

Characterization of a 62mm SiC Power Module with AgileSwitch® Augmented Switching Gate Drivers

ABSTRACT

Switching a SiC MOSFET Power Module creates two significant problems that need to be addressed in order to optimize the performance of the device: turn-off voltage overshoot and ringing. These two parasitic problems need to be controlled while maintaining efficient switching.

Microchip's AgileSwitch® line of patented Gate Drive products address these problems, controlling the turn-off di/dt by varying the gate voltage level and dwell time to one or more intermediate levels during turn-off. This process is typically referred to as Augmented Turn-Off™ or ATOff.

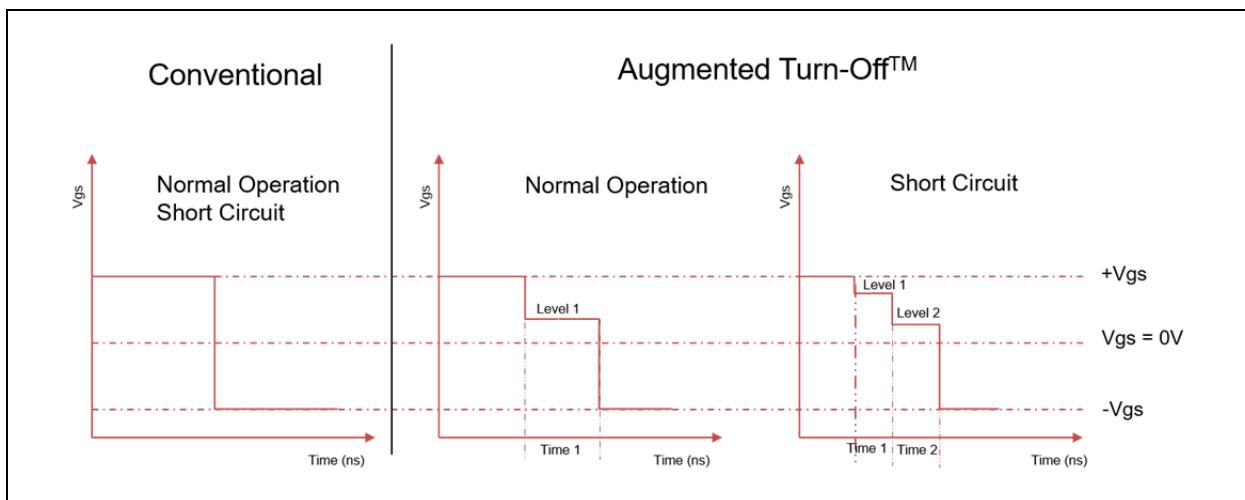


FIGURE 1: Conventional vs. Augmented Turn-Off.

Augmented Turn-Off provides benefits of:

1. Reduction in Switching Losses
2. Fine Control over Turn-On dv/dt
3. Reduced Turn-Off Overshoot Voltage
4. Robust Short Circuit Protection & Response

INTRODUCTION

This report outlines characterization of a 62mm SiC half-bridge module. Tests were performed using the AgileSwitch 2ASC-12A1HP Gate Driver core attached to the AgileSwitch 62CA1 module adapter board.

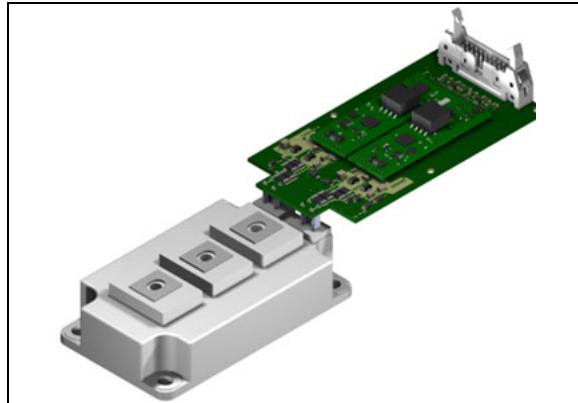


FIGURE 2: 2ASC-12A1HP SiC Driver Core with a 62CA1 Adapter Board on a 62mm Module.

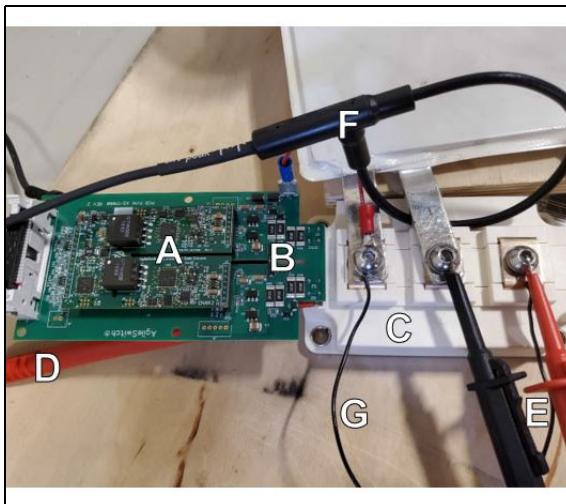


FIGURE 3: Double Pulse Setup
Showing: (A) 2ASC-12A1HP, (B) 62CA1 Adapter Board, (C) FF6MR12KM1 Module, (D) V_{DS} Probes, (E) I_{VGS} Probes, (F) Current Probe, and (G) Inductor.

DOUBLE PULSE TEST

Hardware Setup

Double pulse testing was conducted using an inductor across the high-side MOSFET, as shown in Figure 4. The high-side MOSFET was held at -5 V for the duration of the test, and the low-side MOSFET was switched using the profile described in the [Abstract](#). A Rogowsky coil was placed around the source return bus on pin 2 of the module to measure current.

Tests were performed at 600 V, 250 A to replicate the operating conditions listed in the module datasheet. A smaller gate resistor is used because the 2ASC-12A1HP can digitally control switching edges, so a larger resistor would otherwise cause additional losses with few performance benefits.

TABLE 1: DOUBLE PULSE HARDWARE SETUP

Parameter	Symbol	Value	Unit
DC Link Voltage	V_{DC}	600	V
Pulsed Current	I_D	250	A
Inductive Load	L_{LOAD}	21.6	μ H
Turn-On Gate Resistor	$R_{G(ON)}$	1.1	Ω
Turn-Off Gate Resistor	$R_{G(OFF)}$	1.1	Ω
Ambient Temperature	T_{AMB}	30	$^{\circ}$ C

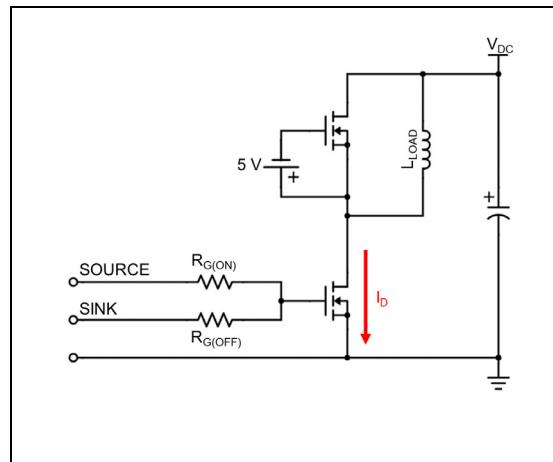


FIGURE 4: Double Pulse Schematic.

Software Setup

DOUBLE PULSE PROFILE

Timing of the double pulse profile was set based on the selected load inductor, DC link voltage and maximum required drain current. With $V_{DC} = 600$ V and $L_{LOAD} = 21.6$ μ H, a pulse of 9 μ s was required to reach 250 A. The full timing of the double pulse waveform is shown below in [Figure 5](#). The turn-on time of the first pulse is defined as time 0. Turn-off measurements were taken at t_{OFF1} , and turn-on measurements were taken at t_{ON2} . The width of the first pulse ($t_{OFF1} - t_{ON1}$) is set to reach the desired current; the width of the second pulse ($t_{OFF2} - t_{ON2}$) is mostly irrelevant, as long as it is wide enough to allow the system to stabilize following the turn-on moment for good measurements.

TABLE 2: DOUBLE PULSE SWITCHING PARAMETERS

Parameter	Symbol	Value	Unit
Pulse 1 On Time	t_{ON1}	0	μ s
Pulse 1 Off Time	t_{OFF1}	9	μ s
Pulse 2 On Time	t_{ON2}	28	μ s
Pulse 2 Off Time	t_{OFF2}	31	μ s
Full On Gate Voltage	$V_{GS(ON)}$	15	V
Full Off Gate Voltage	$V_{GS(OFF)}$	-5	V

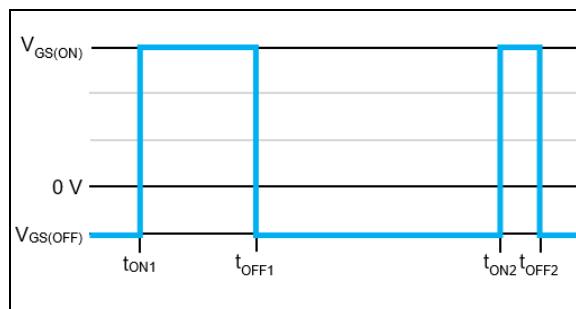


FIGURE 5: Double Pulse Switching Profile.

AUGMENTED SWITCHING PROFILE

For clarity, the switching profile in [Figure 5](#) shows simple turn-on and turn-off edges that switch directly between $V_{GS(ON)}$ and $V_{GS(OFF)}$. AgileSwitch Gate Drivers use Augmented Switching to digitally control these edges with precise timing and voltage steps. For these tests, the driver was programmed with no intermediate steps for turn-on (i.e. the turn-on waveform switches directly from $V_{GS(OFF)}$ to $V_{GS(ON)}$) and a single intermediate step for turn-off, as shown in [Figure 6](#); this setup is called Two-Level Turn-Off (TLTO). Multiple V_{TLTO} and t_{TLTO} settings were tested to observe the module's performance over various switching profiles.

TABLE 3: AUGMENTED SWITCHING PARAMETERS

	Symbol	Value	Unit
Full On Gate Voltage	$V_{GS(ON)}$	15	V
Full Off Gate Voltage	$V_{GS(OFF)}$	-5	V
Two-Level Turn-Off Voltage	V_{TLTO}	varies	V
Full Off Gate Voltage	t_{TLTO}	varies	ns

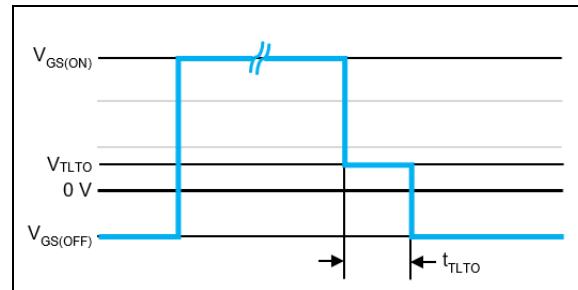


FIGURE 6: Augmented Switching Profile.

Results

TURN-ON

Figure 7 shows the turn-on results from the oscilloscope. The current reaches a peak of 323 A before settling to its set point of 250 A.

Table 4 shows summary values for this test; at 1.67 mJ, the turn-on energy loss is 68% less than the datasheet specification.

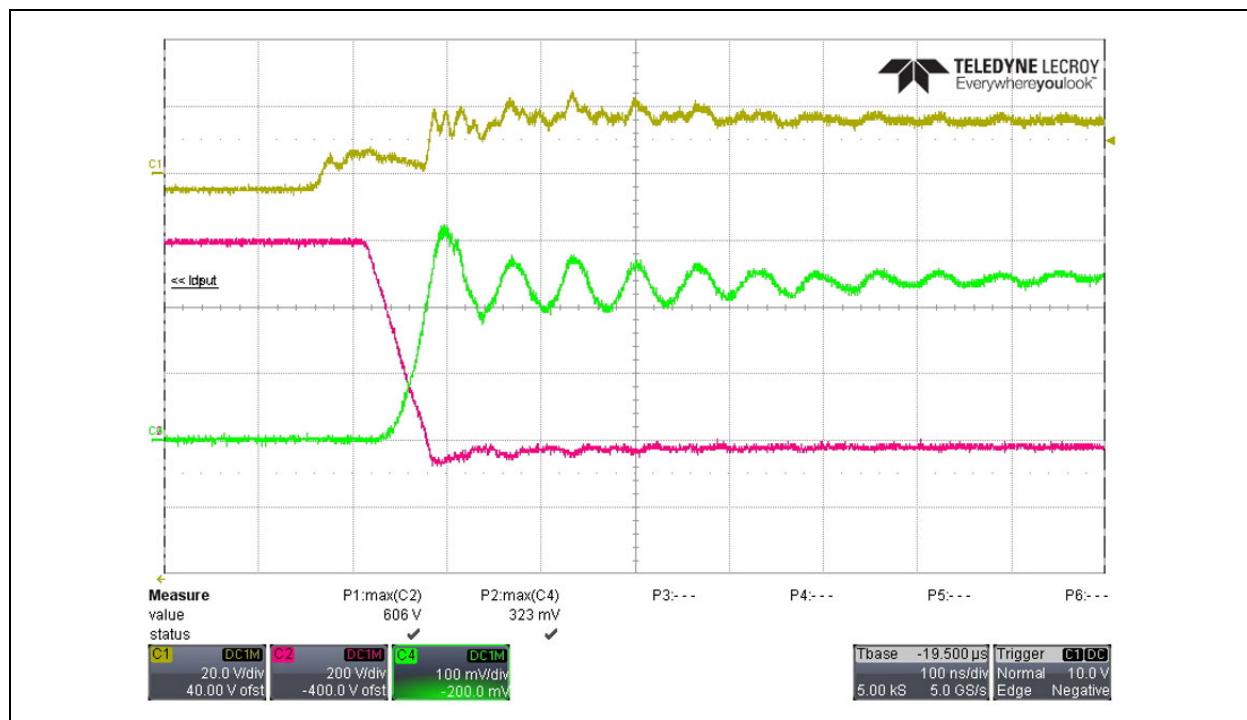


FIGURE 7: Turn-On Waveforms: V_{GS} (channel 1), V_{DS} (channel 2), I_D (channel 4, 1 A/mV).

TABLE 4: DOUBLE PULSE TEST RESULTS, TURN-ON

Parameter	Symbol	Value	Unit
Switching Loss	E_{ON}	1.67	mJ
Voltage Slope	dV/dt	9.06	kV/μs

Note 1: The current probe used for these tests has a delay that must be considered to calculate accurate loss numbers; the oscilloscope images in this document do not reflect the deskew routine used in post-processing.

TURN-OFF

[Figure 8](#) and [Figure 9](#) show the turn-off results for two different settings: one optimized for low switching loss, and the other for low overshoot voltage. In general, a longer intermediate step turns the device off more slowly, resulting in higher losses but less overshoot, as shown by the values given in [Table 6](#).

The lowest switching loss achieved during turn-off was 1.37 mJ (with an overshoot of 513 V), and the lowest overshoot was 228 V (with a loss of 4.94 mJ).

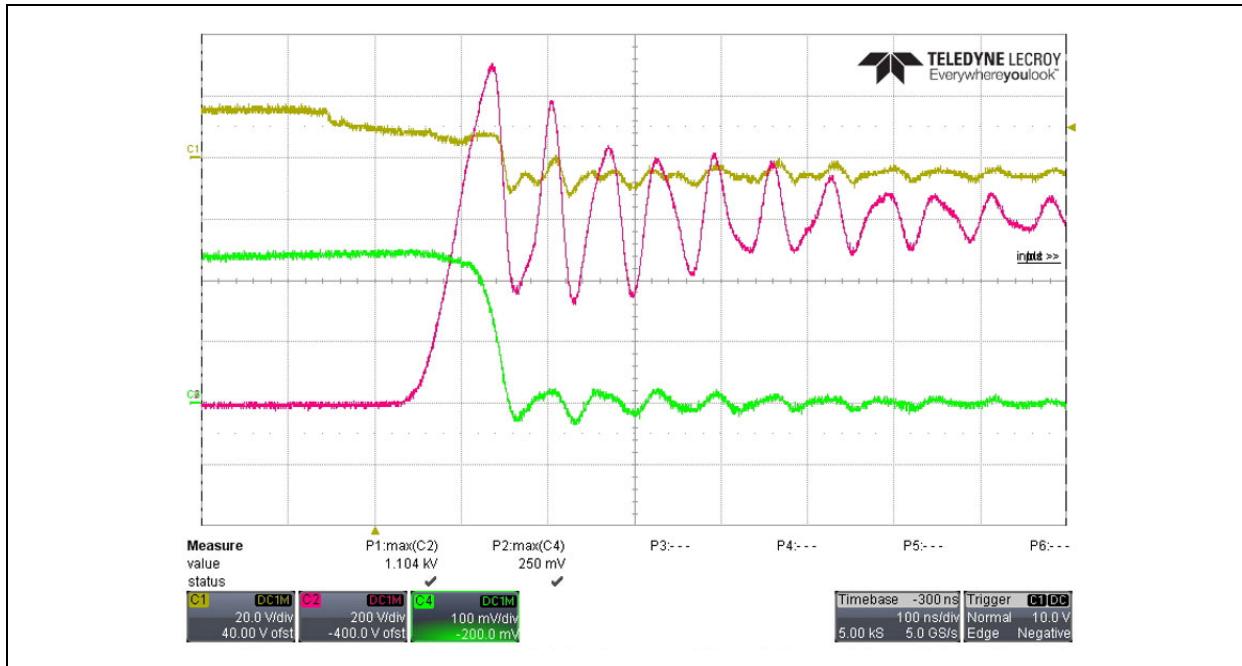


FIGURE 8: Turn-Off Waveforms Optimized for Switching Loss: V_{GS} (channel 1), V_{DS} (channel 2), I_D (channel 4, 1 A/mV).

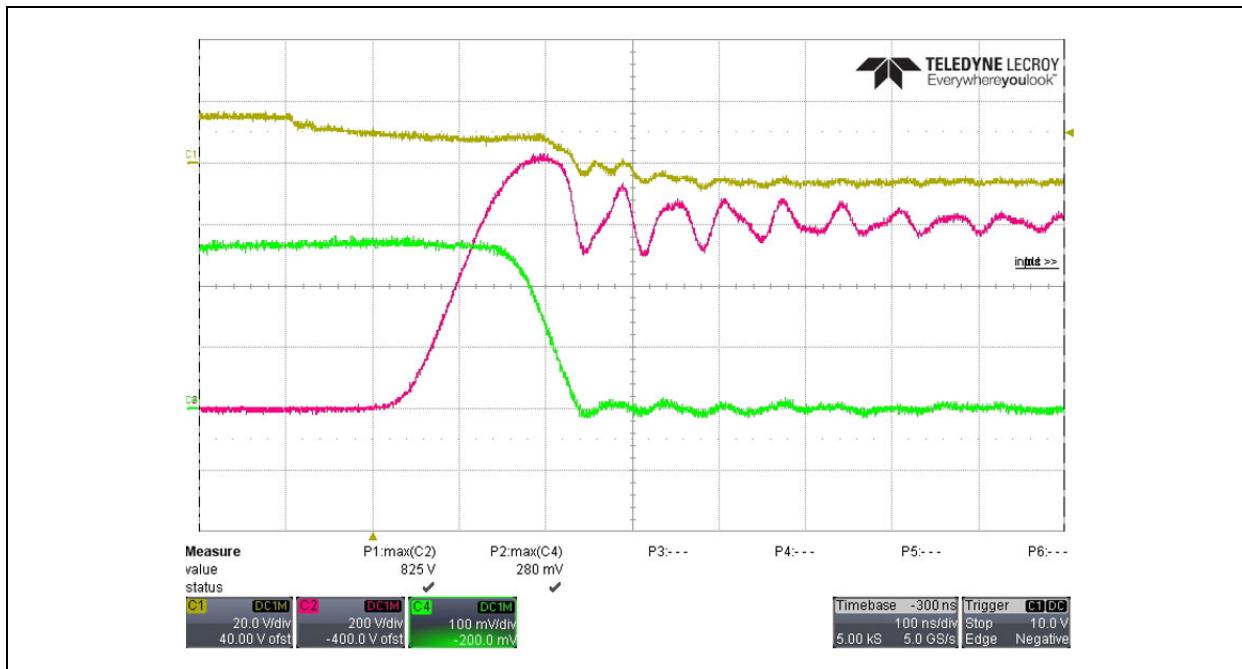


FIGURE 9: Turn-Off Waveforms Optimized for Overshoot: V_{GS} (channel 1), V_{DS} (channel 2), I_D (channel 4, 1 A/mV).

TABLE 5: DOUBLE PULSE TEST RESULTS, TURN-OFF

V_{TLTO} (V)	t_{TLTO} (ns)	Switching Loss (mJ)	Comparison to Datasheet	V_{DS} Overshoot (V)
3	150	1.37	-73%	513
3	200	1.80	-65%	434
3	250	1.94	-62%	387
3	300	2.05	-60%	390
6	150	1.56	-69%	581
6	200	2.67	-48%	526
6	250	4.57	-10%	388
6	300	4.94	-3.1%	228

SHORT-CIRCUIT TESTING

Hardware Setup

Short-circuit testing was performed using a similar setup to double pulse testing, except the inductor was replaced with a small resistor (330 mΩ). Additionally, the DC link voltage was increased to 800 V to match the parameters in the module datasheet.

TABLE 6: SHORT-CIRCUIT HARDWARE SETUP

Paramater	Symbol	Value	Unit
DC Link Voltage	V_{DC}	800	V
Response Time	t_{SC}	1.5	μs
Resistive Load	R_{LOAD}	330	μΩ
Turn-On Gate Resistor	$R_{G(ON)}$	1.1	Ω
Turn-Off Gate Resistor	$R_{G(OFF)}$	1.1	Ω
Ambient Temperature	T_{AMB}	30	°C

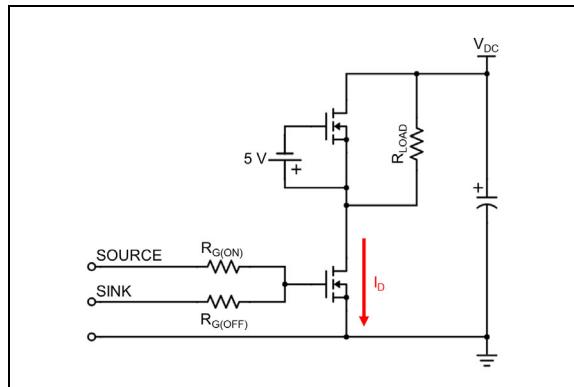


FIGURE 10: Short-Circuit Hardware Setup.

Software Setup

In addition to Two-Level Turn-Off (TLTO) during normal operation, the 2ASC-12A1HP features Multilevel Turn-Off (MLTO) following detection of a desaturation/short-circuit event. This is similar to TLTO but offers an additional intermediate step. The voltage levels and timing of these steps are configurable in software, so several combinations were tested to arrive at a setting to provide adequate turn-off speed while minimizing overshoot voltage; the final settings are listed in Table 7. The desaturation trip level is also configurable; this translates to a particular detection time, which was set at 1.5 μs to allow fast detection time while ensuring zero false positives.

Note 2: Turn-off energy loss is specified as 5.10 mJ (typical).

TABLE 7: MULTI-LEVEL TURN-OFF PARAMETERS

Paramater	Symbol	Value	Unit
Full On Gate Voltage	$V_{GS(ON)}$	15	V
Full Off Gate Voltage	$V_{GS(OFF)}$	-5	V
Multilevel Turn-Off Voltage 1	V_{MLTO1}	9	V
Multilevel Turn-Off Time 1	t_{MLTO1}	500	ns
Multilevel Turn-Off Voltage 2	V_{MLTO1}	4	V
Multilevel Turn-Off Time 2	t_{MLTO1}	400	ns

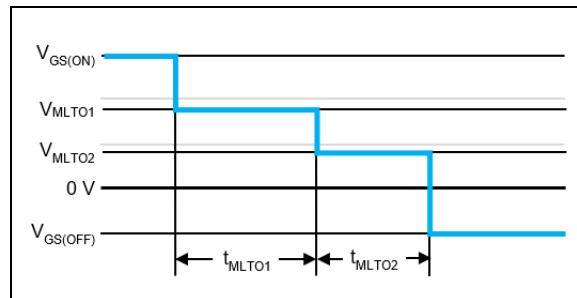


FIGURE 11: Multilevel Turn-Off Profile.

Results

Figure 12 shows three key waveforms during a short-circuit event: Channel 4 (green) shows the current rising quickly due to the 330 mΩ resistor across the high-side MOSFET; channel 1 (yellow) shows the gate signal with multi-level turn-off; and channel 2 (magenta) shows the voltage across the low-side MOSFET. The driver begins to shut off the gate signal after 1.5 µs, by which time the current has risen to a peak of 1.48 kA. Because of the controlled turn-off profile, voltage overshoot is limited to 280 V on an 800 V bus.

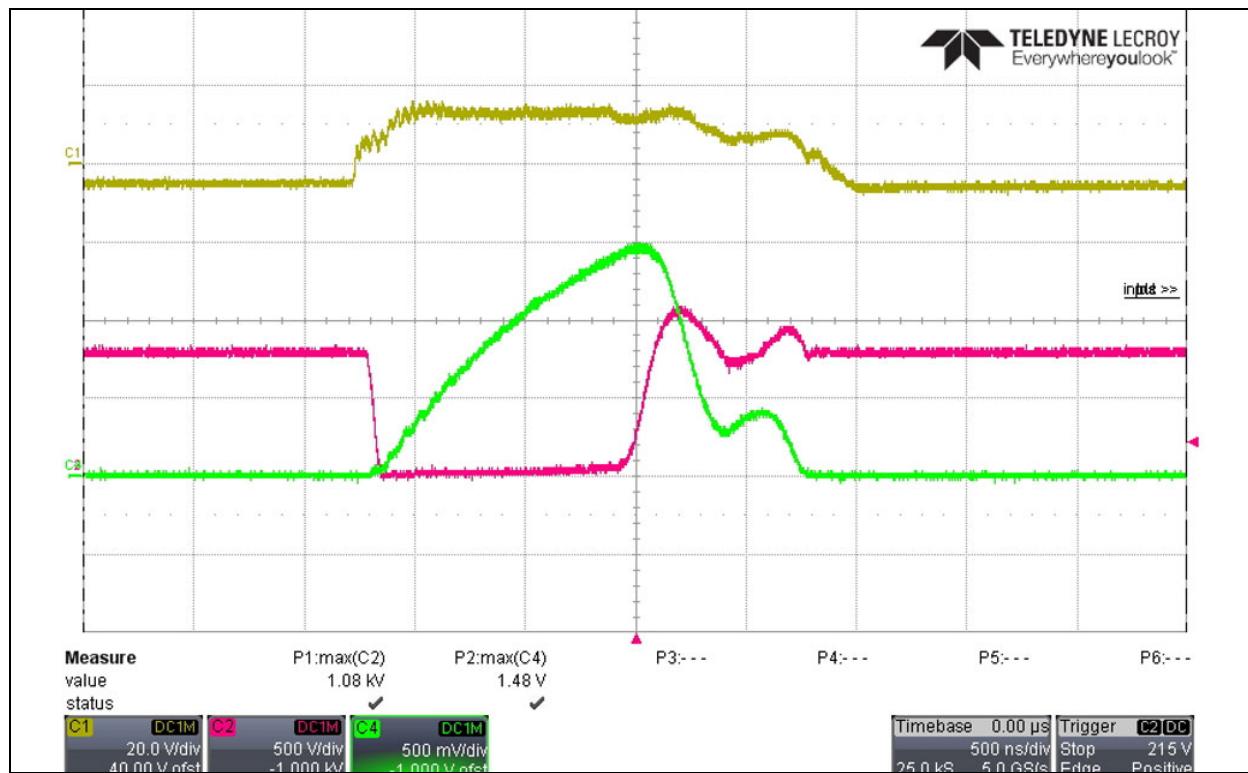


FIGURE 12: Short-Circuit Waveform: V_{GS} (channel 1), V_{DS} (channel 2), I_D (channel 4, 1 A/mV).

SUMMARY

The 62mm SiC module platform has shown to be a robust module through our double pulse tests. The Gate Resistors chosen by the manufacturer (R_g on/off = $3.9\ \Omega$) seems reasonable given the inductance in the package and assumed system.

The losses in the datasheet seem to be in line with comparative products from other manufacturers.

AgileSwitch's Augmented Switching technique is shown to provide performance benefits, as below:

1. Fine-tuning of the trade-off - switching loss vs. V_{ds} overshoot
 - a) 73% lower turn-off loss when optimized for lowest switching loss
 - b) 3% lower turn-off loss when optimized for lowest V_{ds} Overshoot
2. Robust short-circuit protection
 - a) Total short-circuit time of $<2\ \mu s$
 - b) Controlled V_{ds} overshoot and ringing

In conclusion, the Augmented Switching technique is a tool that allows engineers to fine-tune system performance.

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