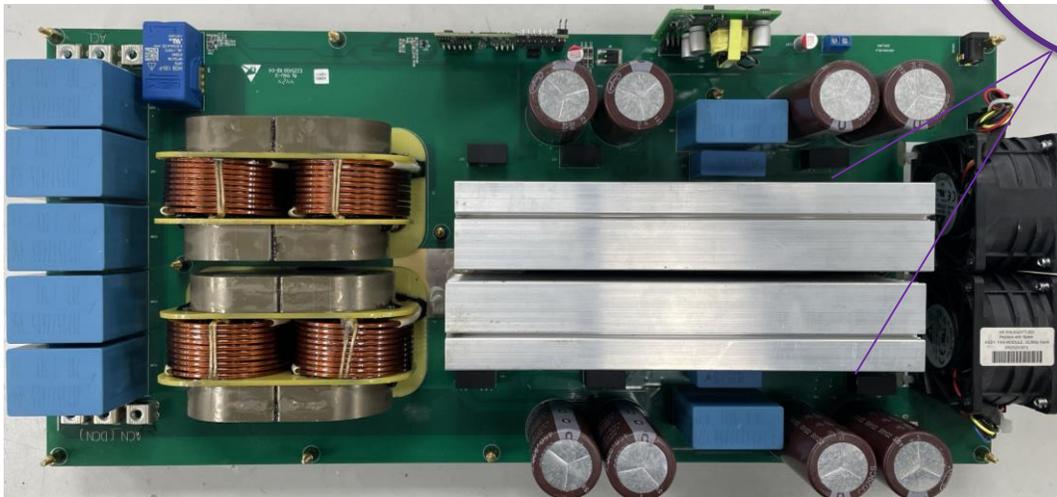
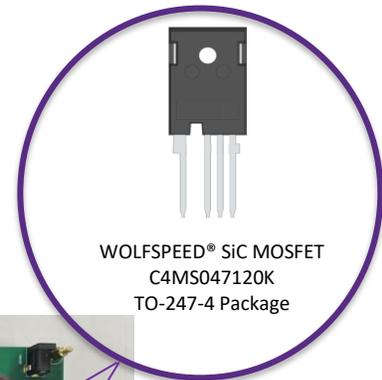


# CRD-33FF12N-K: SiC-based 33kW High-Efficiency Bi-directional ACDC Converter

33kW SiC MOSFET 高效率双向 ACDC 变换器  
33 kW SiC MOSFET 高效率双方向 ACDC 变换器



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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

通電している時、ボードに接触するのは禁止です。ボードを処分する前に、大容量のコンデンサーで電力を完全に解放すべきです。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解放するまで待ってください。

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解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解放した後、試験設備を取り換えることができます。

# 1. Introduction

The purpose of this reference design is to show the capability and performance of a discrete SiC MOSFET solution in ANPC applications at power rating over 100kW. To verify this in a simple system, a single-phase 33kW ANPC prototype is evaluated via this reference design. A 100kW power rating can be achieved when applying three units of this design to the three phases of the grid.

This User Guide provides the schematic, artwork, and test setup necessary to evaluate Wolfspeed’s CRD-33FF12N-K, SiC-Based 33kW Bidirectional ACDC Converter with high efficiency for power conversion systems (PCS), energy storage systems (ESS), and other similar renewable energy applications.

This design is based upon one of Wolfspeed’s fourth-generation SiC MOSFETs - C4MS047120K (1200V, 47mΩ, TO-247-4). A block diagram of the 33kW Bidirectional ACDC Converter (P/N CRD-33FF12N-K) based on SiC is shown in Figure 1. The converter system is a bidirectional ACDC stage in a single-phase ANPC topology. Referring to Figure 1a, it operates from DC-link voltage at bus-side terminals and provides a non-isolated single phase AC output voltage at the AC-side terminals during DCAC mode. During ACDC mode, it operates from a non-isolated single-phase AC input voltage and provides DC voltage at the bus-side output terminals.

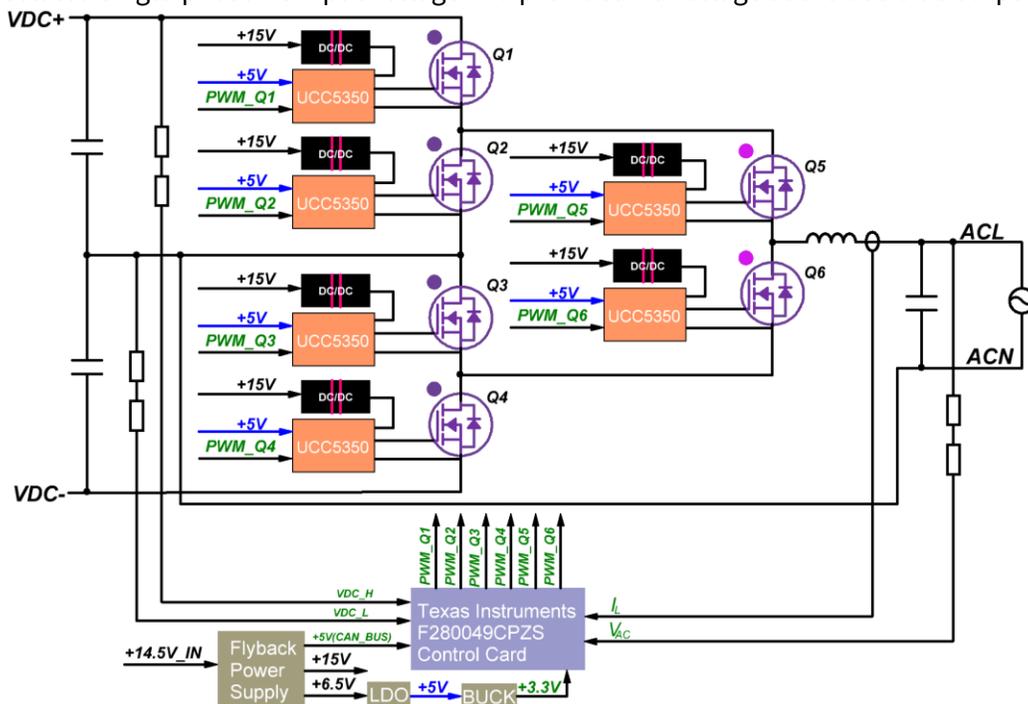


Figure 1a. Block Diagram of Wolfspeed’s CRD-33FF12N-K, 33kW Bidirectional ACDC Converter

The converter operates at 60kHz switching frequency. A tooled heatsink was designed to dissipate the heat generated by the power MOSFETs. An external power source is needed to power the fan to cool the unit. The power density is up to 5KW/L.

To achieve 33kW output power, three discrete C4MS047120K SiC MOSFETs are used in parallel in each of the four positions Q1 to Q4. By utilizing a lower  $R_{DS(on)}$  MOSFET such as C4MS013120K, the power rating can be easily extended to 67kW in a single-phase ANPC system or 200kW in a three-phase ANPC system.

## 2. Description

This reference design uses three Wolfspeed 1200V 47 m $\Omega$  SiC MOSFETs- C4MS047120K (TO-247-4 package) in parallel for each position Q1 to Q4. Two Wolfspeed 1200V 25 m $\Omega$  SiC MOSFET- C4MS025120K (TO-247-4 package) are used in parallel for positions Q5 and Q6.

This evaluation board is compatible for both ACDC mode and DCAC mode. 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 from 200Vdc to 1500Vdc can be set through the CAN interface in ACDC mode. The maximum output voltage is about 450V<sub>L-N</sub> RMS in DCAC mode.

**Do not overload the converter outside of the Safe Operation Area (SOA).** Please refer to Table 4 in Section 7.5 of this User Guide for protection details.

### 3. Electrical Performance Characteristics

Table 1: Specifications of Wolfspeed's CRD-33FF12N-K, 33kW Bidirectional ACDC Converter

PARAMETER		TEST CONDITIONS	MIN	NOM	MAX	UNITS
<b>DC Side Characteristics</b>						
$V_{DC}$	DC-Link voltage			1400	1500	V
$I_{DC}$	DC current			23.6		
$f_{sw}$	Switching frequency			60		kHz
<b>AC Side Characteristics</b>						
$V_{AC}$	AC L-N RMS voltage			400	450	$V_{rms}$
$I_{AC}$	AC RMS current	$V_{DC} = 1400V, P_{AC} = 33kW$		85		A
$P_{AC}$	AC Power			33		kW
$f_{ac}$	AC Line Frequency			50		Hz
<b>System Characteristics</b>						
$\eta_{peak\_DCAC}$	Peak efficiency	$V_{DC} = 1400V, V_{AC} = 420V(L-N RMS), I_{AC} = 20\% \text{ of } I_{AC(nom)}$		99.15%		
$\eta_{full\_load\_DCAC}$	Full load efficiency	$V_{DC} = 1400V, V_{AC} = 420V(L-N RMS), I_{AC} = 100\% \text{ of } I_{AC(nom)}$		97.91%		
$\eta_{peak\_ACDC}$	Peak efficiency	$V_{DC} = 1100V, V_{AC} = 300V(L-N RMS)^1, I_{AC} = 30\% \text{ of } I_{AC(nom)}$		99.14%		
$\eta_{full\_load\_ACDC}$	Full load efficiency	$V_{DC} = 1100V, V_{AC} = 300V(L-N RMS), I_{AC} = 100\% \text{ of } I_{AC(nom)}$		97.92%		
<b>Mechanical</b>						
Dimensions	Width Length Component height			214 467 65		mm

#### 3.1 Application

The primary application of Wolfspeed's CRD-33FF12N-K reference design is Bidirectional ACDC converter for PCS or ESS applications, but the output should be connected to a resistive load or electronic load. A battery test is not allowed since a battery-charging algorithm has not been implemented in the design.

<sup>1</sup> Due to the output voltage of the AC source for ACDC testing is limited to  $300V_{rms}$ , the DC-Link voltage in ACDC mode is then set to 1100V to get a higher efficiency.

## 3.2 Features

Some of the features of Wolfspeed's CRD-33FF12N-K reference design are listed below:

- Bidirectional operation: DC-Link voltage range is 0Vdc-1500Vdc.
- Maximum allowed AC line current is 85A (RMS) and maximum operating power is 33kW single phase (100kW in three phases).
- Can be easily extended to 67kW single phase (200kW in three phases) using lower  $R_{DS(on)}$  MOSFETs
- Peak efficiency > 99%.
- Protection functions are shown in Table 4.
- Easy to test using a GUI communicating via CAN. See Section 6 and Section 13 for details.

## 4. Schematics

Note: Full design files, including full-size schematics and PCB files are available for downloading from the Wolfspeed reference design website ( <https://www.wolfspeed.com/products/power/reference-designs> )

Schematics of the power board, control board, and auxiliary-power board are shown in Figures 2 through Figure 4.

### 4.1 Power Board and Capacitor Board

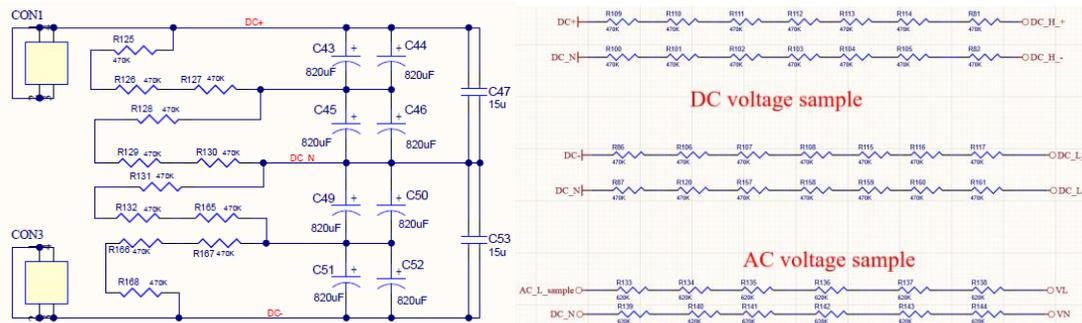


Figure 2a. Schematic of Power Board: DC connectors and voltage sampling circuits

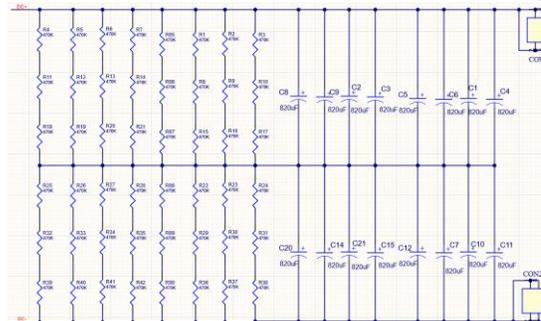


Figure 2b. Schematic of Power Board: DC, FAN connectors and voltage sampling circuits

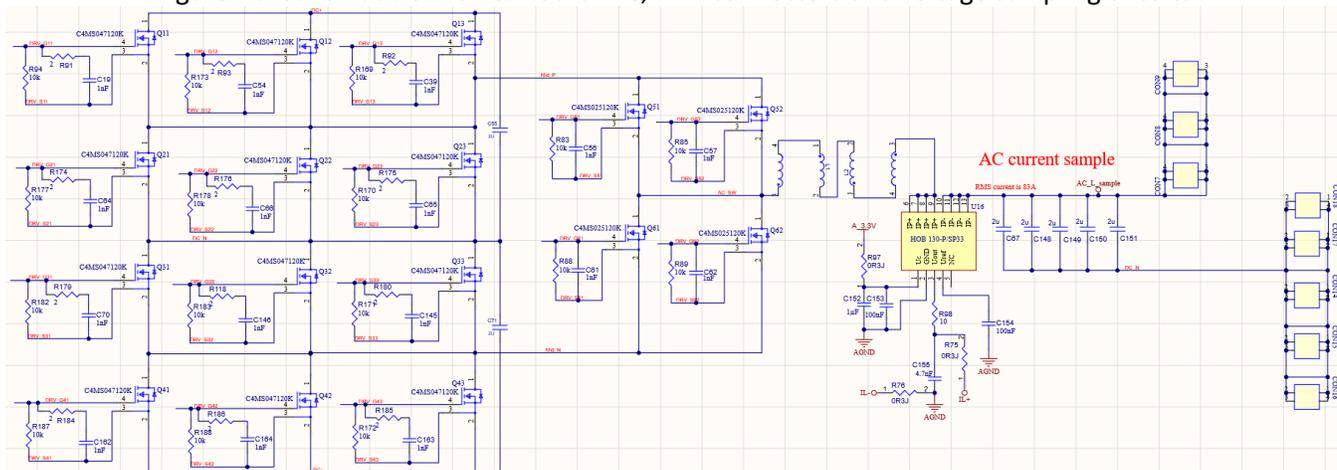


Figure 2c. Schematic of Power Board: Main Converter MOSFETs and AC current sampling circuit

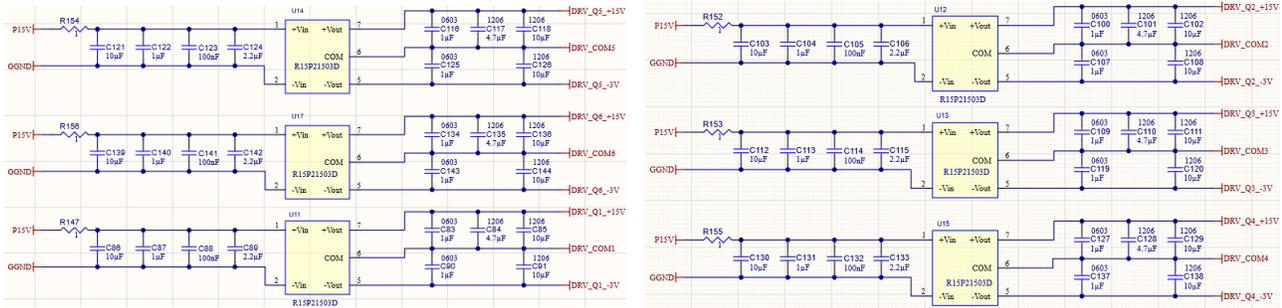


Figure 2d. Schematic of Power Board: gate drive bias power supply

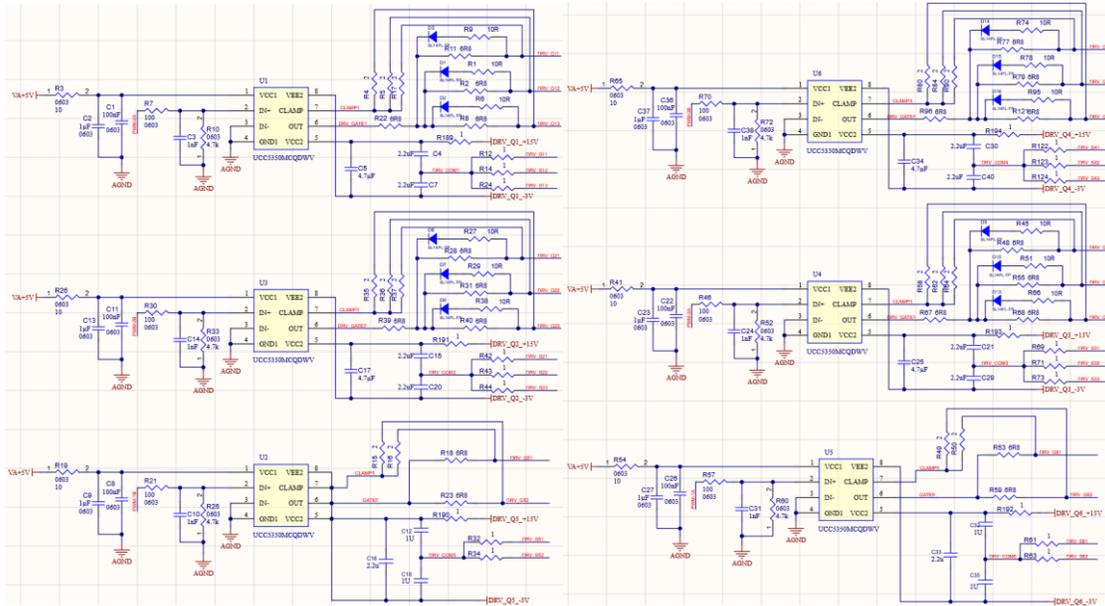


Figure 2e. Schematic of Power Board: Gate Drivers

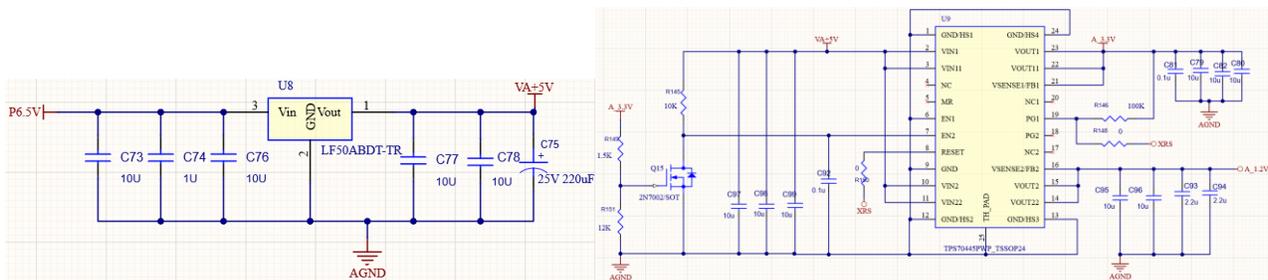


Figure 2f. Schematic of Power Board: +5V power supply and DSP power supply circuits

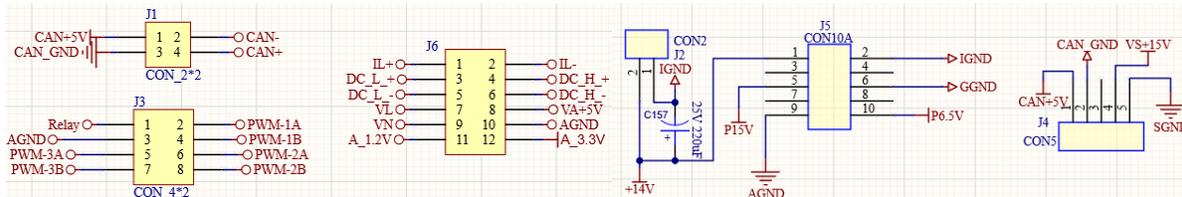


Figure 2g. Schematic of Power Board: Connectors to control board and aux power board

## 4.2 Control board

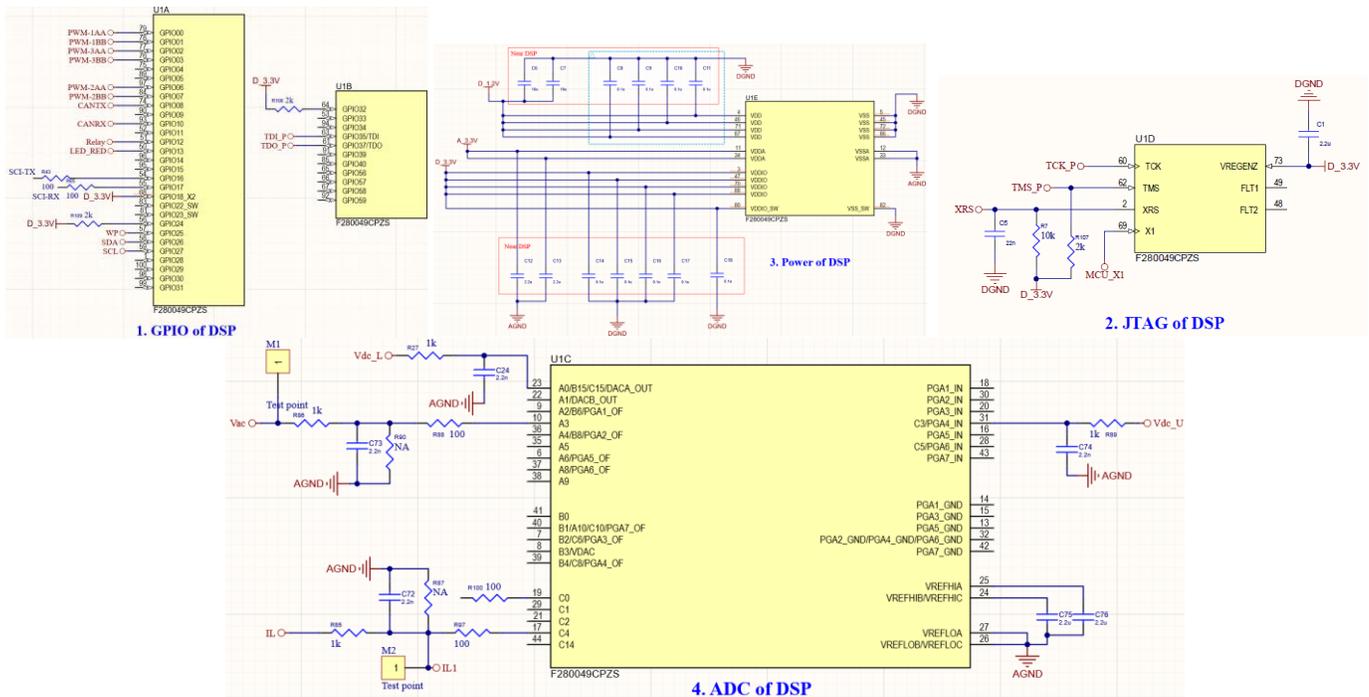


Figure 3a. Schematic of Control Board: DSP Controller

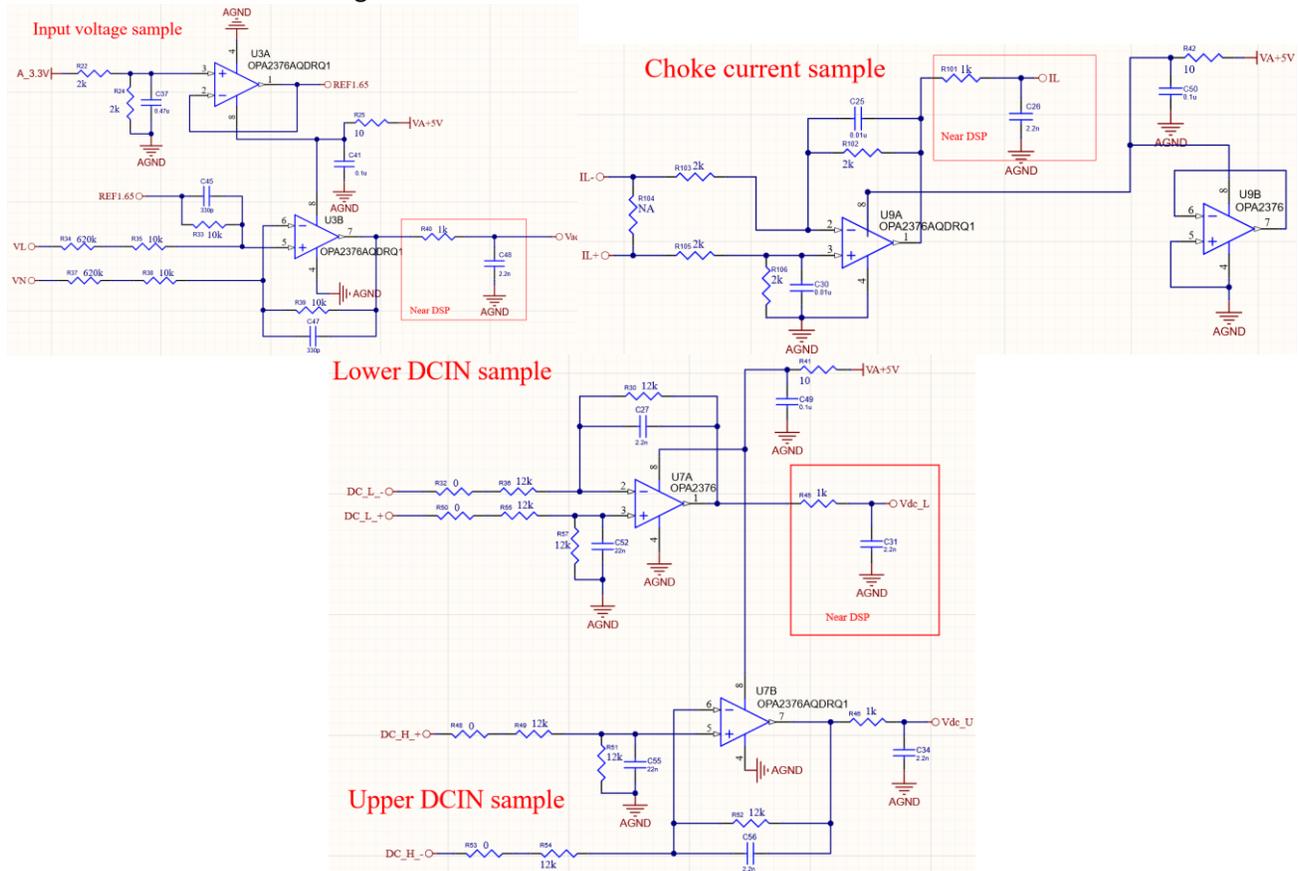


Figure 3b. Schematic of Control Board: Current and Voltage Sample circuits

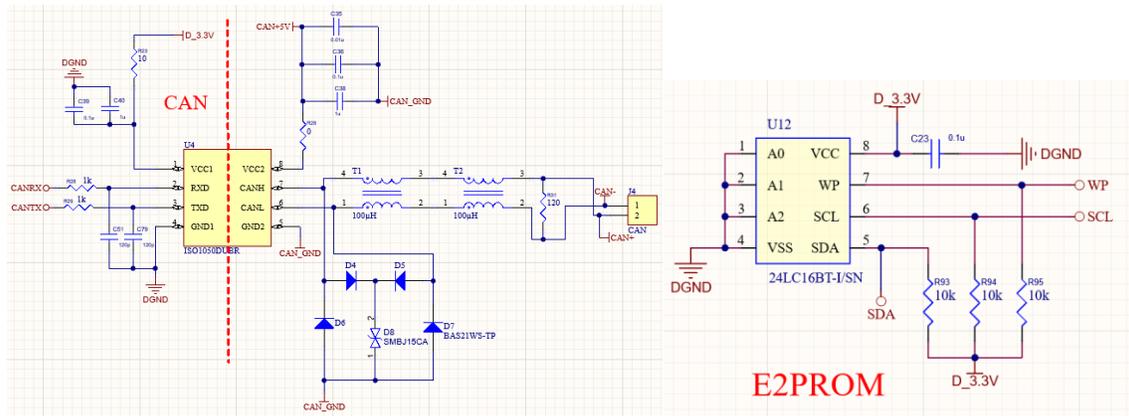


Figure 3c. Schematic of Control Board: CAN Interface and E2PROM

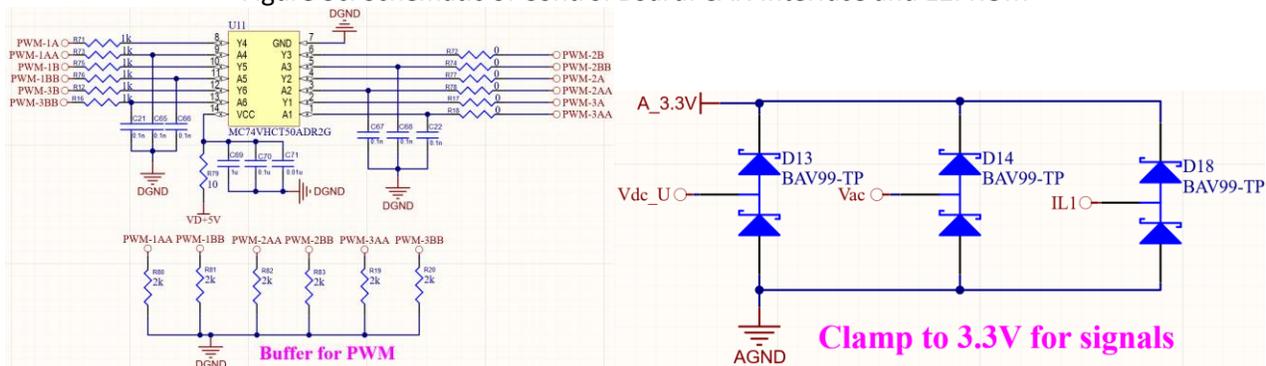


Figure 3d. Schematic of Control Board: PWM Buffer and Signal clamp

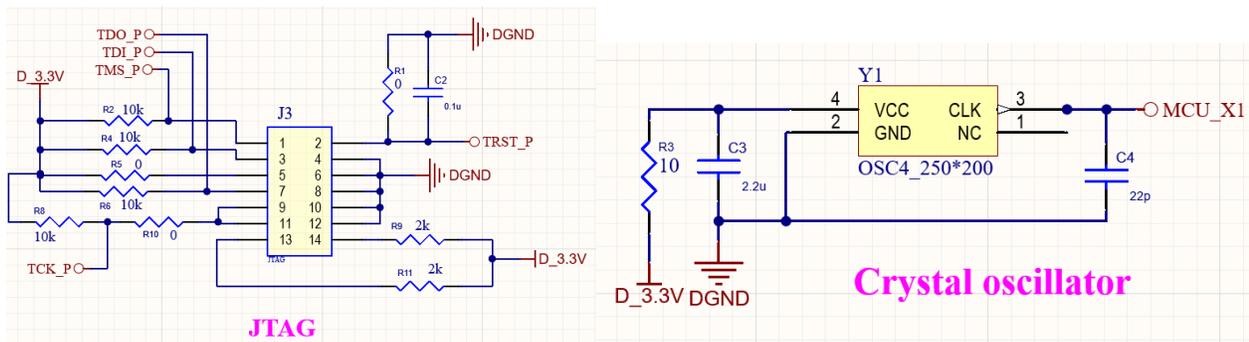
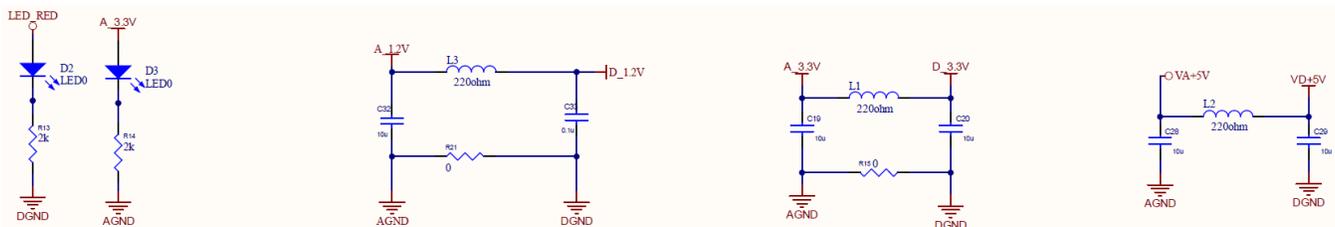


Figure 3e. Schematic of Control Board: JTAG and Crystal oscillator of DSP



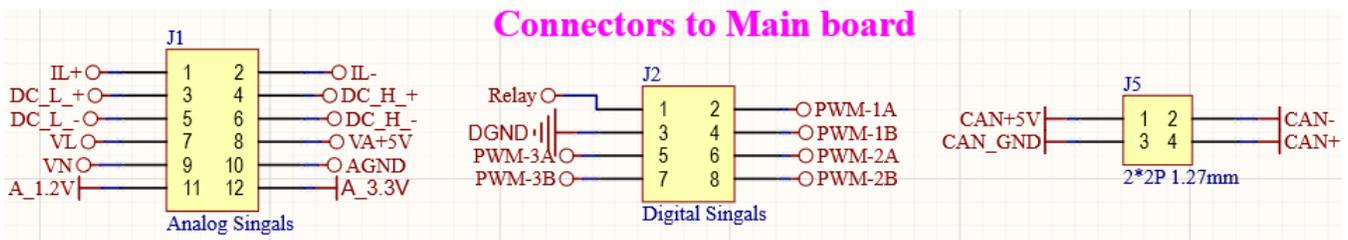


Figure 3f. Schematic of Control Board: Power Supply and Connectors to main board



## 5. Hardware Description

### 5.1 Power Board and Capacitor Board

As illustrated by [Figure 2a](#) to [2g](#), a single-phase ANPC topology is selected for the converter. The bus-side terminals are connected to “DC+” and “DC-” of CON1 and CON3 respectively, followed by four sets (two in parallel each set) of electrolytic capacitors in series which absorb the ripple on the DC port. Several film capacitors are also in parallel at the DC port to absorb the high-frequency ripple. Followed by the capacitors, the ANPC topology consists of Wolfspeed’s SiC MOSFET (Q11~Q62 in [Figure 2b](#)) C4MS047120K connected between the DC-Link and two series connected power inductors. The inductors connect to AC side terminals by connectors “ACL” and “ACN\_(DCN)” of CON7~CON9 and CON14~CON16 respectively.

Since this reference design is evaluating performance of Wolfspeed’s discrete SiC MOSFET in the three-phase ANPC system by a single-phase ANPC topology, the ripple current and ripple voltage of the DC-Link is very big. To reduce the ripple voltage of the DC-Link and make sure the system runs normally, external capacitor boards need to connect to the DC-Link of the unit. As illustrated by [Figure 2b](#), the capacitor board has two sets of capacitors in series, each set paralleling eight electrolytic capacitors, together with their discharging resistors. These additional capacitors would not be required in a three-phase system due to the reduction of ripple current in the DC bus.

As illustrated by [Figures 2d](#) to [2e](#), all Texas Instruments, Inc. gate drivers (P/N: UCC5350MCQDWW) are separately powered by isolated, DC/DC power supplies with  $V_{IN} = +15V$  and  $V_{OUT} = +18V/-3V$  from MORNSUN. (P/N: QA01C-18).

### 5.2 Control Board

As illustrated by [Figure 3a](#) to [Figure 3f](#), the control board, which carries out the control algorithm of the entire system, is designed using a Texas Instruments Inc. (TI) controller (P/N: F280049CPZS). The DC voltages +18.0V generated from an isolated power supply are supplied to the main board via connector J5. The power supply for the control board is an isolated, 5.0V power supply generated from a linear regulator in the main power board. This 5.0V voltage rail then supplies another precision linear regulator, U9, from Texas Instruments Inc. (P/N: TPS70445), which provides both a 3.3V and a 1.2V voltage rail. As shown in [Figure 3f](#), the power supplies for analog and digital circuits are separated by ferrite beads (L1, L2, L3). The analog ground and digital ground are connected finally by a 0Ω resistor. All output drive signals are buffered and shifted to a +5V level by a level-shifter. The reference voltage for the controller’s ADC (Analog-to-Digital Converter) is +3.3V generated internally by the DSP.

### 5.3 Auxiliary Power Board

The typical input voltage of the auxiliary power board is 14 V (J346, net “Aux\_DC+” and net “ISGND” in [Figure 4](#)). It provides four isolated output voltages, as shown in [Table 2](#).

Table 2: Input and Outputs of Auxiliary Power Board

Input/Outputs	Net Name	Comments
<b>Input</b>	+14V	14V Typical Input of the Auxiliary Power Board
<b>Output 1</b>	14V	15V Power Supply for MOSFET Gate Drivers
<b>Output 2</b>	P_15V	15V Power Supply for MOSFET Gate Drivers
<b>Output 3</b>	S_15V	5V Output for CAN Communication
<b>Output 4</b>	5V	Controller Power Supply

On the main board, a +5.0V voltage is generated (tightly regulated) from the +15V output of the auxiliary power by a linear regulator (U6. On the main board, the +5.0V voltage rail powers another precision linear regulator (U2), which generates both the +3.3V and +1.2V voltage rail.

## 6. Communication

### 6.1 Graphical User Interface (GUI)

A Windows C# Graphical User Interface (GUI) in conjunction with USB-CAN tools (GCAN: USBCAN-I) is provided for testing. Connector J5 is used for CAN, as shown in Figure 5.

A USB flash disk containing two folders accompanies the 33kW ANPC unit. Users should select the folder named “USBCANTool” and install this driver first. Another folder named “WolfspeedControlPanel” is the monitor for this reference design. Run the file “ECanTest.exe” in the path “WolfspeedControlPanel>ECanTest>bin>x64>Debug”. Before connecting the GUI with the converter, please make sure the CANH and CANL are connected to the control board located on the mainboard, and the USB to the computer. After that, select the Baud rate as “125k Bit/sec” and click the “CONNECT” button, as shown in Figure 5a. The CAN status is shown as Figure 5b after the connection is successful.

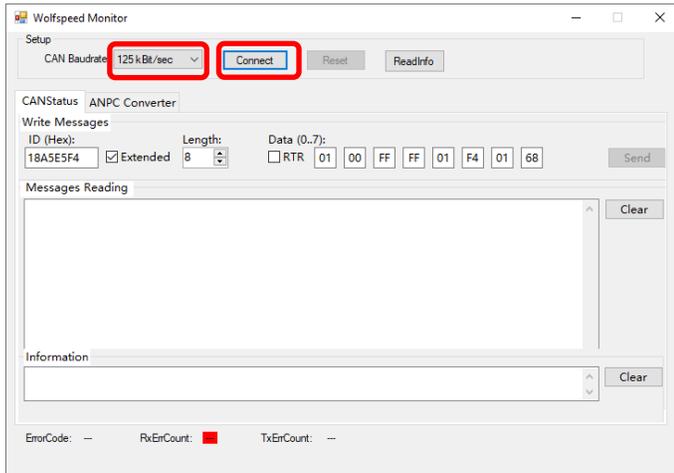


Figure 5a. CAN Status Tab before Connection

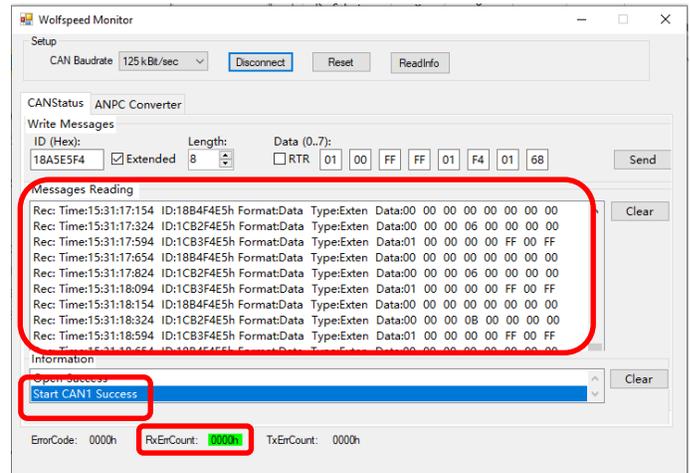


Figure 5b. CAN Status Tab after Connection

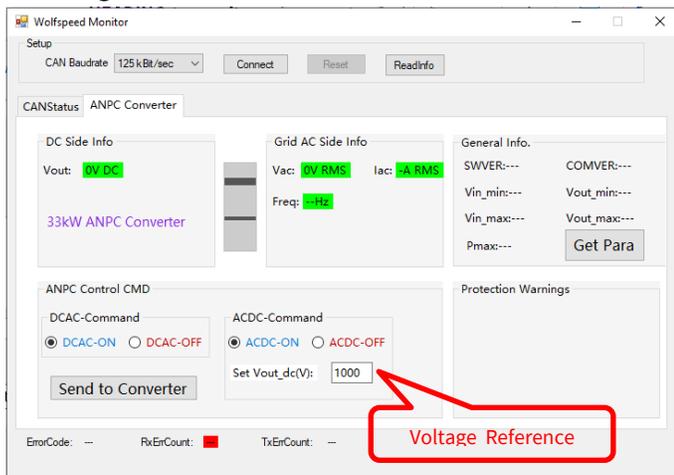


Figure 5c. CAN Status Tab before start up

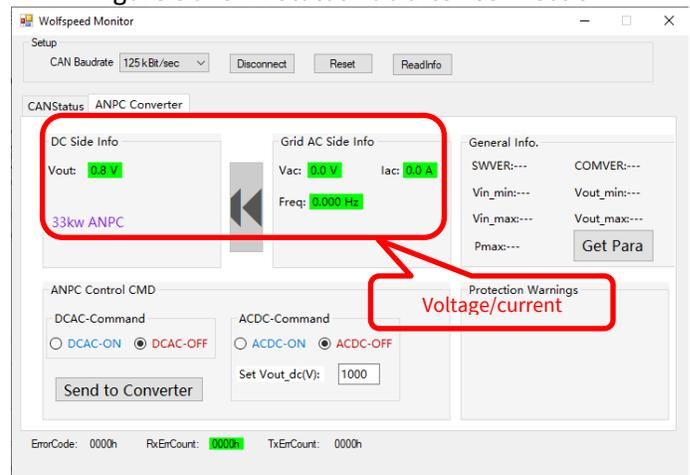


Figure 5d. CAN Status Tab after start up

The over/under voltage protection is indicated by the back color of the voltage value, as shown in Figure 5a to Figure 5d. “Green” indicates “Normal Operation” while “Red” indicates “Warning Issued”. As shown in [Figure 5c and 5d](#), the bus-side voltage will be shown in the “DC Side Info”, while the AC-side voltage, current, and AC frequency will be shown in “Grid AC Side Info”. The specification for this reference design will be shown in “General Info” by clicking the “Get Para” button. The Protection reminder will be shown on the monitor in red text. All the protection reminders are listed in the Section 7.5.

The configuration “DCAC” or “ACDC” can only be changed when the converter is shut down. For example, to run the unit at DCAC mode, select “ACDC-OFF” and “DCAC-OFF” commands then click “Send to Converter” to shut down the converter. Next, select “ACDC-OFF” and “DCAC-ON” commands and click “Send to Converter” to turn the unit on at DCAC mode. Vice versa to run the unit in ACDC mode.

## 6.2 CAN Communication Data Format

The reference design communicates over a CAN V2.0B bus at 125K 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 13.1 and Section 13.2.

Table 3 below provides an example when “0x18A5E5F4” is sent as the message identifier and “0xFF00FFFF0F0AFFFF” is sent as the CAN data.

User should take precautions to prevent overloading.

*Table 3: Example of Control Command*

Message Identifier: 0x18A5E5F4					
Data	Byte0	Byte1= 0x01	Byte2+Byte3	Byte4+Byte5 = 0x0F0A	Byte6+Byte7
Property	Reserved (0xFFFF)	On	Reserved (0xFFFF)	DC Voltage: 0x0F0A*0.1V = 3E8	Reserved (0xFFFF)

## 7. Test Setup



### **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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通电してから、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。

## 7.1 Equipment

**DC Source:** Two DC sources in parallel from ITECH (P/N: IT6036D-1500-60) are applied in this reference design. The input source must be adjustable up to 1500VDC and must be capable of supplying at least 40kW.

**AC Source:** An AC source from Ainuo (P/N: ANFS030A) is applied in this reference design. The input source must be an adjustable AC source whose output can be adjusted up to 300VAC and must be capable of supplying at least 85A(RMS).

**Output Load:** Two high-voltage resistor banks from ZENI THSUN (P/N: 50KW650-1000V DC) in parallel may be used for DCAC testing. The resistor banks must be capable of sinking 85A of load current supplied from the evaluation board, whose output can be 33kW.

A programmable high-voltage electronic load from EA (P/N: ELR 11500-60) is used as resistor load for ACDC testing. This load can draw more than 25A current from the unit.

**Power Meter:** A power analyzer from Tektronix Test and Measurement Corporation (P/N: PA 4000) or any other equivalent power analyzer should be used. An external shunt resistor is used to sense the AC output current since it exceeds the rating of the internal shunt resistor.

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

**Low-voltage power supplies:** The following LV power supplies with isolated grounds should be used and must be obtained separately:

- 1) 14Vdc @ 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 capacitor boards:** In a three-phase ANPC system, the voltage and current ripple of the DC-link is relatively small compared with single-phase operation. However, since this design is to verify the capability and performance of discrete SiC MOSFETs in a single-phase ANPC topology, the ripples of current and voltage of DC-link are very high. To enable the system to operate normally, two extra DC-link capacitor boards are added to the main board via cables as shown in Figure 6a.

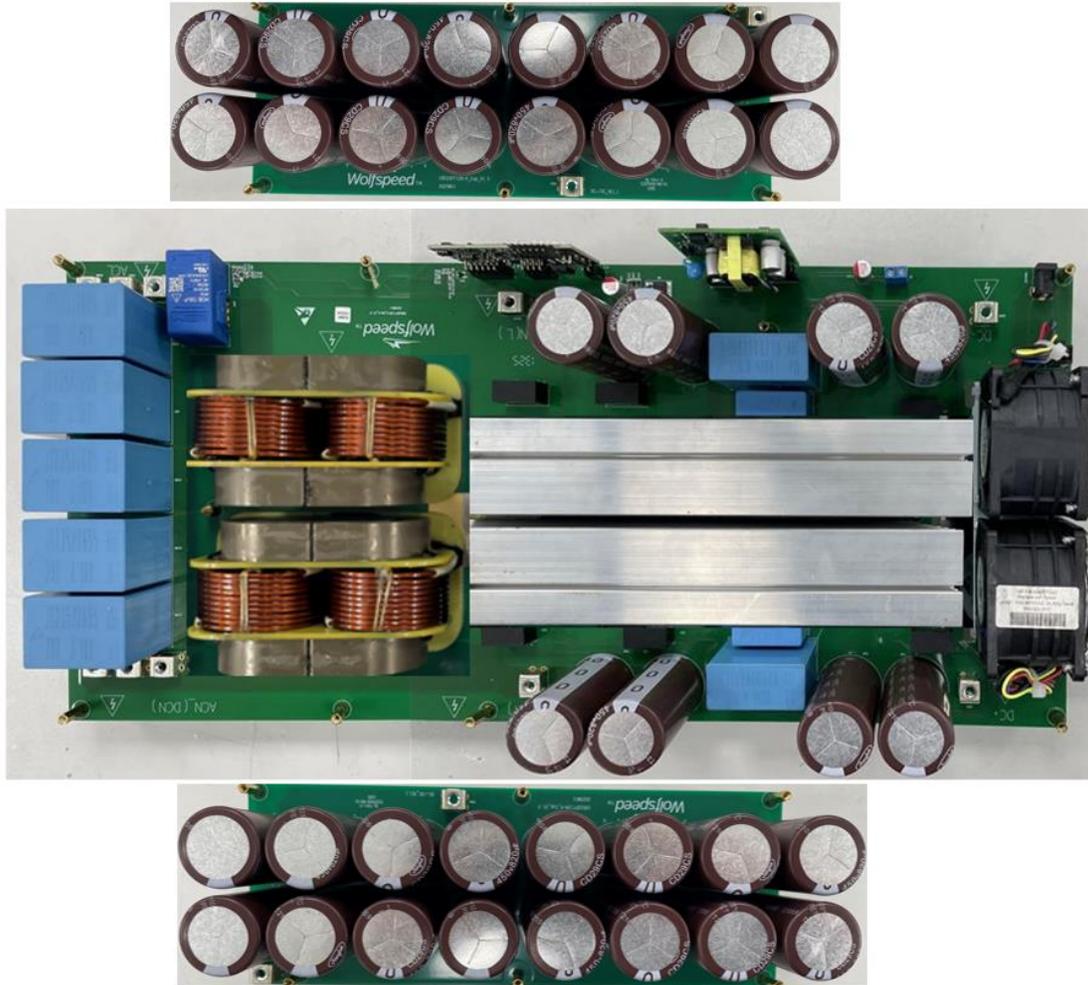


Figure 6a. extra DC-link capacitor boards and main board



Figure 6b. Control board setup and external FANs

## 7.2 Recommended ACDC Test Setup

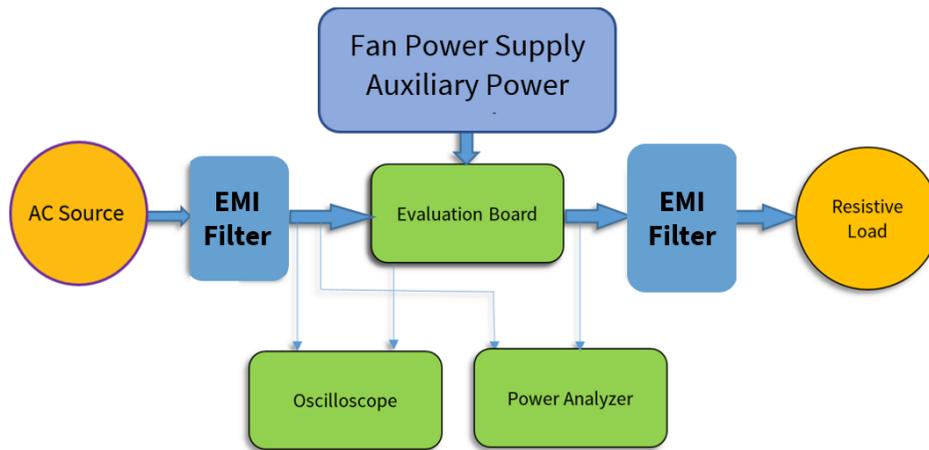


Figure 7. Converter Test Setup

The AC source is connected to the **AC**-side terminals and the load is connected to the **bus**-side terminals.

- Connect AC source + EMI filter to the power board.
- Connect a pure resistive load to the EMI filter, then connect the EMI filter to the **bus-side** terminals of the power board.
- Connect current shunts and multimeters to measure input/output voltage and input/output current.
- Use appropriately rated voltage and current probes and connect to the oscilloscope.

## 7.3 Recommended DCAC Test Setup

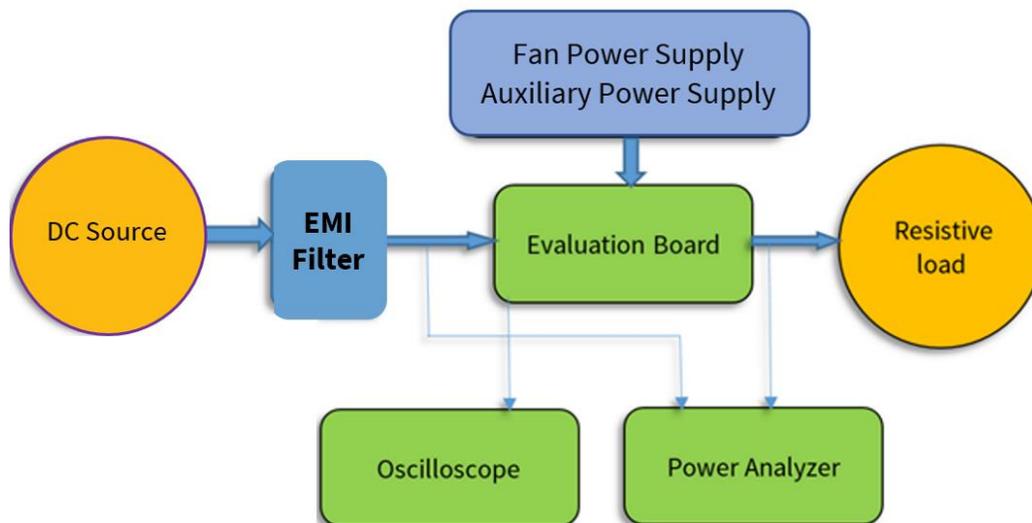


Figure 8. Converter Test Setup

The DC source is connected to **bus**-side terminals through an EMI filter, and the load is connected to the **AC**-

side terminals.

- Connect DC source + EMI filter to the **bus**-side terminals of the evaluation board.
- Connect a pure resistive load to the **AC**-side terminals of the power board.
- Connect current shunts and multimeters to measure input/output voltage and input/output current.
- Use appropriately rated voltage and current probes and connect to the oscilloscope.

## 7.4 Connection Between Power Board and Capacitor Board

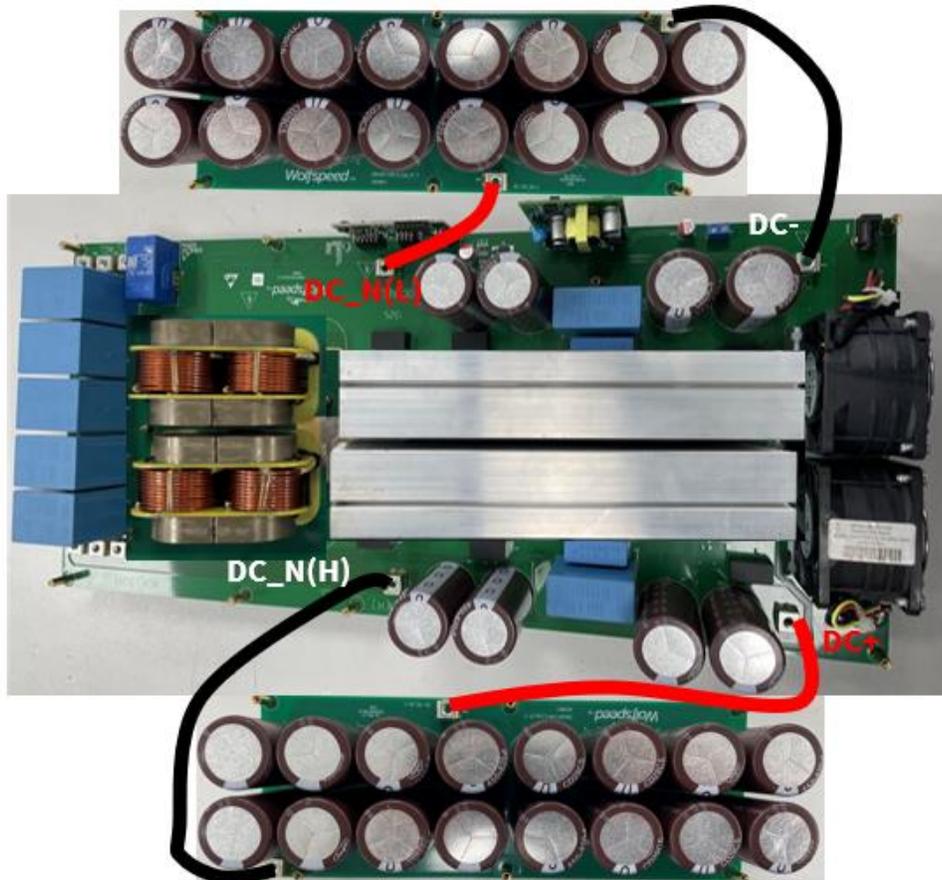


Figure 9. Converter Test Setup

As mentioned in the previous section, external capacitor boards need to be connected to the power board to support the DC-Link voltage in order to run the system properly. The connection can be seen in Figure 9. The DC-Link voltage is series by the upper DC-Link and lower DC-Link, and each of them is connected to an external capacitor board. For the upper DC-Link connection, the “**DC+**” terminal in the power board connects to the terminal “**DC+/DC\_N(L)**” in the capacitor board, and the “**DC\_N(H)**” terminal in the power board connects to the terminal “**DC-/DC\_N(H)**” in the capacitor board. For the lower DC-Link connection, the “**DC\_N(L)**” terminal in the power board connects to the terminal “**DC+/DC\_N(L)**” in the capacitor board, and the “**DC-**” terminal in the power board connects to the terminal “**DC-/DC\_N(H)**” in the capacitor board.

## 7.5 Protections

Table 4 describes over/under voltage protection (OVP/UVP) and over current protection (OCP) functions in the reference design. OCP protection is a one-shot protection that requires a system reset to clear the fault and restart.

To prevent damage to the unit, do not overload the converter outside the operating specs.

Table 4: Protection Details

Power Signal	Protection	Trip Point
DC-Link Voltage (half of DC-Link voltage)	OVP	>900V
Output AC Voltage	OVP	>450V
	UVP	<50V (rms)
Inductor Current	OCP	130A (rms)

## 7.6 Measured Parameters

The gate and drain voltages of the MOSFETs must be measured with caution. **Probes should be connected to them only after the removal of input power and only after the converter is turned off and it has been verified that no voltage remains.**

Table 5: Parameters which can be measured

NAME	DESCRIPTION
Efficiency	Measured with power analyzer
AC /DC Current	AC side current at ACDC and DCAC mode
AC /DC Voltage	bus side voltage at ACDC mode, AC side voltage at DCAC mode
THD	Current THD at ACDC mode and voltage THD at DCAC mode
Vgs /Vds Signals	voltage across gate to source or drain to source of SiC MOSFETs

## 8. 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.

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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。

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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 (ACDC mode or DCAC mode) can't be changed after start-up.
2. Please choose the appropriate power direction matched with the setup.
3. Do not overload the inverter. The output power should not exceed 33kW and the AC-side current should not exceed 85A (RMS).
4. There is no current inrush limiter for bus side or AC side. The **DC input voltage at DCAC mode or AC input voltage at ACDC mode must be increased slowly from zero (soft-start)**.
5. Always remember to connect the cooling fans to their power supplies and power on the cooling fans when operating the board.

## 8.1 Startup Procedure: DCAC Mode with Resistive Load

Please take the following steps in order when starting the unit:

1. Double check the setup: Make sure the polarity is correct, the DC source is connected to the bus-side terminals "DC+" and "DC-", and the load is connected to the AC-side terminals "ACL" and "ACN\_(DCN)".
2. Check the input status and make sure the DC source output is disabled.
3. Apply 14Vdc to main board J2. Check the +3.3V LED (on) and watchdog LED (blinking) on the control board.
4. Connect the GUI to the system. Select "ACDC-OFF" and "DCAC-OFF" commands and click "Send to Converter" after it is connected successfully.
5. Apply 12VDC to the cooling fans and turn them on.
6. Select "DCAC-ON" and "ACDC-OFF" commands and click "Send to Converter". The converter will start up.
7. Turn on the DC supply and increase its output voltage slowly from 0V to the required voltage (1100VDC ~ 1400VDC).
8. Verify that the measured values in the GUI are reported correctly.
9. After the output voltage has reached the required voltage, apply a load to the output with no more than 2kW steps to prevent control loop instability and overload, which may cause hardware damage.

10. Measure the efficiency data at different load conditions through the power analyzer.

## 8.2 Turn Off Procedure: DCAC Mode with Resistive Load

Please take the following steps in order when shutting down the unit:

1. Reduce the load gradually to zero load.
2. Use GUI to select “DCAC-OFF” and “ACDC-OFF” commands and click “Send to Converter”. The converter will be turned off.
3. Turn OFF the DC source, wait until the DC source has fully discharged its output.
4. Turn OFF load after the bus-side capacitors are fully discharged.



- 5. Capacitors may remain charged for up to 30 minutes after the circuit is turned OFF if steps 3 or 4 are skipped or compromised. They must be fully discharged before handling the board. Please check the terminal voltages with the power analyzer or a digital multimeter to ensure that the board is fully discharged and is therefore safe to handle.**
6. Turn OFF the 12Vdc power supply for cooling fans, turn off the 14Vdc power supply on main board J2.

## 8.3 Startup Procedure: ACDC Mode

Please take the following steps in order when starting the unit:

1. Double check the setup: Make sure the polarity is correct, the AC source is connected to the AC-side terminals “ACL” and “ACN\_(DCN)”, and the bus-side terminals “DC+” and “DC-” are connected to the resistor load.
2. Check the input status and make sure the AC source output is disabled.
3. Apply 14Vdc to main board J2. Check the +3.3V LED (on) and watchdog LED (blinking) on the control board.
4. Connect the GUI to the system. Select “DCAC-OFF” and “ACDC-ON” commands and click “Send to Converter”. The converter will start up.
5. Apply 12VDC to the cooling fans and turn them on.
6. Turn on the AC supply and slowly increase the AC voltage to 300V RMS.

7. Verify that the measured values in the GUI were reported correctly.
8. Select “DCAC-OFF” and “ACDC-ON” commands and click “Send to Converter” with the desired output bus voltage. The converter will start up and output the desired bus voltage.
9. Measure and record the efficiency data and current THD at different load conditions using the power analyzer.

## 8.4 Turn Off Procedure: ACDC Mode

Please take the following steps in order when shutting down the unit:

1. Reduce the load gradually to no load.
2. Use GUI to select “DCAC-OFF” and “ACDC-OFF” commands and click “Send to Converter”.
3. Turn OFF the AC source.
-  **4. Capacitors may remain charged for up to 30 minutes after the circuit is turned OFF if steps 3 or 4 are skipped or compromised. They must be fully discharged before handling the board. Please check the terminal voltages with the power analyzer or a digital multimeter to ensure that the board is fully discharged and is therefore safe to handle.**
5. Turn OFF the 12Vdc power supply for cooling fan, turn off the 14Vdc power supply on main board J2.

## 9. Photo of Reference Design

Figure 10 shows the locations of the terminals and key components on the Power Board.

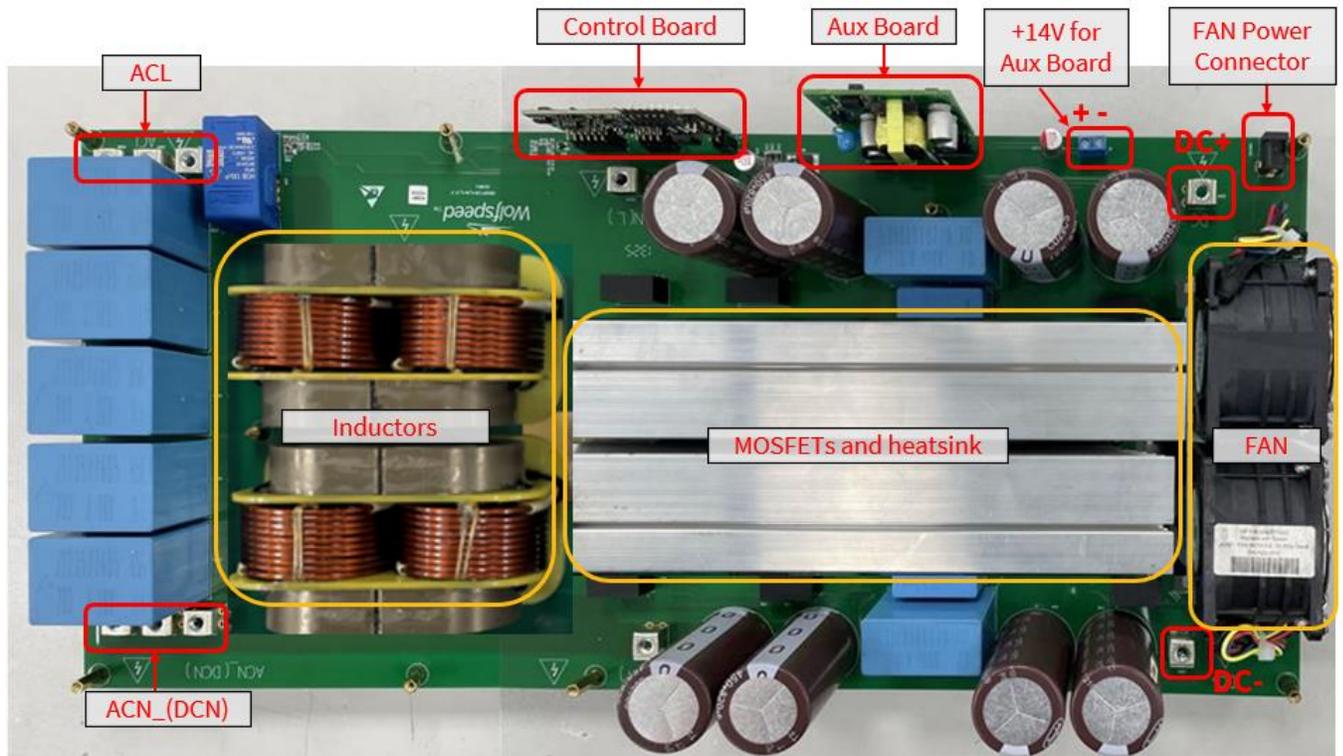


Figure 10: Top View of PCBA (467mm\*214mm\*65mm)

## 10. Performance Data

Shown below is measured performance data of Wolfspeed’s CRD-33FF12N-K reference design board under various conditions. Table 6 shows the performance data in ACDC mode at 300Vac input and 1100Vdc output, Table 7 shows the performance data in DCAC mode at 1400Vdc input and 420Vac output.

Table 6: Efficiency Data of ACDC

Input Voltage (Vac)	Input Power (W)	I <sub>AC</sub> (%)	Output Power (W)	Current THD (%)	Overall Efficiency
300.23	2528.7	10	2493.599	7.53%	98.72%
300.05	5037.3	20	5041.962	5.30%	99.00%
299.88	7586.4	30	7549.831	4.14%	99.14%
299.73	10110	40	10046.528	3.55%	99.05%
299.61	12680	50	12541.965	3.25%	98.72%
299.49	15202	60	15051.267	3.09%	98.59%
299.42	17723	70	17548.285	3.03%	98.40%
299.29	20282	80	19976.690	2.95%	98.27%
299.15	22798	90	22465.007	2.96%	98.07%
298.99	25313	100	24988.183	2.97%	97.92%

Table 7: Efficiency Data of DCAC

Input Voltage (Vdc)	Input Power (W)	I <sub>AC</sub> (%)	Output Power (W)	Voltage THD (%)	Overall Efficiency
1399.763	3412.482	10	3379.9	0.99%	99.05%
1399.674	6720.255	20	6663.1	1.45%	99.15%
1399.576	10006.27	30	9900.3	1.62%	98.94%
1399.501	13451.44	40	13275	1.57%	98.69%
1399.394	16714.08	50	16465	1.55%	98.51%
1399.306	19996.92	60	19673	1.57%	98.38%
1398.902	23516.66	70	23104	1.67%	98.25%
1398.22	26967.75	80	26467	1.78%	98.14%
1397.937	30402.33	90	29802	1.94%	98.03%
1396.848	33825.09	100	33119	2.18%	97.91%

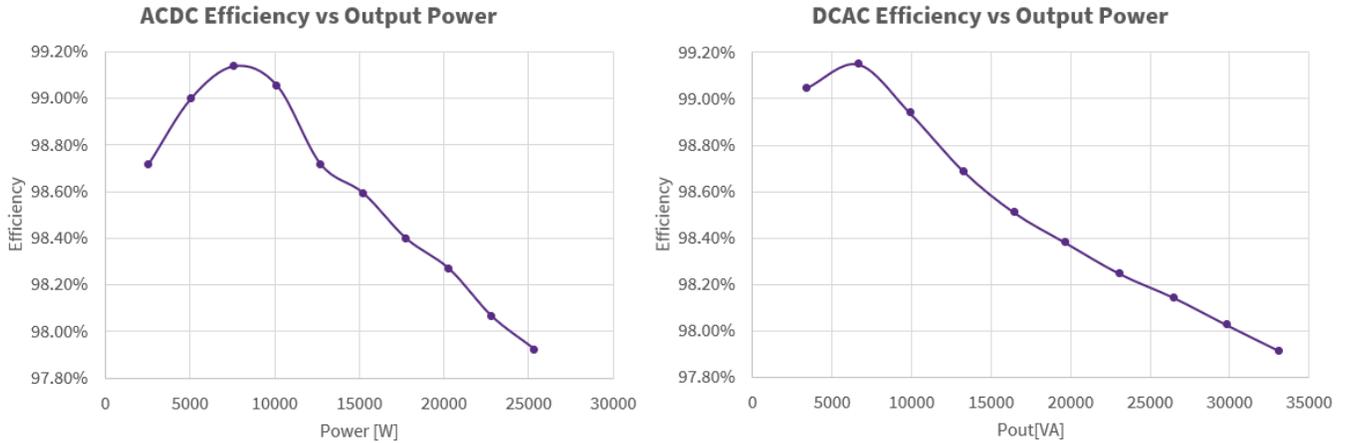
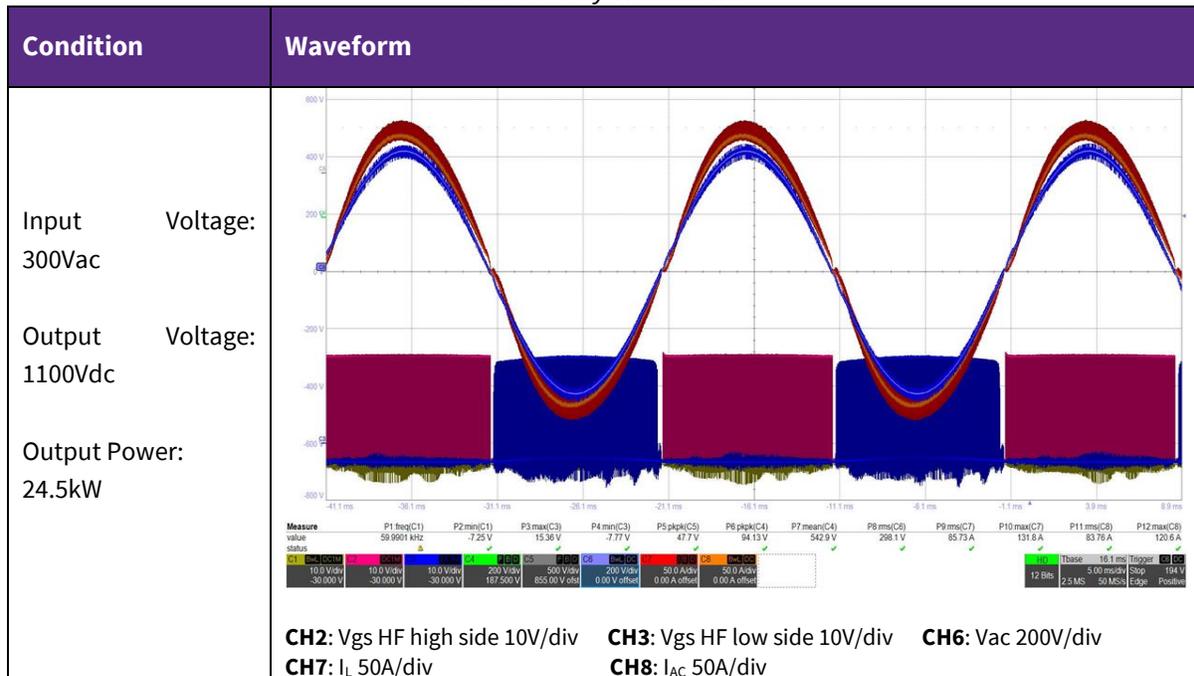


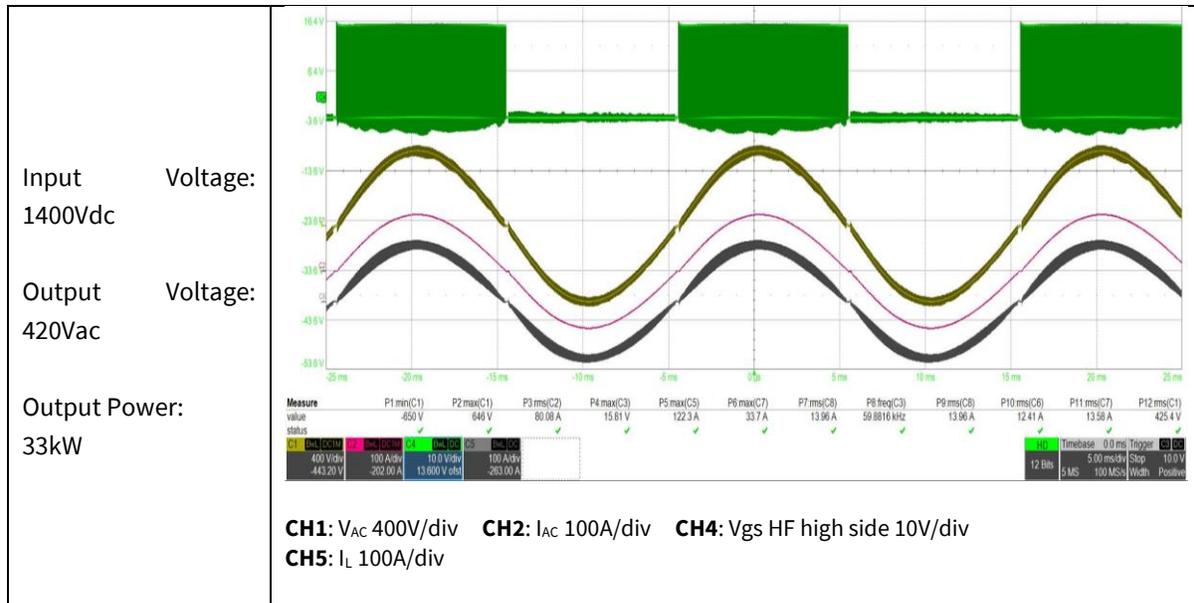
Figure 11: Efficiency Curve

## 11. Typical Waveforms

Operational waveforms are presented in Table 7.

Table 7: Key Waveforms





## 12. Thermal Design and Test Results

In a thermal test of the unit, forced-air cooling is applied to the cooling heatsink to maintain at around 55°C. There will be direct air flow to the power MOSFETs. MOSFETs in the converter operate in full 85A rms AC current under both ACDC and DCAC mode. The thermal test was performed at 1400Vdc input and full load 33kW with 400Vac/85A load at DCAC mode and 300Vac/85A (RMS) input 25kW with 1100Vdc at ACDC mode. K-type thermal couples 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 8. The highest junction temperature of any MOSFETs in the design was determined to be 86.98°C. This value was calculated based on the measured case temperature, the thermal resistance of the MOSFET, and the calculated power loss. The maximum junction temperature of the C4MS047120K is 175°C. The integrated heat sink design allows the MOSFETs to remain within their thermal derating guidelines.

Table 8: Thermal Test Results of SiC Power MOSFETS

Description	Rth (j-c) (c/w)	Calculated Power loss (watts)	Measured Case Temp. (°C)	Calculated Junction Temp. (°C)	Max. operating junction temperature (°C)	Result
<b>ACDC, Vin = 300Vac, Vout = 1300Vdc, 25KW, T<sub>heatsink</sub> = 55C</b>						
<b>MOSFET Q13</b>	0.79	16.82	66.6	79.9	175	Pass
<b>MOSFET Q23</b>	0.79	20.5	68.1	84.3	175	Pass
<b>MOSFET Q33</b>	0.79	20.5	69.4	85.6	175	Pass
<b>MOSFET Q43</b>	0.79	16.82	64.2	77.5	175	Pass
<b>MOSFET Q52</b>	0.42	31.05	71.4	84.4	175	Pass
<b>MOSFET Q62</b>	0.42	31.05	72.7	85.7	175	Pass
<b>DCAC, Vin = 1400Vdc, Vout = 420Vac, 33KW, T<sub>heatsink</sub> = 55C</b>						
<b>MOSFET Q13</b>	0.79	25.66	68.3	88.6	175	Pass
<b>MOSFET Q23</b>	0.79	8.28	61.3	67.8	175	Pass
<b>MOSFET Q33</b>	0.79	8.28	61.2	67.7	175	Pass
<b>MOSFET Q43</b>	0.79	25.66	65.9	86.2	175	Pass
<b>MOSFET Q52</b>	0.42	27.59	66.5	78.1	175	Pass
<b>MOSFET Q62</b>	0.42	27.59	66.6	78.2	175	Pass

## 13. Appendix

### 13.1 CAN Messages from converter

Table 9: Overall Charge Status

Message Identifier	0x18B2F4E5			
<b>Data</b>	Byte0+Byte1	Byte2+Byte3	Byte4+Byte5	Byte6+Byte7
<b>Property</b>	AC Voltage	Output Voltage	AC Frequency	Choke Current
<b>Unit</b>	0.1V	0.1V	0.1Hz	0.1A
<b>Bias</b>	0			
<b>Data Format</b>	integer			
<b>Time interval</b>	0.5 seconds			

Table 10: Temperature

Message Identifier	0x18B0F4E5			
<b>Data</b>	Byte0+Byte1	Byte2+Byte3	Byte4+Byte5	Byte6+Byte7
<b>Property</b>	Temperature	Reserved 0xFFFF	Reserved 0xFFFF	Reserved 0xFFFF
<b>Unit</b>	0.1 °C	NA		
<b>Bias</b>	50 °C	NA		
<b>Data Format</b>	integer			
<b>Time interval</b>	3 seconds			

Table 11: PFC Information

Message Identifier	0x18B3F4E5			
<b>Data</b>	Byte0+Byte1	Byte2+Byte3	Byte4+Byte5	Byte6+Byte7
<b>Property</b>	PFC status. See <a href="#">Table 11a</a> for details.	Reserved 0xFFFF	Reserved 0xFFFF	Reserved 0xFFFF
<b>Unit</b>	NA			
<b>Bias</b>	0			
<b>Data Format</b>	integer			
<b>Time interval</b>	0.5 seconds max.			

Table 11a: Bit Definition for PFC Status

Converter Status	Comments	Converter Status	Comments
<b>Bit15</b>	Reserved	Bit7	1: Output OVP_H 0: normal (default)
<b>Bit14</b>	Reserved	Bit6	1: Output OVP_L 0: normal (default)
<b>Bit13</b>	1: Inductor OCP 0: normal(default)	Bit5	Reserved
<b>Bit12</b>	1: Input OVP 0: normal(default)	Bit4	Reserved

<b>Bit11</b>	Reserved	Bit3	Reserved
<b>Bit10</b>	Reserved	Bit2	Reserved
<b>Bit9</b>	Reserved	Bit1	Reserved
<b>Bit8</b>	Reserved	Bit0	1: CAN error 0: normal (default)

Table 12: Part I of PFC Specification

<b>Message Identifier</b>		<b>0x1AB8F4E5</b>			
<b>Data</b>	Byte0+Byte1	Byte2+Byte3	Byte4+Byte5	Byte6+Byte7	
<b>Property</b>	Com. Software Version	Min. Input Voltage	Max. Input Voltage	Reserved	
<b>Unit</b>	0.01	0.1V	0.1V	NA	
<b>Bias</b>	0				
<b>Data Format</b>	integer				
<b>Time interval</b>	Reply to 0x18A8E5F4				

Table 13: Part II of PFC Specification

<b>Message Identifier</b>		<b>0xAB9F4E5</b>			
<b>Data</b>	Byte0+Byte1	Byte2+Byte3	Byte4+Byte5	Byte6+Byte7	
<b>Property</b>	PFC Software Version	Output Voltage	Max. Output Power	Reserved	
<b>Unit</b>	0.01	0.1V	0.001W	NA	
<b>Bias</b>	0				
<b>Data Format</b>	integer				
<b>Time interval</b>	Reply to 0x18A8E5F4				

## 13.2 CAN Messages to converter

Table 14: Control command

Message Identifier 0x18A5E5F4						
Data	Byte0	Byte1	Byte2	Byte3	Byte4+Byte5	Byte6+Byte7
<b>Property</b>	Reserved 0xFFFF	0: ACDC-OFF 1: ACDC-ON	0: DCAC-OFF 1: DCAC-ON	Reserved 0xFFFF	Output Voltage	Reserved 0xFFFF
<b>Unit</b>	NA				0.1V	NA
<b>Bias</b>			0			
<b>Data Format</b>			integer			

## 14. Revision History

Date	Revision	Changes
June 2025	1	First issue

## 15. IMPORTANT NOTES

### 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. **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 Wolfspeed 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 Wolfspeed 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 Wolfspeed 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 Wolfspeed.

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 end 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 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.**

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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.