APPLICATION NOTE

AN1310: Si823Hx Gate Driver Board Test Report

Description

This document presents electrical test results of the Si823Hx isolated gate driver board (Si823H-AAWA-KIT) driving WolfPACK SiC power modules from Wolfspeed using Wolfspeed's test platform. Included in this report are switching loss measurements, thermal performance and cross-talk measurements.

This test report includes the Si823H2 Gate Driver Board (GDB) performance in switching loss, thermal protection, and cross-talk tests in a half-bridge configuration.

Features

- Test Setup
- Switching loss measurements
- Thermal performance measurements
- Cross-talk measurements

1. Test Platform

The test platform is comprised of Skyworks' Si823H2 Gate Driver Board, Wolfspeed's Clamped Inductive Load (CIL) Evaluation Board, a differential tranceiver board and a Wolfspeed SiC power module. The GDB mounts on top of the CIL and the SiC power module is mounted underneath. The transceiver board connects to the input connector on the GDB and provides an interface for connecting single-ended test equipment to the differential inputs of the GDB.

1.1. Skyworks Gate Driver Board

The Skyworks GDB, Skyworks part number Si823H-AAWA-KIT, includes the Si823H2 isolated dual gate driver integrated circuit and the Si88421 digital isolator. The Si823H2 drives both the high side and low side devices included in the Wolfspeed SiC FET module. The digital isolator provides for transmission of digital data across the isolation barrier as well as an integrated dc-dc controller that operates with an external transformer to generate isolated supply voltages for the dual gate driver.

The schematics for the GDB is provided in Figures 1, 2, and 3. Figure 1 shows the input section which converts differential VIA and VIB input signals to single ended signals for the Si823H2. Figure 2 details the Si823H2 dual isolated gate driver and associated circuitry. Figure 3 details the Si88421 IC and the circuitry used to create the dual isolated power supplies.

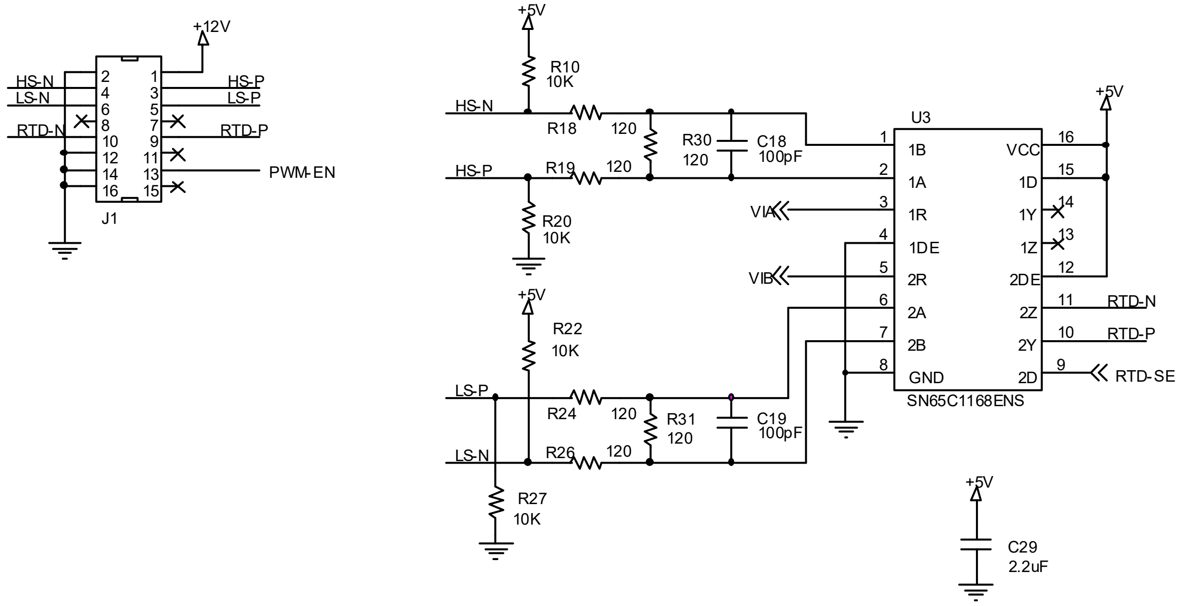

Figure 1. Gate Driver Board Input Section

The Gate Driver Board is offered in two variants. One with the gate series resistors (R37-40) with 1Ω installed and one with 4Ω installed. The 1Ω version was chosen for this report because it is believed the lower gate resistor would be the better option to reduce switching losses and minimize cross-talk between the switching devices.

There is also additional 1Ω (or 4Ω) resistors, with a current steering diode, to reduce the gate resistance in half when turning off the switch device.

The solder bump options J8 through J11 were left in their default states (J9 and J10 shorted, J8 and J11 open) providing for a small negative gate voltage, with respect to the source, for each switch device when that device is being driven to the OFF state.

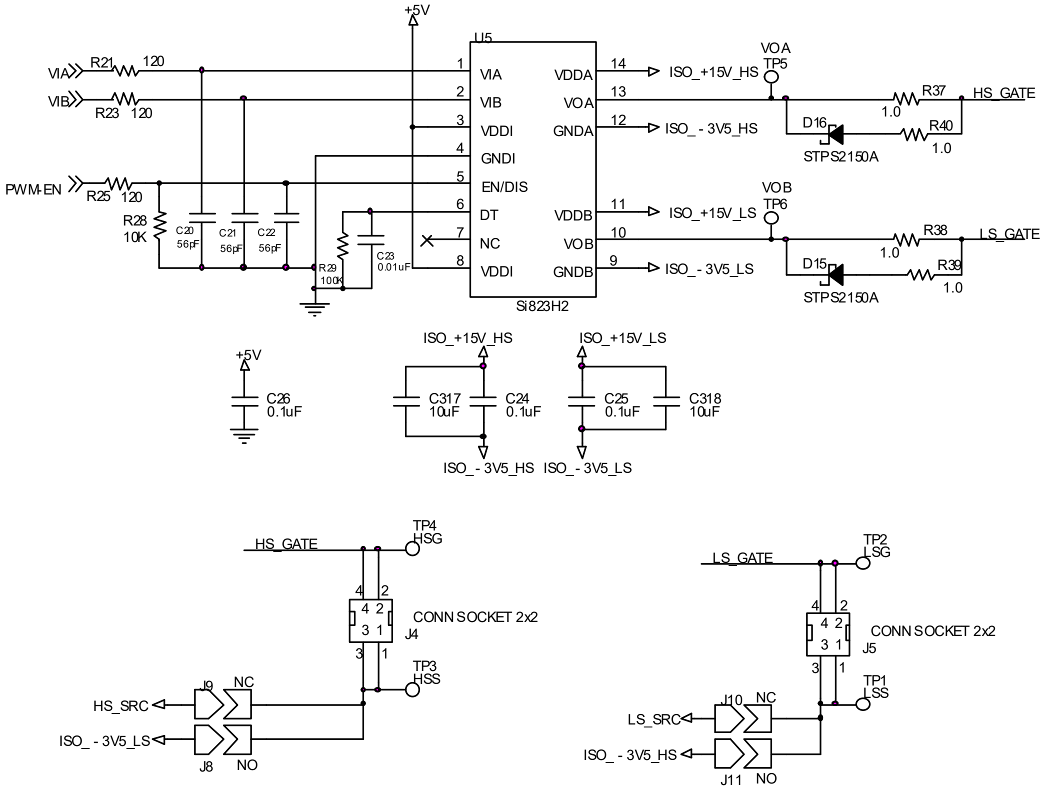

Figure 2. Gate Driver Board Driver Section

Power for the Si823H2 outputs is provided by the integrated dc-dc controller in U4, Si88241 digital isolator. The converter uses a Flyback topology and generates two isolated supplies on the secondary side of T1. Output voltage sensing on U4, Pin 13 provides feedback and regulation. For further details on Si823H-AAWA-KIT, please see "UG475: Si823Hx Gate Driver Board".

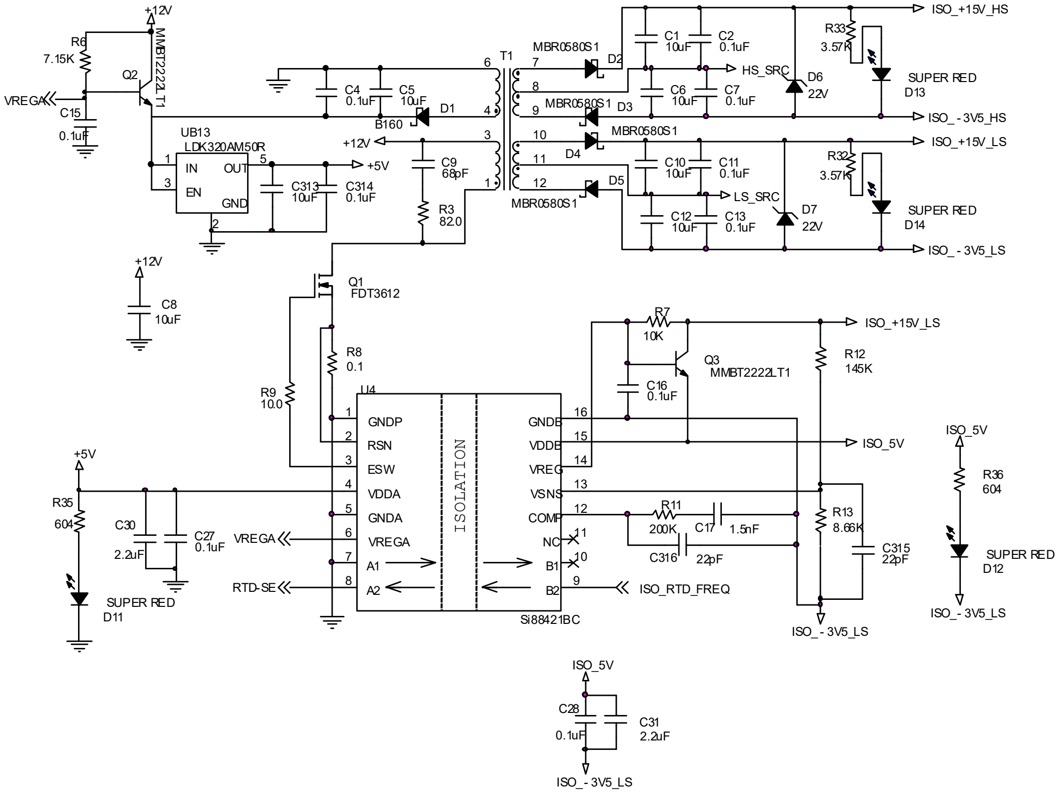

Figure 3. Gate Driver Board Integrated Power Supply

Figure 4 shows Skyworks' Si823H2 Gate Driver Board.

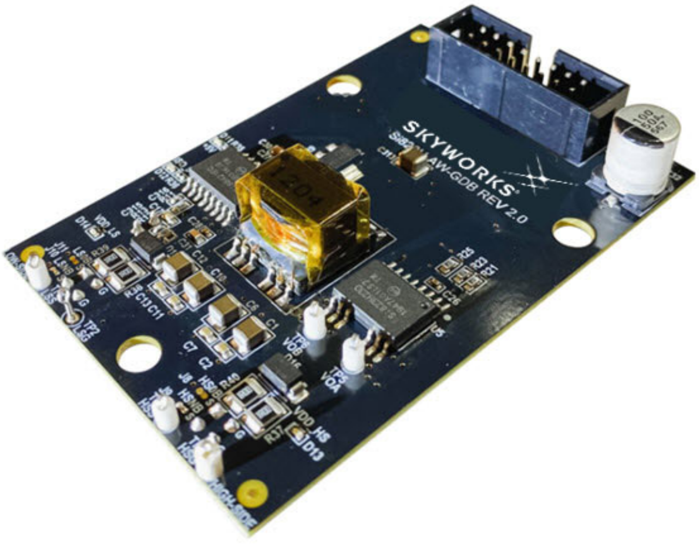

Figure 4. Si823H-AAWA-KIT Evaluation Board

1.2. Wolfspeed's CIL Evaluation Motherboard

Figure 5 shows a simplified schematic of Wolfspeed's KIT-CRD-CIL12N-FMA evaluation board. The board's layout is optimized for low parasitic inductance with minimum interconnect trace distances between the bulk capacitors, the high-frequency bypass capacitors, and the high-bandwidth current measurement via current viewing resistor (CVR).

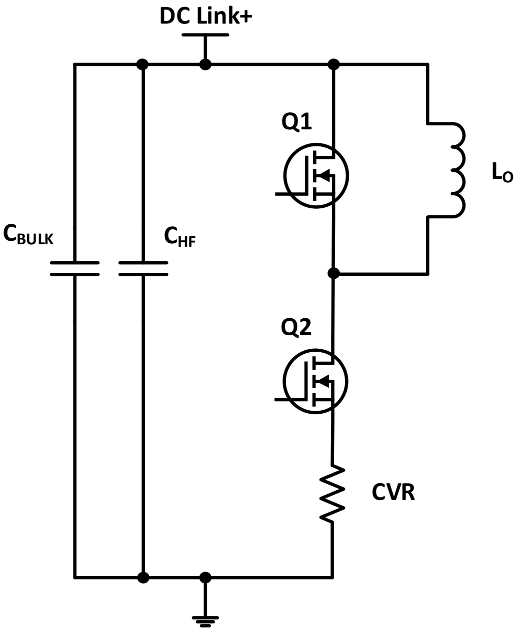

Figure 5. Wolfspeed's KIT-CRD-CIL12N-FMA Simplified Schematic

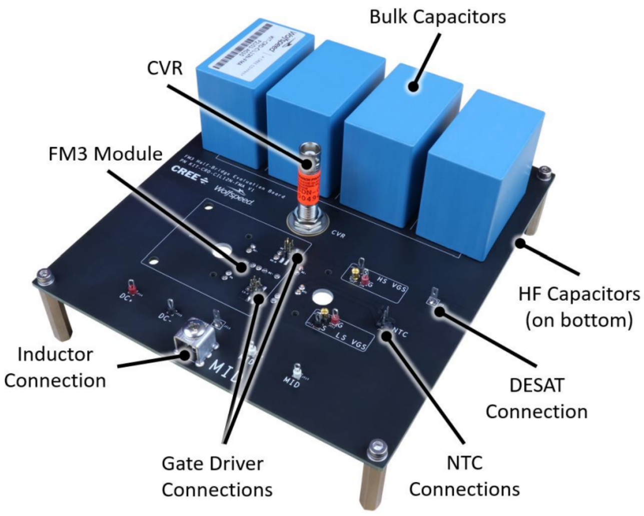

Figure 6. Wolfspeed's KIT-CRD-CIL12N-FMA CIL Evaluation Board

For more information on Wolfspeed's KIT-CRD-CIL12N-FMA CIL Evaluation Board and the test apparatus, see the Cree Wolfspeed CIL CPWR-AN43 User Guide.

1.3. Wolfspeed's Single-Ended to Differential Transceiver

For compatibility with the Wolfspeed CIL, the Skyworks gate driver board uses differential signaling for the gate driver inputs. To interface with single ended test equipment, Wolfspeed's Differential Transceiver Daughter Board Companion Tool (part no. CBD12HB00D) was used. For detailed information about this board, see the Wolfspeed product page.

Figure 7. Differential Transceiver Daughter Board Companion Tool

1.4. Wolfpack Module

Wolfspeed's CAB011M12FM3 and CAB016M12FM3 SiC modules were both evaluated in this test. These modules have an R_{DSON} rating of 11mΩ and 16mΩ respectively, I_{DS} = 105A and 78A respectively and both have a blocking voltage rating of 1.2 kV. For more details about these modules, see the Wolfspeed WolfPACK™ Silicon Carbide Power Modules Family web page.

Figure 8. Wolfspeed's CAB011M12FM3 Half-Bridge SiC Module

2. Switching Loss

Switching loss testing was performed using a double-pulse test circuit as shown in Figure 9. This test measures the power loss in the Skyworks GDB during switching.

2.1. Switching Loss Test Method

In this test, the GDB inputs were driven by a two-channel function generator configured for complimentary outputs. The gate driver then drives Q1 and Q2 so that current can build up through the air-core inductor, L_O. Every time Q2 is switched on (Q1 is switched off), the current in L_O increases linearly. When Q2 is switched off (Q1 is switched on), L_O current is maintained through Q1. This cycle is repeated multiple times to facilitate switching loss measurement of Q2 at different current levels.

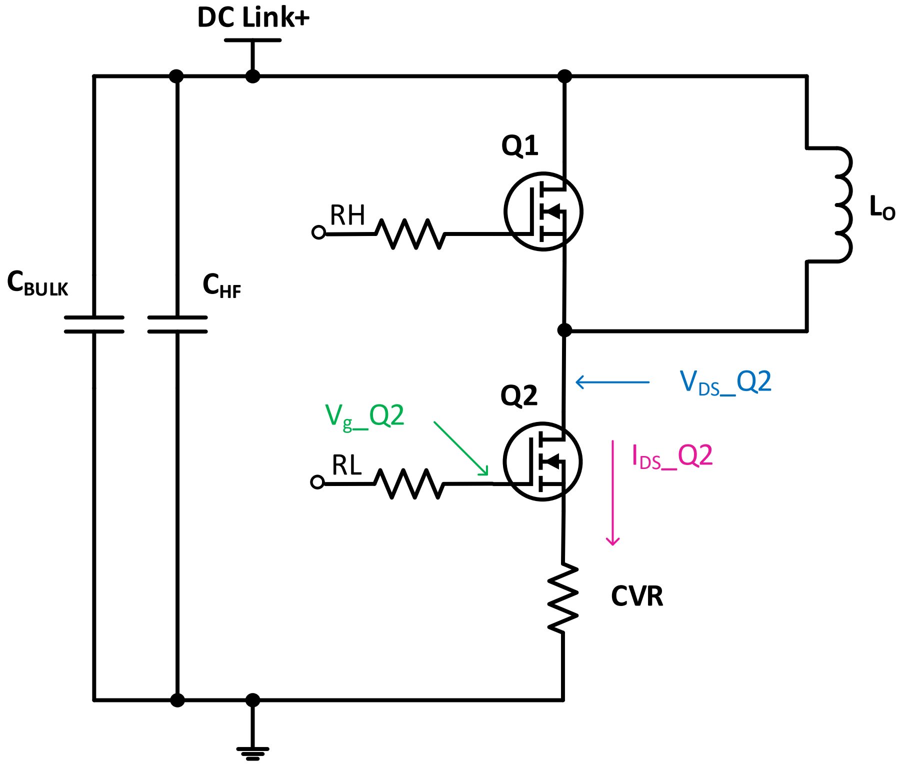

Figure 9. Switching Loss Simplified Schematic

An oscilloscope was used to capture the I_{DS} and V_{DS} waveforms on Q2. The math function, on the oscilloscope, was configured to integrate the product of these two waveforms over time to determine the power dissipated by Q2 during the switching event.

2.2. Switching Loss Performance

Figure 10 shows Q2 being switched several times allowing the I_{DS} to increase linearly when Q2 is on. The waveforms on the bottom of the oscilloscope display show a zoomed in portion of an event when Q2 is turned on.

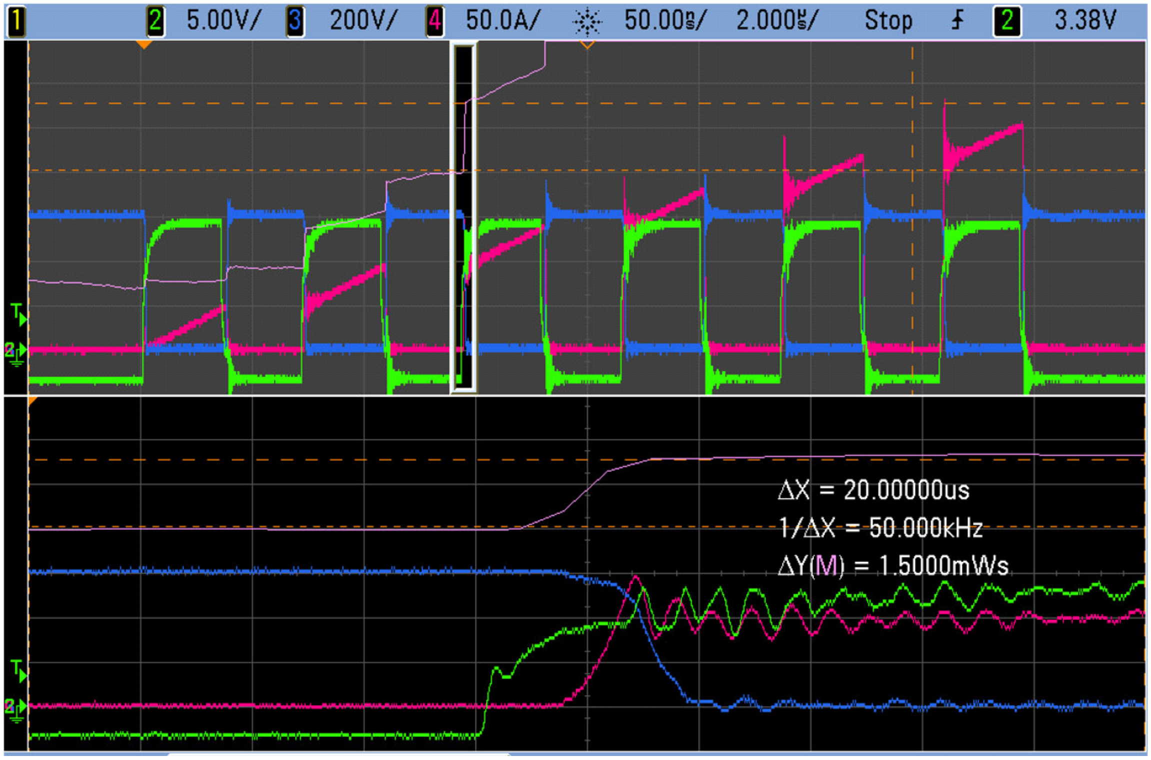

Figure 10. EON Loss IDS = 100A, LO = 18µH, (VDS = 600 V)

In this event, you can see the product of V_{DS} and I_{DS} of Q2 being integrated over time in the trace labeled E_{LOSS}. This value is then measured at several different levels of I_{DS} and placed in the plot in Figure 11. The power lost during the switching off event is similarly measured and plotted.

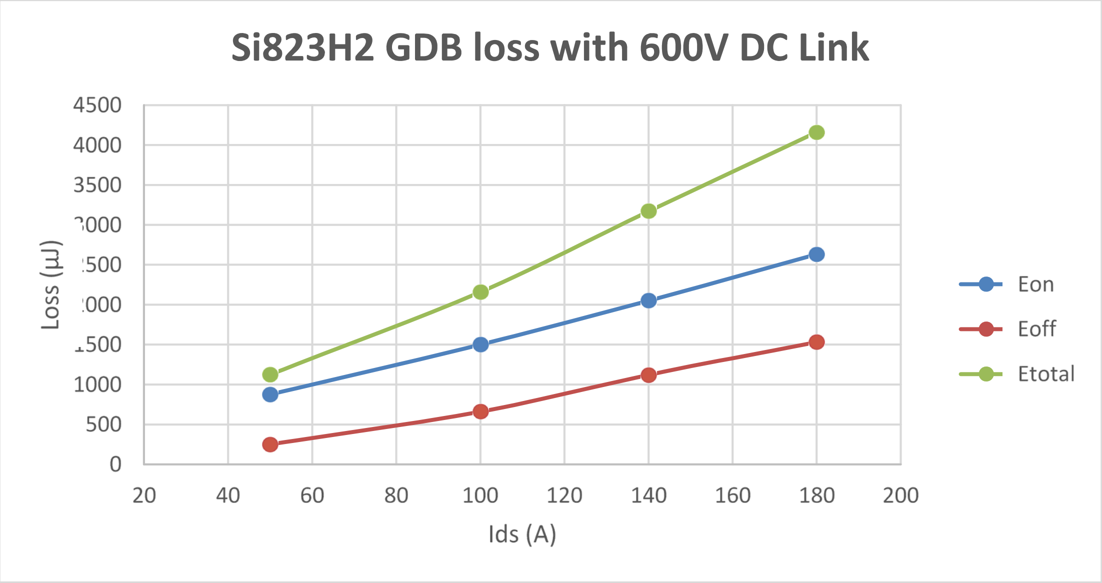

Figure 11. Switching Loss vs. IDS with DC Link = 600 V

This test was repeated with dc link = 800 V. Representative waveforms are shown in Figure 12, and a plot is provided in Figure 13.

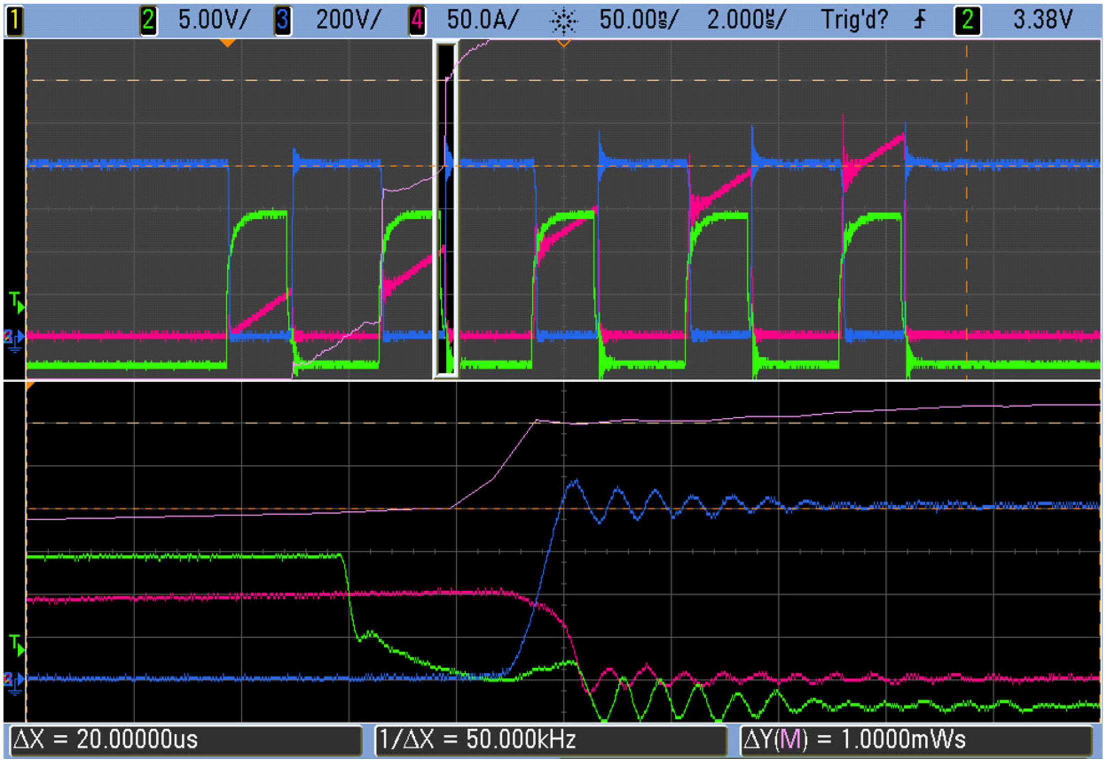

Figure 12. E_{OFF} Loss I_{DS} = 100 A, L_O = 18 µH, (V_{DS} = 800 V)

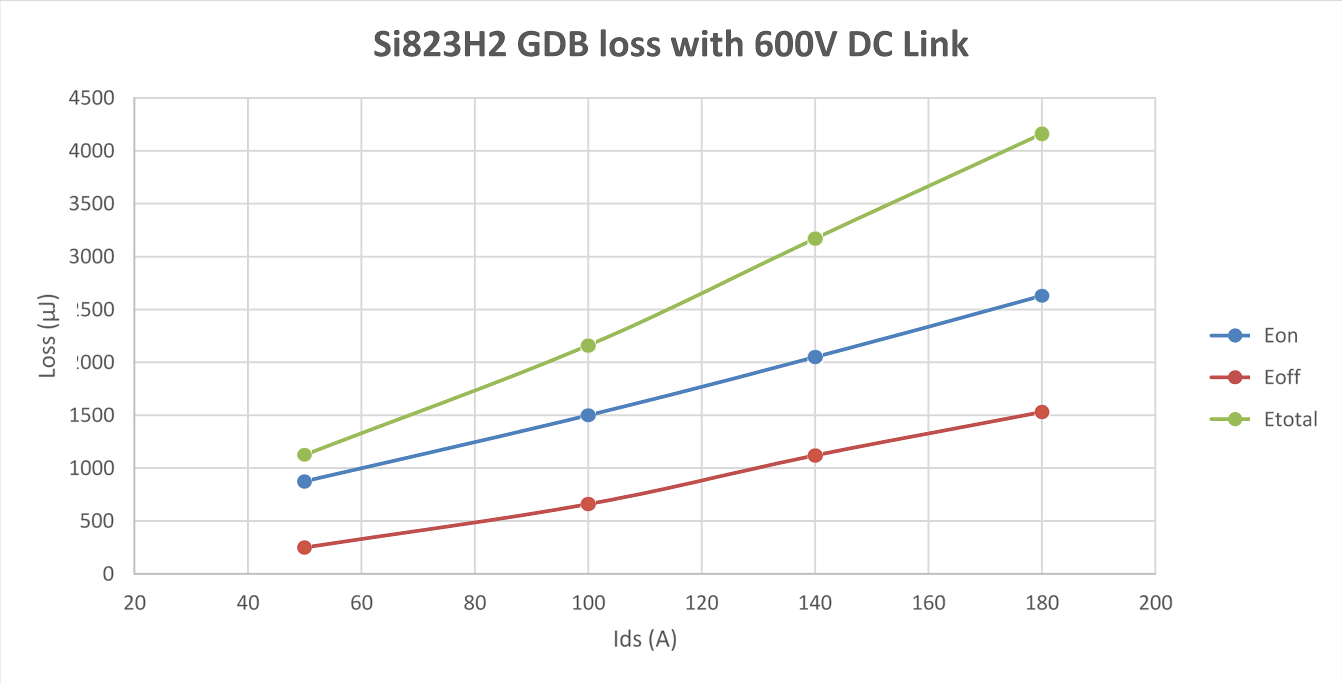

Figure 13. Switching loss vs. IDS with DC Link = 800 V

3. Thermal Safety Shutdown

3.1. Thermal Safety Shutdown Test Method

To demonstrate a key feature of the Si823Hx isolated gate driver, the GDB was removed from the CIL evaluation platform. A capacitive load was attached to the output of each gate driver and the GDB was placed in a temperature chamber set to 100 °C. This temperature was chosen to show the Si823H2 reaching an internal temperature sufficient to trigger the thermal protection feature. The GDB inputs were driven by a two-channel function generator configured for complimentary outputs. The switching frequency of the generator was swept from 10 kHz to 400 kHz while monitoring the case temperature of the driver. This test was repeated for capacitive loads ranging from 5 nf to 65 nf.

3.2. Thermal Safety Shutdown Performance

The plot in Figure 14 shows the behavior of the gate driver during thermal safety shutdown testing. As expected, heavier gate loading resulted in a more rapid increase of case temperature as a function of switching frequency. Except for the 5 nf load, the case temperature of the driver peaks at around 145 °C. This peak is caused by the thermal protection feature of the driver causing the driver to shut down until it cools sufficiently to resume operation. The 5 nf load is small enough that 400 kHz does not trigger a thermal safety shutdown in a 100 °C chamber.

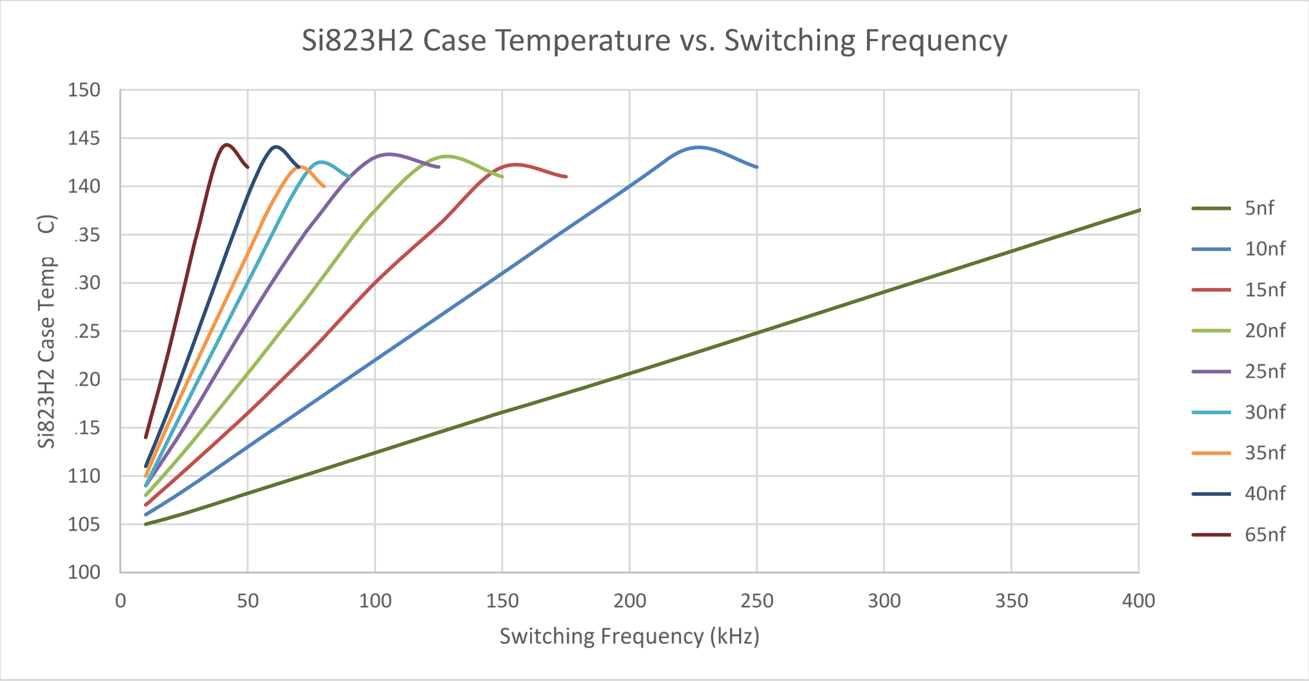

Figure 14. Thermal Safety Shutdown Performance Results

4. Cross-Talk Immunity

4.1. Cross-Talk Immunity Test Method

Cross-talk immunity refers to the ability of a gate driver to hold a switch device off in the presence of transient signals typically due to the parasitic Miller Effect. In a half bridge circuit, the drain voltage of a switch rapidly increases when the opposite side switch is turned on. This dv/dt is applied to the parasitic capacitance present between the switch's gate and drain, causing a bias current to flow through the switch's gate resistor. If the voltage across the switch's gate resistor is too high, it can cause the switch to momentarily turn on, causing shoot through and potential damage.

The faster the transient on the drain of a FET, the higher the potential current flow into the gate. If enough current flows into the gate to raise the gate voltage above the threshold voltage of a device in a half-bridge circuit, it can inadvertently turn the device on, cause shoot-through current and typically catastrophic damage.

Figure 15 shows a simplified schematic and a picture of the test setup. Q1 is switched multiple times while the gate of Q2 is held at a low, fixed voltage. The resulting transients are then measured. The GDB was configured such that the output of the gate driver is negative with respect to the source pin voltage by about 3.5 V when driving the switch off. Along with an effectively lower, 0.5 Ω, turn-off series gate resistor, this provides some margin to prevent Q2 from turning on due to the transient signals induced by Q1 turning on. The V_g, V_{DS} and I_{DS} of Q2 were monitored while Q1 was switched. A signal generator was used to provide the drive signal to the input of the GDB for Q1. The load inductance, L_O, was connected to the output of the half-bridge as shown.

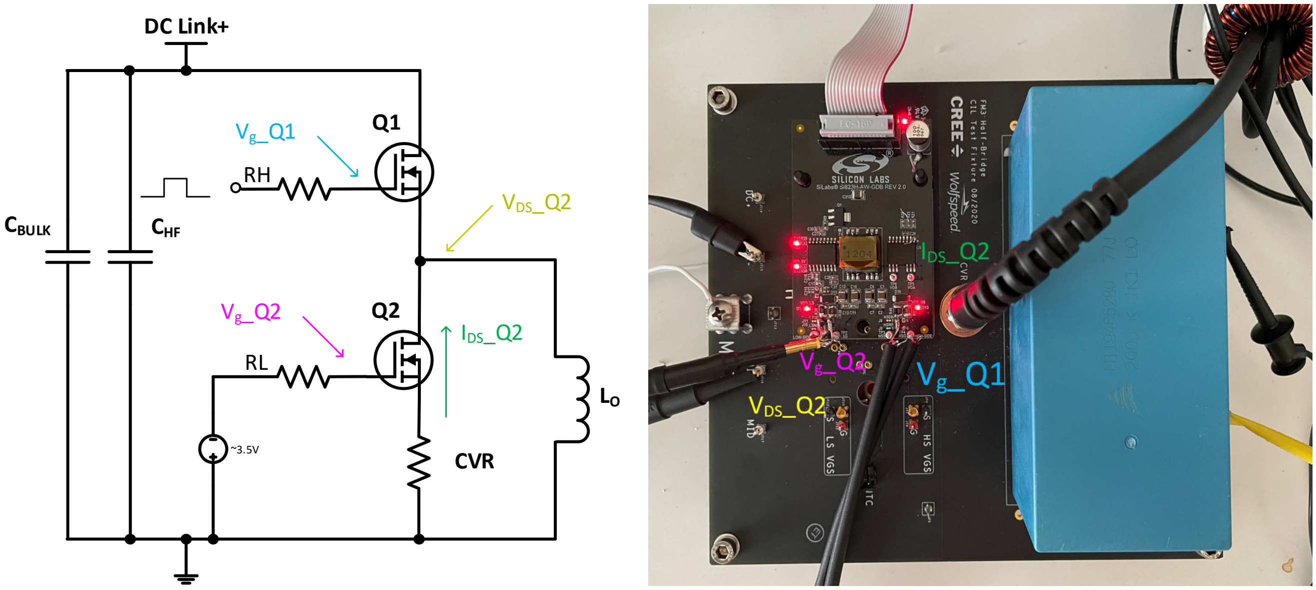

Figure 15. Cross-Talk Test Setup

4.2. Cross-Talk Immunity Performance

The first configuration tested was with dc link = 600 V and the CAB011M12FM3 SiC module. Figure 16 shows the switching event when Q1 switches from the OFF state to the ON state. When Q1 switches ON, a rapid increase in the V_{DS} of Q2 occurs (see cursors in Figure 16). The slope of this increase measures 41 kV/µs and causes a sharp jump in the Q2 V_g. However, since the V_g of Q2 was held at ~ –3.5 V before the event, V_g_Q2 peaked only to approximately 0.5 V. This is not high enough to cause the Q2 to turn on.

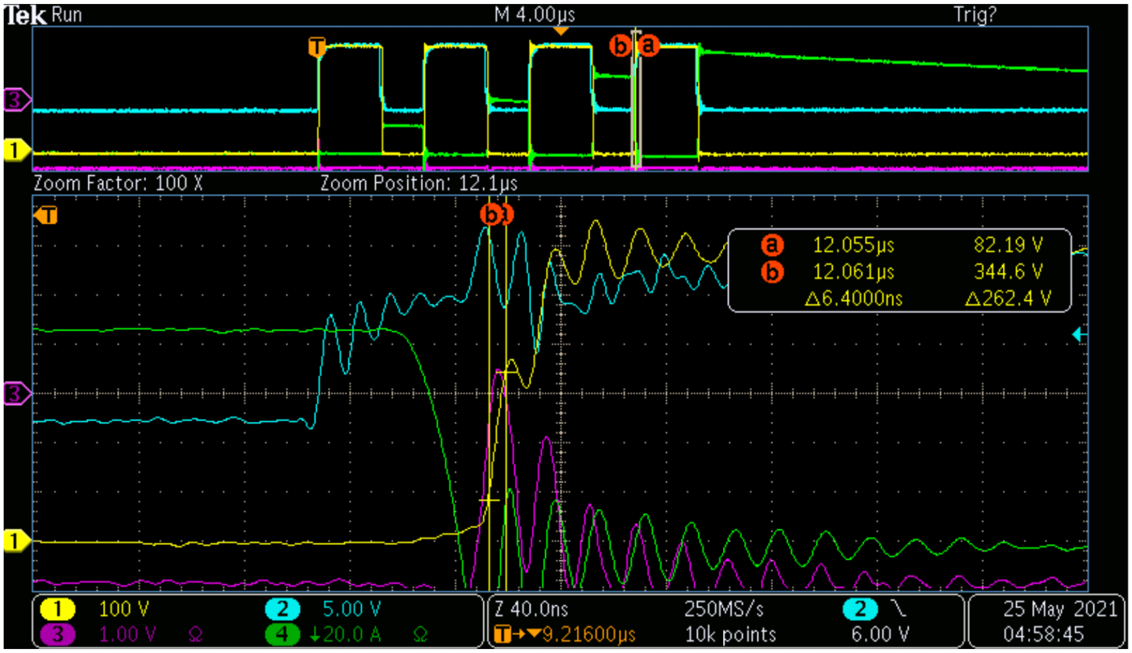

Figure 16. DC Link = 600 V with CAB011M12FM3 Wolfpack Module

The dc link voltage is increased to 800 V. The results of a switching event are shown in Figure 17.

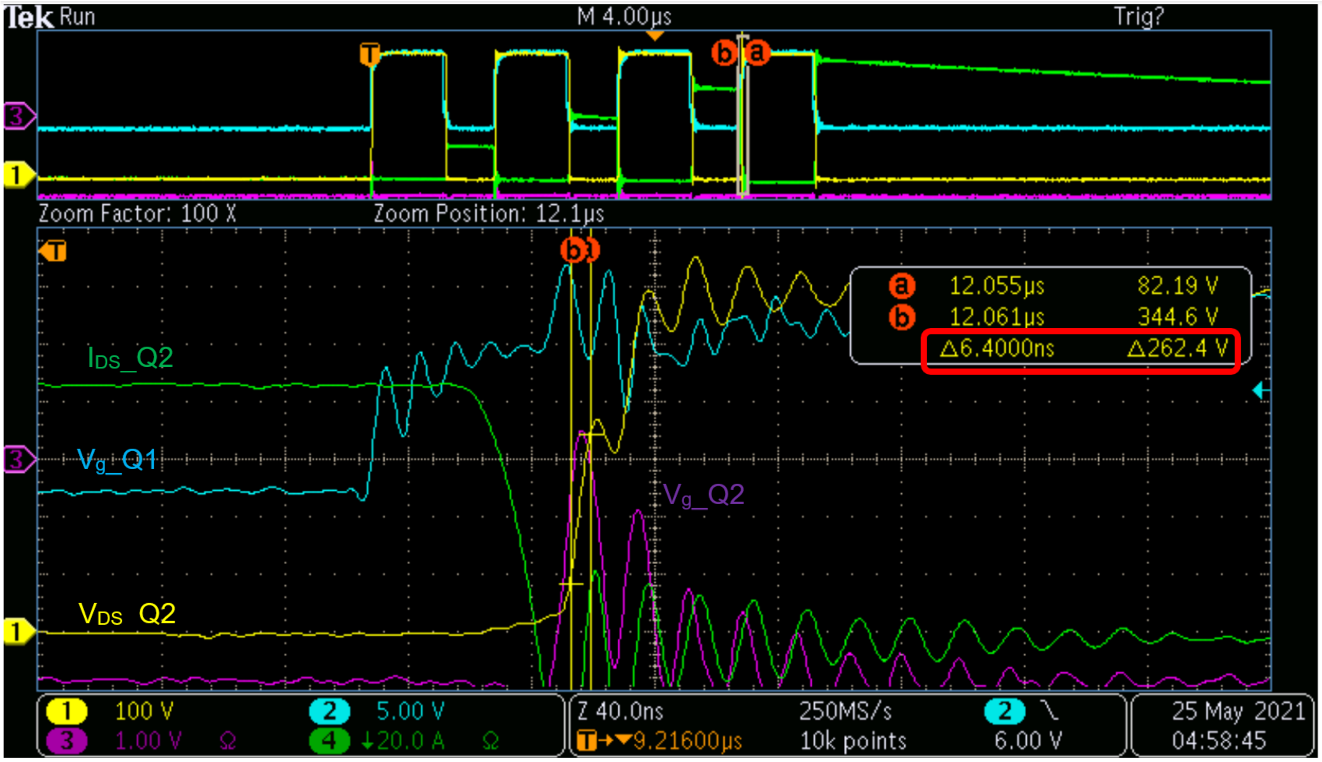

Figure 17. DC Link = 800 V with CAB011M12FM3 Wolfpack Module

Although Q2 V_{DS} is still measured about 41 kV/µs, the increased dc link voltage also increased the measured cross-talk. In this switching event, Q2 V_g peaked at +0.9 V.

Next, the dc link voltage was set to 600 V and the CAB016M12FM3 SiC module was tested. This SiC module has a lower I_{DS} rating, but it has faster switching than the previous module, presenting a worse case for cross-talk.

The results of Q1 switching on are shown in Figure 18. The slope of the spike on Q2 V_{DS} is measured at almost 64 kV/µs resulting in the V_g of Q2 reaching close to 1.25 V. This is still not enough gate voltage to cause Q2 to turn on.

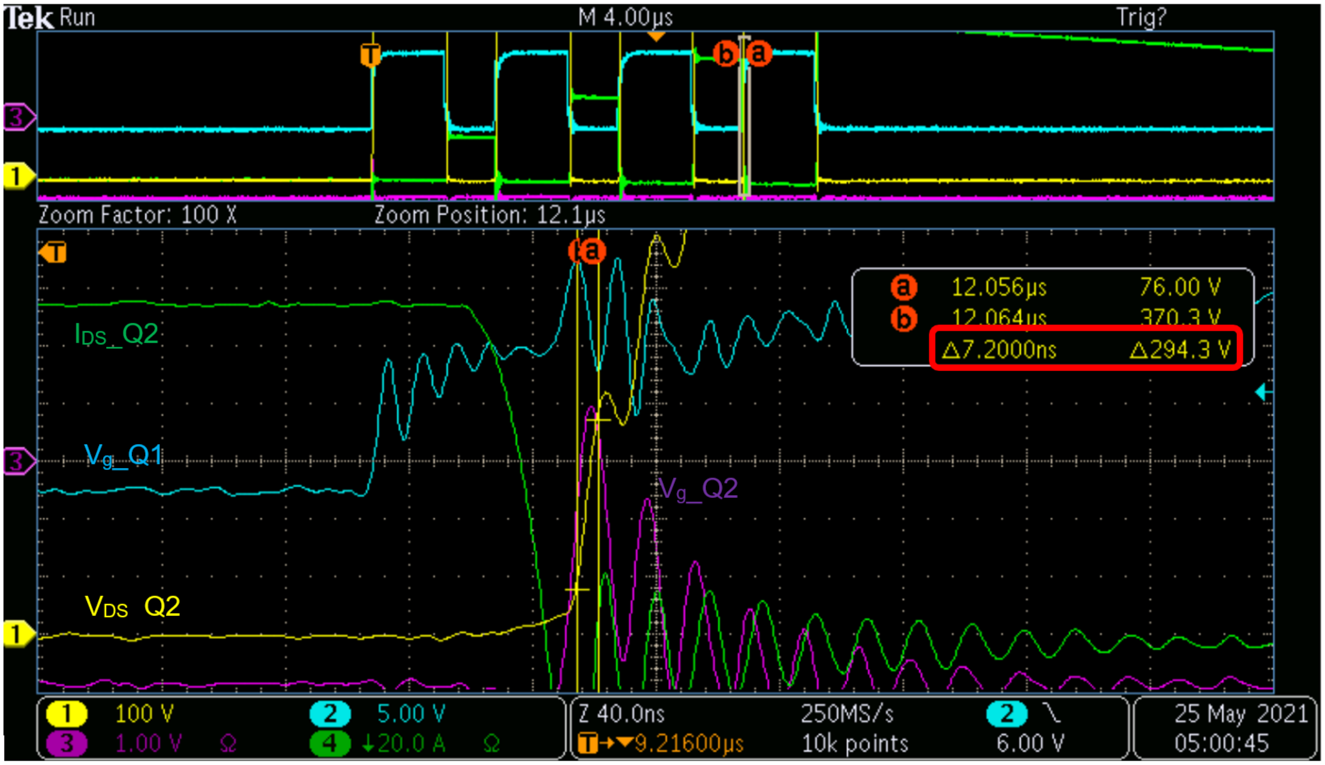

Figure 18. Q2 Switching On. VRAIL = 600 V with CAB016M12FM3 Wolfpack Module

From here, the dc link voltage was increased to 800 V and the test repeated. The results are shown in Figure 19.

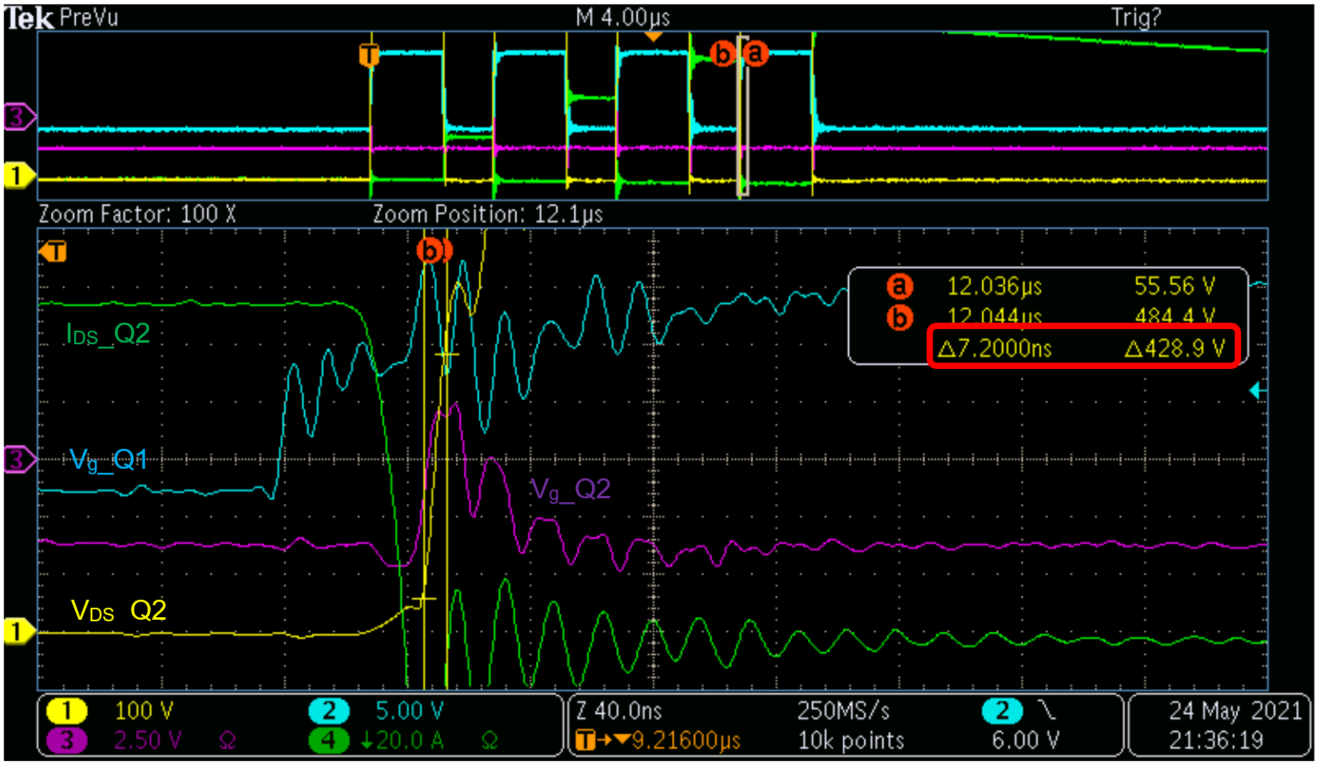

Figure 19. Q2 Switching On. VRAIL = 800 V with CAB016M12FM3 Wolfpack Module

In this test, the V_{DS} of Q2 had a slope of about 60 kV/µs. As a result, the V_g of Q2 spiked to about 2.5 V. Even at this temporary elevated gate voltage, there is no evidence that Q2 experiences a parasitic turn on due to cross-talk.

5. Conclusion

Together, Skyworks' Si823Hx family of drivers and Wolfspeed's SiC modules enable high efficiency and robust power conversion as detailed by the test results presented in this report.

In this report, the Skyworks Si823H-AWAA-KIT, featuring the Si823H2 isolated gate driver, was tested with the Wolfspeed CAB011M12FM3 and CAB016M12FM3 silicon carbide power modules. The Si823H2 demonstrated sufficient drive strength to switch the SiC FET modules efficiently minimizing switching energy losses to heat. The measured switching loss is similar to numbers in Wolfspeed's documentation for these modules.

The Si823H-AWAA-KIT additionally demonstrated immunity to cross-talk by preventing parasitic turn on in the presence of high common mode transients present in switched SiC FET topologies. The thermal protection feature of the Si823H2 also makes the driver very robust in harsh thermal environments as demonstrated in this report.

6. References

Skyworks Application Note: *PCB Design and SMT Assembly/Rework Guidelines for MCM-L Packages*; Document Number 101752

Standard SMT Reflow Profiles: *JEDEC Standard J-STD-020*

Electrostatic Discharge Sensitivity (ESD) Testing: *JEDEC Standard, JESD22-A114 Human Body Model (HBM)*

Electrostatic Discharge Sensitivity (ESD) Testing: *JEDEC Standard, JESD22-A115 Machine Model (MM)*

Electrostatic Discharge Sensitivity (ESD) Testing: *JEDEC Standard, JESD22-C101 Charged Device Model (CDM)*

Testing & Measurement Techniques: *Electrostatic Discharge Immunity Test, IEC 61000-4-2*

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