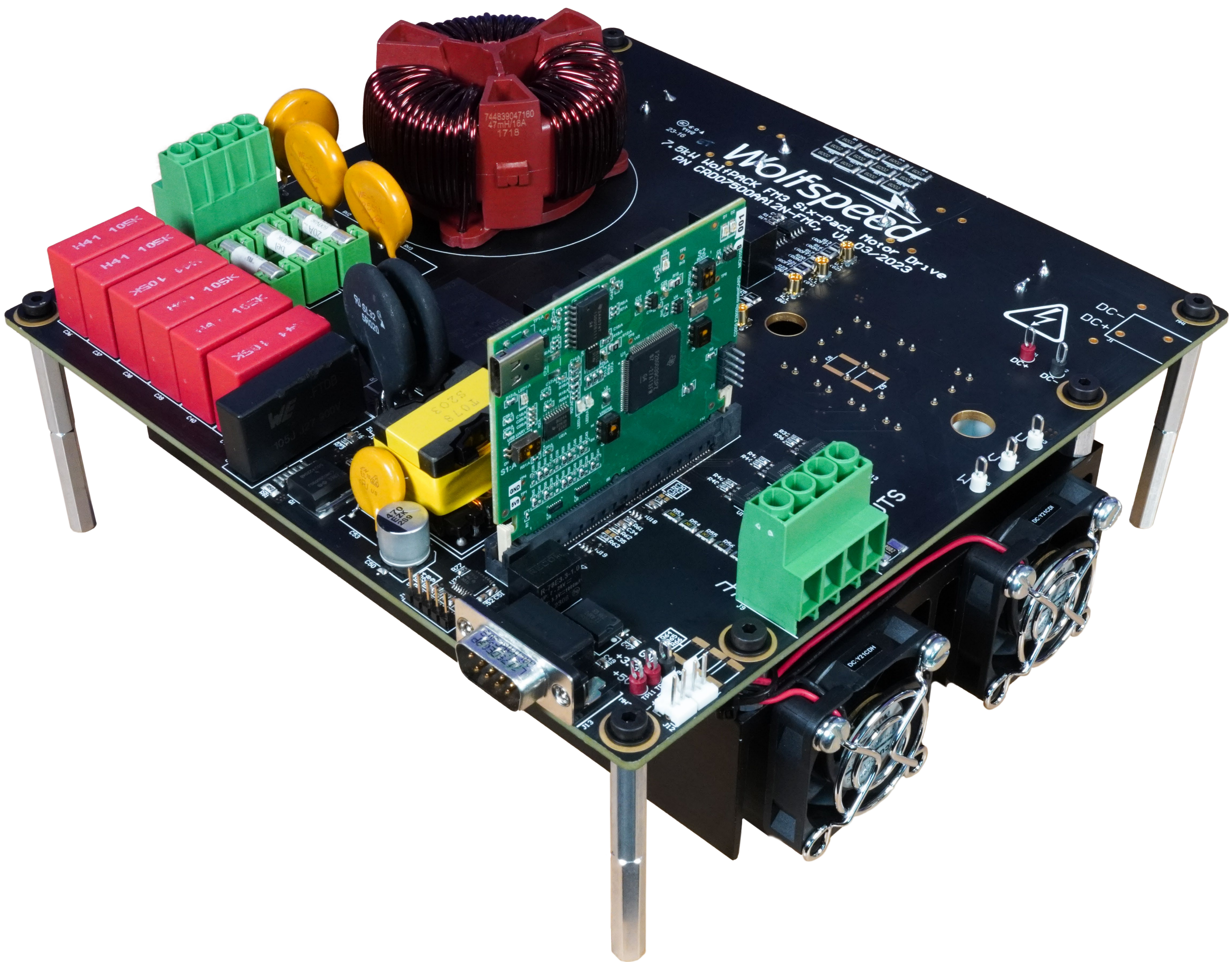
User Guide **PRD-07561**

CRD07500AA12N-FMC 7.5 kW Motor Drive User Guide



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CRD07500AA12N-FMC 7.5 kW Motor Drive User Guide

This user guide provides an overview of Wolfspeed's CRD07500AA12N-FMC 7.5 kW motor drive reference design including key system specifications, sub-system functional descriptions, performance test data, and mechanical assembly. The CRD07500AA12N-FMC is a complete industrial motor drive designed around the CCB032M12FM3 (1200 V / 22 mΩ) Wolfspeed WolfPACK™ six-pack power module.

Contents

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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。

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

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。

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。

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 50^0 CELSIUS. THESE CONDITIONS WILL CONTINUE AFTER THE ELECTRICAL SOURCE IS DISCONNECTED UNTIL THE BULK CAPACITORS ARE FULLY DISCHARGED. DO NOT TOUCH THE BOARD WHEN IT IS ENERGIZED AND ALLOW THE BULK CAPACITORS TO COMPLETELY DISCHARGE PRIOR TO HANDLING THE BOARD.

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

警告

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

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

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

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

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

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

1. Introduction

This user guide provides an overview of Wolfspeed's CRD07500AA12N-FMC 7.5 kW motor drive reference design including key system specifications, sub-system functional descriptions, performance test data, and mechanical assembly. The CRD07500AA12N-FMC design was developed to provide power electronics engineers with a hardware evaluation platform and reference design files to support early design-in activities of the Wolfspeed WolfPACK™ baseplate-less power module platform. In conjunction with this user guide, the complete suite of reference design files including schematics, PCB layout, Gerber files, BOM, and 3D CAD files are available for download from the CRD07500AA12N-FMC landing page on Wolfspeed's website.

The CRD07500AA12N-FMC is a complete industrial motor drive designed around the CCB032M12FM3 (1200 V / 22 mΩ) Wolfspeed WolfPACK™ six-pack power module. As demonstrated in the block diagram below, this design intends to provide everything needed to quickly evaluate performance out of the box while also providing the resources to expand its capabilities to suit target end-application needs. To this end, included on this single-PCB solution is an input EMI filter with diode bridge rectifier, DC-link bus capacitance with low-inductance power planes, gate drivers, current and voltage sensing, thermal management, and various control peripherals.

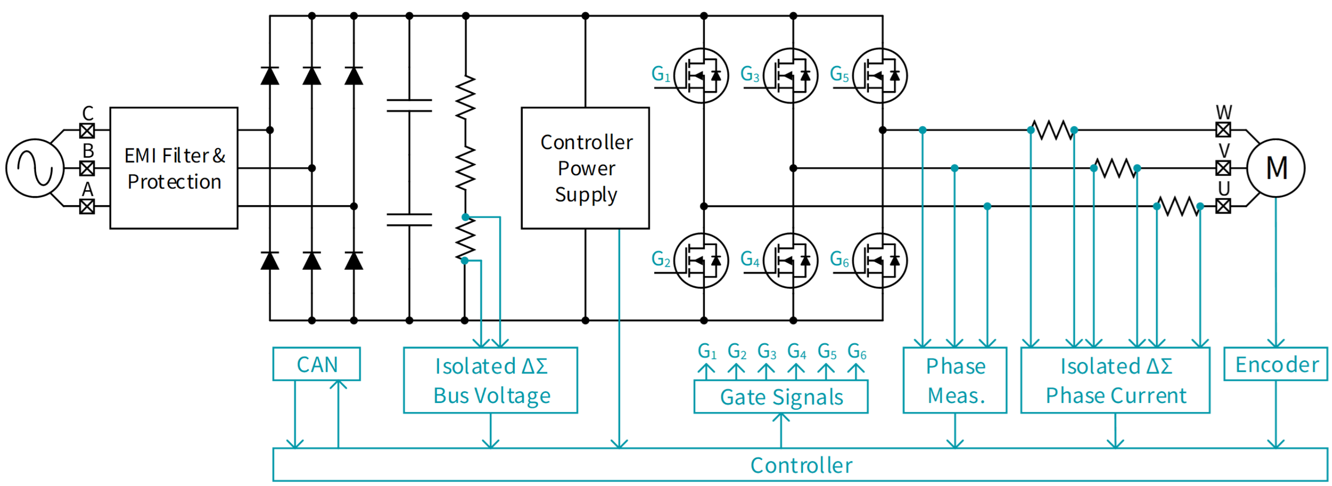


Figure 1: CRD07500AA12N-FMC block diagram

2. Design Features

This section highlights the design features of the CRD07500AA12N-FMC design including key system specifications, a description of the various functional circuit groups, and a general I/O pinout definition.

2.1 Key System Specifications

Table 1: Key System Specifications

SECTION	PARAMETER	SPECIFICATION	COMMENT
Input	Voltage	380 – 480Vrms	
	Current	10Arms	Input 480Vac, Ta = 25C
Inverter	DC bus input voltage	513V – 690V	
	Continuous output current rating	10Arms 16Arms	Input 480Vac, Ta = 25C Input 400Vac Ta = 25C
	Output frequency	0 – 300Hz	
	PWM switching frequency	10 to 100kHz	Output power derating required at higher Fsw
Aux supply		340V – 690V	
DC bus voltage sensing	Measurement Range	0 -800V	ΔΣ bitstream @ 20 MHz
Motor phase current sensing	Measurement range	±23 Apk	ΔΣ bitstream @ 20 MHz 2mΩ shunt resistor is used.
Module temperature sensing	Measurement range	0-175C	NTC is integrated in the module
Protection	Overcurrent	Overcurrent detection	User software implementation
	DC Bus voltage	Overvoltage and Undervoltage detection	User software implementation
	Module temperature	Overtemperature shutdown	User software implementation
Interfacing Voltages	Power	12V	Auxiliary power supply
		15V/-3V	Gate drive power supply
		5V	Sigma-Delta power supplies, Encoder
		5V isolated	CAN communication on connector J13
		3.3V	For microcontroller
Position feedback	Digital encoder		5 pin header J14
PCB	Dimensions	8in x 8in, 0.093in thickness	2 oz copper s, ENIG, 4 layers

2.2 Subsystem Functional Groups

The figures below show the system blocks that makeup the evaluation board from a top-side perspective and a side view. Table 2 describes each labelled subsystem.

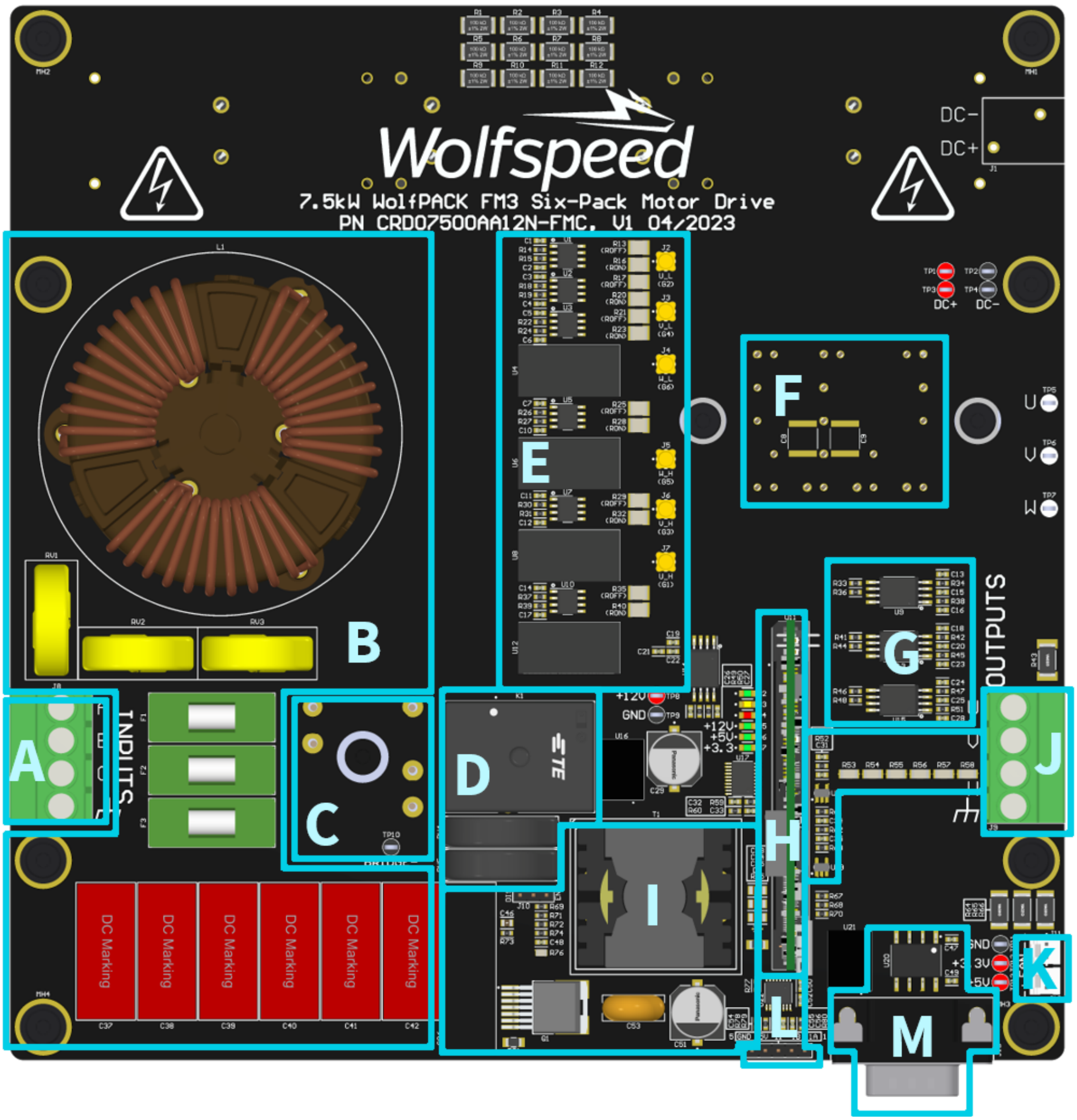


Figure 2: CRD07500AA12N-FMC top view

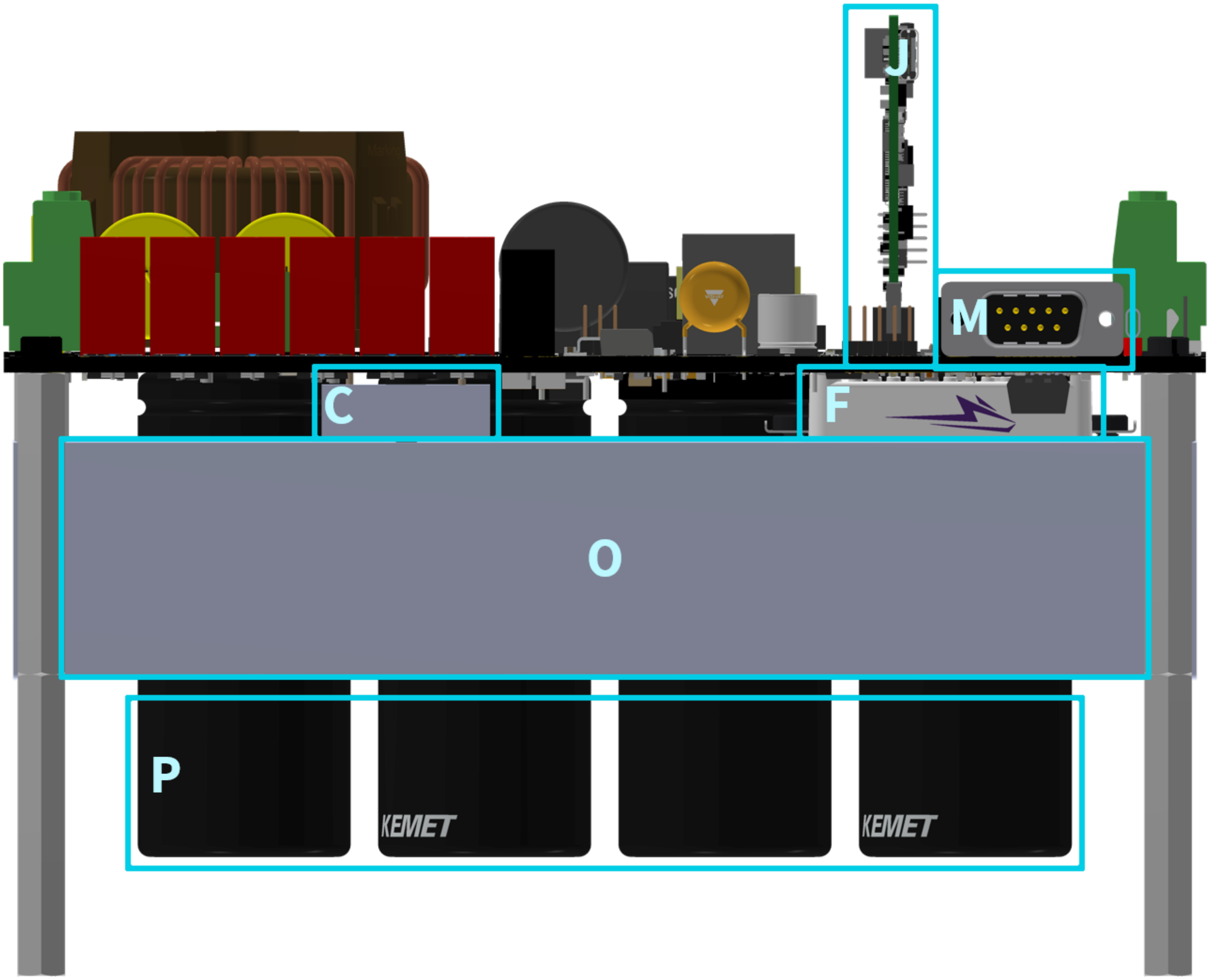


Figure 3: CRD07500AA12N-FMC side view

Table 2: Subsystem Functional Group Descriptions

Label	Description
A	Input AC Voltage Terminals
B	EMI Filtering and Protection
C	Diode Rectifier
D	Inrush Current Protection
E	MOSFET gate drivers
F	Wolfspeed CCB032M12FM3 SiC 1.2kV Six-Pack Module
G	Current Shunt Measurements
Label	**Description**

H	Phase Voltage Sensors
I	Auxiliary Flyback Power Supply
J	Control Card
K	Fan Power
L	Encoder Circuitry
M	Isolated CAN
N	Output AC Voltage Terminals
O	Aluminum Heatsink
P	Bulk DC-Link Capacitor

2.3 I/O Pinout

The design features a variety of ports for connecting external sensors, controlling external hardware, and communicating directly with the onboard controller. Each of these interfaces will be discussed in the later sections of this document. This section provides a quick reference to the pinouts of the various ports.

Input Power Connector Pinout

The input AC power attaches to the board through a Phoenix Contact 1777561 connector with the pinout shown below. The power cables are attached through screw terminals, so no mating connector is required. For safe operation, ensure the Earth ground pin is connected to an unobstructed Earth ground connection.

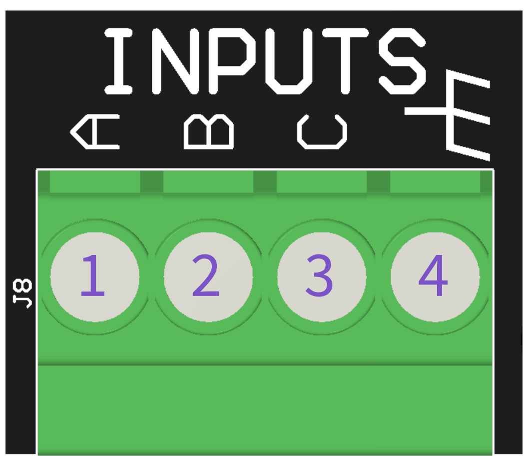


Figure 4: J8 input power connector pin numbers

Table 3: J8 Input Power Connector Pinout

Pin #	Name	Type	Description
1	A	Power	Input AC Power – A Phase
2	B	Power	Input AC Power – B Phase
3	C	Power	Input AC Power – C Phase
4	EGND	Power	Earth Ground

Output Power Connector Pinout

The output AC power also attaches to the board through a Phoenix Contact 1777561 connector with the pinout shown below. The power cables are attached through screw terminals, so no mating connector is required. The Earth ground connection is not required on this connector. It is intended to provide an Earth ground ti the load through the same wiring harness as the power cables. If the load is already properly connected to safety ground, then this connection can be omitted.

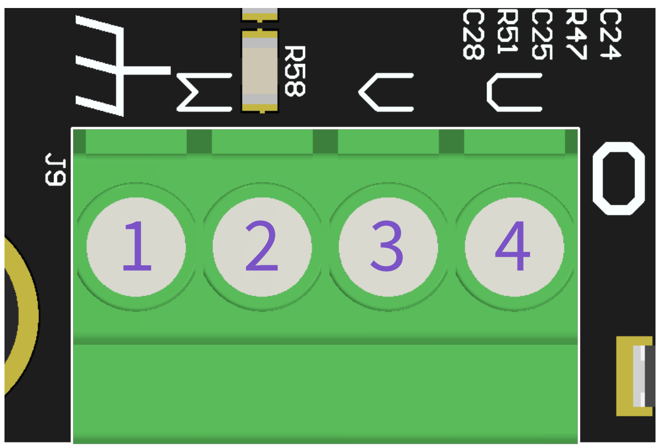


Figure 5: J9 output power connector pin numbers

Table 4: J9 Output Power Connector Pinout

Pin #	Name	Type	Description
1	EGND	Power	Earth Ground for Load/Peripherals
2	W	Power	Output AC Power – W Phase
3	V	Power	Output AC Power – V Phase
4	U	Power	Output AC Power – U Phase

DC Power Connector Pinout (Not Populated)

The design is intended to operate with an AC input voltage and an AC output voltage with an intermediate DC-link between the two stages. During system commissioning and testing, it is possible to evaluate these two stages independently by populating the optional DC power connector (Phoenix Contact 1777545). The pinout of this connector is shown below. By default, this connector is not populated on the board and is not recommended to be populated except by experienced professionals. This connector is directly attached to the DC-link capacitors. When populated, this connector can be used to source the DC-link capacitors with an external DC power supply, or this connector can be used to load the diode-bridge rectifier. However, external DC power should never be sourced through this connector when an AC input voltage is applied to the board. Additionally, all device voltage ratings must still be followed when using this external DC connector. In most case, this connector never needs to be populated.

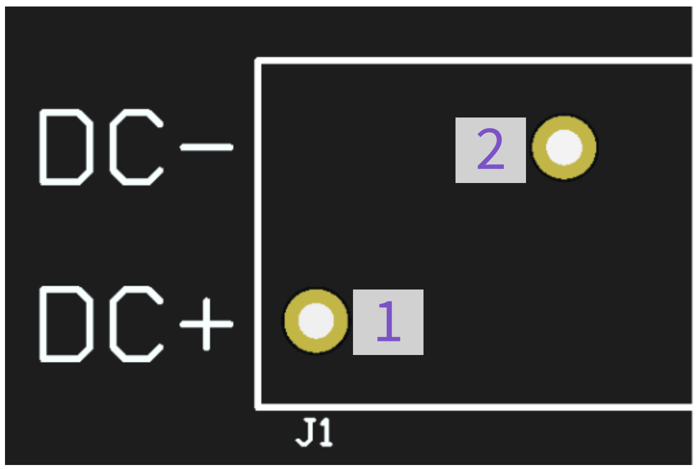


Figure 6: J1 DC power connector pin numbers (not populated)

Table 5: J1 DC Power Connector Pinout (Not Populated)

Pin #	Name	Type	Description
1	DC+	Power	Positive DC-link capacitor voltage
2	DC-	Power	Negative DC-link capacitor voltage

Flyback Enable Connector Pinout

The flyback converter included in the design which powers the controller and low-voltage auxiliary components includes some advanced features such as standby mode to enter ultralow quiescent power consumption. While most users will not require this functionality, this design includes provisions to evaluate standby mode. By default, this feature is disabled by a connected jumper across pins 1 and 2 of J10. J10 uses a Würth Elektronik 61300311121 connector with 0.1 in (2.54 mm) pitch headers. Users interested in evaluating standby mode should move the jumper to pins 2 and 3. This feature has not been tested on this board, so evaluating this feature should only be performed by experienced professionals. Reference the Analog Devices LT8316EFE#PBF datasheet for more information regarding standby mode.

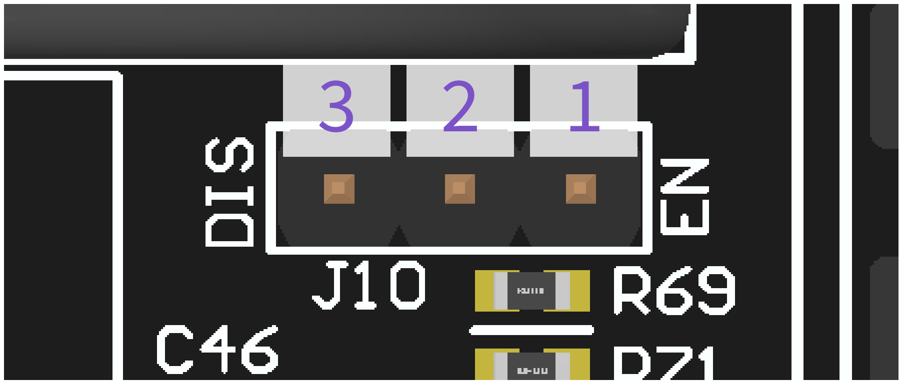


Figure 7: J10 Flyback enable connector pin numbers

Table 6: J10 Flyback Enable Connector Pinout

Pin #	Name	Type	Description
1	DC-	Power	Negative DC-Link Capacitor Voltage
2	SMODE	Digital (I)	Analog Devices LT8316EFE#PBF Standby Mode Pin
3	INTVCC	Digital (O)	Analog Devices LT8316EFE#PBF Internal Gate Driver Bias Voltage

CAN Port Pinout

The isolated CAN port is a standard male DB9 connector (Amphenol L717SDE09PA4CH4RC309) with the pinout shown below. This CAN port can be mated with any standard DB9 female connector.

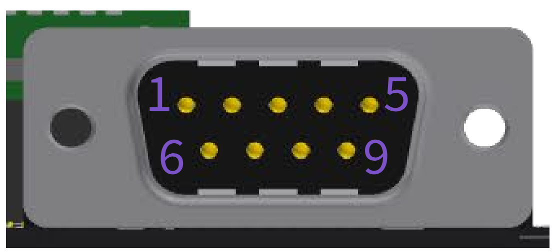


Figure 8: J4 CAN port pin numbers

Table 7: J4 CAN Port Pinout

Pin #	Name	Type	Description
1	NC0	—	No Connect
2	CAN_L	Digital (I/O)	Isolated CAN Low
3	V-	Power	Isolated Ground
4	NC1	—	No Connect
5	SHLD	Power	Isolated Ground
6	O(V-)	—	No Connect
7	CAN_H	Digital (I/O)	Isolated CAN High

8	NC2	—	No Connect
9	V+	Power	Isolated +5V Power

Encoder Connector Pinout

The design supports an external encoder feedback measurement for determining mechanical position. The encoder attaches to the board through a Würth Elektronik 61300511121 connector. This connector uses standard 0.1 in (2.54 mm) spacing, so it can be mated with a female header with the same pitch.

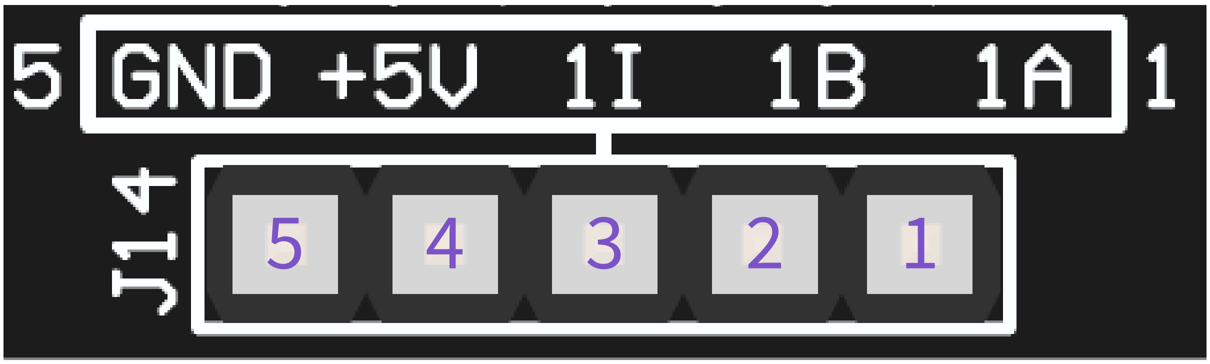


Figure 9: J14 Encoder connector pin numbers

Table 8: J14 Encoder Connector Pinout

Pin #	Name	Type	Description
1	1A	Digital (I/O)	Enhanced Quadrature Encoder Pulse (eQEP) Quadrature Signal
2	1B	Digital (I/O)	Enhanced Quadrature Encoder Pulse (eQEP) Quadrature Signal
3	1I	Digital (I/O)	Enhanced Quadrature Encoder Pulse (eQEP) Index Signal
4	+5V	Power	Output +5V Power for Encoder
5	GND	Power	GND for Encoder Reference

Metrology

This design includes a variety of test points and probe connection points to measure various signals on the board in order to evaluate the design and test various control schemes.

To measure the gate signals, each of the six MOSFETs are connected to a dedicated MMCX connector, which are connected across the MOSFET gate and source terminals. These measurements use Molex 0734151471 connectors and are in the locations shown below. These are standard MMCX connectors intended to be monitored directly with an oscilloscope probe. Notably, during system operation, the gate measurements can float at the full bus voltage. Therefore, the gate measurements should not be monitored using single-ended oscilloscope probes due to the safety risks of high-voltage potentials being applied to the oscilloscope reference. It is recommended to perform these gate measurements with high-isolation probes such as the Tektronix IsoVu series of probes.

The design also includes several through-hole test points to measure the high-power connections and the low-power voltage rails. These test points are in the physical locations indicated in the figure below and are connected to the signals described below. The test points can be used to perform a variety of measurements such as measuring the output phase voltages, the DC-bus voltage, and/or the auxiliary power rails.

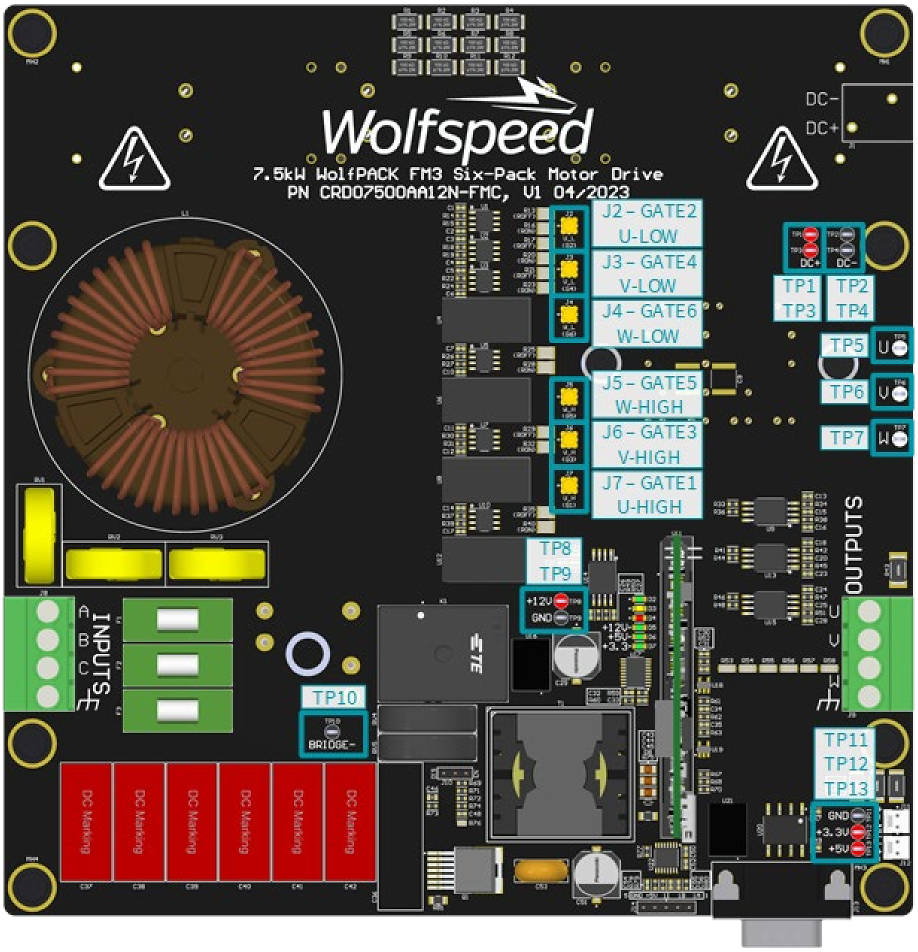


Figure 10: Gate and Test Point Measurement Locations

Table 9: Test Point Descriptions

Ref Designator	Signal	Color	Description
TP1	DC+	Red	Positive DC-Link Voltage
TP2	DC-	Black	Negative DC-Link Voltage
TP3	DC+	Red	Positive DC-Link Voltage
TP4	DC-	Black	Negative DC-Link Voltage
TP5	U	White	U Phase
TP6	V	White	V Phase
TP7	W	White	W Phase
TP8	+12V	Red	+12V Power

TP9	GND	Black	Ground
TP10	BRIDGE-	Black	Diode Bridge Negative Terminal (Should Be Ground Except During System Start-Up)
TP11	GND	Black	Ground
TP12	+3.3V	Red	+3.3V Power
TP13	+5V	Red	+5V Power

3. System description

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 50⁰ CELSIUS. THESE CONDITIONS WILL CONTINUE AFTER THE ELECTRICAL SOURCE IS DISCONNECTED UNTIL THE BULK CAPACITORS ARE FULLY DISCHARGED. DO NOT TOUCH THE BOARD WHEN IT IS ENERGIZED AND ALLOW THE BULK CAPACITORS TO COMPLETELY DISCHARGE PRIOR TO HANDLING THE BOARD.

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

警告

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

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

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

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

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

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

3.1 Input Circuit and EMI Filter

CRD07500AA12N-FMC takes input from the three phase AC grid in the 380V – 480V range, depending on the geographical location. The fuses F1-F3 provided at the input of the design, safeguard the system from fault induced over-currents. 550V varistors RV1-RV3 from Würth Elektronik are connected between the phases to absorb line surge transients. This is followed by an EMI filter in a pi type architecture. The filter consists of 1µF X2 capacitors, a 47mH 16A common mode choke, both from Würth Elektronik and 1.5nF Y1 capacitors. The filtered output is further fed into a three-phase diode rectifier.

Since a major share of the customers are expected to run their motor drives with a switching frequency in the 10kHz – 30 kHz range, a common mode choke with the maximum insertion attenuation in the 10kHz – 300kHz range is selected with the help of REDexpert online tool. This choke in combination with Y1 rated capacitors on both sides, connected between phase and Earth, provides the necessary common mode (CM) attenuation. The stray inductance of the common mode choke combined with X2 capacitors connected between phases provides the necessary different mode (DM) attenuation. Two X2 capacitors are connected in series between all combinations of two phases to reduce the costs, while still being able to meet the X1 safety requirements. High value resistors are added between the phases to bleed out the X2- capacitors.

It is very hard to ensure sufficient different mode attenuation without a measurement of the differential mode noise levels in the system. Also, the stray inductance values of the selected CM choke may not be good enough to keep the X-capacitor sizes within reasonable limits.

This filter design targets to meet the CISPR32 class B requirements, but further test and validation are required to ensure that the targets are met. Modifications to the filter maybe proposed in future revisions based on the experimental results. It is also important to point out here that the EMI signature of the reference design highly depends on the selected switching frequency, gate resistors and supplied AC input voltage and extra effort might be required to further tune the filter to satisfy specific customer requirements.

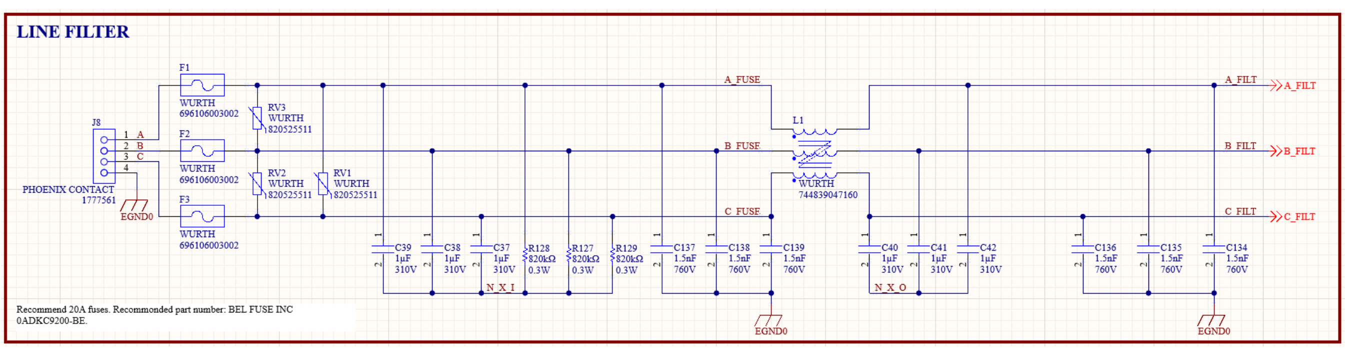


Figure 11: Input circuit and eMI filter

3.2 DC Link Sizing

DC link capacitors are amongst the largest components on any inverter board. The primary goal of DC link capacitor sizing is to meet the ripple current and voltage requirements of the inverter. Size of the DC link capacitors also have a significant impact on power density.

A simplified DC link ripple current equation at 50% duty cycle is given by equation (1):

$$\Delta I = 0.25 * \frac{Vbus}{f * L} \quad (1)$$

Where V_{bus} is the DC link voltage (V), f is the switching frequency in Hz, L is the inductance per phase in Henries.

Similarly, the simplified DC voltage ripple (peak-to-peak) is given by equation (2):

$$\Delta V = \frac{V_{bus}}{32 * L * C * f^2} \quad (2)$$

These equations represent the two primary constraints that are to be satisfied by the DC link capacitors. For DC bus voltage in the range 513V – 648V (corresponding to three phase voltage 380V-480V), switching frequency in 20-40kHz range, inductance L in 1-10mH range, the DC link capacitor sizing requirements can be met by either series-parallel combination of four 400V 1200µF electrolytic capacitors (B43630A9128M000) or parallel combination of 3 x 75µF film capacitors (890724429010CS).

A further constraint demanded by certain applications is the requirement to store a half cycle or full cycle (50Hz) of energy within the DC link capacitors. This requirement can only be met by electrolytic capacitors. The reference design comes assembled with electrolytic capacitors but also includes PCB footprints for DC-link film capacitors.

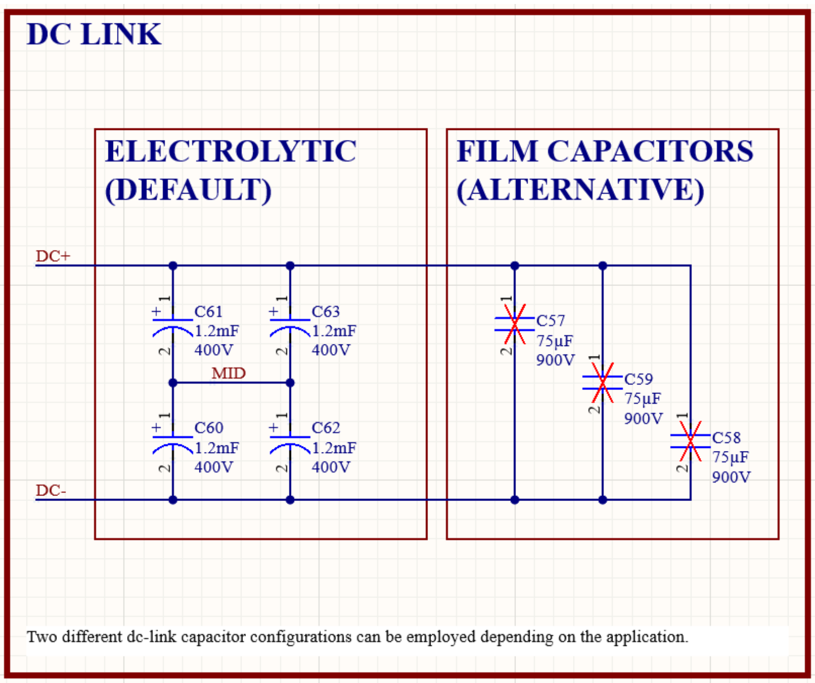


Figure 12: DC link capacitors

3.3 Auxiliary Power Supply

The reference design supports 3 phase RMS grid voltages from 380V to 480V. The wide range in grid voltage translates to a wide DC bus input voltage range of the inverter.

The auxiliary power supply is designed to support this wide DC bus voltage. LT8316 IC, a micropower, high voltage flyback converter without an opto-isolator for voltage regulation is selected to implement the 12V auxiliary power supply. This IC typically supports 16V to 560V. By adding a High Voltage Zener in series with the V_{IN} pin at its input, this range is further extended by 16V + V_z to 560V + V_z. This modification makes the IC compatible with the system requirements of our reference design. However, this means that the auxiliary supply brown-out occurs at a much higher voltage (refer key system specifications section) and care must be taken to ensure that the system DC link voltage doesn't fall below this value. Further implementation details can be found in this Analog Devices Design note.

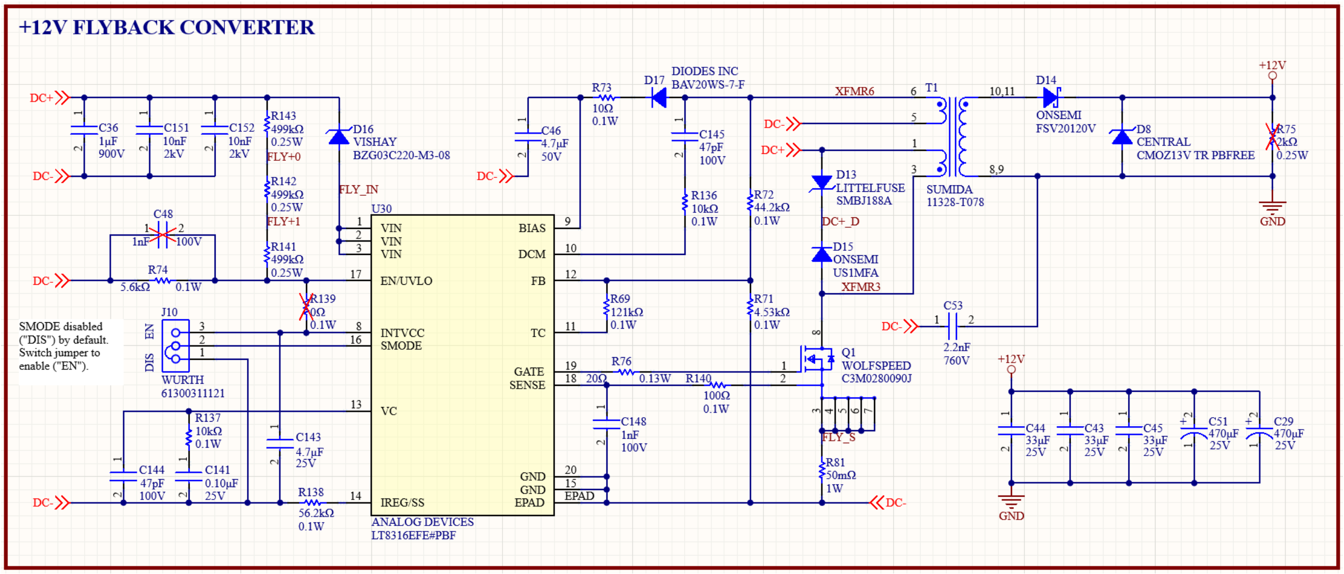


Figure 13: Auxiliary power supply

3.4 Gate Drivers

The MOSFET switch positions are driven with isolated power supplies and gate driver integrated circuits (IC), both of which have continuous isolation barriers of over 2 kV. Since all the high-side switch positions are referenced to separate phase nodes, each of the high-side gate drivers uses a separate dedicated power supply and gate driver IC. The gate driver circuit for one high-side switch position is shown below. Since all the low-side switch positions share a common reference, all three low-side switch positions share the same isolated power supply in this design, though they have separate gate driver ICs. These low-side switch position gate driver circuits are shown below. To prevent undesired coupling, there is an isolation gap between the controller signals and the high-voltage MOSFET connections. No copper crosses this isolation barrier, and the only components which cross the barrier are the isolated power supplies and gate driver ICs. The power supplies generate the isolated +15 V and -3 V rails required to properly bias the MOSFET gates, and they supply enough power to drive the MOSFETs at high switching frequencies.

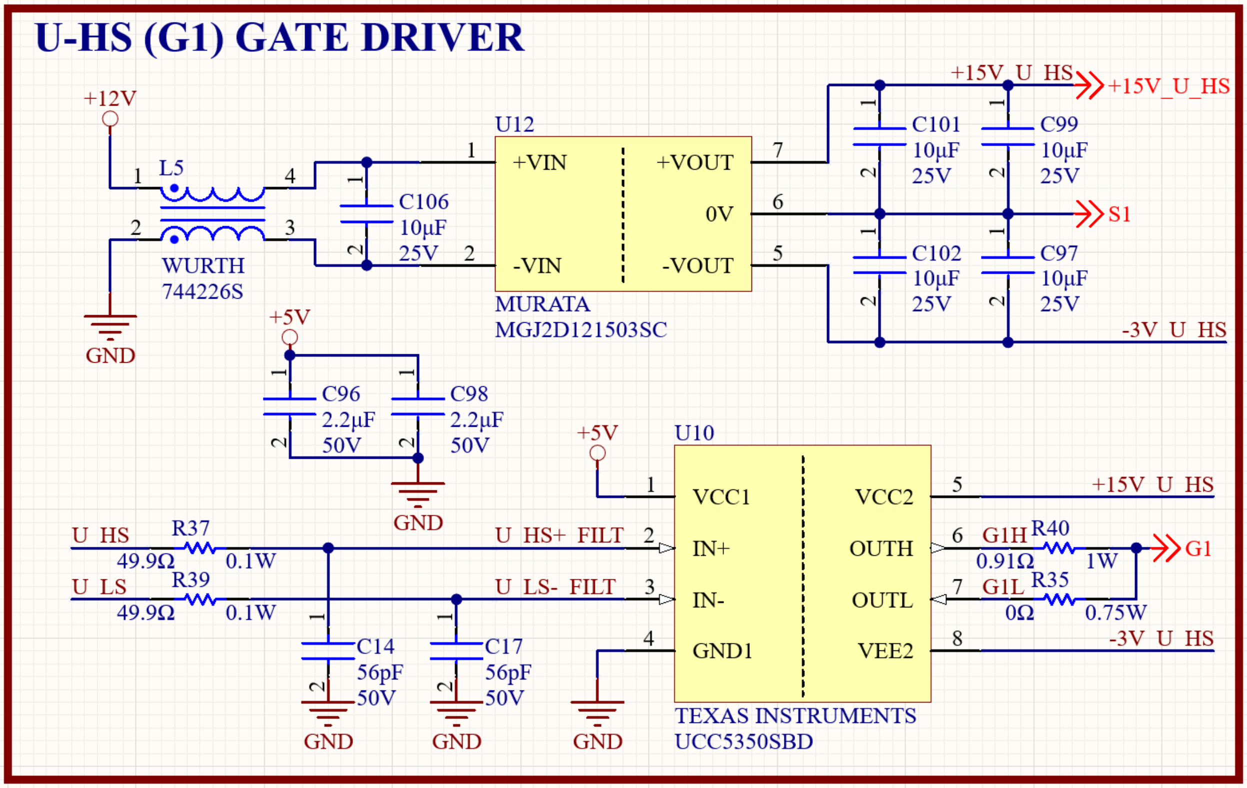


Figure 14: Gate driver circuit for one high-side MOSFET switch position

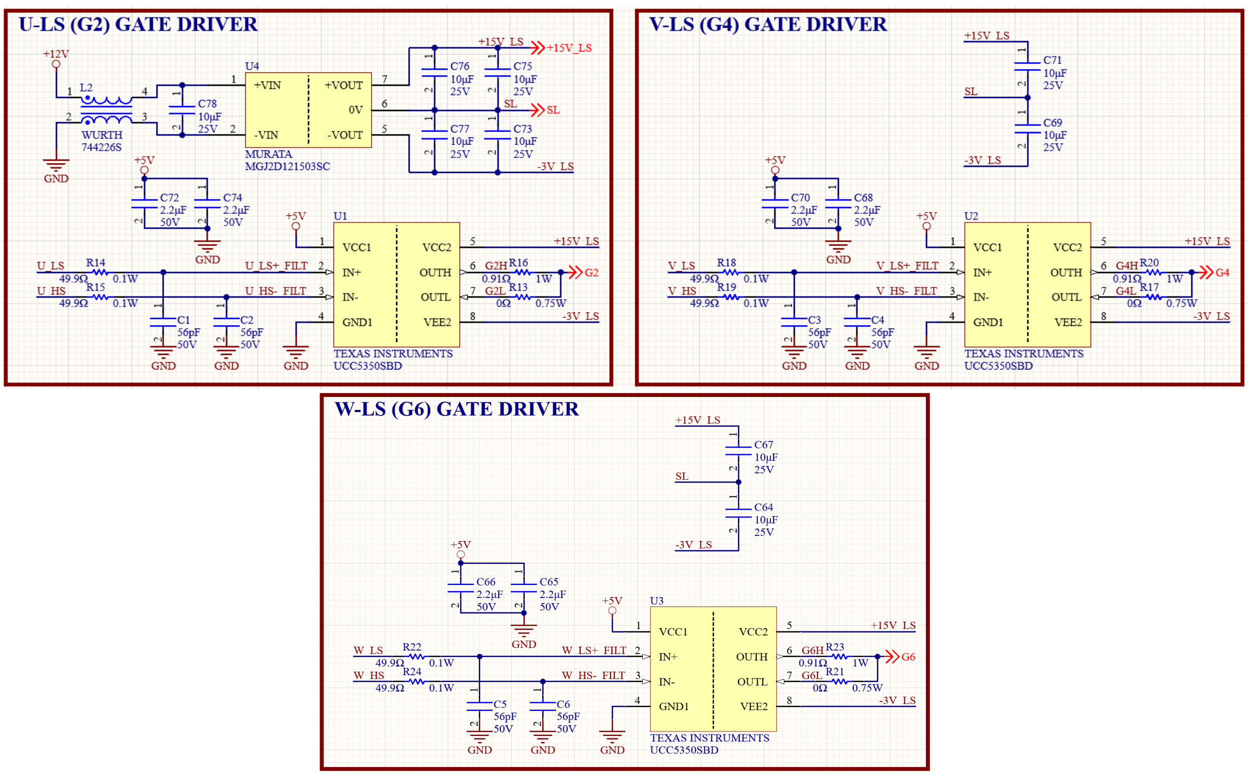


Figure 15: Gate driver circuits for low-side MOSFET switch positions with shared isolated power supply

For the gate driver IC, the design uses the Texas Instruments UCC5350SBD isolated gate driver, which has a sink/source drive strength of ±5 A. The selected gate driver IC includes a split output capable of sinking/sourcing current through separate turn-on and turn-off gate resistors. The split output allows users to independently optimize the turn-on and turn-off switching losses and edge rates. In traditional single output circuits, the same gate resistor must be used for both transition states, which could result in increased switching losses. By default, this design employs a 0.91 Ω turn-on resistor and a 0 Ω turn-off resistor, though these values can easily be changed by a user to reach the desired performance targets. The gate driver circuit includes input signal interlocks which prevent the IC from turning on when the high-side and low-side switch positions are simultaneously commanded on. This feature enables users to confidently evaluate prototype control software without the risk of shoot-through due to command errors from the controller. The gate driver IC also includes other built-in functionalities such as undervoltage lockout, low propagation delay, and high common-mode transient immunity. Some of the general specifications of the gate driver used in this design are shown in Table 10, and more details about the build-in features of the gate driver IC can be found in the Texas Instruments UCC5350SBD datasheet.

Table 10: Gate Driver Operating Parameters

Symbol	Parameter	Min.	Typ.	Max.	Unit
P_{DRIVE}	Power Per Gate Driver[1]	—	—	1.7	W
I_O	Output Peak Current (T_A = 25 °C)	—	—	±5	A
$V_{GATE,HIGH}$	High Level Output Voltage	—	15	—	V
$V_{GATE,LOW}$	Low Level Output Voltage	—	-3	—	
$R_{G(EXT)-ON}$	External Turn-On Resistance	—	0.91	—	Ω
$R_{G(EXT)-OFF}$	External Turn-Off Resistance	—	0	—	

[1] The gate driver power supply can be populated with Murata Power Solutions Inc. MGJ2D121503SC or with RECOM R12P21503D. This rating is the worse-case value of the two options.

3.5 Current Sensing

The motor U, V and W phase currents are sensed with precision shunt resistors. The voltage drop across the shunt resistor is measured by a galvanically isolated delta sigma modulator. This reference design uses Texas Instruments AMC1303M05020 with a ±50mV input range. The peak output current rating of the inverter is ±23 Apk.

$$R_{shunt} = \pm\frac{50mV}{23A} = 2.17m\Omega \quad (3)$$

The shunt resistor value is chosen to be 2mΩ and a 1%, 3W rated precision shunt resistor is selected. The measurement circuit is explained with the help of U-phase as a reference. R38, R34 and C15 forms an input differential filter. This filter improves the signal-to-noise performance of the measured phase current. R33 and R36 are termination resistors on the data and clock output lines. AMC1303M05020 generates an internal clock of 20 MHz. The data and clock lines are connected to the Sigma Delta Filter Modulation (SDFM) peripherals on F280039C control card. Configuration of the SDFM is performed in user software.

The primary-side DVDD is powered by 3.3 V supply and 5 V supply powers the secondary side. A dedicated 5V regulator is used for each of the phase sense measurement circuits. This 5V regulator in turn derives its source from the 15V of the corresponding high side gate driver supply. Supply noise decoupling capacitors for the delta-sigma modulator are added to both the primary and secondary sides.

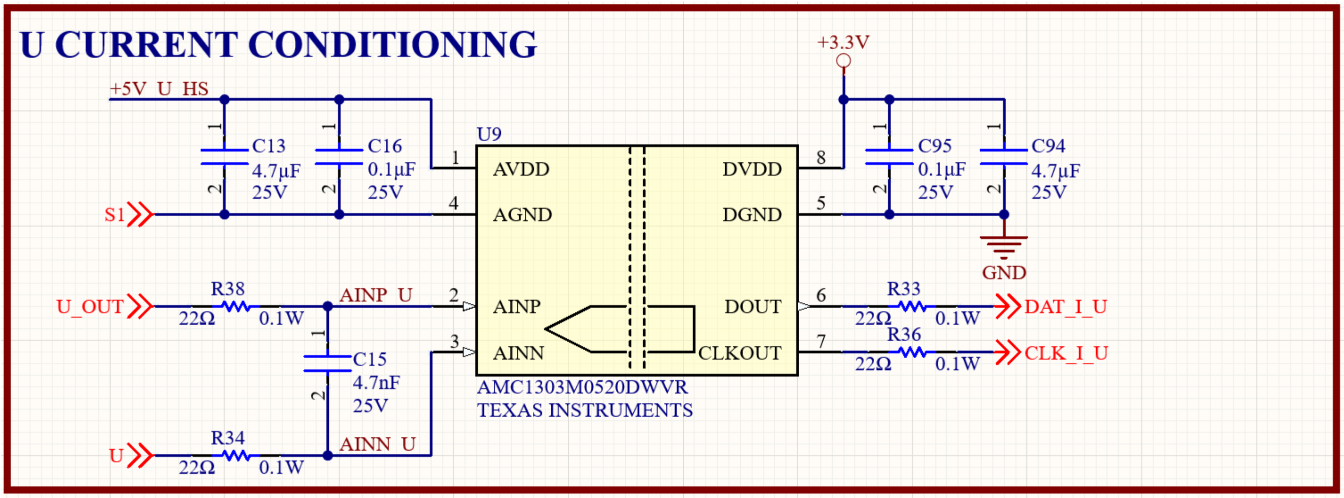


Figure 16: U phase current measurement

3.6 Voltage Sensing

The DC Bus voltage measurement is implemented akin to the phase current measurements. The bus voltage is appropriately scaled-down by a voltage divider and this scaled down signal is fed into a galvanically isolated delta-sigma modulator. Texas Instruments AMC1303M05020 is again used here to lower the part count. The scaling factor can be calculated as follows:

$$SF = \frac{R98}{R86+R90+R91+R92+R93+R98} = 5.88\text{e-}5 \qquad (4)$$

The resistors R86, R90, R91, R92, R93 are each rated for 200V with a 1W power rating. At $V_{DC\,max}$ = 690V, the power dissipation in each of these resistors is 0.28W. The maximum rated DC bus voltage of 690V should not be exceeded to provide safe operating margins for these resistors.

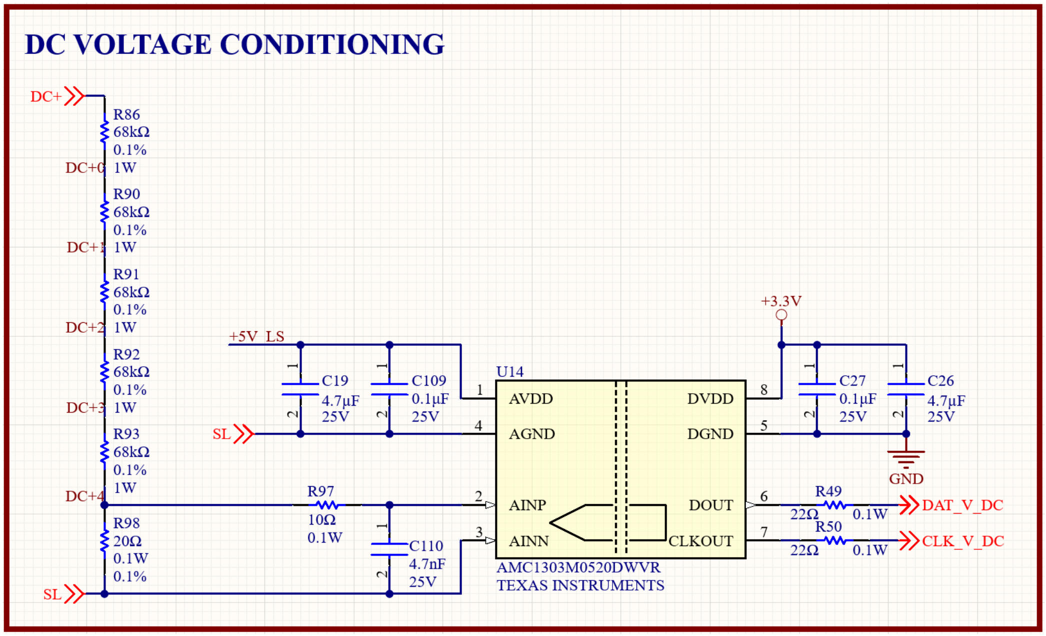


Figure 17: DC voltage measurement

U,V,W phase voltage measurements are supported by this reference design. These measurements enable support for back-emf estimators used in sensorless motor control. The high voltage at the phase output is stepped down to a low voltage by a voltage divider. This low voltage is actively filtered and sensed by the ADC. A ±1200V high voltage input is scaled down to 0.2V -3.1V centered around 1.65V for a 0V input. The voltage sense measurements are brought in as high voltage signals without pre-scaling for better noise immunity.

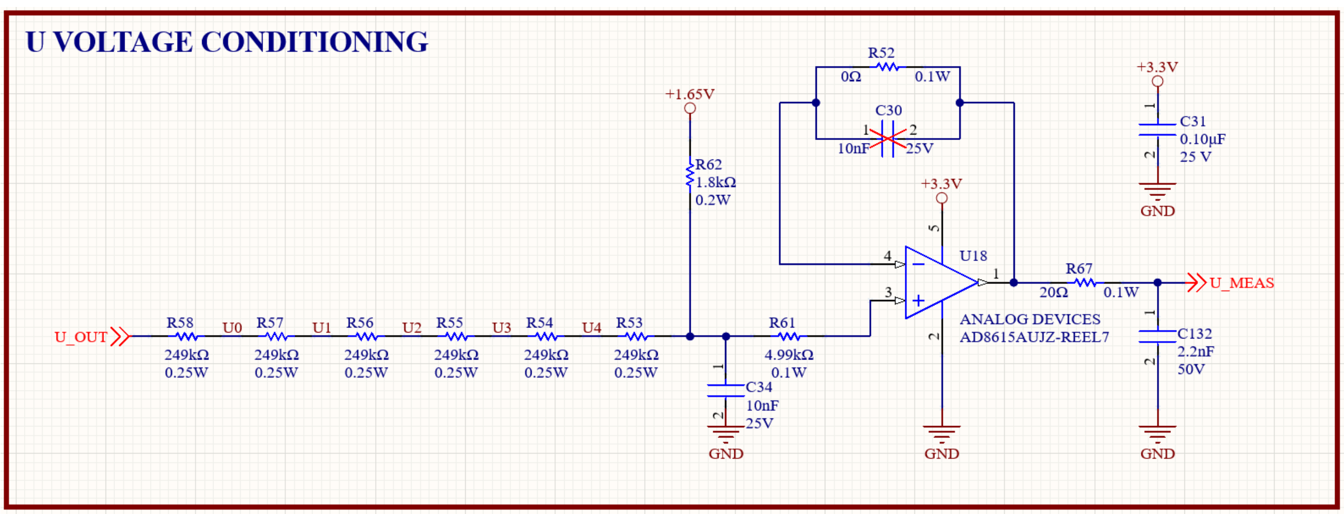


Figure 18: U phase voltage measurement

3.7 NTC

The NTC temperature sensor integrated into the CCB032M12FM3 is sensed and fed back to the controller as a non-isolated analog signal. The NTC signal is routed onto the 2 module pins as shown in figure here:

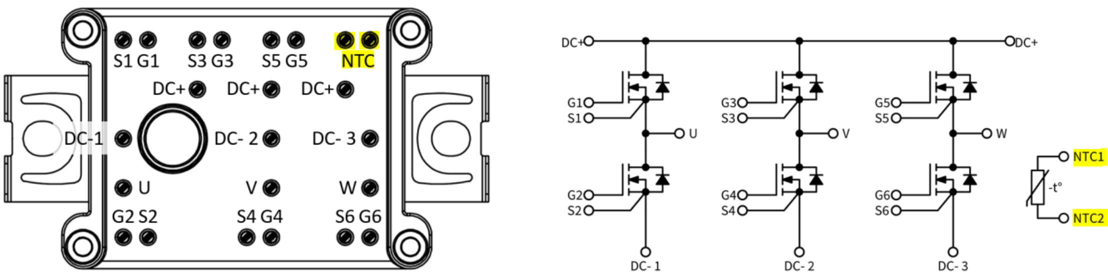


Figure 19: NTC FM3 package pin location

This signal is further fed into a simple, low-cost, second order Sallen-Key low pass filter, implemented with discrete components. The filter transfer function is given by

$$\frac{V_{out}(s)}{V_{in}(s)} = \frac{\frac{1}{R95 * C102 * R94 * C101}}{s^2 + s\left(\frac{1}{R94 * C102} + \frac{1}{R95 * C101}\right) + \frac{1}{R95 * C102 * R94 * C101}} \quad (5)$$

Since the thermal dynamics of the system are expected to be slower than the electrical dynamics by at least an order of magnitude, a filter cut-off frequency of 200Hz is selected. The combination of R128 and C125 acts as a first order noise filter at the input of the microcontroller.

AD8541 rail-to-rail operational amplifier is selected to implement the active filter. This enables the utilization of the full-scale input range of the 3.3V ADC available on the F280039C microcontroller.

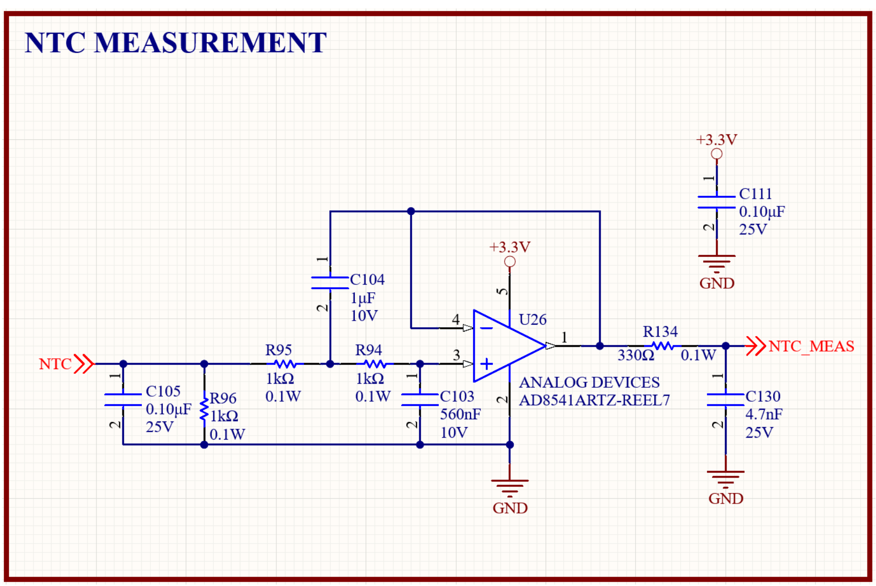


Figure 20: NTC measurement

3.8 Position Sensing

F280039C microcontroller supports encoder based sensored motor control solutions using the enhanced quadrature encoder pulse (eQEP) peripheral. This reference design supports eQEP1 peripheral enabling the interfacing of an incremental encoder to the inverter. 5V EQEP1A, EQEP1B (quadrature signals) and EQEP1I (index signal) are made available on connector J14. These digital signals are level shifted to 3.3V before interfacing with the microcontroller.

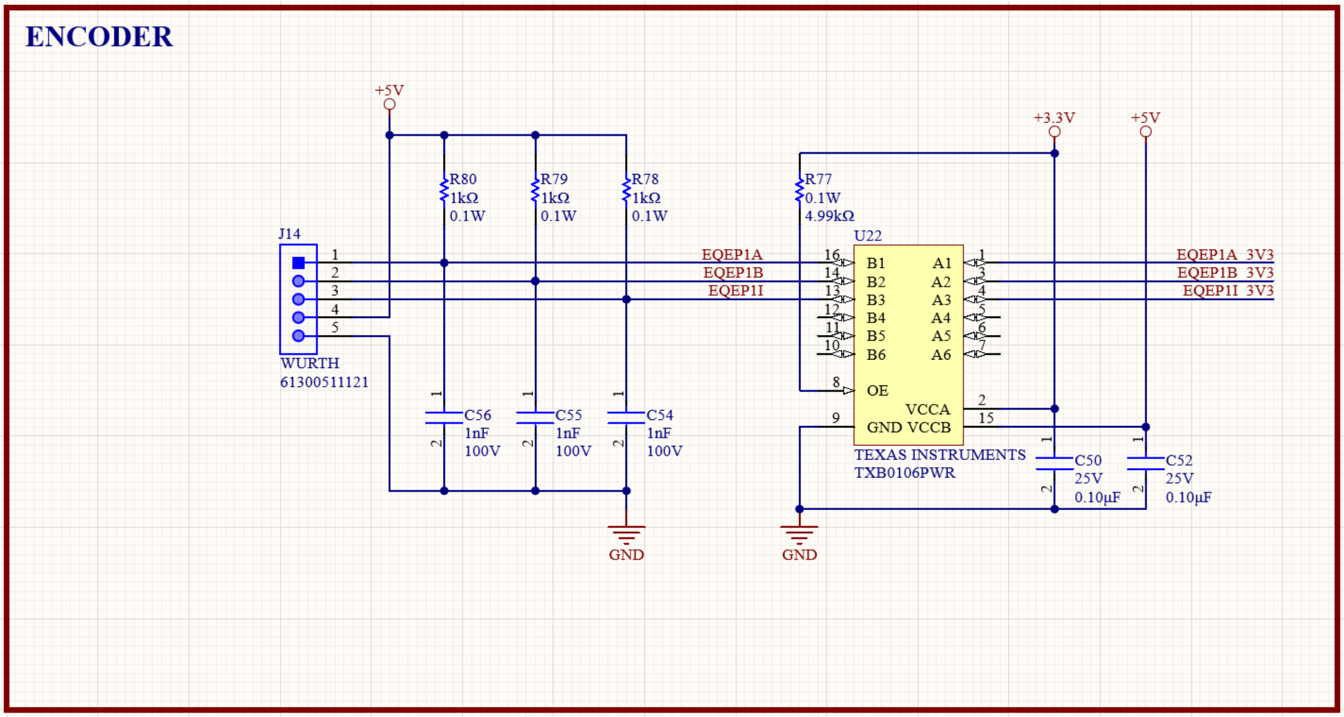


Figure 21: Encoder position sensing circuit

3.9 Grounding

Depending on the target application, users may have different requirements for applying Earth ground to the circuit. This design features two configurations to address these different requirements. The default configuration is to have Earth ground and controller ground decoupled from each other. This is done by not including any direct connection between the two grounds. The second optional configuration is to directly connect the two ground potentials by populating the 0 Ω 2512 resistors R64, R65, and R66, shown the figure below. By default, these resistors are not populated in the circuit.

The circuit is designed to be connected directly to Earth ground through the input power connector, J8. The circuit does not support ungrounded operation since the electromagnetic interference (EMI) components would not function as intended and the heat sink could reach high-voltage potentials. Ensure that the Earth ground input is always connected when operating this circuit.

The Earth ground pin of the output power connector, J9, is intended to provide users with easy methods of attaching the load to Earth ground. This pin is not required for system operation if the load is already connected to Earth ground through other means. Note that the output Earth ground pin is connected to the input Earth ground pin through the heat sink. The output Earth ground should not be relied upon if the heat sink is removed from the circuit.

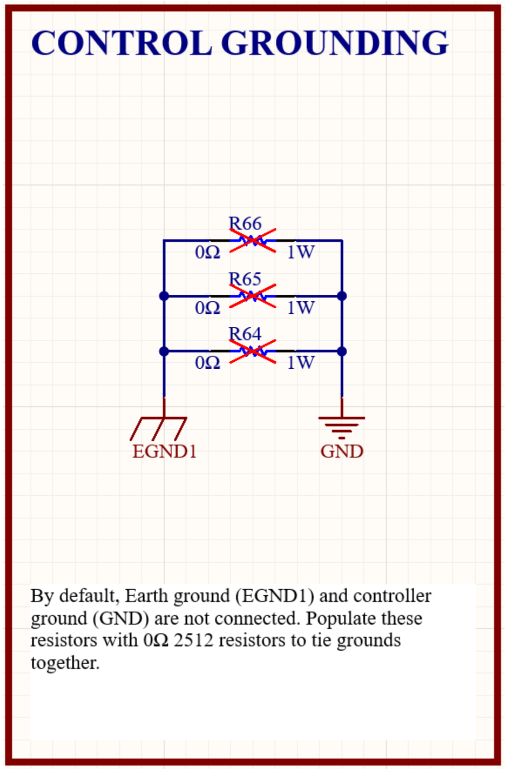


Figure 22: Optional connection between control ground (GND) and Earth ground (EGND)

3.10 Controller

The controller connector is Samtec HSEC8-160-01-L-DV-A-BL with the pinout shown below. The system has been tested with the Texas Instruments TMDSCNCD280039C controller. However, any controller with equivalent pinout could be utilized.

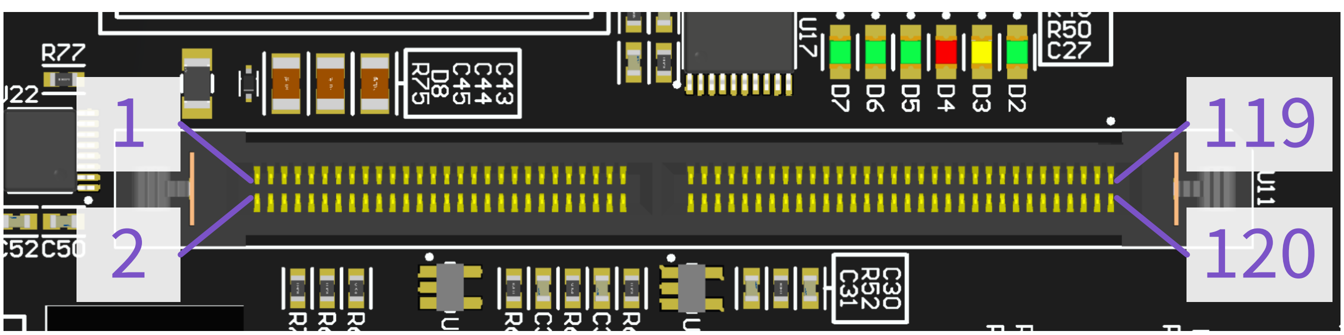


Figure 23: U11 controller connector pin numbers

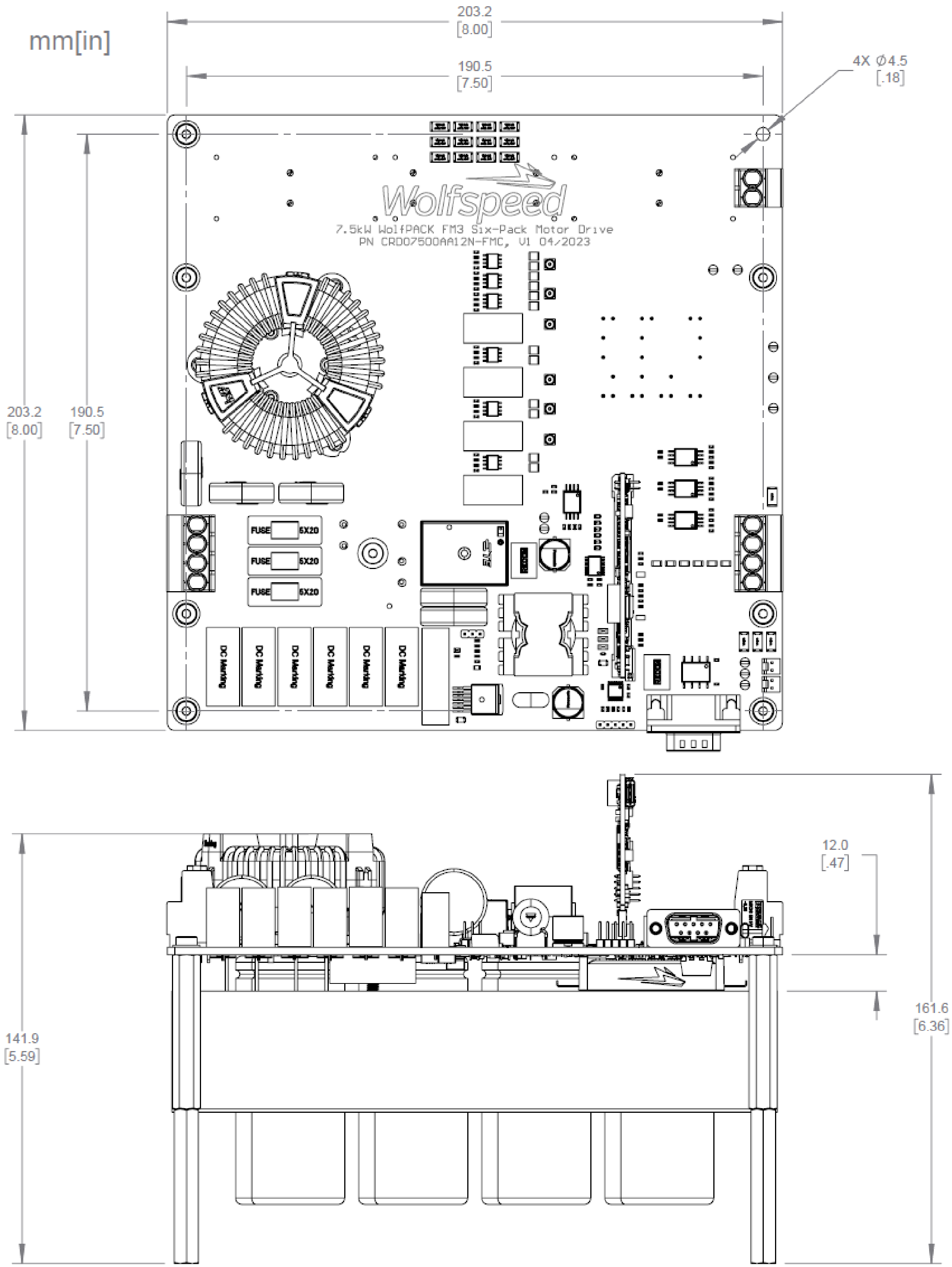
Table 11: U11 Controller Connector Pinout

#	Name	Type	Description	Description	Type	Name	#
1	NC	—	No Connect	No Connect	—	NC	2
3	NC	—	No Connect	No Connect	—	NC	4
5	NC	—	No Connect	No Connect	—	NC	6
7	GND_0	Power	Ground	No Connect	—	NC	8
9	W_MEAS	Analog (I)	W Differential Voltage Meas.	Ground	Power	GND_1	10
11	V_MEAS	Analog (I)	V Differential Voltage Meas.	No Connect	—	NC	12
13	GND_2	Power	Ground	No Connect	—	NC	14
15	NC	—	No Connect	Ground	Power	GND_3	16
17	U_MEAS	Analog (I)	U Differential Voltage Meas.	No Connect	—	NC	18
19	GND_4	Power	Ground	No Connect	—	NC	20
21	NC	—	No Connect	Ground	Power	GND_5	22
23	NC	—	No Connect	No Connect	—	NC	24
25	NC	—	No Connect	No Connect	—	NC	26
27	NC	—	No Connect	No Connect	—	NC	28
29	GND_6	Power	Ground	NTC Measurement	Analog (I)	NTC_MEAS	30
31	NC	—	No Connect	No Connect	—	NC	32
33	NC	—	No Connect	No Connect	—	NC	34
35	GND_7	Power	Ground	No Connect	—	NC	36
37	NC	—	No Connect	Ground	Power	GND_8	38
39	NC	—	No Connect	No Connect	—	NC	40
41	NC	—	No Connect	No Connect	—	NC	42
43	NC	—	No Connect	No Connect	—	NC	44
45	NC	—	No Connect	Ground	Power	GND_9	46
47	GND_10	Power	Ground	+5V Power	Power	5V_0	48
49	U_HS_PWM	Digital (O)	High-Side Phase U PWM Control	High-Side Phase W PWM Control	Digital (O)	W_HS_PWM	50

	Name	Type	Description		Description	Type	Name	#
51	U_LS_PWM	Digital (O)	High-Side Phase U PWM Control		Low-Side Phase W PWM Control	Digital (O)	W_LS_PWM	52
53	V_HS_PWM	Digital (O)	High-Side Phase V PWM Control		No Connect	—	NC	54
55	V_LS_PWM	Digital (O)	Low-Side Phase V PWM Control		No Connect	—	NC	56
57	NC	—	No Connect		No Connect	—	NC	58
59	NC	—	No Connect		No Connect	—	NC	60
61	NC	—	No Connect		No Connect	—	NC	62
63	NC	—	No Connect		No Connect	—	NC	64
65	GND_11	Power	Ground		No Connect	—	NC	66
67	NC	—	No Connect		Encoder Quadrature Signal	Digital (I/O)	EQEP1A_3V3	68
69	NC	—	No Connect		Encoder Quadrature Signal	Digital (I/O)	EQEP1B_3V3	70
71	NC	—	No Connect		No Connect	—	NC	72
73	NC	—	No Connect		Encoder Index Signal	Digital (I/O)	EQEP1I_3V3	74
75	NC	—	No Connect		No Connect	—	NC	76
77	NC	—	No Connect		No Connect	—	NC	78
79	NC	—	No Connect		No Connect	—	NC	80
81	NC	—	No Connect		No Connect	—	NC	82
83	GND_12	Power	Ground		+5V Power	Power	5V_1	84
85	NC	—	No Connect		No Connect	—	NC	86
87	CAN_RX	Digital (I/O)	Non-isolated CAN RX		Non-Isolated CAN TX	Digital (I/O)	CAN_TX	88
89	NC	—	No Connect		No Connect	—	NC	90
91	NC	—	No Connect		Spare Controller GPIO	Digital (I/O)	GPIO44	92
93	GD_DIS	Digital (O)	Gate Driver Disable		No Connect	—	NC	94
95	LED_R	Digital (O)	Red LED Control		Yellow LED Control	Digital (O)	LED_Y	96

#	Name	Type	Description		Description	Type	Name	#
97	GND_13	Power	Ground		+5V Power	Power	5V_2	98
99	DAT_I_W	Digital (I)	W Current Meas. Bitstream		DC Bus Meas. Bitstream	Digital (I)	DAT_V_DC	100
101	CLK_I_W	Digital (I)	W Current Meas. Modulator Clock		DC Bus Meas. Modulator Clock	Digital (I)	CLK_V_DC	102
103	DAT_I_V	Digital (I)	V Current Meas. Bitstream		No Connect	—	NC	104
105	CLK_I_V	Digital (I)	V Current Meas. Modulator Clock		No Connect	—	NC	106
107	DAT_I_U	Digital (I)	U Current Meas. Bitstream		Green LED Control	Digital (O)	LED_G	108
109	CLK_I_U	Digital (I)	U Current Meas. Modulator Clock		No Connect	—	NC	110
111	GND_14	Power	Ground		+5V Power	Power	5V_3	112
113	NC	—	No Connect		No Connect	—	NC	114
115	NC	—	No Connect		No Connect	—	NC	116
117	NC	—	No Connect		No Connect	—	NC	118
119	NC	—	No Connect		+5V Power (Disabled)	Digital (I)	~RST	120

4. Mechanical Assembly



Revision History

Date	Revision	Changes
January 2024	1	Initial Release

Purposes and Use

Wolfspeed, Inc. (on behalf of itself and its affiliates, "Wolfspeed") reserves the right in its sole discretion to make corrections, enhancements, improvements, or other changes to the board or to discontinue the board.

THE BOARD DESCRIBED IS AN ENGINEERING TOOL INTENDED SOLELY FOR LABORATORY USE BY HIGHLY QUALIFIED AND EXPERIENCED ELECTRICAL ENGINEERS TO EVALUATE THE PERFORMANCE OF WOLFSPEED POWER SWITCHING DEVICES. THE BOARD SHOULD NOT BE USED AS ALL OR PART OF A FINISHED PRODUCT. THIS BOARD IS NOT SUITABLE FOR SALE TO OR USE BY CONSUMERS AND CAN BE HIGHLY DANGEROUS IF NOT USED PROPERLY. THIS BOARD IS NOT DESIGNED OR INTENDED TO BE INCORPORATED INTO ANY OTHER PRODUCT FOR RESALE. THE USER SHOULD CAREFULLY REVIEW THE DOCUMENT TO WHICH THESE NOTIFICATIONS ARE ATTACHED AND OTHER WRITTEN USER DOCUMENTATION THAT MAY BE PROVIDED BY WOLFSPEED (TOGETHER, THE "DOCUMENTATION") PRIOR TO USE. USE OF THIS BOARD IS AT THE USER'S SOLE RISK.

Operation of Board

It is important to operate the board within Wolfspeed's recommended specifications and environmental considerations as described in the Documentation. Exceeding specified ratings (such as input and output voltage, current, power, or environmental ranges) may cause property damage. If you have questions about these ratings, please contact Wolfspeed prior to connecting interface electronics (including input power and intended loads). Any loads applied outside of a specified output range may result in adverse consequences, including unintended or inaccurate evaluations or possible permanent damage to the board or its interfaced electronics. Please consult the Documentation prior to connecting any load to the board. If you have any questions about load specifications for the board, please contact Wolfspeed 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 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 end product and therefore may not meet such standards. Users are also responsible for properly disposing of a board's components and materials.

No Warranty

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

Limitation of Liability

IN NO EVENT SHALL WOLFSPEED BE LIABLE FOR ANY DAMAGES OF ANY KIND ARISING FROM USE OF THE BOARD. WOLFSPEED'S AGGREGATE LIABILITY IN DAMAGES OR OTHERWISE SHALL IN NO EVENT EXCEED THE AMOUNT, IF ANY, RECEIVED BY WOLFSPEED IN EXCHANGE FOR THE BOARD. IN NO EVENT SHALL WOLFSPEED BE LIABLE FOR INCIDENTAL, CONSEQUENTIAL, OR SPECIAL LOSS OR DAMAGES OF ANY KIND, HOWEVER CAUSED, OR ANY PUNITIVE, EXEMPLARY, OR OTHER DAMAGES. NO ACTION, REGARDLESS OF FORM, ARISING OUT OF OR IN ANY WAY CONNECTED WITH ANY BOARD FURNISHED BY WOLFSPEED MAY BE BROUGHT AGAINST WOLFSPEED MORE THAN ONE (1) YEAR AFTER THE CAUSE OF ACTION ACCRUED.

Indemnification

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