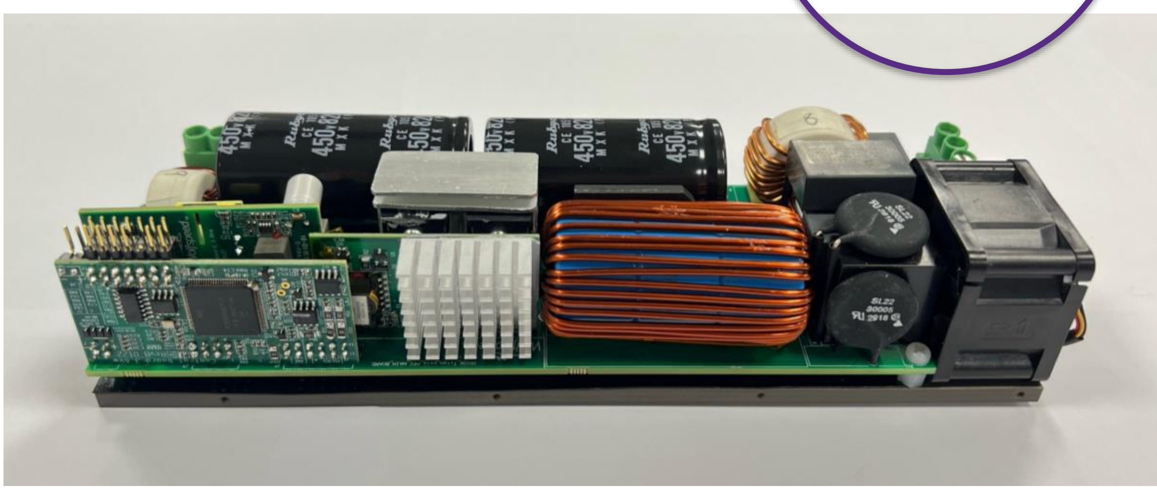
USER GUIDE PRD-06616

CRD-03600AD065E-L: 3.6kW HIGH-EFFICIENCY AND HIGH-POWER-DENSITY TOTEM-POLE PFC CONVERTER

3.6kW 高效率高功率密度图腾柱功率因数校正变换器

3.6kW 高効率高出力密度トーテムポール力率補正コンバーター



User Guide

Wolfspeed Power Applications

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CAUTION

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

警告

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

警告

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

CAUTION

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

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

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

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

警告

请勿在通电情况下接触板子，在操作板子前应使大容量电容器的电荷完全释放。接通电源后，该评估板上通常会存在危险的高电压，板子上一些组件的温度可能超过 50 摄氏度。此外，移除电源后，上述情况可能会短时持续，直至大容量电容器电量完全释放。

操作板子时应确保遵守正确的安全规程，否则可能会出现下列危险：

- 死亡
- 严重伤害
- 触电
- 电击
- 电灼伤
- 严重的热烧伤

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

警告

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釈放すべきです。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釈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ーをつないでください。通電している時に無人監視やボードを操作するのは禁止です。ボードを操作する前に、大容量のコンデンサーで電力を完全に釈放するのを必ず確保してください。ボードの電源を切った後、また大容量のコンデンサーで電力を完全に釈放した後、試験設備を取り換えることができます。

Contents

1. Introduction

This User Guide provides the schematic, artwork, and test setup necessary to evaluate Wolfspeed's CRD-03600AD065E-L, 3.6kW High-Efficiency High-Power-Density Totem-Pole Power Factor Correction (PFC) converter for data centers, telecom base station, mining power and similar applications.

A block diagram of the 3.6kW Totem-Pole PFC Converter (P/N CRD-03600AD065E-L) based on SiC MOSFETs is shown in Figure 1. This design is based upon one of Wolfspeed's latest generation of SiC MOSFETs - C3M0045065L (650V, 45mΩ, TOLL). This reference design is the grid connected stage of a totem-pole PFC converter. As shown in Figure 1, it operates from grid supply at AC terminals and provides a non-isolated DC output voltage at the DC terminals.

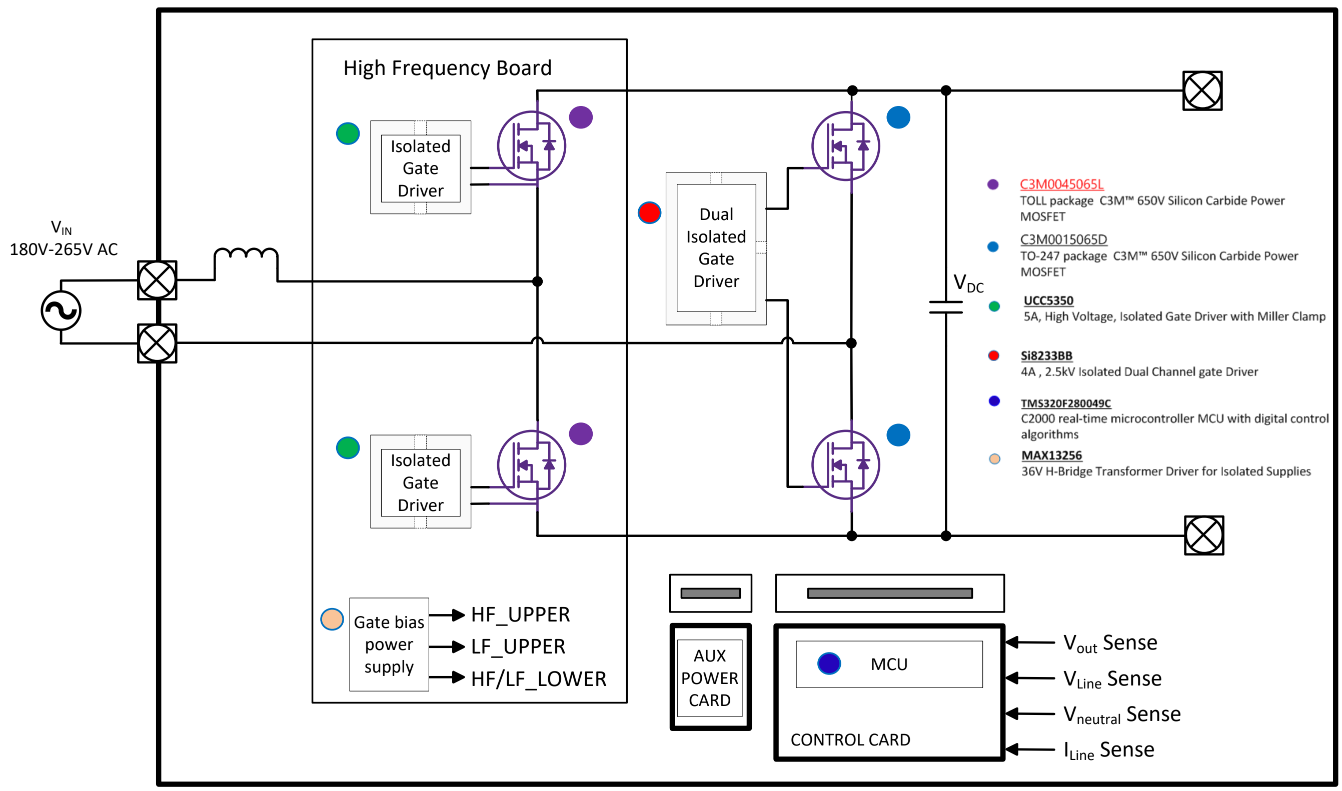

Figure 1. Block Diagram of Wolfspeed's CRD-03600AD065E-L, 3.6KW Totem-Pole PFC converter

The front-end AC/DC PFC stage uses a single-phase bridgeless totem-pole PFC topology. It creates a DC link voltage for the later DCDC stage. This topology can further reduce the number of semiconductors compared with traditional PFC topology and achieve higher efficiency by using Silicon carbide products. The 3.6kW Totem-pole PFC operates under continuous conduction mode (CCM) with low power loss thanks to the low Qrr of the SiC device.

This Totem-Pole PFC evaluation board uses our latest TOLL package SiC MOSFET - C3M0045065L. Compared to the standard TO-263-7L Package, the TOLL package has lower lead inductance which enables higher efficiency; and a larger back metal tab that enables better thermal performance and lower junction temperature. The TOLL package has a 25% smaller footprint and a 50 % height reduction. In this reference design, the high-frequency devices and corresponding driving circuits are integrated on one single small daughter card, making full use of the vertical space and effectively improving the overall power density (92 kW/in^3) with a size of 220mm (L)×73mm (W)×40mm (H).

To meet different requirements, the output voltage is adjustable between 380 Vdc and 420 Vdc by GUI. A resistive load connected to the DC output is recommended for testing.

2. Description

This reference design uses Wolfspeed's 650V/45mΩ SiC MOSFET- C3M0045065L (TOLL package). A single SiC MOSFET is used for each position (high-side and low-side).

The unit's input accepts a single-phase voltage between 180 Vac and 265 Vac, and its output provides a voltage between 380 Vdc and 420 Vdc. The AC input of the unit is protected by fuses. The input's under-voltage protection and the output's over-voltage protection are controlled by the digital controller (refer to Section 7.3 of this User Guide). An external power source is needed to power the fan to cool the unit.

The unit must be started with open load to prevent damage of the NTC during startup. The load may be increased incrementally after the output voltage has reached steady-state regulation. A graphical user interface (GUI) communicates with the unit via a CAN communication bus. It is used to monitor and display operational information and to provide related user controls. The output voltage is configurable through the CAN interface.

3. Electrical Performance Characteristics

PARAMETER		TEST CONDITIONS	MIN	NOM	MAX	UNITS
Input Characteristics						
$V_{IN(AC)}$	Input voltage		180	230	265	V_{rms}
f_{grid}	Frequency		48	50/60	62	Hz
f_{sw}	Switching frequency			60		kHz
Output Characteristics						
V_{OUT}	Output voltage	$V_{IN} = V_{MIN}$ to V_{MAX}, $I_{OUT} = 0$ to I_{NOM}	380	400	420	V
V_{ripple}	Output voltage ripple	$V_{IN} = 230V$, $V_{OUT} = 400V$, $P_{OUT} = 3.6kW$		25		V
$P_{OUT\ max}$	Output power	V_{IN} = 180Vac to 265Vac			3600	W
System Characteristics						
η_{peak}	Peak efficiency	$V_{IN} = V_{NOM}$, $V_{OUT} = 400V$, I_{OUT} = 40% of $I_{OUT(nom)}$		99%		
$\eta_{full\ load}$	Full load efficiency	$V_{IN} = V_{NOM}$, $V_{OUT} = 400V$ I_{OUT} = 100% of $I_{OUT(nom)}$		98.6%		
Mechanical						
	Dimensions	Width Length Component height		73 220 40		mm

Table 1: Specifications of Wolfspeed's CRD-03600AD065E-L, 3.6 kW Totem-Pole PFC converter

3.1. Application

The primary application of the Wolfspeed CRD-03600AD065E-L reference design is a bridgeless totem-pole PFC. The output should be connected to a resistive load or an electronic load. For the electronic load, CR - Constant Resistor mode, is recommended.

3.2. Features

Some of the features and limitations of Wolfspeed's CRD-03600AD065E-L reference design are listed below:

- Wide AC input voltage range: 180V – 265 Vrms
- 380 Vdc – 420 Vdc output voltage
- Maximum output power: 3.6kW between 180 Vac to 265 Vac
- Switching frequency: 60 kHz.
- Peak efficiency > 99%.
- Protection functions are shown in Table 4.
- 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, high-frequency half-bridge daughter card, control board, and auxiliary-power board are shown in Figures 2 through Figure 5.

4.1. Power Board

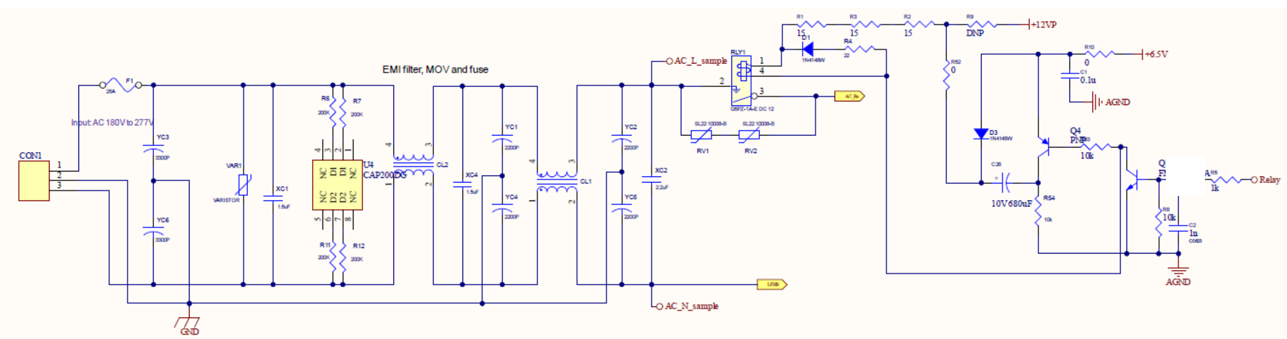

Figure 2a. Schematic of Power Board: Input EMI Filtering and Inrush Limiting Pre-charge Circuit

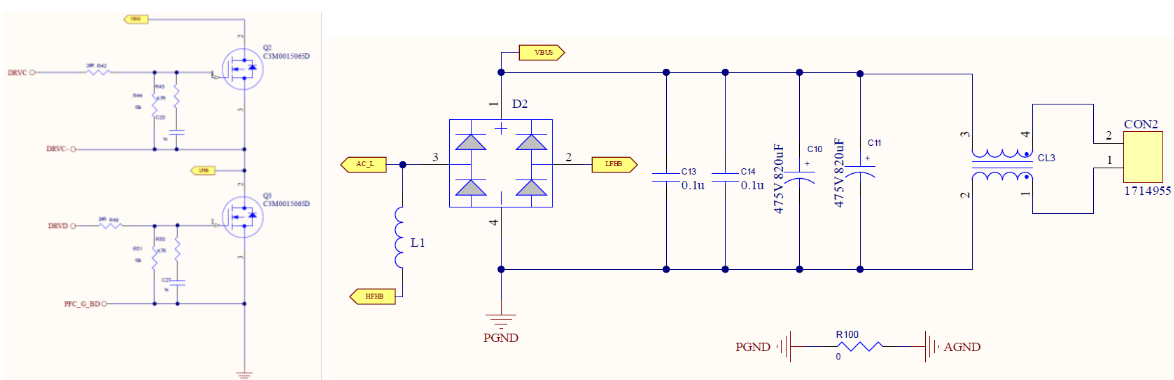

Figure 2b. Schematic of Power Board: Main Converter MOSFETs and DC Bus

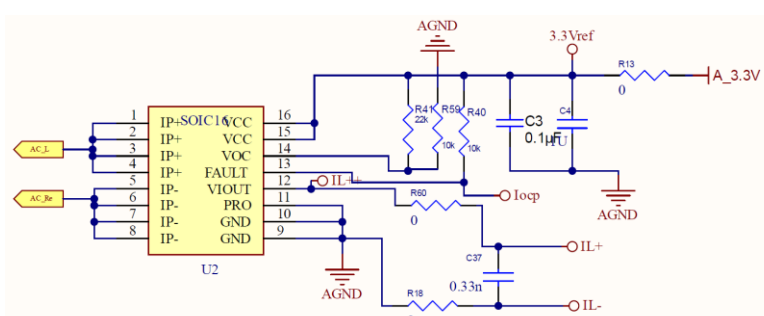

Figure 2c. Schematic of Power Board: Current Sensing

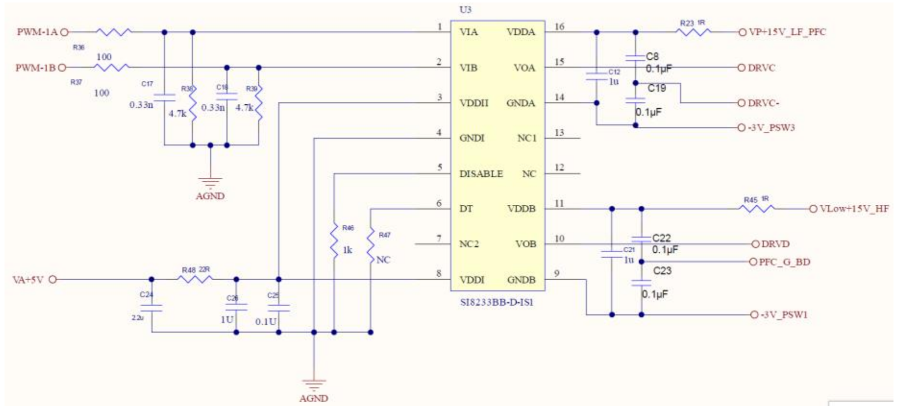

Figure 2d. Schematic of Power Board: Gate Drivers of Low Frequency MOSFETs

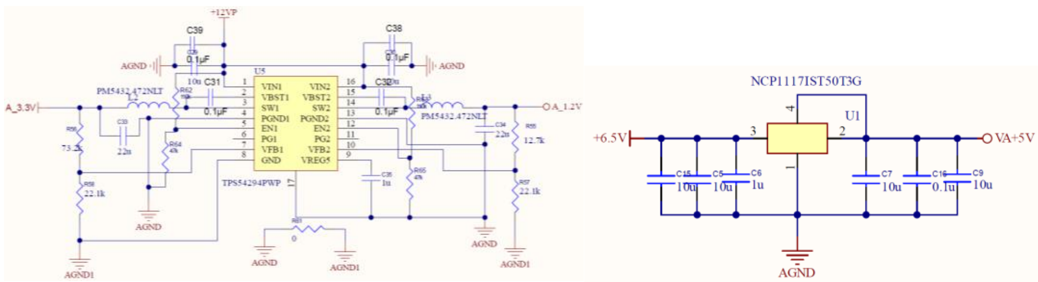

Figure 2e. Schematic of Power Board: DSP Power Supplies

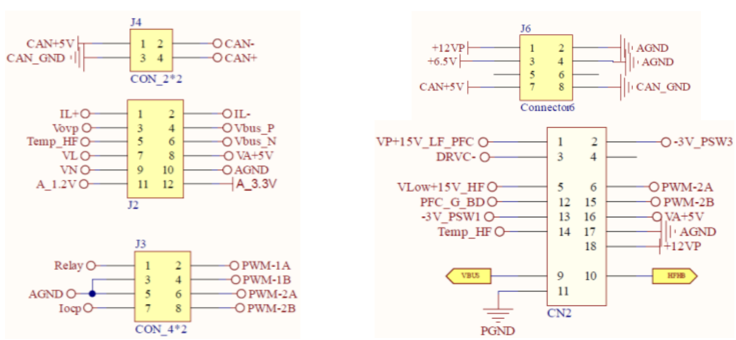

Figure 2f. Schematic of Power Board: Connectors to other boards

4.2. High-Frequency Half-Bridge Board

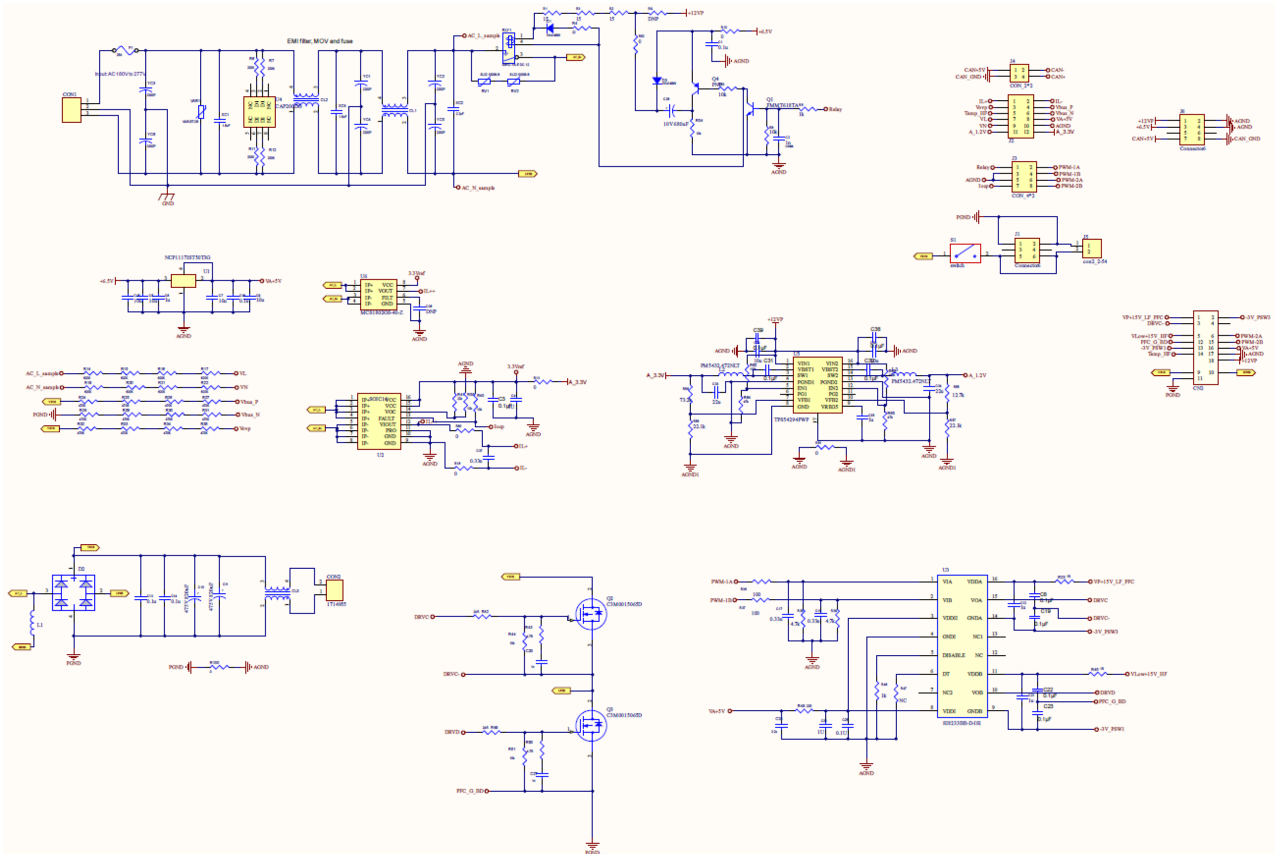

Figure 3. Schematic of High-Frequency Half-Bridge Board

4.3. Control Board

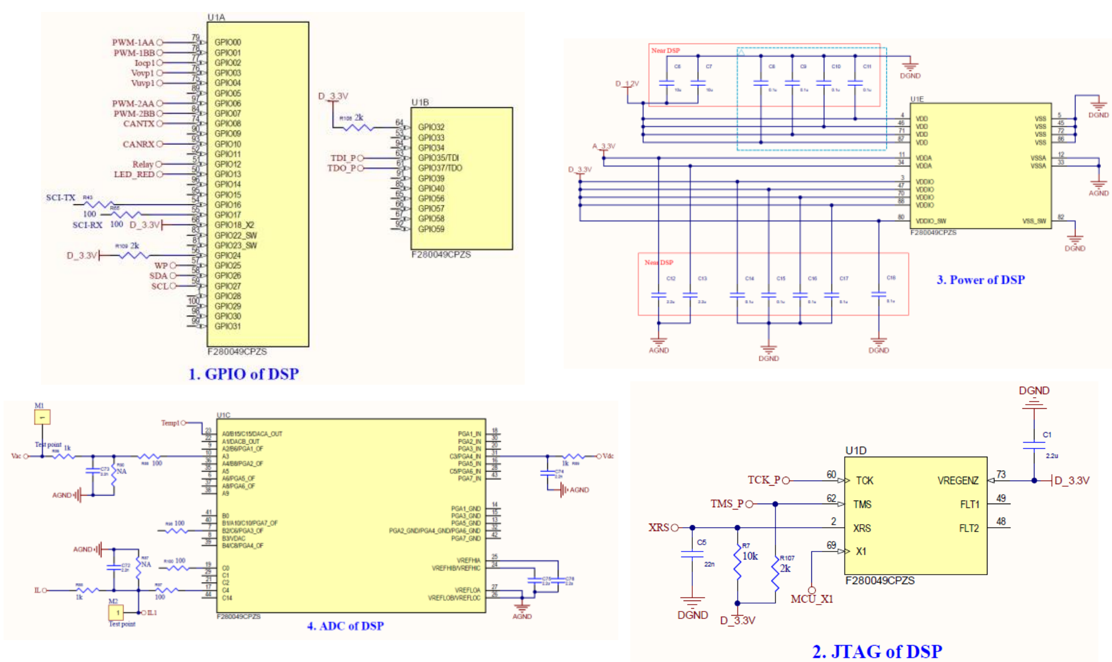

Figure 4a. Schematic of Control Board: Controller

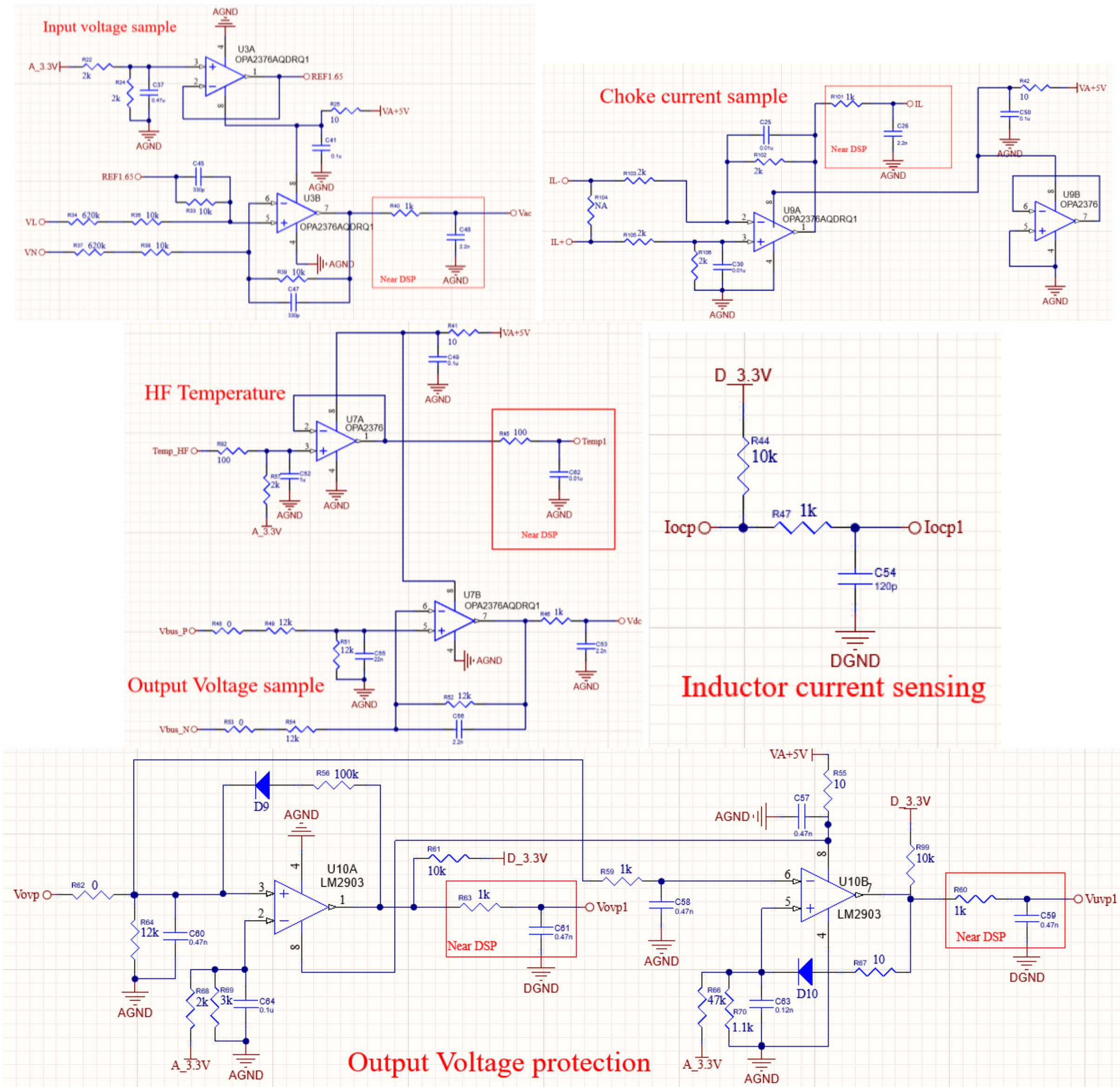

Figure 4b. Schematic of Control Board: Sample circuits

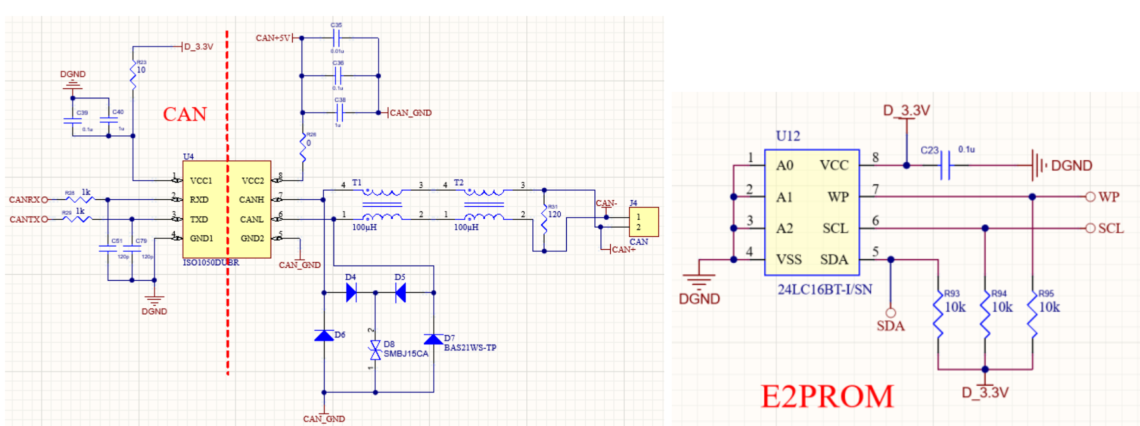

Figure 4c. Schematic of Control Board: CAN Interface and E2PROM

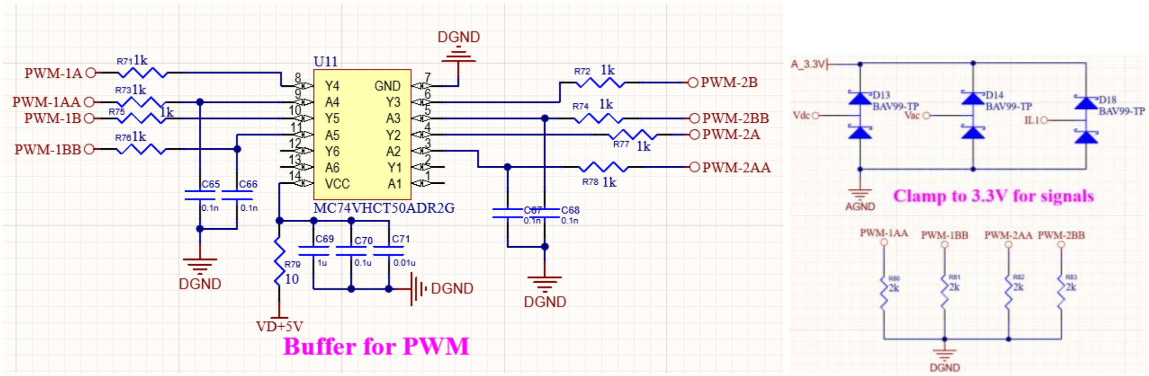

Figure 4d. Schematic of Control Board: PWM Buffer and Signal clamp

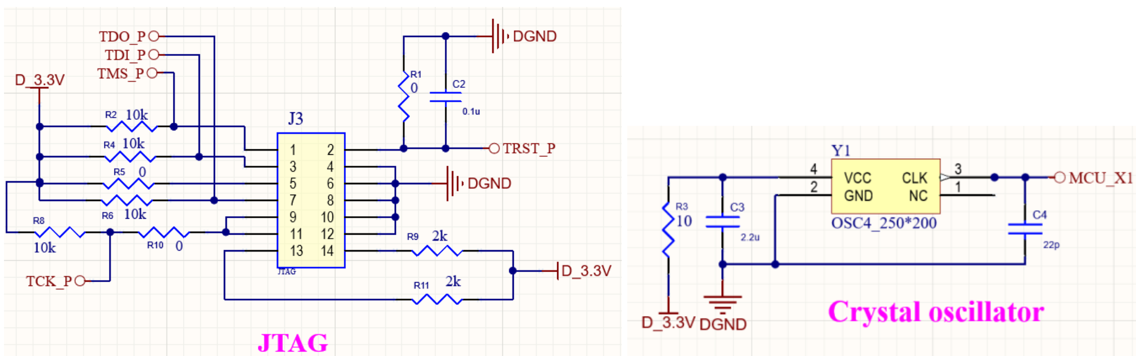

Figure 4e. Schematic of Control Board: JTAG and Crystal oscillator of DSP

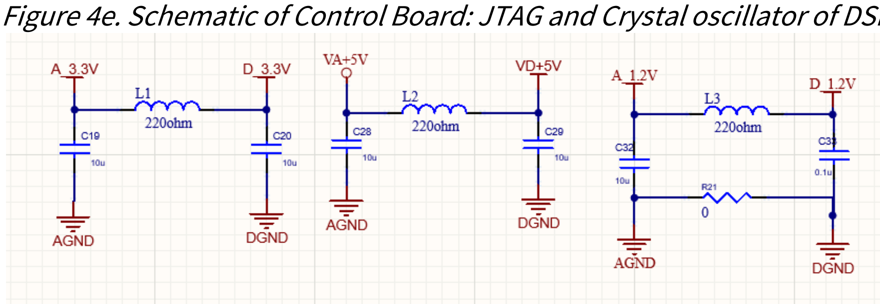

Figure 4f. Schematic of Control Board: Power supplies

4.4. Auxiliary Power Board

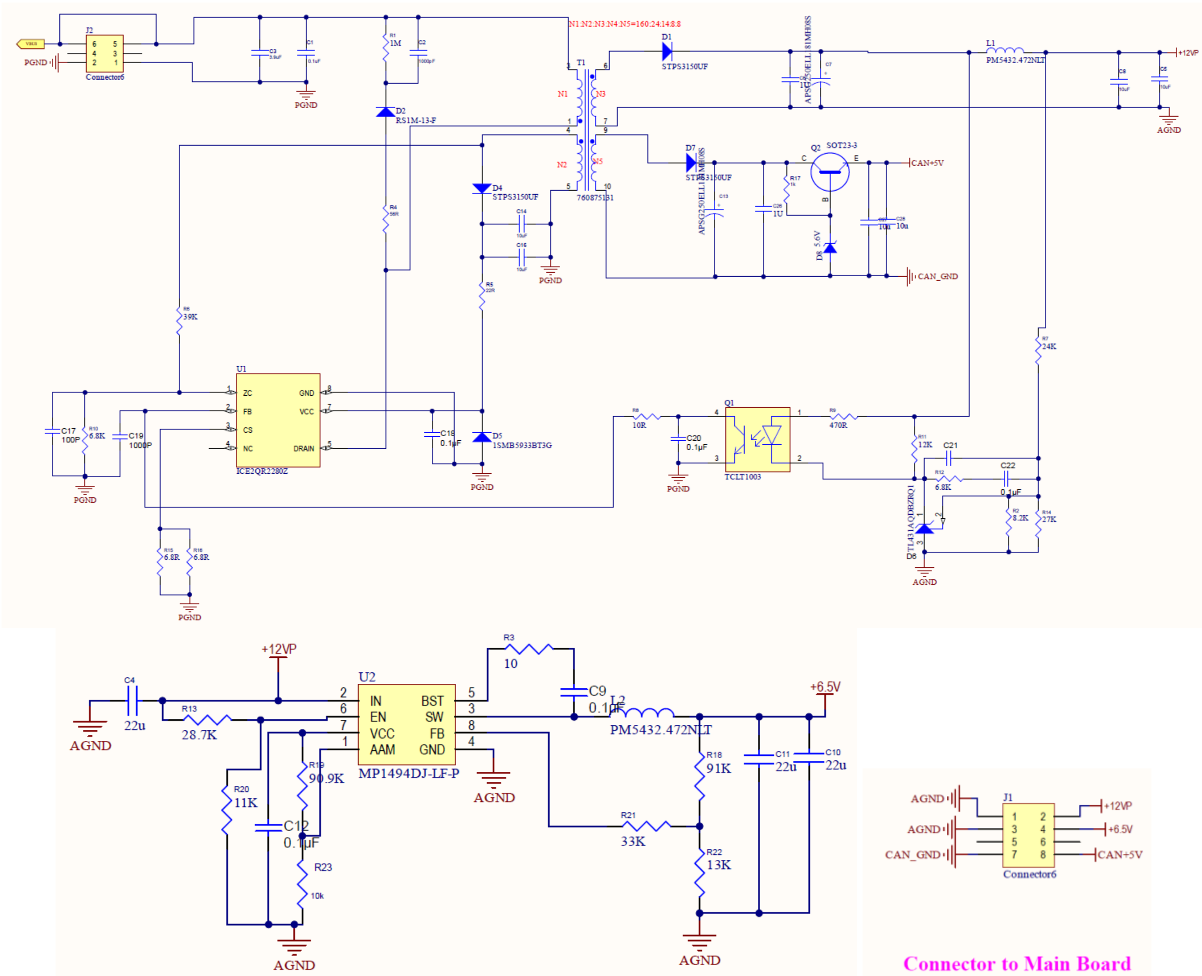

Figure 5. Schematic of Auxiliary Power Board

5. Hardware Description

5.1. Power Board

As illustrated by Figure 2a to 2f and Figure 3, a totem-pole PFC topology with four MOSFETs is selected for the converter. Single-phase AC line supply is connected to terminals "AC-L" and "AC-N" CON1 and 3, respectively, followed by a fuse (F1) and MOV (VAR1). Electro-magnetic interference (EMI) filters CL1_A1 and CL2_A1 and X/Y capacitors are connected next. These are followed by a solid relay (RLY1) and negative temperature coefficient (NTC) resistors (RV1~RV2) through which the DC link capacitors are charged. NTC resistors will be short-circuited by the relay when the output capacitors are charged. The power factor correction (PFC) choke and current sensor (U2) are connected between the relay and the midpoint of the high-frequency bridge consisting of two Wolfspeed SiC MOSFETs (Q2~Q3) located on a separate high-frequency half-bridge board. As illustrated by Figures 2b, two Wolfspeed SiC MOSFETs (C3M0015065D, 15mΩ/650V) are used on the low-frequency bridge for low power loss. A gate driver from Skyworks Solutions Inc. (P/N: SI8233BB-D-IS1) is used for the low-frequency MOSFETs. The bus-side DC terminals are CON2(+) and CON2(-), followed by two electrolytic capacitors which absorb the high-frequency ripple on the DC port. Several film and ceramic capacitors are also arranged in parallel to filter the high-frequency components.

As illustrated by Figures 3, the TOLL package SiC MOSFETs (C3M0045065L) are selected for the high-frequency bridge daughter card. All of the gate drivers from Texas Instruments Inc. (P/N: UCC5350MCQDQ1) are separately powered by isolated bias power supplies. A half-bridge driver (P/N: MAX13256ATB+T) and a transformer custom designed by Wurth provide three isolated outputs that power the gate drivers.

5.2. Control Board

As illustrated by Figure 4a to Figure 4f, the control board, which carries out the control algorithm of the entire system, is designed using a Texas Instruments Inc. controller (P/N: F280049CPZS). The DC voltages +5V, +3.3V and +1.2V needed for the control board are generated from an isolated power supply on the main board and supplied to the control card via connector J1. As shown in Figure 4f, 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 (R21). All output drive signals are buffered and shifted to a +5V level by a level-shifter from Fairchild Semiconductor International Inc. (P/N: MC74HCT50A). 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 input voltage of the auxiliary power board is from the output of the converter. It provides four isolated output voltages, as shown in Table 2.

Input/Outputs	Net Name	Comments
Input	VBUS/PGND	Typical Input of the Auxiliary Power Board
Output 1	+12VP/AGND	15V Power Supply for MOSFET Gate Drivers
Output 2	+6.5V/AGND	5V Power Supply for control board
Output 3	CAN+5V/CAN_GND	5V Output for CAN Communication

Table 2: Input and Outputs of Auxiliary Power Board

On the main board, a +5.0V voltage is generated (tightly regulated) from the +6.5V output of the auxiliary power by a linear regulator (U1 P/N: NCP1117IST50T3G). The +12V voltage rail powers another precision linear regulator from Texas Instruments Inc. (U5, P/N: TPS54294PWP), 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 J4 is used for CAN, as shown in Figure 7.

Accompanied with the 3.6kW totem-pole PFC unit is a USB flash disk containing two file folders. First, find the folder named by “USBCANTool”, and install this driver on your computer. Another folder named “WolfspeedControlPannel” is the monitor for this reference design. Run the file “ECanTest.exe” in the path “WolfspeedControlPannel>ECanTest>bin>x64>Debug”. Before you connect the GUI with the converter, please make sure the CANH and CANL are connected with the control board located on the mainboard, and the USB is connected to your computer. After that, select the Baudrate as “125k Bit/sec” and click the “CONNECT” button, as shown in Figure 6a. The CAN status is shown as Figure 6b after the connection is successful.

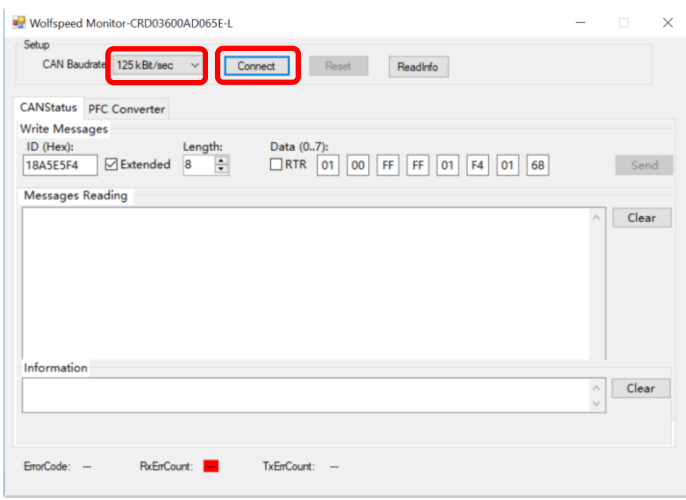

Figure 6a. CAN Status Tab before Connection

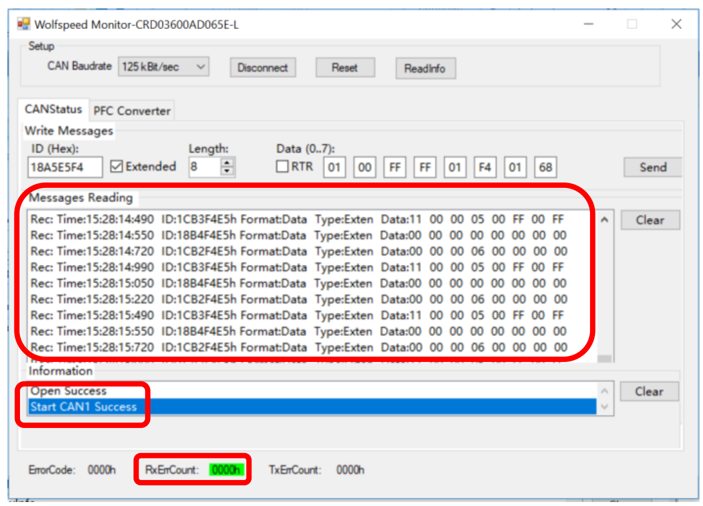

Figure 6b. CAN Status Tab after Connection

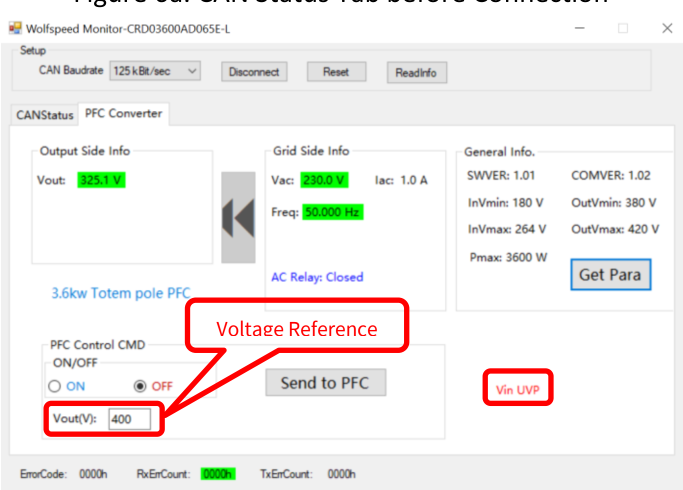

Figure 6c. CAN Status Tab before Start Up

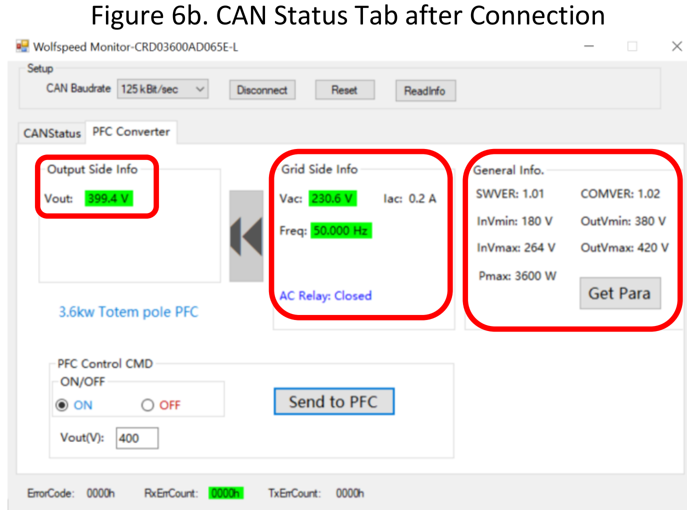

Figure 6d. CAN Status Tab after Start Up

The over/under voltage-protection is indicated by the background color of the voltage value. "Green" indicates "Normal Operation" while "Red" indicates "Warning Issued." The ambient temperature sensed by the IC is displayed in the panel as well. You will see the initial status "Vin UVP" reminder before start up, as shown in Figure 6c . This is normal, and it will disappear when the control command is sent.

As shown in Figure 6d, the input voltage, frequency and inductor current will be shown in the "Grid Side Info". The output voltage will be shown in "DC-Link Info". The specification about this reference design will be shown in "General Info" by clicking the "Get Para" button. Voltage reference is the desired output DC voltage. 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 once it receives the CAN frame with the "OFF" configuration. Protection reminder 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 3 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 voltage 385V.

User must take precautions to prevent overloading.

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 = 385V	Reserved (0xFFFF)

Table 3: Example of Control Command

7. Test Setup

<u>CAUTION</u>

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

*****高压危险*****

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

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

警告

*****高圧危険*****

通電してから、ボードにひどく高い電圧が存在している可能性があります。ボードのモジュールの温度は 50 度以上になるかもしれません。また、電源を切った後、上記の状況がしばらく持続する可能性がありますので、大容量のコンデンサーで電力を完全に釈放するまで待ってください。通電している時にボードに接触するのは禁止です。
大容量のコンデンサーで電力をまだ完全に釈放していない時、ボードに接触しないでください。ボードのコネクターは充電中また充電した後、ひどく高い電圧が存在しているので、大容量のコンデンサーで電力を完全に釈放するまで待ってください。ボードを操作している時、正確な安全ルールを守っているのを確保してください。さもなければ、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。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。使用後、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

AC Input Source: The input source must be an adjustable AC source whose output can be adjusted between 90Vac and 300Vac. It must be capable of supplying at least 5000W.

Output Load: A programmable high-voltage electronic load or a high-voltage resistor bank may be used. Each must be capable of sinking 10A of load current supplied from the evaluation board whose output can be 420Vdc/3.6kW.

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 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 power supply with an isolated ground should be used and must be obtained separately:

1) 12Vdc @ 1.2A capability in total is required to power the cooling fans.

External Fans: Cooling fans should be used and must be obtained separately. As shown in Figure 7, a fan such as the Protechnic DC12V/1.20A fan (P/N: MGT4012WB-W28) or an equivalent fan is used for cooling the magnetics. The cooling fan can be placed to let the air flow to the PFC inductor and the CM inductor. The red wire of the fan is the positive terminal and the black wire is the negative terminal. The temperature of the magnetics should be monitored by an infrared scanner to verify the cooling fan setup during first-time testing.

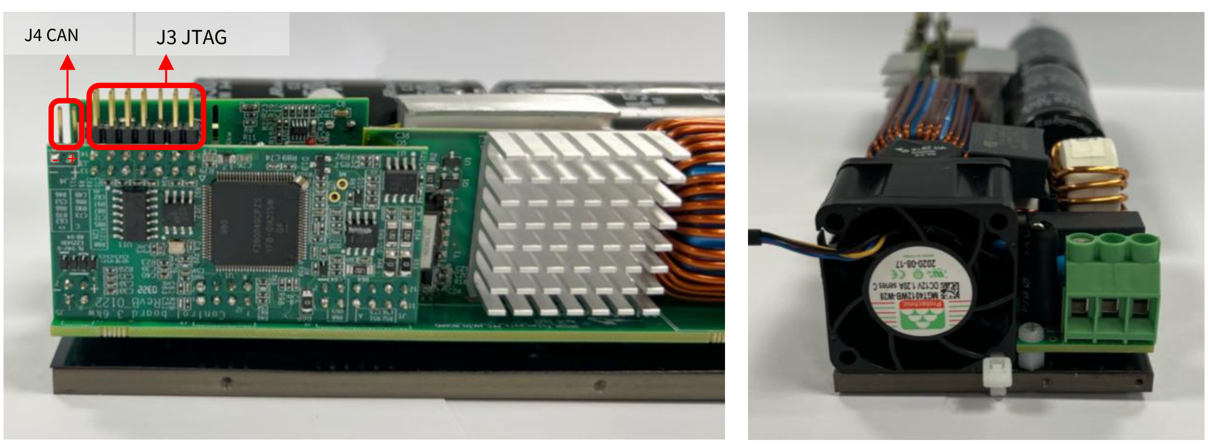

Figure 7. Setup of the Reference Design

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

7.2. Recommended Test Setup

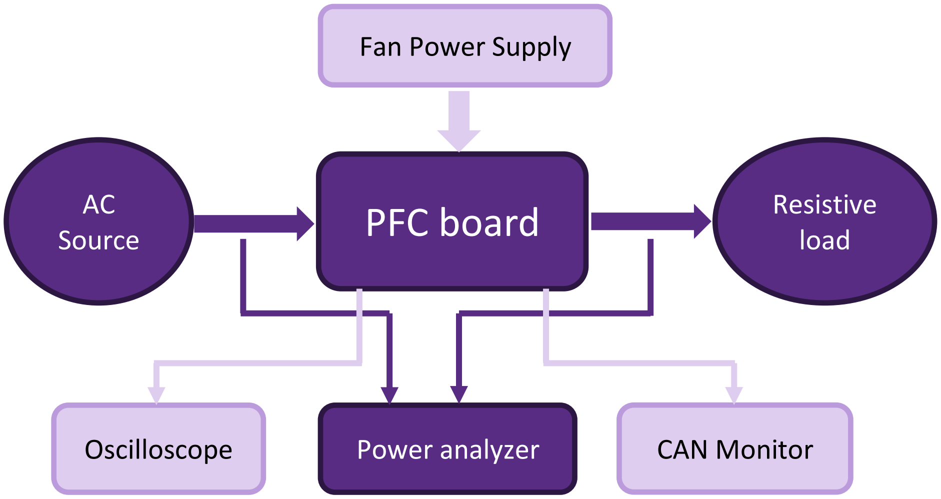

Figure 8. Converter Test Setup

- Connect single phase AC source to the AC terminal (input).
- Connect the resistive load bank to the DC 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 fans.

7.3. 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.

Power Signal	Protection	Trip Point
Input Voltage	UVP	<180V
Output Voltage	OVP	>450V
PFC Tank Current	OCP	35A (rms)

Table 4: Protection Details

7.4. Measured Parameters

The MOSFETs pins of the low-frequency bridge are exposed. Their gate and drain voltages must be measured with caution. Probes should be connected to them only after the removal of input power and only after all bulk capacitors have fully discharged. The power MOSFET pins of the high-frequency bridge are on the daughter board, which are not easy to probe for TOLL package. We remove the test wires before shipment to prevent a short circuit. Probing the pins of high-frequency MOSFETs is not recommended.

NAME	DESCRIPTION
Efficiency	Measured with power analyzer
Input /Output Current	AC current at input and DC current at output
Input /Output Voltage	AC input voltage and DC output voltage
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

Table 5: Parameters that can be Measured

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 ELECTRCIAL SOURCE IS DISCONNECTED UNTIL THE BULK CAPACITORS ARE FULLY DISCHARGED. DO NOT TOUCH THE BOARD WHEN IT IS ENERGIZED AND ALLOW THE BULK CAPACITORS TO COMPLETELY DISCHARGE PRIOR TO HANDLING THE BOARD.

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

警告

*****高压危险*****

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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。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。使用後、すぐにボードの電源を切ってください。電源を切った後、大容量のコンデンサーに貯蓄している電量はコネクターに持続的に入るので、ボードを操作する前に、必ず大容量のコンデンサーの電力を完全に釈放するのを確保してください。

Notes:

1. Keep the output with no load when the converter starts up.
2. Do not overload the converter. The output power should not exceed 3.6kW.
3. There is no current inrush limiter for DC port.
4. Always remember to connect the cooling fans to their power supplies and operate the cooling fans when operating the board.

8.1. Startup Procedure

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

1. Double check the setup: Make sure the AC source is connected to the AC terminals, and the load is connected to the DC terminals.
2. Check the input status and make sure the AC source output is disabled.
3. Make sure no load or only a light load (10%) is applied to the DC terminals until step 10.
4. Apply 12Vdc to the cooling fan on the power board.
5. Turn on the AC supply (180V~265V RMS line-to-neutral).
6. Connect the GUI to the system. Send "OFF" command after it is connected successfully.
7. Verify that the measured values (input voltage and current, line frequency, and output voltages) in the GUI were reported correctly.
8. Send "ON" command with the desired output voltage (e.g., 400V). The converter will start up with the desired voltage.
9. After the output voltage has reached steady-state regulation, apply a load to the output with no more than 2kW 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.
11. The output voltage can be changed using the GUI, User should make sure the load is also adjusted to

avoid overloading. For example, the resistance of the resistive load needs to be increased accordingly if the output voltage is increased.

8.2. Turn Off Procedure

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 AC source.
4. Add a high resistance (1kΩ) to slowly discharge the output capacitors
5. Turn “OFF” the load completely after the capacitors are fully discharged, i.e., the voltage reading on the power analyzer reaches zero.
6. Capacitors may remain charged for up to 30 minutes after the circuit is turned OFF if steps 4 or 5 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.
7. Turn OFF the 12Vdc power supply for cooling fan.

9. Photo of Reference Design

Figure 9 shows the locations of the terminals, key components and daughter-boards on the Power Board.

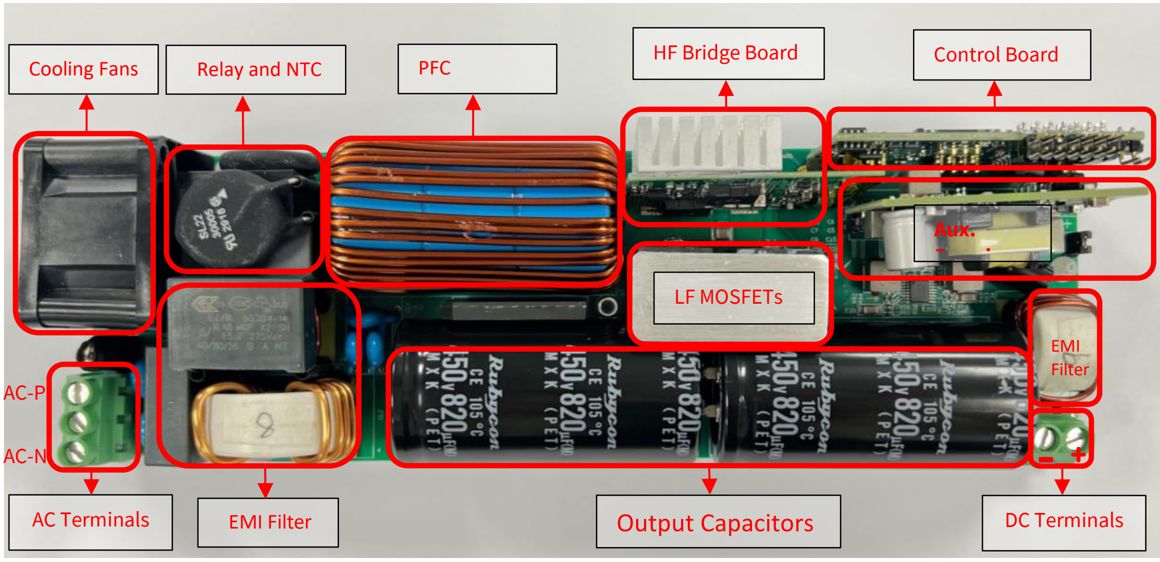


*Figure 9: Top View of PCBA (220mm*73mm*40mm)*

10. Performance Data

Shown below is measured performance data of Wolfspeed's CRD-03600AD065E-L reference design board under various conditions. Table 6 shows the performance data.

Input Voltage (Vac)	Input Power (W)	Load (%)	Output Voltage (Vdc)	Output Power (W)	ITHD	Power Factor	Overall Efficiency (%)
180	0.4041	10	400	0.39669	9.1998	0.9652	98.164
180	0.71963	20	400	0.70961	6.8056	0.9863	98.608
180	1.127	30	400	1.1129	4.7323	0.9931	98.743
180	1.4451	40	400	1.4264	3.7907	0.9952	98.703
180	1.8564	50	400	1.832	2.9334	0.9962	98.684
180	2.1762	60	400	2.1454	2.491	0.9966	98.584
180	2.5661	70	400	2.5246	2.0759	0.9972	98.38
180	2.9722	80	400	2.9179	1.782	0.9979	98.173
180	3.2991	90	400	3.2335	1.6023	0.998	98.013
180	3.7084	100	400	3.6281	1.4488	0.998	97.836
230	0.40275	10	400	0.39653	9.2174	0.9384	98.455
230	0.7183	20	400	0.71027	7.9509	0.9793	98.883
230	1.1234	30	400	1.1122	5.7366	0.9914	99.007
230	1.4397	40	400	1.4258	4.6291	0.9945	99.035
230	1.8246	50	400	1.8068	3.6952	0.9963	99.022
230	2.2227	60	400	2.1997	3.0207	0.9972	98.965
230	2.5465	70	400	2.5186	2.6224	0.9975	98.895
230	2.9463	80	400	2.9124	2.2236	0.9978	98.847
230	3.2548	90	400	3.214	1.9957	0.998	98.746
230	3.6601	100	400	3.6081	1.7761	0.9985	98.58
265	0.40277	10	400	0.39688	11.06	0.9035	98.546
265	0.71784	20	400	0.71011	8.707	0.9665	98.923
265	1.0992	30	400	1.0895	6.7125	0.986	99.123
265	1.4151	40	400	1.4031	5.4112	0.9922	99.152
265	1.821	50	400	1.8057	4.3021	0.9955	99.16
265	2.2155	60	400	2.1972	3.5152	0.9968	99.171
265	2.5452	70	400	2.5227	3.0576	0.9974	99.115
265	2.9434	80	400	2.9154	2.5895	0.9979	99.046
265	3.2648	90	400	3.2323	2.3387	0.9982	99.006
265	3.6665	100	400	3.6262	2.0556	0.9985	98.902

Table 6: Efficiency Data

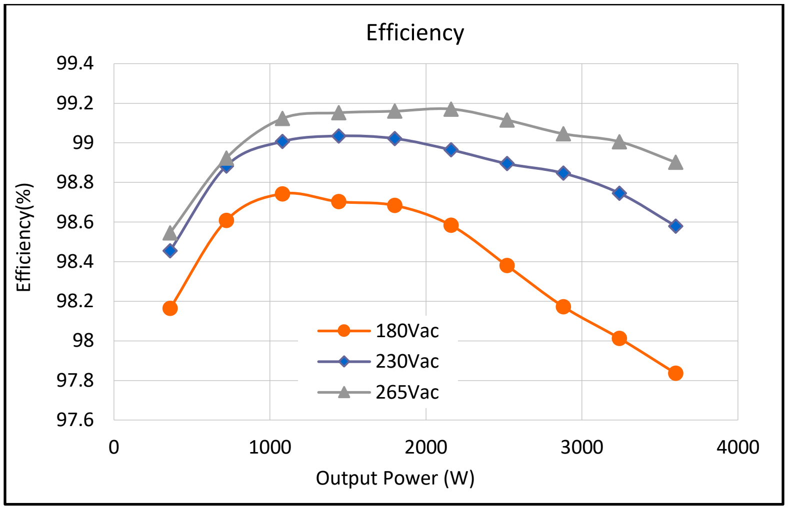


Figure 10: Efficiency Curve

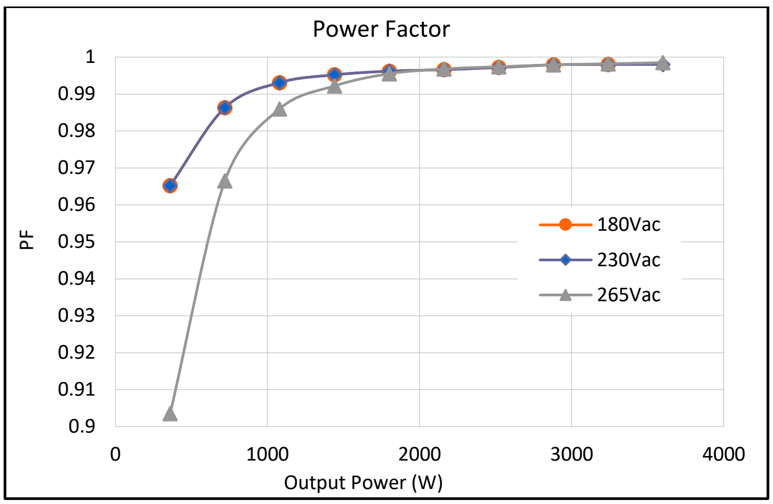


Figure 11: Power Factor Curve

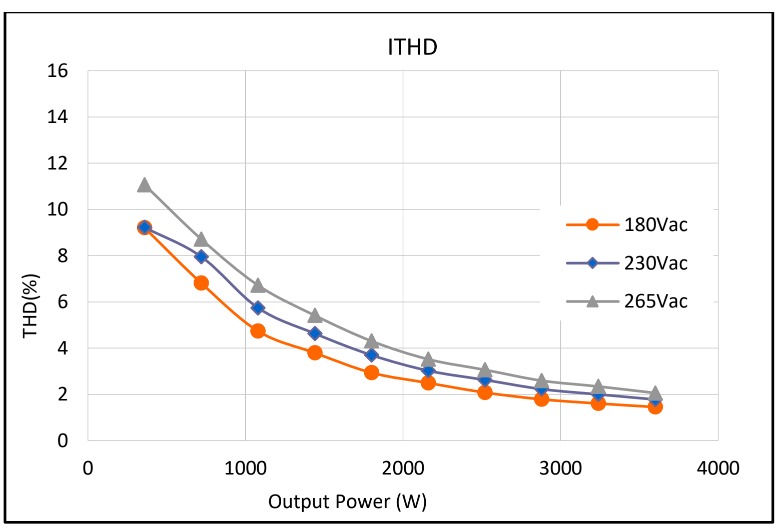
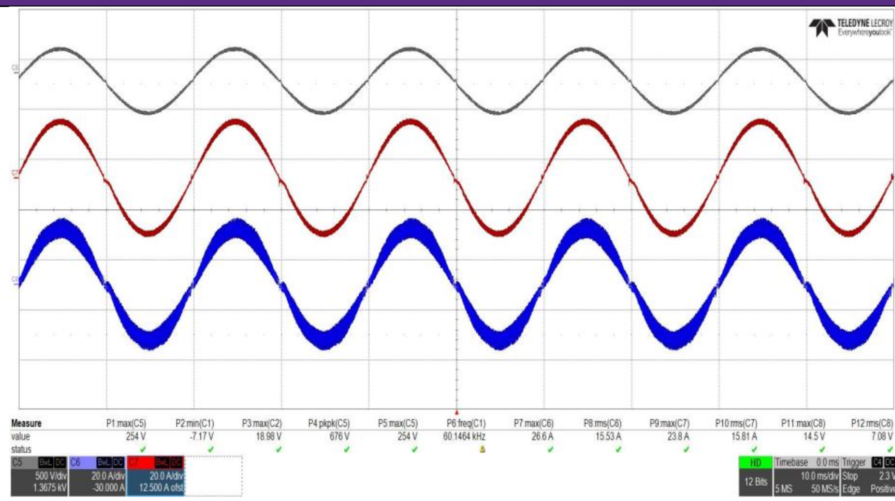
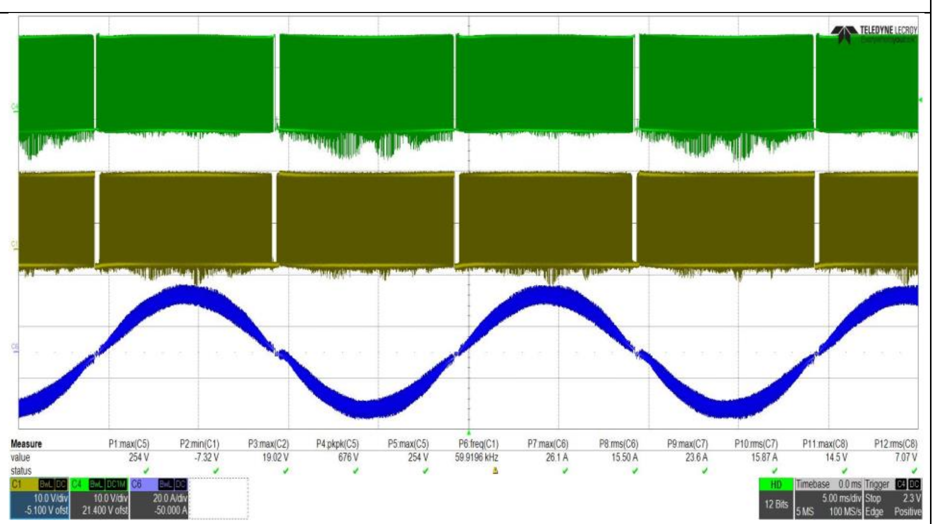


Figure 12: THD Curve

11. Typical Waveforms

Operational waveforms are presented in Table 7.

Condition	Waveform
Input Voltage: 230Vac Output Voltage: 400Vdc Output Power: 3.6kW	 **CH5**: Vin 500V/div **CH6**: PFC choke current 20A/div **CH7**: Iin 20A/div
Input Voltage: 230Vac Output Voltage: 400Vdc Output Power: 3.6kW	 **CH1**: Vgs HF high side 10V/div **CH4**: Vgs HF low side 10V/div **CH6**: I_L 20A/div

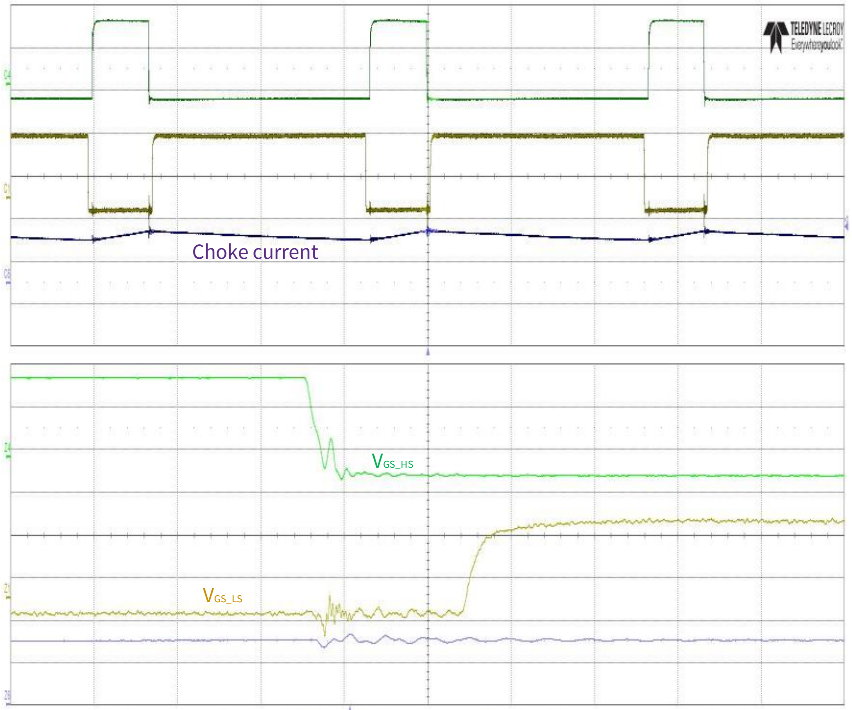
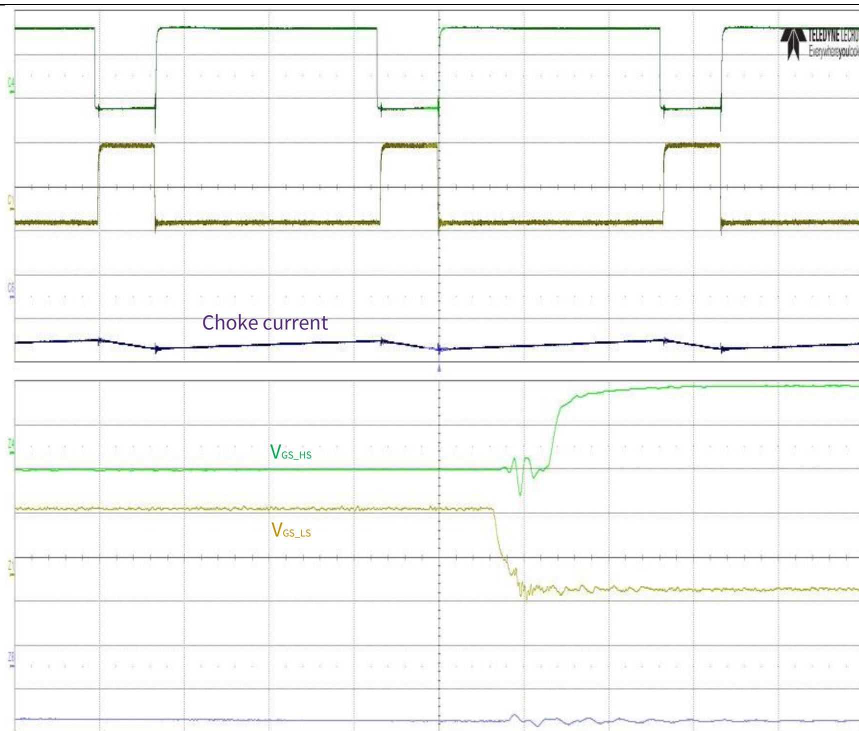
Input Voltage: 230Vac Output Voltage: 400Vdc Output Power: 3.6kW	
Input Voltage: 230Vac Output Voltage: 400Vdc Output Power: 3.6kW	

Table 7: PFC Key Waveforms

12. Thermal Design and Test Results

In a thermal test of the unit, forced-air cooling is applied for the magnetics cooling such as that PFC inductor and CM inductor. There is no direct air flow to the power MOSFETs. The MOSFETs of the high-frequency bridge are TOLL package in the daughter card. The thermal test was performed at 180V AC input and 400V DC output under 3.6kW full load, 230V AC input and 400V DC output under 3.6kW. K-type thermal couples and a data acquisition unit from Keysight Technologies Inc. (P/N:34972A) are used to measure the package temperature (near the die) of components.

The temperature of semiconductors is shown in the Table 8. The estimated highest junction temperature of MOSFETs in the design was below 100°C. This value was calculated based on the measured package temperature, the thermal resistance of the MOSFET, and the calculated power loss. Because the maximum junction temperature of the C3M0045065L is 175°C, the integrated heat sink design has allowed the MOSFETs to remain within their thermal derating guidelines.

The heat generated by the MOSFETs of the high frequency bridge is transferred through the PCB vias, TIM between the PCB and the heatsink, and finally the heatsink to the ambient. The heatsink is fixed to the PCB with an adhesive TIM from Momentive Performance Materials (TIA520R, 5.2W/mK). The use of this thermally conductive adhesive TIM material with electrical insulation eliminates the need for screws and nuts, especially in the precious PCB space.

Description	Rth (j-c) (c/w)	Calculated Power loss (watts)	Measured Package Temp. (°C)	Max. Operating Case temp (°C)	Calculated Junction Temp. (°C)	Max. Operating junction temp (°C)	Derating Requirement (°C)	Result
		180Vac 400Vdc 3.6 kW						
Mos_HF_HS	0.64	13.38	82.5	150	91.06	175 °C	130°C	Pass
Mos_HF_LS	0.64	13.38	85	150	93.56	175 °C	130°C	Pass
Mos_LF	0.35	3.33	43		44.16	175 °C	130°C	Pass
		230Vac 400Vdc 3.6 kW						
Mos_HF_HS	0.64	8.24	63.5	150	68.77	175 °C	130°C	Pass
Mos_HF_LS	0.64	8.24	62	150	67.27	175 °C	130°C	Pass
Mos_LF	0.35	2.03	33		33.7	175 °C	130°C	Pass

Table 8: Thermal Test Results of SiC Power MOSFETS with TIM (TIA520R)

13. Appendix

13.1. CAN Messages from PFC

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

Table 10: Overall Charge Status

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

Table 11: Temperature

Message Identifier	0x18B3F4E5			
Data	Byte0+Byte1	Byte2+Byte3	Byte4+Byte5	Byte6+Byte7
Property	PFC 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 12: PFC Information

Converter Status	Comments	Converter Status	Comments
Bit15	Reserved	Bit7	1: Output OVP 0: normal (default)
Bit14	Reserved	Bit6	Reserved
Bit13	1: Inductor OCP 0: normal(default)	Bit5	Reserved
Bit12	1: Input UVP 0: normal(default)	Bit4	Reserved
Bit11	Reserved	Bit3	Reserved
Bit10	Reserved	Bit2	Reserved

Bit9	Reserved	Bit1	Reserved
Bit8	1: Relay Open 0: Relay Closed (default)	Bit0	1: CAN error 0: normal (default)

Table 12a: Bit Definition for PFC Status

Message Identifier	**0x1AB8F4E5**			
Data	Byte0+Byte1	Byte2+Byte3	Byte4+Byte5	Byte6+Byte7
Property	Com. 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			

Table 13: Part I of PFC Specification

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

Table 14: Part II of PFC Specification

13.2. CAN Messages to PFC

Message Identifier	**0x18A5E5F4**				
Data	Byte0	Byte1	Byte2+Byte3	Byte4+Byte5	Byte6+Byte7
Property	Reserved 0xFFFF	0: OFF 1: ON	Reserved 0xFFFF	Output Voltage	Reserved 0xFFFF
Unit	NA			0.1V	NA
Bias	0				
Data Format	integer				

Table 15: Control command

14. Revision History

Date	Revision	Changes
September 2022	1	First issue