AgileSwitch Intelligent Configuration Tool User Manual

2ASC-12A1HP

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1. Abstract

AgileSwitch Digital Programmable Gate Drivers offer multiple levels of software configurability that allow system designers to fine-tune performance to their specific systems and applications. This Intelligent Configuration Tool (ICT) User Manual describes the software-configurable parameters, including individual parameter ranges, and also includes recommended settings where appropriate.

One note of caution regarding the use of the software configuration tool: It is advised that designers use conservative parameter settings when performing the initial testing of the gate driver or gate driver in combination with a SiC module. Refer to Appendix A for a procedure which outlines how to safely derive the parameter settings for both Normal and DSAT operation for any SiC module.

An overview of the Gate Driver configuration process is shown below:

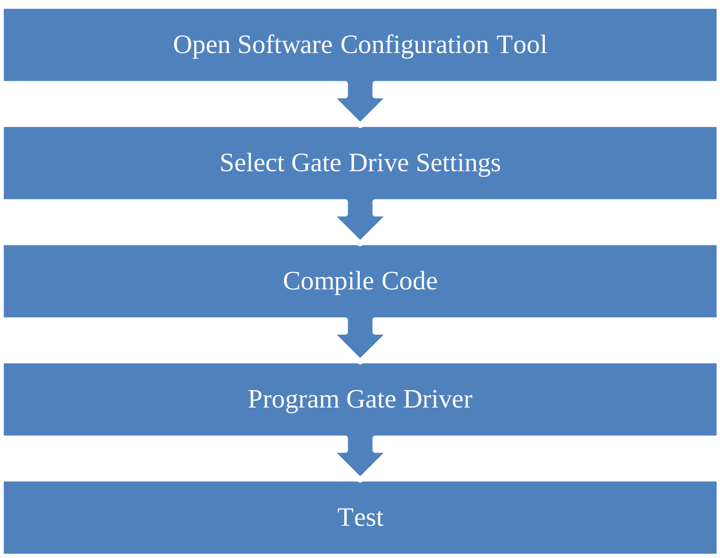

Figure 1: Process Overview

2. Equipment and Software

Qty	Description	Manufacturer	Part Number	Notes
1	Windows 7 or better PC	-	-	
1	MPLAB X IPE	Microchip		http://www.agileswitch.com/program.html
1	Intelligent Configuration Tool	AgileSwitch	ICT – 2ASC-12A1HP	
1	Device Programmer	AgileSwitch	ASBK-007	Connects PC to Gate Driver

Table 1: Hardware and software required

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3. Configuration Procedure

This section outlines the steps required to run the Intelligent Configuration Tool, change parameter settings, enter a software part number and version number, and compile a piece of software for the 2ASC-12A1HP.

3.1. Intelligent Configuration Tool Introduction

Open the ICT-2ASC-12A1HP. If prompted, select Accept to allow the program to make changes to your device and accept the AgileSwitch Product Agreement shown in Figure 2.

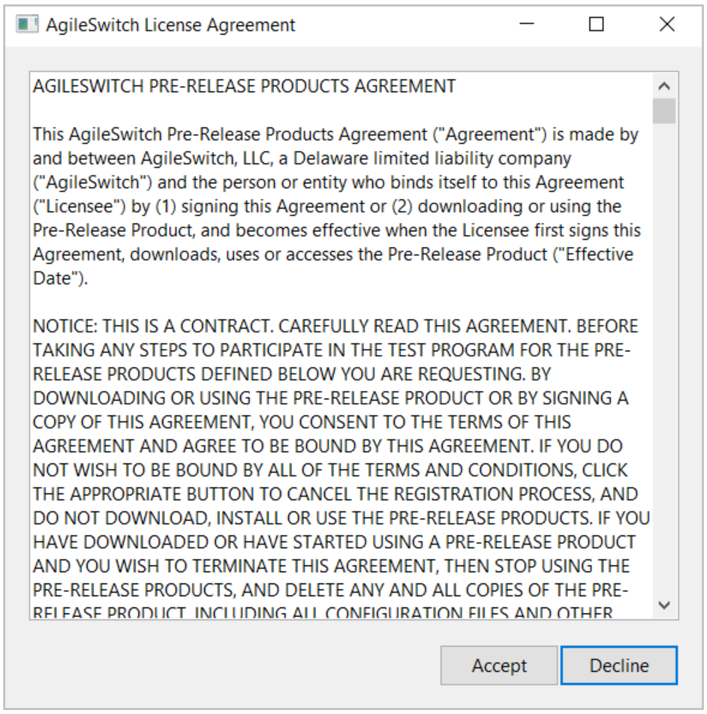

Figure 2: Pre-Release Products Agreement

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The ICT will open with no parameter settings. The user has the option to enter their own configuration parameters, load the default settings, select settings from a list of tested SiC modules, or load in previously saved parameter settings. AgileSwitch recommends first selecting your device from our list of tested SiC modules. A detailed explanation of this process and additional details is covered in Configuration Parameters.

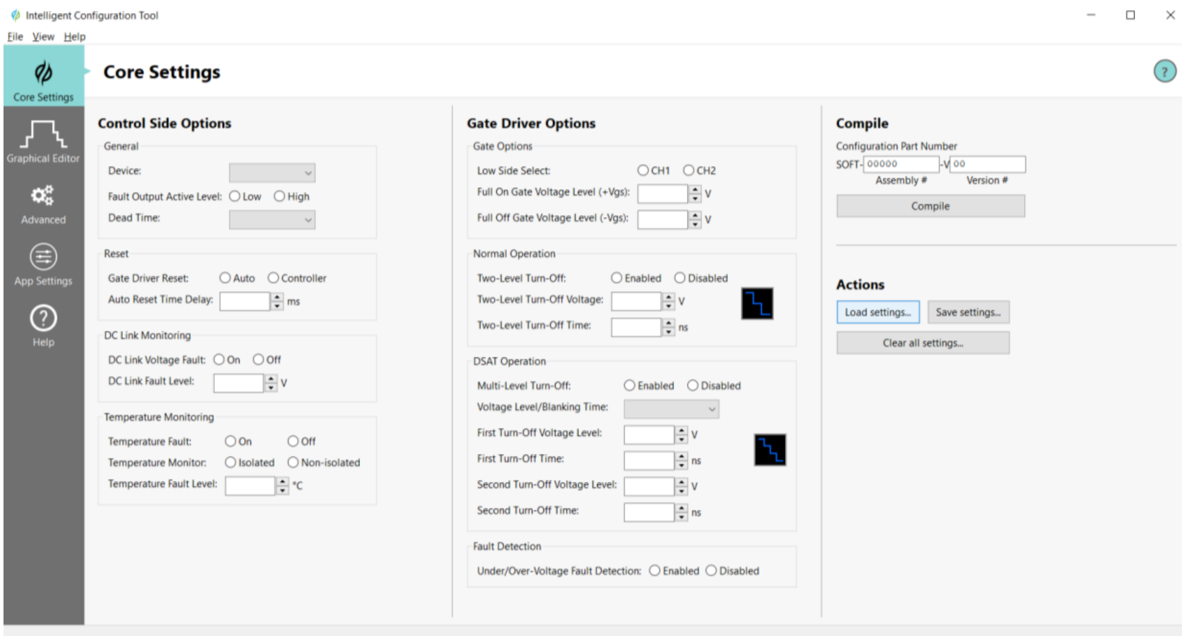

Figure 3: ICT blank after open

3.1.1. Generate Code

Once the user has selected the desired configuration parameters, we can generate a compiled output file to program the Gate Driver. To generate this file, follow these steps:

1. Enter a Software Assembly Number.
2. Enter a Version Number.
3. Click the Compile button.
   a. A Save Settings box will open to add additional notes for this specific version. This is optional.

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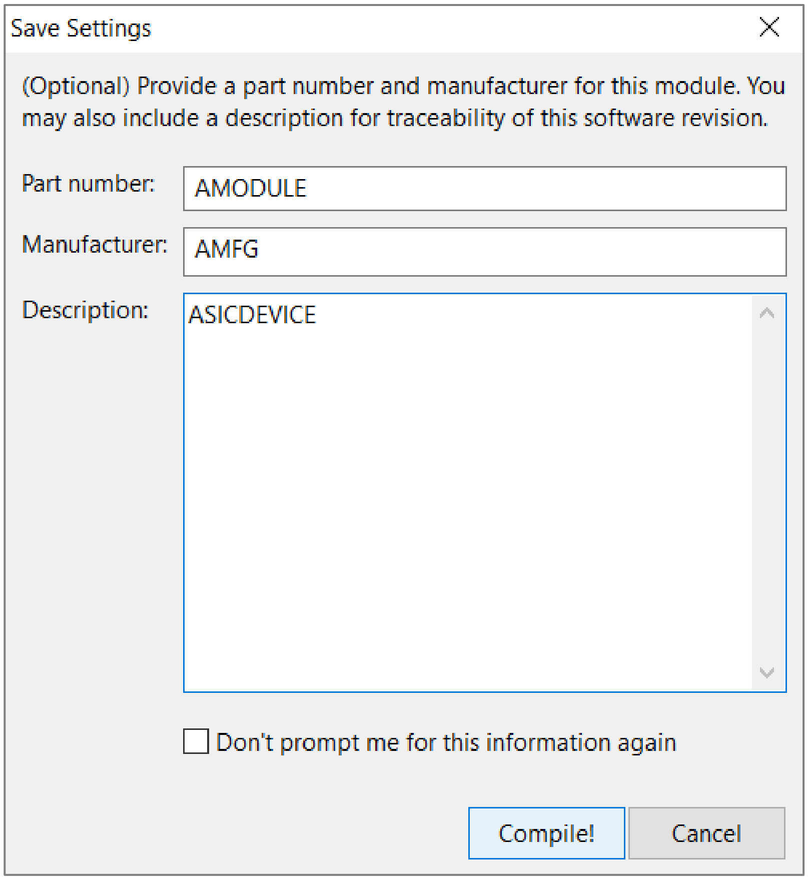

   b. Hit Compile again and a Save As dialogue box will open.

4. Navigate to the desired folder where you wish to save the compiled output file. The ICT will create a folder named SOFT-[ASSEMBLY NUMBER]-[VERSION NUMBER].
   ex: SOFT-00000-V01

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5. If the Software and Version Number already exist in this location, you will be prompted to copy, overwrite or create a new version.

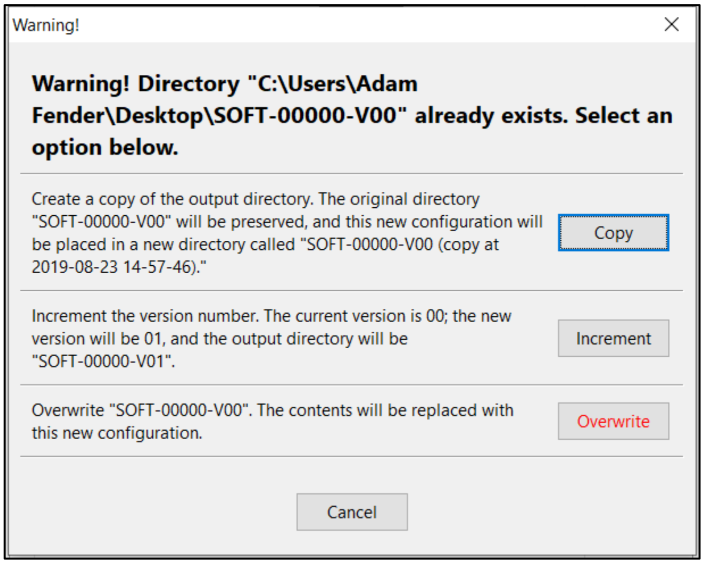

Figure 4: Version Already Exists Warning

6. The compilation process takes a few moments to complete. When complete, you will see the following message:

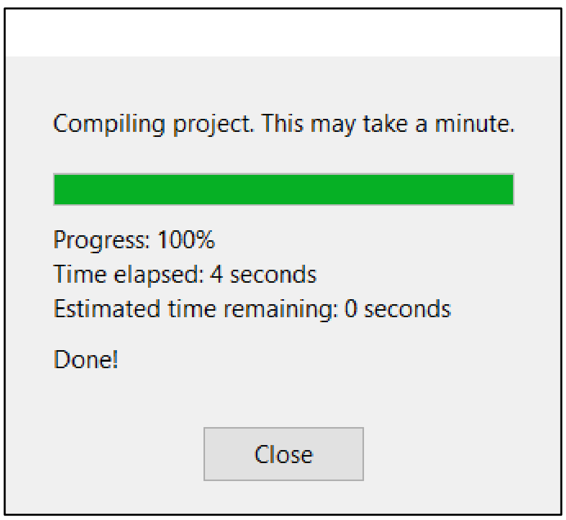

Figure 5: Compilation complete

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3.1.2. Review

The 2ASC-12A1HP folder created in the location selected will contain the following information:

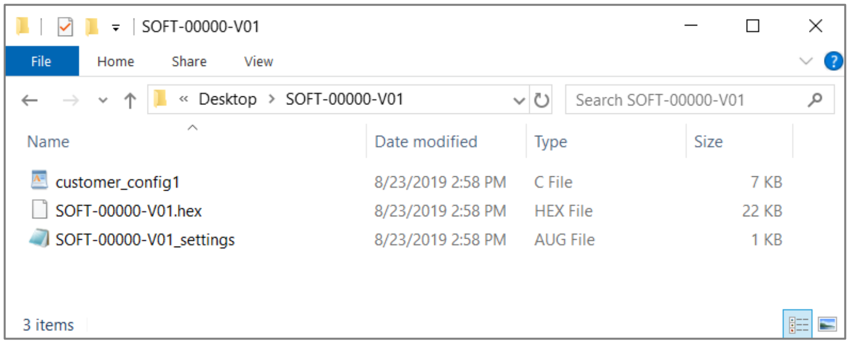

Figure 6: Folders created

1. Cutomer_config1
    a. File used to create compiled output file
2. SOFT-00000-V01.hex
    a. This is the compiled output file
3. SOFT-00000-V01_settings
    a. Contains files with specific build information for each assembly and version
    b. These can be loaded into the ICT using the Load Settings button, see Additional Functions

3.1.3. Program Gate Driver

To program an AgileSwitch Gate Driver, follow the Device Programming Instructions.

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3.1.4. Additional Functions

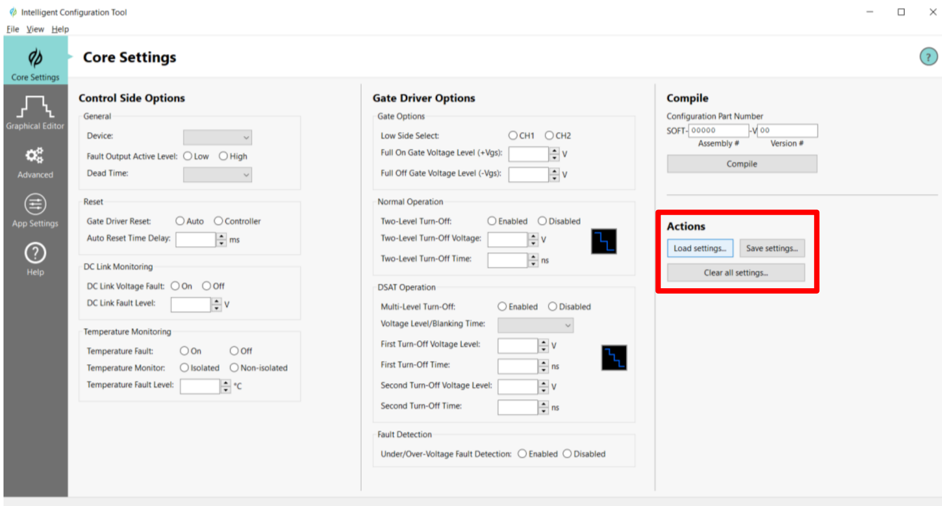

Figure 7: Additional functions

1. Load Settings
    a. Loads in default settings for all Gate Driver Options parameters for specific SiC Device Part Numbers.
2. Save Settings
    a. Saves all current parameters in the ICT. This is not a compiled output file for use on a Gate Driver. The file can be loaded back into the ICT for modifications.
3. Clear Settings
    a. Resets all settings to be empty.

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4. Configuration Parameters

4.1. Control Processor Configuration Options

The Control Processor Configuration option selections include any configuration parameters which configure the control processor operation. The Control Processor is responsible for power up initialization for both the Gate Driver and Gate Driver ICs, monitoring for Fault conditions, reporting Fault conditions, generating the Temperature and DC Link PWM outputs, and monitoring the Reset input line. The Control Processor Configuration includes the following parameters which will be discussed in detail in the following sections:

- Device Rating
- Gate Driver Reset
- Auto Reset Time Delay
- Dead Time
- DC Link Voltage Fault Detection Enable and Level
- Temperature Fault Detection Enable and Level
- Temperature Monitor Isolation
- Fault Output Active Level

A summary table of all the parameter default values and ranges can be found in Parameter Settings Summary and Ranges.

4.1.1. Device

Select your Gate Driver.

4.1.2. Fault Output Active Level

The Fault Output Active Level allows the user to select the active level for the three Gate Driver fault status output lines (HI, LO, and All Fault outputs).

For the Low Active Fault selection, the HI, LO, and All Fault outputs will be low (0V) when a fault occurs. The HI, LO, and All Fault outputs will be at the user's pull-up voltage on the Host Controller board when no fault condition exists. Fault outputs are open-drain.

For the High Active Fault selection, the HI, LO, and All Fault outputs will be at the user's pull-up voltage on the Host Controller board when a fault condition exists. The HI, LO, and All Fault outputs will be low (0V) when no fault condition exists.

The user can select either Low or High active levels for the fault lines as shown in Table 2 below. The HI, LO, and All fault lines are not individually selectable – they will either be all low active or all high active.

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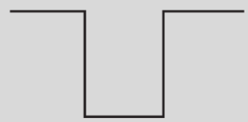
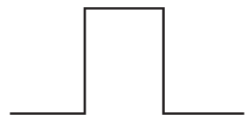
Fault Output Active Level		
Option	Description	Diagram
Low	User Pullup Voltage = No Fault 0V = Fault	
High	User Pullup Voltage = Fault 0V = No Fault	

Table 2: Fault Output Active Levels

4.1.3. Dead Time

The Dead Time Setting parameter will select the Dead Time value that will be applied to the Trigger inputs. The Dead Time setting will be the minimum Dead Time enforced between the LO and HI trigger outputs. Refer to parameter Tnov in Figure 8: Normal Operation Timing Diagram.

The Dead Time setting will be overridden in two instances:

1. The user (Host Controller) generated input triggers have a Dead Time that is greater than the Dead Time Setting.
2. The user has enabled Trigger Pass Thru mode.

Dead Time Setting Selections (ns)
280
330
430
600
900
1100
1400
1700

Table 3: Dead Time Settings

4.1.4. Gate Driver Reset

The Gate Driver Reset parameter is used to select how the Gate Driver is reset when a fault occurs. The two parameter selections are Auto and Controller.

If Auto is selected, the gate driver will automatically reset itself based on the Auto Reset Delay Time parameter, which is entered in milliseconds.

If Controller is selected, the gate driver will remain in fault mode (triggers disabled) until the user Host Controller issues a reset to the gate driver. The reset input on the gate driver is a low active signal. Refer to the Gate Driver specification for the minimum width of the reset input.

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4.1.5. Auto Reset Time Delay

The Auto Reset Time Delay is the time in milliseconds that the gate driver will remain in fault mode until it automatically resets itself and returns to normal operation. The valid range is 1 to 255 milliseconds. This parameter is only used when the Auto Reset Mode is selected.

4.1.6. DC Link Voltage Fault Detection Enable and Level

4.1.6.1. Enable/Disable DC Link Voltage Fault Detection

On – DC Link Fault Checking Enabled
Off – DC Link Fault Checking Disabled

If enabled, the All Fault Output will be set active if the DC Link Voltage Measurement is greater than the DC Link Fault Level parameter setting.

4.1.6.2. Set DC Link Fault Level

If DC Link Voltage Fault Detection is enabled, a DC Link Fault Level must be entered. The valid entry range is dependent on the Device Rating selection. For the 1200V selection the valid range is 0-1000V.

4.1.7. Temperature Fault Detection Enable, Level, and Isolation

4.1.7.1. Enable/Disable Temperature Fault Detection

On – Temperature Fault Checking Enabled
Off – Temperature Fault Checking Disabled

If enabled, the All Fault Output will be set active if the Temperature Measurement is greater than the Temperature Fault Level parameter setting.

4.1.7.2. Temperature Monitor Isolation

Isolated – Typically used for modules with an NTC connection built in. The Temperature Monitor output to the Host Controller will be isolated.

Non-Isolated – Typically used for modules without an NTC connection built in. The Temperature Monitor output to the Host Controller will not be isolated.

This selection depends on the design of the module adapter board.

Note: If Temperature Fault Detection is Disabled, this will be ignored.

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4.1.7.3. Set Temperature Fault Level

If Temperature Fault Detection is enabled, a Temperature Level must be entered. The valid entry range is 20-175C.

4.1.8. Advanced

Select the Advanced tab on the ICT to view the following options. Note: * = Standard setting.

4.1.8.1. Trigger Pass Thru

The Trigger Pass Thru allows the user's Host Controller to directly control the Dead Time between the Low and High Trigger inputs. This mode will bypass the Dead Time circuitry on the 2ASC-12A1HP Gate Driver. It is important to note that because the 2ASC-12A1HP gate driver Dead Time circuitry is being bypassed, the user must implement Dead Time between the Low and High triggers in their controller.

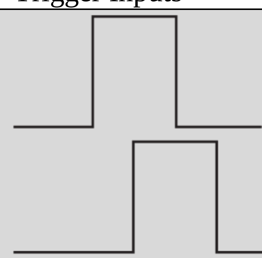
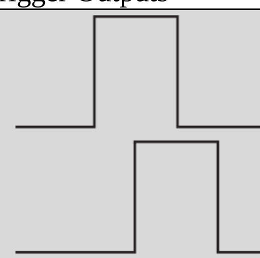
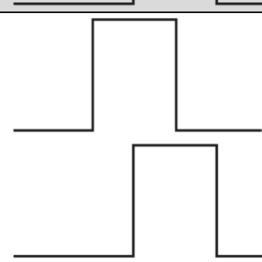
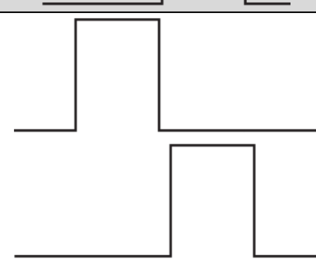
Trigger Pass Thru			
Option	Description	Trigger Inputs	Trigger Outputs
ON	Allows input triggers from host to overlap – Host Controls Dead Time		
OFF*	Gate driver will force Dead Time for overlapping trigger inputs		

Table 4: Trigger Pass Thru

4.1.8.2. Single Trigger Input HI

The Single Trigger Input HI mode uses the HI Trigger input to generate the LO and HI Trigger outputs. The LO Trigger Input is used as an enable control signal for the LO and HI Trigger outputs.

When the LO Trigger input is high, the HI Trigger output is controlled by the user Host Controller and the LO Trigger output generated will be the opposite signal level of the High trigger input.

When the LO Trigger input is low, both the HI and LO Trigger outputs will be low (off).

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The Dead Time circuitry on the 2ASC-12A1HP will enforce Dead Time between the LO and HI Trigger outputs. Due to the Dead Time, the HI and LO Trigger outputs will not have the same high (on) pulse width.

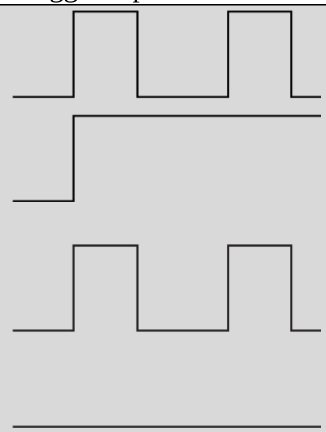
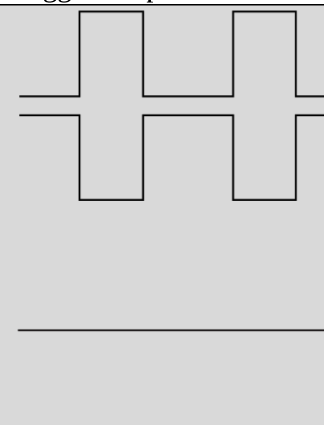
Single Input Trigger High			
Option	Description	Trigger Inputs	Trigger Outputs
ON	-Host supplies HI side trigger -LO side Trigger is enable input (high enables Trigger outputs)		
OFF*	Gate driver accepts triggers as sent by the Host controller		

Table 5: Single Trigger Input HI

4.1.8.3. PWM Scaling

The PWM Scaling mode will create a 10 to 90 percent duty cycle range for the Temperature and DC Link Voltage output PWM signals. This selection will guarantee that the Temperature and DC Link Voltage output PWM signals will always be a frequency output signal which can be measured as a frequency input by the host controller.

When PWM Scaling mode is not selected the Temperature and DC Link Voltage output PWM signals can be either fixed low (0% duty cycle) or high (100% duty cycle) outputs if the Temperature and DC Link Voltage inputs are at their minimum or maximum input levels, respectively.

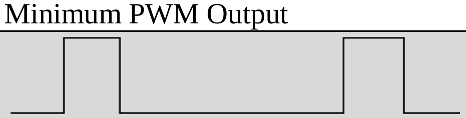
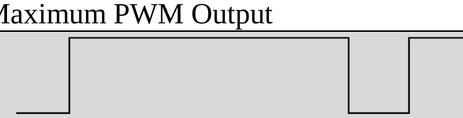
PWM Scaling		
Option	Minimum PWM Output	Maximum PWM Output
ON		
OFF*		

Table 6: PWM Scaling

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4.1.8.4. Trigger Input Threshold

The Trigger Input Threshold selection allows the user to set the voltage threshold for a logic high input level. This selection can be used to improve the noise immunity of the Trigger inputs by setting the logic high input threshold to a higher value. The default input threshold is 2.5V.

4.1.8.5. Compilation Settings – Full Compilation

When checked, this action recompiles the entire source code instead of only the user settings. This should remain unchecked unless the Gate Driver is not appropriately responding based on the Core Settings. i.e. Auto Reset is selected, but the Gate Driver is in Controller Reset.

4.1.8.6. Compile Log (Tab)

If you receive unexpected compilation errors, review the error code in this log and report it to AgileSwitch.

4.2. Gate Driver Configuration Parameters

4.2.1.1. Gate Options

4.2.1.1.1. LO Side Select

The LO Side Select parameter selects which channel on the Gate Driver is connected to the LO Side of the SiC module. This selection will determine which channel is connected to the LO Side of the SiC module and this channel will transmit the Temperature and DC Link information to the Control processor.

4.2.1.1.2. Full On Gate Voltage Level (+VGS)

The Full On Gate Voltage parameter is the voltage level that will be driving the SiC Gate when the trigger input is high (on). The voltage limits for the Full On Gate Voltage are listed in Section 5 below. The user should enter the desired Full On Gate voltage, and the Configuration tool will account for the voltage drop across the output driver on the 2ASC-12A1HP core.

4.2.1.1.3. Full Off Gate Voltage Level (-VGS)

The Full Off Gate Voltage parameter is the voltage level that will be driving the SiC Gate when the trigger input is low (off). The Full Off Gate Voltage is entered as a positive value, but the voltage entered will be converted to a negative voltage on the gate driver. The voltage limits for the Full Off Gate Voltage are listed in Section 5 below. The user should enter the desired Full Off Gate voltage, and the Configuration tool will account for the voltage drop across the output driver on the 2ASC-12A1HP core.

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4.2.1.2. Normal Operation

4.2.1.2.1. Normal Two Level Turn-Off

When selected, the Normal Two Level Turn Off Enable parameter enables an intermediate step down in the Trigger output voltage (Normal Two Level Turn Off Voltage) for a specified time (Normal Two Level Turn Off Time) when the Input Trigger is turned off before the Trigger output voltage reaches its full off voltage. This selection will allow the user to control the overshoot of the voltage on the output when the input trigger is turned off.

When this parameter is disabled, the input trigger will directly control the output trigger (gate signal of the SIC module). Enabling the Normal Two Level Turn off option requires the user to enter valid values for the Normal Two Level Turn Off Voltage and Time parameters. A process to determine the correct Normal Two Level Turn Off Voltage and Time parameters is discussed in Appendix A.

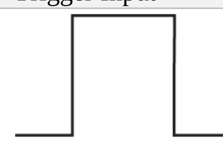
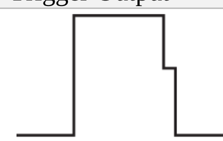
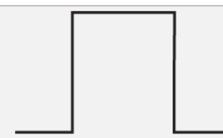
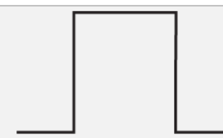
Normal Two Level Turn Off Enable (2LTO)			
Option	Description	Trigger Input	Trigger Output
ON	2LTO Enabled for Normal Operation *Voltage level and dwell time settings below		
OFF	2LTO Disabled		

Table 7: Normal Two Level Turn-Off Options

4.2.1.2.2. Normal Two Level Turn-Off Voltage

The Normal Two Level Turn Off Voltage parameter is the trigger (gate) output voltage level (Vsoft) that the trigger output will step down to as an intermediate turn off step. This parameter is only valid when the Normal Two Level Turn Off Enable parameter is enabled. Refer to Table 7 for a diagram of the Normal Two Level Turn Off function. Also refer to Figure 8 for the Normal Operation Timing Diagram.

4.2.1.2.3. Normal Two Level Turn-Off Time

The Normal Two Level Turn Off Time parameter is the time (Ts) that the trigger (gate) output will remain at the Normal Two Level Turn Off Voltage level (Vsoft). This parameter is only valid when the Normal Two Level Turn Off Enable parameter is enabled. Refer to Table 7 for a diagram of the Normal Two Level Turn Off function. Also refer to Figure 8 for the Normal Operation Timing Diagram.

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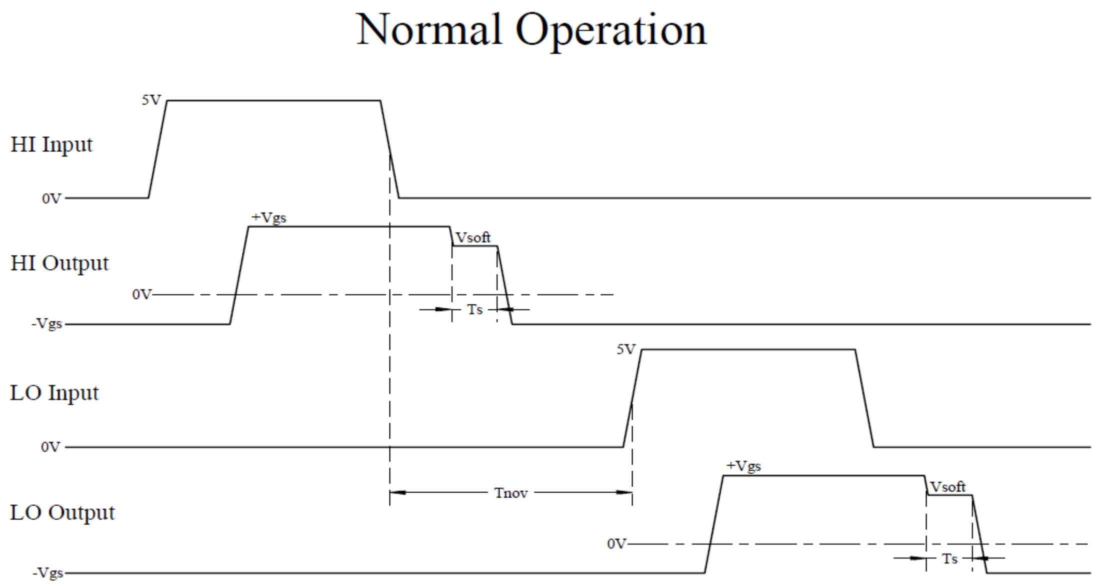

Figure 8: Normal Operation Timing Diagram

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4.2.1.3. DSAT Operation

4.2.1.3.1. DSAT Multi Level Turn-Off

When selected, the DSAT Multi Level Turn Off Enable parameter enables up to two intermediate step down voltages in the Trigger output voltage (DSAT First and Second Turn Off Voltages) for specified times (DSAT First and Second Turn Off Times) when a DSAT Fault condition occurs before the Trigger output voltage is allowed to reach its full off voltage. This selection will allow the user to control the overshoot voltage on the output when a DSAT fault condition occurs.

When this parameter is disabled, the DSAT operation will implement a single level step down voltage (DSAT First Turn Off Voltage) for a specified time (DSAT First Turn Off Time), like the Normal Two level Turn off implementation.

Enabling the DSAT Multi Level Turn off option requires the user to enter valid values for the DSAT First and Second Turn Off Voltage and Time parameters. A process to determine the correct DSAT Multi Level Turn Off Voltage and Time parameters is discussed in Appendix A. Refer to Figure 18 for a diagram of the DSAT Multi Level Turn Off Enable parameter.

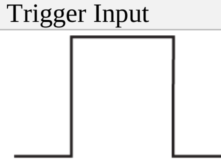
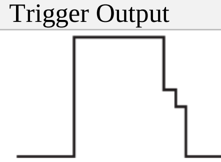
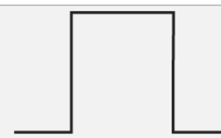
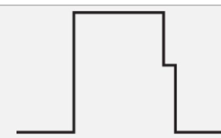
DSAT Multi Level Turn Off (MLTO)			
Option	Description	Trigger Input	Trigger Output
ON	MTLO Enabled for DSAT condition *Voltage levels and dwell times settings below		
OFF	MLTO Disabled *Voltage level and dwell time settings below		

Table 8: DSAT Multi Level Turn-Off Options

4.2.1.3.2. DSAT Voltage Level (Blanking Time)

The DSAT Voltage Level parameter is the DSAT Input voltage level that will initiate a DSAT condition in the 2ASC-12A1HP Gate Driver. The DSAT Voltage level parameter setting will directly translate to a response time for a DSAT Fault condition. For SIC modules the response time is important. If the response time is set too slow, this may result in damage to the SIC module. If the response time is set too fast this will result in a false DSAT condition—the 2ASC-12A1HP Gate Driver would start the DSAT shut down process when in fact a DSAT condition has not occurred.

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Refer to the table below for the DSAT Voltage Level (Blanking Time) Selections.

DSAT Voltage Level Selections	DSAT Response Time (ns)
3V	500
3.5V	600
4V	670
4.5V	730
5V	800
5.5V	880
6V	980
6.5V	1040
7V	1120
8V	1250
9V	1500
10V	1750

Table 9: DSAT Voltage Level & Blanking Time Options

4.2.1.3.3. DSAT First Turn-Off Voltage Level

The DSAT First Turn Off Voltage Level parameter is the trigger (gate) output voltage level (VsoftD1) that the trigger output will initially step down to as an intermediate turn off step. This parameter is valid when the DSAT Multi Level Turn Off Enable parameter is either enabled or disabled. Refer to Table 8 for a diagram of the DSAT Multi Level Turn Off function. Also refer to Figure 9 for the DSAT Fault Timing Diagram.

4.2.1.3.4. DSAT First Turn-Off Time

The DSAT First Turn Off Time parameter is the time (TSD1) that the trigger (gate) output will remain at the DSAT First Turn Off Voltage level (VsoftD1). This parameter is valid when the DSAT Multi Level Turn Off Enable parameter is either enabled or disabled. Refer to Table 8 for a diagram of the DSAT Multi Level Turn Off function. Also refer to Figure 9 for the DSAT Fault Timing Diagram.

4.2.1.3.5. DSAT Second Turn-Off Voltage Level

The DSAT Second Turn Off Voltage Level parameter is the trigger (gate) output voltage level (VsoftD2) that the trigger output will step down to as a secondary turn off step. This parameter is only valid when the DSAT Multi Level Turn Off Enable parameter is enabled. Refer to Table 8 for a diagram of the DSAT Multi Level Turn Off function. Also refer to Figure 9 for the DSAT Fault Timing Diagram.

4.2.1.3.6. DSAT Second Turn-Off Time

The DSAT Second Turn Off Time parameter is the time (TSD2) that the trigger (gate) output will remain at the DSAT Second Turn Off Voltage level (VsoftD2). This parameter is only valid when the DSAT Multi Level Turn Off Enable parameter is enabled. Refer to Table 8 for a

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diagram of the DSAT Multi Level Turn Off function. Also refer to Figure 9 for the DSAT Fault Timing Diagram.

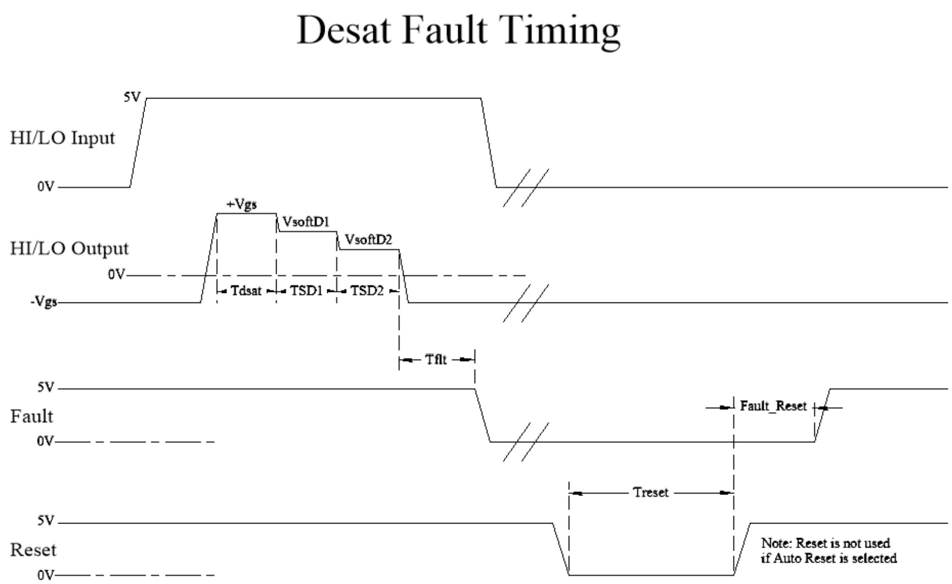

Figure 9: DSAT Operation Timing Diagram

4.2.1.4. Fault Detection

4.2.1.4.1. Under/Over Voltage Fault Detection

The Under/Over Voltage Fault Detection parameter enables or disables Under/Over Voltage fault detection on the High voltage side of the Gate Driver. This selection applies to both Channels 1 and 2. If Under/Over Voltage Fault Detection is disabled then only the primary input voltage (+15V) will be monitored for an Under/Over Voltage fault.

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5. Parameter Settings Summary and Ranges

Table 10 provides a summary of all the Parameter settings available in the AgileSwitch Customer Software Configuration Tool, including the valid ranges for these parameters.

Parameter		Default Setting	Min	Max	Units
Gate Driver Reset (Auto or Host Controller)		Controller	-	-	-
Auto Reset Time Delay		5ms	1	255	ms
Fault Output Active Level (Low or High)		Low	-	-	-
Temperature Fault Enable (On or Off)		On	-	-	-
Temperature Fault Level		125 °C	20	175	°C
DC Link Voltage Fault Enable (On or Off)		On	-	-	-
DC Link Trip Level	1200V module	950V	0	1000	V
	1700V module	Not Implemented	-	-	V
Device Rating (SIC Module Voltage)		1200V	1200	-	V
Temperature Non-Isolated Enable (On or Off)		Off	-	-	-
Input Trigger Threshold		2.5V	1.5	4.5	V
Trigger Pass Thru (On or Off)		Off	-	-	-
Single Trigger Input High (On or Off)		Off	-	-	-
PWM Scaling (On or Off)		Off	-	-	-
+15V Low Limit		13.2V	-	-	Fixed
+15V Low Hysteresis		13.7V	-	-	Fixed
+15V High Limit		16.5V	-	-	Fixed
+15V High Hysteresis		16V	-	-	Fixed
Dead Time Setting		900 ns	280	1700	ns
Normal Two Level Turn Off (On or Off)		On	-	-	-
Normal Two Level Turn Off Voltage		0V	0	19	V
Normal Two Level Turn Off Time		200 ns	30	8000	ns
DSAT Multi Level Turn Off (On or Off)		On	-	-	-
DSAT First Turn Off Voltage		9V	0	19	V
DSAT First Turn Off Time		400 ns	30	8000	ns
DSAT Second Turn Off Voltage		5V	0	19	V
DSAT Second Turn Off Time		200 ns	30	8000	ns
DSAT Voltage Level (Blanking Time)		730 ns	500	1750	ns
Under/Over Voltage Fault Detection (On or Off)		On	-	-	-
Over Voltage Fault Level		24.65V	-	-	Fixed
Over Voltage Fault Level Hysteresis		24.15V	-	.-	Fixed
Under Voltage Fault Level		20.2V	-	-	Fixed
Under Voltage Fault Level Hysteresis		20.7V	-	-	Fixed
Low Side Select (CH1 = 1; CH2 = 0)		CH1	0	-	-
Full On Gate Voltage		20V	12	21.3	V
Full Off Gate Voltage (Negative Voltage)		-5V	0	5	V

Table 10: Summary of Parameters and Settings

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6. Appendix A

Note: The following descriptions and procedures are written with the assumption that the user has a fundamental understanding of pulse testing, measurement, and safety protocol in high power environments.

6.1. Normal Operation Settings Procedure

6.1.1. Introduction

There are two primary characteristics that define the overall performance of the SiC MOSFET: switching efficiency and overshoot. Augmented Switching™ during Normal Operation can be used to optimize the trade-off between these two characteristics. Properly setting the Normal Two Level Turn-Off Voltage and Time parameters can result in a reduced overshoot voltage and improved switching efficiency of the SiC MOSFET compared to a traditional gate resistor solution.

6.1.2. Gate Resistors

It is not necessary or recommended to use a large gate resistor while using Augmented Switching. Typically, a 1Ω gate resistor is recommended. This low resistance eliminates the need for a Miller Clamp because this technique is only necessary when using a relatively high value gate resistor. There is an inversely proportional relationship between the gate resistance value and the speed that the driver can move the gate of the MOSFET. It is not unusual to use a 0 Ω resistor.

6.1.3. Determine the Initial Parameter Settings

The first step to characterize a device is to understand the basic performance of the SiC MOSFET.

AgileSwitch has characterized several commercially available SiC MOSFETs, and the settings we found to be most optimal are included with the Intelligent Configuration Tool (ICT) download from Equipment and Software.

For new or custom modules, an inductive double pulse test can be used to evaluate the performance. See Figure 10 for a simple double pulse testing circuit diagram and probe locations.

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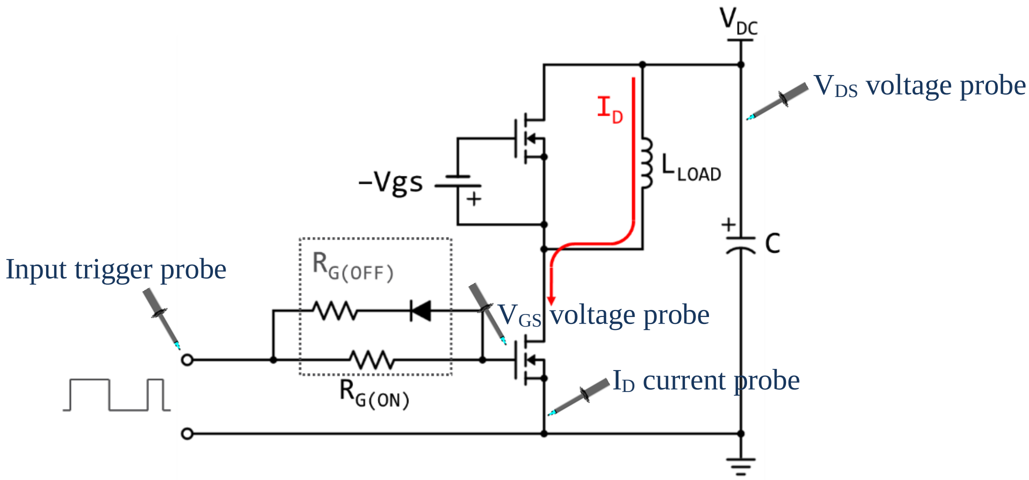

Figure 10: Double Pulse Test Schematic diagram

The general procedure is:

1. Setup the Double Pulse Circuit.
    a. Probe the following with a standard probe:
        i. Drive signal from host
    b. Probe the following with a high voltage differential probe:
        i. Vgs_{LO}
        ii. Vds
    c. Probe the following with a current probe:
        i. Id
2. Select appropriate values for the:
    a. DC Link Voltage
    b. Current
    c. Load Inductor
    d. Double Pulse Width Settings ($t_{ON1} – t_{OFF} – t_{ON2}$)

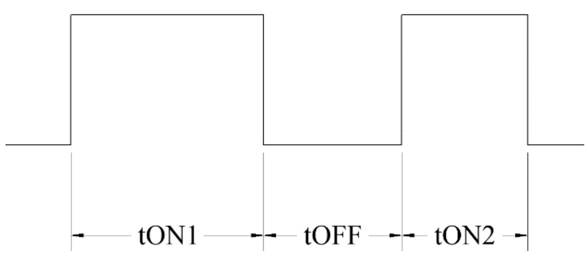

Figure 11: DPT pulse width settings

i. t_{ON1}
The DC Link Voltage and Current are determined by your system. Select a load inductor based on the target application.

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Determine the pulse width using this equation:

$$V(t) = L\frac{di}{dt} \longrightarrow t = L\frac{I}{V}$$

For example: A 7.5µs pulse is required for an 800V DC Link, 60A, 100uH load.

ii. t_{OFF}

Typically, a good starting point is t_{ON1}. The ideal time should be long enough to allow V_{DS} to stop ringing after turn-off.

iii. t_{ON2}

This should be equal to or less than t_{ON1}.

3. In the ICT, set the Normal Two Level Turn-Off Voltage to 1.5 to 2V greater than the device threshold voltage ($V_{GS(th)}$). Set the Normal Two Level Turn-Off Time to 300ns. This is a good starting point for most modules.
   a. As a fail-safe, input the following DSAT settings:

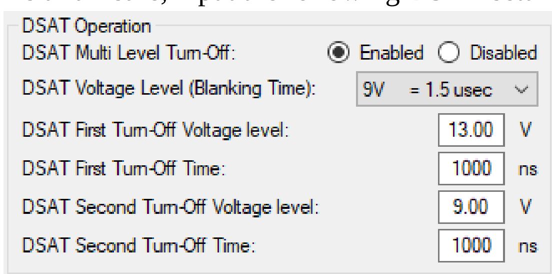

Figure 12: Default DSAT Operation Settings

Note: These will be characterized in the next section.

4. Compile and program the gate driver.
5. With the **DC Link Voltage OFF**, probe the LO Gate and send the double pulse signals.
6. Check that the LO Gate behaves as expected based on these Normal Operation settings.
   a. Figure 13 below shows an unloaded LO side Two Level Turn-Off waveform (purple) and the HI side Gate turning on after a specified dead time (green). Both were measured from the LO and HI Vgs.
   b. The Normal Operation settings for this test were 5V, 200ns. Notice that the Two Level Turn-Off Voltage is slightly above 5V, this is normal and expected.

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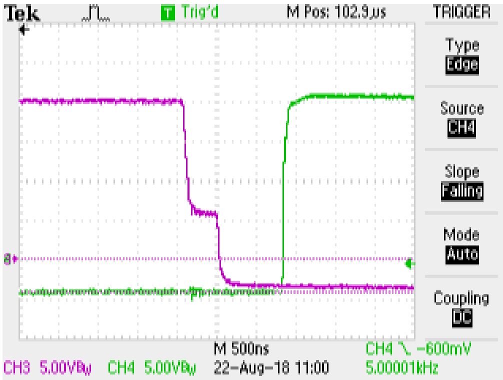

Figure 13: Normal Operation Turn-Off Example 5V, 200ns

7. Turn the DC Link Voltage ON and perform the Double Pulse Test.
    a. It is recommended to start at a low voltage (100V) and slowly increase to the desired DC Link Voltage verifying that the overshoot does not exceed the device rating.

6.1.4. Optimizing the Parameter Settings

The two variables, Normal Two Level Turn-Off Voltage and Time can be independently adjusted based on your results above. It is recommended to vary one parameter at a time. The goal is to place the voltage setting just above the Miller Plateau voltage and keep it at that level for an amount of time slightly less than the normal Miller Plateau time. This is trial and error process that must be executed to determine the optimal settings.

AgileSwitch recommends proceeding as follows:

1. Investigate the performance of the device with various Two Level Turn-Off Voltage settings in 0.25-0.5V steps.
2. Once an appropriate Turn-Off Voltage range is found, adjust the Turn-Off Time by 30-90ns for a small range of those voltages.

The optimum performance settings are a function of the system and final settings are a trade-off between switching efficiency and voltage overshoot. Other factors include DC Link busbar routing and system inductance.

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A summary table and graph of experiments that AgileSwitch performed is shown below.

Test Conditions: Vdc = 600V, Id = 200A, Rg = 0.5 Ω, T_j = 25C

Test	Rg (Ω)	2LTO Voltage (V)	2LTO Time (ns)	Overshoot (V)	Switching Loss (mJ)
BASE	0.5	OFF	OFF	502	0.88
1	0.5	3	400	342	1.13
2	0.5	4	400	318	1.22
3	0.5	4.5	400	297	1.26
4	0.5	6	400	230	1.45

Table 11: DPT Characterization Results

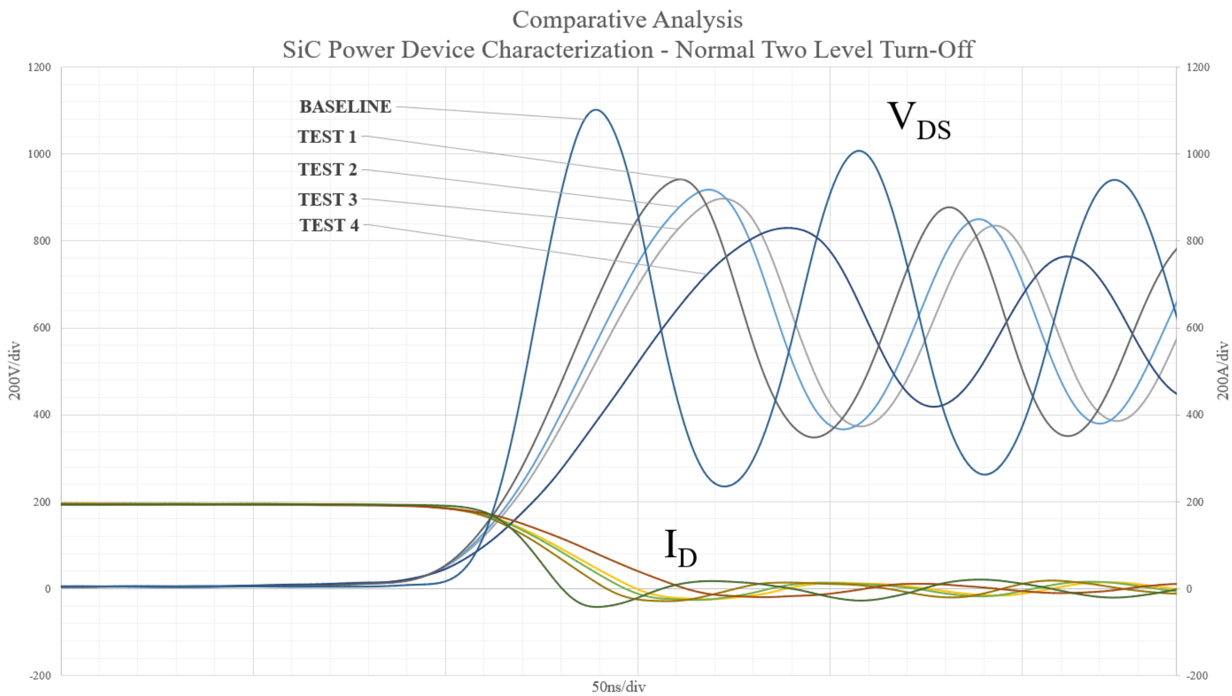

Figure 14:DPT Characterization Results

In this test, our goal for voltage overshoot was 300V or less. From the above example, we can see that using a 0.5 Ω gate resistor, a Two Level Turn-Off voltage setting of 4.5V and a Two Level Turn-Off time setting of 400ns resulted in meeting this goal while also keeping the switching losses to a relative minimum. The baseline test of a conventional gate driver using the same Rg without Augmented Switching offers better efficiency at the cost of a much higher overshoot and more ringing on the Vds.

The performance of the MOSFET switching characteristics can change with temperature and age. It is recommended that this test be performed at the nominal operating temperature of the system. Generally, at higher temperatures the threshold of the MOSFET will reduce and it may be necessary to set the Normal Two Level Turn-Off voltage slightly lower to achieve optimum switching performance at temperature.

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6.2. DSAT Operation Settings Procedure

6.2.1. Introduction

In a desaturation (DSAT), or short circuit, condition the MOSFET is conducting a very high amount of power. The turn-off must be managed to control the di/dt, overshoot voltage, and most importantly the device.

Augmented Switching™ does this by quickly detecting a short circuit condition by monitoring the Vds and then turning off the device. The power in the device is dissipated over a period of time that is long enough to manage the peak current and voltage overshoot below the device rating and short enough to make sure the device does not overheat and fail.

Each time the gate voltage level is reduced, the R_{DSon} of the MOSFET increases, which reduces the amount of current flowing through the MOSFET.

6.2.2. Determining the Initial Parameter Settings

Warning: DSAT (short circuit) is a destructive test. It is highly recommended to proceed with caution and use conservative turn-off settings to gain some familiarity with the device and test procedure.

A typical DSAT test condition simulates 10 times the modules' rated current at a given temperature at the systems nominal DC Link Voltage.

This condition can be simulated by replacing the inductor from Figure 10 with a power resistor or wire short. Using a small known resistance allows for the measurement of the drain current without needing a current probe, as current can be calculated using the voltage across the resistor.

The general procedure is:

1. Set up the DSAT Test Circuit.
   a. Probe the following with a standard probe:
      i. Drive signal from host
   b. Probe the following with a high voltage differential probe:
      i. Vgs_{LO}
      ii. Vds
   c. Probe the following with a current probe:
      i. Id
2. Select appropriate values for the:
   a. DC Link Voltage – Nominal system voltage
   b. Peak Current – 10x module rating
   c. Power Resistors
      i. R1 = Simulates 50% of peak current
      ii. R2 = Simulates 75% of peak current
      iii. R3 = Simulates 100% of peak current
   d. Single Pulse Setting (t_{ON1})

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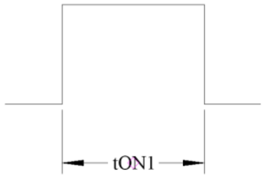

Figure 15: DSAT Pulse Setting

i. t_{ON1}
Set to 1µs longer than the DSAT Blanking Time.
Ex: DSAT Blanking Time = 500ns; t_{ON1} = 1.5µs

3. In the ICT, set the DSAT Operating settings to the following:

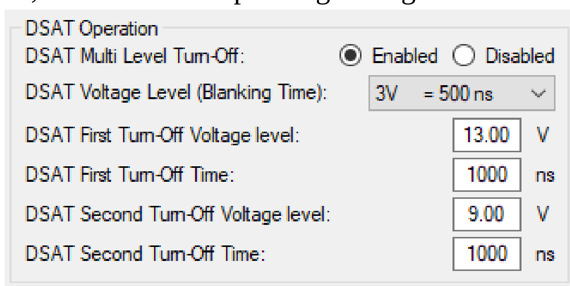

Figure 16: DSAT Operation starting settings

Note: We are purposely setting the DSAT Voltage Level (Blanking Time) to a very low value. This may be increased later depending on the target application and system.

4. Compile and program the gate driver.
5. With the **DC Link Voltage OFF**, probe the LO Gate and send the single pulse signal.
   a. To make the Gate Driver sense a DSAT without using high power, remove it from the Gate and Source pins on the power module.
6. Check that the LO Gate behaves as expected based on these DSAT Operation settings.
   a. The figure below shows an unloaded DSAT waveform measured from the LO side Vgs.
   b. The settings for this particular test were:
      i. DSAT Voltage Level (Blanking Time) = 500ns
      ii. DSAT First Turn-Off = 13V, 1000ns
      iii. DSAT Second Turn-Off = 9V, 1000ns

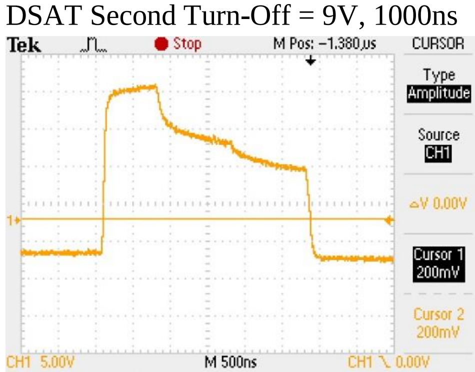

Figure 17: DSAT Operation Turn-Off Example, Vgs

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7. Turn the DC Link Voltage ON and perform the DSAT Test.
    a. Use the power resistor that simulates 50% of the nominal current. This will keep the current relatively low and allow you to experience a DSAT condition without pulsing high current through the module.
        i. AgileSwitch recommends adjusting one parameter at a time at this stage to see how it affects the di/dt and overshoot voltage.

6.2.3. Optimizing the Parameter Settings

Proceed with caution. Characterizing DSAT settings can be a difficult task due to the destructive nature of this test.

The general procedure is:

1. Replace R1 with R2 to simulate 75% of the peak current.
2. Use the settings you found most appropriate from the initial setup (50% nominal current).
3. Set the DC Link Voltage to 50% of your nominal system voltage.
4. Send a single pulse.
5. Review results.
    a. Vgs
        i. Did the driver detect a short circuit?
            1. Vgs should look similar to Figure 17.
            2. If it looks like Figure 13 from Normal Operation, it did not detect a short circuit. Increase DC Link voltage in 25V increments until DSAT is detected.
    b. Peak Current - Id
        i. Did it reach the current you set using the power resistor?
            1. If yes, keep the blanking time the same.
            2. If no, considering increasing blanking time by one step. (i.e. from 500ns to 600ns)
    c. Vds
        i. Did the overshoot voltage exceed the maximum rating of the device?
            1. If no, good.
            2. If yes, stop and reduce the DC Link Voltage and adjust the DSAT Operation settings one parameter at a time.
6. Replace R2 with R3 to simulate 100% of the peak current.
7. Repeat steps 3-5.
8. Once you have narrowed in on a certain set of parameters, raise the DC Link Voltage to your nominal system voltage and repeat steps 3-5 again.

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The table and figure below show DSAT Testing results from an AgileSwitch Gate Driver and a Conventional Gate Driver with gate resistor control only.

Test Conditions: Vdc = 600V, Id = 1000A, T_j = 25C

Test	Rg (Ω)	DSAT Blanking Time (us)	1st Off Voltage Level (V)	1st Off Time (ns)	2nd Off Voltage Level (V)	2nd Off Time (ns)	Overshoot (V)
BASE	5	1.5	N/A	N/A	N/A	N/A	759
AGILESWITCH	0.5	1.5	9	400	5	200	278

Table 12: DSAT Testing Results

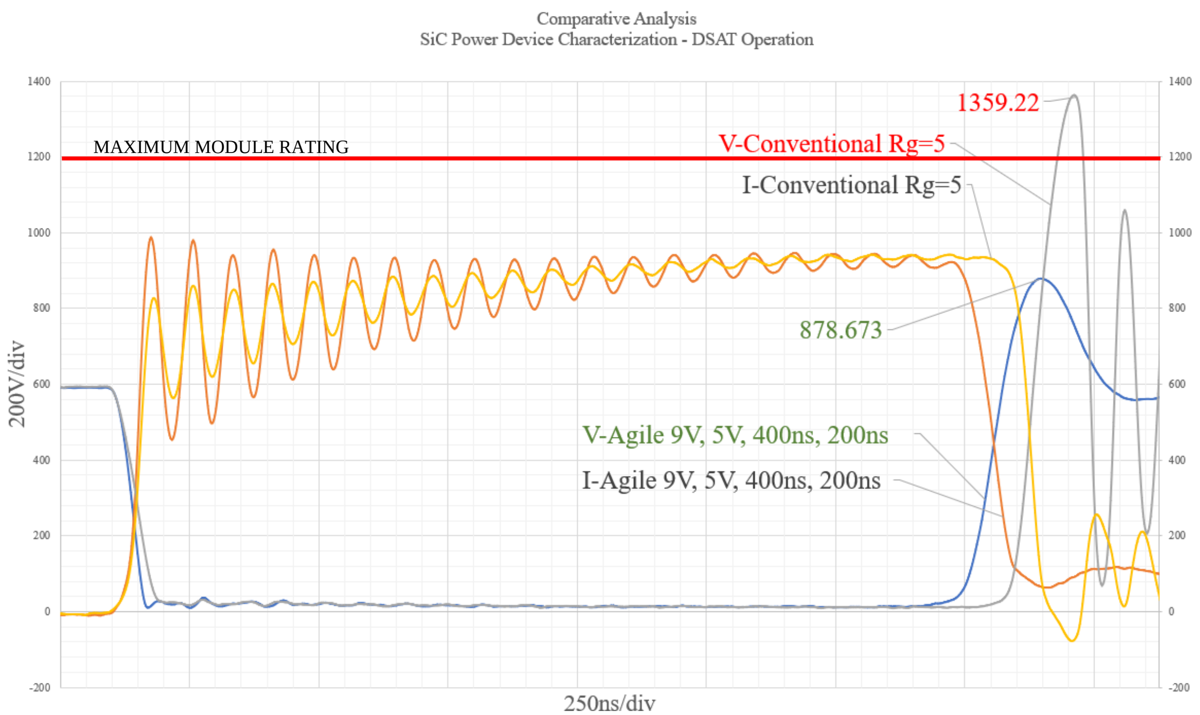

Figure 18: DSAT Testing Results

These results show that Augmented Switching with an Rg = 0.5 **Ω** was able to react to a DSAT condition quickly and safely shut the device off. The Vds did not exceed 900V and the di/dt was controlled to reduce system noise that could turn the gate back on.

The Conventional Gate Driver, with an Rg = 5 **Ω**, was not able to safely protect this device. The overshoot voltage exceeded the device rating of 1200V and the ringing on the di/dt was excessive.

7. Appendix B

A log file is generated during the compilation process and includes all the parameter settings. The parameter settings in the Log file can be used to document any experiments performed by the user when they are determining the optimal settings for Normal and DSAT operation.

A sample log file is shown below:

[Module Information]
Part Number = N/A
Manufacturer = N/A

[Description]
Description = N/A

[Software Information]
Assembly Number = 00000
Version Number = 00

[Control Side]
Device = 2ASC-12A1HP
Gate Driver Reset = Auto
DC Link Voltage Fault = On
Temperature Fault = On
Temperature Monitor = Isolated
Fault Output Active Level = Low
Dead Time = 280
Auto Reset Time Delay = 1
DC Link Fault Level = 1
Temperature Fault Level = 25

[Gate Options]
Low Side Select = CH2
Full-On Gate Voltage = 20.0
Full-Off Gate Voltage = -5.0

[Normal Operation]
TLTO = On
TLTOV = 0.0
TLTOT = 300

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[DSAT Operation]
MLTO = On
DSAT Blanking Time = 730
MLTOV1 = 9.0
MLTOT1 = 400
MLTOV2 = 5.0
MLTOT2 = 200

[Fault Detection]
UVLO = On

8. Appendix C

AgileSwitch Gate Drivers will detect Over and Under Voltage faults on both the +15V primary voltage input and the Secondary (Low and High side) generated voltages. The trip levels for these voltages are fixed and are not configurable by the user. The user does have the option of disabling the Secondary voltage detection (see Under/Over Voltage Fault Detection). The +15V primary voltage input detection cannot be disabled. The Over and Under voltage fault levels on the +15V input voltage are determined by the operating conditions of the Gate Driver.

8.1. Primary +15V Low and High Limits

The +15V Low and High Limit parameters are used to set the Fault levels for an Under or Over voltage condition on the +15V power input to the Gate Driver. The All Fault output will be active if the +15V power input is greater than the +15V High Limit parameter setting or if the +15V power input is less than the +15V Low Limit parameter setting.

The Low and High Hysteresis values are set to be 0.5V below or above the High and Low Limit values respectively.

The All Fault output will be automatically cleared if the +15V power input goes below the +15V High Hysteresis voltage value for an over voltage fault condition or if the +15V power input goes above the Low Hysteresis voltage value for a under voltage fault condition. Refer to Figure 19 for a diagram of the +15V Power Input Fault operation.

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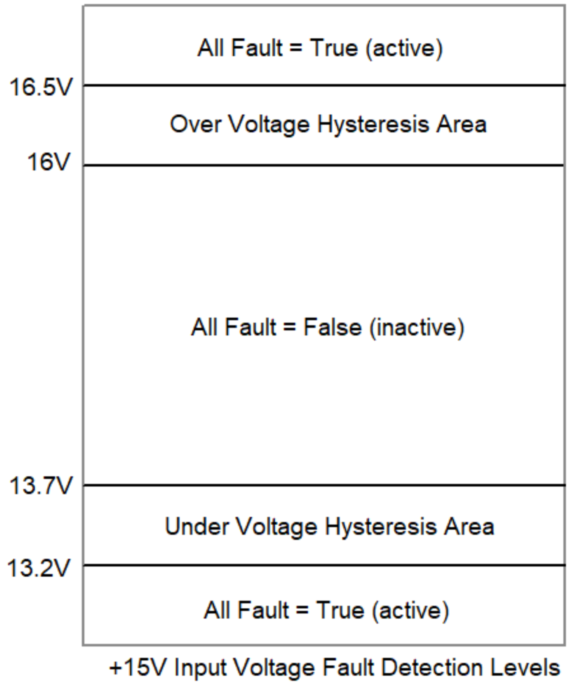

Figure 19: +15V voltage checking limits

8.2. Secondary Over and Under Voltage Fault Levels

The Over and Under Voltage Fault level parameters are used to set the Fault levels for an Over or Under voltage condition on the Secondary unregulated voltage output which is used to set the Gate voltage. The Gate Driver IC Fault output will be active (Fault output is Low Active) if the unregulated voltage is greater than the Over Voltage Fault Level parameter setting or if the UnRegulated+ voltage is less than the Under Voltage Fault Level parameter setting.

The Over and Under Fault Level Hysteresis values are set to be 0.5V below or above the Over and Under Limit values respectively.

The Gate Driver IC Fault output will be automatically cleared if the UnRegulated+ voltage goes below the Over Voltage Fault Level Hysteresis voltage value for an over voltage fault condition or if the UnRegulated+ voltage goes above the Under Voltage Fault Level Hysteresis voltage value for an under voltage fault condition. Refer to Figure 20 for a diagram of the Over and Under Voltage Fault operation.

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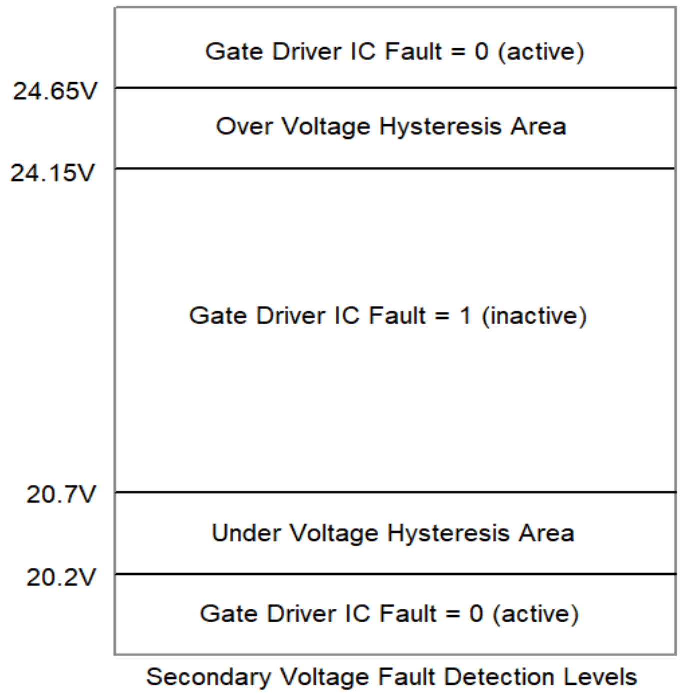

Figure 20: Secondary Voltage Checking limits

9. Revisions

Prepared By	Approved By	Version	Date	Description
AKS		0.1	9/7/2018	Initial release
AKS		1.0	10/18/2018	Initial Beta release
AF		2.0	5/2/2019	Initial Production Release
AF	DW	3.0	8/26/2019	Updated to reflect new ICT layout

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Patent Notices

Offering	Issued U.S. Patent Numbers
AgileStack^{TM} Power Stack	8,984,197
Silicon Carbide Gate Drivers	9,490,798

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