

CRD-22DD12N

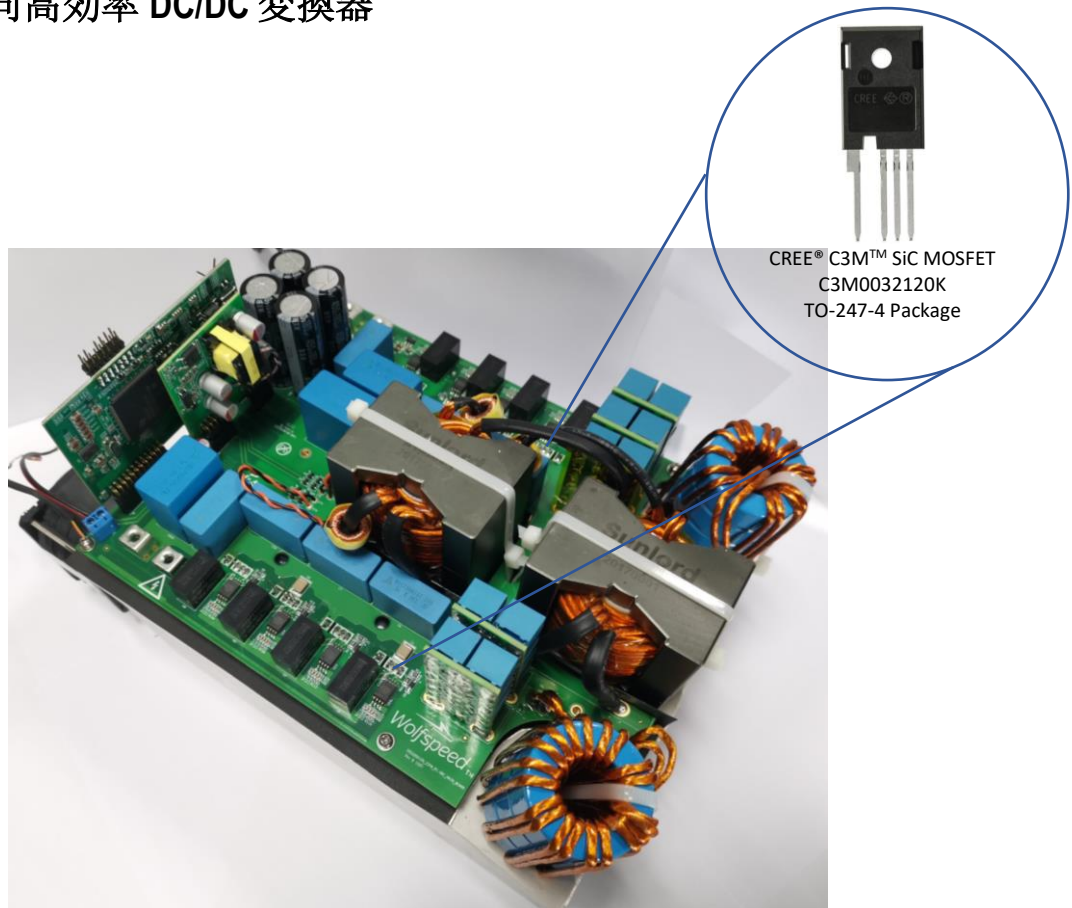
22kW Bi-directional High Efficiency DC/DC Converter

CRD-22DD12N

22kW 双向高效直流—直流变换器

CRD-22DD12N

22kW 双方向高效率 DC/DC 变换器



User Guide

PRD-01218, Rev A

Cree Power Applications

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CAUTION

PLEASE CAREFULLY REVIEW THE FOLLOWING PAGES, AS THEY CONTAIN 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隐患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むので、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° CELSIUS. 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，在操作板子前应使大容量电容器的电荷完全释放。接通电源后，该评估板上通常会存在危险的高电压，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，上述情况可能会短时持续，直至大容量电容器电量完全释放。

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。通电时禁止接触板子。所有测试与测量探针或附件必须在板子通电前连接。通电时，禁止使板子处于无人看护状态，且禁止操作板子。必须确保在操作板子前，大容量电容器已释放了所有电量。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's Guide provides the schematic, artwork, and test setup necessary to evaluate Cree's CRD-22DD12N, 22KW Bi-Directional DC/DC converter for an electric vehicle (EV) On-board charger (OBC) and similar applications.

The design of Cree's 22KW, Bi-Directional DC/DC converter (P/N CRD-22DD12N) is based upon one of Cree's latest generation of SiC MOSFETs - C3M0032120K (1200V, 32mΩ, TO-247-4). The converter is the DC/DC stage of a bi-directional OBC converter. Referring to 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 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 switch arrangement isolated by two high frequency transformers. The converter operates in a 135-250kHz switching frequency range. A tooled heatsink was designed to simulate the cooling plate in an OBC application. It dissipates the heat generated by all the power MOSFETs. The power density is up to 8kW/L. A block diagram is shown in Figure 1.

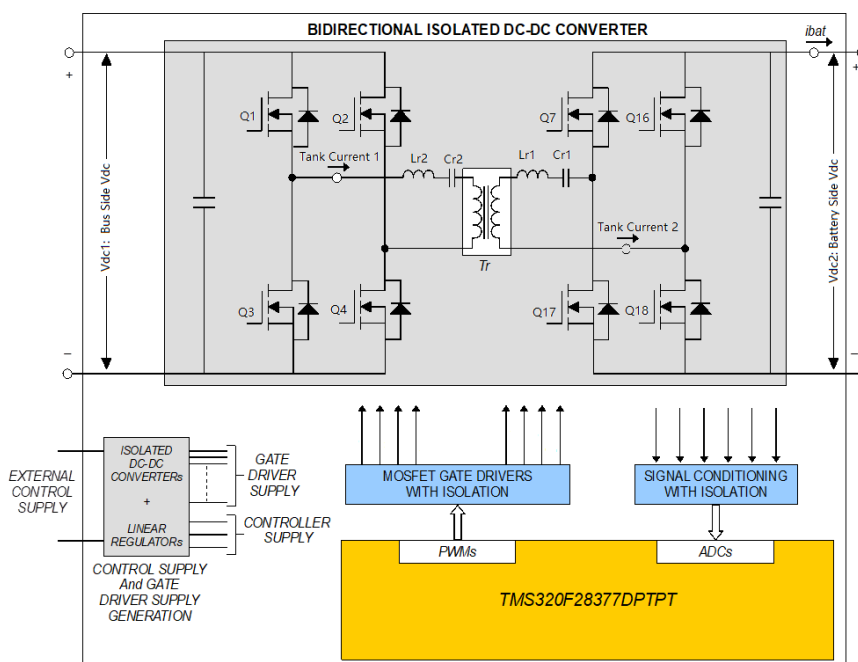


Figure 1. Block Diagram of Cree's CRD-22DD12N, 22KW Bi-Directional High Efficiency DC/DC

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

the reconfiguration of half-bridge and full-bridge operation without any additional power component, makes it possible to realize wide output voltage range between 200Vdc and 800Vdc with high efficiency and high density. The same technique is applied to discharging mode and thus the bus voltage can be designed between 360V and 750V to support single phase output with high efficiency. A 480Vdc-800Vdc is the typical OBC output range for high voltage battery. The operation at an output range of 200Vdc-480Vdc will result in lower efficiency, but it demonstrates the effectiveness of a proposed control method. The peak efficiency of the DC/DC CLLC resonant can be above 98.5% in both charging and discharging modes.

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

2. Description

This reference design board uses Cree's C3M0032120K, 1200V, 32mΩ, SiC MOSFETs (TO-247-4) in both primary-side and battery-side full bridges. A single SiC MOSFET is used for each position.

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 1200V SiC MOSFETs enable high efficiency operation for wide output range in both directions. When the required voltage gain is lower, it is out of the high efficiency range of the hybrid control (variable frequency and phase shift) in both charging and discharging mode at full bridge configuration, the primary-side full bridge will be reconfigured as a half bridge. 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 as 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 is regulated by the PFC stage according to the battery side voltage. However, with a controlled PFC output, the output voltage at battery side is regulated to maintain the same relation curve as shown in Figure 2a and 2b. This is to simulate the real conditions in the application. The equation is " $V_{dc2} = (V_{dc1} - 30\text{Volts}) * 19/24$ " for full bridge and " $V_{dc2} = (V_{dc1} - 44\text{Volts}) * 19/24/2$ " for half bridge. The start-up voltage is calculated by using the same equations. The output

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

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

Table 1: Overall Charging Operation

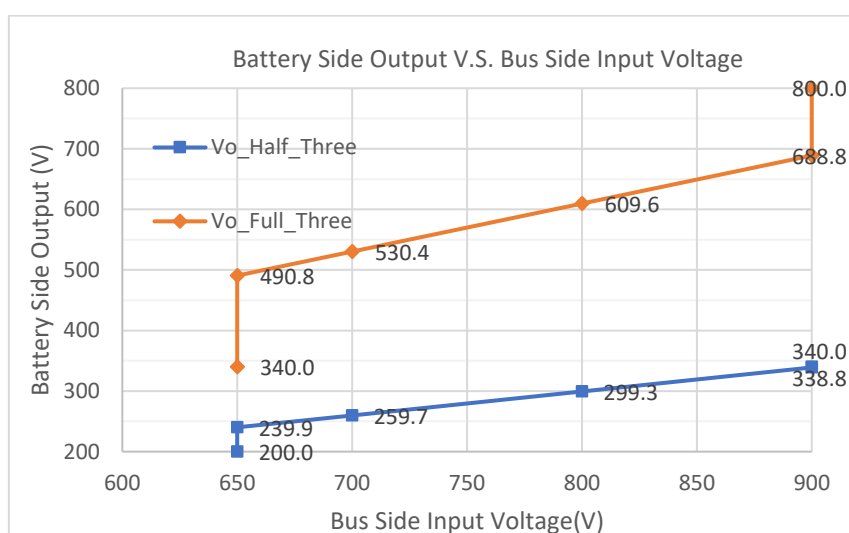


Figure 2a. Battery Voltage V.S. Bus Voltage in Charging Mode for Three-Phase Application

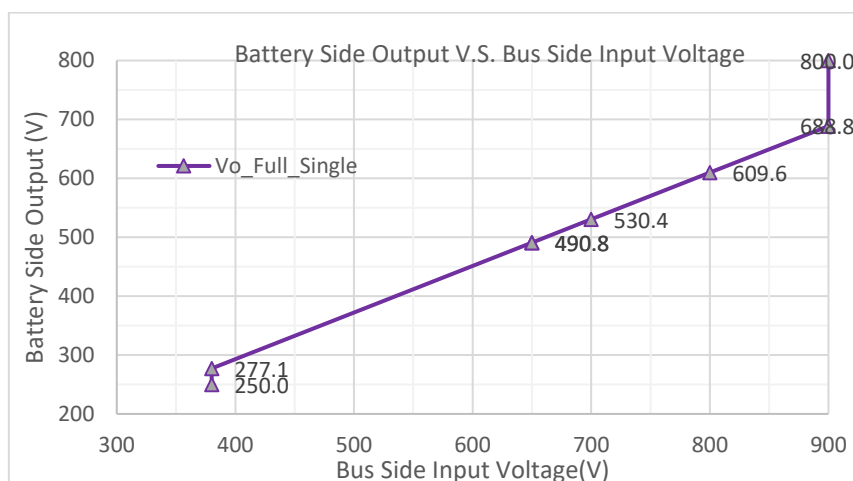


Figure 2b. Battery Voltage V.S. Bus Voltage in Charging Mode for Single-Phase Application

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 CLLC stage and DC/AC stages. The equation is “ $V_{dc1}=V_{dc2}*24/19-10\text{Volts}$ ” for full bridge and “ $V_{dc1}=V_{dc2}*24/19/2-10\text{Volts}$ ” for half bridge. The start-up voltage is also calculated using the same equations.

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

Table 2: Overall Discharging Operation

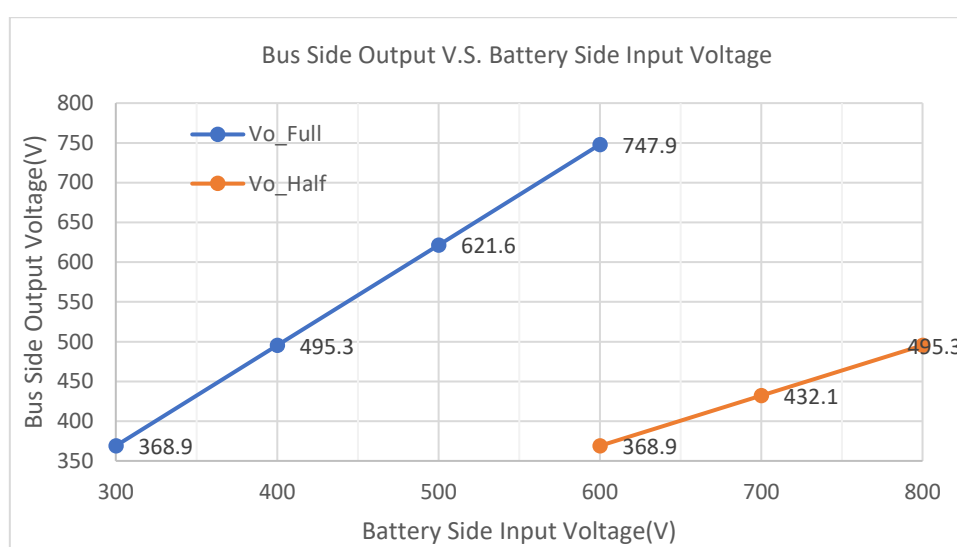


Figure 3: Bus Voltage V.S. Battery Voltage in Discharging Mode

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 to 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 380Vdc, 650Vdc and 900Vdc 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} = 650Vdc~900Vdc Full / Half Bridge	200*1	611	800	V
P _{OUT1 max}	Output power				22000	W
I _{OUT1}	Output current				36	A
V _{OUT2}	Output voltage	V _{in} = 380Vdc~900Vdc Full Bridge	250		800	V
P _{OUT2 max}	Output power				6600	W
I _{OUT2}	Output current				26.4	A
V _{ripple}	Output voltage ripple				±2%	
System Characteristics*2						
η _{peak}	Peak efficiency	V _{in} = 800V, V _{OUT} = 610V, I _{OUT} = 11A Full Bridge	98.3%	98.5%		
η _{full load}	Full load efficiency	V _{in} = 900V, V _{OUT} = 800V, I _{OUT} = 20A Full Bridge	98.0%	98.2%		
		V _{in} = 800V, V _{OUT} = 610V, I _{OUT} = 32A Full Bridge	97.8%	98.0%		
		V _{in} = 650V, V _{OUT} = 480V, I _{OUT} = 32A Full Bridge	97.3%	97.5%		
		V _{in} = 650V, V _{OUT} = 240V, I _{OUT} = 30A Half Bridge	95.2%	95.4%		

Table 3: Characteristics of Cree's CRD-22DD12N, 22 kW Bi-Directional DC/DC in Charging Modes

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

*2: Maximum load current is about 32A for the efficiency test due to the limitation of the power analyzer.

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} = 600Vdc~800Vdc Half Bridge V _{in} = 300Vdc~600Vdc Full Bridge			6600	W
I _{OUT}	output current				19	A
V _{ripple}	Output voltage ripple				±2%	
System Characteristics						
η _{peak}	Peak efficiency	V _{in} = 480V, V _{OUT} = 600V, P _O = 6.6KW Full Bridge	98.2%	98.4%		
η _{full load}	Full load efficiency (P _O = 6.6KW)	V _{in} = 300V, V _{OUT} = 366V Full Bridge	97.0%	97.2%		
		V _{in} = 600V, V _{OUT} = 755V Full Bridge	98.2%	98.4%		

		$V_{IN} = 600V, V_{OUT} = 365V$ Half Bridge	96.8%	97.0%		
		$V_{IN} = 800V, V_{OUT} = 495V$ Half Bridge	97.6%	97.8%		

Table 4: Characteristics of Cree's CRD-22DD12N, 22 kW Bi-Directional DC/DC in Discharging Mode

3.1 Applications

The primary application for Cree's CRD-22DD12N reference design board is isolated Bi-Directional EV charging systems, but the output must be connected to a resistive load or electronic load (CR (Constant Resistor) mode recommended). A battery test 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 Cree's CRD-22DD12N reference design board are listed below:

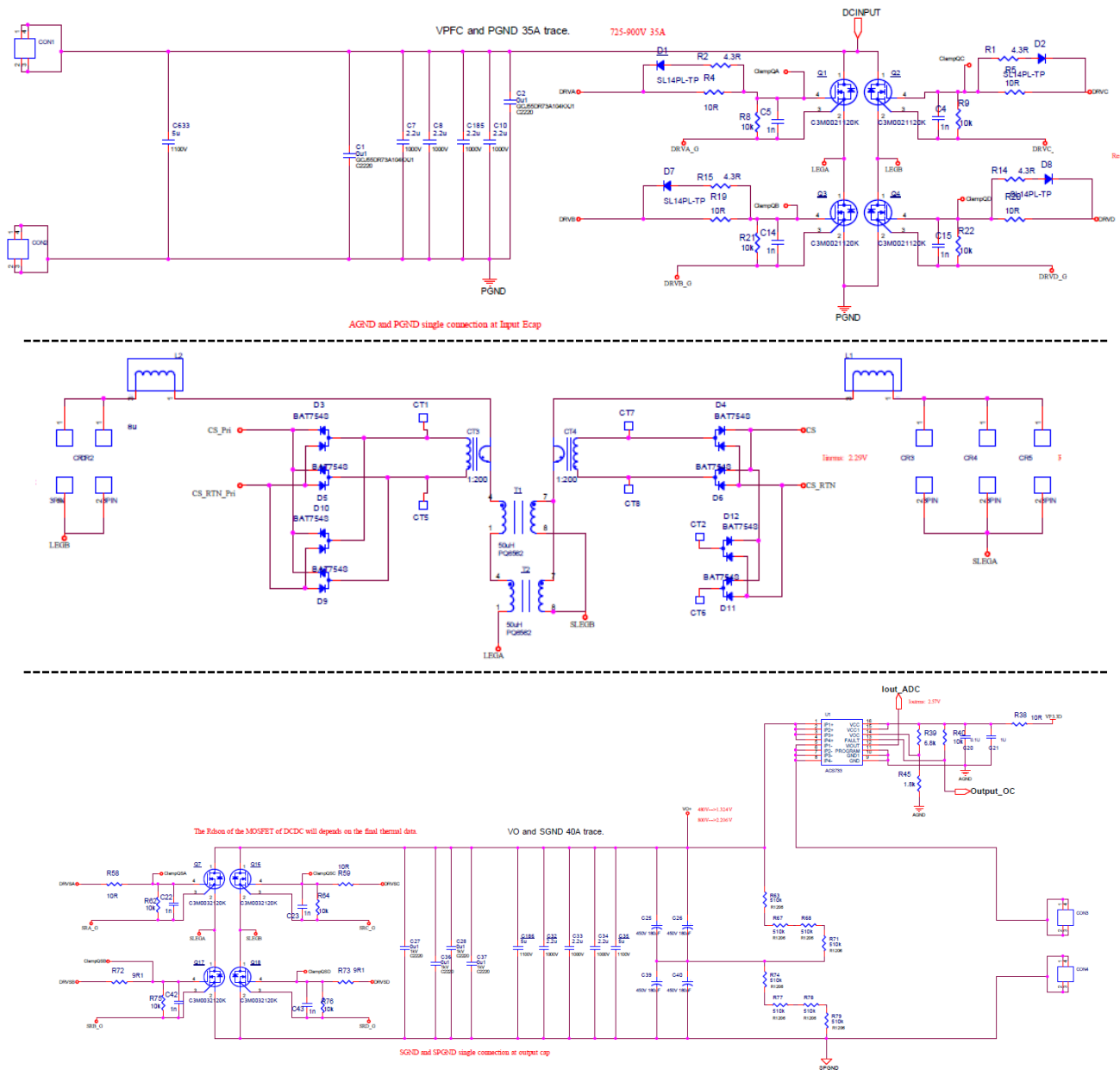
- Wide voltage range. 380Vdc-900Vdc voltage range for bus side terminals and 200Vdc-800Vdc voltage range for battery side terminals.
- Bidirectional operation with flexible control. However, please operate the evaluation board within the safe operation area as described in Section 2.
- Maximum output current is limited to 36A and maximum output power is limited to 22kW at the input voltage range of 650Vdc-900Vdc in charging mode. Note: output power is linearly derating from 22kW to 16kW when the output voltage is between 770Vdc and 800Vdc under 900V input.
- Maximum output power is 6.6kW at the input voltage range of 380Vdc-650Vdc in charging mode. Without AC input info, the controller cannot identify the operation mode, so the 6.6kW power limit function is not accurate in this input range.
- Maximum output power is 6.6kW in discharging mode.
- Peak efficiency > 98.5% 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 5A, and it is disabled when the load current is lower than 2.5A.
- Easy to test using a GUI communicating via CAN. See Section 5 and Section 12 for details.

4. Schematics of Power Board and Control 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 Cree at sic_power@cree.com.

Schematics of the power, control, and auxiliary-power boards are shown in Figures 4 through 7.

Power Board Schematic:



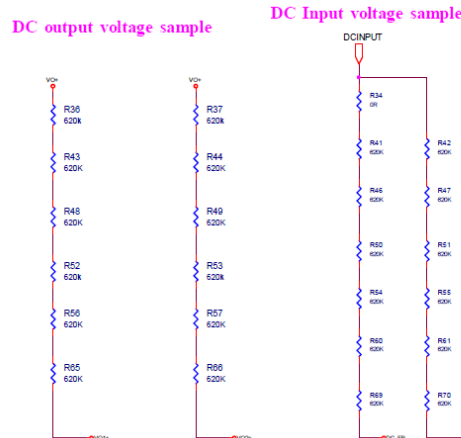


Figure 4a. Schematic of Power Board: DC/DC Main Power

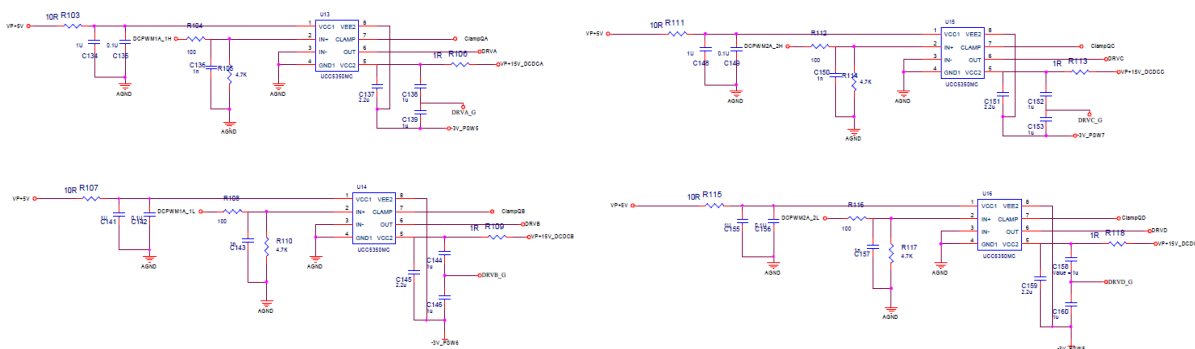


Figure 4b. Schematic of Power Board: DC/DC Bus-Side Gate Drives

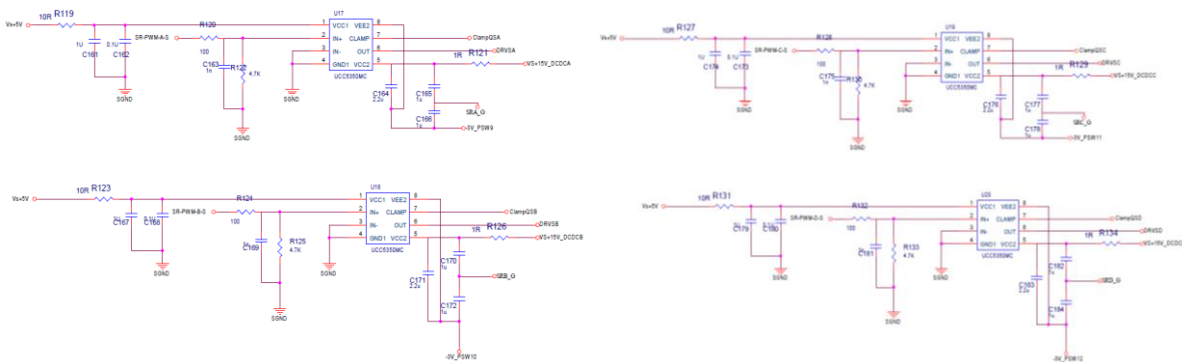
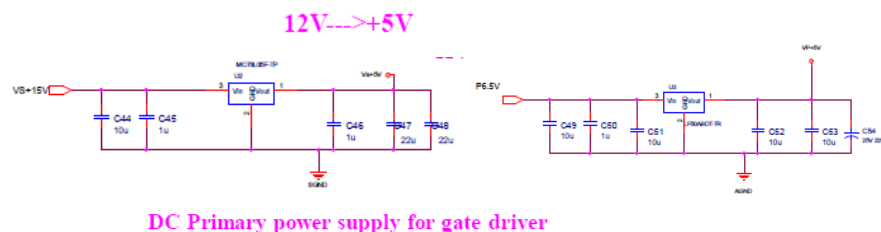


Figure 4c. Schematic of Power Board: DC/DC Battery-Side Gate Drives



DC Primary power supply for gate driver

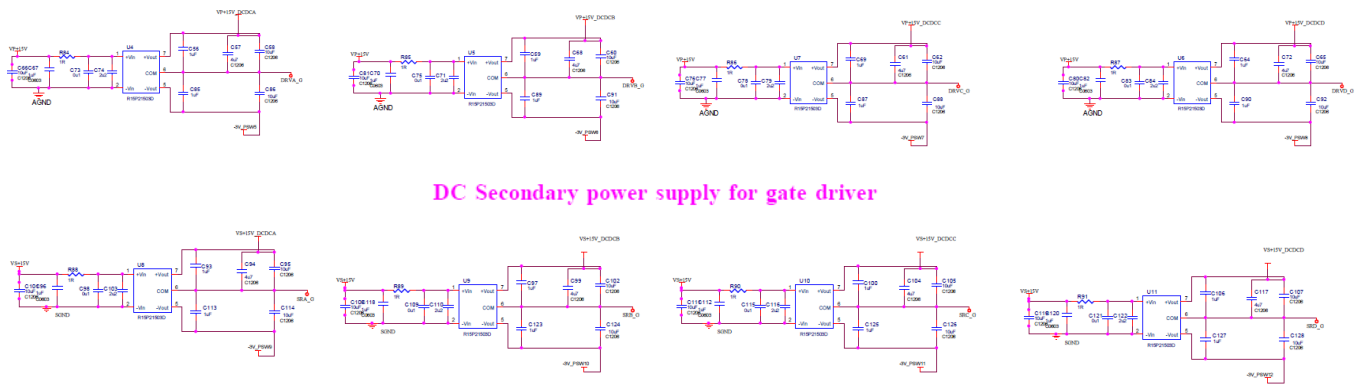


Figure 4d. Schematic of Power Board: Power Supply

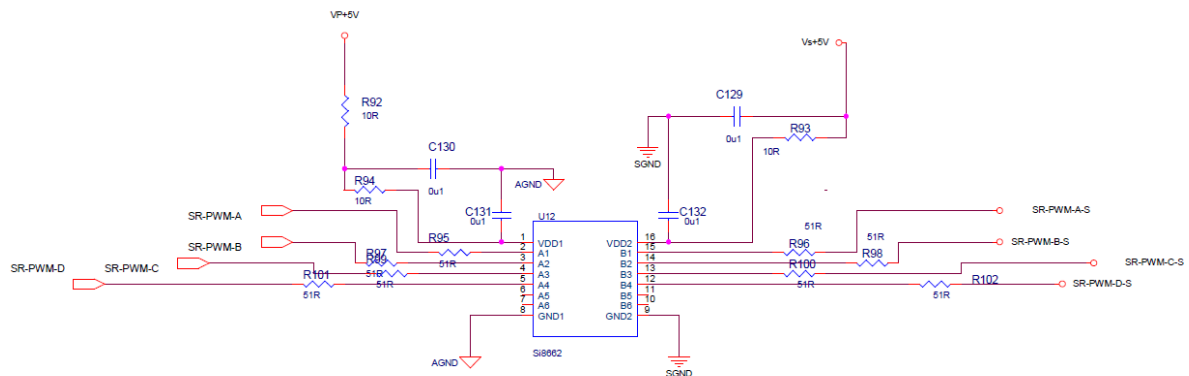


Figure 4e. Schematic of Power Board: Signal Isolation

Control Board Schematic:

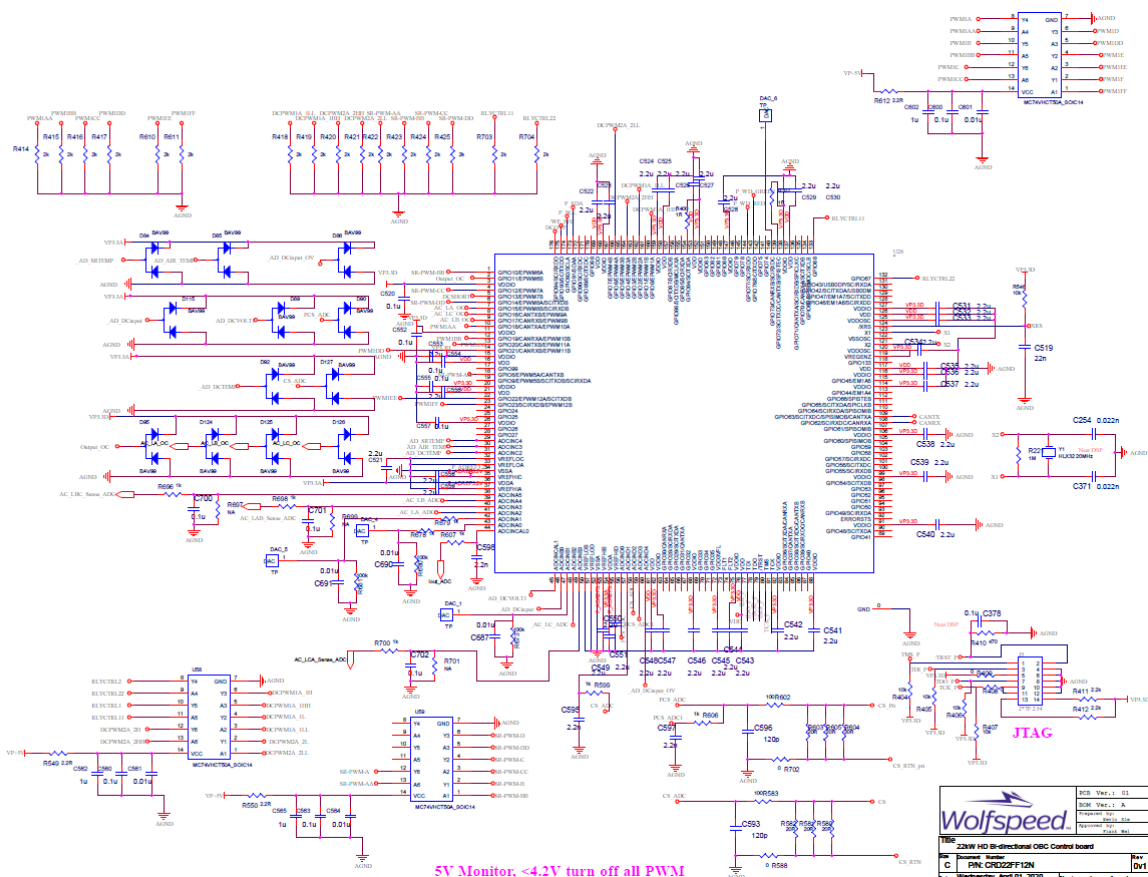


Figure 5a. Schematic of Control Board: Controller

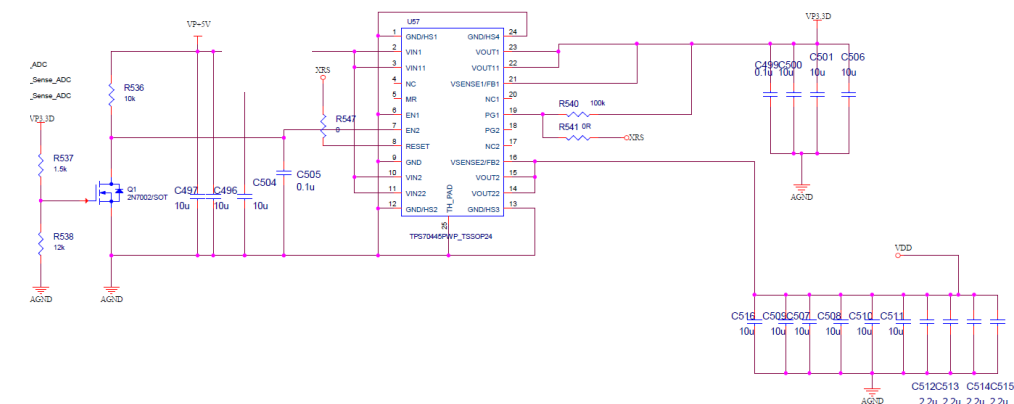
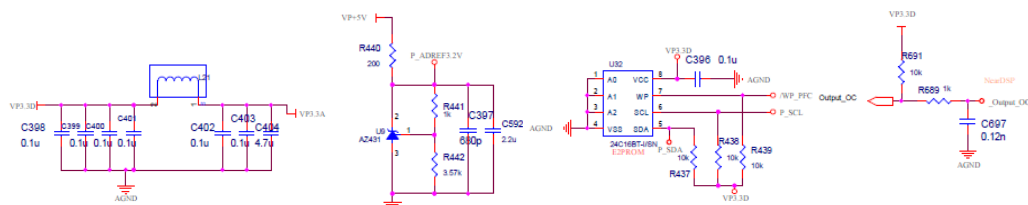


Figure 5b. Schematic of Control Board: Controller Power Supply



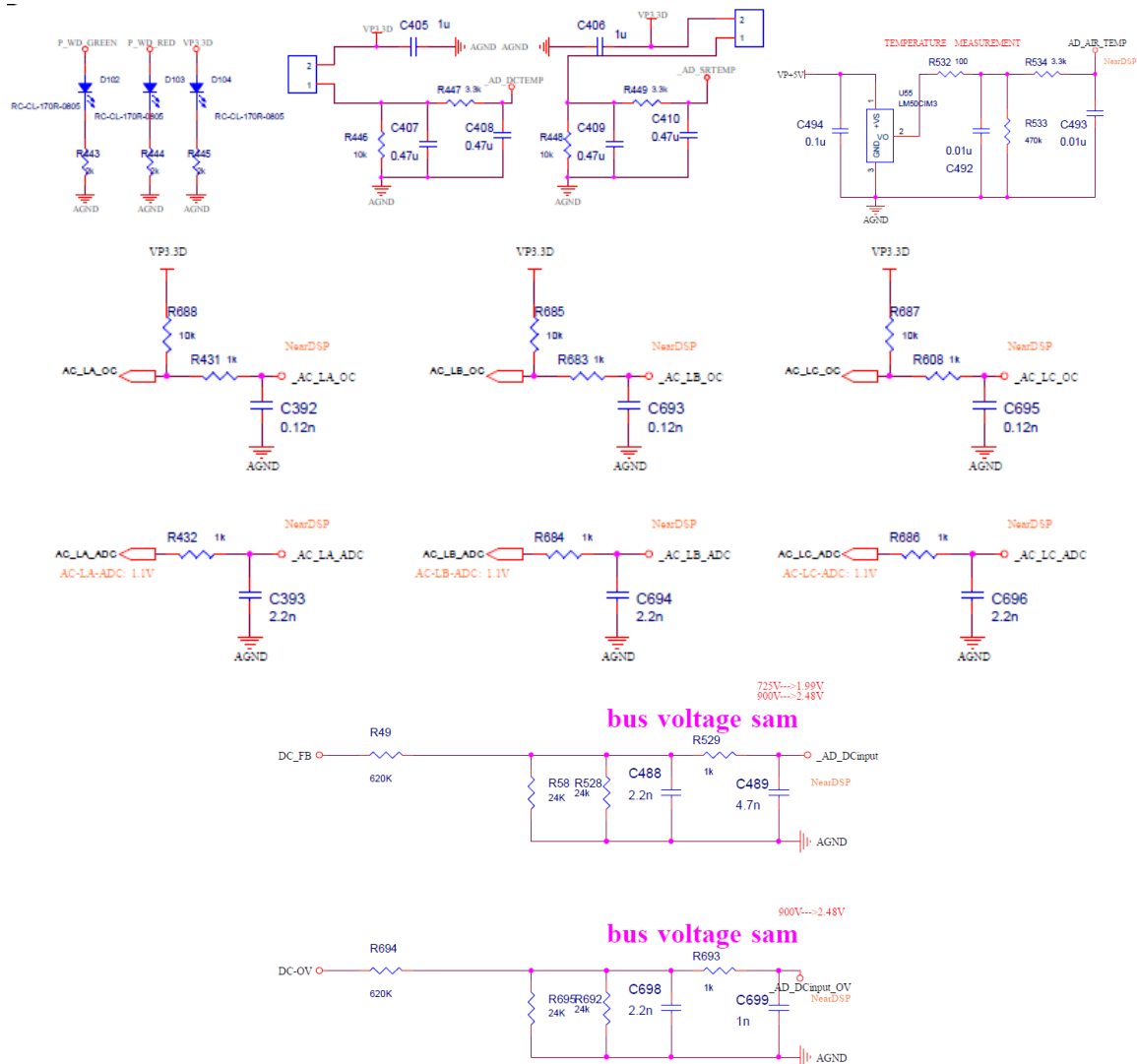
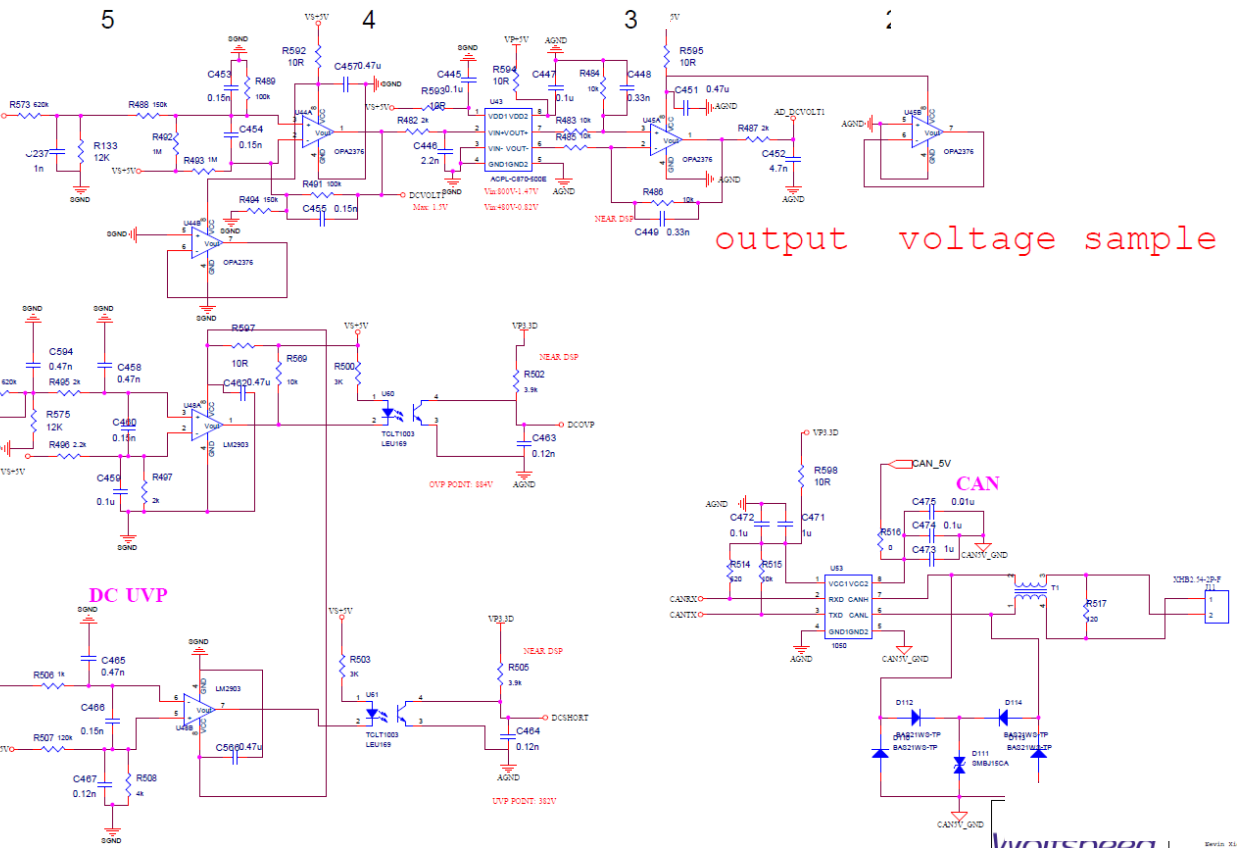
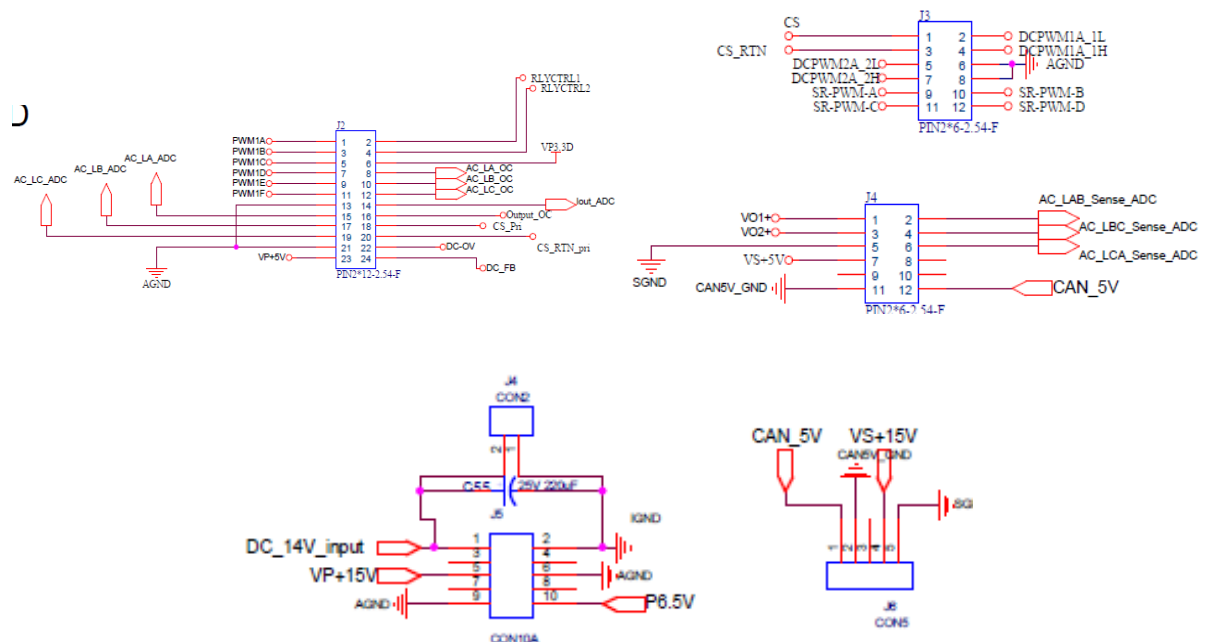


Figure 5c. Schematic of Control Board: Bus Voltage Sample



Connections of Control and Auxiliary Power Board to Main Board:



5. Hardware Description of Power Board and Control Board

Description of Power Board:

As illustrated by Figure 4a, a full bridge CLLC topology is selected for the converter. The bus side DC terminals are CON1(+) and CON2(-) followed by five film capacitors which absorb the high frequency ripple on the DC port. The battery side DC terminals are CON3(+) and CON4(-). The H-bridge at DC bus side is composed of SiC MOSFETs Q1, Q3, Q2 and Q4. The battery side H-bridge is composed of SiC MOSFETs Q7, Q17, Q16 and Q18 followed by five film capacitors and four electrolytic capacitors. 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 in series for the bus side and in parallel for the battery side. The final turns ratio is 24:19. One current transformer is used to sense tank current at bus side. Two current transformers, one for each main transformer that are paralleled after bridge diodes, are used to sense battery side tank current.

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

	Resonant Inductor	Resonant Capacitor
Bus Side Tank	12.8uH	$6.8\text{nF}/2 \times 8 \times 2 = 54.4\text{nF}$
Battery Side Tank	9.9uH	$6.8\text{nF}/2 \times 7 \times 3 = 71.4\text{nF}$

Table 5: Key Parameters of Resonant Tanks

As illustrated by Figures 4b to 4d, all Texas Instruments, Inc. gate drivers (P/N: UCC5350MCQDQ1) are separately powered by isolated, DC/DC power supplies with $V_{IN} = +15\text{V}$ and $V_{OUT} = +15\text{V}/-3\text{V}$ from RECOM Power GmbH.(P/N: R15P21503D). Gate drives at battery side are isolated from the control board by digital isolator U12 from Analog Devices, Inc. (P/N: ADUM262N0BRIZ) as illustrated by Figure 4e.

Description of Control Board:

As illustrated by Figure 5a and 5d, 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, 7V@1A, power supply whose output is then tightly regulated to +5.0V by a linear regulator. This 5.0V voltage rail then supplies another precision linear regulator IC, U57, from Texas Instruments Inc. (P/N: TPS70445), which provides both a 3.3V and a 1.2V voltage rail. All output drive signals are buffered and shifted to a +5V 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 3.3V. This reference is created by a reference IC U9, (P/N: AZ431-2.5V) from the +5.0V rail.

The reference ground of control board is the negative terminal of bus side port. The voltage sample signal and OVP/UV (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.

Description of Auxiliary Power Board:

The typical input voltage of the auxiliary power board is 14 V (J6, net "Aux_DC+" and net "ISGND" in Figure 7). It provides four isolated output voltages, as shown in Table 6.

Input/Outputs	Net Name	comments
Input	14V	14V Typical Input of the Auxiliary Power Board
Output 1	P_15V	15V Power Supply for MOSFET Gate Drivers
Output 2	S_15V	15V Power Supply for MOSFET Gate Drivers
Output 3	5V	5V Output for CAN Communication
Output 4	D_6.5V	Controller Power Supply

Table 6: Input and Outputs of Auxiliary Power Board

5.1 Hardware

DC Input Source: The input source must be an adjustable DC source whose output can be adjusted between 300Vdc and 900Vdc. It must be capable of supplying at least 25000W.

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

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

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

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

- 1) 14V @ 1.5A capability is required to supply the auxiliary power board.
- 2) 12VDC @ 12A 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 8, at least two cooling fans, such as the Delta Electronics Inc. DC12V/3.30A fan (P/N: PFR0612XHE-CV52) or an equivalent must be used for cooling the baseplate. Another two fans are used for the magnetics. They can be placed to let the air flow go to the two resonant inductors and the transformers. The red wire of the fan is the positive terminal and the black wire is the negative terminal. The temperature of the magnetics should be monitored by an infrared scanner to verify the cooling fan setup during first-time testing.

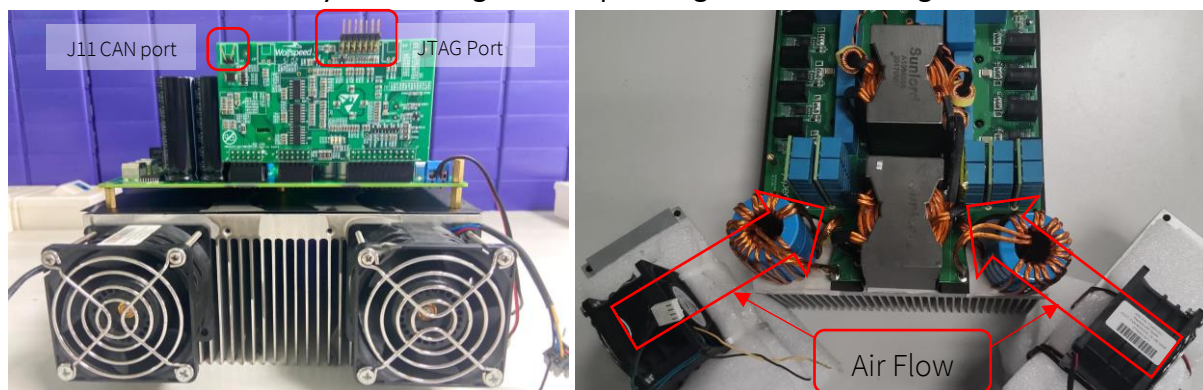


Figure 8. Setup of the Reference Design

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 8. 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 9. “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 9c, 9e, and 9f. 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.

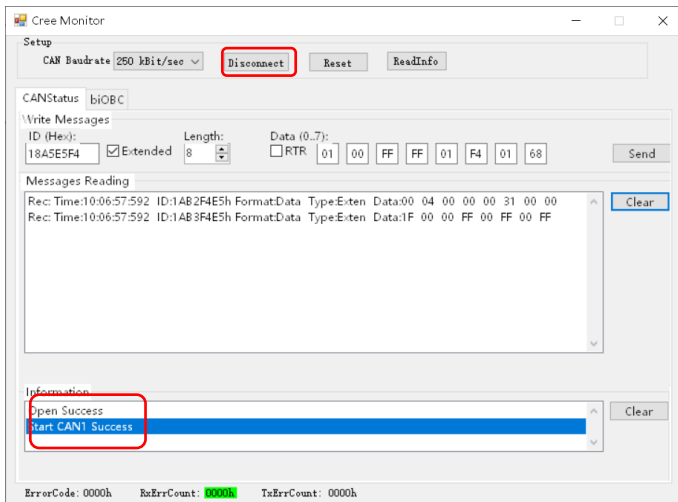


Figure 9a. CAN Status Tab after Connection

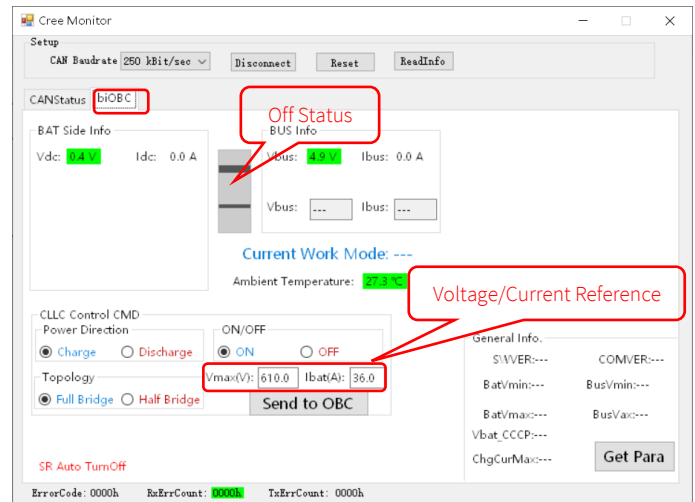


Figure 9b. Connected to Control Board <Off Mode>

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 display in the left bottom area.

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

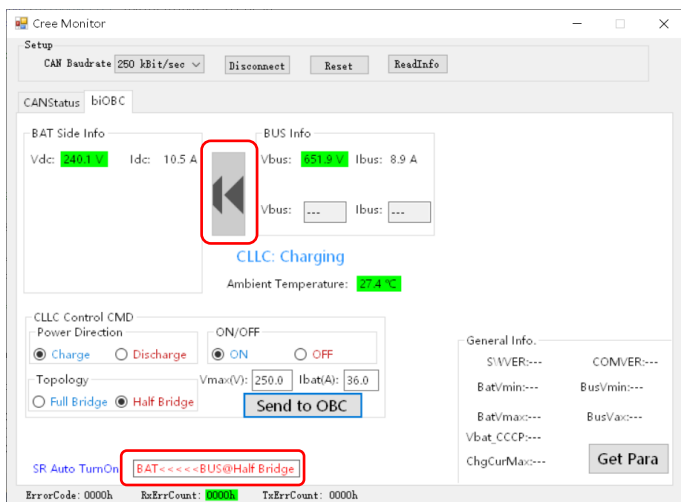


Figure 9c. Charging Operation in Half Bridge

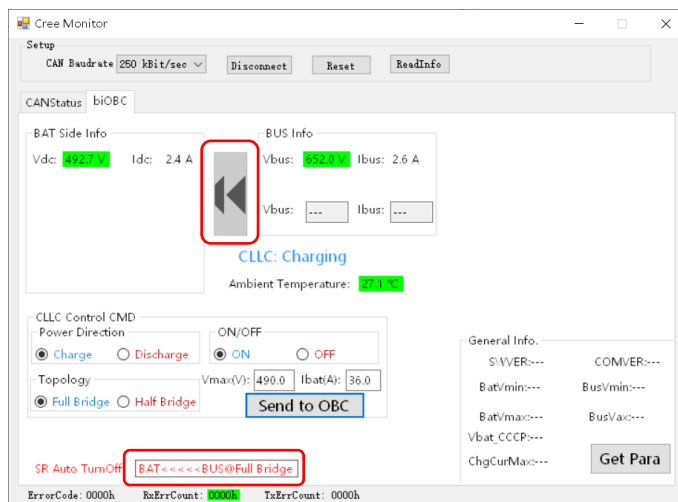


Figure 9d. Charging Operation in Full Bridge

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

In discharging mode, these reference values have no impact all the time.

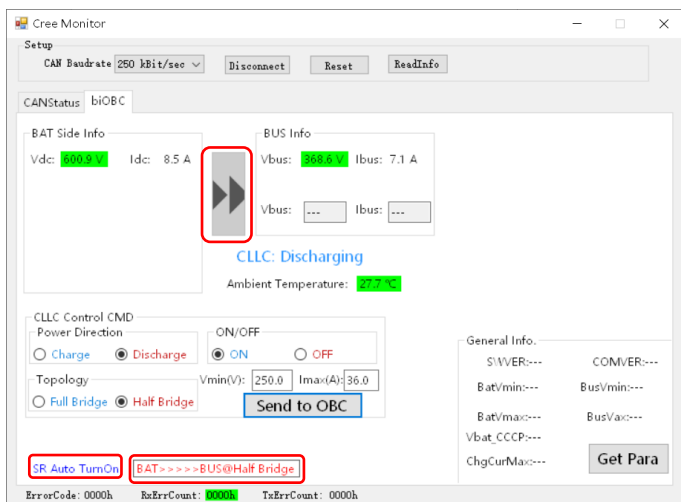


Figure 9e. Discharging Operation in Half Bridge

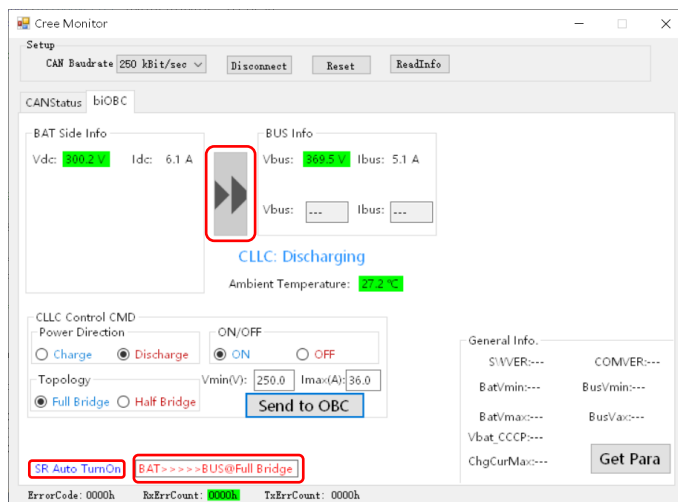


Figure 9f. Discharging Operation in Full Bridge

5.3 CAN Communication Data Format

The reference design communicates over a CAN V2.0B bus at 250K 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 480V and it will supply its maximum rated current 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*0.1V = 480V	DC Current: 0x0168*0.1A = 36A

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

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

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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。

6.1 Recommended Test Setup

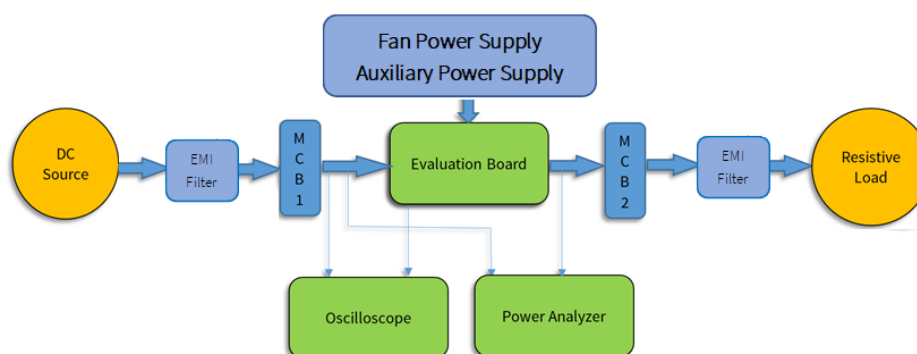


Figure 10. Converter Test Setup

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 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 damage.

Power Signal	Protection	Trip Point for Battery Side	Trip Point for Bus Side
DC Voltage	OVP/UVP	>950V, <370V	>880V, <195V
Short Protection	short	---	<60V
CLLC Tank Current	OCP	40A	40A
Start-up Voltage		>350V	>280V
Output Power Limitation		22kW±1.5kW	---
Output Current Limitation		30A±1.5A@<240V, 36A±1.5A others	---

Table 8: Protection Details

6.3 Isolated Power Supplies – Voltage and Current Settings

The requirements for the isolated power supplies are shown in Table 9. A single power supply connected to J6 is used to power the on-board auxiliary power board.

Control Board Connector Designator	Power Supply	Voltage (V)	Current 1 (A) (PWM Off)	Current 2 (A) (Full Bridge Normal Operation)	Current 3 (A) (Half Bridge Normal Operation)
J6	+14V for AUX power	+14V +/-5%	0.45	0.57	0.61

Table 9: Auxiliary Power Supply Requirements

6.4 Measured Parameters

All power MOSFET pins are exposed. Their 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 all bulk capacitors have been 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 sides
Vgs /Vds Signals	voltage across gate to source or drain to source of SiC MOSFETs
Auxiliary Power Board Outputs	Please refer to Figure 6 and Table 3 for details
3.3V /1.2V Controller Supply	+3.3V supply for Controller's I/O; +1.2V 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

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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 start-up.
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 340-800Vdc and as half bridge topology for 200-340Vdc when the input DC voltage is above 650V.
 - b. In discharging mode, the converter should operate as full bridge topology when the battery side input voltage is in the range of 300-600Vdc and as half bridge topology for 600-800Vdc.
4. Please 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 with Resistive Load

1. Double check the setup: Make sure the polarity is right, the DC 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 1KW and then close MCB2.
4. Apply 14Vdc to J6 on the power board. Check the output voltage of the Auxiliary Power Supply at J7 (P6.5V, VP+15V) and J8 (VS+15V, CAN_5V). Check that the current draw is approximately the same as shown in Table 9. Check the +3.3V 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 (300Vdc – 800Vdc).
8. Verify that the measured values in the GUI were 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 start-up. Start-up voltage is calculated according to Figure 3.
10. After the output voltage has reached steady-state regulation, increase the load up to

desired value within 6.6kW. The step-load change should not be larger than 1KW for each step.

11. Check the efficiency under load conditions of interest. Check if SR is turned on automatically when DC input current is above 5A. SR should be enabled by increasing load to >5A. The load may be decreased to a lighter target load.

7.2 Turnoff Procedure: Discharging Mode with Resistive Load


1. Decrease the load to 1KW in less than 1KW steps.
2. Use GUI to send OFF command.
3. Disable the output of the DC power supply.
4. Open MCB1 after the DC source has fully discharged its output.
5. Turn OFF load and MCB2 after the bus 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 is skipped. They must be allowed to fully discharge before handling the board. Please check both the terminal voltages with a multimeter to ensure that the board has fully discharged and is therefore safe to handle.**
7. Turn OFF the 14Vdc power supply on J6. 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 right, 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 1KW to the DC terminals and then close MCB2.
4. Apply 14Vdc to J6 on the power board. Check the output voltage of the Auxiliary Power Supply at J7 (P6.5V, VP+15V) and J8 (VS+15V, CAN_5V). Check that the current draw is approximately the same as shown in Table 9. Check the +3.3V 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 (380Vdc – 900Vdc).
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 36A 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 380V, 650V and 900V. Otherwise, the output voltage is calculated according to Figure 2.
11. After the output voltage has reached steady-state regulation, apply a load to the output in no more than 2KW 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 5A. SR should be enabled by increasing load to >5A. The load may be decreased to a lighter target load.

7.4 Turnoff Procedure : Charging Mode

1. Decrease the load to 1KW. The step of load change should be less than 2KW 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 is skipped. They must be allowed to fully discharge before handling the board. Please check both the terminal voltages with a multimeter to ensure that the board has fully discharged and is therefore safe to handle.**
7. Turn OFF the 14Vdc power supply on J6.

8. Photos of the Reference Design

Figure 11 shows the locations of the terminals, key components and daughter-boards on the Power Board.

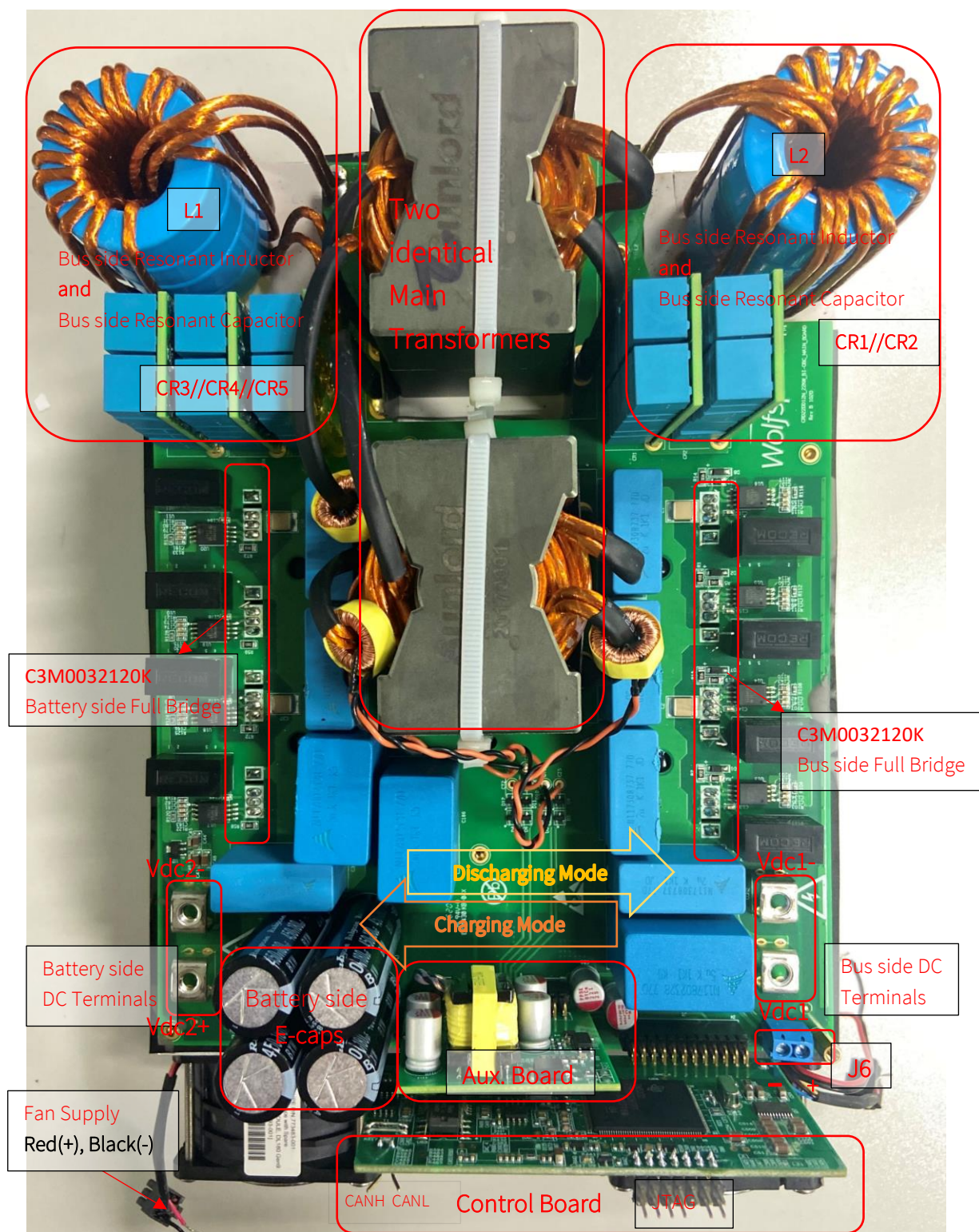


Figure 11. Top View of PCBA (250mm*190mm*55mm)

9. Performance Data

The performance data of Cree's CRD-22DD12N reference design board is taken in both DC/DC Charging and DC/DC Discharging modes. Table 11 to Table 14 indicates the performance data.

Input Voltage (Vac)	Input Power (W)	Load (%)	Output Voltage (Vdc)	Output Power (W)	Overall Efficiency (%)
650	905.9	10	240	871.5	96.204
650	1783	20	240	1734.3	97.269
650	2666.3	30	240	2597.1	97.405
650	3555.8	40	240	3458.4	97.261
650	4451.3	50	240	4319.2	97.032
650	5356.4	60	240	5179	96.688
650	6277.6	70	240	6046.9	96.325
650	7197.9	80	240	6905.8	95.942
650	8130.5	90	240	7766.7	95.525
650	1323.3	10	340	1245.2	94.097
650	2585.5	20	340	2471.1	95.577
650	3841.1	30	340	3665.1	95.417
650	5085.3	40	340	4863.5	95.638
650	6364	50	340	6109.7	96.005
650	7668.7	60	340	7385.8	96.31
650	8957.6	70	340	8622.6	96.26
650	10218.3	80	340	9803.5	95.941
650	11518.8	90	340	11012.4	95.604
650	1517	10	400	1440.4	94.952
650	2951.2	20	400	2847.5	96.487
650	4441.1	30	400	4291.1	96.623
650	5887.5	40	400	5707.7	96.946
650	7383.9	50	400	7199.6	97.504
650	8827	60	400	8592.9	97.349
650	10365.3	70	400	10067.5	97.127
650	11780.6	80	400	11415.2	96.898
650	13344.1	90	400	12901.1	96.68
650	1793.2	10	480	1735.2	96.766
650	3501.6	20	480	3421.9	97.725
650	5202.5	30	480	5120.5	98.423
650	6916.7	40	480	6806.9	98.413

650	8767.1	50	480	8620.3	98.326
650	10506.4	60	480	10317.8	98.205
650	12352.2	70	480	12111	98.047
650	14085.6	80	480	13785.4	97.869
650	15875.8	90	480	15506.9	97.677

Table 11: Efficiency Data (DC/DC mode), VIN = 650VDC

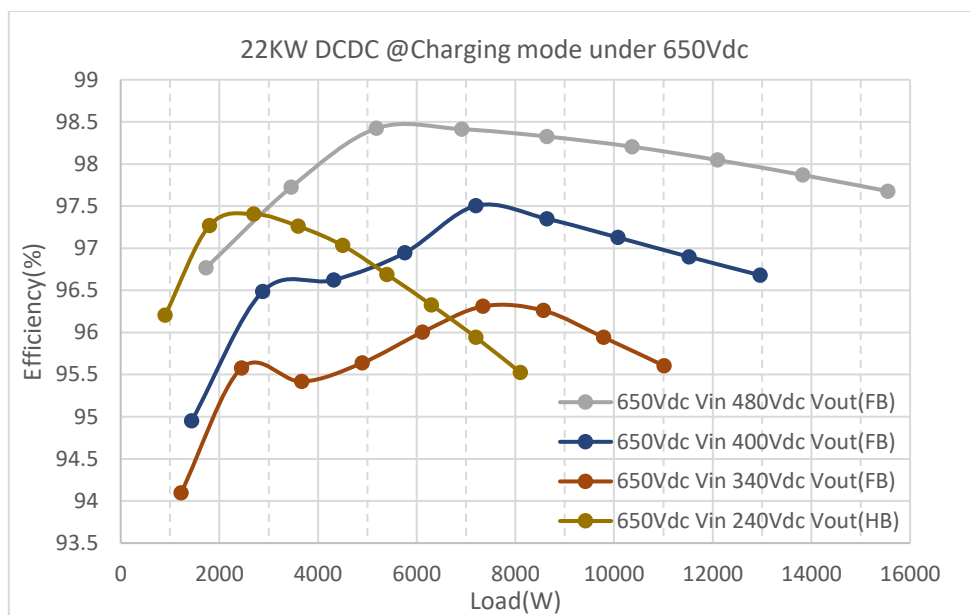


Figure 12: Efficiency Data (DC/DC Charging mode), VIN = 650 VDC

Input Voltage (Vac)	Input Power (W)	Load (%)	Output Voltage (Vdc)	Output Power (W)	Overall Efficiency (%)
900	1231.1	10	340	1186.6	96.387
900	2483.3	20	340	2416.8	97.324
900	3749.3	30	340	3662	97.673
900	5040.3	40	340	4920.8	97.629
900	6239.4	50	340	6085.7	97.537
900	7532.1	60	340	7332.2	97.347
900	8829	70	340	8582.7	97.21
900	10136.8	80	340	9826.1	96.934
900	11413.9	90	340	11031.6	96.651
900	2114.2	10	770	2050.1	96.968
900	4457.7	20	770	4381.5	98.291
900	6784	30	770	6692.8	98.656
900	8835.6	40	770	8723	98.725
900	11188	50	770	11042.6	98.701

900	13536.9	60	770	13355.9	98.663
900	15593.4	70	770	15375.7	98.604
900	17912.8	80	770	17646.2	98.512
900	19989.3	90	770	19671.1	98.408
900	22049.7	100	770	21665.2	98.256
900	1651.4	10	800	1580.6	95.714
900	3255.6	20	800	3179.7	97.669
900	4830.1	30	800	4748	98.299
900	6416.3	40	800	6322.6	98.54
900	8308.7	50	800	8197.6	98.664
900	9838.1	60	800	9707.3	98.671
900	11422.9	70	800	11268.4	98.647
900	13009.9	80	800	12830.3	98.619
900	14596.9	90	800	14386.6	98.56
900	16424.8	100	800	16180.1	98.511

Table 12: Efficiency Data (DC/DC Charging mode), VIN = 900 VDC

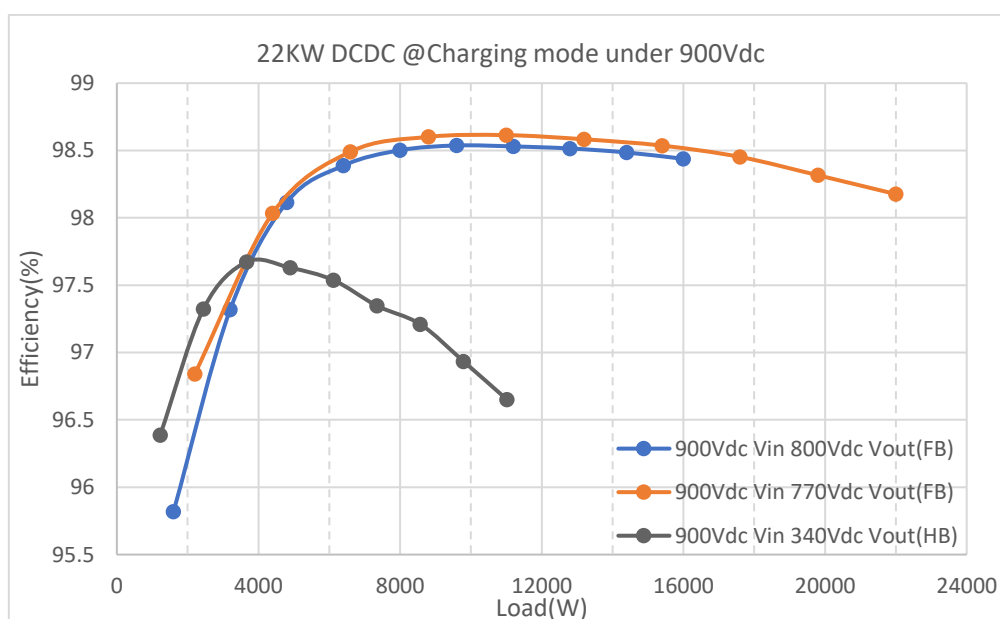


Figure 13: Efficiency Data (DC/DC Charging mode), VIN = 900 VDC

Input Voltage (Vdc)	Input Power (W)	Load (%)	Output voltage (Vac)	Output Power (W)	Overall Efficiency (%)
300	690.3	10%	370	679.3	98.395
300	1363.5	20%	370	1346.5	98.755
300	1970.1	30%	368.6	1944.6	98.706
300	2642.1	40%	367.6	2605.1	98.6
300	3303.3	50%	367.2	3251.2	98.425
300	4049.9	60%	367	3978.3	98.234
300	4725.1	70%	366.4	4632.8	98.047
300	5409.1	80%	366.3	5291.9	97.833
300	6084.3	90%	366.1	5939.6	97.623
300	6773	100%	365	6596.7	97.398
480	763.4	10%	600	733.5	96.081
480	1465.9	20%	600	1441.1	98.305
480	1977	30%	600	1948.2	98.539
480	2687.7	40%	600	2652.5	98.69
480	3260.9	50%	600	3221.1	98.779
480	3959.5	60%	600	3913.4	98.834
480	4672.7	70%	600	4618	98.828
480	5388.9	80%	600	5325.2	98.818
480	6084.3	90%	600	6009.9	98.777
480	6608.7	100%	600	6525.5	98.742
600	629.6	10%	755	585	89.764
600	1474.9	20%	755	1436.4	93.011
600	2037.1	30%	755	1995.3	95.739
600	2604.2	40%	755	2559.2	96.296
600	3441.2	50%	755	3389.6	96.565
600	4017.3	60%	755	3962.3	96.675
600	4580.7	70%	755	4522.3	96.715
600	5431.1	80%	755	5364.5	96.67
600	6036.7	90%	755	5962.1	96.595
600	6608	100%	755	6528.1	96.478

Table 13: Efficiency Data (DC/DC Discharging mode), VIN = 300V/480V/600 VDC Full Bridge

Input Voltage (Vdc)	Input Power (W)	Load (%)	Output voltage (Vac)	Output Power (W)	Overall Efficiency (%)
600	683.7	10%	365	666.8	97.534
600	1361.1	20%	365	1333.1	97.949
600	2013.6	30%	365	1979.3	98.296
600	2662.7	40%	365	2615.6	98.23

600	3345.2	50%	365	3281.5	98.094
600	4082	60%	365	3995.5	97.882
600	4730.7	70%	365	4623.4	97.731
600	5458.3	80%	365	5325.5	97.567
600	6133.8	90%	365	5972.5	97.371
600	6800.4	100%	365	6607.7	97.166
802	768.5	10%	495	735.1	95.653
802	1376.8	20%	495	1346.4	97.797
801.8	1988	30%	495	1953.4	98.259
801.8	2602.4	40%	495	2559.7	98.36
801.7	3326.7	50%	495	3274.3	98.423
801.5	4068.8	60%	495	4004.2	98.411
801.5	4673.9	70%	495	4597.8	98.372
801.4	5408.9	80%	495	5317.9	98.319
801.3	6011.3	90%	495	5906.5	98.256
801.2	6765.3	100%	495	6640.3	98.153

Table 14: Efficiency Data (DC/DC Discharging mode), VIN = 600V/800 VDC Half Bridge

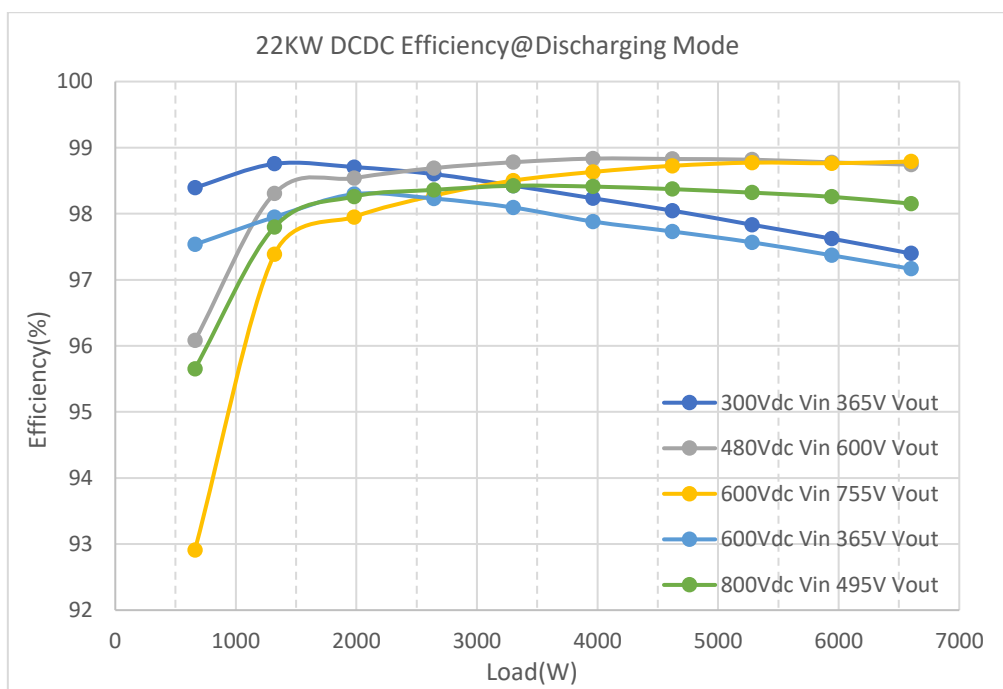
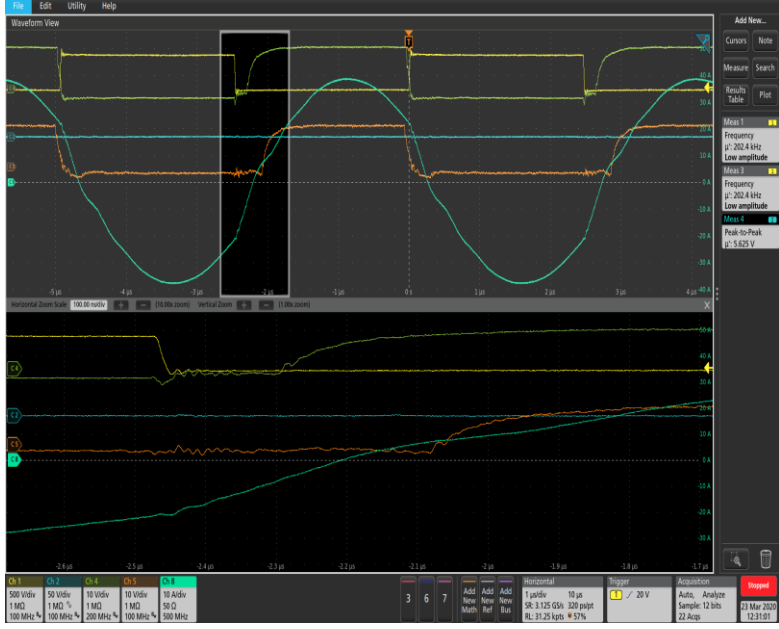
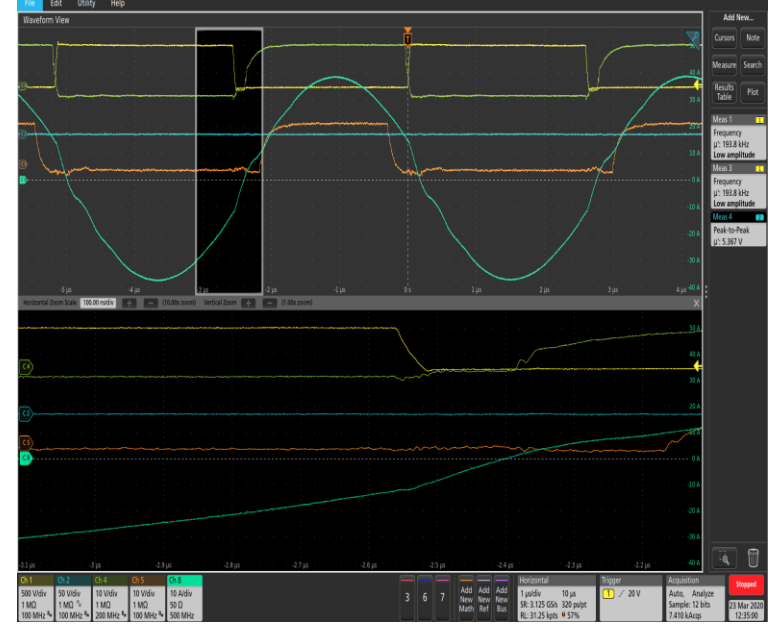


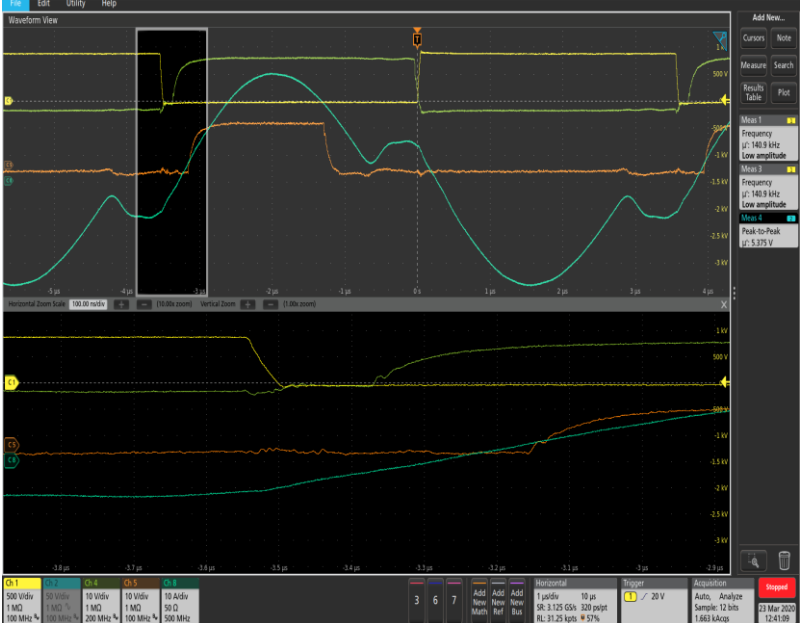
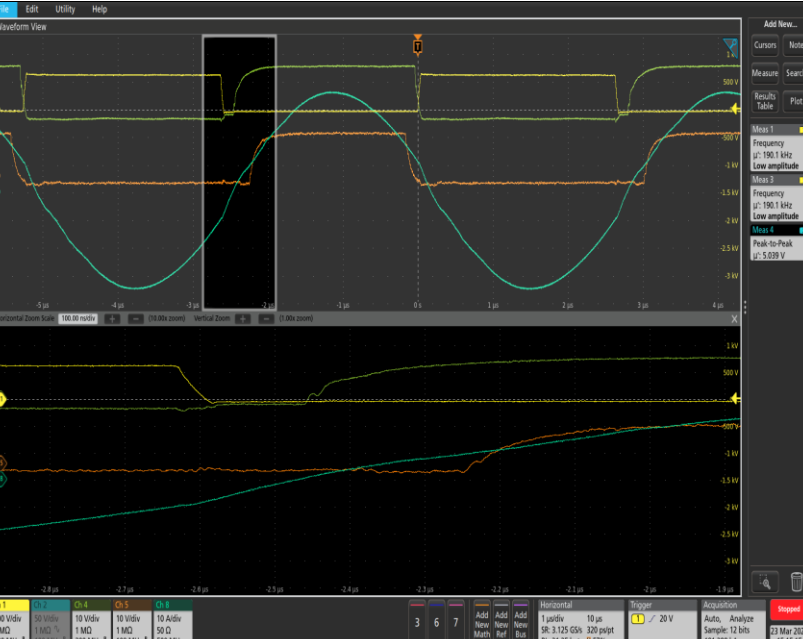
Figure 14: Efficiency Data (DC/DC Discharging mode)

10. Typical Waveforms

Operational waveforms are presented in Table 15 and Table 16.

DC/DC Charging Mode:

Condition	Waveform
DC/DC Charging Mode (Full Bridge) Bus Side Input: 650Vdc Battery Side Output: 480Vdc Full Load	 <p>CH1: Vds Primary Low Side, 500V/div CH4: Vgs Primary Low Side, 10V/div CH5: Vgs Secondary Low Side, 10V/div CH8: Primary Resonant Choke Current, 10A/div</p>
DC/DC Charging Mode (Full Bridge) Bus Side Input: 780Vdc Battery Side Output: 610Vdc Full Load	 <p>CH1: Vds Primary Low Side, 500V/div CH4: Vgs Primary Low Side, 10V/div CH5: Vgs Secondary Low Side, 10V/div CH8: Primary Resonant Choke Current, 10A/div</p>

<p>DC/DC Charging Mode (Full Bridge)</p> <p>Bus Side Input: 900Vdc</p> <p>Battery Side Output: 800Vdc</p> <p>Full Load</p>	 <p>CH1: Vds Primary Low Side, 500V/div CH4: Vgs Primary Low Side, 10V/div CH5: Vgs Secondary Low Side, 10V/div CH8: Primary Resonant Choke Current, 10A/div</p>
<p>DC/DC Charging Mode (Half Bridge)</p> <p>Bus Side Input: 650Vdc</p> <p>Battery Side Output: 200Vdc</p> <p>Full Load</p>	 <p>CH1: Vds Primary Low Side, 500V/div CH4: Vgs Primary Low Side, 10V/div CH5: Vgs Secondary Low Side, 10V/div CH8: Primary Resonant Choke Current, 10A/div</p>

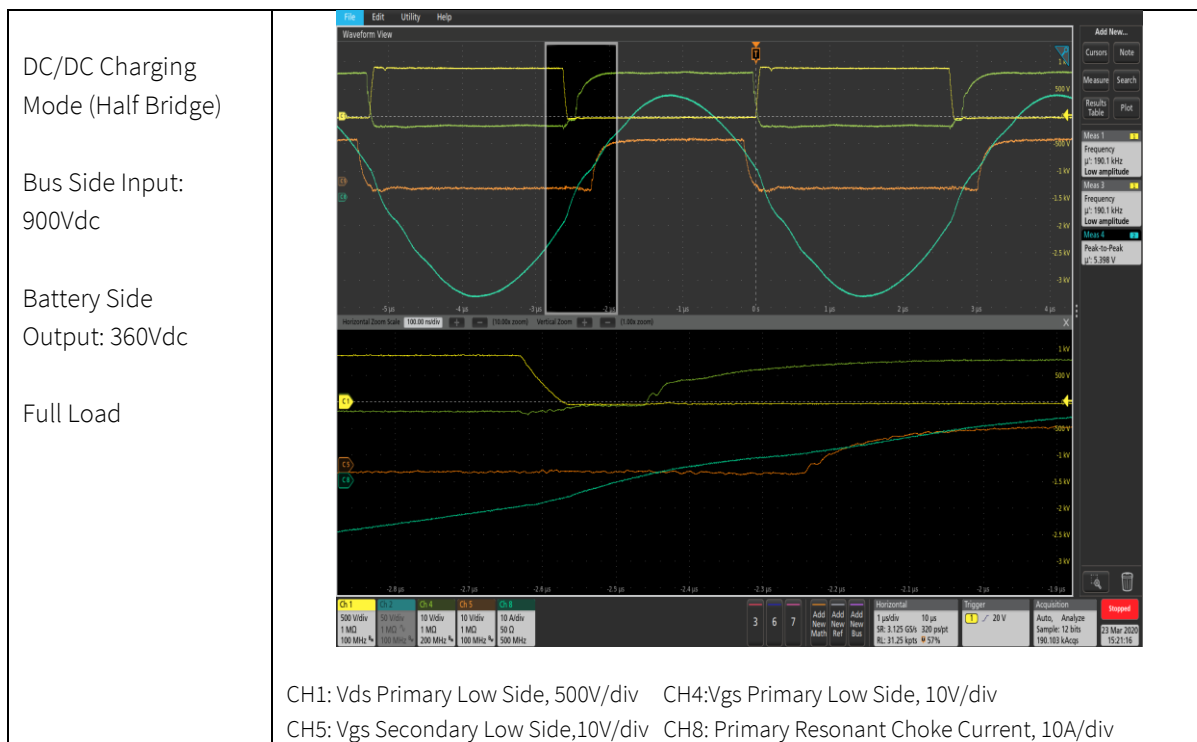
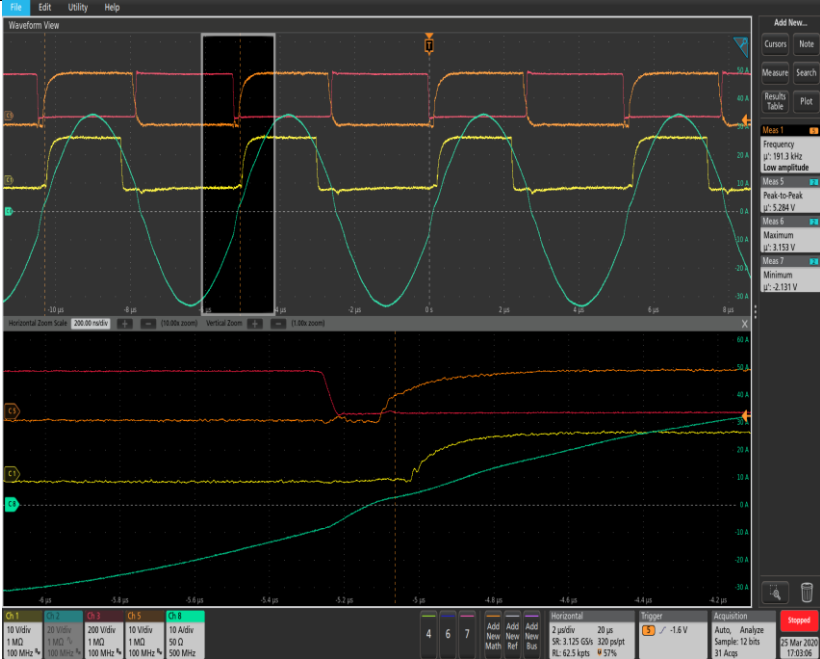
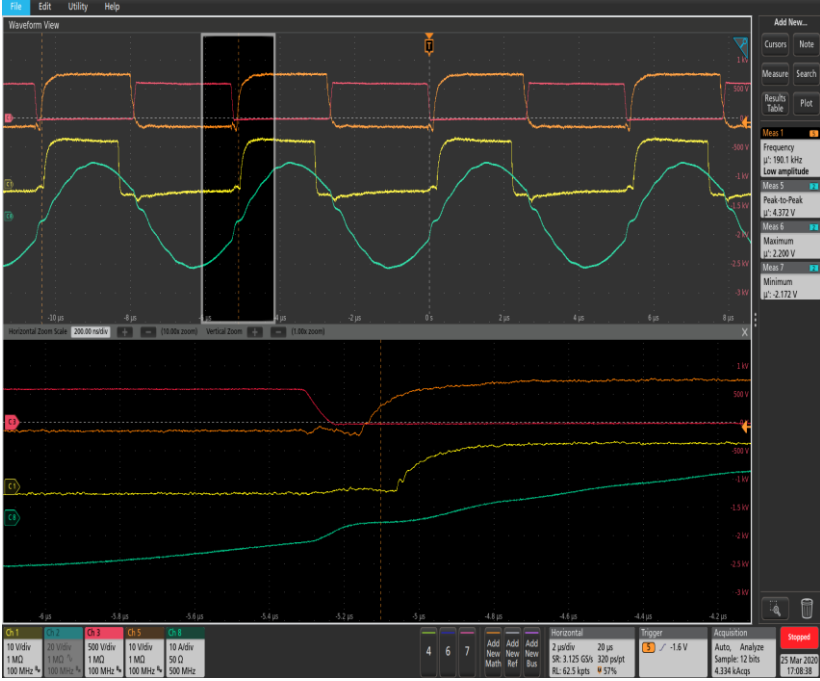


Table 15: DC/DC Charging Mode Waveforms

DC/DC Discharging Mode: (Resistive load)

Condition	Waveform
DC/DC Discharging Mode (Full Bridge) Battery Side Input: 300Vdc Bus Side Output: 365Vdc Full Load	 <p>CH1: Vgs Secondary Low Side, 10V/div CH3: Vds Primary Low Side, 200V/div CH5: Vgs Primary Low Side, 10V/div CH8: Primary Resonant Choke Current, 10A/div</p>
DC/DC Discharging Mode (Full Bridge) Battery Side Input: 600Vdc Bus Side Output: 750Vdc Full Load	 <p>CH1: Vgs Secondary Low Side, 10V/div CH3: Vds Primary Low Side, 500V/div CH5: Vgs Primary Low Side, 10V/div CH8: Primary Resonant Choke Current, 10A/div</p>

<p>DC/DC Discharging Mode (Half Bridge)</p> <p>Battery Side Input: 600Vdc</p> <p>Bus Side Output: 360Vdc</p> <p>Full Load</p>	<p>CH1: Vgs Secondary Low Side, 10V/div CH3: Vds Primary Low Side, 500V/div CH5: Vgs Primary Low Side, 10V/div CH8: Primary Resonant Choke Current, 10A/div</p>
<p>DC/DC Discharging Mode (Half Bridge)</p> <p>Battery Side Input: 800Vdc</p> <p>Bus Side Output: 490Vdc</p> <p>Full Load</p>	<p>CH1: Vgs Secondary Low Side, 10V/div CH3: Vds Primary Low Side, 500V/div CH5: Vgs Primary Low Side, 10V/div CH8: Primary Resonant Choke Current, 10A/div</p>

Table 16. DC/DC Discharging Mode Waveforms

11. Thermal Design and Test Results

In a thermal test of the unit, forced air cooling is applied to the cooling base plate at the bottom side to get a 65°C cooling plate to simulate the thermal condition in an OBC application. There is no air flow to the power MOSFETs. MOSFETs in the CLLC resonant converter operate in full load thermal condition with a 611V/36A load. So, the thermal test was performed at 800V DC input and full load 22kW with 611V/36A load in charging mode. T-type thermal couplers and an acquisition unit from Keysight Technologies Inc. (P/N:34972A) are used to measure the case temperature of components.

The test results under these conditions are shown in Table 17 and Table 18. The highest junction temperature of any MOSFET in the design was determined to be 113.9°C. This value was calculated based on the measured case temperature, the thermal resistance of the MOSFET, and the calculated power loss. Because the maximum junction temperature of the C3M0032120K is 175°C, the integrated heat sink design has allowed the MOSFETs to remain within their thermal derating guidelines.

Description	Scenario 1. 480V/36A charging	Scenario 2. 610V/36A charging	Scenario 3. 400V/36A charging	Rated Temperature	Derating Requirement	Comments
Base Plate	65°C	65°C	65°C	NA	NA	NA
Resonant Choke1	98.7°C	80.2°C	105.6°C	155 °C	130 °C	Pass
Resonant Choke2	92°C	76.9°C	102.5°C	155 °C	130 °C	Pass
Main-Tx	99.1°C	92°C	93.6°C	155 °C	130 °C	Pass

Table 17: Thermal Test Results of Magnetic components

Temperature of semiconductors is shown in the table below.

Description	Rth(j-c) (°C/W)	Calculated Power Loss	Measured Case Temperature	Calculated Junction Temperature	Max. Operating Junction Temperature	Derating Requirement	Comments
Charging Output = 480Vdc 36A							
CLLC MOSFET	0.45	42W	86.9°C	105.8°C	175 °C	140°C	Pass
CLLC SR MOSFET	0.45	38W	83.6°C	100.7°C	175 °C	140°C	Pass
Charging Output = 610Vdc 36A							

CLLC MOSFET	0.45	32.5W	81.7°C	96.4°C	175 °C	140°C	Pass
CLLC SR MOSFET	0.45	38W	83.3°C	100.4°C	175 °C	140°C	Pass
Charging Output = 400Vdc 36A							
CLLC MOSFET	0.45	53W	90.1°C	113.9°C	175 °C	140°C	Pass
CLLC SR MOSFET	0.45	38W	83.7°C	100.8°C	175 °C	140°C	Pass

Table 18: Thermal Test Results of SiC power Mosfets

12. Appendix

12.1 PWM Timing

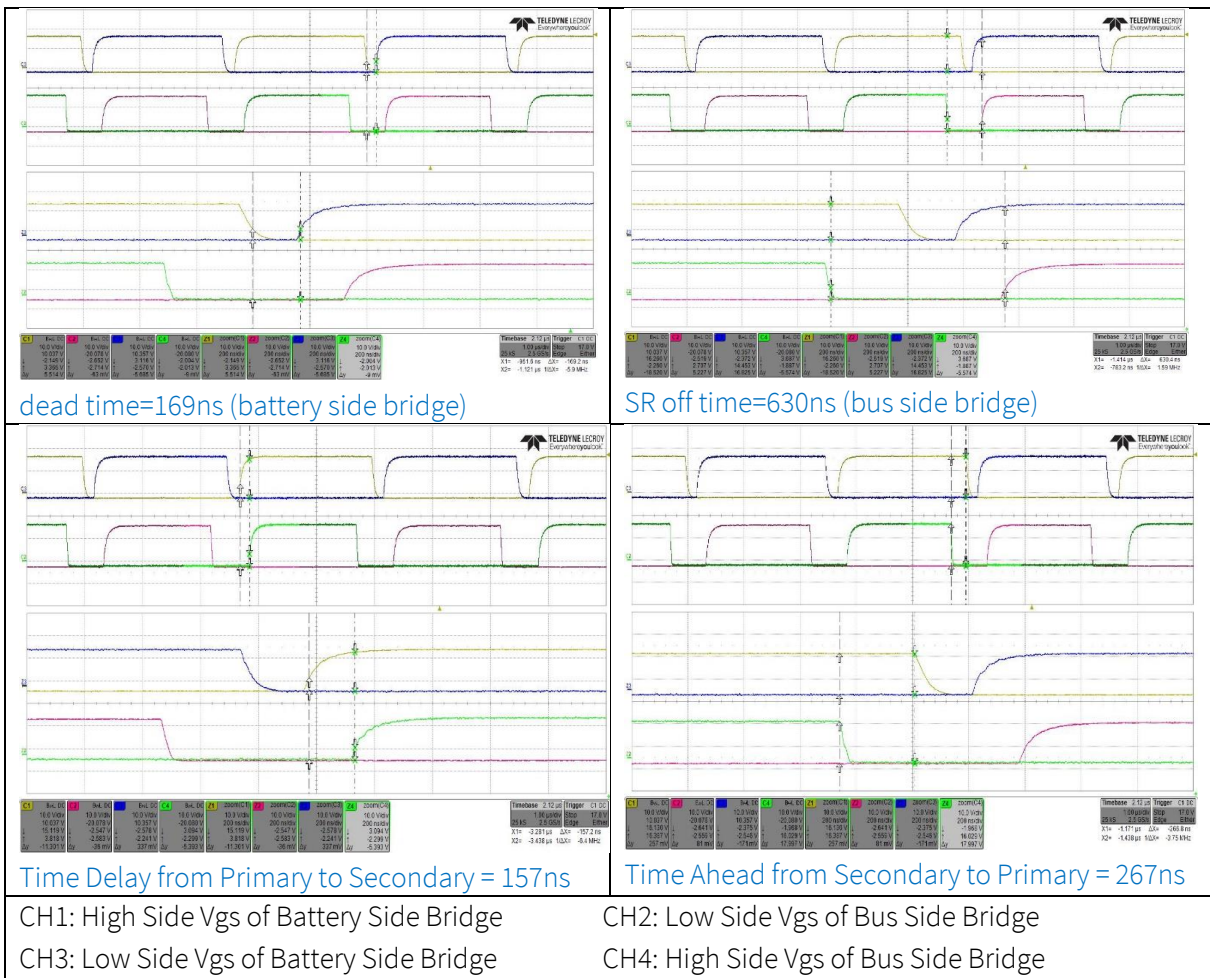


Table 19: Gate Signals and Timings in Discharging Mode

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	0.1V	0.1A	0.1V	0.1A
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
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)		
Bit9~8	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	0.1V	0.1V	0.1A
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	0.1V		
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			0.1V	0.1A
Bias	0				
Data Format	Integer				

Table 26: Control Command

13. Revision History

Date	Revision	Changes
July, 2020	A	First issue

14. Reference

None

15. IMPORTANT NOTES

Purposes and Use

Cree, Inc. (on behalf of itself and its affiliates, “Cree”) 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 CREE 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 CREE (TOGETHER, THE “DOCUMENTATION”) PRIOR TO USE. USE OF THIS BOARD IS AT THE USER’S SOLE RISK.

Operation of Board

It is important to operate the board within Cree’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 Cree at sic_power@cree.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 Cree at sic_power@cree.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 Cree at sic_power@cree.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.

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 Cree at sic_power@cree.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.

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.

Limitation of Liability

IN NO EVENT SHALL CREE BE LIABLE FOR ANY DAMAGES OF ANY KIND ARISING FROM USE OF THE BOARD. CREE'S AGGREGATE LIABILITY IN DAMAGES OR OTHERWISE SHALL IN NO EVENT EXCEED THE AMOUNT, IF ANY, RECEIVED BY CREE IN EXCHANGE FOR THE BOARD. IN NO EVENT SHALL CREE 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 CREE MAY BE BROUGHT AGAINST CREE MORE THAN ONE (1) YEAR AFTER THE CAUSE OF ACTION ACCRUED.

Indemnification

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