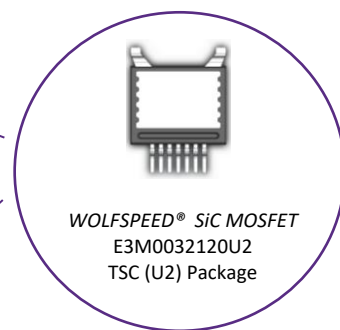
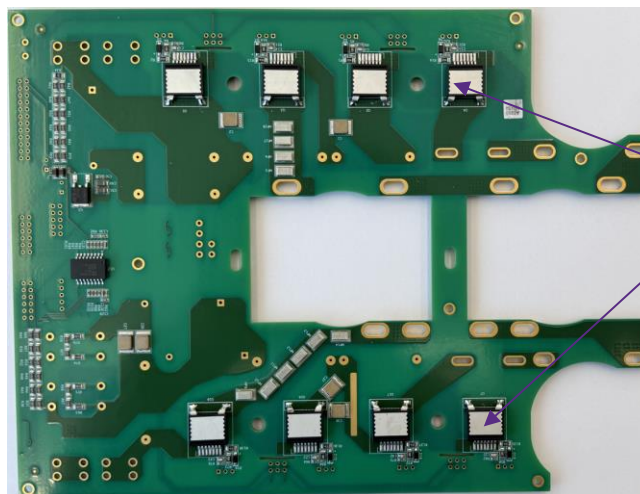
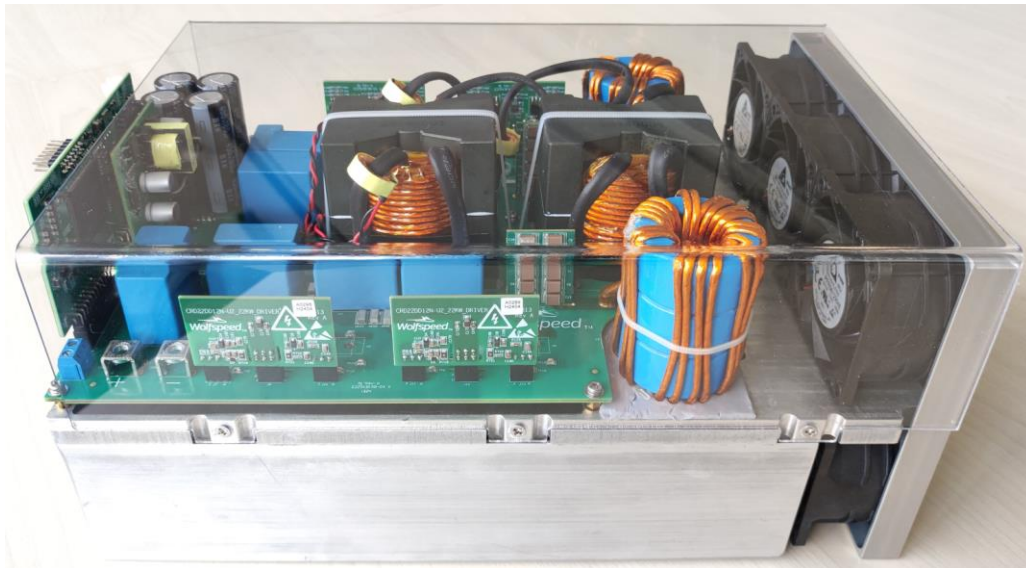


CRD-22DD12N-U2

22 kW Bi-Directional CLLC with TSC SiC MOSFETs



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CAUTION

PLEASE CAREFULLY REVIEW THE FOLLOWING PAGES, AS THEY CONTAINS IMPORTANT INFORMATION REGARDING THE HAZARDS AND SAFE OPERATING REQUIREMENTS RELATED TO THE HANDLING AND USE OF THIS BOARD.

警告

请认真阅读以下内容，因为其中包含了处理和使用本板子有关的危险和安全操作要求方面的重要信息。

警告

ボードの使用、危険の対応、そして安全に操作する要求などの大切な情報を含んでいるため、以下の内容をよく読んでください。



CAUTION

DO NOT TOUCH THE BOARD WHEN IT IS ENERGIZED AND ALLOW THE BULK CAPACITORS TO COMPLETELY DISCHARGE PRIOR TO HANDLING THE BOARD. THERE CAN BE VERY HIGH VOLTAGES PRESENT ON THIS EVALUATION BOARD WHEN CONNECTED TO AN ELECTRICAL SOURCE, AND SOME COMPONENTS ON THIS BOARD CAN REACH TEMPERATURES ABOVE 50° C FURTHER, THESE CONDITIONS WILL CONTINUE FOR A SHORT TIME AFTER THE ELECTRICAL SOURCE IS DISCONNECTED UNTIL THE BULK CAPACITORS ARE FULLY DISCHARGED.

Please ensure that appropriate safety procedures are followed when operating this board, as any of the following can occur if you handle or use this board without following proper safety precautions:

- Death
- Serious injury
- Electrocution
- Electrical shock
- Electrical burns
- Severe heat burns

You must read this document in its entirety before operating this board. It is not necessary for you to touch the board while it is energized. All test and measurement probes or attachments must be attached before the board is energized. You must never leave this board unattended or handle it when energized, and you must always ensure that all bulk capacitors have completely discharged prior to handling the board. Do not change the devices to be tested until the board is disconnected from the electrical source and the bulk capacitors have fully discharged.

警告

请勿在通电情况下接触板子，在处理板子前应使大容量电容器完全释放电力。接通电源后，该评估板上可能存在非常高的电压，板子上一些组件的温度可能超过 50 摄氏度。此外，移除电源后，上述情况可能会短暂持续，直至大容量电容器完全释放电量。

操作板子时应确保遵守正确的安全规程，否则可能会出现下列危险：

- 死亡
- 严重伤害
- 触电
- 电击
- 电灼伤
- 严重的热烧伤

请在操作本板子前完整阅读本文件。通电时不必接触板子。在为板子通电前必须连接所有测试与测量探针或附件。通电时，禁止使板子处于无人看护状态，或操作板子。必须确保在操作板子前，大容量电容器释放了所有电量。只有在切断板子电源，且大容量电容器完全放电后，才可更换待测试器件。

警告

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ボードを操作するとき、正確な安全ルールを守るのを確保すべきです。さもないと、以下の危険がある可能性があります：

- 死亡
- 重症
- 感電
- 電撃
- 電気の火傷
- 厳しい火傷

当ボードを操作する前に、完全に当書類をよく読んでください。通電している時にボードに接触する必要がありません。通電する前に必ずすべての試験用のプローブあるいはアクセサリーをつないでください。通電している時に無人監視やボードを操作するのは禁止です。ボードを操作する前に、大容量のコンデンサーで電力を完全に釈放するのを必ず確保してください。ボードの電源を切った後、また大容量のコンデンサーで電力を完全に釈放した後、試験設備を取り換えることができます。

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1. INTRODUCTION

This User Guide provides the schematic, artwork, and test setup necessary to evaluate Wolfspeed's CRD-22DD12N-U2, 22 kW Bi-Directional DC/DC converter for an electric vehicle (EV) on-board charger (OBC) and similar applications. Top-side-cooled (TSC) SiC MOSFETs - E3M0032120U2 (32 mΩ/1200 V, U2 package) from Wolfspeed are used in the design. The top-side-cooled power device offers lower parasitic inductances and facilitates automated assembly while delivering superior thermal performance. The design achieves high power density (9.4 kW/L), high peak efficiency (> 98.6%), and supports a wide battery voltage range from 200 VDC to 800 VDC.

This converter is the DC/DC stage of a bi-directional OBC converter. A block diagram is shown in Figure 1. It operates from a rectified DC voltage at bus-side DC terminals and provides an isolated output voltage at the battery-side DC terminals (referred to as charging mode) or vice versa (referred to as discharging mode).

The bidirectional full-bridge CLLC resonant topology is selected for the converter to achieve both high efficiency and wide voltage regulation. Both the bus side and the battery side of the converter use a full-bridge topology that is isolated by a high-frequency transformer. The converter operates at 135 kHz-250 kHz switching frequency range.

A tooled heatsink is designed to dissipate the heat generated by the power MOSFETs. An external power source is required to power the fans to cool the unit.

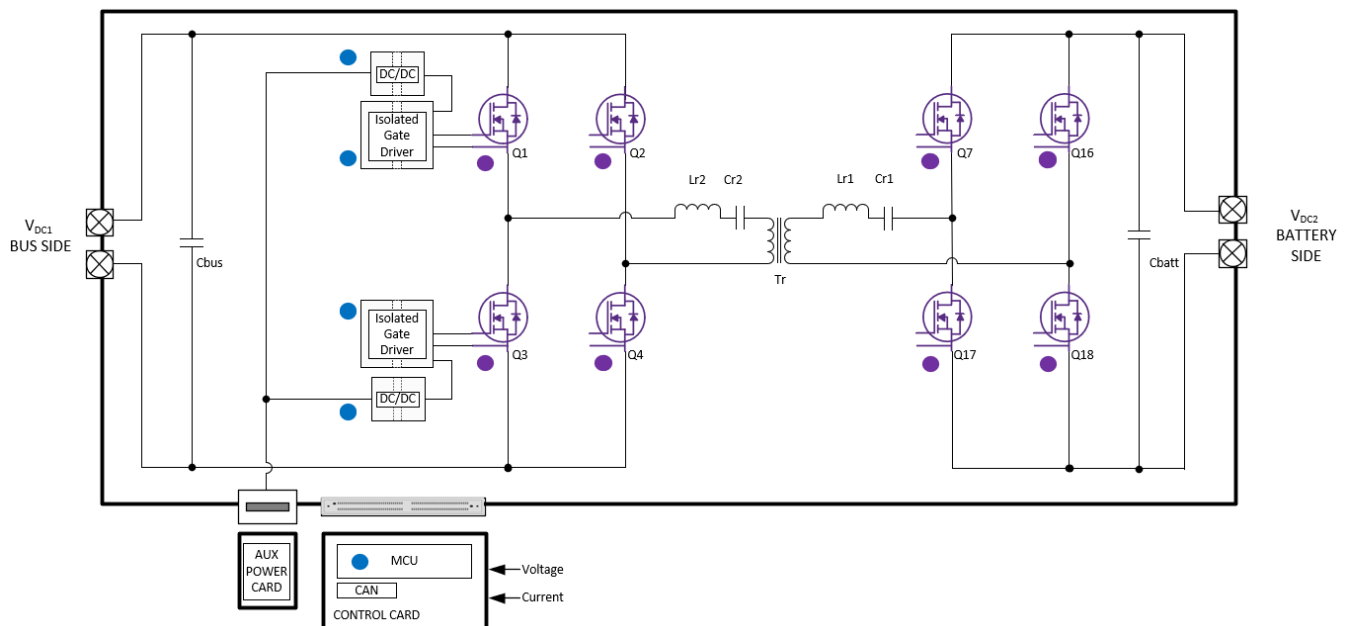


Figure 1: Block Diagram of Wolfspeed's CRD-22DD12N-U2, 22 kW bi-directional high-efficiency DC/DC.

In charging mode, the bus voltage varies between 650 VDC and 900 VDC for three-phase input or between 380 VDC and 900 VDC in a single-phase input. This varied bus voltage, along with the reconfiguration of half-bridge

and full-bridge operation without any additional power components, makes it possible to realize wide output voltage range between 200 VDC and 800 VDC with high efficiency and high density. The same technique is applied to discharging mode and thus the bus voltage can be designed between 360 V and 750 V to support single-phase output with high efficiency. A 480 VDC ~ 800 VDC is the typical OBC output range for a high-voltage battery. The operation at an output range of 200 VDC ~ 480 VDC will result in lower efficiency, but it demonstrates the effectiveness of the proposed control method. The peak efficiency of the DC/DC stage can be above 98.6% in both charging and discharging modes.

Since the main purpose of the reference design is to show the performance of SiC devices in the power converter for EV applications, it does not focus on battery charging technique. Therefore, there is neither a battery charging nor discharging algorithm built in. It must not be connected to any battery directly. An electronic load or a resistive load should be used in both charging mode and discharging mode.

2. DESCRIPTION

This reference design uses Wolfspeed's E3M0032120U2 (32 mΩ/1200 V, U2 package) SiC MOSFETs on both the primary side and the battery side. A single SiC MOSFET is used for each position as shown in Figure 1.

Flexible gain control methods include the conventional variable frequency control, phase shift control, and reconfigured structure between half bridge and full bridge. The flexible control method plus the high performance of 1200 V SiC MOSFETs enable high-efficiency operation for a wide output range in both directions. The primary-side full bridge will be reconfigured as half bridge when the required voltage gain is low, which is out of the high-efficiency range of the hybrid control (variable frequency and phase shift) in both charging mode and discharging mode at full-bridge configuration. Thus, the power direction and converter configuration should be selected properly via the graphical user interface (GUI) before turning on the unit.

The operation range of the evaluation board in charging mode is shown in Table 1. The evaluation board is designed to support the DC bus voltage of a PFC (Power Factor Correction) with both single-phase input and three-phase input. In a typical application, the bus voltage (V_{DC1}) is regulated by the PFC stage according to the battery-side voltage. However, with a controlled PFC output, the output voltage at battery side (V_{DC2}) is regulated to maintain the same relation curve as shown in Figures 2a and 2b. This is to simulate real conditions in OBC application.

The battery voltage can be expressed as follows:

$$\begin{aligned} V_{DC2} &= (V_{DC1} - 30V) \times \frac{19}{24} && \text{for full bridge} \\ V_{DC2} &= (V_{DC1} - 44V) \times \frac{19}{24} \times \frac{1}{2} && \text{for half bridge} \end{aligned}$$

The startup voltage is calculated by using the same equations.

The output power at 650 VDC ~ 900 VDC input is 22 kW maximum, and the output current is up to 36 A. When the output voltage is above 770 V, the output power is limited by its lowest operation frequency. Output power at 800 V output is 16 kW.

Bus side Volt. <input>	Battery side Volt. <output>	Max. Output Power/ Max. Output Current	Topology	Comments
380 V ~ 900 V	250 V~ 800 V	6.6 kW	Full Bridge	Single Phase Input
650 V ~ 900 V	340 V ~ 770 V	22 kW/36 A	Full Bridge	Three Phase Input
	770 V ~ 800 V	22 kW to 16 kW		
650 V ~ 900 V	240 V ~ 340 V	30 A to 36 A	Half Bridge	
	200 V ~ 240 V	30 A		

Table 1: Overall charging operation.

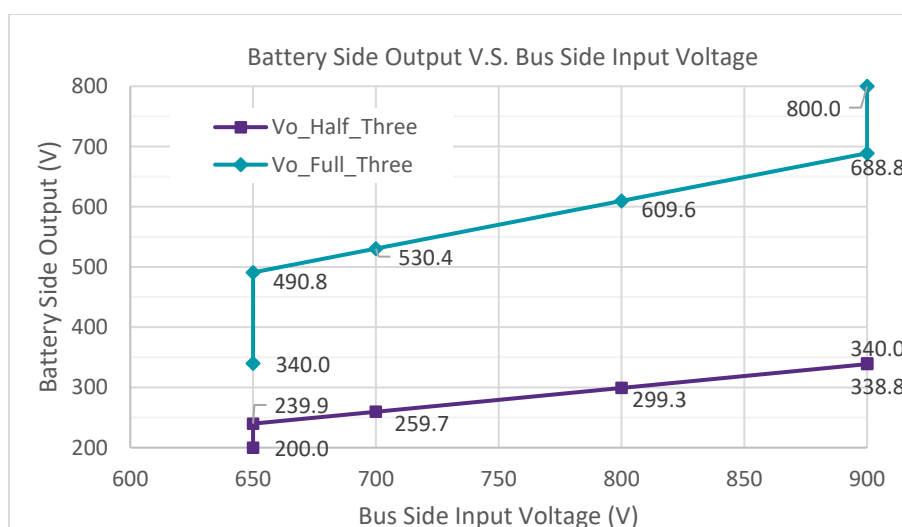


Figure 2a. Battery voltage vs. bus voltage in charging mode for three-phase application.

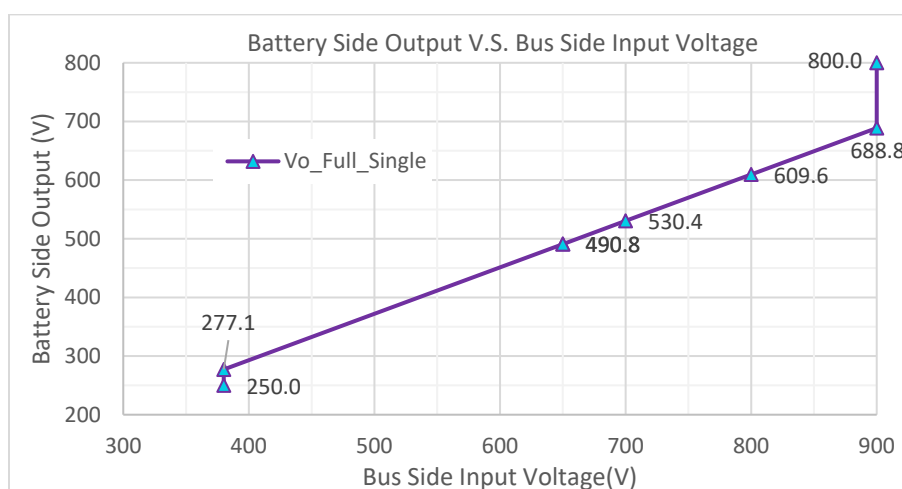


Figure 2b. Battery voltage vs. bus voltage in charging mode for single-phase application.

For discharging mode, the overall discharging operations are shown in Table 2. The output bus voltage is regulated, as shown in Figure 3, to enable high efficiency for both DC/DC stage and DC/AC stages.

The bus voltage can be expressed as follows:

$$V_{DC1} = V_{DC2} \times \frac{24}{19} - 10V \quad \text{for full bridge}$$

$$V_{DC1} = V_{DC2} \times \frac{24}{19} \times \frac{1}{2} - 10V \quad \text{for half bridge}$$

The startup voltage is also calculated using the same equations.

Bus side Volt. <input>	Battery side Volt. <output>	Max. Output Power/ Max. Output Current	Topology
300 V ~ 600 V	360 V ~ 750 V	6.6 kW	Full Bridge
600 V ~ 800 V	360 V ~ 500 V		Half Bridge

Table 2: Overall discharging operation.

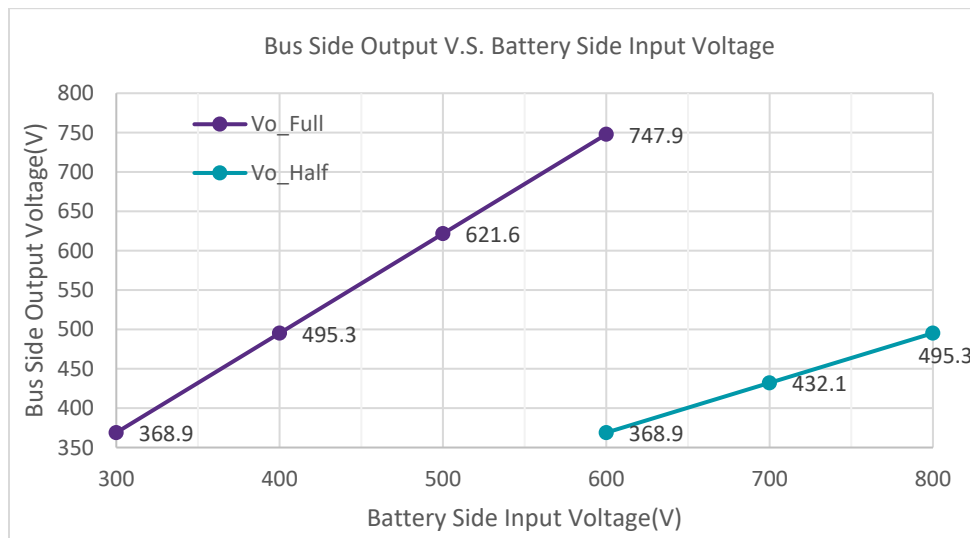


Figure 3: Bus voltage vs. battery voltage in discharging mode.

A user should follow the operations as shown in Figure 2a, Figure 2b and Figure 3, and not overload the converter out of the SOA (Safe Operation Area). Please refer to Table 8 in Section 6.2 of this User's Guide for protection details.

A GUI communicates with the unit via a controller area network (CAN) communication bus. It is used to display operational information and provide related user controls, such as the selection of power direction and topology. The output voltage and/or current with 380 VDC, 650 VDC and 900 VDC input can all be set according to Figure 2a and Figure 2b through CAN interface in charging mode. The output voltage is calculated based on the input DC voltage to enable high efficiency for other inputs in charging mode, or any inputs in discharging mode.

3. ELECTRICAL PERFORMANCE CHARACTERISTICS

Parameter		Test Conditions	Min	Nom	Max	Units
Input Characteristics						
V_{in}	Input voltage		380	800	900	V
I_{in}	Input current				35	A
Output Characteristics						
V_{OUT1}	Output voltage	$V_{IN} = 650 \text{ VDC} \sim 900 \text{ VDC}$ Full / Half Bridge	200 ^{*1}	611	800	V
$P_{OUT1 \text{ max}}$	Output power				22000	W
I_{OUT1}	Output current				36	A
V_{OUT2}	Output voltage	$V_{IN} = 380 \text{ VDC} \sim 900 \text{ VDC}$ Full Bridge	250		800	V
$P_{OUT2 \text{ max}}$	Output power				6600	W
I_{OUT2}	Output current				26.4	A
V_{ripple}	Output voltage ripple				±2	%
System Characteristics						
η_{peak}	Peak efficiency	$V_{IN} = 800 \text{ V}, V_{OUT} = 610 \text{ V},$ $I_{OUT} = 15 \text{ A}, \text{ Full Bridge}$		98.64		%
$\eta_{full \text{ load}}$	Full load efficiency	$V_{IN} = 900 \text{ V}, V_{OUT} = 800 \text{ V},$ $I_{OUT} = 20 \text{ A}, \text{ Full Bridge}$		98.3		%
		$V_{IN} = 800 \text{ V}, V_{OUT} = 610 \text{ V},$ $I_{OUT} = 36 \text{ A}, \text{ Full Bridge}$		98.2		%
		$V_{IN} = 650 \text{ V}, V_{OUT} = 490 \text{ V},$ $I_{OUT} = 36 \text{ A}, \text{ Full Bridge}$		97.6		%
		$V_{IN} = 650 \text{ V}, V_{OUT} = 240 \text{ V},$ $I_{OUT} = 30 \text{ A}, \text{ Half Bridge}$		95.7		%

Table 2: Characteristics of Wolfspeed's CRD-22DD12N-U2, 22 kW bi-directional DC/DC in charging modes.

*1: 480 V ~ 800 V is the preferred output range. 200 V ~ 480 V is the extended output range for study.

Parameter	Test Conditions	Min	Nom	Max	Units
Input Characteristics					
V_{in}	Input voltage	300		800	V
I_{in}	Input current			25	A
Output Characteristics					
V_{out}	Output voltage	360		750	V
P_{out max}	Output power	V _{IN} = 600 VDC ~ 800 VDC Half Bridge V _{IN} = 300 VDC ~ 600 VDC Full Bridge		6600	W
I_{out}	Output current			19	A
V_{ripple}	Output voltage ripple			±2	%
System Characteristics					
η_{peak}	Peak efficiency	V _{IN} = 600 V, V _{OUT} = 748 V, P _O = 6.6 kW Full Bridge		98.69	%
η_{full load}	Full load efficiency (P _O = 6.6 kW)	V _{IN} = 300 V, V _{OUT} = 369 V Full Bridge		97.5	%
		V _{IN} = 600 V, V _{OUT} = 748 V Full Bridge		98.7	%
		V _{IN} = 600 V, V _{OUT} = 369 V Half Bridge		97.3	%
		V _{IN} = 800 V, V _{OUT} = 495 V Half Bridge		98.0	%

Table 3: Characteristics of Wolfspeed's CRD-22DD12N-U2, 22 kW bi-directional DC/DC in discharging mode.

3.1 APPLICATIONS

The main application for Wolfspeed's CRD-22DD12N-U2 reference design board is isolated bidirectional EV charging systems, but the output must be connected to a resistive load or electronic load (Constant Resistor mode is recommended). A test with battery is not allowed since a battery-charging algorithm has not been implemented in the design.

3.2 FEATURES

Some of the features and limitations of Wolfspeed's CRD-22DD12N-U2 reference design board are listed below:

- Wide voltage range: 380 VDC ~ 900 VDC voltage range for bus-side terminals and 200 VDC ~ 800 VDC voltage range for battery-side terminals.
- Bi-directional operation with flexible control: However, please operate the evaluation board within the safe operation area as described in Section 2.
- The maximum output current is limited to 36 A and maximum output power is limited to 22 kW at the input voltage range of 650 VDC ~ 900 VDC in charging mode. Note: output power is linearly derated from 22 kW to 16 kW when the output voltage is between 770 VDC and 800 VDC under 900 V input.

- The maximum output power is 6.6 kW at the input voltage range of 380 VDC ~ 650 VDC in charging mode. Without AC input information, the controller cannot identify the operation mode, so the 6.6kW power limit function is not accurate in this input range.
- The maximum output power is 6.6 kW in discharging mode.
- Peak efficiency > 98.6% in both charging and discharging mode.
- Protection functions are shown in Table 8.
- Synchronous rectification (SR) is automatically controlled based on operation conditions. SR is typically enabled when the load current exceeds 5 A, and it is disabled when the load current is lower than 2.5 A.
- Easy to test using a GUI communicating via CAN. See Section 5 and Section 12 for more details.

4. HARDWARE DESCRIPTION OF MAIN BOARD, DRIVER BOARD, CONTROL BOARD AND AUXILIARY POWER BOARD

Note: A larger copy of any diagram in Section 4 may be downloaded from the Wolfspeed® reference design website (<https://www.wolfspeed.com/power/products/reference-designs/>) or obtained upon request by contacting Wolfspeed at forum.wolfspeed.com.

Schematics of Main Board, Driver Board, Control Board, and Auxiliary Power Board are shown in Figure 4 to Figure 11.

4.1 DESCRIPTION OF MAIN BOARD

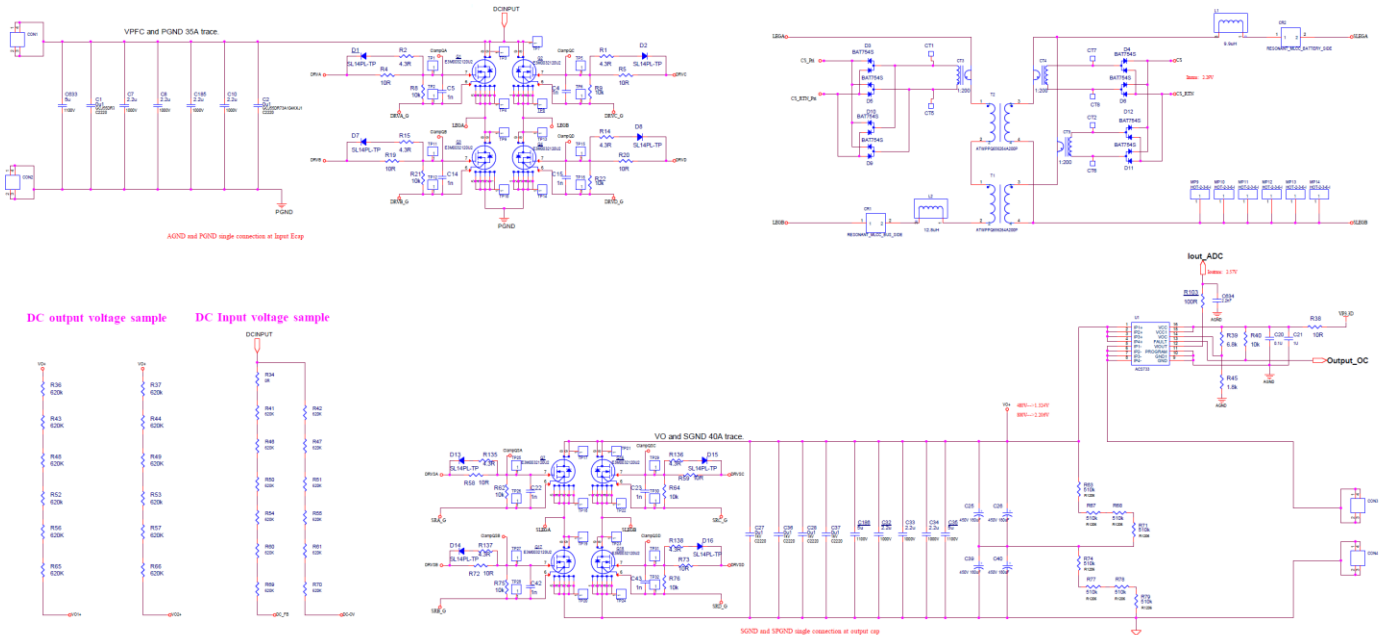


Figure 4. Schematic of DC/DC main board.

As illustrated by Figure 4, a full-bridge CLLC topology is selected for the converter. The bus-side DC terminals are CON1(+) and CON2(-) followed by five film capacitors that absorb the high-frequency ripple on the DC port. The battery-side DC terminals are CON3(+) and CON4(-). The full bridge at DC bus side is composed of SiC MOSFETs Q1, Q3, Q2, Q4. The battery-side full bridge is composed of SiC MOSFETs Q7, Q17, Q16, Q18. Two identical transformers isolate these two sides from each other. The main transformer is constructed with a center-leg gapped PQ6562 ferrite core and has a turns ratio of 12:19. The windings of these two transformers are connected in series on the primary side and in parallel on the battery side. The final turns ratio is 24:19. One current transformer is used to sense resonant tank current on the primary side. Two current transformers are used to sense resonant tank currents on the battery side, and these two current signals are paralleled after full-bridge rectification diodes.

The key parameters for these two resonant tanks are shown as below:

	Resonant Inductor	Resonant Capacitor
Bus Side Tank	12.8 μ H	$\frac{12nF}{2} \times 9 = 54nF$
Battery Side Tank	9.9 μ H	$\frac{12nF}{2} \times 12 = 72nF$

Table 5: Key parameters of resonant tanks.

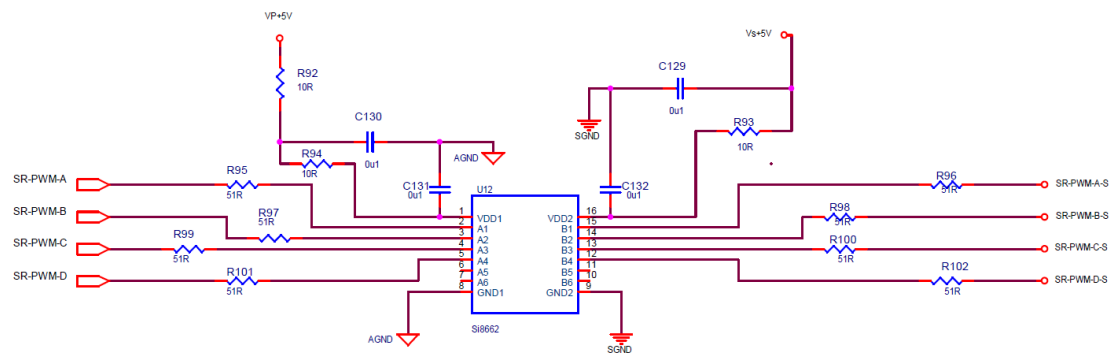


Figure 5. Schematic of DC/DC main board: signal isolation.

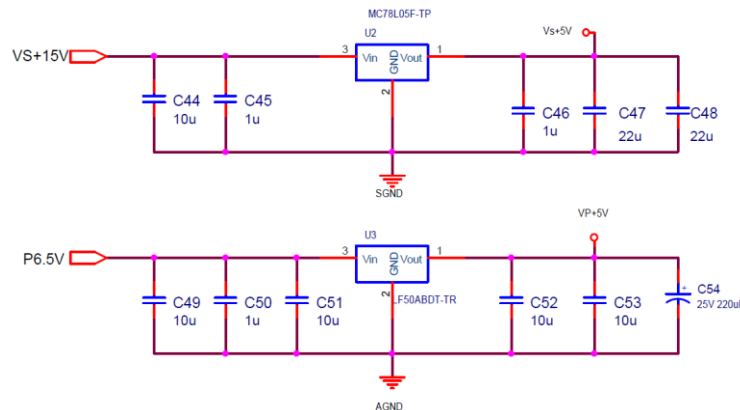


Figure 6. Schematic of DC/DC main board: power supply.

4.3 DESCRIPTION OF CONTROL BOARD

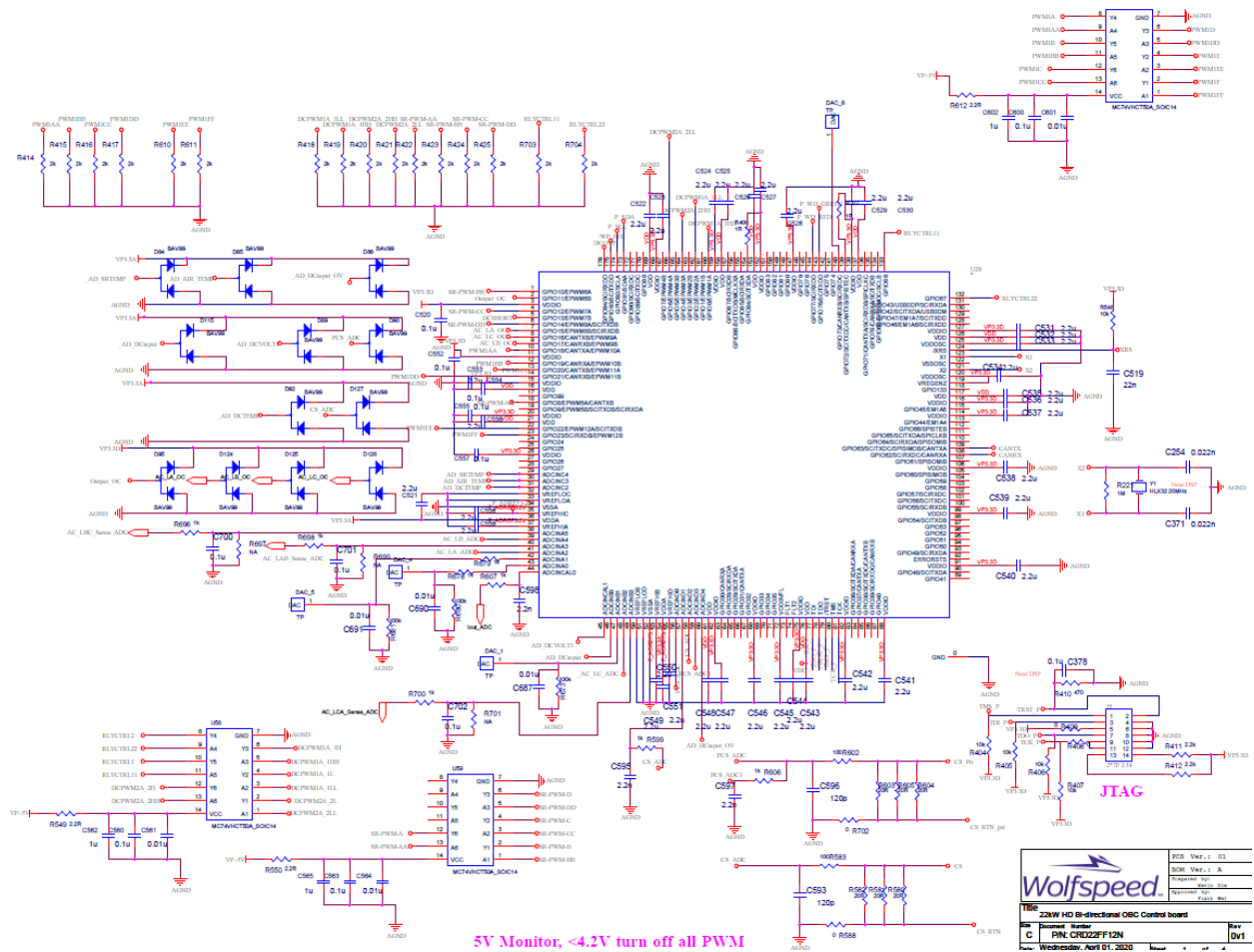


Figure 9a. Schematic of control board: Controller.

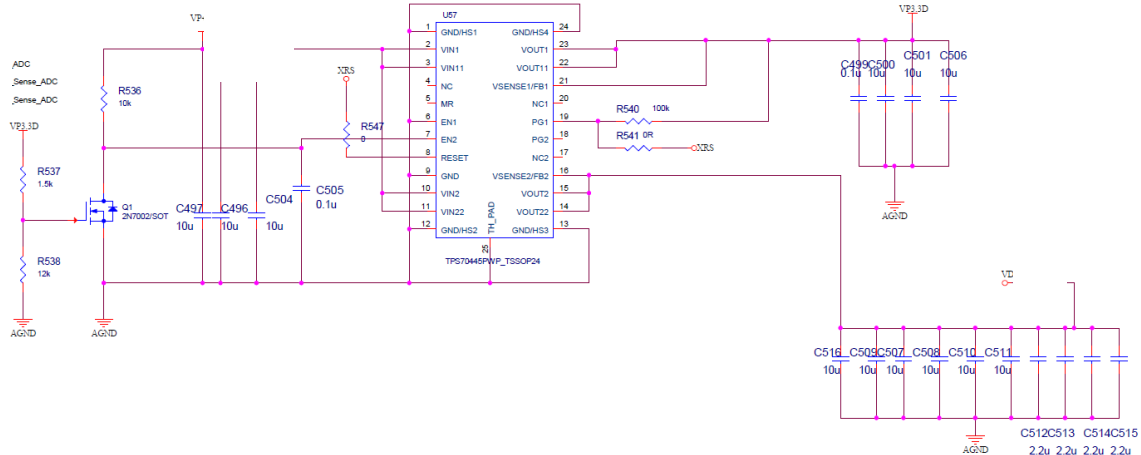


Figure 9b. Schematic of control board: Controller power supply.

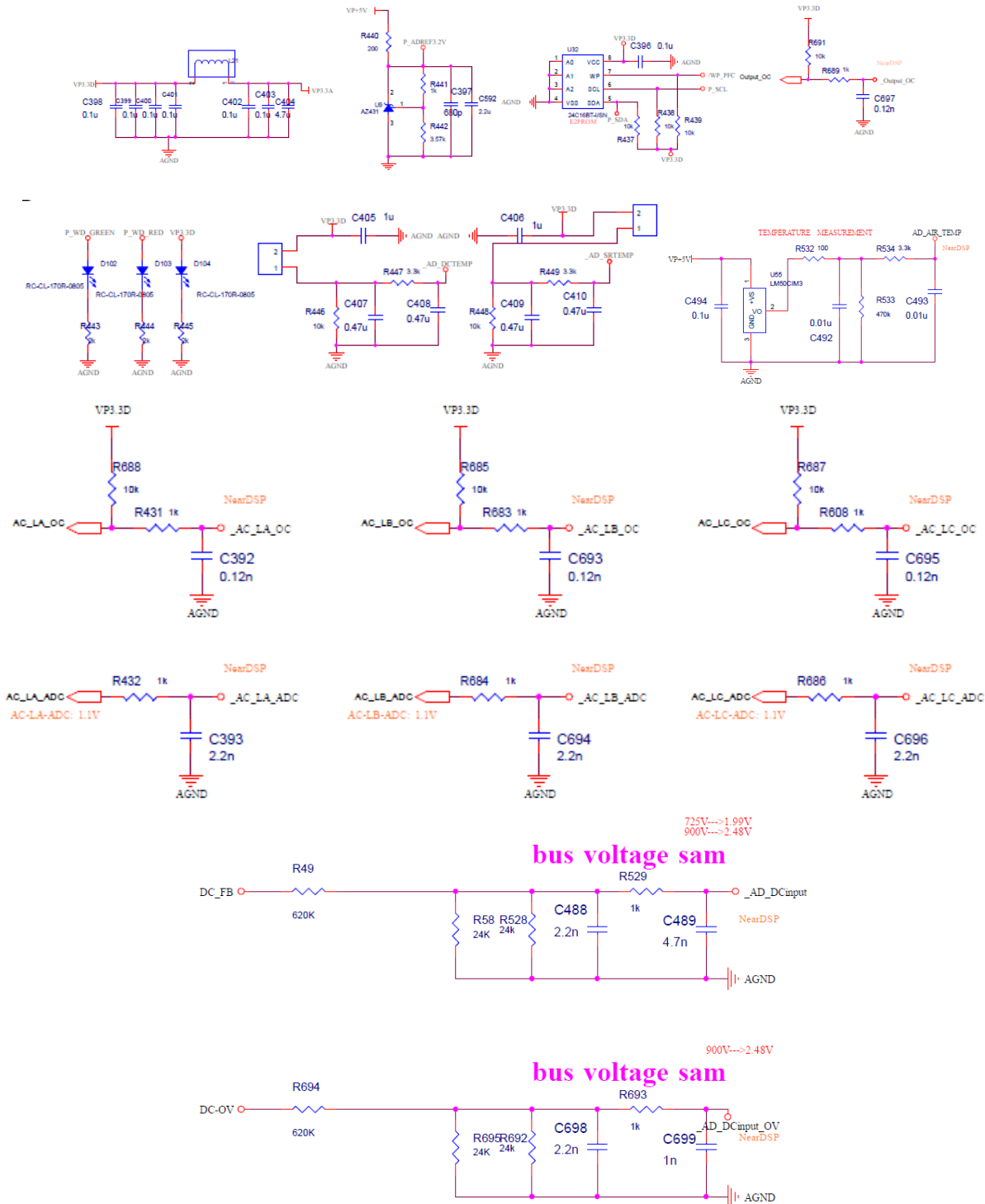


Figure 9c. Schematic of control board: Bus voltage sample.

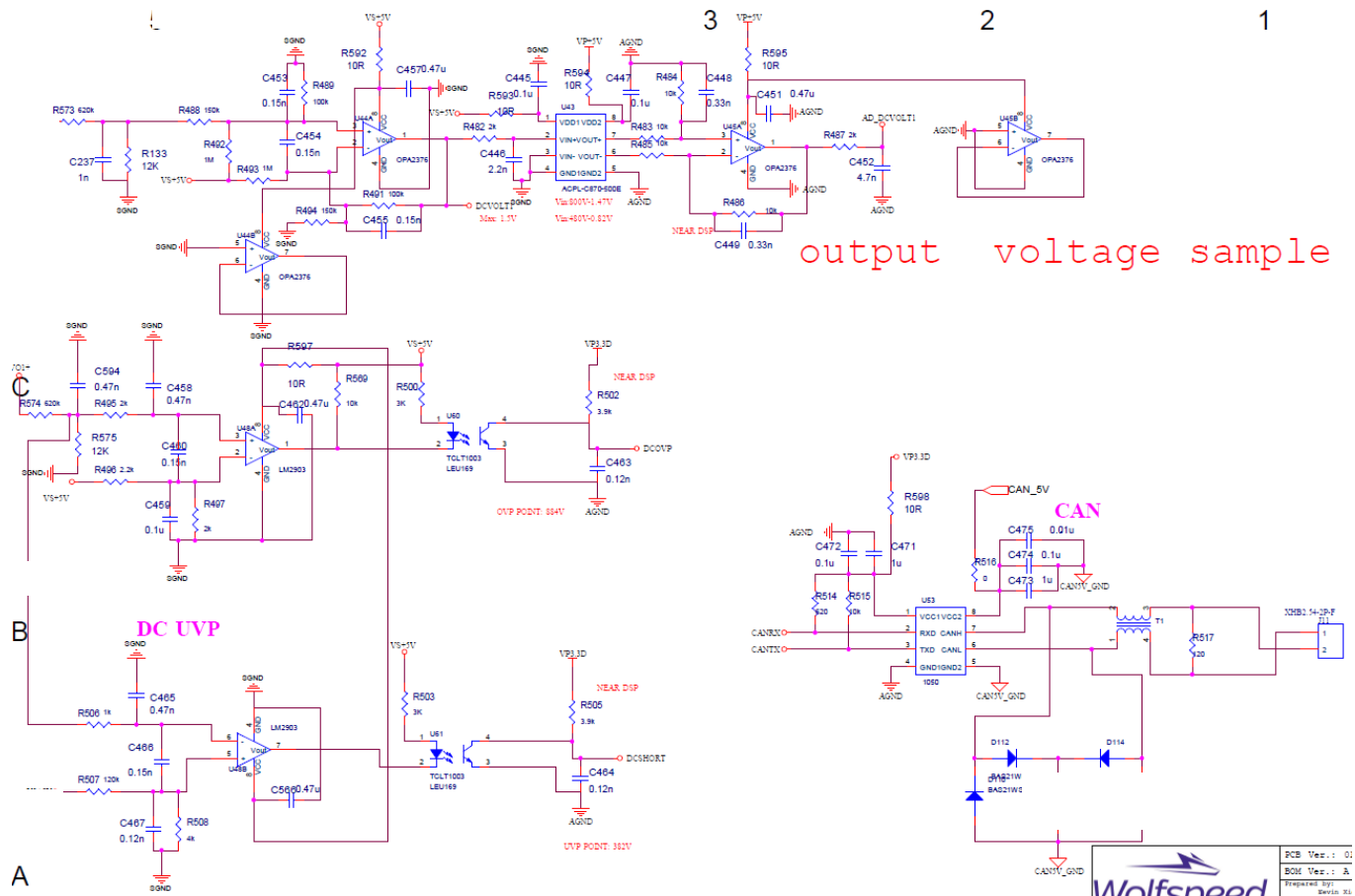


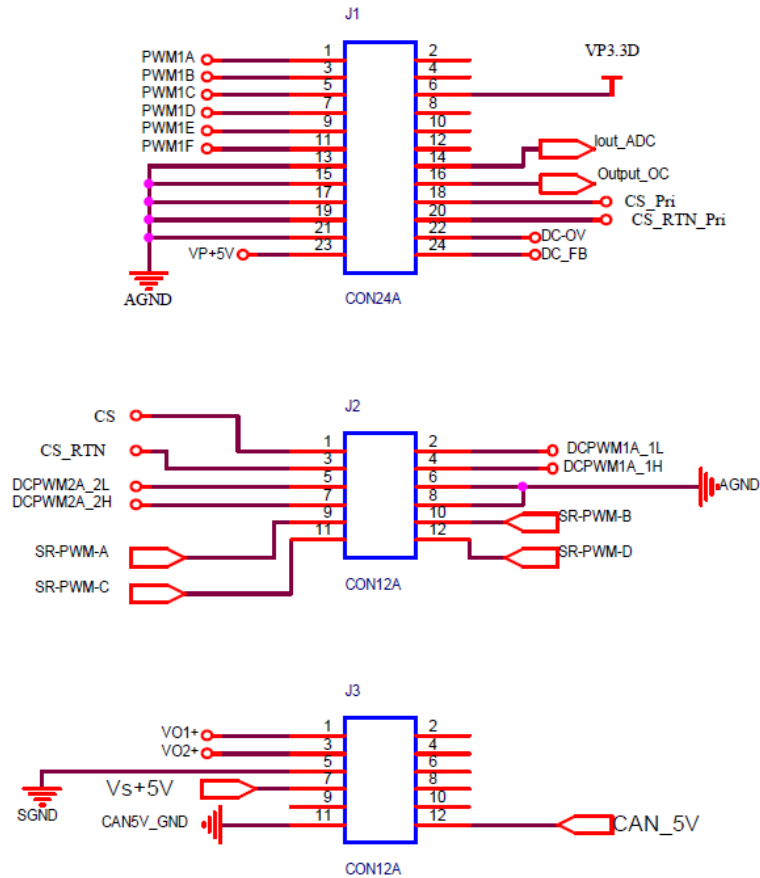
Figure 9d. Schematic of control board: Battery voltage sample and CAN interface.

As illustrated by Figure 9a to 9d, the control board, which carries out the control algorithm of the entire system, is designed around a Texas Instruments Inc. controller (P/N: TMS320F28377D). The power supply for the control board is an isolated, 7 V @ 1 A, power supply whose output is then tightly regulated to +5.0 V by a linear regulator. This 5.0 V voltage rail then supplies another precision linear regulator IC, U57, from Texas Instruments Inc. (P/N: TPS70445), which provides both a 3.3 V and a 1.2 V voltage rail. All output drive signals are buffered and shifted to a +5 V level by a Fairchild Semiconductor International Inc. level-shifter (P/N: MC74HCT50A). The reference voltage for the controller's ADC (Analog-to-Digital Converter) is 3.3 V. This reference is created by a reference IC U9, (P/N: AZ431-2.5 V) from the +5.0 V rail.

The reference ground of the control board is the negative terminal of the bus-side port. The voltage sample signal and OVP/UVP (Over/Under Voltage Protection) protection signals of the battery-side DC port are isolated by optocouplers before they are fed into the controller for further processing. The bus-side voltage sample and OVP signals are directly fed to the controller after voltage divider.

4.4 CONNECTIONS OF CONTROL BOARD AND AUXILIARY POWER BOARD TO MAIN BOARD

Connect to CONTROL BOARD



Connect to AUX power board

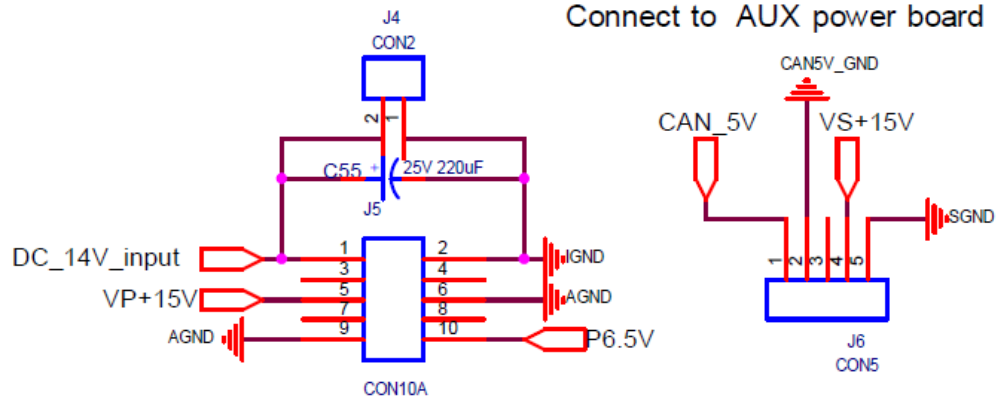


Figure 10. Schematic of connectors on Main Board.

4.5 DESCRIPTION OF AUXILIARY POWER BOARD

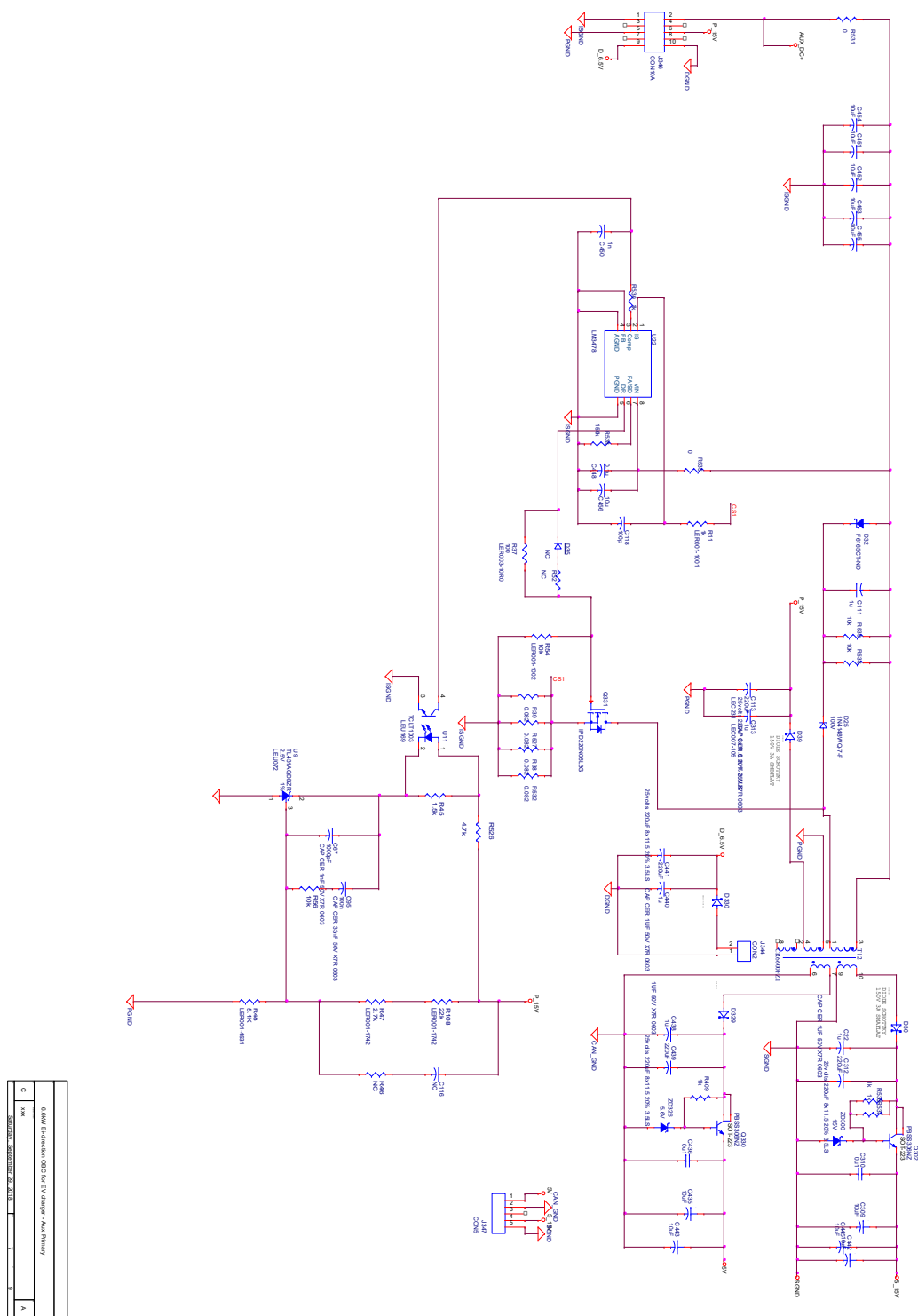


Figure 11. Schematic of Auxiliary Power Board.

The typical input voltage of the Auxiliary Power Board is 14 V (J346, net 'Aux_DC+' and net 'ISGND' in Figure 11). It provides four isolated output voltages, as shown in Table 6.

Input/Outputs	Net Name	Comments
Input	14 V	14 V Typical input of the auxiliary power board
Output 1	P_15 V	15 V Power supply for primary side MOSFET gate drivers
Output 2	S_15 V	15 V Power supply for Battery side MOSFET gate drivers
Output 3	5 V	5 V output for CAN communication
Output 4	D_6.5 V	Controller power supply

Table 6: Input and outputs of Auxiliary Power Board.

5. INTERFACE OF HARDWARE AND SOFTWARE

5.1 HARDWARE INTERFACE

DC Input Source: The input source must be an adjustable DC source whose output can be adjusted between 300 VDC and 900 VDC. It must be capable of supplying at least 25 kW.

Output Load: A programmable high-voltage electronic load or a high-voltage resistor bank may be used. Each must be capable of sinking 36 A of load current supplied from the evaluation board whose output can be 1000 VDC/22 kW.

Power Meter: A power analyzer from Yokogawa Test and Measurement Corporation (P/N: WT 3000) or any other equivalent power analyzer should be used. An external shunt resistor should be used when the output current exceeds the rating of the internal shunt resistor.

Oscilloscope: A 300 MHz or greater digital or analog oscilloscope with 100 MHz or greater isolated differential voltage probes and isolated current probes (i.e., Hall effect current sensor) should be used.

Power Supplies: The following power supplies with isolated grounds should be used and must be obtained separately:

- 1) 14 VDC @ 2 A capability is required to supply the auxiliary power board.
- 2) 12 VDC @ 16 A capability in total is required to power the cooling fans.

External Fans: Cooling fans should be used and must be obtained separately. As shown in Figure 12, six cooling fans, such as the Delta Electronics Inc. DC12 V/2.76 A fan (P/N: PFR0612XHE-CV52) or an equivalent must be used for cooling the system. The red wire of the fan is the positive terminal, and the black wire is the negative terminal. The temperature of the magnetics and heatsinks should be monitored by an infrared scanner to verify the cooling fan setup during first-time testing.

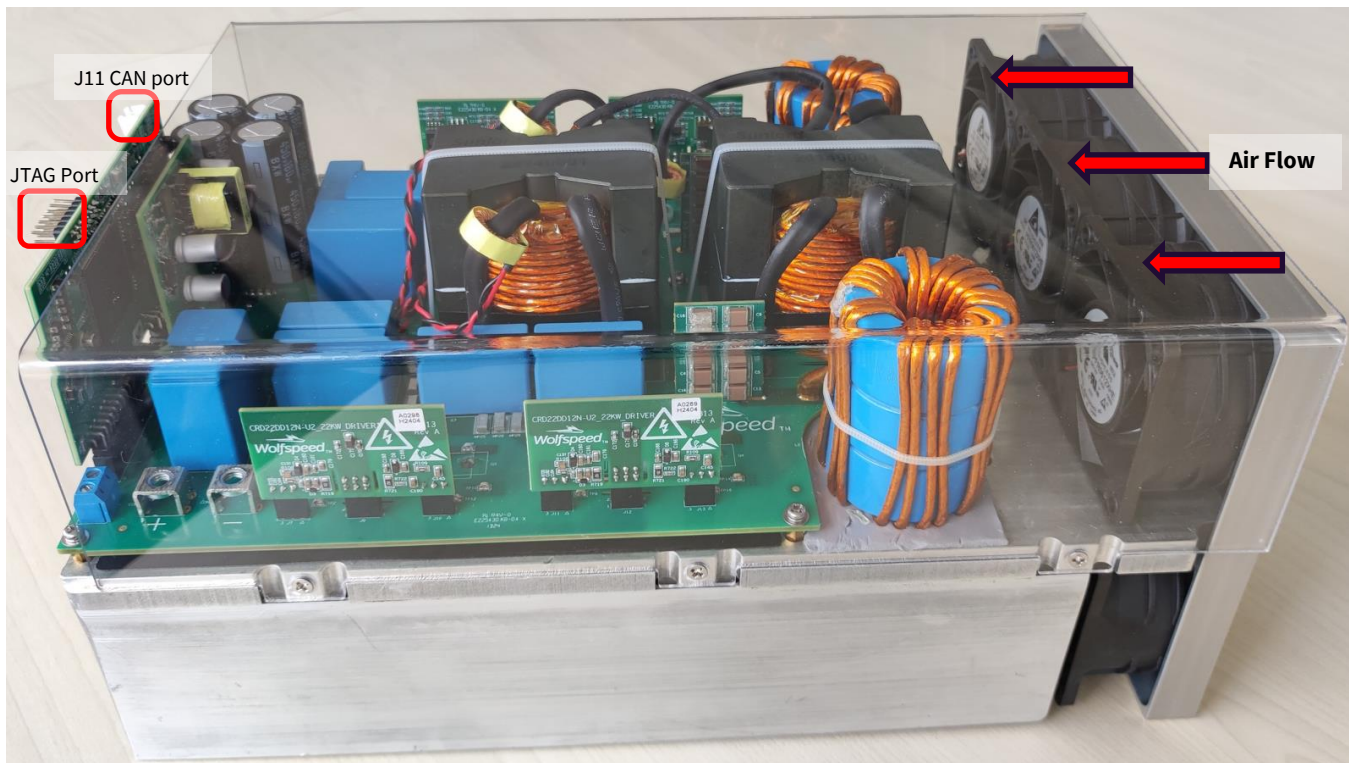


Figure 12. Test setup of the reference design.

Recommended Wire Gauge: Cable with a minimum AWG #10 wire gauge is recommended to carry the DC input and output currents.

5.2 GUI

A Windows C# GUI in conjunction with USB-CAN tools (GCAN: USBCAN-I) is provided for testing. Connector J11 is used for CAN, as shown in Figure 12. The detailed CAN data format is shown in Section 5.3 and Section 12.2.

The over/under voltage protection is indicated by the back color of the voltage value, as shown in Figure 13. “Green” indicates “Normal Operation” while “Red” means “Warning Issued.” The ambient temperature sensed by the IC is displayed in the panel as well.

To conduct an efficiency test with the output lightly loaded, it is recommended that the SR be enabled as shown in Figures 13c, 13e, and 13f. This can be done by increasing the load sufficiently and then decreasing the load to the required test load. The SR status is shown in the left bottom of the GUI window.

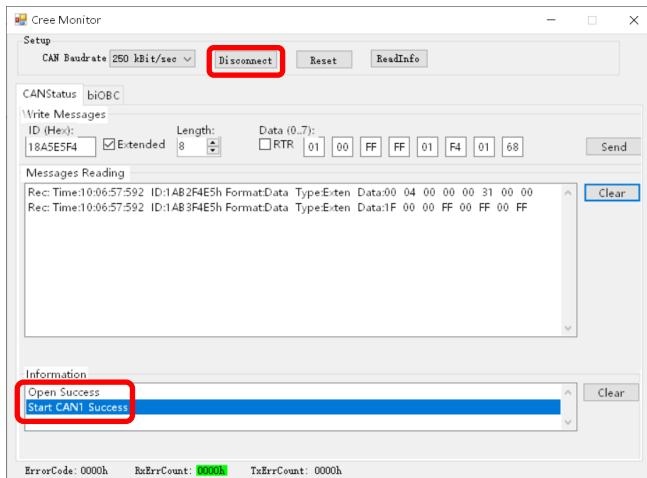


Figure 13a. CAN status tab after connection.

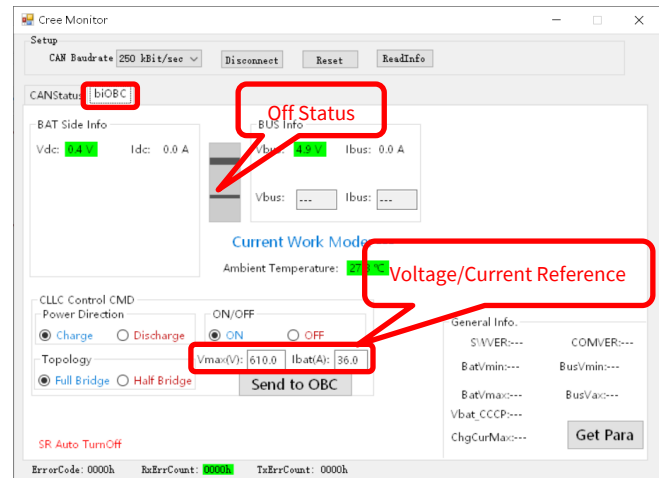


Figure 13b. Connected to control board <Off Mode>.

The power direction and topology can only be changed when the rectifier is shut down. This can be done in two steps: first send an “OFF” command to shut down the converter, then send an “ON” command with desired power direction and topology. The converter will shut down and ignore any other configuration bits once it receives the CAN frame with the “OFF” configuration. If the converter is shut down, it will start, as configured, once it receives the CAN frame with the “ON” configuration. The power direction and topology will also be displayed in the bottom left area.

Voltage reference is the desired output voltage while current reference is the desired output current. The current reference is recommended to be 36 A. The digital controller will check the value range each time. Startup voltage will always be calculated by the controller based on the equation mentioned in Section 2, and thus does not rely upon the input voltage reference.

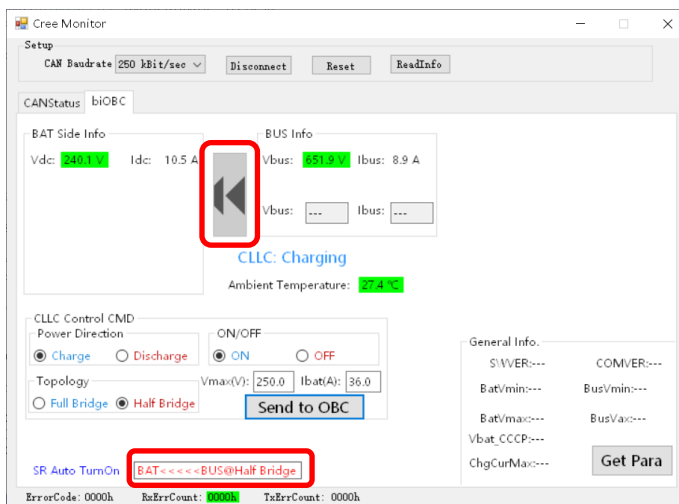


Figure 13c. Charging operation in half bridge.

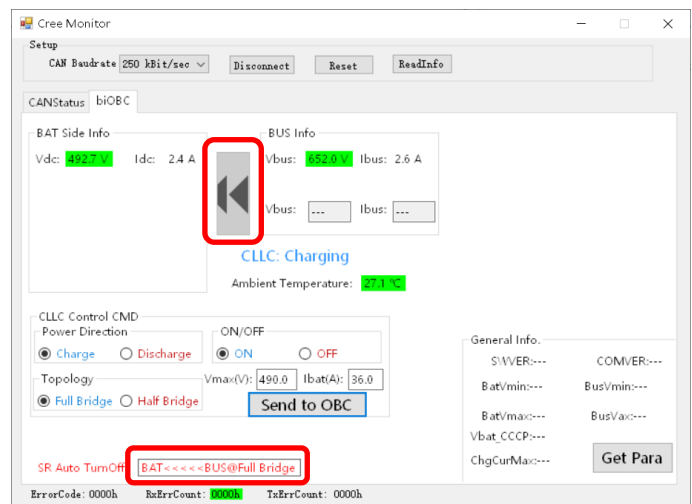


Figure 13d. Charging operation in full bridge.

In charging mode, the output voltage is calculated by the digital controller when the input voltage is between 650 V and 900 V, and the output voltage setting is disabled when the input voltage is between 650 V+3 V or 900 V-3 V after startup.

In discharging mode, these reference values have no impact.

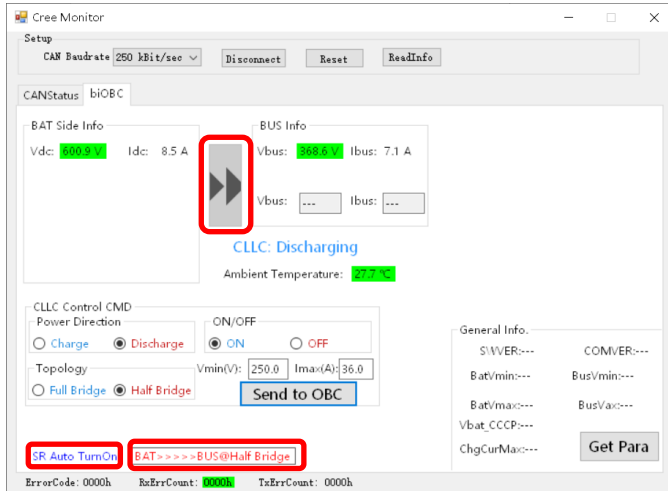


Figure 13e. Discharging operation in half bridge.

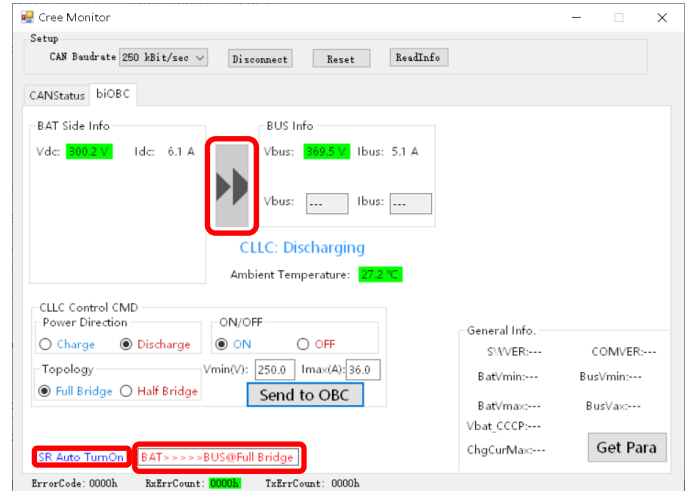


Figure 13f. Discharging operation in full bridge.

5.3 CAN COMMUNICATION DATA FORMAT

The reference design communicates over a CAN V2.0 B bus at 250 K bps (bits per second) using extended frame format (29 bits extend ID). The data length is 8 bytes in big endian format. All registered CAN messages are listed in Section 12.2 and 12.3.

Table 7 below provides an example when “0x18A5E5F4” is sent as the message identifier and “0x0100FFFF12C00168” as the CAN data. When the OBC is placed in charging mode, its output voltage is set to 650 V and care must be taken to ensure that the first byte in the CAN instruction matches the correct operating mode when the second byte is zero. Otherwise, that instruction will be ignored by the reference board.

Message Identifier: 0x18A5E5F4					
Data	Byte0 = 01	Byte1= 00	Byte2+Byte3	Byte4+Byte5 = 0x12C0	Byte6+Byte7 = 0x0168
Property	Charging Mode; Full Bridge	On	Reserved 0xFFFF	DC Voltage: 0x12C0*0.1 V = 480 V	DC Current: 0x0168*0.1 A = 36 A

Table 7: Example of control command.

6. TEST EQUIPMENT



CAUTION

IT IS NOT NECESSARY FOR YOU TO TOUCH THE BOARD WHILE IT IS ENERGIZED. WHEN DEVICES ARE BEING ATTACHED FOR TESTING, THE BOARD MUST BE DISCONNECTED FROM THE ELECTRICAL SOURCE AND ALL BULK CAPACITORS MUST BE FULLY DISCHARGED.

SOME COMPONENTS ON THE BOARD REACH TEMPERATURES ABOVE 50° CELSIUS. THESE CONDITIONS WILL CONTINUE AFTER THE ELECTRICAL SOURCE IS DISCONNECTED UNTIL THE BULK CAPACITORS ARE FULLY DISCHARGED. DO NOT TOUCH THE BOARD WHEN IT IS ENERGIZED AND ALLOW THE BULK CAPACITORS TO COMPLETELY DISCHARGE PRIOR TO HANDLING THE BOARD.

PLEASE ENSURE THAT APPROPRIATE SAFETY PROCEDURES ARE FOLLOWED WHEN OPERATING THIS BOARD AS SERIOUS INJURY, INCLUDING DEATH BY ELECTROCUTION OR SERIOUS INJURY BY ELECTRICAL SHOCK OR ELECTRICAL BURNS, CAN OCCUR IF YOU DO NOT FOLLOW PROPER SAFETY PRECAUTIONS.

警告

通电时不必接触板子。连接器件进行测试时，必须切断板子电源，且大容量电容器必须释放完所有电量。

板子上一些组件的温度可能超过 50 摄氏度。移除电源后，上述情况可能会短暂持续，直至大容量电容器完全释放电量。通电时禁止触摸板子，应在大容量电容器完全释放电量后，再操作板子。请确保在操作板子时已经遵守了正确的安全规程，否则可能会造成严重伤害，包括触电死亡、电击伤害、或电灼伤。

警告

通电している時にボードに接触する必要がありません。設備をつないで試験する時、必ずボードの電源を切ってください。また、大容量のコンデンサーで電力を完全に釈放してください。

ボードのモジュールの温度は 50 度以上になるかもしれません。電源を切った後、上記の状況がしばらく持続する可能性がありますので、大容量のコンデンサーで電力を完全に釈放するまで待ってください。通电している時にボードに接触するのは禁止です。大容量のコンデンサーで電力をまだ完全に釈放していない時、ボードを操作しないでください。

ボードを操作している時、正確な安全ルールを守っているのを確保してください。さもなければ、感電、電撃、厳しい火傷などの死傷が出る可能性があります。

6.1 RECOMMENDED TEST SETUP

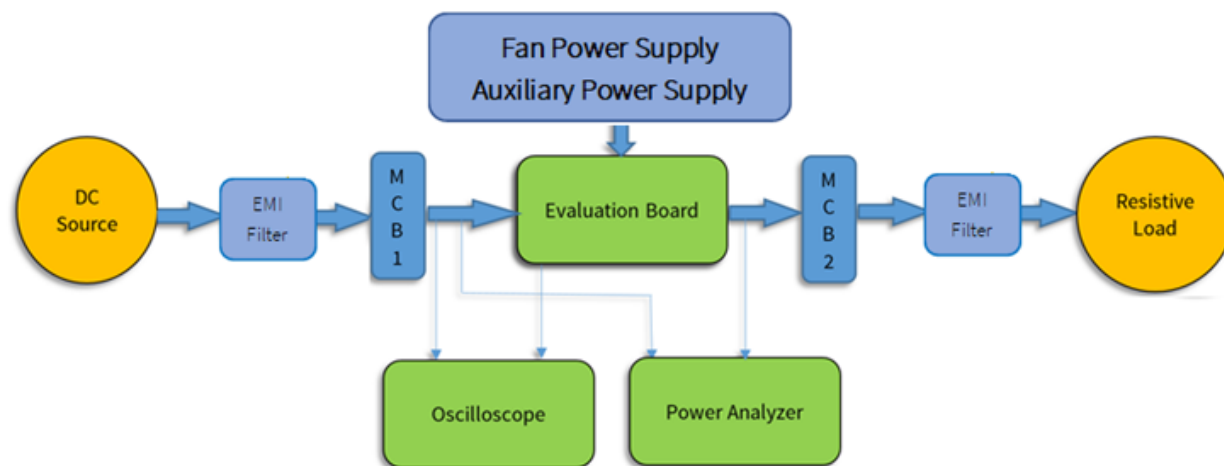


Figure 14: Converter test setup.

Charging mode means the DC source is connected to bus-side terminals and the load is connected to the battery-side terminals. Discharging mode means the DC source is connected to battery-side terminals and the load is connected to the bus-side terminals.

- Connect resistive load to the evaluation board through MCB2.
- Connect DC source to the evaluation board through MCB1.
- Connect power analyzer to measure input and output power.
- Use appropriately rated voltage and current probes and connect to the oscilloscope.
- Place and operate the external fans.

6.2 PROTECTIONS

Table 8 describes various protection functions in the reference design. OCP (Over Current Protection) for the CLLC resonant tank and short protection are one-shot protections that require a system reset to clear and restart.

In addition, do not overload the converter outside the operating specs. In both charging mode and discharging mode, the power/current limitation function based on resonant tank current is only a precaution with limited accuracy and therefore should not be relied upon. More importantly, overload will lead to operation under unexpected input and output relation, which may cause part and board damage.

Power Signal	Protection	Trip Point for Battery Side	Trip Point for Bus Side
DC Voltage	OVP/UVP	> 950 V, < 370 V	> 880 V, < 195 V
Short Protection	Short	---	< 60 V
CLLC Tank Current	OCP	40 A	40 A
Startup Voltage		> 350 V	> 280 V

Power Signal	Protection	Trip Point for Battery Side	Trip Point for Bus Side
Output Power Limitation		22 kW $\pm$ 1.5 kW	
Output Current Limitation		30 A $\pm$ 1.5 A when < 240 V, 36 A $\pm$ 1.5 A for other battery voltages	

Table 8: Protection details.

6.3 ISOLATED POWER SUPPLY: VOLTAGE AND CURRENT SETTINGS

The requirements for the isolated power supplies are shown in Table 9. A single power supply connected to J4 on the main board is used to power the auxiliary power board.

Main Board Connector Designator	Power Supply	Voltage (V)	Current 1 (A) (startup)	Current 2 (A) (standby)	Current 3 (A) (normal)
J4	+14 V for AUX power	+14 V $\pm$ 5%	2.7	0.5	1.0

Table 9: Auxiliary power supply requirements.

6.4 MEASURED PARAMETERS

All power MOSFETs are mounted on the bottom side of the main board, but there are test points on the top side of the PCBA for the measurements of V_{GS} and V_{DS} . **Gate and drain voltages must be measured with caution. Probes should be connected to them only after the removal of input power and only after confirming that all bulk capacitors have fully discharged.**

Name	Description
Efficiency	Measured with power analyzer
Input/Output Current	DC current at DC terminal
Input/Output Voltage	High voltage at DC terminal
CLLC Tank Current	CLLC tank current at both BUS side and battery side
VGS /VDS Signals	Voltage across gate to source or drain to source of SiC MOSFETs
Auxiliary Power Board Outputs	Please refer to Figure 10 and Table 6 for details
3.3 V /1.2 V Controller Supply	+3.3 V supply for Controller's I/O; +1.2 V supply for Controller's core

Table 10: Parameters which can be measured.

7. TESTING THE UNIT



CAUTION

HIGH VOLTAGE RISK

THERE CAN BE VERY HIGH VOLTAGES PRESENT ON THIS BOARD WHEN CONNECTED TO AN ELECTRICAL SOURCE, AND SOME COMPONENTS ON THIS BOARD CAN REACH TEMPERATURES ABOVE 50° CELSIUS. FURTHER, THESE CONDITIONS WILL CONTINUE AFTER THE ELECTRICAL SOURCE IS DISCONNECTED UNTIL THE BULK CAPACITORS ARE FULLY DISCHARGED. DO NOT TOUCH THE BOARD WHEN IT IS ENERGIZED AND ALLOW THE BULK CAPACITORS TO COMPLETELY DISCHARGE PRIOR TO HANDLING THE BOARD.

The connectors on the board have very high voltage levels present when the board is connected to an electrical source, and thereafter until the bulk capacitors are fully discharged. Please ensure that appropriate safety procedures are followed when working with these connectors as serious injury, including death by electrocution or serious injury by electrical shock or electrical burns, can occur if you do not follow proper safety precautions. When devices are being attached for testing, the board must be disconnected from the electrical source and all bulk capacitors must be fully discharged. After use the board should immediately be disconnected from the electrical source. After disconnection any stored up charge in the bulk capacitors will continue to charge the connectors. Therefore, you must always ensure that all bulk capacitors have completely discharged prior to handling the board.

警告

高压危险

通电后，评估板上会存在危险的高电压，且板子上一些组件的温度会超过 50 摄氏度。断电后，上述情况可能会持续存在，尤其是大容量电容器可能会残存危险的高电压。通电时禁止对板子进行任何操作。

操作板子前，请确保大容量电容器电量已完全释放。

板子上的连接器在通电时存在危险的高电压。即使已断电情况下，在大容量电容电量完全释放前，其连接器仍可能存在危险的高电压。请确保在正确的安全流程下进行操作，否则可能会造成严重伤害，包括触电死亡、电击伤害或电灼伤。操作板子前，请务必切断供电电源，并且确认大容量电容器电量已完全释放。使用后应立即切断板子电源。切断电源后，其连接器由于大容量电容存在而仍可能有危险的高电压。因此，在接触板子前，除断电外还需要确保大容量电容器电量已完全释放。

警告

高压危险

通電してから、ボードにひどく高い電圧が存在している可能性があります。ボードのモジュールの温度は 50 度以上になるかもしれません。また、電源を切った後、上記の状況がしばらく持続する可能性がありますので、大容量のコンデンサーで電力を完全に釈放するまで待ってください。通電している時にボードに接触するのは禁止です。

大容量のコンデンサーで電力をまだ完全に釈放していない時、ボードに接触しないでください。ボードのコネクターは充電中また充電した後、ひどく高い電圧が存在しているので、大容量のコンデンサーで電力を完全に釈放するまで待ってください。ボードを操作している時、正確な安全ルールを守っているのを確保してください。さもないと、感電、電撃、厳しい火傷などの死傷が出る可能性があります。設備をつないで試験する時、必ずボードの電源を切ってください。また、大容量のコンデンサーで電力を完全に釈放してください。使用后、すぐにボードの電源を切ってください。電源を切った後、大容量のコンデンサーに貯蓄している電量はコネクターに持続的に入るので、ボードを操作する前に、必ず大容量のコンデンサーの電力を完全に釈放するのを確保してください。

Notes:

1. Power direction and topology can't be changed via CAN communication after startup.
2. Please choose the appropriate power direction matched with the setup.
3. Please choose the appropriate topology according to the desired output voltage in charging mode at given input bus voltage or according to the input voltage in discharging mode.
 - a. In charging mode, the converter should operate as full-bridge topology when the battery-side output voltage is targeted in the range of 340 VDC ~ 800 VDC and as half-bridge topology for 200 VDC ~ 340 VDC when the input DC voltage is above 650 VDC.
 - b. In discharging mode, the converter should operate as full-bridge topology when the battery-side input voltage is in the range of 300 VDC ~ 600 VDC and as half-bridge topology for 600 VDC ~ 800 VDC.
4. **Do not overload the converter.** Please refer to Table 1, Table 2, and Section 3.2.
5. There is no current inrush limiter for either port. The DC input voltage must be increased slowly (soft start) for either power direction.
6. Always remember to connect the cooling fans to their power supplies and operate the cooling fans when operating the board.

7.1 STARTUP PROCEDURE: DISCHARGING MODE

1. Double check the setup: Make sure the polarity is correct, the source is connected to the **battery-side** terminals, and the load is connected to the **bus-side** terminals.
2. Keep MCB1 (DC supply) in open position and the DC source output disabled.
3. Ensure that the load is less than 1 kW, and then close MCB2.
4. Apply 14 VDC to J4 on the main board. Check the output voltage of the Auxiliary Power Supply at J5 (P6.5 V, VP+15 V) and J6 (VS+15 V, CAN_5 V). Check that the current draw is approximately the same as shown in Table 9. Check the +3.3 V LED (on) and watchdog LED (blinking) on the control board.
5. Connect the GUI to the system. Send "OFF" command after it is connected successfully.
6. Apply power to the cooling fans.
7. Put MCB1 in the ON position. Turn on the DC supply and increase its output voltage slowly from 0 V to the required voltage (300 VDC ~ 800 VDC).
8. Verify that the measured values in the GUI are reported correctly.
9. Send ON command with settings of "**Discharge**" and "Full Bridge" or "Half Bridge" according to the input voltage. Voltage reference and current reference have no impact for startup. Startup voltage is calculated according to Figure 3.
10. After the output voltage has reached steady-state target value, increase the load up to desired value within 6.6 kW. The step-load change should not be more than 1 kW for each step.
11. Check the efficiency under load conditions of interest. Check if SR is turned on automatically when DC output current is above 5 A. SR should be active by increasing output current to be higher than 5 A.

7.2 TURNOFF PROCEDURE: DISCHARGING MODE

1. Decrease the load to 1 kW within 1 kW steps.
2. Use GUI to send OFF command.
3. Disable the output of the DC power supply.
4. Wait until the DC source has fully discharged its output.
5. Turn OFF load after the bus-side capacitors are fully discharged.
6.  **Capacitors may remain charged for up to 30 minutes after the circuit is turned OFF if step 4 or step 5 are skipped or compromised. They must be allowed to fully discharge before handling the board. Please check the terminal voltages with a multimeter to ensure that the board has fully discharged and is therefore safe to handle.**
7. Turn OFF the 14 VDC power supply on J4. The unit should be fully discharged before the auxiliary power supply is disabled.

7.3 STARTUP PROCEDURE: CHARGING MODE

1. Double check the setup: Make sure the polarity is correct, the DC source is connected to the **bus-side** terminals, and the load is connected to the **battery-side** terminals.
2. Keep MCB1 (DC supply) in the open position and the DC source output disabled.
3. Apply a load of no more than 1 kW to the DC terminals, and then close MCB2.
4. Apply 14 VDC to J4 on the main board. Check the output voltage of the Auxiliary Power Supply at J5 (P6.5 V, VP+15 V) and J6 (VS+15 V, CAN_5 V). Check that the current draw is approximately the same as shown in Table 9. Check the +3.3 V LED (on) and watchdog LED (blinking) on the control board.
5. Connect the GUI to the system. Send “OFF” command after it is connected successfully.
6. Apply power to the cooling fans.
7. Put MCB1 in the ON position, turn on the DC supply, and increase it slowly from 0V to the required voltage (380 VDC ~ 900 VDC).
8. Verify that the measured values in the GUI were reported correctly.
9. Send ON command with settings of “**Charge**” and “Full Bridge” or “Half Bridge,” according to desired output voltage. Use 36 A as current reference for start-up. The converter will start up with voltage calculated according to Figure 2.
10. The output voltage can be regulated using GUI only when the input voltage is 380 V, 650 V and 900 V. Otherwise, the output voltage is calculated according to Figure 2.
11. After the output voltage has reached steady-state target value, apply a load to the output in no more than 2 kW steps. Permanent overload damage may occur during sustained operation with unmatched input and output relation.
12. Check the efficiency under load conditions of interest. Check if SR is turned on automatically when DC output current is above 5 A. SR should be active by increasing output current to >5 A.

7.4 TURNOFF PROCEDURE: CHARGING MODE

1. Decrease the load to 1 kW. The step of load change should be less than 2 kW for each step.
2. Use GUI to send OFF command.
3. Turn OFF the DC source.
4. Open MCB1 after the DC source has fully discharged its output.
5. Turn OFF load and MCB2 after the battery side capacitors are fully discharged.
6.  **Capacitors may remain charged for at least 30 minutes after the circuit is turned OFF if step 4 or step 5 are skipped or compromised. They must be allowed to fully discharge before handling the board. Please check the terminal voltages with a multimeter to ensure that the board has fully discharged and is therefore safe to handle.**
7. Turn OFF the 14 VDC power supply on J4.

8. PHOTOS OF THE REFERENCE DESIGN

Figure 15 shows the locations of the terminals, key components, and daughterboards on the main board.

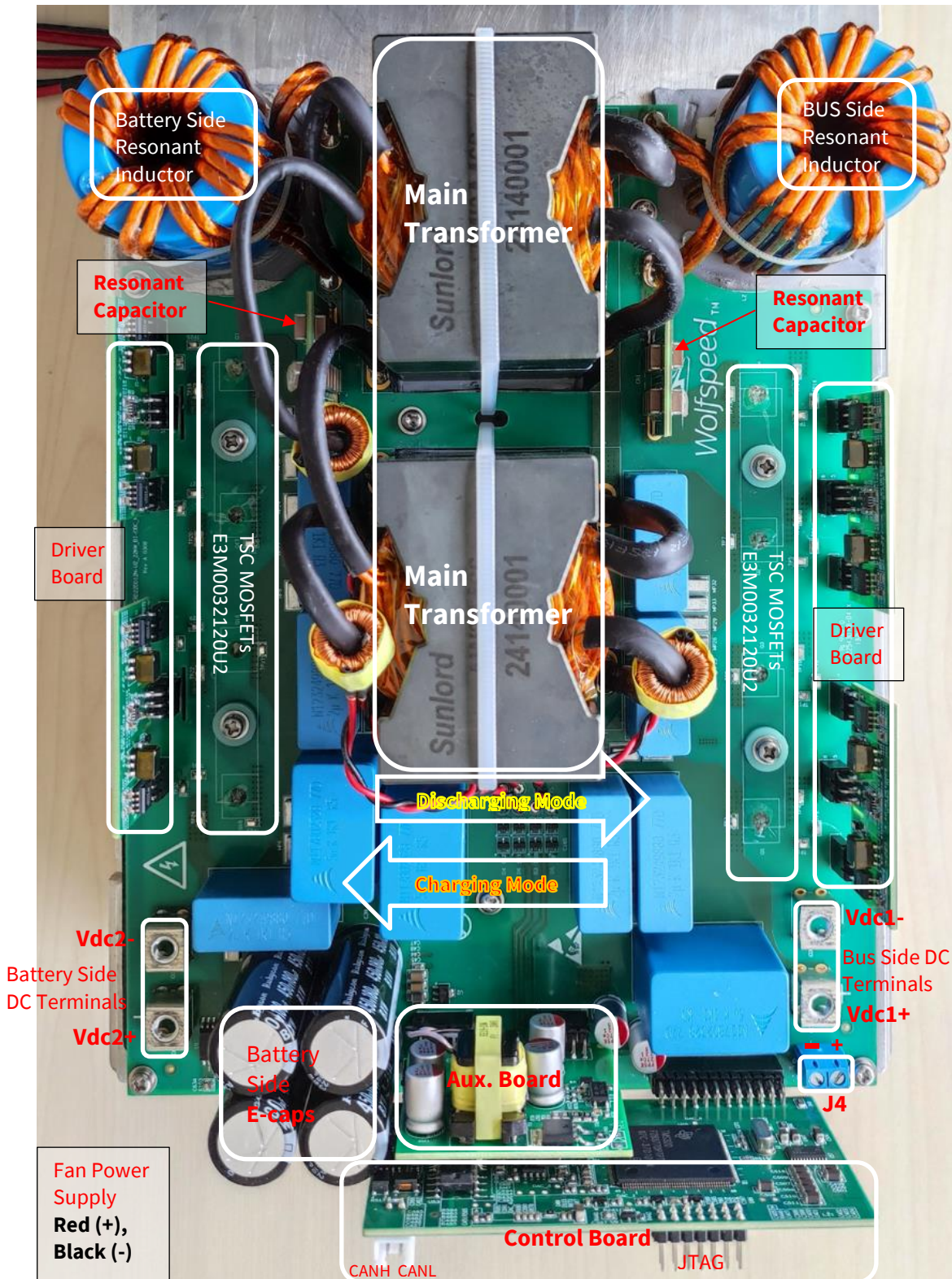


Figure 15. Top view of PCBAs (236 mm*180 mm*55 mm).

9. PERFORMANCE DATA

The performance data of Wolfspeed's CRD-22DD12N-U2 reference design board is taken in both DC/DC Charging Mode and Discharging Mode. Table 11 to Table 14 show the performance data. All tests are done at room temperature unless otherwise specified.

Input Voltage (VDC)	Input Power (W)	Load (%)	Output Voltage (VDC)	Output Power (W)	Overall Efficiency (%)
650	2280.40	10	240	2217.82	97.256
650	4516.13	20	240	4378.52	96.953
650	6899.28	30	240	6631.77	96.123
650	2358.66	10	340	2213.54	93.847
650	4755.29	20	340	4464.62	93.887
650	7016.20	30	340	6670.52	95.073
650	9243.44	40	340	8899.12	96.275
650	11555.49	50	340	11082.48	95.907
650	12564.50	60	340	12009.29	95.581
650	2352.07	10	400	2257.45	95.977
650	4653.00	20	400	4463.42	95.926
650	6861.86	30	400	6654.57	96.979
650	9161.05	40	400	8906.07	97.217
650	11394.95	50	400	11063.45	97.091
650	13779.22	60	400	13325.95	96.711
650	2332.03	10	490	2263.26	97.051
650	4536.88	20	490	4471.64	98.562
650	6784.49	30	490	6687.89	98.576
650	8999.13	40	490	8865.05	98.510
650	11322.94	50	490	11133.70	98.329
650	13554.31	60	490	13299.59	98.121
650	15850.92	70	490	15520.02	97.912
650	18014.90	80	490	17589.13	97.637

Table 11: Efficiency data (DC/DC charging mode), $V_{IN} = 650$ VDC.

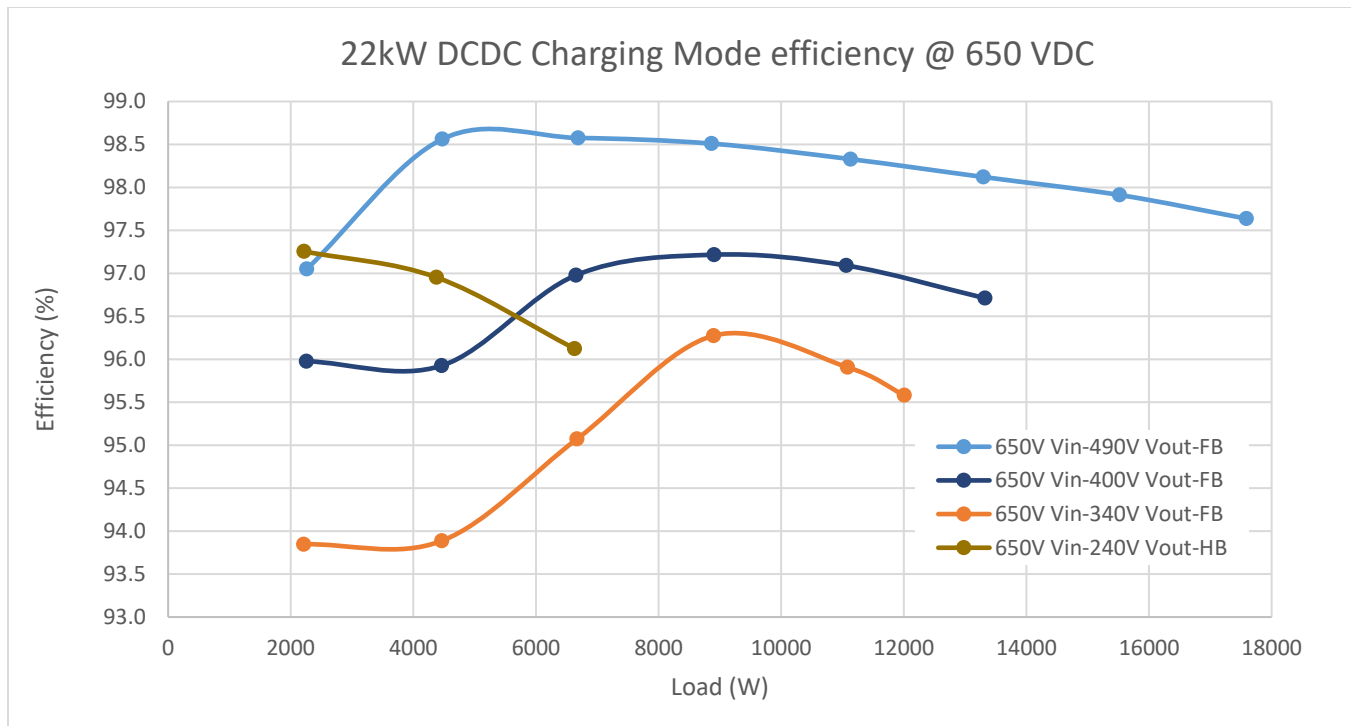


Figure 16: Efficiency data (DC/DC Charging Mode), $V_{IN} = 650$ VDC.

Input Voltage (VDC)	Input Power (W)	Load (%)	Output Voltage (VDC)	Output Power (W)	Overall Efficiency (%)
900	2303.85	10	340	2251.11	97.711
900	4565.87	20	340	4464.34	97.776
900	6797.27	30	340	6632.21	97.572
900	9050.29	40	340	8797.52	97.207
900	11463.93	50	340	11085.81	96.702
900	12437.83	60	340	11986.22	96.369
900	2365.42	10	685	2283.94	96.555
900	4581.27	20	685	4498.33	98.190
900	6836.94	30	685	6733.15	98.482
900	9047.62	40	685	8918.83	98.577
900	11294.14	50	685	11135.48	98.595
900	13534.47	60	685	13338.27	98.550
900	15791.58	70	685	15557.55	98.518
900	18041.16	80	685	17764.86	98.468
900	20254.01	90	685	19922.86	98.365
900	22540.49	100	685	22155.11	98.290

Input Voltage (VDC)	Input Power (W)	Load (%)	Output Voltage (VDC)	Output Power (W)	Overall Efficiency (%)
900	2458.21	10	800	2316.55	94.237
900	4660.55	20	800	4519.21	96.967
900	6896.67	30	800	6748.73	97.855
900	9122.53	40	800	8952.20	98.133
900	11307.06	50	800	11107.79	98.238
900	13569.02	60	800	13335.95	98.282
900	15803.49	70	800	15536.71	98.312
900	18061.99	80	800	17768.02	98.372
900	20289.59	90	800	19963.52	98.393
900	22546.99	100	800	22145.33	98.219

Table 12: Efficiency data (DC/DC Charging Mode), $V_{IN} = 900$ VDC.

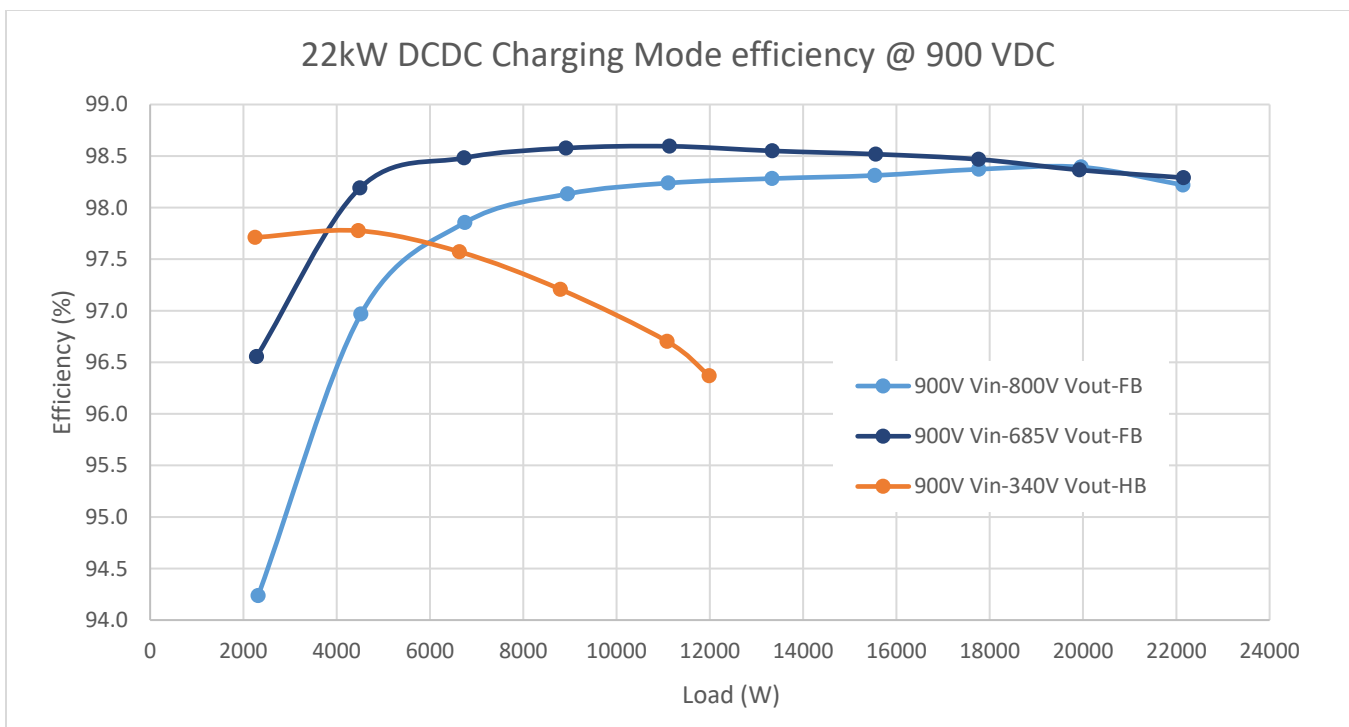


Figure 17: Efficiency data (DC/DC Charging Mode), $V_{IN} = 900$ VDC.

Input Voltage (VDC)	Input Power (W)	Load (%)	Output Voltage (VDC)	Output Power (W)	Overall Efficiency (%)
300	727.73	10%	369	702.26	96.501
300	1394.21	20%	369	1351.53	96.939
300	2048.64	30%	369	2016.39	98.426

Input Voltage (VDC)	Input Power (W)	Load (%)	Output Voltage (VDC)	Output Power (W)	Overall Efficiency (%)
300	2726.63	40%	369	2683.40	98.415
300	3410.14	50%	369	3353.03	98.325
300	4086.11	60%	369	4011.60	98.177
300	4768.75	70%	369	4674.31	98.020
300	5438.27	80%	369	5321.14	97.846
300	6133.98	90%	369	5992.09	97.687
300	6797.87	100%	369	6627.67	97.496
500	831.85	10%	622	805.14	96.789
500	1428.22	20%	622	1384.01	96.905
500	2106.83	30%	622	2050.42	97.323
500	2778.71	40%	622	2712.90	97.632
500	3413.70	50%	622	3363.41	98.527
500	4098.03	60%	622	4041.41	98.618
500	4776.70	70%	622	4711.16	98.628
500	5419.68	80%	622	5345.76	98.636
500	6115.05	90%	622	6031.10	98.627
500	6780.19	100%	622	6683.97	98.581
600	878.81	10%	745	844.57	96.103
600	1456.15	20%	745	1406.31	96.577
600	2125.80	30%	745	2067.07	97.237
600	2797.49	40%	745	2729.88	97.583
600	3463.82	50%	745	3388.60	97.829
600	4096.58	60%	745	4036.65	98.537
600	4774.41	70%	745	4707.92	98.607
600	5451.90	80%	745	5379.14	98.665
600	6116.24	90%	745	6036.16	98.691
600	6786.32	100%	745	6697.49	98.691

Table 13: Efficiency data (DC/DC Discharging Mode), $V_{IN} = 300\text{ V}/500\text{ V}/600\text{ VDC}$ full bridge.

Input Voltage (VDC)	Input Power (W)	Load (%)	Output Voltage (VDC)	Output Power (W)	Overall Efficiency (%)
600	742.76	10%	369	706.11	95.066
600	1423.39	20%	369	1370.91	96.313
600	2069.97	30%	369	2029.04	98.022
600	2736.30	40%	369	2683.31	98.063
600	3391.93	50%	369	3324.81	98.021
600	4101.74	60%	369	4015.95	97.908
600	4785.05	70%	369	4678.99	97.784
600	5455.44	80%	369	5326.54	97.637
600	6100.05	90%	369	5945.75	97.471
600	6819.04	100%	369	6633.72	97.282
800	761.02	10%	495	717.87	94.329
800	1435.43	20%	495	1377.27	95.948
800	2104.12	30%	495	2034.44	96.688
800	2773.18	40%	495	2718.13	98.015
800	3428.09	50%	495	3363.94	98.129
800	4104.53	60%	495	4030.21	98.189
800	4776.99	70%	495	4689.39	98.166
800	5464.47	80%	495	5363.87	98.159
800	6134.74	90%	495	6018.71	98.109
800	6810.12	100%	495	6676.81	98.042

Table 14: Efficiency data (DC/DC Discharging Mode), $V_{IN} = 600\text{ V}/800\text{ VDC}$ half bridge.

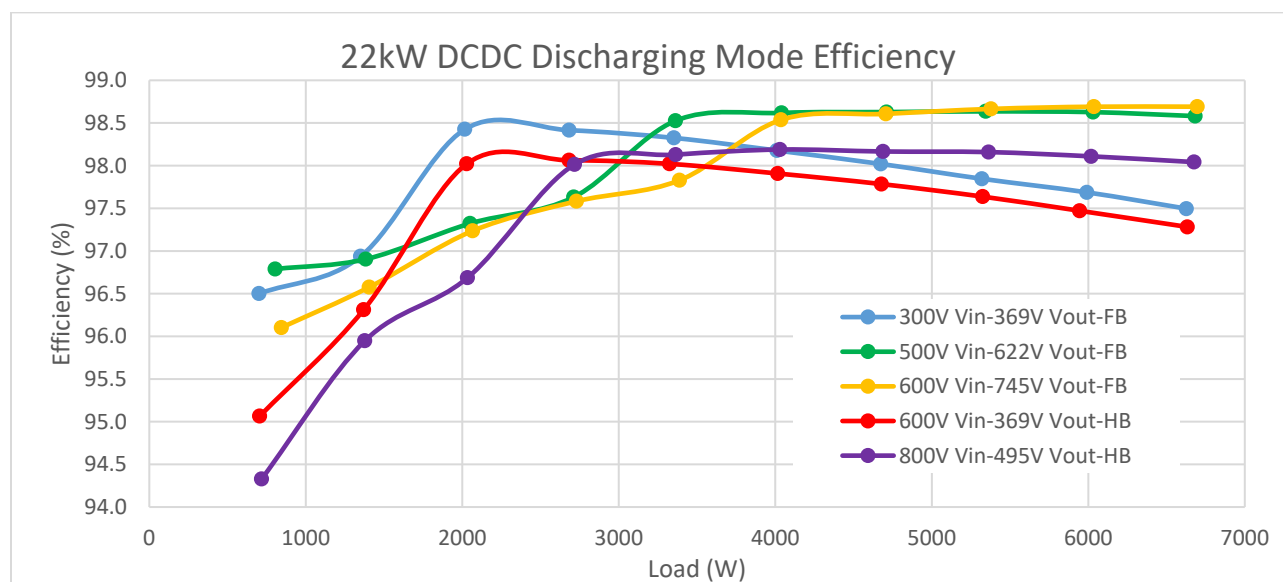
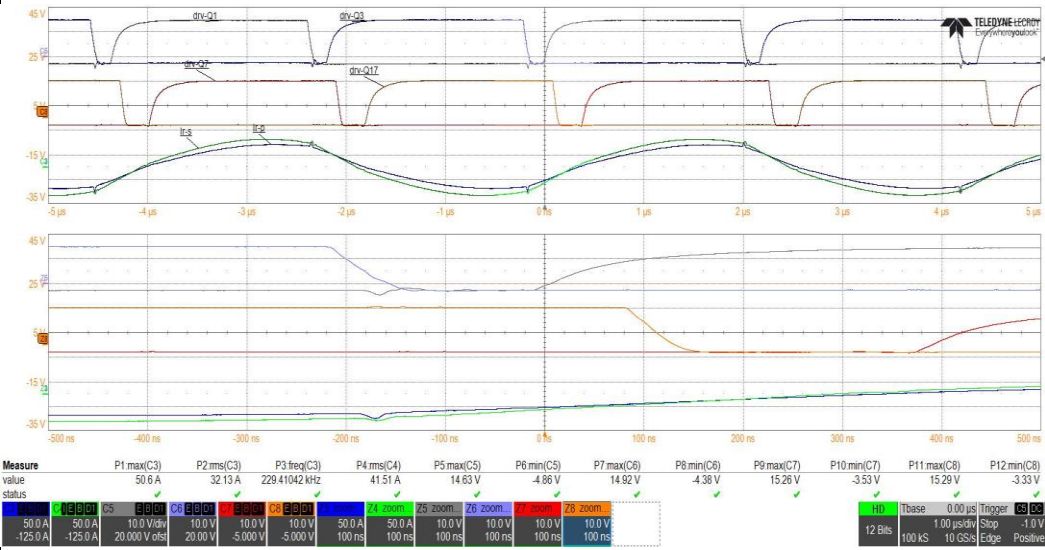
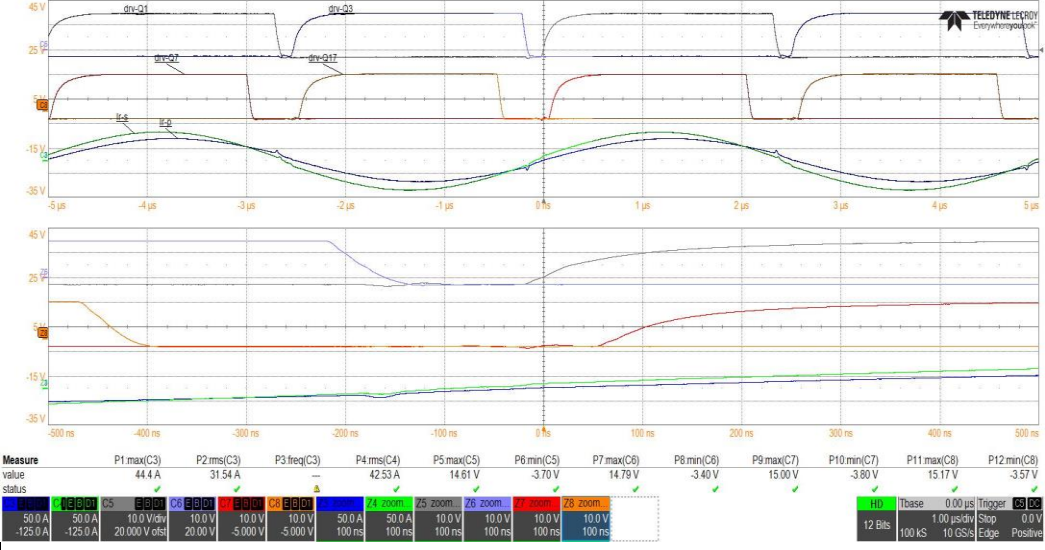


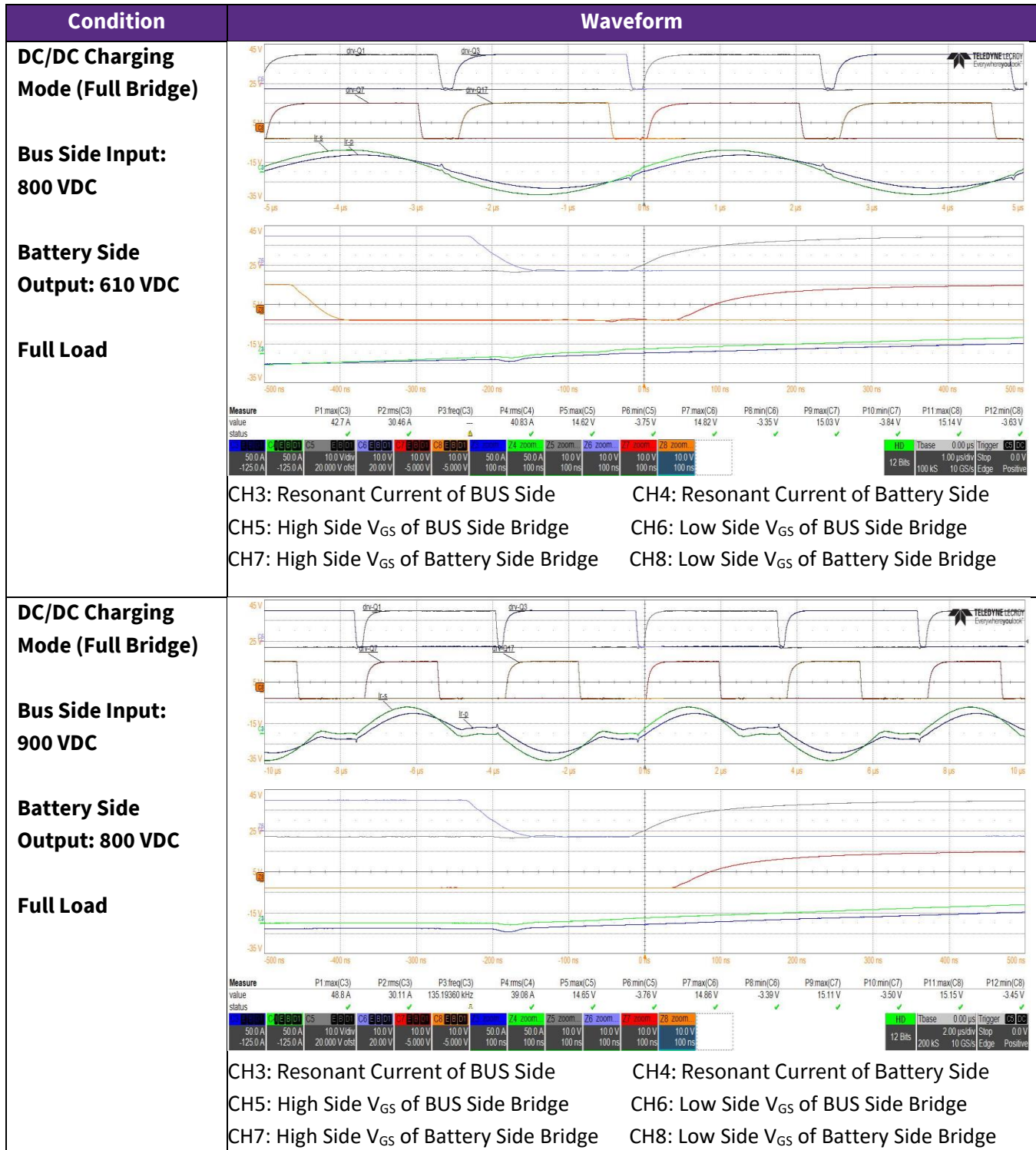
Figure 18: Efficiency data (DC/DC Discharging Mode).

10. TYPICAL WAVEFORMS

Operational waveforms are presented in Table 15 and Table 16.

10.1 DC/DC CHARGING MODE

Condition	Waveform
DC/DC Charging Mode (Full Bridge) Bus Side Input: 650 VDC Battery Side Output: 340 VDC Full Load	 CH3: Resonant Current of BUS Side CH4: Resonant Current of Battery Side CH5: High Side V_{GS} of BUS Side Bridge CH6: Low Side V_{GS} of BUS Side Bridge CH7: High Side V_{GS} of Battery Side Bridge CH8: Low Side V_{GS} of Battery Side Bridge
DC/DC Charging Mode (Full Bridge) Bus Side Input: 650 VDC Battery Side Output: 490 VDC Full Load	 CH3: Resonant Current of BUS Side CH4: Resonant Current of Battery Side CH5: High Side V_{GS} of BUS Side Bridge CH6: Low Side V_{GS} of BUS Side Bridge CH7: High Side V_{GS} of Battery Side Bridge CH8: Low Side V_{GS} of Battery Side Bridge



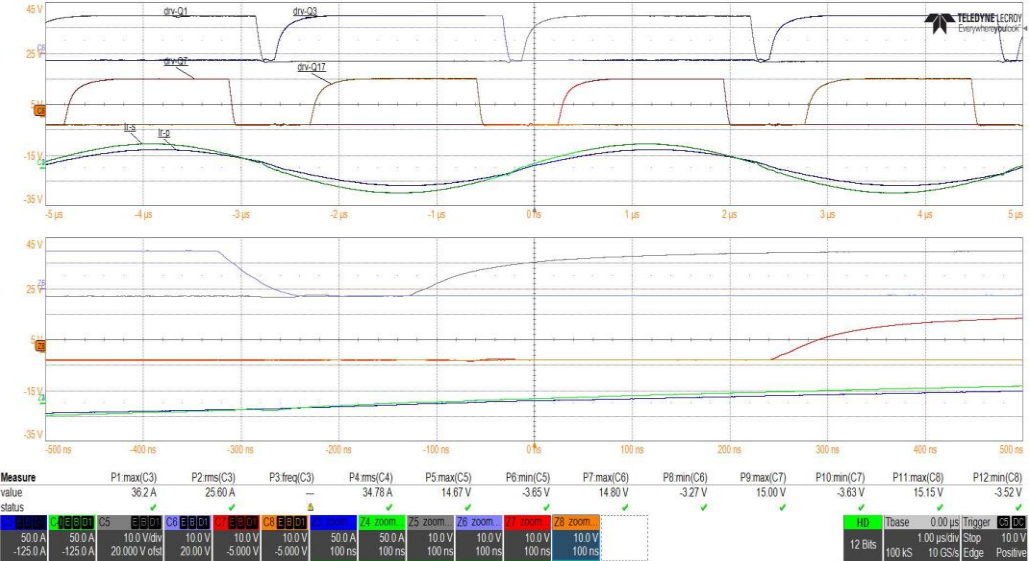
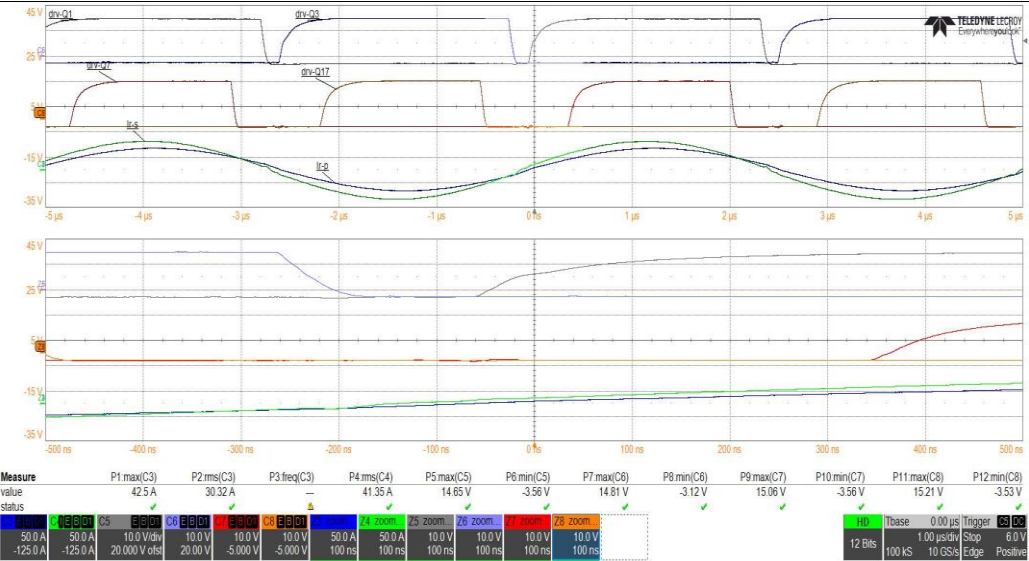
Condition	Waveform
DC/DC Charging Mode (Half Bridge) Bus Side Input: 650 VDC Battery Side Output: 240 VDC Full Load	 CH3: Resonant Current of BUS Side CH4: Resonant Current of Battery Side CH5: High Side V_{GS} of BUS Side Bridge CH6: Low Side V_{GS} of BUS Side Bridge CH7: High Side V_{GS} of Battery Side Bridge CH8: Low Side V_{GS} of Battery Side Bridge
DC/DC Charging Mode (Half Bridge) Bus Side Input: 900 VDC Battery Side Output: 340 VDC Full Load	 CH3: Resonant Current of BUS Side CH4: Resonant Current of Battery Side CH5: High Side V_{GS} of BUS Side Bridge CH6: Low Side V_{GS} of BUS Side Bridge CH7: High Side V_{GS} of Battery Side Bridge CH8: Low Side V_{GS} of Battery Side Bridge

Table 15: DC/DC Charging Mode waveforms.

10.2 DC/DC DISCHARGING MODE

Condition	Waveform																								
DC/DC Discharging Mode (Full Bridge) Battery Side Input: 300 VDC Bus Side Output: 369 VDC Full Load	Measure value status <table><tr><td>P1 max(C3)</td><td>28.2 A</td><td>P2 rms(C3)</td><td>20.06 A</td><td>P3 freq(C3)</td><td>198.37358 kHz</td><td>P4 rms(C4)</td><td>27.76 A</td><td>P5 max(C5)</td><td>14.80 V</td><td>P6 min(C5)</td><td>-3.37 V</td><td>P7 max(C6)</td><td>14.74 V</td><td>P8 min(C6)</td><td>-3.27 V</td><td>P9 max(C7)</td><td>14.98 V</td><td>P10 min(C7)</td><td>-4.27 V</td><td>P11 max(C8)</td><td>15.07 V</td><td>P12 min(C8)</td><td>-3.95 V</td></tr></table> CH3: Resonant Current of BUS Side CH4: Resonant Current of Battery Side CH5: High Side V_{GS} of BUS Side Bridge CH6: Low Side V_{GS} of BUS Side Bridge CH7: High Side V_{GS} of Battery Side Bridge CH8: Low Side V_{GS} of Battery Side Bridge	P1 max(C3)	28.2 A	P2 rms(C3)	20.06 A	P3 freq(C3)	198.37358 kHz	P4 rms(C4)	27.76 A	P5 max(C5)	14.80 V	P6 min(C5)	-3.37 V	P7 max(C6)	14.74 V	P8 min(C6)	-3.27 V	P9 max(C7)	14.98 V	P10 min(C7)	-4.27 V	P11 max(C8)	15.07 V	P12 min(C8)	-3.95 V
P1 max(C3)	28.2 A	P2 rms(C3)	20.06 A	P3 freq(C3)	198.37358 kHz	P4 rms(C4)	27.76 A	P5 max(C5)	14.80 V	P6 min(C5)	-3.37 V	P7 max(C6)	14.74 V	P8 min(C6)	-3.27 V	P9 max(C7)	14.98 V	P10 min(C7)	-4.27 V	P11 max(C8)	15.07 V	P12 min(C8)	-3.95 V		
DC/DC Discharging Mode (Full Bridge) Battery Side Input: 600 VDC Bus Side Output: 750 V VDC dc Full Load	Measure value status <table><tr><td>P1 max(C3)</td><td>13.1 A</td><td>P2 rms(C3)</td><td>9.64 A</td><td>P3 freq(C3)</td><td>216.49649 kHz</td><td>P4 rms(C4)</td><td>13.77 A</td><td>P5 max(C5)</td><td>14.76 V</td><td>P6 min(C5)</td><td>-3.48 V</td><td>P7 max(C6)</td><td>14.68 V</td><td>P8 min(C6)</td><td>-3.36 V</td><td>P9 max(C7)</td><td>14.95 V</td><td>P10 min(C7)</td><td>-4.19 V</td><td>P11 max(C8)</td><td>15.21 V</td><td>P12 min(C8)</td><td>-3.75 V</td></tr></table> CH1: Low Side V_{DS} of BUS Side Bridge CH2: Low Side V_{DS} of Battery Side Bridge CH3: Resonant Current of BUS Side CH4: Resonant Current of Battery Side CH5: High Side V_{GS} of BUS Side Bridge CH6: Low Side V_{GS} of BUS Side Bridge CH7: High Side V_{GS} of Battery Side Bridge CH8: Low Side V_{GS} of Battery Side Bridge	P1 max(C3)	13.1 A	P2 rms(C3)	9.64 A	P3 freq(C3)	216.49649 kHz	P4 rms(C4)	13.77 A	P5 max(C5)	14.76 V	P6 min(C5)	-3.48 V	P7 max(C6)	14.68 V	P8 min(C6)	-3.36 V	P9 max(C7)	14.95 V	P10 min(C7)	-4.19 V	P11 max(C8)	15.21 V	P12 min(C8)	-3.75 V
P1 max(C3)	13.1 A	P2 rms(C3)	9.64 A	P3 freq(C3)	216.49649 kHz	P4 rms(C4)	13.77 A	P5 max(C5)	14.76 V	P6 min(C5)	-3.48 V	P7 max(C6)	14.68 V	P8 min(C6)	-3.36 V	P9 max(C7)	14.95 V	P10 min(C7)	-4.19 V	P11 max(C8)	15.21 V	P12 min(C8)	-3.75 V		

Condition	Waveform
DC/DC Discharging Mode (Half Bridge) Battery Side Input: 600 VDC Bus Side Output: 369 VDC Full Load	CH1: Low Side V_{DS} of BUS Side Bridge CH2: Low Side V_{DS} of Battery Side Bridge CH3: Resonant Current of BUS Side CH4: Resonant Current of Battery Side CH5: High Side V_{GS} of BUS Side Bridge CH6: Low Side V_{GS} of BUS Side Bridge CH7: High Side V_{GS} of Battery Side Bridge CH8: Low Side V_{GS} of Battery Side Bridge
DC/DC Discharging Mode (Half Bridge) Battery Side Input: 800 VDC Bus Side Output: 495 VDC Full Load	CH1: Low Side V_{DS} of BUS Side Bridge CH2: Low Side V_{DS} of Battery Side Bridge CH3: Resonant Current of BUS Side CH4: Resonant Current of Battery Side CH5: High Side V_{GS} of BUS Side Bridge CH6: Low Side V_{GS} of BUS Side Bridge CH7: High Side V_{GS} of Battery Side Bridge CH8: Low Side V_{GS} of Battery Side Bridge

Table 16: DC/DC Discharging Mode waveforms.

11. THERMAL DESIGN AND TEST RESULTS

In a thermal test of the unit using heatsink and forced-air cooling, the temperature of the heatsink is kept as 65 °C to simulate the liquid cooling system in an automotive application. There is no air flow to the surface of SiC MOSFETs.

Considering multiple TSC SiC MOSFETs are mounted on the same PCB, the devices may not be perfectly coplanar. The flatness differences among all the TSC MOSFETs cannot be ignored in the assembly process. A thermal interface material (TIM) that can accommodate these flatness differences is required. In this design, an Al₂O₃ ceramic substrate is used for insulation and heat transfer, and a thin (0.5 mm) and soft gap pad (CIP2100) is used as thermal interface material (TIM) to compensate for the flatness of the PCB and MOSFET tab.

The thermal test was performed at 650 VDC input and 340 VDC output with 36 A current in charging mode, which is the worst operating condition for a thermal test. K-type thermal couplers and a 34970A data acquisition unit from Keysight Technologies Inc. are used during the thermal test.

The test results are shown in Table 17 and Table 18. The highest junction temperature among all MOSFETs in this design is less than 99°C. This value is calculated based on the measured case temperature, the thermal resistance, and the calculated power loss. Because the maximum junction temperature of E3M0032120U2 is 175°C, there is a large margin of T_j.

Description	Scenario 1. Input: 650 V Output:340 V/36 A Charging Mode	Scenario 2. Input: 900 V Output:340 V/36 A Charging Mode	Rated Temperature	Derating Requirement	Comments
Base Plate	65	65	NA	NA	NA
Resonant Choke of BUS Side	70.0	63.8	155 °C	130 °C	PASS
Resonant Choke of Battery Side	79.3	80.4	155 °C	130 °C	PASS
Core of Main Transformer	121.9	112.4	155 °C	130 °C	PASS

Table 17: Thermal test results of magnetic components.

Temperature of semiconductors is shown in the table below.

Description	R _{TH_J-C} (°C/W)	Calculated Power Loss (W)	Measured Case Temperature (°C)	Calculated Junction Temperature (°C)	Max. Operating Junction Temperature (°C)	Derating Requirement (°C)	Comments
Charging Mode; Input: 650VDC; Output: 340VDC * 36A; Temperature of heatsink is 65°C							
High Side MOSFET of BUS Side	0.45	33.6	83.8	98.9	175	140	PASS
Low Side MOSFET of BUS Side	0.45	33.6	81.7	96.8	175	140	PASS
High Side MOSFET of BAT Side	0.45	32.9	78.1	92.9	175	140	PASS
Low Side MOSFET of BAT Side	0.45	32.9	80.1	94.9	175	140	PASS

Table 18: Thermal test results of SiC MOSFETS.

12. APPENDIX

12.1 PWM TIMING

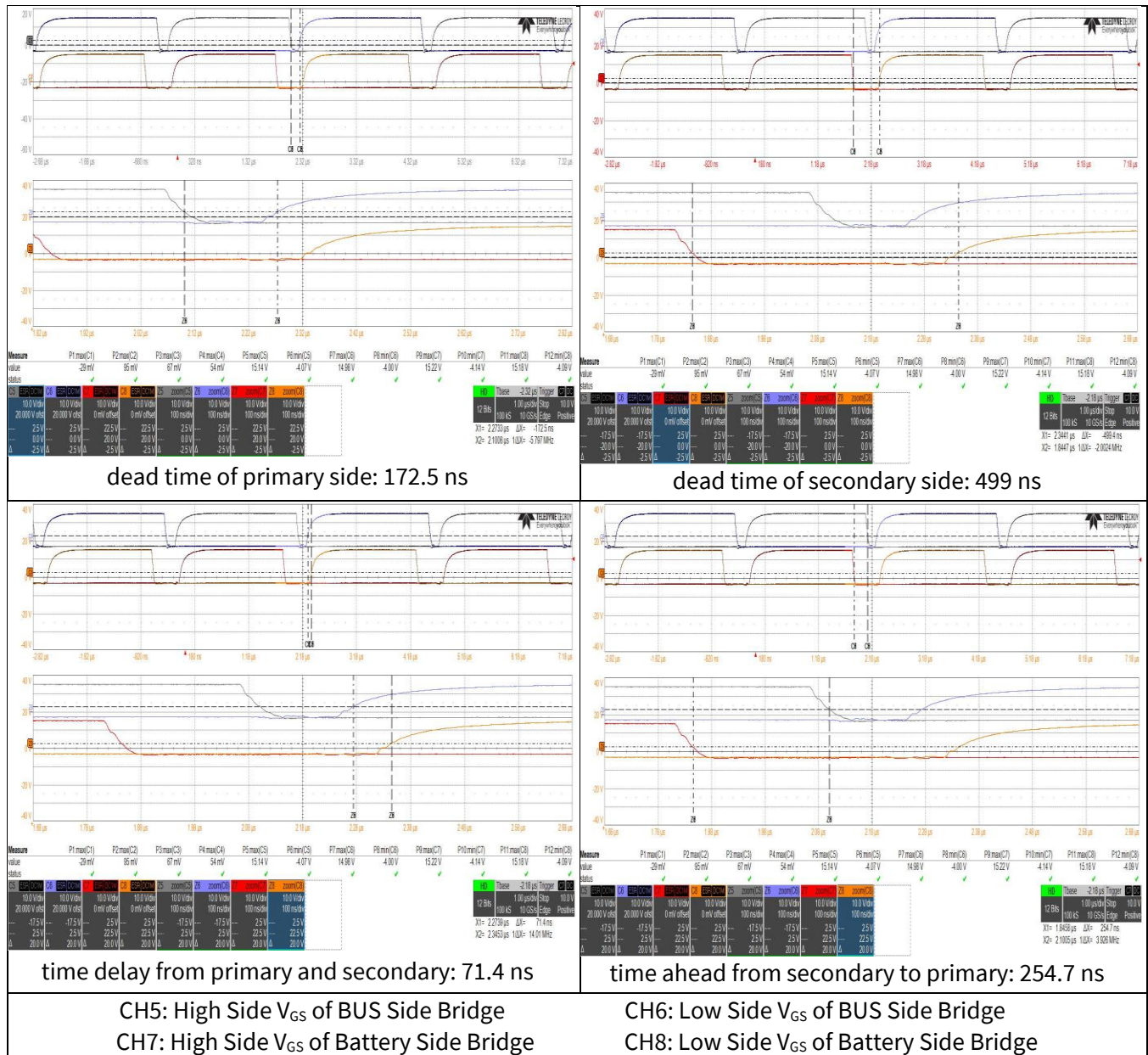


Table 19: Gate signals and timings in Charging Mode.

12.2 CAN MESSAGES FROM OBC

Message Identifier: 0x1AB2F4E5				
Data	Byte0+Byte1	Byte2+Byte3	Byte4+Byte5	Byte6+Byte7
Property	DC Voltage at Battery Side	Tank Current at Battery Side	DC Voltage at Bus Side	Tank Current at Bus Side
Unit	0.1 V	0.1 A	0.1 V	0.1 A
Bias	0			
Data Format	Integer			
Time Interval	3 seconds			

Table 20: Overall charge status.

Message Identifier: 0x18B0F4E5				
Data	Byte0+Byte1	Byte2+Byte3	Byte4+Byte5	Byte6+Byte7
Property	Ambient Temperature	Reserved		Reserved
Unit	0.1°C			NA
Bias	50°C			NA
Data Format	Integer			
Time Interval	30 seconds			

Table 21: Temperature and charge mode.

Message Identifier: 0x1AB3F4E5				
Data	Byte0+Byte1	Byte2+Byte3	Byte4+Byte5	Byte6+Byte7
	1			
Property	OBC status. See Table 23 for details.	Work Mode 0xFF: Invalid, default 0x0: Charge, Half bridge 0x1: Charge, Full bridge 0x2: Discharge, Half bridge 0x3: Discharge, Full bridge	Reserved 0x00FF	Reserved 0x00FF
Unit	NA			
Bias	0			
Data Format	Integer			
Time Interval	3 seconds max.			

Table 22: Charge status, AC and CLLC information.

OBC Status	Comments	OBC Status	Comments
Bit15	1: Discharging mode 0: Charging mode (default)	Bit7	1: DC OVP at Battery Side 0: Normal (default)
Bit14	1: Output shorted 0: Normal (default)	Bit6	1: Abnormal Bus Side Voltage 0: Normal (default)
Bit13	1: CLLC Tank1/Tank2 OCP 0: Normal(default)	Bit5~1	Reserved
Bit12	1: SR OFF 0: SR ON (default)		
Bit11	Reserved		
Bit10	1: OFF 0: ON (default)		
Bit8	Reserved	Bit0	1: CAN error 0: Normal (default)

Table 23: Bit definition for OBC status.

Message Identifier: 0x1AB8F4E5				
Data	Byte0+Byte1	Byte2+Byte3	Byte4+Byte5	Byte6+Byte7
Property	Com. Software Version	Min. Bus Voltage	Max. Bus Voltage	Max. Charge Current
Unit	0.01	0.1 V	0.1 V	0.1 A
Bias	0			
Data Format	Integer			
Time Interval	Reply to 0x18A8E5F4			

Table 24: Part I of OBC specification.

Message Identifier: 0x1AB9F4E5				
Data	Byte0+Byte1	Byte2+Byte3	Byte4+Byte5	Byte6+Byte7
Property	OBC Software Version	Min. Battery Voltage	Max. Battery Voltage	Max. Voltage with max. Current
Unit	0.01	0.1 V		
Bias	0			
Data Format	Integer			
Time Interval	Reply to 0x18A8E5F4			

Table 25: Part II of OBC specification.

12.3 CAN MESSAGES TO OBC

Message Identifier: 0x18A5E5F4					
Data	Byte0	Byte1	Byte2+Byte3	Byte4+Byte5	Byte6+Byte7
Property	0x0: Charge, Half bridge 0x1: Charge, Full bridge 0x2: Discharge, Half bridge 0x3: Discharge, Full bridge	0: On 1: OFF	Reserved 0xFFFF	DC Voltage	DC Current
Unit	NA			0.1 V	0.1 A
Bias	0				
Data Format	Integer				

Table 26: Control command.

13. REVISION HISTORY

Date	Revision	Changes
July, 2025	1	Initial Release

14. REFERENCE

None

15. IMPORTANT NOTES

15.1 PURPOSES AND USE

Wolfspeed, Inc. (on behalf of itself and its affiliates, “Wolfspeed”) reserves the right in its sole discretion to make corrections, enhancements, improvements, or other changes to the board or to discontinue the board.

THE BOARD DESCRIBED IS AN ENGINEERING TOOL INTENDED SOLELY FOR LABORATORY USE BY HIGHLY QUALIFIED AND EXPERIENCED ELECTRICAL ENGINEERS TO EVALUATE THE PERFORMANCE OF WOLFSPEED® POWER SWITCHING DEVICES. THE BOARD SHOULD NOT BE USED AS ALL OR PART OF A FINISHED PRODUCT. THIS BOARD IS NOT SUITABLE FOR SALE TO OR USE BY CONSUMERS AND CAN BE HIGHLY DANGEROUS IF NOT USED PROPERLY. THIS BOARD IS NOT DESIGNED OR INTENDED TO BE INCORPORATED INTO ANY OTHER PRODUCT FOR RESALE. THE USER SHOULD CAREFULLY REVIEW THE DOCUMENT TO WHICH THESE NOTIFICATIONS ARE ATTACHED AND OTHER WRITTEN USER DOCUMENTATION THAT MAY BE PROVIDED BY WOLFSPEED (TOGETHER, THE “DOCUMENTATION”) PRIOR TO USE. USE OF THIS BOARD IS AT THE USER’S SOLE RISK.

15.2 OPERATION OF BOARD

It is important to operate the board within Wolfspeed’s recommended specifications and environmental considerations as described in the Documentation. Exceeding specified ratings (such as input and output

voltage, current, power, or environmental ranges) may cause property damage. If you have questions about these ratings, please contact Wolfsp speed at forum.wolfsp speed.com prior to connecting interface electronics (including input power and intended loads). Any loads applied outside of a specified output range may result in adverse consequences, including unintended or inaccurate evaluations or possible permanent damage to the board or its interfaced electronics. Please consult the Documentation prior to connecting any load to the board. If you have any questions about load specifications for the board, please contact Wolfsp speed at forum.wolfsp speed.com for assistance.

Users should ensure that appropriate safety procedures are followed when working with the board as serious injury, including death by electrocution or serious injury by electrical shock or electrical burns can occur if you do not follow proper safety precautions. It is not necessary in proper operation for the user to touch the board while it is energized. When devices are being attached to the board for testing, the board must be disconnected from the electrical source and any bulk capacitors must be fully discharged. When the board is connected to an electrical source and for a short time thereafter until board components are fully discharged, some board components will be electrically charged and/or have temperatures greater than 50° Celsius. These components may include bulk capacitors, connectors, linear regulators, switching transistors, heatsinks, resistors and SiC diodes that can be identified using board schematic. Users should contact Wolfsp speed at forum.wolfsp speed.com for assistance if a board schematic is not included in the Documentation or if users have questions about a board's components. When operating the board, users should be aware that these components will be hot and could electrocute or electrically shock the user. As with all electronic evaluation tools, only qualified personnel knowledgeable in handling electronic performance evaluation, measurement, and diagnostic tools should use the board.

15.3 USER RESPONSIBILITY FOR SAFE HANDLING AND COMPLIANCE WITH LAWS

Users should read the Documentation and, specifically, the various hazard descriptions and warnings contained in the Documentation, prior to handling the board. The Documentation contains important safety information about voltages and temperatures.

Users assume all responsibility and liability for the proper and safe handling of the board. Users are responsible for complying with all safety laws, rules, and regulations related to the use of the board. Users are responsible for (1) establishing protections and safeguards to ensure that a user's use of the board will not result in any property damage, injury, or death, even if the board should fail to perform as described, intended, or expected, and (2) ensuring the safety of any activities to be conducted by the user or the user's employees, affiliates, contractors, representatives, agents, or designees in the use of the board. User questions regarding the safe usage of the board should be directed to Wolfsp speed at forum.wolfsp speed.com.

In addition, users are responsible for:

- Compliance with all international, national, state, and local laws, rules, and regulations that apply to the handling or use of the board by a user or the user's employees, affiliates, contractors, representatives, agents, or designees.

- Taking necessary measures, at the user's expense, to correct radio interference if operation of the board causes interference with radio communications. The board may generate, use, and/or radiate radio frequency energy, but it has not been tested for compliance within the limits of computing devices pursuant to Federal Communications Commission or Industry Canada rules, which are designed to provide protection against radio frequency interference.
- Compliance with applicable regulatory or safety compliance or certification standards that may normally be associated with other products, such as those established by EU Directive 2011/65/EU of the European Parliament and of the Council on 8 June 2011 about the Restriction of Use of Hazardous Substances (or the RoHS 2 Directive) and EU Directive 2002/96/EC on Waste Electrical and Electronic Equipment (or WEEE). The board is not a finished product and therefore may not meet such standards. Users are also responsible for properly disposing of a board's components and materials.

15.4 NO WARRANTY

THE BOARD IS PROVIDED "AS IS" WITHOUT WARRANTY OF ANY KIND, INCLUDING BUT NOT LIMITED TO ANY WARRANTY OF NON-INFRINGEMENT, MERCHANTABILITY, OR FITNESS FOR A PARTICULAR PURPOSE, WHETHER EXPRESS OR IMPLIED. THERE IS NO REPRESENTATION THAT OPERATION OF THIS BOARD WILL BE UNINTERRUPTED OR ERROR-FREE.

15.5 LIMITATION OF LIABILITY

IN NO EVENT SHALL WOLFSPEED BE LIABLE FOR ANY DAMAGES OF ANY KIND ARISING FROM USE OF THE BOARD. WOLFSPEED'S AGGREGATE LIABILITY IN DAMAGES OR OTHERWISE SHALL IN NO EVENT EXCEED THE AMOUNT, IF ANY, RECEIVED BY WOLFSPEED IN EXCHANGE FOR THE BOARD. IN NO EVENT SHALL WOLFSPEED BE LIABLE FOR INCIDENTAL, CONSEQUENTIAL, OR SPECIAL LOSS OR DAMAGES OF ANY KIND, HOWEVER CAUSED, OR ANY PUNITIVE, EXEMPLARY, OR OTHER DAMAGES. NO ACTION, REGARDLESS OF FORM, ARISING OUT OF OR IN ANY WAY CONNECTED WITH ANY BOARD FURNISHED BY WOLFSPEED MAY BE BROUGHT AGAINST WOLFSPEED MORE THAN ONE (1) YEAR AFTER THE CAUSE OF ACTION ACCRUED.

15.6 INDEMNIFICATION

The board is not a standard consumer or commercial product. As a result, any indemnification obligations imposed upon Wolfspeed by contract with respect to product safety, product liability, or intellectual property infringement do not apply to the board.