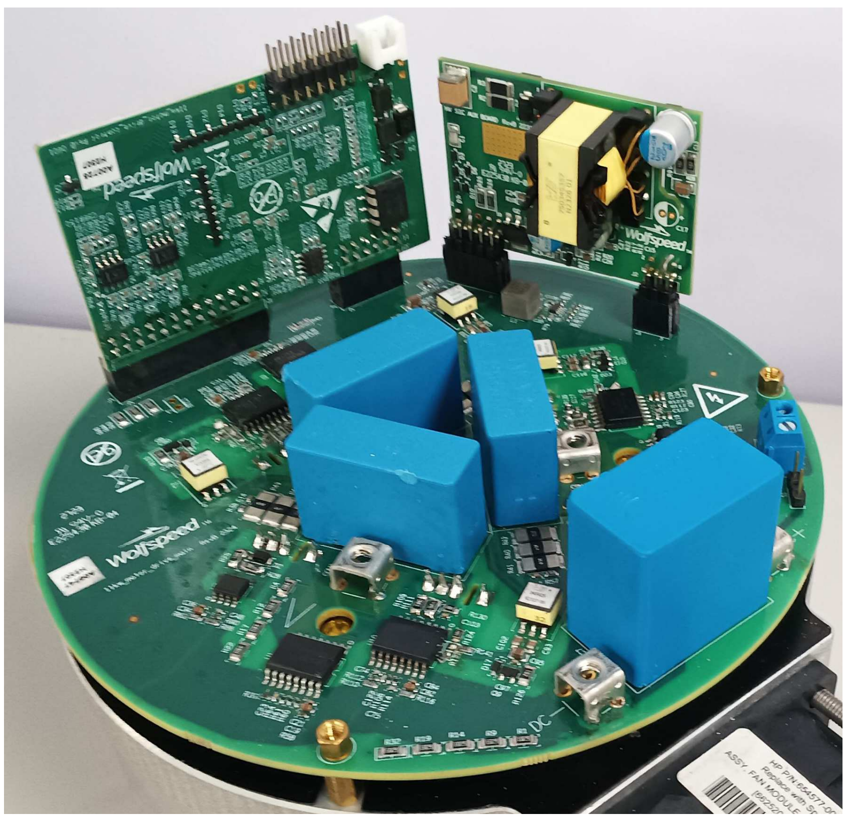
User Guide **PRD-08373**

CRD-11DA12N-K and CRD-20DA12N-K:

11 and 20 kW High-Efficiency Motor Drive Inverters

11 / 20 kW SiC MOSFET 高效率电机驱动逆变器
11 / 20kW 高効率モーターくどう駆動インバータ



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CRD-11DA12N-K and CRD-20DA12N-K: 11 and 20 kW High-Efficiency Motor Drive Inverter

This reference design demonstrates how to use silicon carbide (SiC) MOSFETs to optimize the performance of a motor drive for auxiliary motors in electric vehicles, as well as Heating Ventilation and Air Conditioning (HVAC) and other similar applications. Utilizing SiC MOSFETs for these applications can increase system efficiency, reduce audible noise, and increase power density compared to silicon solutions. Although SiC MOSFETs are capable of achieving very high dv/dt switching transitions, the speed can also be easily controlled with the gate resistor to lower levels that are compatible with standard motor insulation while still achieving lower switching losses than silicon IGBTs.

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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。

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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

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1. Introduction

This User's Guide provides the schematic, artwork, and test setup necessary to evaluate Wolfspeed's CRD-11DA12N-K and CRD20DA12N-K, 11/20kW SiC Motor Drive Inverter with high efficiency for Vehicle Electrification (VE), Heating Ventilation Air Conditioning (HVAC), and other similar drive applications.

This design is based upon Wolfspeed's third-generation SiC MOSFETs - C3M0075120K (1200V, 75mΩ, TO-247-4) and C3M0040120K (1200V, 40mΩ, TO-247-4) for the 11 kW and 20 kW designs respectively. A block diagram of 11 /20 kW Motor Drive Inverter (P/N CRD-11DA12N-K) based on SiC is shown in Figure 1. The converter is a DCAC stage working with a three-phase Permanent Magnet Synchronous Motor (PMSM). Referring to Figure 1, it operates from DC-link voltage at input-side DC terminals and provides a non-isolated three-phase AC output voltage at the output-side AC terminals.

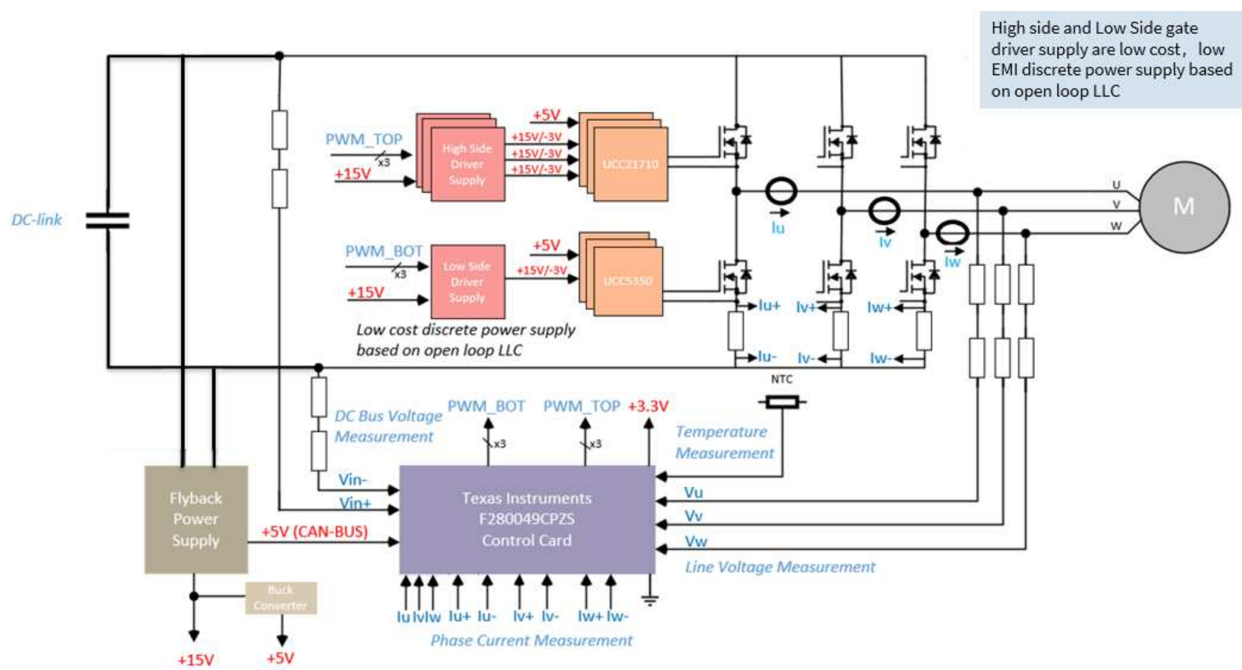


Figure 1: Block Diagram of Wolfspeed's CRD-11DA12N-K, 11kW Motor Drive Converter

This reference design uses a SiC-based 11 kW three-phase 6 switch topology, creating a three-phase AC voltage for the later motor. This converter can further reduce the number of semiconductors and achieve higher efficiency by using silicon carbide products. The converter operates at 16-32 kHz switching frequency. A tooled heatsink was designed to dissipate the heat generated by the power MOSFETs. An external power source is required to power the fan to cool the unit. The power density is up to 27kW/L.

Due to the inherent limitation of the motor insulation, the switching speed (rise and fall times) must be reduced compared to what SiC MOSFETs are capable of. Therefore, the dv/dt of V_{DS} during turn on/off are reduced to a target range according to the motors by adjusting the gate resistance value. In this design, the dv/dt is configured to about 15V/ns and30V/ns for different motor requirements.

The purpose of this reference design is to show the SiC performance in motor drive applications. A resistive load may be used for hardware validation and power testing, or a motor can be used with closed loop control. The sensorless field-oriented control (FOC) scheme is optimized for the speed control loop. The DC input voltage is adjustable between 550 VDC and 850 VDC for three-phase AC output. This variable bus voltage helps to meet the requirements of different motors and applications.

The closed loop control firmware for this design has been optimized for a specific motor. If using this design with another motor, the firmware and control loop will need to be modified by the user to operate properly. It is recommended to use a three-phase resistive load operating in open loop mode to evaluate the switching performance and efficiency of the inverter.

2. Description

The CRD11DA12N version of this reference design uses Wolfspeed's 1200V 75mΩ SiC MOSFET, C3M0075120K in a TO-247-4 package to achieve 11 kW of output power. The CRD20DA12N version uses a 40 mΩ device in the same family, C3M0040120K, to achieve 20 kW of output power.

This evaluation board is compatible for both open-loop mode and closed-loop mode. In open loop mode, it is only used for gate driver signal verification and power performance testing with resistive load, not for motor testing. Thus, different graphical user interfaces (GUIs) are prepared for the two control modes configuration. In closed-loop mode, the unit must be started with a constant current to force the motor to run. That can be configured by the GUI command directly.

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 control mode and configuration of motor parameters. To achieve optimized motor performance, accurate motor parameters are needed for the angle estimation and speed control loop. The motor speed is configurable through the CAN interface in closed-loop mode. The maximum speed is 3000rpm of the motor we used.

3. Electrical Performance Characteristics

Table 1: Specifications of Wolfspeed's CRD-11DA12N-K, 11kW Motor Drive Converter

Parameter		Test Conditions	Min.	Nom.	Max.	Units
Input Characteristics						
$V_{IN(DC)}$	Input voltage		550	700	850	V_{rms}
f_{sw}	Switching frequency		16		32	kHz
Output Characteristics						
$V_{OUT(AC)}$	Output L-L RMS voltage		380	400	420	V
$I_{OUT(RMS)}$	Output RMS current	V_{IN} = 700V, P_{OUT} = 11kW V_{IN} = 700V, P_{OUT} = 20kW		25 50		A
$P_{OUT\ max}$	Output Power	11KW with C3M0075120K 20kW with C3M0040120K			11000 20000	W
f_{ac}	Output Line Frequency				200	Hz
Motor Characteristics						
$V_{IN(AC)}$	Rated RMS L-L Input voltage			320		V
I_{IN}	Rated RMS L-L Input current			38		A
f_{ac}	AC Frequency			200		Hz
$P_{MOTOR\ max}$				20		kW
S_{motor}	Speed of Motor			3000		R/min
System Characteristics						
η_{peak}	Peak efficiency	V_{IN} = V_{NOM}, 380V(L-L RMS), I_{OUT} = 40% of $I_{OUT(nom)}$		99%		
$\eta_{full\ load}$	Full load efficiency	V_{IN} = V_{NOM}, V_{OUT} = 380V(L-L RMS), I_{OUT} = 100% of $I_{OUT(nom)}$		98.6%		
Mechanical						
	Dimensions	Width Length Component height		133 145 60		mm

3.1 Application

The primary application of the CRD-11DA12N-K and CRD-20DA12N-K reference designs are three-phase motor drive applications, but the output could be connected to a resistive load or an electronic load under open-loop operation. For the electronic load, Constant Resistor (CR) mode is recommended.

3.2 Features

Some of the features and limitations of the reference designs are listed below:

- Wide DC link voltage range: 550 – 850 VDC

- Maximum output power: 11kW for C3M0075120K version, 20kW for C3M0040120K version
- Switching frequency: 16-32 kHz
- Peak efficiency > 99%
- Protection functions are shown in Table 4.
- Electrical performance of the inverter can be evaluated in open-loop mode
- Sensorless FOC scheme is optimized with a three phase AC PMSM
- Easy to test using GUI communication via CAN. See Section 6 and Section 13 for details.

4. Schematics

Note: Complete design files, including full-size schematics, are available for download 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

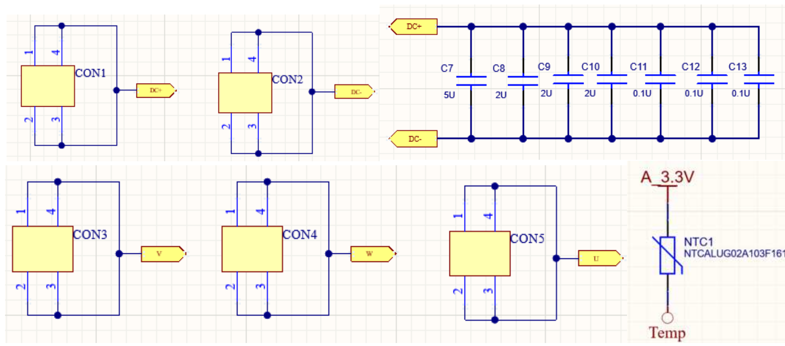


Figure 2a: Input and output terminals

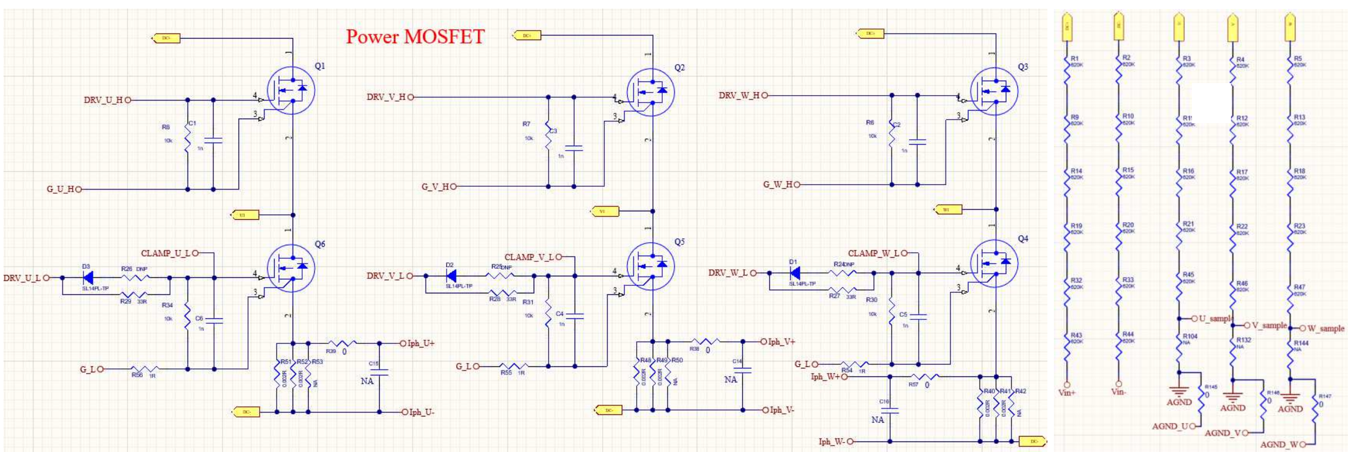


Figure 2b: Main converter MOSFETs and voltage sampling circuit

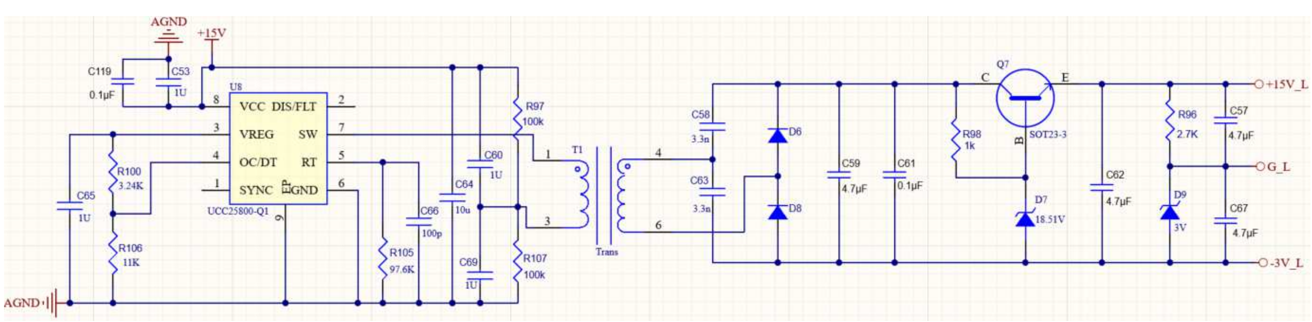


Figure 2c: Low-side gate drive bias power supply

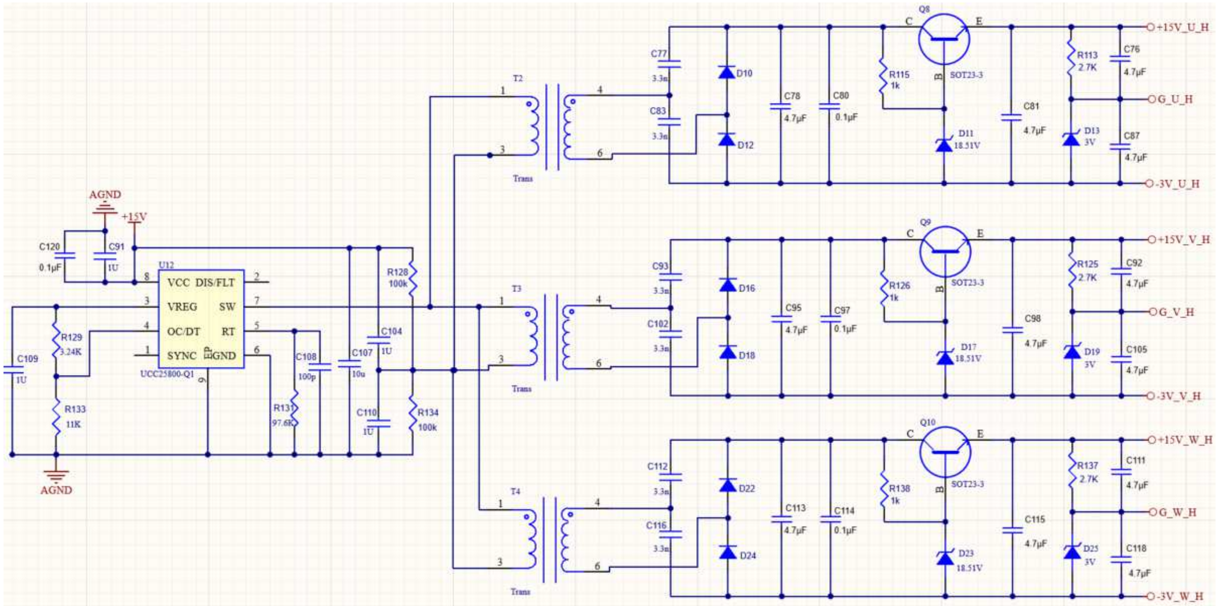


Figure 2d: High-side gate drive bias power supply

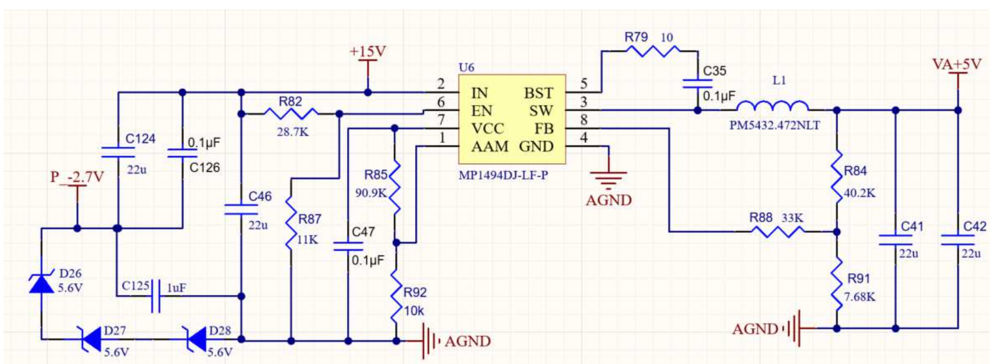


Figure 2e: Power supplies for control board

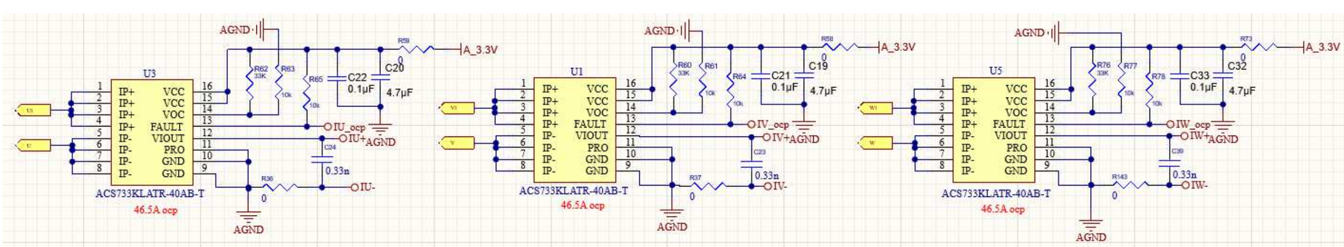


Figure 2f: Phase current sensing

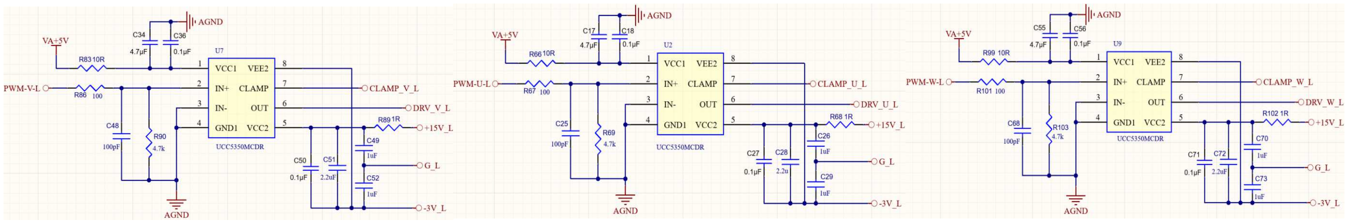


Figure 2g: Gate drivers of low-side MOSFETs

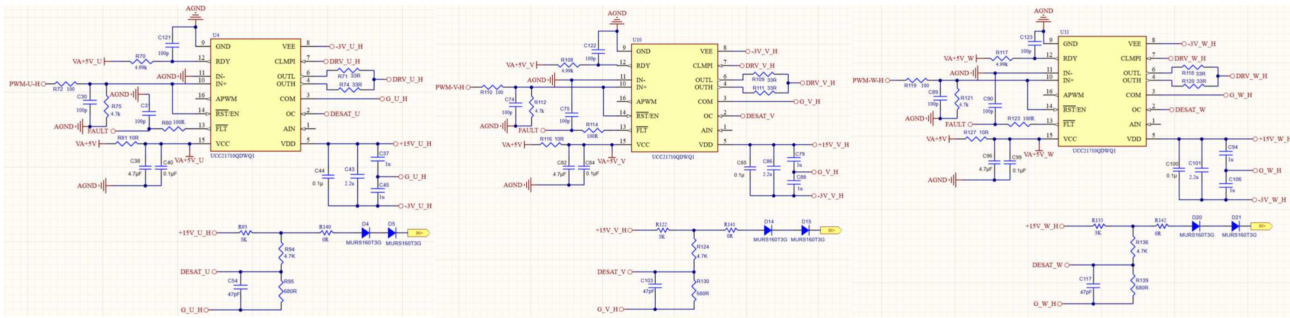


Figure 2h: Gate drivers of high -ide MOSFETs

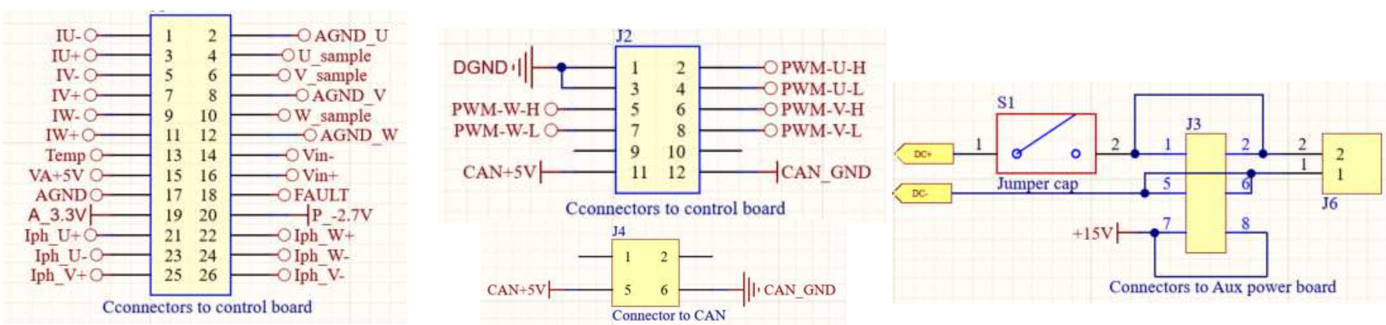
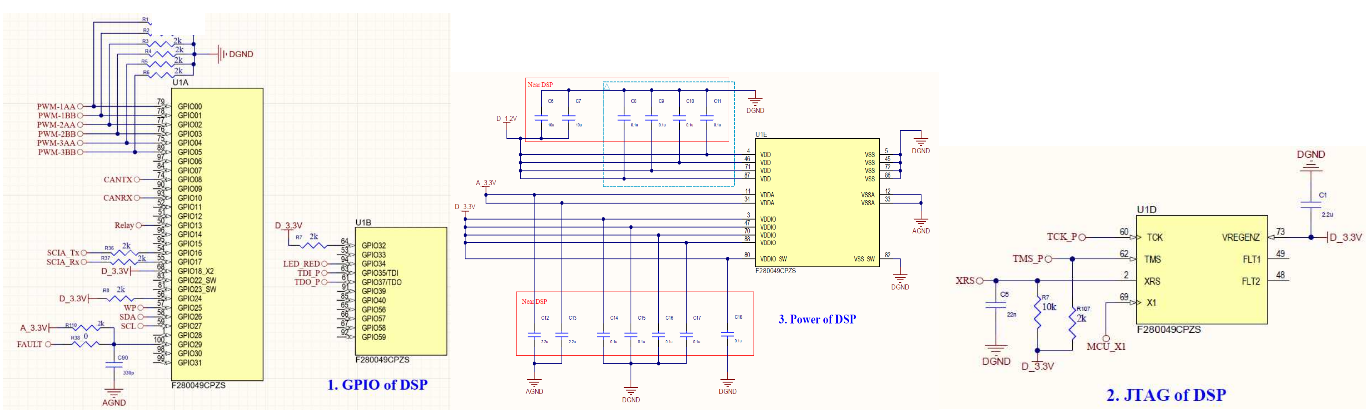


Figure 2i: Connectors to other boards

4.2 Control board



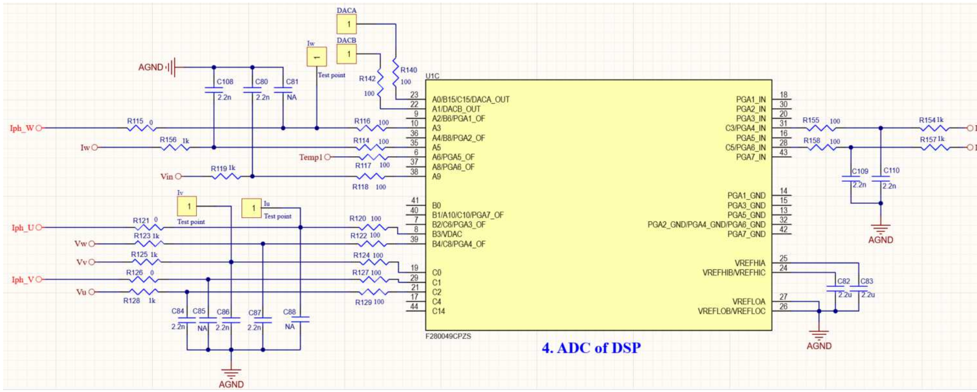


Figure 3a: DSP controller

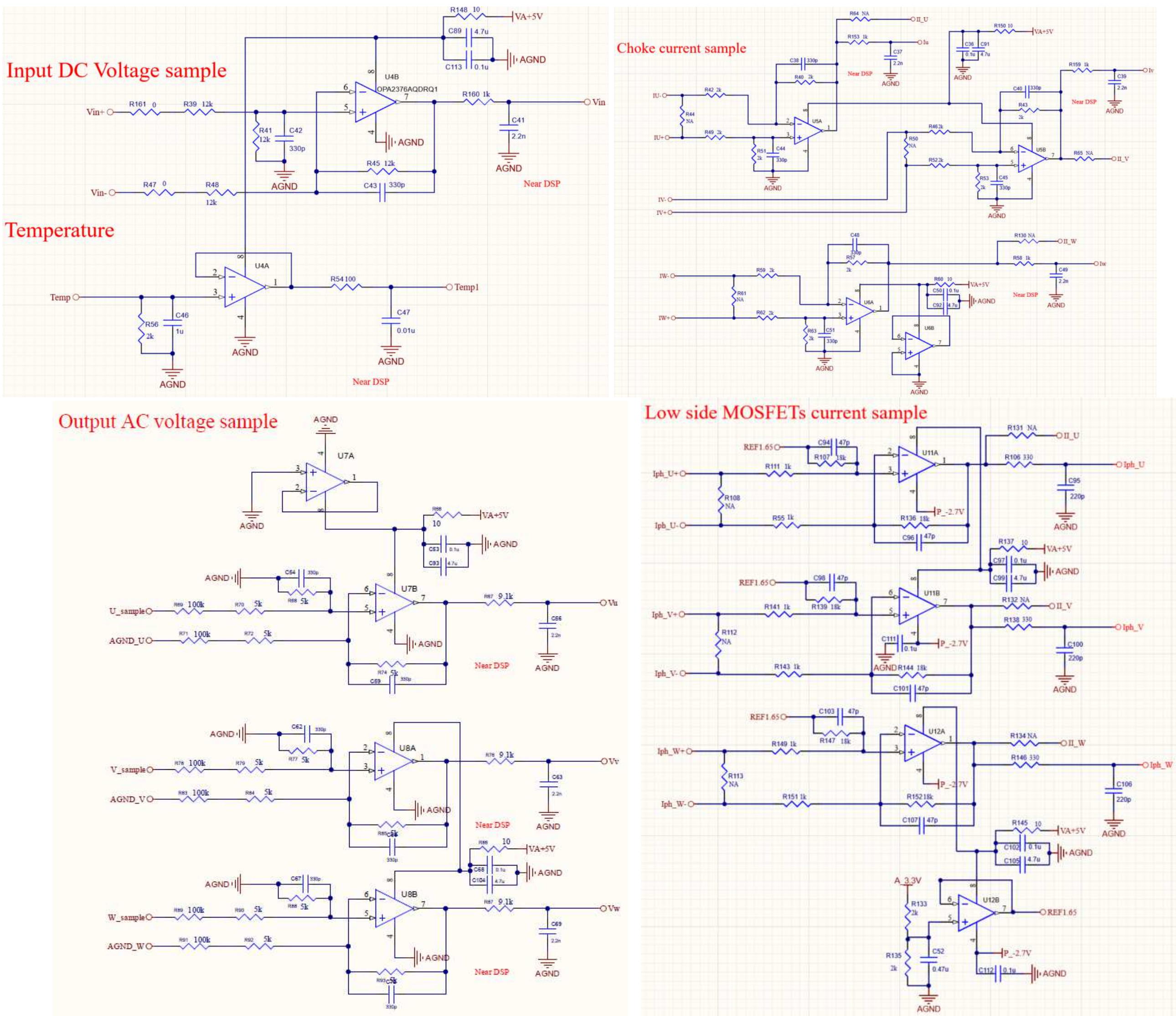


Figure 3b: Current and voltage sample circuits

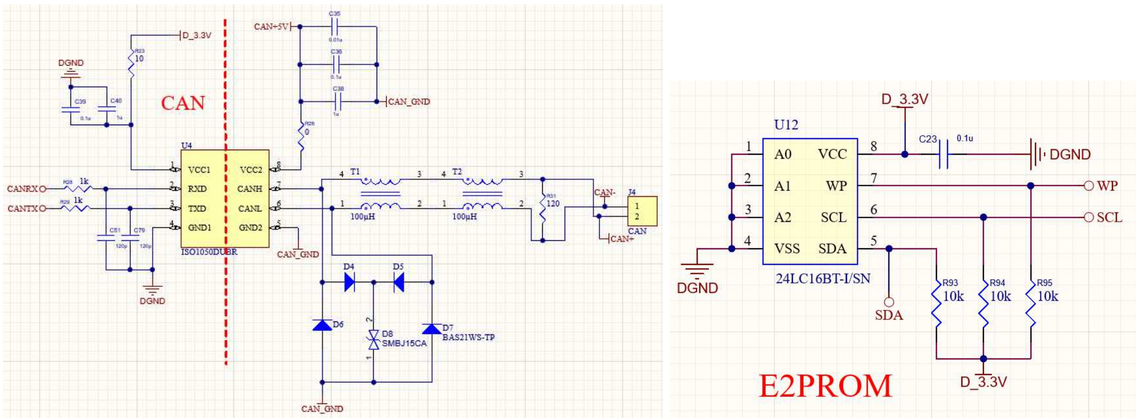


Figure 3c: CAN interface and E2PROM

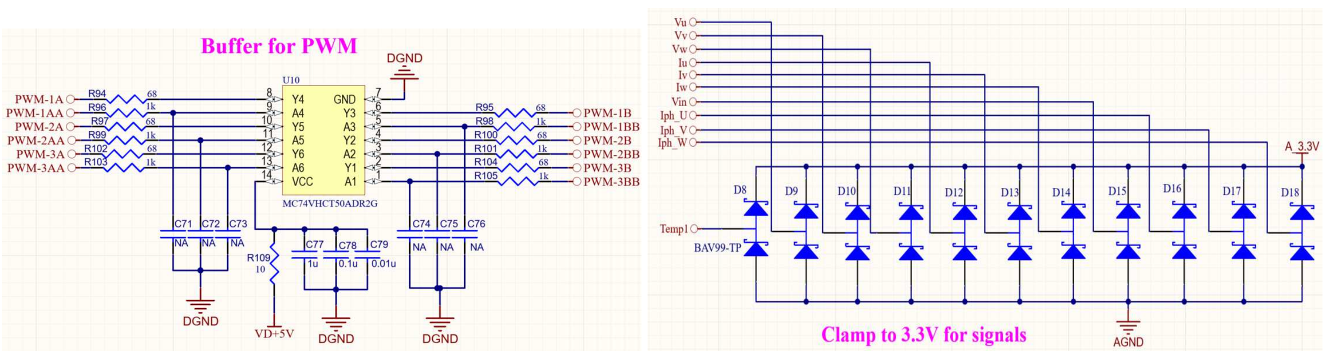


Figure 3d: PWM buffer and analog signal clamp

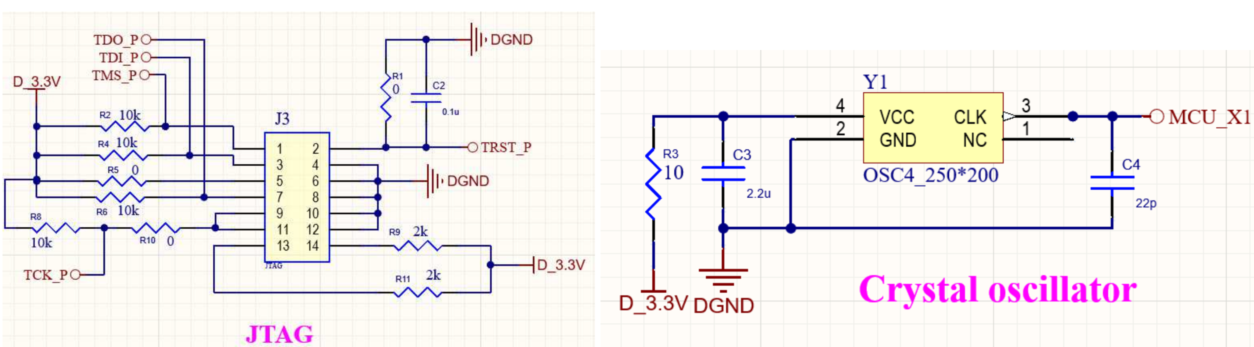


Figure 3e: JTAG and crystal oscillator for DSP

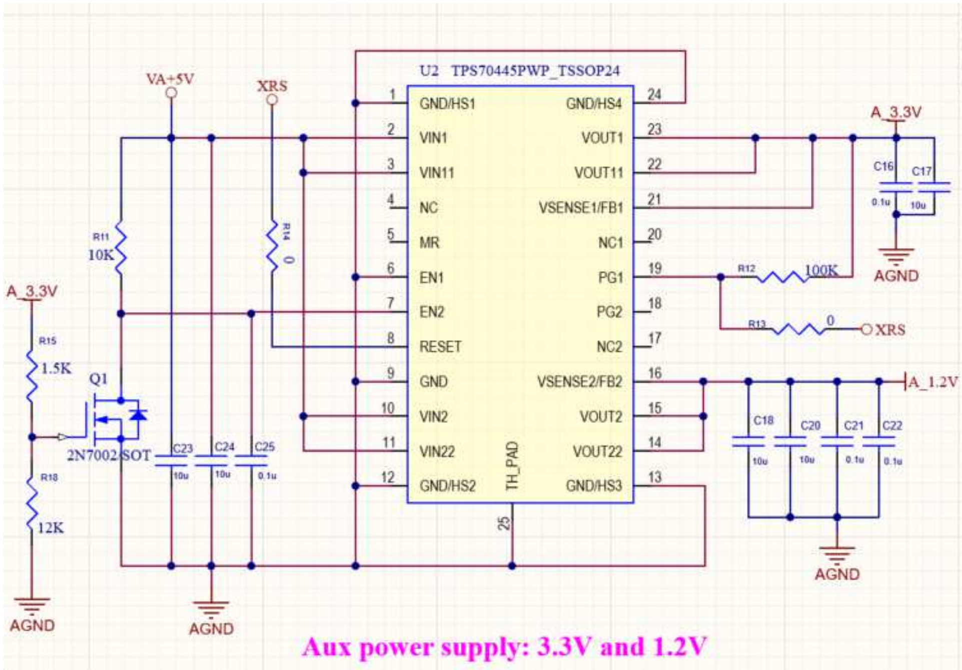


Figure 3f: Power supplies

4.3 Auxiliary Power Board

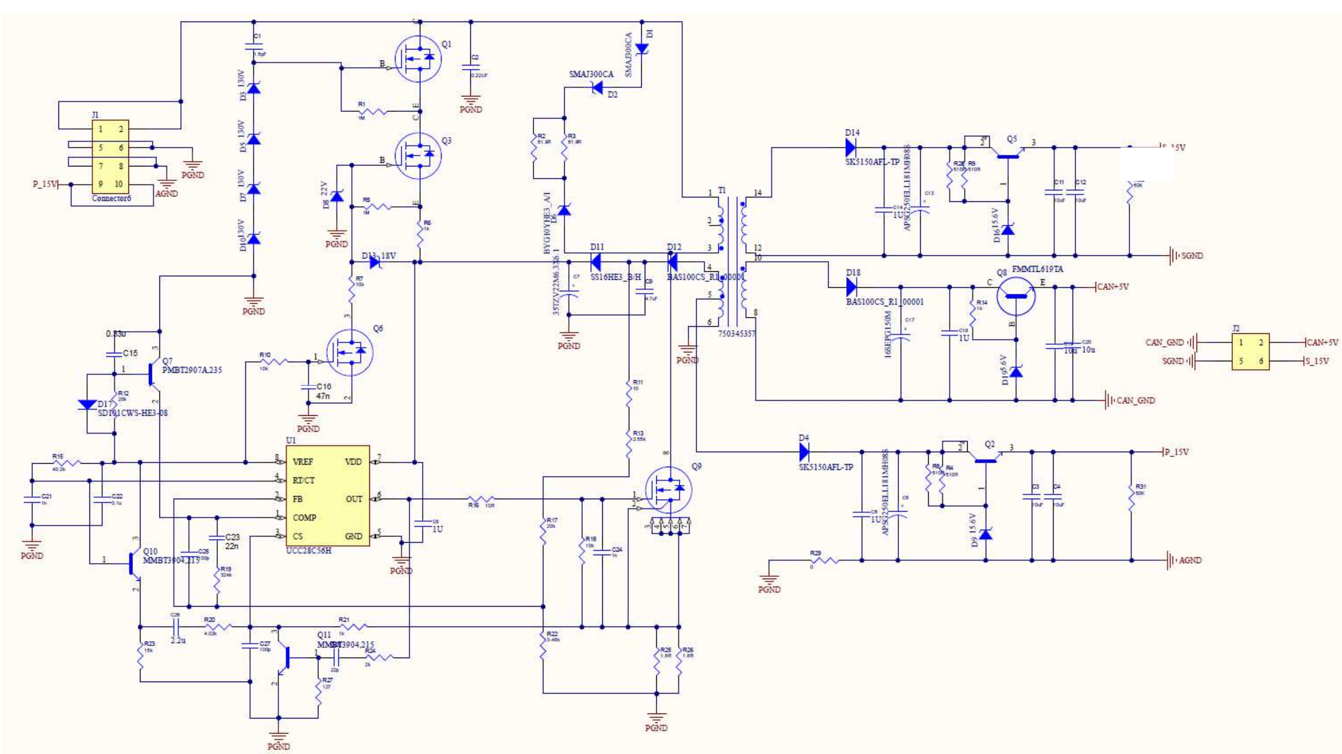


Figure 4: Schematic of auxiliary power board

5. Hardware Description

5.1 Power Board

As illustrated by Figure 2a to 2i, a two-level three-phase 6 switch topology with six MOSFETs is selected for the inverter. The input DC power supply is connected to terminals “DC+” and “DC-” of CON1 and CON2 respectively. High-frequency film capacitors C7-C13 are connected to form the DC bus. These are followed by three phase legs consisting of six Wolfspeed SiC MOSFETs (Q1~Q6). There are three resistors for measuring the low-side MOSFET’s current, and the three hall sensors (U1, U3, U5) are connected to the midpoint of three phase bridges. The resistor currents are used by the DSP for over current protection, and the three phase currents from hall sensors are used for closed-loop control.

Most motor drive applications require the inverter to protect itself in the event of a short circuit in the motor windings. In order to achieve this protection while also minimizing cost and size of the solution, two different gate driver ICs are used. The high-side devices utilize a Texas Instruments Inc.® UCC21710QDWQ1, which has fast Desat protection to detect a short circuit and shut down the system. The low-side MOSFETs are driven with a Texas Instruments UCC5350MCDR, which is a cost-effective driver with a small footprint. The high-side gate drivers are each independently powered by isolated bias supplies. The three low-side gate drivers share a single bias supply that is isolated from the system and control ground. The three-phase AC output terminals, U1, V1, and W1, of the inverter connect directly to the motor or load.

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 controller (P/N: F280049CPZS). The DC 15.0 V rail is generated from an isolated power supply and is supplied to the main board via connector J3. The power supply for the control board is an isolated 5.0 V power supply generated from a linear regulator on the main power board. This 5.0 V rail then supplies another precision linear regulator, U2, which provides both a 3.3 V and a 1.2 V 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 3.3V reference voltage for the controller’s Analog-to-Digital Converter (ADC) is generated internally by the DSP.

5.3 Auxiliary Power Board

The input voltage of the auxiliary power board is the DC bus (DC+ and DC- nets) provided by a connector from the main board. It provides three isolated output voltages, as shown in Table 2.

Table 2: Input and Outputs of Auxiliary Power Board

Input/Outputs	Net Name	Comments
Input	VBUS/PGND	Typical Input of the Auxiliary Power Board
Output 1	+15VP/AGND	15V Power Supply for MOSFET Gate Drivers
Output 2	+15VS/AGND	15V Power Supply for control board
Output 3	CAN+5V/CAN_GND	5V Output for CAN Communication

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

6. Communication

6.1 Graphical User Interface (GUI)

A Microsoft 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 6.

The firmware and GUI can be requested using the link on the reference design page on Wolfspeed.com (https://www.wolfspeed.com/products/power/reference-designs). Find the folder named "USBCANTool", then install this driver on your computer. Another folder named by "WolfspeedControlPanel" is the monitor for this reference design. Run the "ECanTest.exe" in the path "WolfspeedControlPanel>ECanTest>bin>x64>Debug". Before you connect the GUI with the converter, please make sure the CANH and CANL are connected to J5 on control board, and the USB to your computer. After that, you should select the Baudrate 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.

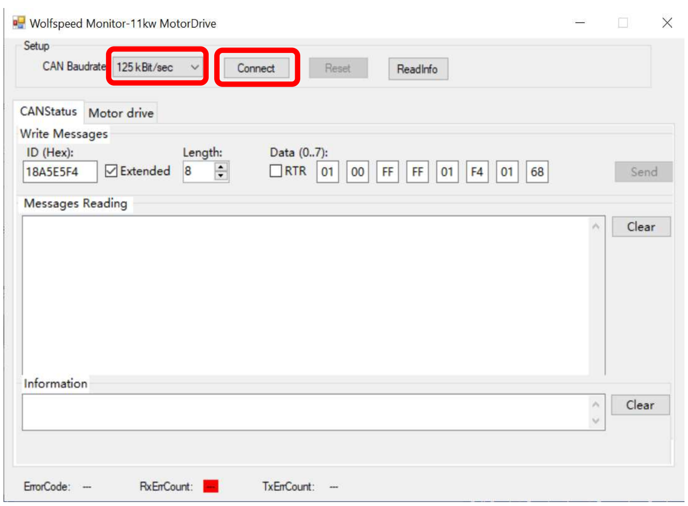


Figure 5a: CAN status tab before connection

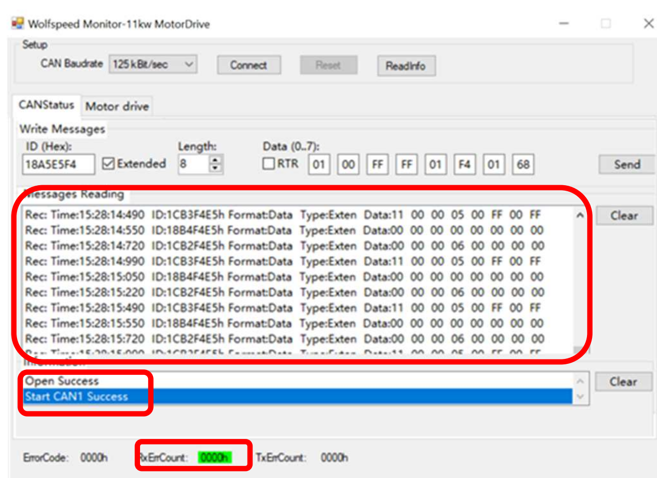


Figure 5b: CAN status tab after connection

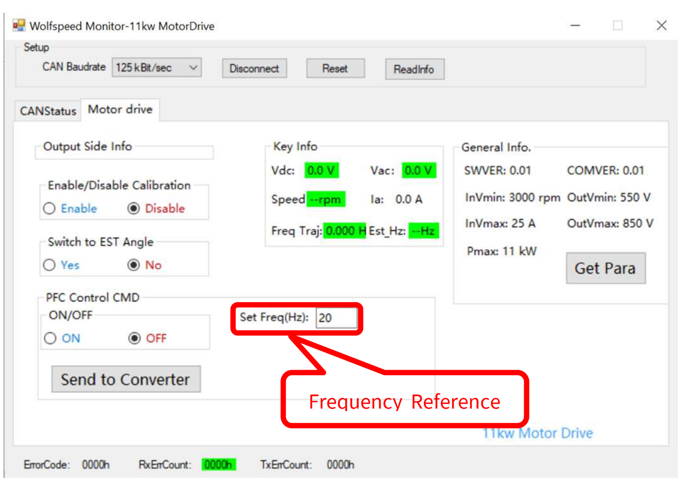


Figure 5c: CAN status tab before start up

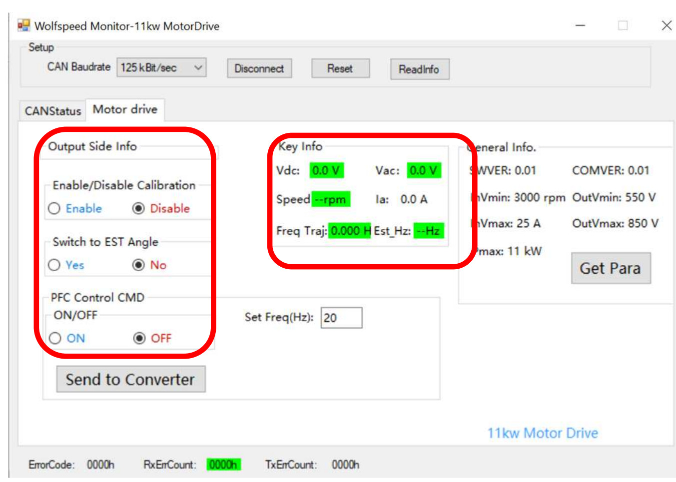


Figure 5d: CAN status tab after start up

The over/under voltage-protection is indicated by the back color of the voltage value, as shown in Figure 6a to Figure 5d. "Green" indicates "Normal Operation" while "Red" indicates "Warning Issued". As shown in Figure 5a, the input voltage will be shown in the "Input Side Info", while the output voltage, current, AC frequency, and motor speed will be shown in "Output Side Info". The specification for this reference design will be shown in "General Info" by clicking the "Get Para" button. Electrical frequency reference is the desired output AC frequency to the motor. The online calibration and forced angle for close loop can be controlled by the control CMD button.

You should calibrate the offset of voltage and current sampling after the DC input voltage is supplied and before sending the "ON" command. This can be accomplished in two steps: first send an "OFF" command to shut down the inverter, then send a calibration command. Then you can send an "ON" command with the desired output AC frequency or motor speed (it is suggested to start at 20Hz). You can switch to the angle getting from the FAST Estimation by the command of disenable the forced angle once the motor is running stably.

The table below shows the steps to take in the GUI to perform the calibration and start the motor.

Table 3: Input and Outputs of Auxiliary Power Board

Step	Calibration	EST Angle	Motor Drive CMD	Note
1	DISABLE	NO	OFF	Stand by
2	ENABLE	NO	OFF	The calibration process needs about 3s (50000 switching period) to be done. Please ignore and keep the "ENABLE" status after the calibration. You should restart the unit if you want to do the calibration again.
3	ENABLE	NO	ON	Start motor with open loop at constant speed. 20Hz is recommended. You can go to the next step after the frequency trajectory changes to the desired frequency, which can be read from GUI "Freq".
4	ENABLE	YES	ON	Switch to closed loop control after the motor is running at a stable speed. Then you can change the required frequency under the closed loop condition.
5	-	-	OFF	Turn off the unit

After sending the CAN frame with voltage reference, the digital controller will check the value range each time. The converter will start up once it receives the CAN frame with the "ON" configuration. 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. Protection reminders will be shown in the monitor in red text. All protection reminders are listed in Section 7.3.

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 13.2 and Section 13.3.

Table 4 below provides an example when "0x18A5E5F4" is sent as the message identifier and "0xFF00FFFF0F0AFFFF" is sent as the CAN data. When the converter receives this CAN frame, it will start up with the output frequency 20Hz.

User should take precautions to prevent overloading.

Table 4: Example of Control Command

Message Identifier: 0x18A5E5F4					
Data	Byte0	Byte1= 0x01	Byte2+Byte3	Byte4+Byte5 = 0xOF0A	Byte6+Byte7
Property	Reserved (0xFFFF)	On	Reserved (0xFFFF)	DC Voltage: 0x0F0A*0.1V = 20Hz	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 MUCH BE FULLY DISCHARGED.

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

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

警告

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

板子上一些组件的温度可能超过50摄氏度。移除电源后，上述情况可能会短暂持续，直至大容量电容器完全释放电荷。通电时禁止触摸板子，应在大容量电容器完全释放电荷后，再操作电路板。

请确保在操作电路板时已经遵守了正确的安全规程，否则可能会造成严重伤害，包括触电死亡、电击伤害、或电灼伤。

警告

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

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

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

7.1 Equipment

DC Input Source: The input source must be an adjustable DC source whose output can be adjusted up to the maximum bus voltage desired for testing. It must be capable of supplying at least the rated power of the intended load with 10-20% headroom.

Output Load: A programmable high-voltage electronic load or a high-voltage resistor bank may be used for open-loop testing. The reference design can provide 11 or 20 kW maximum depending on which model is being tested. Alternatively, or in addition, a three-phase high-voltage PMSM motor with a maximum power smaller than the reference design can also be tested in closed-loop operation.

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 should be used when the output current exceeds the rating of the internal shunt resistor.

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

Low voltage power supplies: A 12 VDC power supply with isolated ground and at least 1.2A output capability is required for the cooling fan.

External Fans: A fan such as the Protechnic® DC12V/1.20A fan (P/N: MGT4012WB-W28) or equivalent is used for cooling the heatsink as shown in Figure 6. The red wire of the fan is the positive terminal, and the black wire is the negative terminal.

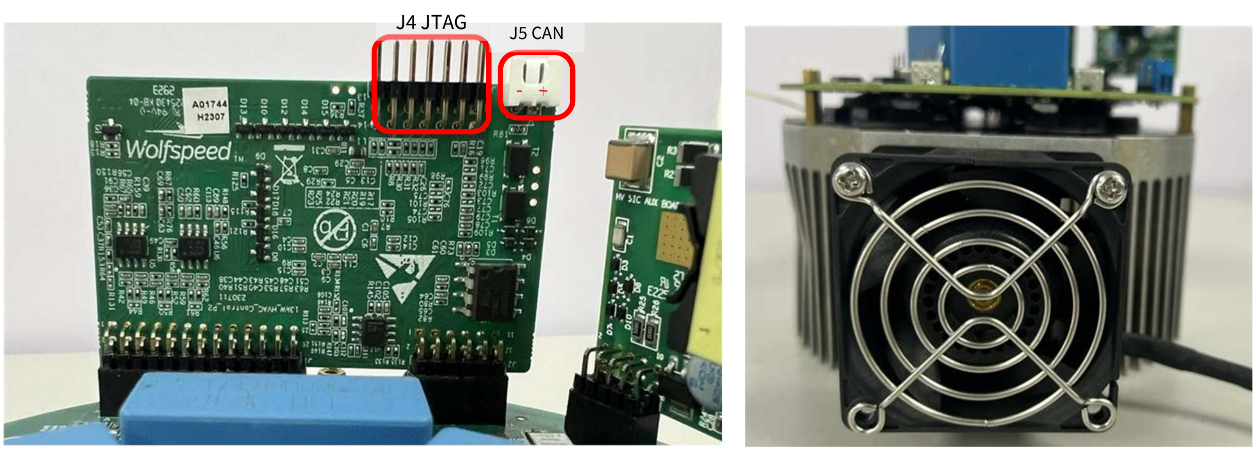


Figure 6: Setup of the Reference Design

Recommended Wire Gauge: Cable with a minimum AWG #10 wire gauge and suitable voltage rating is recommended to carry the DC input and output currents. Please follow all applicable safety standards.

7.2 Recommended Test Setup

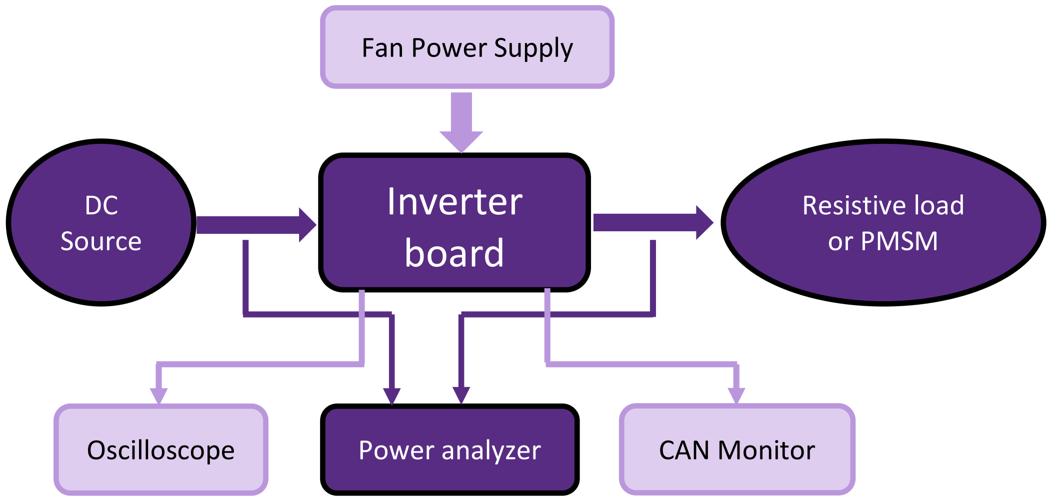


Figure 7: Converter Test Setup

- Connect DC source to the DC terminal (input).
- Connect the resistive load bank or input of PMSM to the three-phase AC terminal (output).
- Connect power analyzer to measure input and output power.
- Connect CAN communication wires to the control board.
- Use appropriately rated voltage and current probes and connect to the oscilloscope.
- Place and operate the external fan.

7.3 Protections

Table 5 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.

A user should not overload the converter out of the SOA (Safe Operation Area). This may damage the unit.

Table 5: Protection Details

Power Signal	Protection	Trip Point
Input DC Voltage	OVP	>900V
Output AC Voltage	OVP	>700V
Phase Current	OCP	40A (rms)

7.4 Measured Parameters

The gate and drain voltages of MOSFETs must be measured with caution. Probes should be connected to them only after the removal of input power and only after the inverter is turned off, and it has been verified that no voltage remains on the DC bus. The efficiency testing should not include the motor side, so the sensing wires should be connected between the DC input terminals and three phase AC terminals of the inverter.

Table 6: Parameters which can be measured.

NAME	DESCRIPTION
Efficiency	Measured with power analyzer
Input /Output Current	AC current at output and DC current at input
Input /Output Voltage	AC output voltage and DC input voltage
Output Frequency	AC output frequency
Speed / Torque	Speed and torque of PMSM
Vgs /Vds Signals	voltage across gate to source or drain to source of SiC MOSFETs
Auxiliary Power Board Outputs	Please refer to Figure 5 and Table 2 for details
3.3V /1.2V Controller Supply	+3.3V supply for Controller's I/O; +1.2V supply for Controller's core

8. Testing the Unit

Notes:

1. Make sure the sequence of AC output terminals of inverter to load or motor is correct.
2. Make sure the sequence of AC source and terminals of inverter are connected correctly. The terminals “U” “V” and “W” should connect with phases “U” “V” and “W” of the motor.
3. Do not overload the inverter. The output power should not exceed 11 kW with C3M0075120K and 20 kW with C3M0040120K.
4. There is no current inrush limiter for DC port. The DC input voltage must be increased slowly (soft-start) for inverter mode.
5. Always remember to connect the cooling fans to their power supplies and operate the cooling fans when operating the board.
6. The firmware is not available for all of the motors; motor parameter identification and current/speed control tuning must be performed for a new motor.

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 DC terminals, and the load is connected to the AC terminals “U” “V” and “W”.
2. Check the input status and make sure the DC source output is disabled.
3. Make sure no load or only a light load (10%) is added to the AC terminals until step 9.
4. Apply 12 VDC to the cooling fan.
5. Turn on the DC supply and increase it slowly from 0 V to the required voltage (550 VDC – 850 VDC).
6. Connect the GUI to the system. Send “OFF” command after it is connected successfully.
7. Verify that the measured values in the GUI were reported correctly.
8. Send “ON” command with the desired frequency. The converter will start up with the desired voltage.
9. After the output voltage has reached the required voltage, apply a load to the output with no more than 2 kW steps to prevent loop instability and overloading which can cause hardware damage.
10. Collect data such as efficiency, power factor, and current THD at different load conditions using 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 no load.
2. Use GUI to send "OFF" command.
3. Turn OFF the DC source, wait until the DC source has fully discharged its output.
4. Turn OFF load after the bus 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 allowed to fully discharge before handling the board. Please check the terminal voltages with the power analyzer or a digital multimeter to ensure that the board has fully discharged and is therefore safe to handle.
6. Turn OFF the 12 VDC power supply for the cooling fan.

8.3 Startup Procedure: DCAC Mode with PMSM

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 DC terminals, and the motor's input terminals are connected to the inverter's AC terminals "U" "V" "W".
2. Check the input status and make sure the DC source output is disabled.
3. Make sure no load is added to the motor side until step 12.
4. Apply 12 VDC to the cooling fan on the power board.
5. Turn on the DC supply and increase it slowly from 0 V to the required voltage (550 VDC – 850 VDC).
6. Connect the GUI to the system. Select "Disable" "No" "OFF" concurrently and send command after it is connected successfully.
7. Verify that the measured values in the GUI were reported correctly.
8. Send "Enable the calibration" command, about three seconds the calibration will be done. Once calibration per power cycle is allowed. Turn off the DC source is needed if you want to reset the calibration.
9. Send "ON" command with set a desired AC frequency (20-30 Hz). The motor will run with a forced angle.
10. After the frequency and speed has reached the set value, send a "Yes" command to enable the calculated angle from the estimator.
11. Increase the frequency and speed to the desired value (max 200 Hz) by sending an "ON" command. The motor will slowly run to the desired speed.
12. After the speed has reached the required speed, increase the torque slowly.

13. Collect data such as efficiency, power factor, and current THD at different load condition using the power analyzer.

The Table 3 in section 6.1 shows the steps of commands to take in the GUI to perform the calibration and start the motor.

8.4 Turn Off Procedure: DCAC Mode with PMSM

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

1. Reduce the load gradually to no load.
2. Use GUI to send “OFF” command.
3. Turn OFF the DC source.
4. The motor will decrease the speed slowly after receiving the “OFF” command. At that time, counter electromotive force will be generated from the motor side to the inverter. Please wait for the motor to fully stop running and verify no voltage is present on the board before handling the board.
5. Turn OFF the 12 VDC power supply for cooling fan.

9. Photo of Reference Design

Figure 8 shows the locations of the terminals and key components on the Power Board.

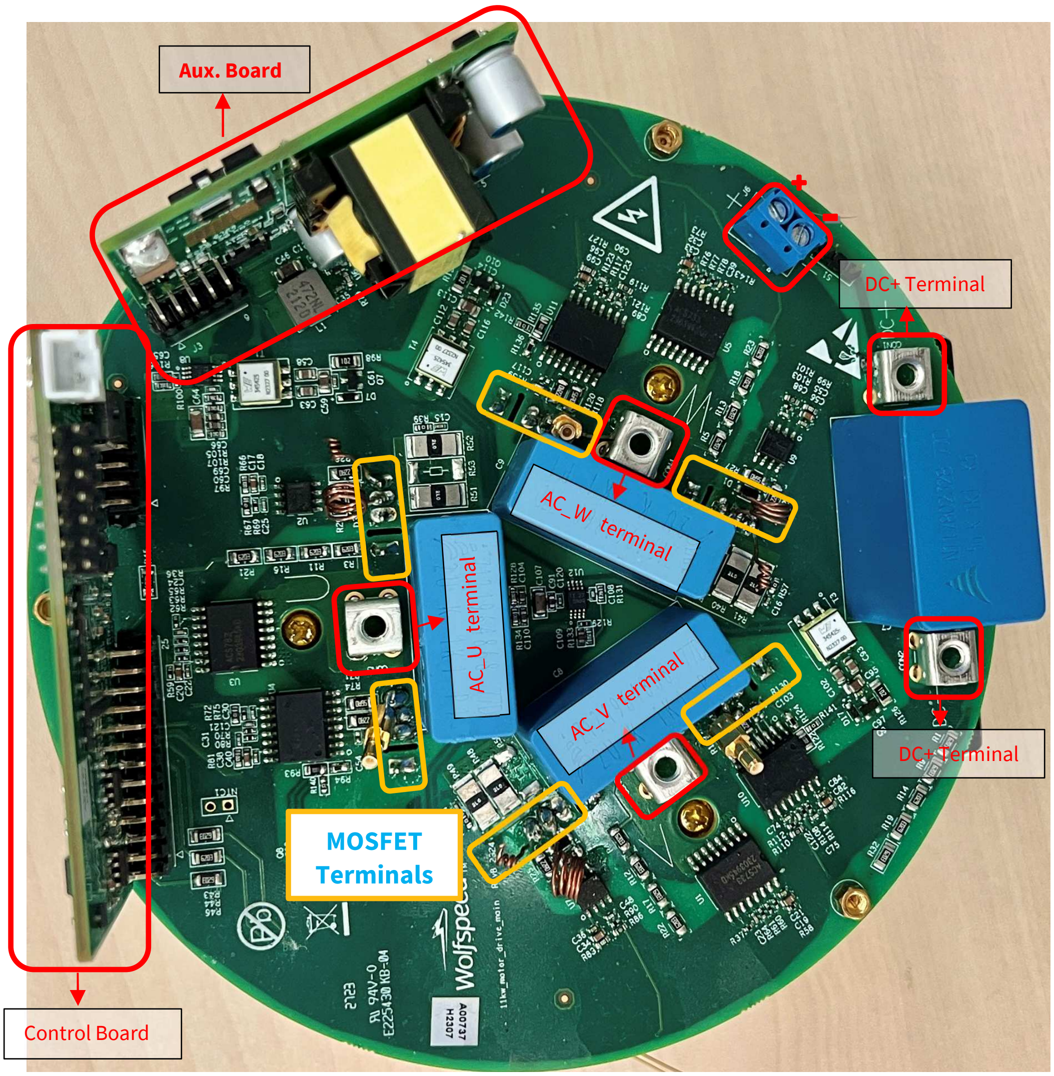


*Figure 8: Top View of PCBA (145mm*133mm*60mm)*

10. Performance Data

Shown below is measured performance data of Wolfspeed's CRD-11DA12N-K reference design board under various conditions. Table 7 shows the performance data. Figures 10-12 show the SiC efficiency curve and the comparison with IGBT's.

Table 7: Efficiency Data

Input Voltage (VDC)	Input Power (W)	Load (%)	Output Voltage (VAC)	Output Power (W)	Overall Efficiency (%)
700	545.796	5	380	528.864	96.898
700	1059.91	10	380	1041.52	98.265
700	1600.67	15	380	1580.82	98.759
700	2114.54	20	380	2092.53	98.959
700	3074.75	30	380	3047.47	99.113
700	5172.48	50	380	5128.04	99.141
700	7580.37	70	380	7509.03	99.059
700	9104.1	80	380	9010.63	98.973
700	11175.6	100	380	11042.6	98.81
850	558.501	5	380	535.921	95.957
850	1077.93	10	380	1053.76	97.758
850	1624.69	15	380	1598.03	98.359
850	2038.24	20	380	2009.08	98.569
850	3109.98	30	380	3074.84	98.87
850	5122.51	50	380	5069.49	98.965
850	7654.08	70	380	7566.85	98.86
850	9191.9	80	380	9082.47	98.809
850	11202.6	100	380	11046.9	98.61
640	542.877	5	380	527.822	97.227
640	1058.08	10	380	1042.02	98.482
640	1600.75	15	380	1583.08	98.896
640	2113.82	20	380	2093.96	99.06
640	3075.22	30	380	3050.33	99.191
640	5074.39	50	380	5034.52	99.214
640	7585.16	70	380	7519.26	99.131
640	9111.16	80	380	9022.9	99.031
640	11194.5	100	380	11068.7	98.877
550	553.147	5	325	541.673	97.926
550	1031.42	10	325	1018.9	98.786
550	1561.5	15	325	1547.1	99.077

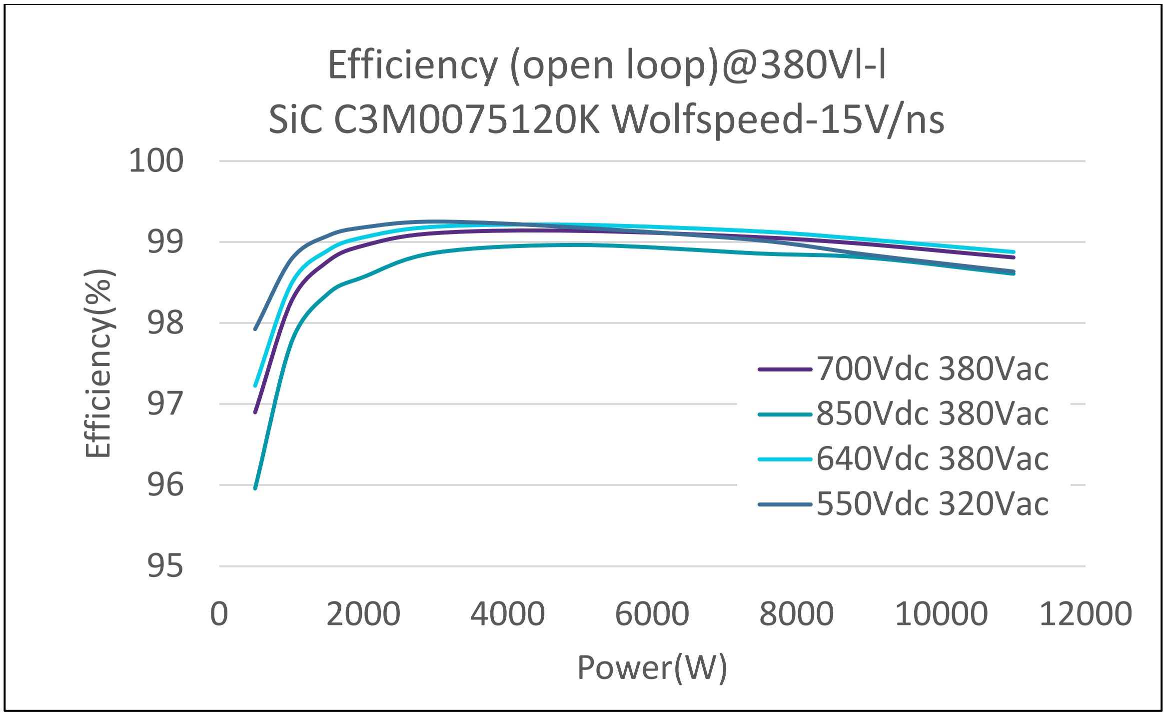


Figure 10: Efficiency curve

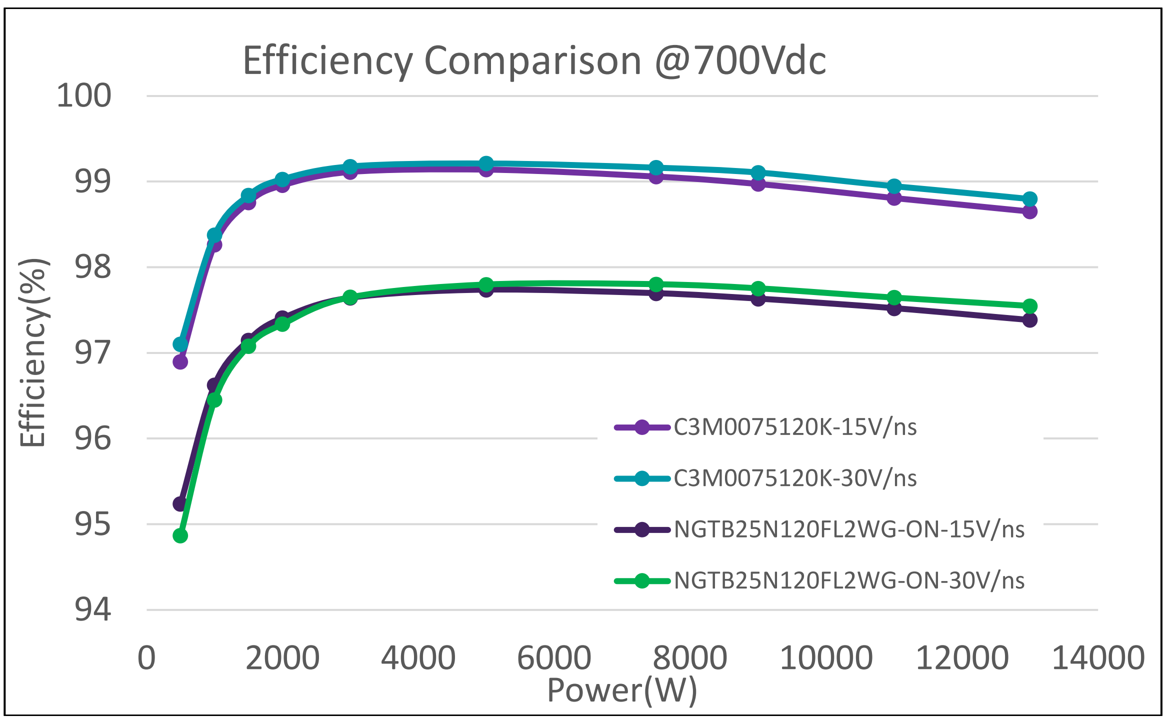


Figure 11: IGBT & SiC efficiency comparison

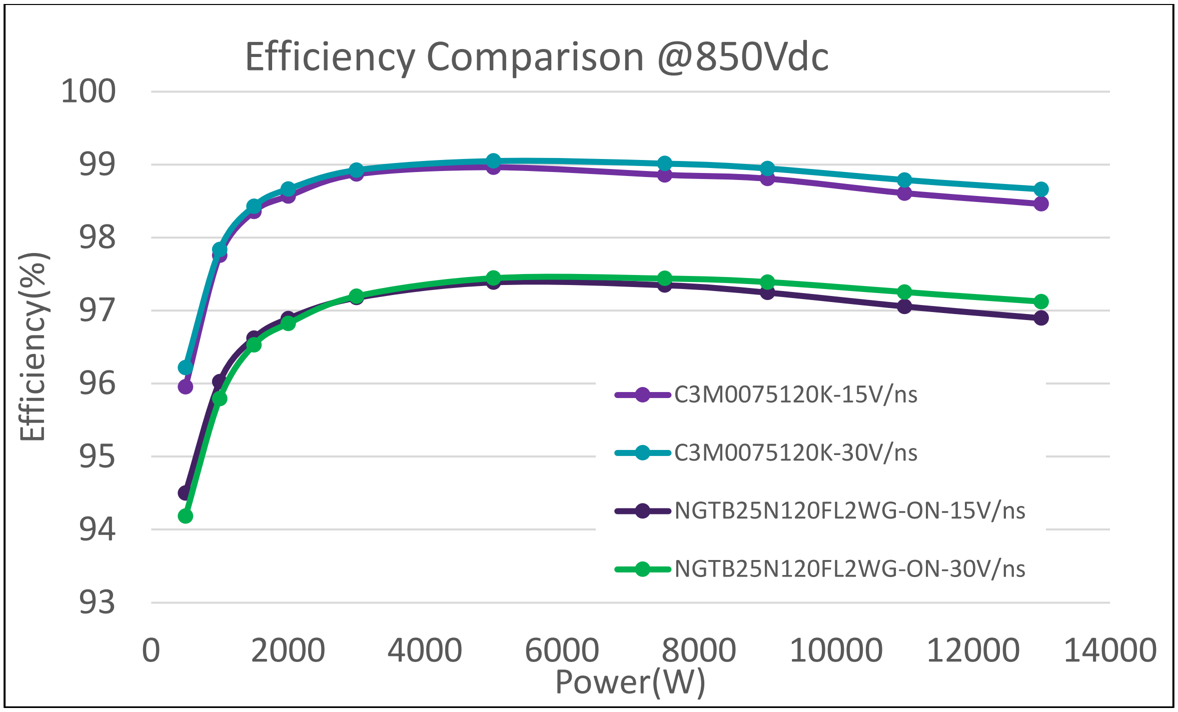
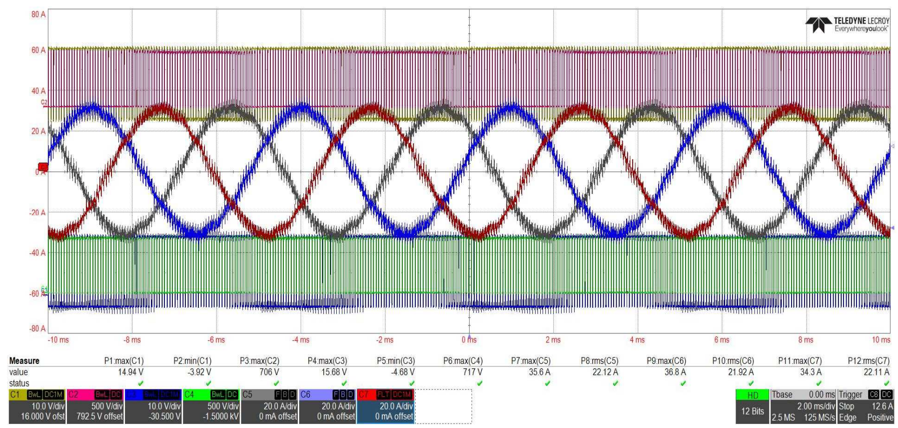
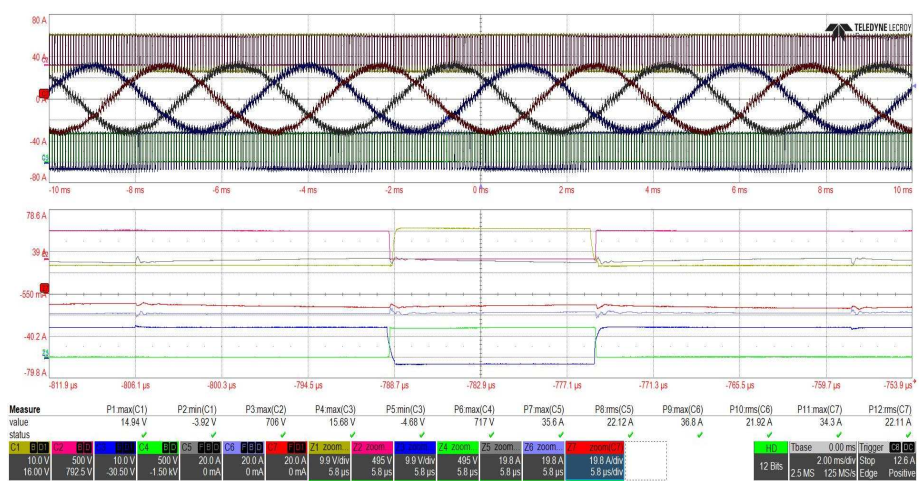


Figure 12: IGBT & SiC efficiency comparison

11. Typical Waveforms

Operational waveforms are presented in Table 8.

Table 8: 11kW motor drive key waveforms

Condition	Waveform
Input Voltage: 680 VDC Motor Drive Output Power: 11 kW Motor speed: 3000 rpm	 **CH1**: Vgs Q1 **CH2**: Vds Q1 **CH3**: Vgs Q6 **CH4**: Vds Q6 **CH5**: Iu **CH6**: Iv **CH7**: Iw
Input Voltage: 680 VDC Motor Drive Output Power: 11 kW Motor speed: 3000 rpm	 **CH1**: Vgs Q1 **CH2**: Vds Q1 **CH3**: Vgs Q6 **CH4**: Vds Q6 **CH5**: Iu **CH6**: Iv **CH7**: Iw

12. Thermal Design and Test Results

In a thermal test of the 11 kW unit, forced-air cooling is applied to the bottom side of the cooling baseplate to achieve and maintain a 65°C cooling plate. There is no direct air flow to the power MOSFETs. MOSFETs in the inverter operate in full-load thermal condition with a 25A load. The thermal testing was performed at 11 kW at two different operating points; 850 VDC input with 380 VAC 25 A load, and at 550 VDC input with 320V/25A load in DC/AC open-loop 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 9. The highest junction temperature of any MOSFET in the design was determined to be 101.84°C. This value was calculated based on the measured case temperature, the internal thermal resistance of the MOSFET, and the calculated power loss.

The 20 kW unit was also tested at full power with 850 VDC input, and 380 VAC output. The maximum junction temperature in this case is calculated to be 91.1°C.

Since the maximum junction temperature of the C3M0075120K and C3M004012K is 175°C, the integrated heat sink design has allowed the MOSFETs to remain within their thermal derating guidelines.

Table 9: 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 temp (°C)	Derating Requirem ent (°C)	Result
850Vdc 380Vac 11 kW							
C3M0075120K Q1	1.1	21.7	69.67	93.54	175 °C	135°C	Pass
550Vdc 320Vac 11 kW							
C3M0075120K Q1	1.1	27.76	71.3	101.84	175 °C	135°C	Pass
850Vdc 380Vac 20 kW							
C3M0040120K Q1	0.46	42.85	71.4	91.1	175 °C	135°C	Pass

13. Appendix

13.1 CAN Messages from Inverter

Table 10: Overall charge status

Message Identifier	**0x18B2F4E5**			
Data	Byte0+Byte1	Byte2+Byte3	Byte4+Byte5	Byte6+Byte7
Property	Vdc	AC voltage	Real Freq trajectory	AC RMS Current
Unit	0.1V	0.1V	0.1Hz	0.1Hz
Bias	0			
Data Format	integer			
Time interval	0.5 seconds			

Table 11: PMSM status

Message Identifier	**0x18B0F4E5**			
Data	Byte0+Byte1	Byte2+Byte3	Byte4+Byte5	Byte6+Byte7
Property	Motor speed	EST Freq	Reserved 0xFFFF	Reserved 0xFFFF
Unit	1 rpm	0.1Hz	NA	
Bias	0			
Data Format	integer			
Time interval	3 seconds			

Table 12: Inverter information

Message Identifier	**0x18B3F4E5**			
Data	Byte0+Byte1	Byte2+Byte3	Byte4+Byte5	Byte6+Byte7
Property	Inverter status. See Table 12a for details.	Reserved 0xFFFF	Reserved 0xFFFF	Reserved 0xFFFF
Unit	NA			
Bias	0			
Data Format	integer			
Time interval	0.5 seconds max.			

Table 12a: Bit definition for inverter status

Converter Status	**Comments**	**Converter Status**	**Comments**
Bit15	Reserved	Bit7	1: AC side OVP 0: normal (default)
Bit14	Reserved	Bit6	Reserved
Bit13	1: OCP	Bit5	Reserved

	0: normal(default)		
Bit12	1: AC side UVP 0: normal(default)	Bit4	Reserved
Bit11	Reserved	Bit3	Reserved
Bit10	Reserved	Bit2	Reserved
Bit9	Reserved	Bit1	Reserved
Bit8	Reserved	Bit0	1: CAN error 0: normal (default)

Table 13: Part I of inverter specification

Message Identifier	**0x1AB8F4E5**			
Data	Byte0+Byte1	Byte2+Byte3	Byte4+Byte5	Byte6+Byte7
Property	Com. Software Version	Max. Motor Speed	Max. AC Current	Reserved
Unit	0.01	0.1rpm	0.1A	NA
Bias	0			
Data Format	integer			
Time interval	Reply to 0x18A8E5F4			

Table 14: Part II of inverter specification

Message Identifier	**0xAB9F4E5**			
Data	Byte0+Byte1	Byte2+Byte3	Byte4+Byte5	Byte6+Byte7
Property	Software Version	Min. Input Voltage	Max. Input Voltage	Reserved
Unit	0.01	0.1V	0.1V	NA
Bias	0			
Data Format	integer			
Time interval	Reply to 0x18A8E5F4			

13.2 CAN Messages to Inverter

Table 15: Control command

Message Identifier	**0x18A5E5F4**					
Data	Byte0	Byte1	Byte2	Byte3	Byte4+Byte5	Byte6+Byte7
Property	Reserved 0xFFFF	0: OFF 1: ON	0: Disable 1: Enable	0: Yes 1: No	AC Frequency	Reserved 0xFFFF
Unit	NA	NA	NA	NA	0.1Hz	NA
Bias	0					
Data Format	integer					

14. Revision History

Date	Revision	Changes
January 2024	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.

Indemnification

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