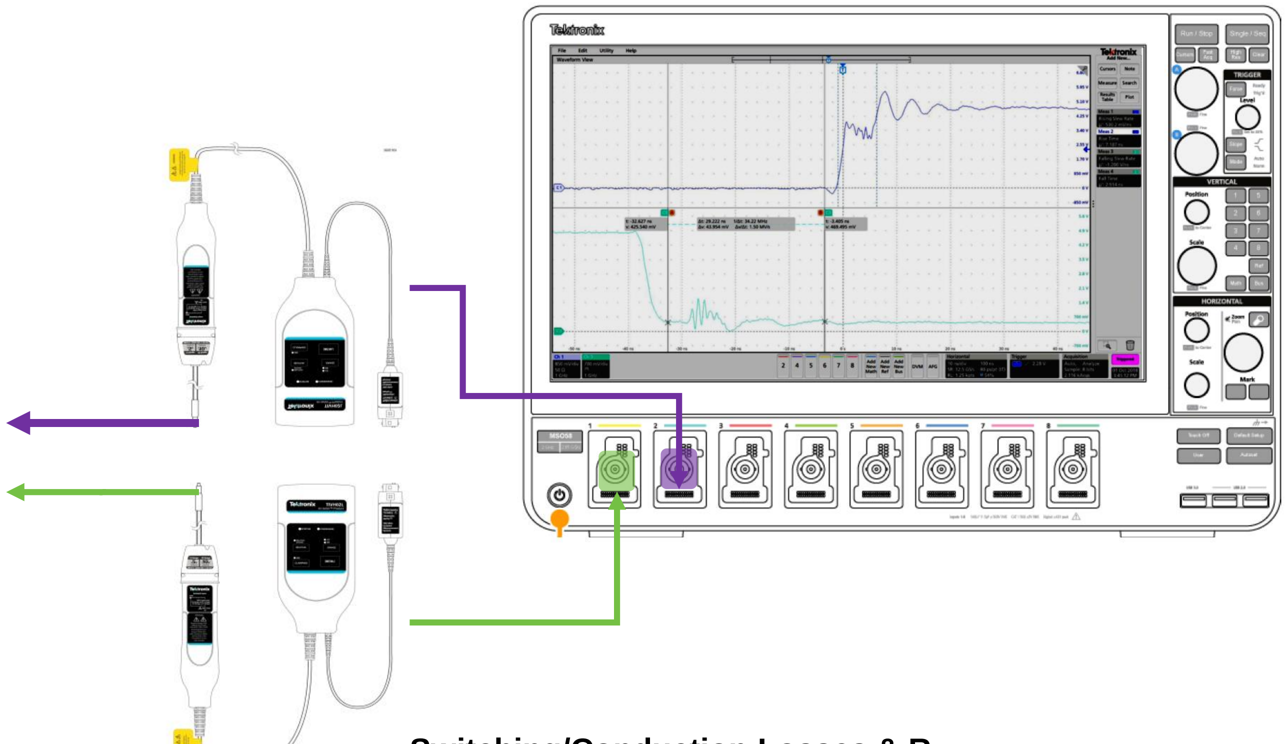
The following section uses the built-in demo to demonstrate the capabilities of the 5 PWR software for switching and conduction losses.

Use your own DUT to test any of the demonstrated parameters.




# Make Connections – Switching/Conduction/Magnetic



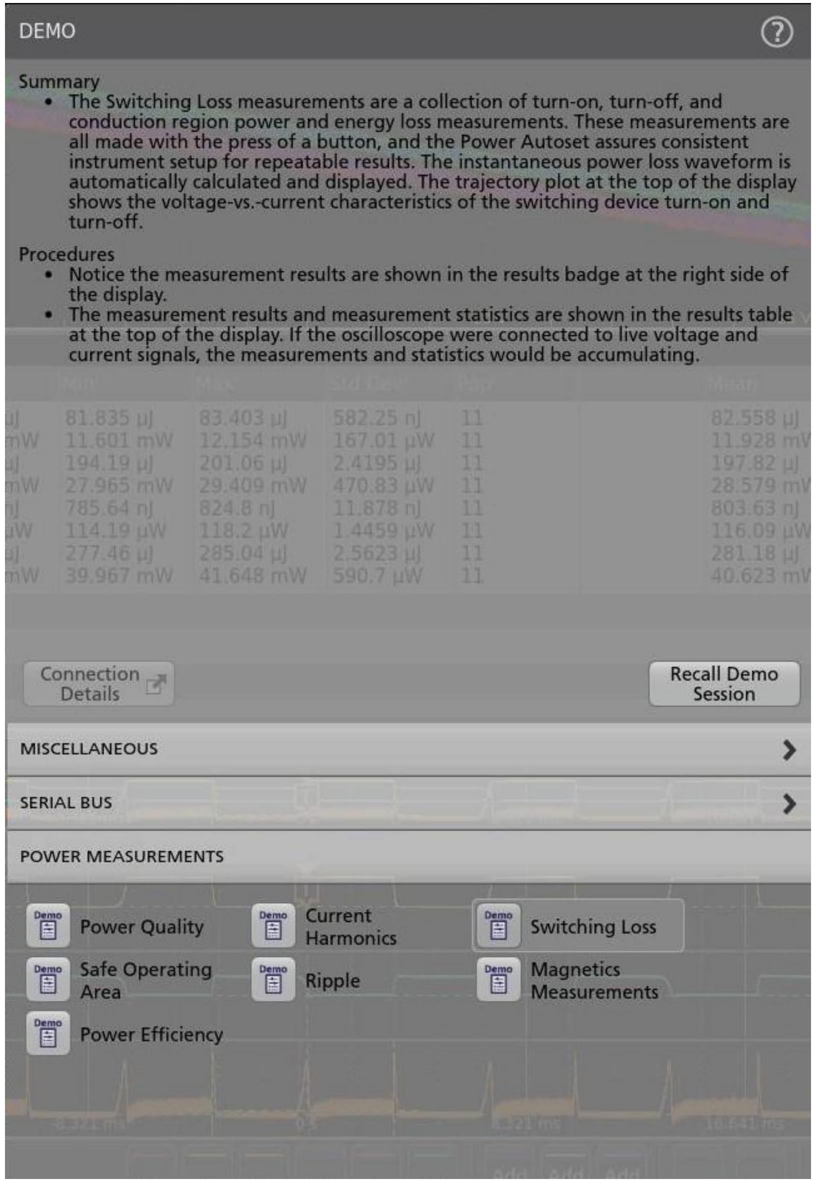

**Switching/Conduction Losses & $R_{DSON}$:**
Channel 1: Voltage across the switch ($V_{DS}$) – TIVH08 and MMCX50x sensor tip.
Channel 2: Drain current ($I_D$) (Through shunt) – TIVM1 and MMCX25X sensor tip.

**Magnetic Measurements:**
Channel 1: Coil Voltage ($V_L$) – TIVH08 and MMCX50x sensor tip.
Channel 2: Coil current ($I_L$) (Through shunt) – TIVM1 and MMCX25X sensor tip.

Representative circuit for demonstration purposes only. GaN Evaluation board does not have test points for drain current measurements.

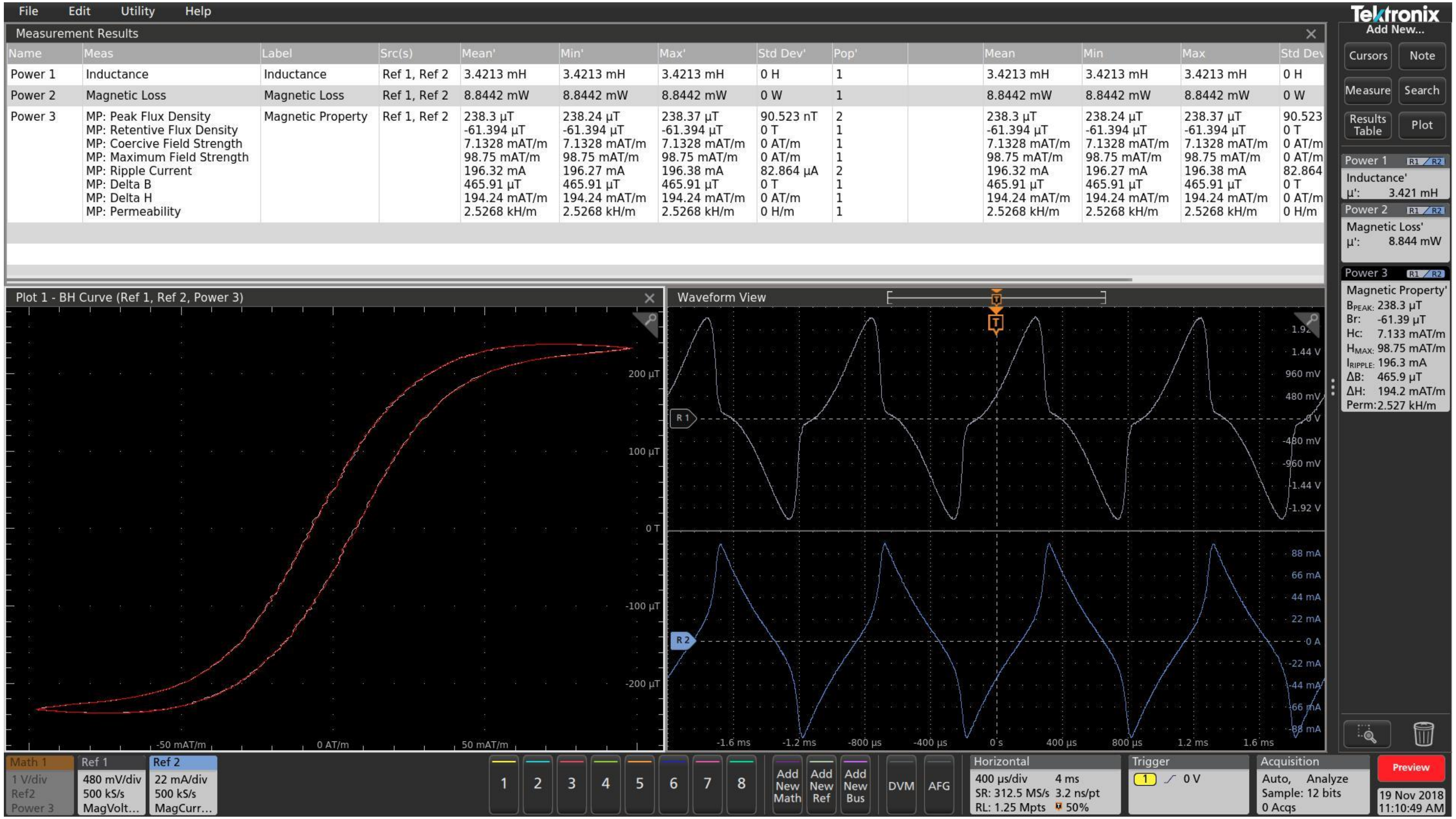
# Power Measurements Demo

- No connections are required to enable the 5-PWR scope demo.
- Tap ‘Utility→Demo’ on the top ribbon.
- Tap ‘Power Measurements’ under the Demo popup.
- Select between the available choices.
- The following pages show the screenshots and capabilities of these functions:
  - Switching/Conduction Loss
  - Magnetic Measurements



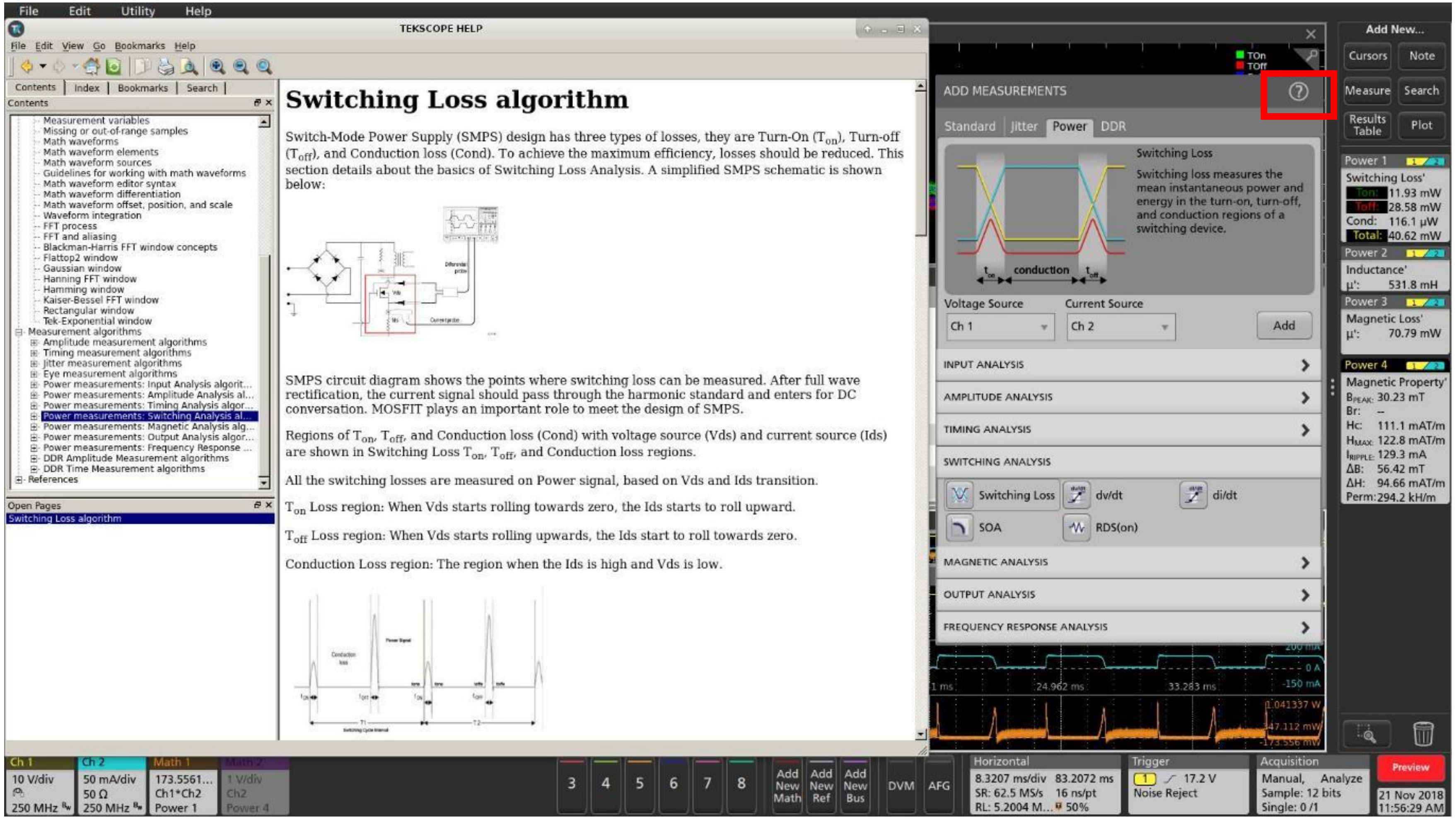
# Switching/Conduction Losses Demo

# Magnetic Measurements Demo



# Power Measurements Software Help

For detailed set-up steps and a full description of 5-PWR software features, please refer to the on-screen help by tapping the Help button.



# Specifications

# IsoVu Technology Specifications

| | ISOVU TIVM SERIES | ISOVU TIVH SERIES |
|---|---|---|
| Bandwidth | Up to 1 GHz | Up to 800 MHz |
| Rise Time | Down to 350 ps | Down to 450 ps |
| Differential Voltage Range | ±5 mV up to ±50 V | ±5 mV up to ±2.5 kV |
| Common Mode Voltage Range | 60 kV | 60 kV |
| Common Mode Rejection Ratio | DC – 1 MHz: 160 dB (100 Million to 1)<br>1 MHz – 100 MHz: 120 dB (1 Million to 1)<br>1 GHz: 80 dB (10,000 to 1) | DC – 1 MHz: 160 dB (100 Million to 1)<br>1 MHz – 100 MHz: 120 dB (1 Million to 1)<br>800 MHz: 80 dB (10,000 to 1) |
| Input Impedance | Up to 2.5 kΩ<br>< 1 pF | Up to 40 MΩ<br>As low as 2 pF |
| Fiber Cable Length | 3 meters or 10 meters | 3 meters or 10 meters |
| Power Over Fiber | Powered over the fiber connection – no batteries required | Powered over the fiber connection – no batteries required |
| Input Offset | Up to ± 100 V | Up to ± 1000 V |
| Input Coupling | DC | DC or AC |

*Note: Specifications are dependent on the probe tip cable.*

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