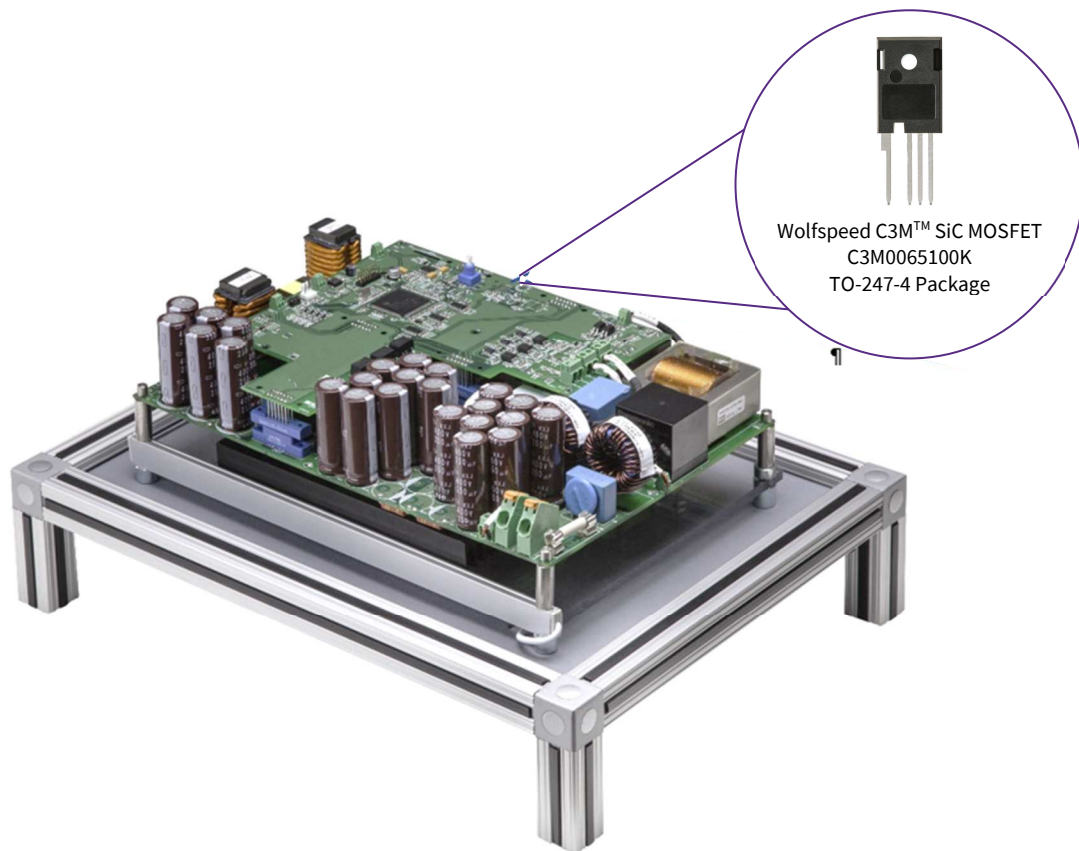


CRD-06600FF10N

6.6kW Bi-Directional EV On-Board Charger User Guide



CRD-06600FF10N

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This document is prepared as a user guide to install and operate Wolfspeed® evaluation hardware. All parts of this user guide are provided in English, and the cautions are provided in English, Mandarin, and Japanese. If the end user of this board is not fluent in any of these languages, it is your responsibility to ensure that they understand the terms and conditions described in this document, including without limitation the hazards of and safe operating conditions for this board.

本文件中的所有内容均以英文书写，“注意”部分的内容以英文、中文和日语书写。作为本板子的终端用户，即使您不熟悉上述任何一种语言，您也应当确保正确理解本文件中的条款与条件，包括且不限于本板子的危险隐患以及安全操作条款。

当書類のすべての内容は英語で書きます。「注意点」の内容は英語、中国語、また日本語で書きます。当ボードの端末使用者は上記の言語が一つでもわからないなら、当端末使用者は当書類の条約と条件が理解できるのを確保すべきです。そして、当ボードの危険や安全に使用する条件を含み、また限りません。

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このクリーのコンポーネント用評価ハードウェアは壊れやすい高電圧の高温パワーエレクトロニクスシステムであり、ラボ環境での評価ツールとして使用され、優秀な技術者やエンジニアによって処理され、操作されることを意図している。ハードウェアが使用されていない場合、保管温度が-40°Cから105°Cの範囲に保管してください。このハードウェアを輸送する場合は、輸送中にボードまたはその壊れやすいコンポーネントに損傷を与えないよう特別な注意を払う必要がある。また電子部品の損傷を避けるためにボードを静電気放電(ESD)袋に静置して慎重に輸送すべき。ハードウェアの輸送中の保護について質問があれば <https://forum.wolfspeed.com/> に連絡してください。ハードウェアには危険物質が含まれていないが、工業的、技術的、安全性の基準または分類に適合するように設計されておらず、生産適格組立品でもない。



CAUTION

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

警告

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

警告

ボードの使用、危険の対応、そして安全に操作する要求などの大切な情報を含むので、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
- Electrocutation
- Electrical shock
- Electrical burns
- Severe heat burns

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

警告

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

操作板子时应确保遵守正确的安全规程，否则可能会出现下列危险：

- 死亡
- 严重伤害
- 触电
- 电击
- 电灼伤
- 严重的热烧伤

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

警告

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

Wolfspeed’s CRD-06600FF10N, 6.6 kW Bi-Directional EV On-board charger (OBC) is designed to operate from universal single-phase input and provide an output voltage in the range of 250 VDC to 450 VDC. The front-end AC/DC PFC (Power Factor Correction) stage consists of a Totem-Pole Bi-Directional topology followed by a Bi-Directional Isolated DC/DC stage which uses a symmetric CLLC converter. The input and output sides of the Bi-Directional Isolated DC/DC stage carry H-bridge topologies. Input is isolated from the output through a high-frequency transformer. Even though this board is designed for electric vehicle (EV) application, there is no battery charging algorithm built in and the board must be tested on resistive load only. Output current is limited to 20 A at 250 VDC output. AC/DC PFC stage runs at a fixed frequency of 67 kHz and DC/DC CLLC stage runs at fixed frequency close to 200 kHz. The output voltage is regulated by varying DC link voltage, which is an open loop control. Output voltage can be set by a potentiometer provided on the control board. A block diagram of Wolfspeed’s CRD-06600FF10N, 6.6 kW Bi-Directional EV On-board charger is shown in Figure 1.

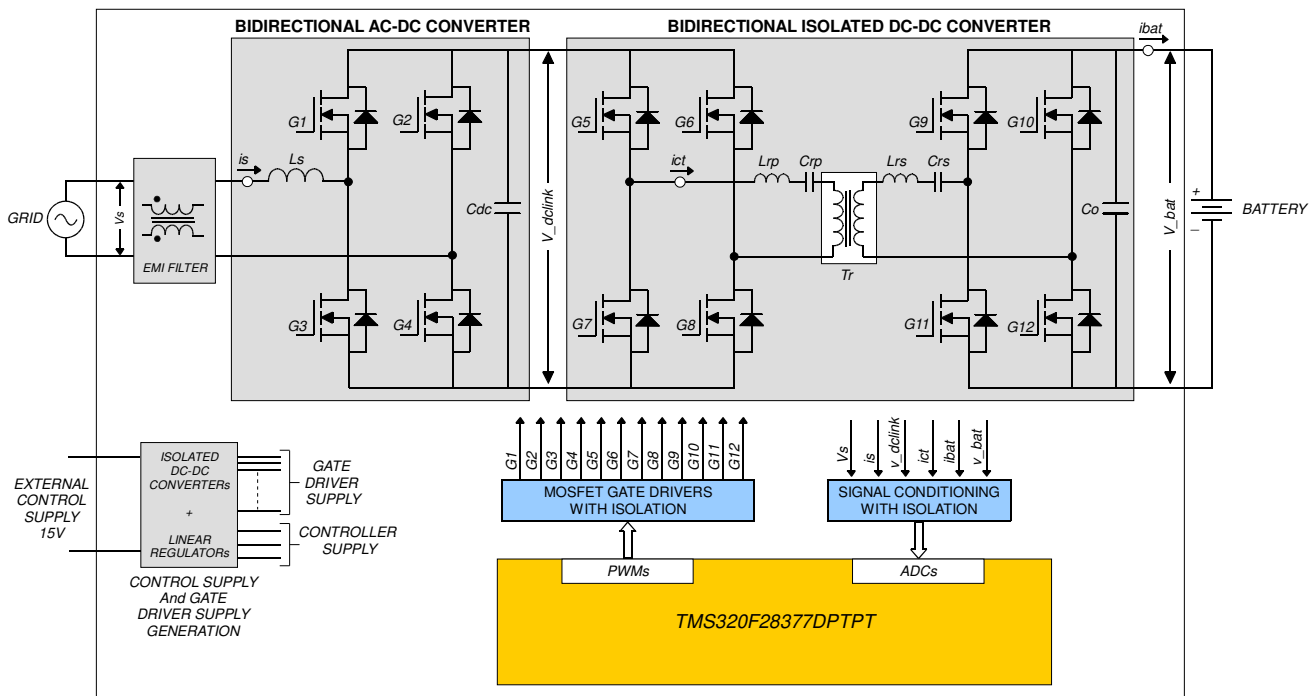


Figure 1. Block diagram of Wolfspeed’s CRD-06600FF10N, 6.6 kW bi-directional EV on-board charger

2. Description

This User’s Guide provides the schematic, PCB layout, and test set up necessary to evaluate Wolfspeed’s CRD-06600FF10N, 6.6 kW Bi-Directional EV On-board charger (OBC) with a resistive load connected at the output. Please refer to Wolfspeed’s Application Note for this board if you need more design details about this reference design board. You may obtain a copy of Wolfspeed’s Application Note for this board by accessing the Reference Design page under Power Products on www.wolfspeed.com.

This reference design board uses Wolfspeed’s C3M0065100K, 65mΩ, 1000V, SiC MOSFETs (TO-247-4) in both AC/DC stage and the DC/DC stage. AC/DC stage has 2 MOSFETs in parallel for each switch position in the Totem-Pole topology (i.e., the high-frequency switch position as well as the line-frequency switch position). DC/DC stage has a single MOSFET in both input and output stages. The input accepts universal input single phase

voltage from 90 VAC – 265 VAC and provides an isolated voltage from 250 VDC – 450 VDC. The input and output stages are protected by fuses. External power supplies for the control board and gate drivers and the cooling fans for the heat sink, among other things, must be obtained separately. The input undervoltage and overvoltage protection and the output overvoltage protection are provided by the Firmware. The unit must be started under a no-load condition only and the load should be switched ON only after voltage has built up at the output in order to avoid excessive inrush current at starting while the output capacitors are not charged up to the required voltage. The ON/OFF switch, which has been provided on the top of the control board, controls the release of gate pulses to the MOSFETs. The unit switches OFF in case of input overvoltage, input undervoltage, output overvoltage and the overload current conditions. If the unit switches off for any of the reasons in the preceding sentence, it can be re-started after a power ON reset to the control board and fault conditions have been removed.

3. Electrical Performance Specifications

Table 1: Performance Specifications - AC/DC Mode

Parameter	Test Conditions	Min	Nom	Max	Units
Input Characteristics					
Input voltage		90	230	265	V
Frequency		48	50-60	62	Hz
Brownout Voltage	$I_{OUT} = I_{NOM}$		80		V
Brownout recovery voltage			100		V
Input Current	$V_{IN} = 200V$		34.7		A
Output Characteristics					
Output Voltage	$V_{IN} = V_{MIN}$ to V_{MAX} , $I_{OUT} = 0$ to I_{NOM}	250	325	450	V
Nominal output current	$V_{IN} = V_{MIN}$ to V_{MAX}		20		A
Maximum output current	$V_{IN} = V_{MIN}$ to V_{MAX}		24		A
Output voltage ripple	$V_{IN} = V_{MIN}$ to V_{MAX} , $I_{OUT} = 0$ to I_{NOM}		10		V
Output power	$V_{IN} = 200V$ to V_{MAX} $V_{IN} = 90V$		6600 2000		W
System Characteristics					
Average efficiency	$V_{IN} = V_{NOM}$ $I_{OUT} = 25\%, 50\%, 75\%, 100\%$ of $I_{OUT(nom)}$	95%	95.5%		
10% load efficiency	$V_{IN} = V_{NOM}$, $I_{OUT} = 10\%$ of $I_{OUT(nom)}$	91%	92%		
No load power	$V_{IN} = V_{NOM}$, $I_{OUT} = 0$		60	75	W

Table 2: Performance Specifications - DC/AC Mode

Parameter	Test Conditions	Min	Nom	Max	Units	
Input Characteristics						
$V_{IN(DC)}$	Input voltage	320	380	450	V	
f_{DC}	Frequency (grid mode)		50-60		Hz	
	Frequency (standalone mode)		60			
V_{DC}	Brownout voltage	$I_{OUT} = I_{NOM}$	310		V	
$V_{IN(DC)}$	Brownout recovery voltage		330		V	
$I_{IN(DC)}$	Input current	$V_{IN} = 310V$	10.3		A	
Output Characteristics						
V_{OUT}	Output voltage (grid mode)	$V_{IN} = V_{MIN}$ to V_{MAX} , $I_{OUT} = 0$ to I_{NOM}	90	230	265	V
	Output voltage (standalone)	$V_{IN} = V_{MIN}$ to V_{MAX}		230		
$I_{OUT(nom)}$	Nominal output current	$V_{IN} = V_{MIN}$ to V_{MAX}		14.3		A
$I_{OUT(max)}$	Maximum output current	$V_{IN} = V_{MIN}$ to V_{MAX}		20		A
V_{OUT}	Output voltage ripple	$V_{IN} = V_{MIN}$ to V_{MAX} , $I_{OUT} = 0$ to I_{NOM}		10		V
$P_{OUT max}$	Output power	$V_{IN} = V_{MIN}$ to V_{MAX}		3300		W
System Characteristics						
η_{avg}	Average efficiency	$V_{IN} = V_{NOM}$, $I_{OUT} = 25\%, 50\%, 75\%, 100\%$ of $I_{OUT(nom)}$	95%	95.5%		
$\eta_{10\%}$	10% load efficiency	$V_{IN} = V_{NOM}$, $I_{OUT} = 10\%$ of $I_{OUT(nom)}$	91%	92%		
P_{NL}	No load power	$V_{IN} = V_{NOM}$, $I_{OUT} = 0$		60	75	W

3.1 Applications

The main application of this reference design board is isolated Bi-Directional EV charging systems, which charge an EV battery when connected to the grid. For this reference design board, the board must be connected to the resistive load only (specifically in AC/DC Mode) since a battery charging algorithm is not implemented.

The CRD-06600FF10N reference design board feeds power back into the grid when running in DC/AC mode and the DC side is connected to a battery or a voltage source greater than 320 VDC. If the DC input voltage is less than 320 VDC, it does not feed power back into the grid.

3.2 Features

Some of the features of Wolfspeed's CRD-06600FF10N reference design board are given below:

- Isolated 250 VDC – 450 VDC output
- Maximum output current limited to 20 A
- Maximum output power limited to 6.6 kW (AC/DC mode)
- Maximum power at 250 VDC output limited to 5 kW.
- Power is limited to 3.3 kW in DC/AC mode.
- Universal input voltage range.
- Full load THD < 5%.
- Peak efficiency > 96%.
- Firmware-controlled input under voltage/over voltage protection
- Firmware-controlled output overvoltage protection.
- Input overcurrent and output overcurrent protection.
- LEDs for various fault indications on the control board.
- Toggle switch ON control board for choosing AC/DC or DC/AC mode.
- Potentiometer ON control board to set output voltage in case of AC/DC mode and grid current in case of DC/AC (grid connected) mode.

4. Schematics of Power Board and Control Board

Note: A larger copy of any schematic in the Section 4 may be obtained by accessing the Reference Design Page under Power Products on www.wolfspeed.com or by requesting a copy from Wolfspeed using forum.wolfspeed.com

The schematics of the power board and the control board are shown in Figure 2 to Figure 5.

Power Board Schematic:

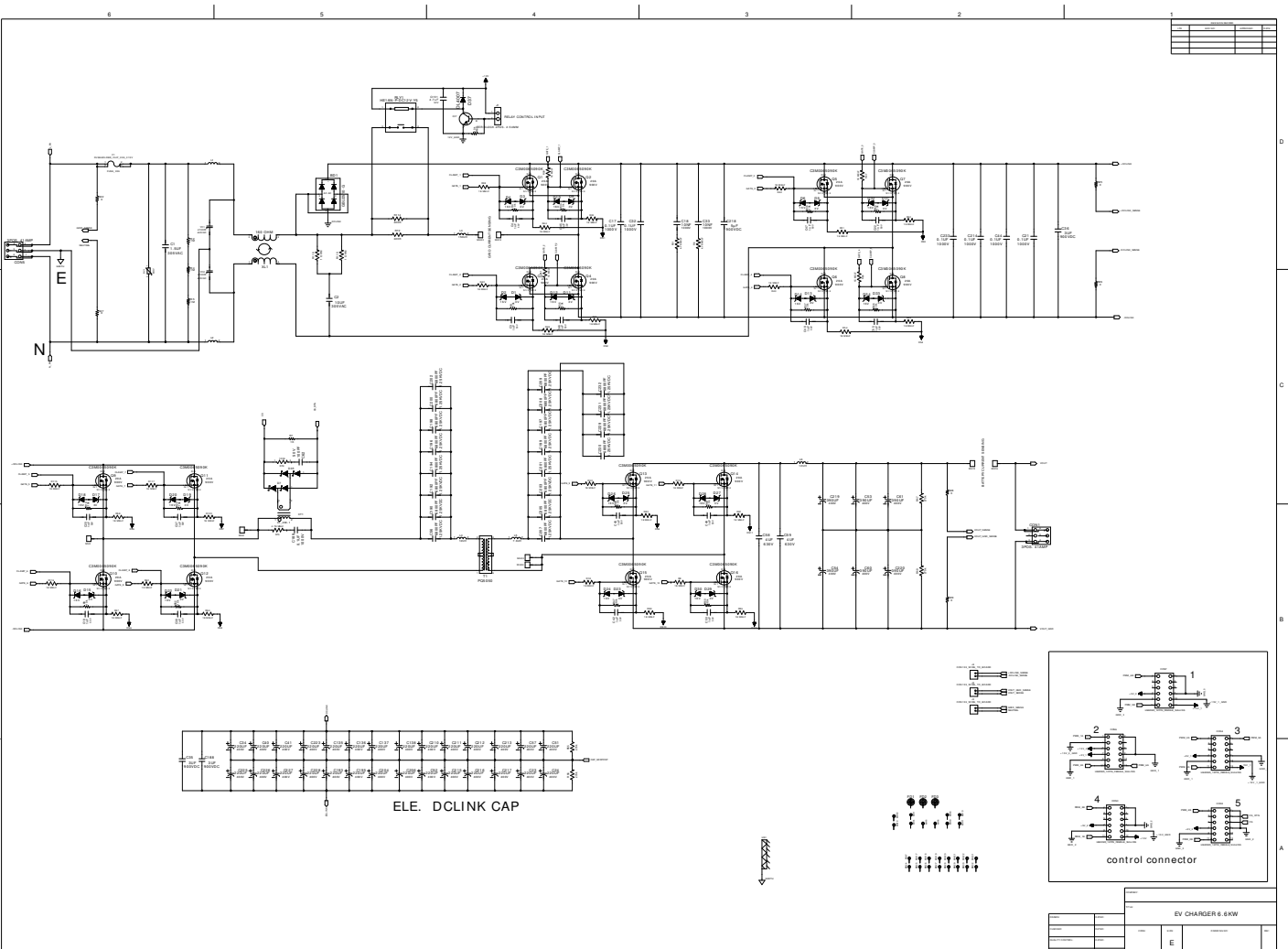


Figure 2. Schematic of power board

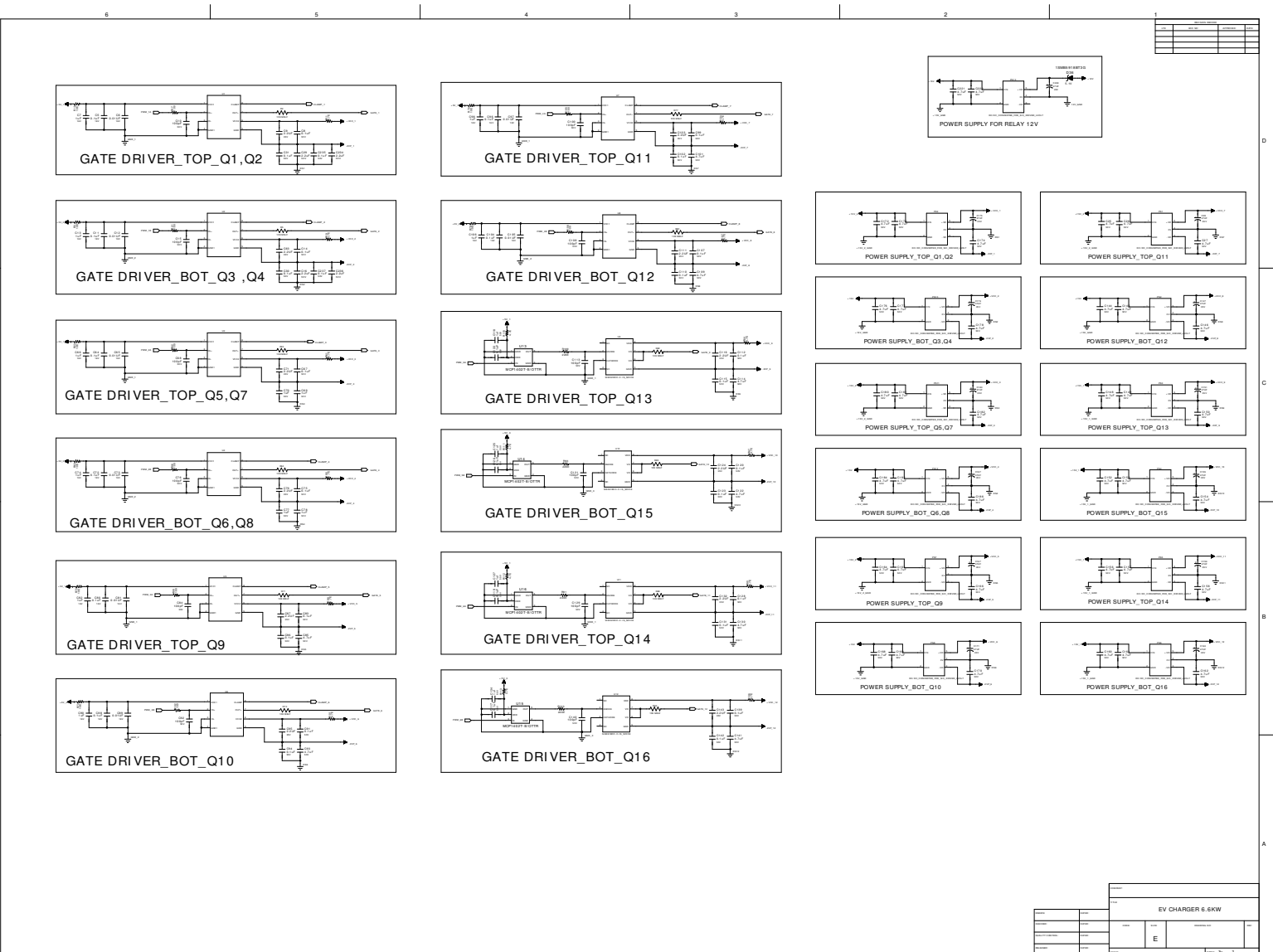


Figure 3. Schematic of power board (with gate drivers)

Control Board Schematic:

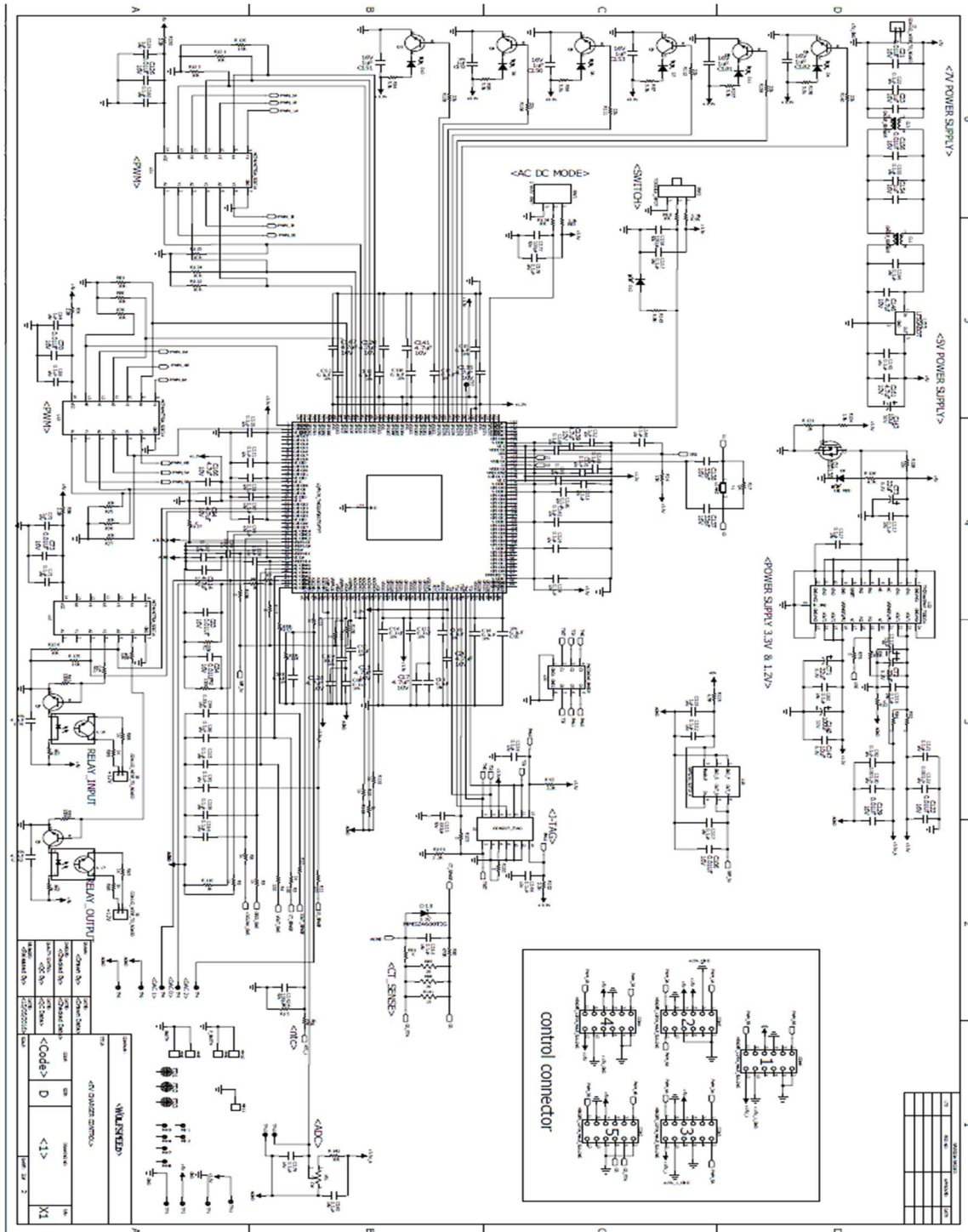


Figure 4. Schematic of control board

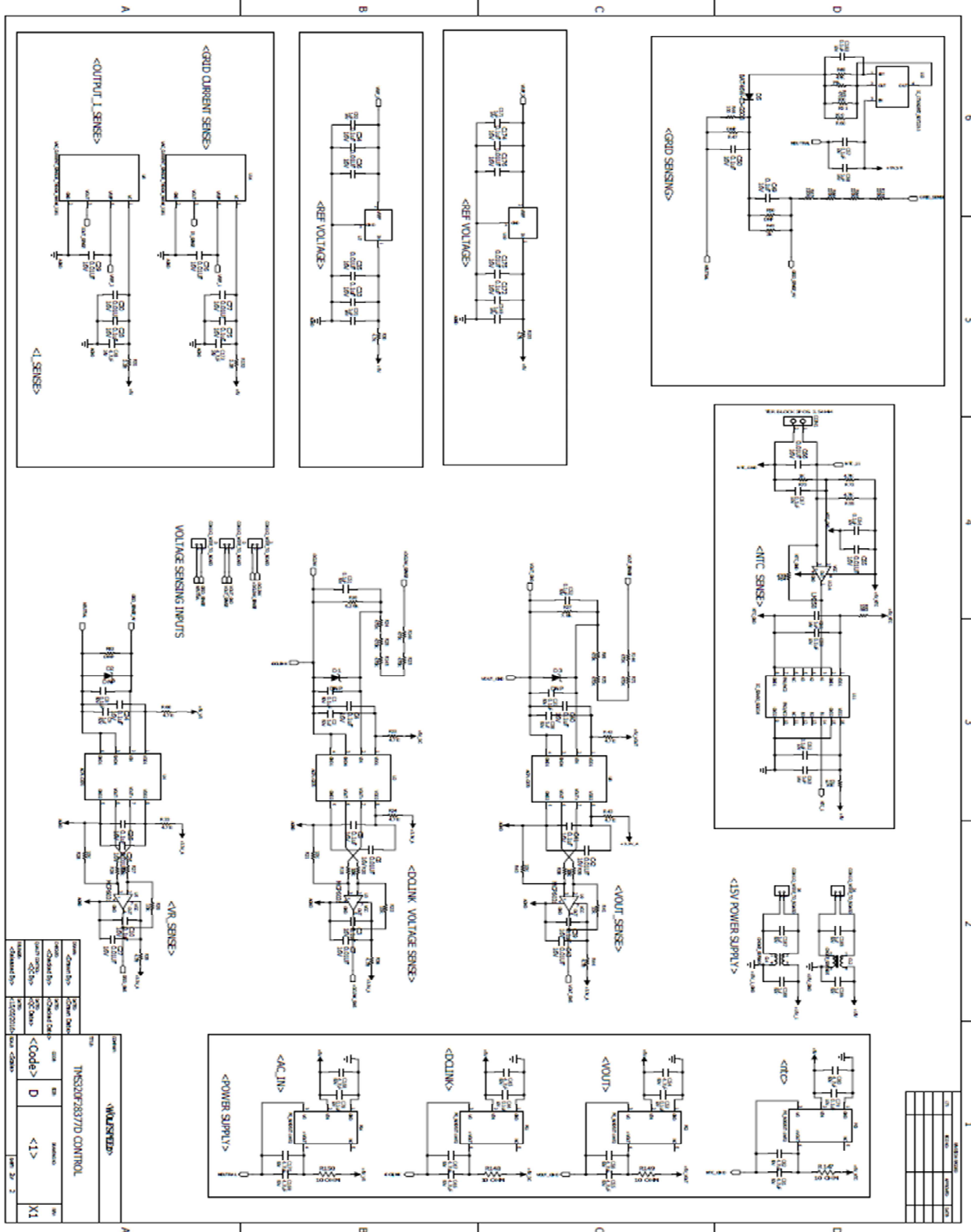


Figure 5. Schematic of control board

5. Hardware Description of Power Board and Control Board

Description of Power Board:

As shown in Figure 2, the Input AC voltage is connected to terminals 1 and 3 of CON5 followed by the fuse F1 and MOV (Metal Oxide Varistor) RV1. Differential mode filters L1 and L2 and common mode filter XL1 are then connected, and the filters are followed by a low-frequency rectifier BD1 that charges the output DC link capacitors through positive temperature coefficient (PTC) resistors RV1 and RV2. RV1 and RV2 are shorted by relay; if the DC link voltage crosses the peak value of the input grid voltage, then rectifier BD1 becomes reverse biased and no current flows through the rectifier BD1. The main PFC inductor L3 is connected after the relay. The other end of L3 is connected to the midpoint of the high-frequency half-bridge Totem-Pole MOSFETs Q1, Q2, Q3, and Q4. After passing through the differential and common mode filters, the neutral point of the grid is connected to the low-frequency half-bridge Q5, Q6, Q7, and Q8. The DC link capacitor bank consists of 18 pieces of 250 μf , 400 V capacitors connected in series and parallel combination. There are some film capacitors and RC snubber circuits as well to absorb the high-frequency ripple and reduce EMI (Electromagnetic Interference).

The DC link is connected to an H-bridge comprised of MOSFETs Q9, Q10, Q11, and Q12 that forms the primary side of the bi-directional CLLC converter. The resonance tank is composed of an inductor (L4) and a resonance capacitor bank of 12 pieces of 4.7nF film capacitor. The inductance of the main CLLC transformer is 100 μH with a PQ5050 core. The secondary side of PQ5050 core is connected to the secondary side resonance inductor L5 and a bank of 18 pieces of secondary side resonance capacitors. The secondary side H-bridge is composed of MOSFETs Q13, Q14, Q15, and Q16 followed by film capacitors C58 and C59 and an electrolytic capacitor.

As shown in Figure 3, the gate drive signals for the MOSFETs of the PFC stage and the resonance stage are generated by the DSP (Digital Signal Processing) controller and each MOSFET is further isolated by their respective gate drivers. There are separate isolated DC/DC ($V_{\text{IN}} = +15\text{V}$, $V_{\text{OUT}} = +15\text{V}$, -3V) supplies for all gate drivers. The input currents and output load currents are sensed by a current sensor for processing in the DSP controller. All voltage sensing (grid as well as the output voltage) signals are isolated with an analog optocoupler before being fed into the DSP controller for further processing.

Description of Control Board:

As shown in Figure 4 and Figure 5, the DSP controller from Texas Instruments Inc. (P/N: TMS320F28337) is the main component of the control board carrying the control algorithm of the whole system. The input of the control board is an isolated 7 V, 1 A power supply which is regulated to +5V using a linear regulator. The 3.3 V and 1.2 V power supplies are further created from the +5V supply using a precision regulator U22 from Texas Instruments Inc. (P/N: TPS70445). All output PWM (Pulse Width Modulation) signals are buffered and shifted to +5V level by using a Fairchild Semiconductor International Inc. level shifter (P/N: MC74HCT50A) and a buffer IC (U13, U15, and U21) before being fed to their respective gate drivers. The reference for the ADC (Analog to Digital Converter) of the DSP is generated through a precision reference IC (U18) from Texas Instruments Inc. (P/N: REF3230AIDBVT). All incoming signals to the DSP such as voltages and currents are galvanically isolated from the high-power side.

6. Test Equipment



CAUTION

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

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

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

警告

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

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

警告

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

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

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

You should use each of the items summarized below when operating this board. The board may not operate properly if you fail to use them.

AC Input Source: An isolated variable AC source capable of supplying between 90 VAC and 265 VAC and at least 7000 W capacity.

Output Load: A programmable electronic load or a resistor bank capable of operating at 250 V to 450 V and 25 A of current.

Power Meter: A YOKOGAWA® WT 1800 power analyzer or any other power analyzer with the same specifications.

MCB: Single-phase MCB (Miniature Circuit Breaker) rated for 415 V, 32 A

Multimeters: Two digital multimeters (DMMs) to measure the regulated output voltage and the input RMS (Root Mean Square) voltage.

Oscilloscope: A digital or analog oscilloscope (300MHz or higher ideally) and differential voltage probes (100Mhz or higher ideally) plus isolated current probes (i.e., hall effect).

- Power Supplies:**
- 1) 7V, 1A for control board
 - 2) 15V, .5A for gate drivers on primary side (PFC + input H bridge)
 - 3) 15V, .5A for gate drivers on secondary side (H bridge)
 - 4) 24V, 2A for cooling fans

All power supplies must have isolated grounds.

External Fan: Used to provide a small air flow to the top side of the control board, as the boost inductor can get very hot.

Wire Gauge: A minimum of (American Wire Gauge) AWG #10 wire is required for the input and output connections. Each of the wire connections between the AC source and the reference design board, and the wire connections between the reference design board and the load, should be less than two feet long.

6.1 Recommended Test Set Up (AC/DC Mode)

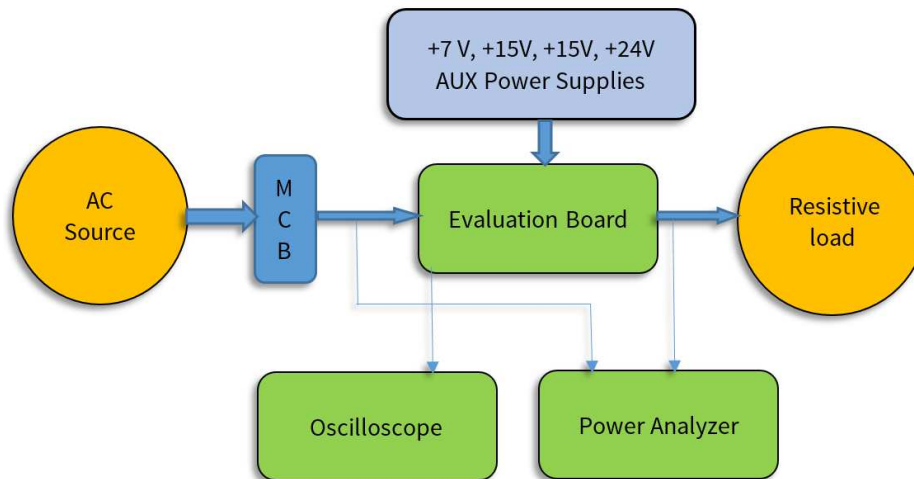


Figure 6. AC-DC mode test setup

- Connect single-phase AC source to the AC terminal (input) of the evaluation board through MCB.
- Connect the resistive load bank to the DC terminal (output).
- Connect power analyzer to measure input and output power.
- Use appropriately rated voltage and current probes and connect to the oscilloscope.

6.2 Recommended Test Set Up (DC/AC -Grid Connected Mode)

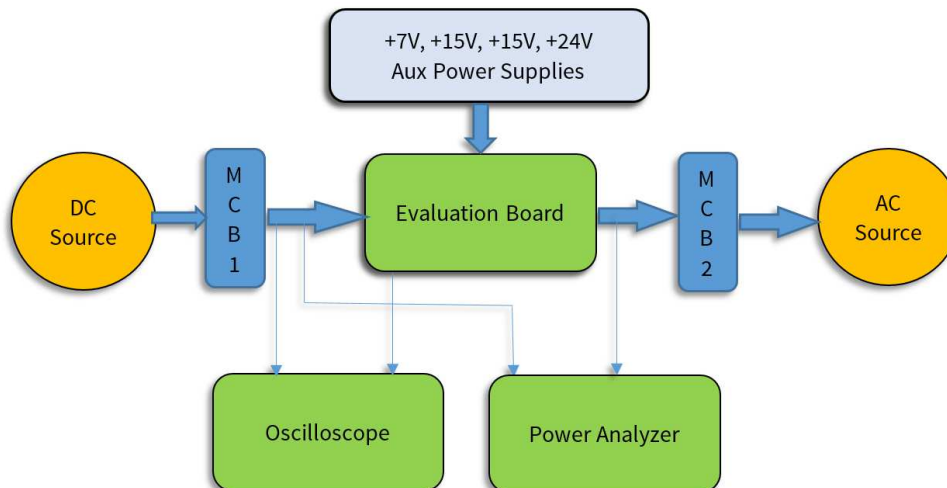


Figure 7. DC-AC grid connected mode test setup

- Connect AC source to AC terminals (output) of the evaluation board through MCB2. AC source must be able to absorb the current fed from the converter.
- Connect DC source to the evaluation board's DC terminals (input) through MCB1.
- Connect power analyzer to measure input and output power.
- Use appropriately rated voltage and current probes and connect to the oscilloscope

6.3 Recommended Test Set Up (DC/AC – OFF Grid Mode)

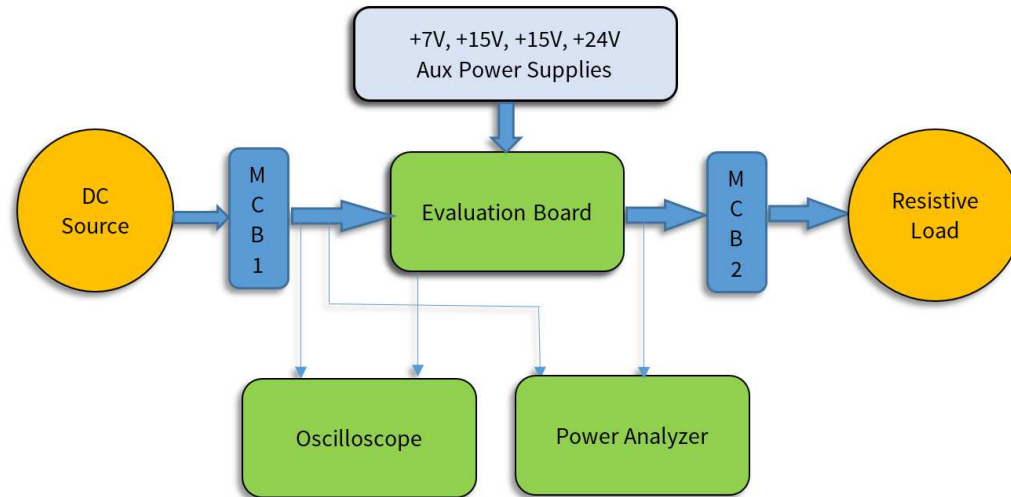


Figure 8. DC-AC OFF grid mode with resistive load test setup

- Connect AC terminals (output) of the evaluation board to resistive load through MCB2.
- Connect DC source to the evaluation board’s DC terminals (input) through MCB1.
- Connect power analyzer to measure input and output power.
- Use appropriately rated voltage and current probes and connect to the oscilloscope

6.4 Parameters Which Can Be Measured

The MOSFET signals such as gate voltage and drain voltage are inaccessible; therefore, the parameters shown in Table 3 should be checked and measured.

Table 3: Parameters Which Can Be Measured

Name	Description
Input AC Current	Input AC current from grid side
Input AC Voltage	High voltage AC input voltage
Output DC Voltage	Isolated DC voltage
Output Current	Isolated DC load current
Output Ripple Voltage	Output load ripple voltage
3.3V DSP Supply	+3.3V supply for DSP
1.2V DSP Supply	+1.2V supply for DSP
DAC Parameters	Internal parameters of DSP for outside monitoring
PWM pulses from control board	MOSFET pulses on control board side
THD	THD in input current
Efficiency	Measured with power analyzer

6.5 LED Indicators

LED indicators are provided for certain fault conditions. **Please check these conditions only when the board is disconnected from the electrical source and all bulk capacitors are fully discharged, as serious injury, including death by electrocution or serious injury by electrical shock or electrical burns, can occur if you touch the board when it is energized.** These LED indicators are shown in Table 4.

Table 4: LED Indicators

LED	On(bright)	Off(dark)
D4	PLL unlocked	PLL locked
D7	DC link Over Voltage	
D8	CLLC Over Current	
D9	Battery Over Current	
D10	Frequency (50Hz)	Frequency (60Hz)
D11	AC grid Over Current	

6.6 Isolated Power Supplies – Voltage and Current Settings

All power supplies mentioned in Table 5 must have isolated grounds with respect to each other. Please check their nominal values before applying high voltage to the unit. Requirements of power supplies are shown in Table 5.

Table 5: (Auxiliary) Power Supply Requirements

Control Board Connector Designator	Power Supply	Voltage (V)	Current 1 (A)	Current 2 (A)	Current 3 (A)
J7	+7V	+7V +/-5%	0.36	0.36	0.4
J4	+15V for input MOSFETs	+15V +/- 5%	0.15	0.3	0.36
J6	+15V_1 for output MOSFETs	+15V +/- 5%	0.06	0.06	0.11
JX (Not on control board)	+24V for Fan	+24V +/- 5%	0.92	0.92	0.92

6.7 Potentiometer VR1 Settings for Various Output Voltages in AC/DC Mode

Table 6 shows three output voltage settings. By varying the potentiometer VR1 voltage, the output voltage can be adjusted to any value between 260 VDC and 450 VDC.

Table 6: Potentiometer VR1 Settings for Different Output Voltages in AC/DC Mode

VR1 Voltage	Output Voltage
0V	260V
1V	325V

3V	450V
-----------	------

6.8 Potentiometer VR1 Settings for Various Grid Current Values in DC/AC Mode

Table 7 shows three values of peak grid current. By varying the potentiometer VR1 voltage, the grid peak current can be adjusted to any value between 0 A and 22 A.

Table 7: Potentiometer VR1 Settings for Different Grid Current Values in DC/AC Mode

VR1 Voltage	Grid Peak Current
0.67V	5A
1.33V	10A
3V	22A

NOTE: TEST POINT FOR “VR1” IS INDICATED IN FIGURE 10.

7. Preparations for Testing the Unit for the First Time

Please take the following steps before starting the unit for the first time:

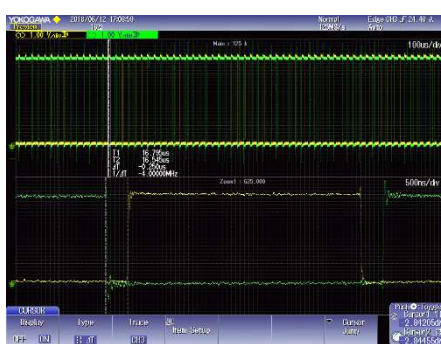
- Check sensing connections (shown in Table 8) from the power board to the controller board

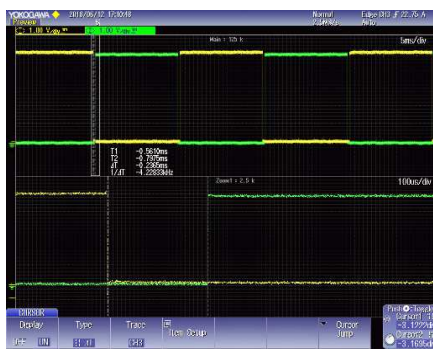

Table 8: Sensing connections from Power Board to the Control Board


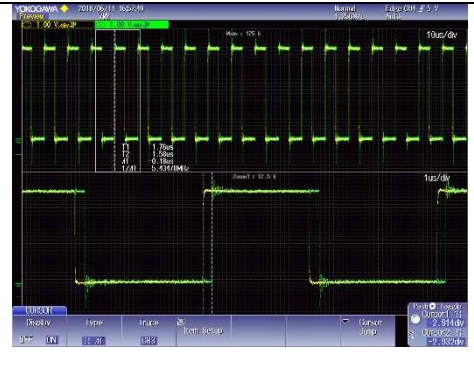
Sensing	Power Board Connector	Control Board Connector
Vout (Battery) sensing	J2	J2
DC link (PFC output) Sensing	J4	J1
Grid sensing	J3	J3
Relay	J1	J8

- Put PWM ON/OFF switch (sw2) in OFF position.
- Put mode switch (sw1) in DC/AC position (i.e. 1).
- For all digital logic supply inputs, the white wire is positive (+) and the blue wire is negative (-)
- Connect +7V supply to connector J7 (positive (+) to pin 1 and negative (-) to pin 2). Check that the current drawn is approximately equal to the values specified under “Current 1” in Table 5.
- Check for +3.3V (across CT2), +1.2V (across CT1), and +5V (across CT3) supplies on control board.
- Connect and switch ON both +15V and +15V_1 power supplies. Check the current drawn from both 15V power supplies. The current drawn should be approximately equal to the values specified under “Current 1” in Table 5.
- Put PWM ON/OFF switch (sw2) in ON position.
- Check the following pulses on control board connectors (for purposes of the following chart, Conn2 is marked as 2, Conn3 is marked as 3, Conn4 is marked as 4 and Conn5 is marked as 5):

Control Signals and Timings:

PFC high frequency top	Con2 pin1 with respect to GND (Ground) (Con2 reference designator only appears on the controller card silkscreen)	Yellow: PFC high frequency top	
PFC high frequency bottom	Con4 pin11 with respect to GND (Con4 reference designator only appears on the controller card)	Green: PFC high frequency bottom. Check the frequency (67kHz) and dead band (250ns)	

	silkscreen)		
<p>PFC low frequency top</p> <p>PFC low frequency bottom</p>	<p>Con2 pin11 with respect to GND</p> <p>Con4 pin1 with respect to GND</p>	<p>Yellow: PFC Low frequency top</p> <p>Green: PFC Low frequency bottom. Check the frequency (50Hz) and dead band (250us)</p>	
<p>CLLC primary top</p> <p>CLLC primary bottom</p>	<p>Con3 pin1 with respect to GND</p> <p>Con5 pin11 with respect to GND</p>	<p>Check the frequency (190kHz) and dead band (228ns).</p>	

CLLC secondary top	Con3 pin2 with respect to GND	Check the frequency (190khz) and dead bad (200ns).	
CLLC secondary bottom	Con1 pin11 with respect to GND		
CLLC primary top	Con3 pin1 with respect to GND	Check the delay between the primary to secondary pulse. It should be approx. 180ns.	
CLLC secondary bottom	Con3 pin2 with respect to GND		

- If your measurements reflect the measurements described above, then turn the PWM ON/OFF switch (sw2) to the OFF position, switch OFF +15V_1 and +15V, and then switch OFF the +7V power supply and proceed to the appropriate starting procedure.

7.1 Starting Procedure of the Unit in AC/DC Mode

Please take the following steps in order when starting the unit in AC/DC mode:

- If the board is being tested for the first time, follow the procedure described at the beginning of Section 7.
- The board should be connected as shown in Figure 6.
- Do not close MCB yet.
- Ensure that the PWM ON/OFF switch (sw2) is in the OFF position.
- **Put mode switch (sw1) in AC/DC position.**
- Turn ON the +7V supply (J7). Check the current draw from the 7V supply; it should be same as the value of “CURRENT 1” listed in Table 5.
- Turn ON +15V, +15V_1, and the power supplies and check the current draw to be sure it is similar to the stated amount “CURRENT 1” in Table 5.
- Ensure that there is no load at the output.
- Set the output voltage for 260 VDC operation with the help of potentiometer VR1. Turn the potentiometer until the voltages across the ADC test points yield the values given in table 6. The measurement points are ADC+ and ADC-. **There is an error in the silk screen of some of the Control**

Board PCBs. The ADC+ marking on the silk screen of the PCB should be ADC- and vice versa. Please see Figure 10 in Section 8 for accurate designations (in red).

- Increase the AC voltage to the required value (nominal voltage 230 VAC) and check that the AC voltage is in between the universal range (110 VAC -230 VAC) (for relay to close, the minimum required AC voltage is 105 VAC). Next, turn ON the MCB. The relay closing sound should be audible after a few seconds. Check the DC link voltage with the help of a multimeter. It should be close to the peak of the AC input voltage.
- Check the current drawn by the +7V, +15V and +15V_1 inputs. The current drawn should be similar to the specified values under “CURRENT 2” listed in table 5.
- Check LED (D10) for frequency detection. The detected frequency must match with grid frequency or AC source frequency. If it does not match (which can happen when the input voltage is lower than 100V), switch OFF the AC input and switch it ON again.
- Put sw2 in ON position and measure the output voltage. The output voltage should be within +/- 3% of the set voltage. Check the currents drawn by the +7V, +15V and +15V_1 inputs. They should be similar to the specified values under “CURRENT 3” in table 5.
- Turn ON the 24V supply and a cooling fan that should be attached to the supply.
- Switch ON the output load in a MAXIMUM step of up to 2 kW. The maximum load should be no more than 5200 W for 260 VDC output voltage operation or 6600 W for 450 VDC output voltage operation.
- There is no output current control loop in this mode, so you must size your load resistor so that the output current does not exceed 20 A and the total output power does not exceed 6600W. This means when VOUT is greater than 330 VDC, the output current must be de-rated so that POUT does not exceed 6600 W. Failure to do this may result in damage to the circuit.
- Check for the overall AC/DC Stage efficiency and THD (Total Harmonic Distortion).

7.2 Stopping Procedure of the Unit in AC/DC Mode

Please take the following steps in order when stopping the unit in AC/DC mode:

- Decrease the output load in steps no greater than 2 kW (MAXIMUM) until no load.
- Put switch sw2 in the OFF position.
- Open MCB to remove the AC source. Turn OFF the AC source.
- **The DC link capacitors remain charged for at least 30 minutes after the circuit is turned OFF, although you may decrease the time that it takes for the board to be fully discharged by adding a discharge circuit to the DC link. Allow the unit to fully discharge before turning OFF any of the digital logic/DSP power supplies, and do not touch the unit until it has been fully discharged. Please check the DC link voltage with a DMM to ensure that the board has fully discharged and is therefore safe to handle.**
- Switch OFF the +15V and +24V power supplies first.
- Switch OFF +7V power supply. The +7V must be turned OFF last since it serves as the DSP supply voltage. Failure to turn OFF the +7V last may cause damage to the circuit.

7.3 Starting Procedure of the Unit in DC/AC Grid Connected Mode

Please take the following steps in order when starting the unit in DC/AC grid connected mode:

- If the board is being tested for the first time, follow the procedures described at the beginning of Section 7.
- The board should be connected as shown in Figure 7.
- Keep MCB1 (DC supply) in open position
- Keep output isolated from grid AC Voltage by keeping MCB2 in open position.
- Put ON/OFF switch (sw2) in OFF position
- **Put mode switch (sw1) in DC/AC position.**
- Connect +7V supply to J7 (positive (+) to pin 1 and negative (-) to pin 2). Confirm that the current drawn from the 7V supply is similar to the value specified in Table 5.
- Switch ON +15V, +15V_1 and the power supplies and confirm that the current drawn is the same mentioned as in table 5.
- Set the required peak grid current as per Table 7.
- Check the grid voltage, which should be between 105 VAC - 230 VAC.
- Close MCB2, tying the output of the converter to the grid. The relay connect sound should be audible after a few seconds.
- Check for the DC link voltage with the help of a multimeter. It should be similar to the peak of the input AC voltage. Confirm that the output voltage frequency is 50Hz or 60Hz as per Table 4.
- LED (D10) indication (as shown in Table 4) must match the grid frequency. If it does not match, then switch OFF the grid voltage and then switch it ON again.
- Turn ON the 24V supply and a cooling fan that should be attached to the supply.
- Close MCB1 and slowly increase the DC supply voltage to the required value (320 VDC to 450 VDC). DC supply voltage should be increased gradually because there is no inrush current limiter at this end.
- Put sw2 in ON position and check the input and output voltages
- Check for the overall efficiency of the DC/AC stage and the THD.

7.4 Stopping Procedure of the Unit in DC/AC Grid Connected Mode

Please take the following steps in order when stopping the unit in DC/AC grid connected mode:

- Decrease the output load in steps no greater than 1 kW (MAXIMUM) until no load.
- Put switch sw2 into the OFF position.
- Open MCB2, disconnecting the output from the grid.
- Open MCB1, disconnecting the DC power supply from the input.
- **The DC link capacitors remain charged for at least 30 minutes after the circuit is turned OFF, although you may decrease the time that it takes for the board to be fully discharged by adding a discharge circuit to the DC link. Allow the unit to fully discharge before turning OFF any of the digital logic/DSP power supplies, and do not touch the unit until it has been fully discharged. Please check the DC link voltage with a multimeter to ensure that the board has fully discharged and is therefore safe to handle.**

- Switch OFF +15V and +24V power supplies first.
- Switch OFF +7V power supply. The +7V must be turned OFF last since it serves as the DSP supply voltage. Failure to turn OFF the +7V last may cause damage to the circuit.

7.5 Starting Procedure of the Unit in DC/AC OFF Grid Mode with Resistive Load

Please take the following steps in order when starting the unit in DC/AC OFF grid mode with resistive load:

- If the board is being tested for the first time, follow the procedures described at the beginning of Section 7.
- The board should be connected as shown in Figure 8.
- Keep MCB1 (DC supply) in open position
- Keep output isolated from the load by keeping MCB2 in the open position.
- Put ON/OFF switch (sw2) in OFF position
- **Put mode switch (sw1) in DC/AC position.**
- Connect +7V supply to J7 connector (positive (+) to pin 1 and negative (-) to pin 2). Confirm that the current drawn from the 7V supply is similar to the current value shown in Table 5.
- Switch ON +15V, +15V_1, and the power supplies and confirm that the current drawn is the same as shown in Table 5.
- Keep the Resistive load in No load position and then turn ON MCB2.
- Turn ON the 24V supply and a cooling fan that should be attached to the supply.
- Put MCB1 in ON position and slowly increase the DC supply voltage to the required value (320 VDC – 450 VDC). DC supply voltage should be increased gradually because there is no inrush current limiter at this end.
- Put sw2 in ON position and check the output voltage.
- Increase the load up to 3.3kW in steps of 1kW maximum.
- Check for the overall efficiency of the DC/AC stage and the THD.

7.6 Stopping Procedure of the Unit in DC/AC OFF Grid Mode with Resistive Load

Please take the following steps in order when stopping the unit in DC/AC OFF grid mode with resistive load:

- Decrease the output load in maximum steps of 1kW until no load condition is reached.
- Put switch sw2 in OFF position.
- Open MCB1, disconnecting the DC power supply from the input. Turn the voltage all the way down on the DC power supply.
- **The DC link capacitors remain charged for at least 30 minutes after the circuit is turned OFF, although you may decrease the time that it takes for the board to be fully discharged by adding a discharge circuit to the DC link. Allow the unit to fully discharge before turning OFF any of the digital logic/DSP power supplies, and do not touch the unit until it has been fully discharged. Please check the DC link voltage with a multimeter to ensure that the board has fully discharged and is therefore safe to handle.**

- Turn OFF resistive Load MCB2
- Switch OFF +15V and +24V power supplies first.
- Switch OFF +7V power supply. The +7V must be turned OFF last since it serves as the DSP supply voltage. Failure to turn OFF the +7V last may cause damage to the circuit.

8. Location of the Connectors (Power Board and Control Board)

Figure 9 Indicates the location of the connectors on the power board.

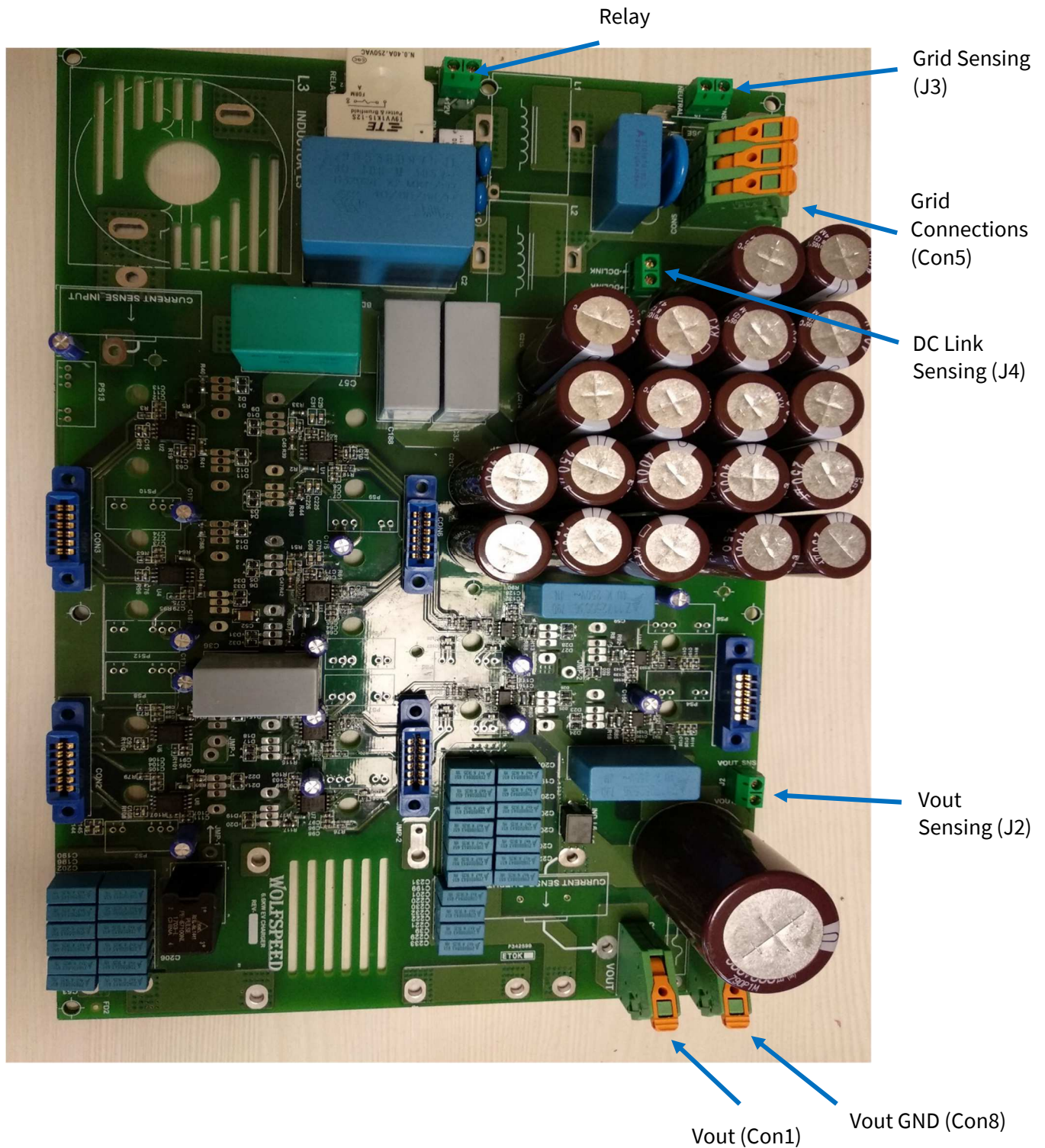


Figure 9. Location of the power board connectors

Figure 10 indicates the location of the connectors, VR1 and the switches on the Control Board

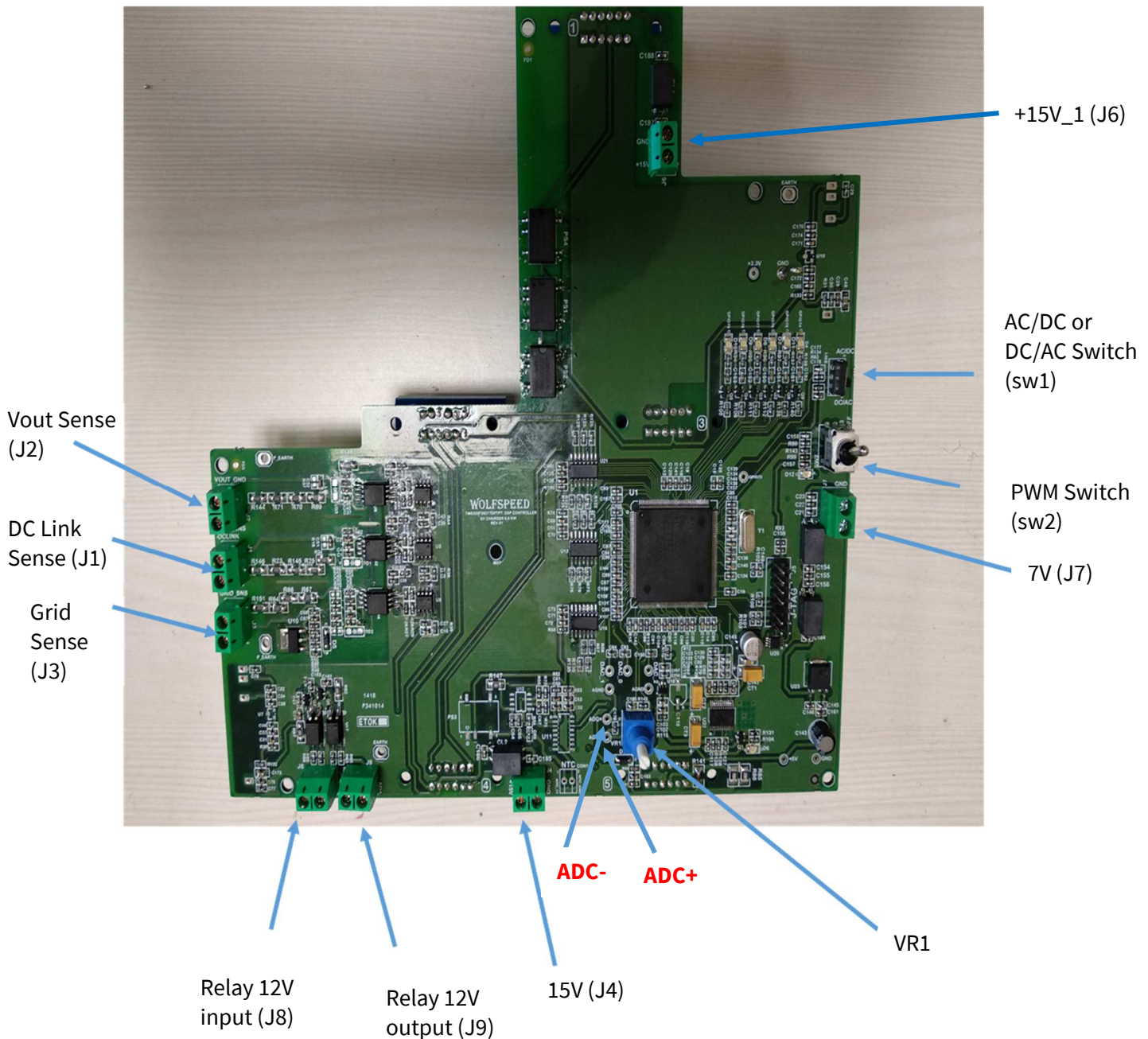


Figure 10. Location of the connectors, VR1 and the switches on the control board

9. Trip Points of Wolfspeed’s CRD-06600FF10N Reference Design Board

Wolfspeed’s CRD-06600FF10N reference design board has certain overvoltage, undervoltage and overcurrent protection functions. The trip points are the set points that will trigger the protection functions. If the voltage or current approaches the level indicated in Table 9, the unit will stop operating. Table 9 also indicates how to reset the fault after the fault condition is cleared.

Table 9: Trip Points

Parameter	Value	Indication (LED)	Restart/Reset
Input AC Voltage	>275V		Reset on sw2 off
Input AC Voltage	<85V		Reset on sw2 off
PFC Inductor Current	>65A	D11	Power on reset
DC Output Current	>25A	D9	Power on reset
DC Output Voltage	>500V		Power on reset
CLLC Resonant Overcurrent	>25A	D8	Power on reset
DC link Overvoltage	>760V	D7	Power on reset
PLL Unlock		D4	Reset on sw2 off
Relay open	If sw2 turned ON too quickly after applying AC voltage. Need 5 seconds' delay		Reset on sw2 off
DC/AC mode DC Input Voltage	<310V		Reset on sw2 off

If a trip point occurs so that the board must be reset or powered back ON, you must first turn the board OFF. The DC link capacitors remain charged for at least 30 minutes after the circuit is turned OFF, although you may decrease the time that it takes for the board to be fully discharged by adding a discharge circuit to the DC link. Allow the unit to fully discharge before turning OFF any of the digital logic/DSP power supplies, and do not touch the unit until it has been fully discharged. Please check the DC link voltage with a multimeter to ensure that the board has fully discharged and is therefore safe to handle and power ON or reset.

10. Performance Data

The performance data of Wolfspeed's CRD-06600FF10N reference design board is taken in both AC/DC and DC/AC modes. Tables 10 to Table 15 indicate the performance data.

Table 10: Efficiency Data (AC/DC Mode), $V_{IN} = 230\text{ VAC}$

V_{IN} (V _{AC})	P_{IN} (W)	DC link Voltage	Output Voltage	THD	EFF (%)
230	488	400	265	35.0	95.67
	995	400	265	13.4	96.20
	1400	400	265	11.6	96.93
	2350	400	265	7.9	96.86
	2770	400	265	5.4	96.70
	4510	400	265	4.4	95.69
	5200	400	265	3.3	94.87
	159	530	360	21.3	93.35
	840	530	360	10.4	95.90

V_{IN} (V _{AC})	P_{IN} (W)	DC link Voltage	Output Voltage	THD	EFF (%)
230	2310	530	360	6.7	96.37
	3910	530	360	4.9	96.33
	4680	530	360	4.0	96.08
	5960	530	360	3.7	95.53
	1420	680	450	15.7	93.44
	2720	680	450	6.6	95.41
	4000	680	450	5.2	95.82
	5485	680	450	4.1	95.65
	6770	680	450	3.5	95.41

Table 11: Efficiency Data (AC/DC Mode), $V_{IN} = 90$ VAC

V_{IN} (V _{AC})	P_{IN} (W)	DC link Voltage	THD	Battery Voltage	EFF (%)
90V	29	394	66.97	271	0.17
	334	394	19.11	268	90.45
	944	395	11.40	262	94.91
	1530	394	10.97	260	94.62
	2144	393	9.87	259	93.82
	569	516	16.24	349	90.43
	1081	516	12.36	343	93.54
	1595	515	9.84	342	93.67
	2206	522	5.32	348	93.42
	1008	678	9.59	461	89.49
	1925	674	9.18	450	90.75

Table 12: Efficiency Data (DC/AC Mode), $V_{IN} = 320$ VDC

V_{in} (DC)	P_{in} (W)	V_{out} (AC)	I_{out} (A)	P_{out} (W)	Efficiency (%)	THD
320	97	228	1.26	63	65.07	85.38
320	827	233	3.63	784	94.85	15.97
320	1621	235	6.85	1564	96.48	10.58
320	1945	233	8.27	1872	96.27	12.27
327	2375	235	9.95	2296	96.70	7.60

V_{in} (DC)	P_{in} (W)	V_{out} (AC)	I_{out} (A)	P_{out} (W)	Efficiency (%)	THD
320	3182	236	13.17	3070	96.49	5.82
319	4014	238	16.35	3862	96.23	4.63
321	44	101	0.61	12	27.49	107.18
320	367	102	3.36	330	90.00	12.24
320	708	103	6.51	660	93.21	6.58
320	1061	104	9.71	1016	95.75	4.74

Table 13: Efficiency Data (DC/AC Mode), VIN = 450 VDC

V_{in} (DC)	P_{in} (W)	V_{out} (AC)	I_{out} (A)	P_{out} (W)	Efficiency (%)	THD
450	131	222	1.39	59	45.29	99.4
450	834	223	3.77	758	90.90	20.2
450	1568	227	6.83	1481	94.42	14.1
450	2327	229	9.95	2218	95.30	10.2
450	3014	224	13.11	2887	95.75	7.1
450	3521	225	15.22	3366	95.59	7.5
451	77	102	0.65	15	19.85	88.6
451	404	104	3.40	336	82.98	14.3
451	754	105	6.56	676	89.51	8.3
451	1108	106	9.70	1014	91.51	5.9

Table 14: No Load Power AC/DC Mode

V input	V_{out}	P_{in} (W)
230V AC	250V	23
230V AC	450V	69
90V AC	250V	29

Table 15: No Load Power DC/AC Mode

V input	V_{out} (AC)	P_{in}
320V DC	230V	97
320V AC	90V	44
450V DC	230V	131
450V DC	90V	76

11. Typical Waveforms

AC/DC Mode:

Condition		Waveform
<p>AC/DC Mode</p> <p>230V grid voltage</p> <p>250V output voltage</p> <p>No load</p>	<p>Blue trace: grid voltage, 100V/div</p> <p>Pink trace: inductor current, 5A/div</p>	
<p>AC/DC Mode</p> <p>230V grid voltage, 450V output voltage</p> <p>No load</p>	<p>Blue trace: grid voltage, 100V/div</p> <p>Pink trace: inductor current, 5A/div</p>	
<p>AC/DC Mode</p> <p>90V grid voltage</p> <p>250V output voltage 1.9kW load</p>	<p>Blue trace: grid voltage, 50V/div</p> <p>Pink trace: inductor current, 10A/div</p>	

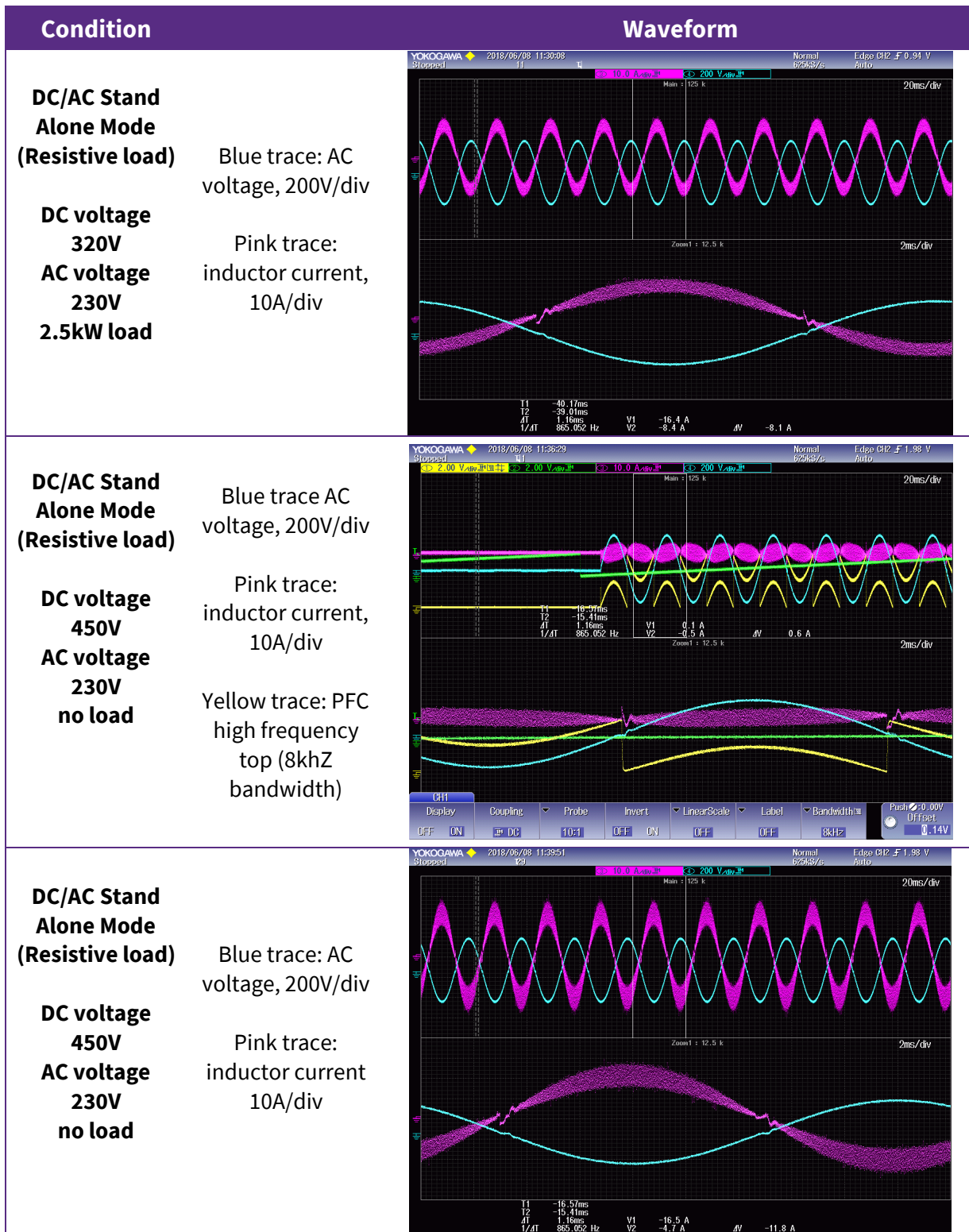
Condition		Waveform
<p>AC/DC Mode</p> <p>230V grid voltage</p> <p>250V output voltage</p> <p>4.6kW load</p>	<p>Blue trace: grid voltage, 100V/div</p> <p>Pink trace: inductor current, 20A/div</p>	
<p>AC/DC Mode</p> <p>230V grid voltage</p> <p>450V output voltage</p> <p>6.4kW load</p>	<p>Blue trace: grid voltage, 100V/div</p> <p>Pink trace: inductor current, 20A/div</p>	
<p>AC/DC Mode</p> <p>90V grid voltage</p> <p>450V output voltage</p> <p>1.9kW load</p>	<p>Blue trace: grid voltage, 100V/div</p> <p>Pink trace: inductor current, 20A/div</p>	

DC/AC Mode:

Condition		Waveform
<p>DC/AC Mode grid connected</p> <p>DC voltage 450V</p> <p>grid voltage 230V</p> <p>No load</p>	<p>Blue trace: grid voltage, 200V/div</p> <p>Pink trace: inductor current, 5A/div</p>	
<p>DC/AC Mode grid connected</p> <p>DC voltage 450V</p> <p>grid voltage 230V</p> <p>3.4kW load</p>	<p>Blue trace: grid voltage, 200V/div</p> <p>Pink trace: inductor current, 10A/div</p>	
<p>DC/AC Mode grid connected</p> <p>DC voltage 320V</p> <p>grid voltage 230V</p> <p>No load</p>	<p>Blue trace: grid voltage, 200V/div</p> <p>Pink trace: inductor current, 5A/div</p>	

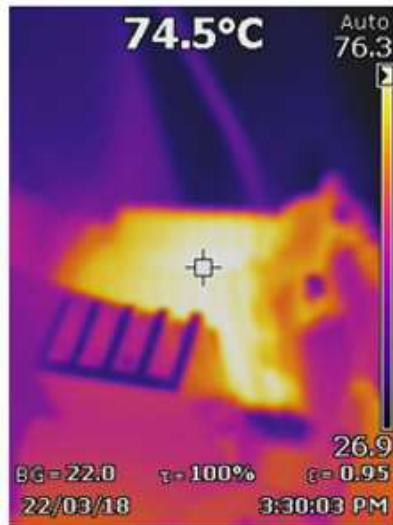
Condition	Waveform
<p>DC/AC Mode grid connected</p> <p>DC voltage 320V</p> <p>grid voltage 230V</p> <p>3.6kW load</p>	<p>Blue trace: grid voltage, 200V/div</p> <p>Pink trace: inductor current, 5A/div</p>
<p>DC/AC Mode grid connected</p> <p>DC voltage 320V</p> <p>grid voltage 100V</p> <p>no load</p>	<p>Blue trace: grid voltage, 50V/div</p> <p>Pink trace: inductor current, 5A/div</p>
<p>DC/AC Mode grid connected</p> <p>DC voltage 320V</p> <p>grid voltage 100V</p> <p>1.1kW load</p>	<p>Blue trace: grid voltage, 50V/div</p> <p>Pink trace: inductor current, 10A/div</p>

Condition		Waveform
<p>DC/AC Mode grid connected</p> <p>DC voltage 450V</p> <p>grid voltage 100V</p> <p>no load</p>	<p>Blue trace: grid voltage, 100V/div</p> <p>Pink trace: inductor current, 5A/div</p>	
<p>DC/AC Mode grid connected</p> <p>DC voltage 450V</p> <p>grid voltage 100V</p> <p>1kW load</p>	<p>Blue trace: grid voltage, 100V/div</p> <p>Pink trace: inductor current, 5A/div</p>	
<p>DC/AC Stand Alone Mode (Resistive load)</p> <p>DC voltage 320V</p> <p>AC voltage 230V</p> <p>No load</p>	<p>Blue trace: AC voltage, 200V/div</p> <p>Pink trace: inductor current, 10A/div</p>	

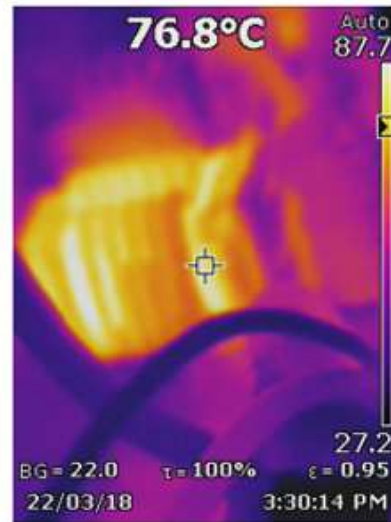


12. Thermal Data

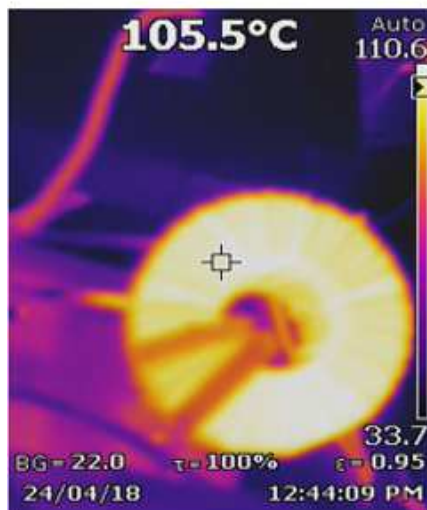
The thermal data is taken at full load. Figure 11 indicates the thermal data of Inductor L1, Inductor L2, PFC Boost Inductor and Transformer.



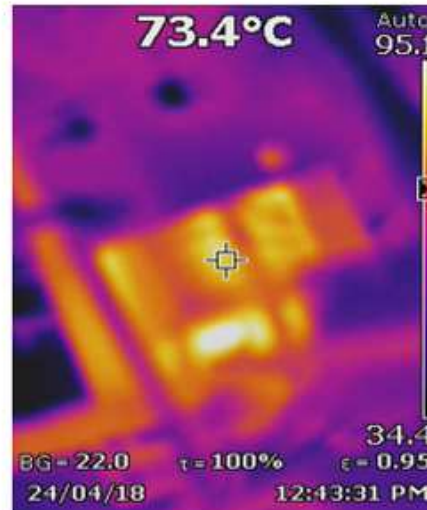
L1 Inductor



L2 Inductor



PFC Inductor at Full Load



Transformer (680V, Full Load)

Figure 11: Thermal measurements of various components

As illustrated by the images above, the boost inductor can reach extremely high temperatures, particularly if the board is tested under full load for an extended period of time. A user should direct air flow over the top side of the control board in order to reduce the temperature of the boost inductor. Failure to use air flow in this manner to manage the temperature of the boost inductor could result in a reduction in performance of, or damage to, the board.

13. Revision History

Date	Revision	Changes
August 2018	A	1 st issue
January 2024	2	Branding and formatting updates

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

Users should ensure that appropriate safety procedures are followed when working with the board as serious injury, including death by electrocution or serious injury by electrical shock or electrical burns can occur if you do not follow proper safety precautions. It is not necessary in proper operation for the user to touch the board while it is energized. When devices are being attached to the board for testing, the board must be disconnected from the electrical source and any bulk capacitors must be fully discharged. When the board is connected to an electrical source and for a short time thereafter until board components are fully discharged, some board components will be electrically charged and/or have temperatures greater than 50° Celsius. These components may include bulk capacitors, connectors, linear regulators, switching transistors, heatsinks, resistors and SiC diodes that can be identified using board schematic. Users should contact Wolfspeed at forum.wolfspeed.com

for assistance if a board schematic is not included in the Documentation or if users have questions about a board's components. When operating the board, users should be aware that these components will be hot and could electrocute or electrically shock the user. As with all electronic evaluation tools, only qualified personnel knowledgeable in handling electronic performance evaluation, measurement, and diagnostic tools should use the board.

User Responsibility for Safe Handling and Compliance with Laws

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

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

In addition, users are responsible for:

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

No Warranty

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

Limitation of Liability

IN NO EVENT SHALL 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.