Demonstration Board EPC9164 Quick Start Guide

3 kW Universal Input AC Voltage to 400 V DC Output Multi-level Totem Pole PFC Converter

Revision 2.0

EFFICIENT POWER CONVERSION

DESCRIPTION

The EPC9164 is a universal AC voltage (90 V_{RMS} through 264 V_{RMS}) and frequency 50/60 Hz input 4-level totem pole converter and is capable of delivering up to 3 kW into a 400 V_{DC} output load. The EPC9164 uses the 8mΩ 200 V rated EPC2215 in a 4-level flying capacitor topology.

The EPC9164 comprises a number of interlocking boards, shown in figure 1:

1) Main board that includes connections for the supply and load, AC voltage EMI filter, in-rush current limter circuits and accepts the GaN power card, controller card, housekeeping power supply, in-rush current limit relay card and sensor card.
2) GaN card with EPC2215 device and gate drivers and low frequency MOSFETs used as the rectifier.
3) Controller card – Texas Instruments TMDSCNCD28379D
4) Housekeeping power supply – CUI Inc. PBO-5-S12
5) In-rush current relay card that closes once the output capacitors have sufficiently charged thus bypassing the in-rush current limiting resistors.
6) Sensor card

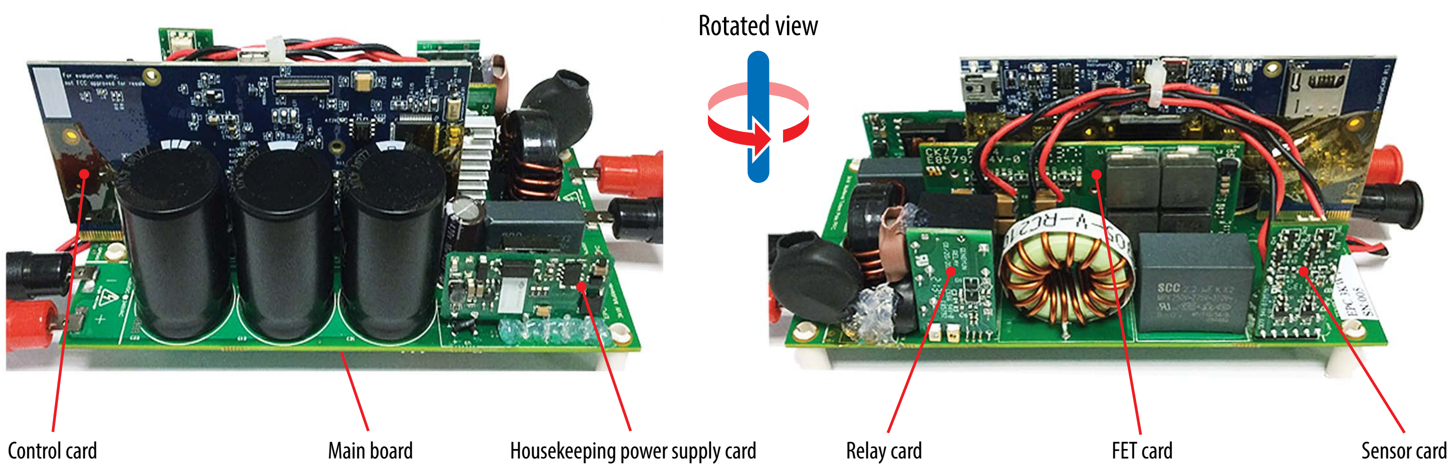


Figure 1: 3kW Multi-level Totem Pole PFC

In this 4-level topology, six, cascade connected, high frequency devices, EPC2215, (Q1 through Q6) are used in the high frequency leg shown in figure 2. The 3 kW four-level flying capacitor totem-pole bridgeless PFC rectifier utilizes 200 V rated eGaN FETs in a multi-level topology that significantly reduces the voltage seconds across the main input inductor while tripling the effective frequency resulting in a significant size and efficiency improvement over a traditional two level approach.. The board operates at 240 V_{RMS} AC, 60 Hz switching frequency, 12.5 A maximum input current. The 200 V rated EPC2215 eGaN FET, with $R_{DS(on)}$ of 8 mΩ, offers low switching loss, low driving power consumption, and zero reverse recovery compared to traditional silicon devices, enabling a high efficiency solution. The output DC voltage is set to 400 V so the voltage stress for each of the high frequency devices is only 133 V, plus margin, ensuring that 200 V devices are well suited for this topology.

HIGHLIGHTED PARTS

Main Board

The main board contains both input and output filter circuits and signal conditioning circuits. Figure 1 shows an overview of the PFC converter and measures 121 mm x 77 mm x 43 mm (L x W x H). It also contains multiple transformer isolated power sources for other HV sensors such as Vout and AC Line In. Additional current protection circuits along with generating a 5 V_{DC} supply. The PFC board interfaces with several cards such as a FET Card, Relay Card, Sensor Card, Control Card, and Load Disconnect.

FET Card

The FET Card features both low frequency MOSFETs (IPT60R028G7XTMA1) and High Frequency GaN FETs (EPC2215). The power board contains all of the active processing parts with the exception of the diodes and relay. It includes the isolated drivers, Bootstrap supplies, AC current sensor, inductors and level shift capacitors. The board fits into slots cut into the main board and is soldered into position at the card edge fingers.

The heat sink is only thermally connected to the GaN FETs through a copper heat spreader. The MOSFETs use the PCB board for thermal dissipation.

The main inductor is constructed out of 4 series connected "off the shelf" low profile high current inductors. The inductor switching frequency is 3 times that of a traditional PFC topology allowing for a significantly smaller inductor solution.

Diodes D8 and D9 are located on the main board and are only used during initial startup pre-charging the main output capacitors C_{DC} to a DC voltage equal to the peak of the incoming AC line voltage.

The FET card is configured in a full bridge topology to both synchronously rectify and boost the incoming AC line voltage to a regulated higher DC voltage output. There are 4 legs of the rectifier. High Frequency PWM GaN FETs Q1-Q3 for the upper Leg and Q4-Q6 for the lower leg. Line switching frequency (50/60Hz) MOSFETs Q7, Q8 are used for the upper leg and Q9, Q10 are used for the lower leg.

Control Card

The Control Card is a TI compatible 120-pin F28379D controlCARD that uses C2000Ware to implement state control and PWM regulation loops in software. The DSP processor is programmed via USB serial port, and plugs into a main board socket (J1) to facilitate programming outside the system. On startup, no PWM boost switching takes place. "Flying" level shift capacitors C_{F1} and C_{F2} must pre-charged to $^1/_3$ of the target regulated V_{OUT} voltage using the GaN FETs to control the charging process from the output DC capacitor voltage. When complete, PWM boost starts to generate the regulated output voltage. During PWM operation the level shift capacitors are individually or simultaneously switched in and out in series with the power inductor adding or subtracting $^1/_3$ or $^2/_3$ of the regulated V_{OUT} from the AC line voltage such that at no time over a complete AC sinewave cycle will the inductor see a differential voltage greater than $^1/_3$ V_{OUT} or below 0 V (reverse current) relative to the current phase polarity.

Sensor Card

The Sensor card is a dual isolated HV differential input voltage sensor with level shifting and signal conditioning suitable to be read by the processor ADC. One input is used for each GaN FET board "Flying Capacitor" C_{F1} and C_{F2}. The onboard transformer has two fully isolated secondaries generating two DC power sources for each HV differential input front end. The primary is driven from a driver located on the main board. The sensor card allows the controller card to monitor the DC voltage of the two flying capacitors so it can adjust the PWM timing such they maintain their respective $^1/_3$ V_{OUT} fixed DC voltage averaged over a given AC line cycle. The board is soldered to the main board.

Relay Card

The Relay card is part of the current inrush control system. The Controller Card will enable the relay when the startup sequence has been completed and it is time to start PWM Boost operation. The relay bypasses the series connected current limiting thermistor located on the main board. The relay card is soldered to the main board.

Flyback Card

The Flyback card generates a regulated 12 V from V_{OUT} to power the control circuits on the PFC system. It is solder to the main board.

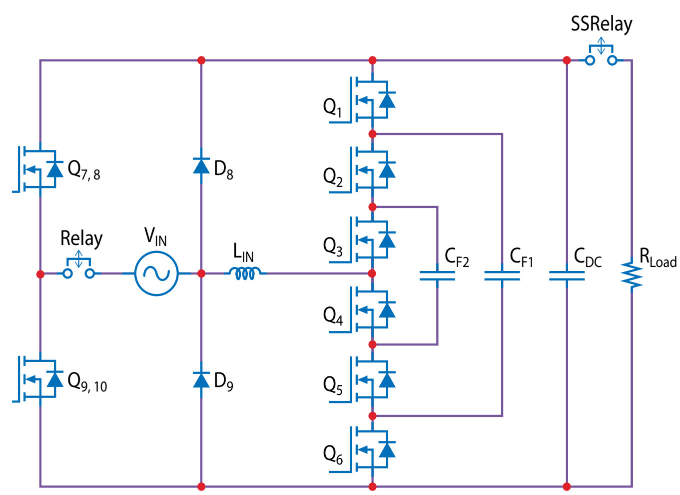


Figure 2: Power Schematic of FCML Totem Pole Bridgeless PFC rectifier

QUICK START PROCEDURE

The procedure documented here is provided as a simple guide and example only. **Caution should be exercised when operating this board as high voltage is present.**

1. Ensure the Control Card is inserted into socket J1 and locked/secured.
2. Connect PFC board to the Load Disconnect Board. See figure 3.
3. With power off, connect the line voltage of the AC Source (60 Hz, 240 VAC) to red and neutral voltage of AC source to black, as shown in figure 3.
4. With power off, connect the resistor load bank to the Load disconnect board, as shown in figure 3.
5. Tun on the AC source. Do not increase the AC supply voltage slow as this prevents the controller from properly charging the flying capacitors. The system will self-start and begin normal operation.
6. During system pre-charging, the relay will close. If protection occurs, the system will turn off the entire device. If this occurs, then switch off the AC source as soon as possible to protect the system.
7. Once operational, adjust the load and take necessary measurements.
8. For shutdown, switch off the AC source, discharge the DC capacitors, and allow the inrush current limiter to cool below 35°C.

Operation Notes

1. See figure 3 for setup connections.
2. Please inspect the 2 pairs of wire run from the FET card to the Sensor Card for any sign of a broken connection at the solder joint locations. Repair as necessary prior to applying any power to the system. Polarity is important.
3. **Warning: The PFC must not start into a load on initial power up.** You may need to connect a processor-controlled DC load switch between the output and the load to allow the PFC board to properly startup. Otherwise, you will need to manually turn on the load after the PFC has started.
4. It is recommended to use a true resistor load as an electronic load is not currently supported.

Protection

The PFC board includes the following protection features:

- Startup/Shutdown
- Flying capacitor voltage balance (prevents over voltage)

Warnings:

1) The GND of the board is not isolated from the AC grid and caution must be exercised when taking measurements. This also means the heatsink is not at neutral. The GND should also not be connected to earth.
2) This demo board has not been tested for EMI and is not FCC approved.

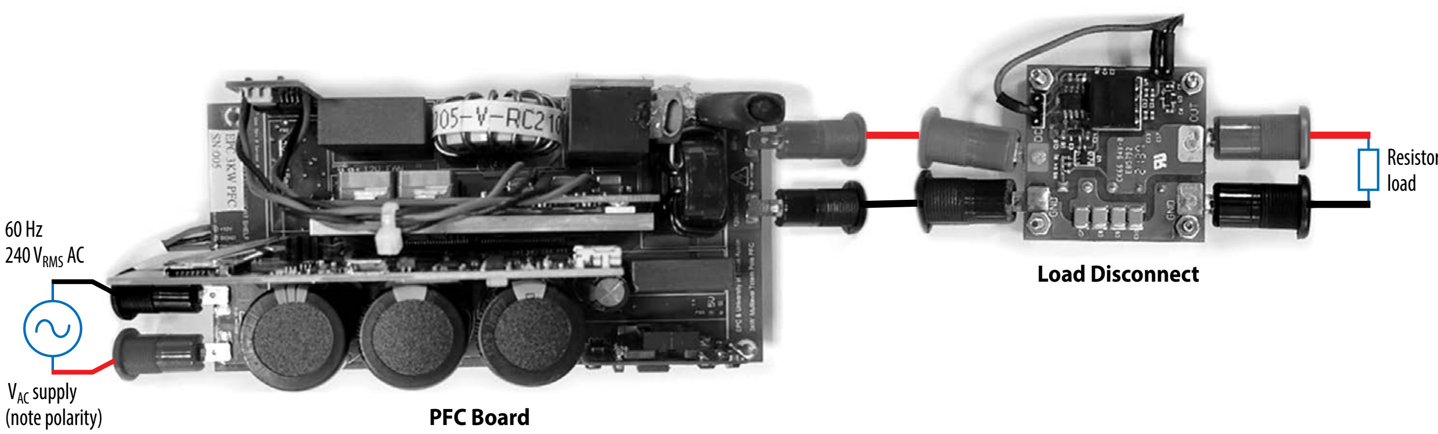


Figure 3: Test Setup and Procedure for PFC Board showing the supply and load connections

CONNECTION DETAILS

Controller Card

A 120-pin connector is used to implement state control and PWM regulation loops in software between the main board and the controller card. Table 1 gives the map (J1) for each signal.

Table 1: DSP interface connection (J1) pi n allocation map

Pin #	Pin name		Pin #
1	JTAG-EMU1	JTAG-EMU0	2
3	JTAG-TMS	JTAG-TRSTn	4
5	JTAG-TCK	JTAG-TDO	6
7	AGND	JTAG-TDI	8
9	ADC-A0	AGND	10
11	ADC-A1	ADC-B0	12
13	RSVD	ADC-B1	14
15	ADC-A2	RSVD	16
17	ADC-A3	ADC-B2	18
19	AGND	ADC-B3	20
21	ADC-A4	AGND	22
23	ADC-A5	ADC-B4	24
25	ADC-C0	ADC-B5	26
27	ADC-C1	ADC-D0	28
29	RSVD	ADC-D1	30
31	ADC-C2	RSVD	32
33	ADC-C3	ADC-D2	34
35	AGND	ADC-D3	36
37	ADC-C4	AGND	38
39	ADC-C5	ADC-D4	40
41	RSVD	ADC-D5	42
44	RSVD	RSVD	44
45	RSVD	AGND	46
47	AGND	RSVD(5V)	48
49	PWM1A	PWM3A	50
51	PWM1B	PWM3B	52
53	PWM2A	PWM4A	54
55	PWM2B	PWM4B	56
57	PWM5A	PWM7A	58
59	PWM5B	PWM7B	60

Table 1: (continued)

Pin #	Pin name		Pin #
61	PWM6A	PWM8A	62
63	PWM6B	PWM8B	64
65	DGND	RSVD	66
67	PWM9A	PWM11A	68
69	PWM9B	PWM11B	70
71	PWM10A	PWM12A	72
73	PWM10B	PWM12B	74
75	GPIO24	GPIO28	76
77	GPIO25	GPIO29	78
79	GPIO26	GPIO30	80
81	GPIO27	GPIO31	82
83	DGND	VCC_DSP5V	84
85	GPIO32	GPIO34	86
87	GPIO33	GPIO39	88
89	GPIO40	GPIO44	90
91	GPIO41	GPIO45	92
93	GPIO42	GPIO46	94
95	GPIO43	GPIO47	96
97	DGND	5V	98
99	GPIO48	GPIO54	100
101	GPIO49	GPIO55	102
103	GPIO50	GPIO56	104
105	GPIO51	GPIO57	106
107	GPIO52	GPIO58	108
109	GPIO53	GPIO59	110
111	DGND	5V	112
113	RSVD	RSVD	114
115	RSVD	RSVD	116
117	RSVD	RSVD	118
119	RSVD	XRSn	120

PROGRAMMING

The TMDSCNCD28379D controller card can be programmed using a mini-USB cable connected between A:J1 and your computer. This programming port supports Code Composer Studio (CCS), which is an Integrated Development Environment (IDE) used to debug and develop software for the C2000 series of MCUs. Consult TI website for installation instructions.

Loading PFC .out File

1. In CCS, select **Target Configuration** under View (Figure 4).

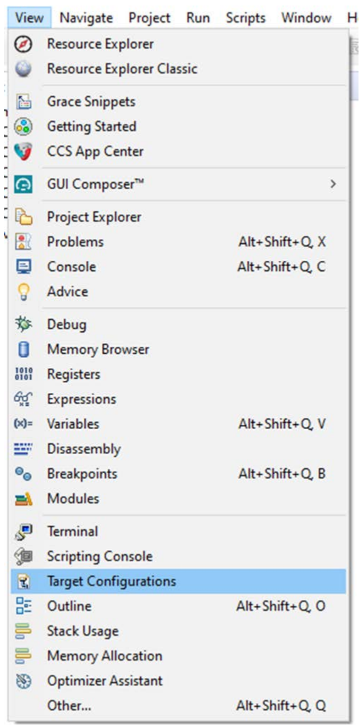


Figure 4: Target Configuration

2. Figure 5 shows the location of the **Target Configuration window**.

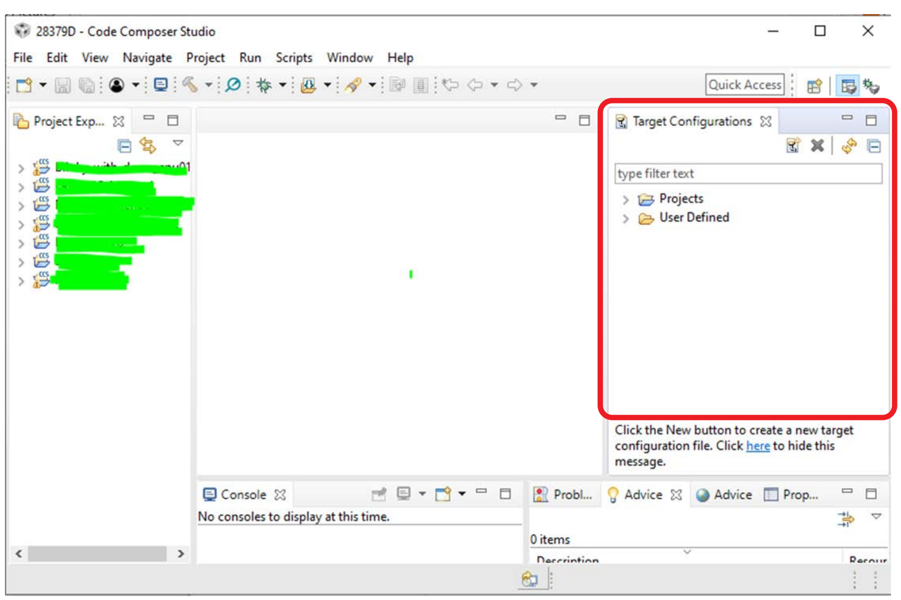


Figure 5: Target Configuration Window

3. Right click on **User Defined**. Choose **Import Target Configuration** (Figure 6).

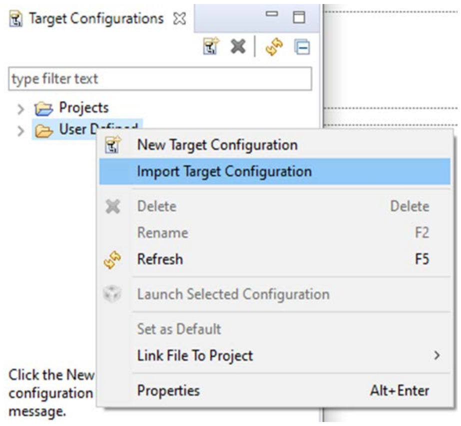


Figure 6: Import Target Configuration

4. Import the provided target configuration file by selecting it and clicking the **Open** button (Figure 7).

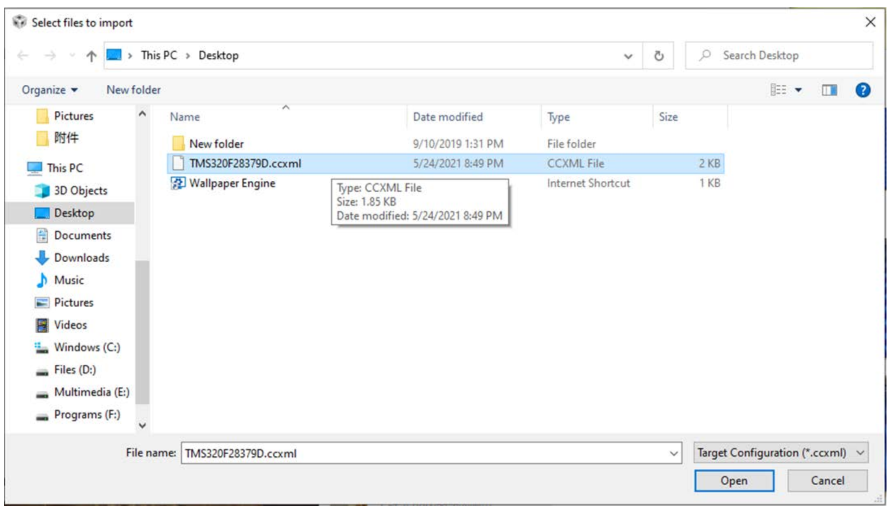


Figure 7: Import Target Configuration

5. Under the **User Defined folder**, right click the configuration file and choose **Launch Selected Configuration** (Figure 8).

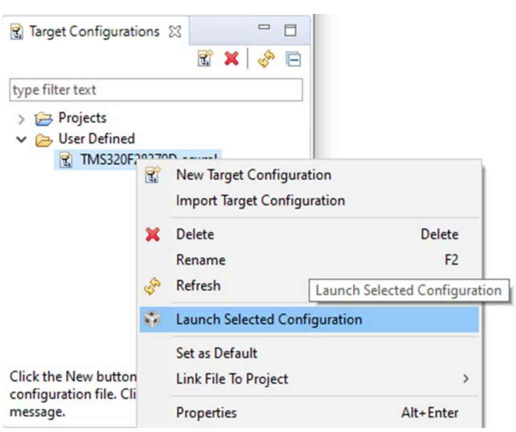


Figure 8: Launch Configuration

6. **Make sure the DSP is powered up**. Choose **Connect Target** (Figure 9).

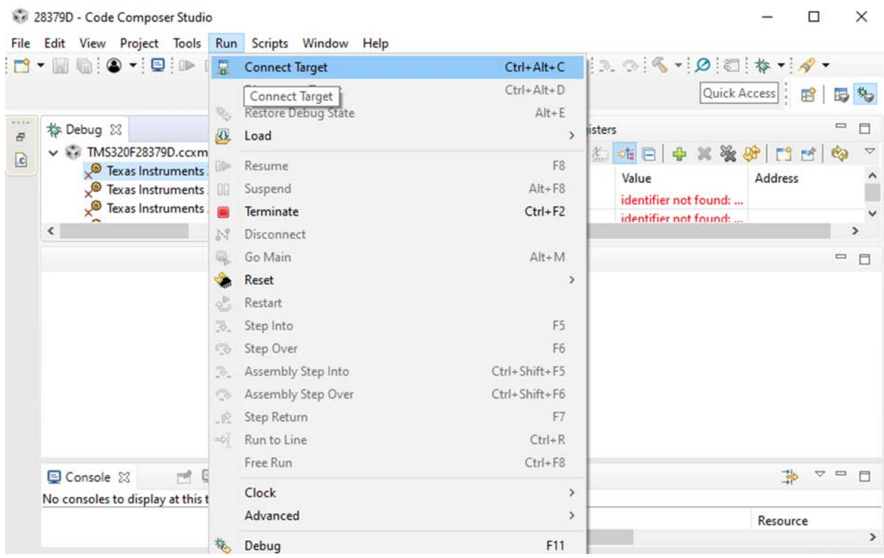


Figure 9: Connect Target

7. Choose **Load**, then **Load Program** to load the selected **.out file** (Figure 10).

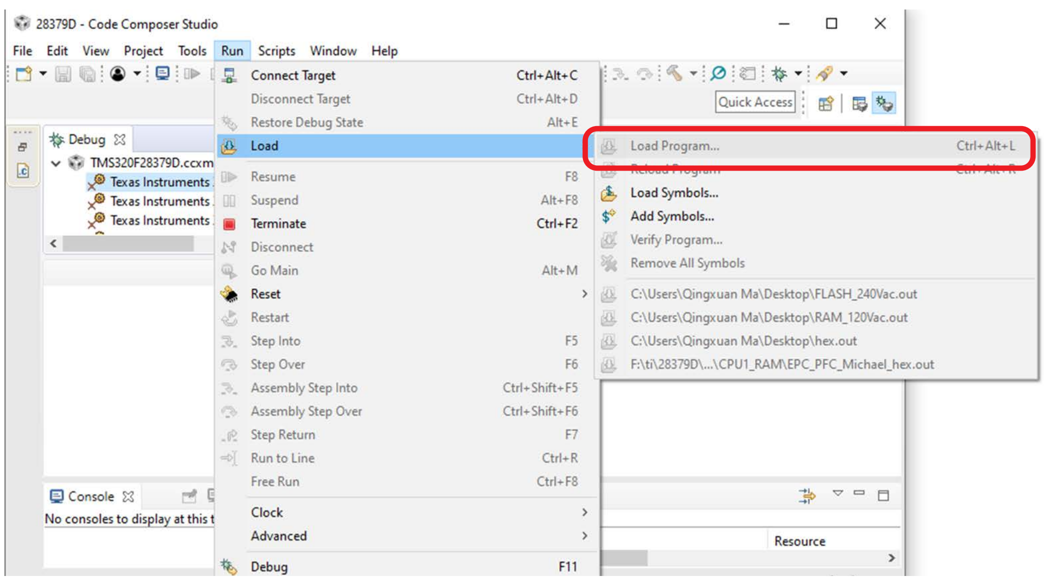


Figure 10: Load .out file

8. **After the .out file is loaded**, the circled button below will turn green. Once green, **click on it to run the code**. (Figure 11).

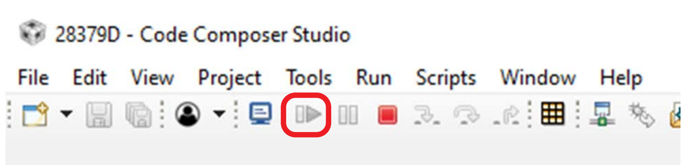


Figure 11: Run Code

One .out file provided:

FLASH_240Vac.out: Works with 60 Hz 240 V_{RMS} AC voltage and would generate 400 V DC output. The code is loaded to FLASH.

THERMAL CONSIDERATIONS

The FET Card on the PFC board is equipped with four mechanical spacers that can be used to easily attach a heat-spreader or heatsink as shown in figure 12, and only requires a thermal interface material (TIM), a custom shape heat-spreader/ heatsink, and screws.

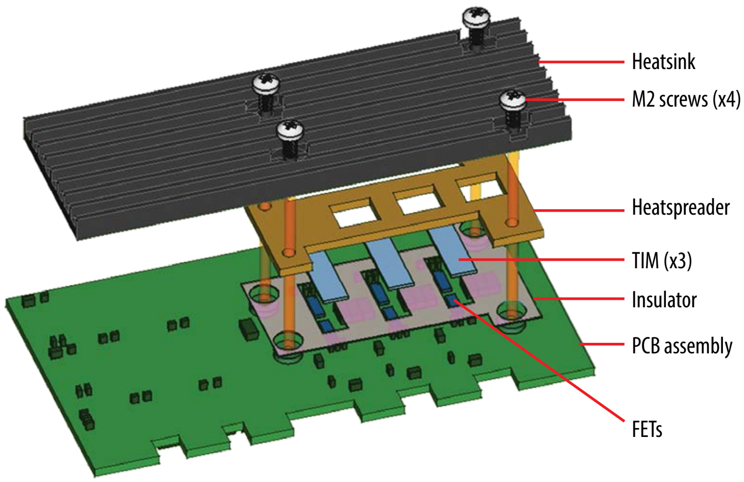


Figure 12: Heatspreader and Heatsink Assembly

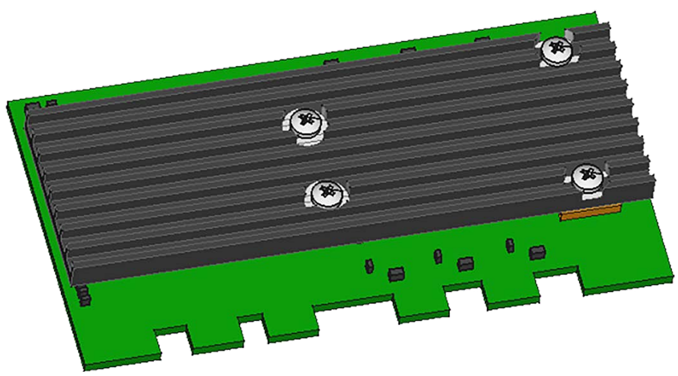


Figure 13: Heatspreader and Heatsink Assembled

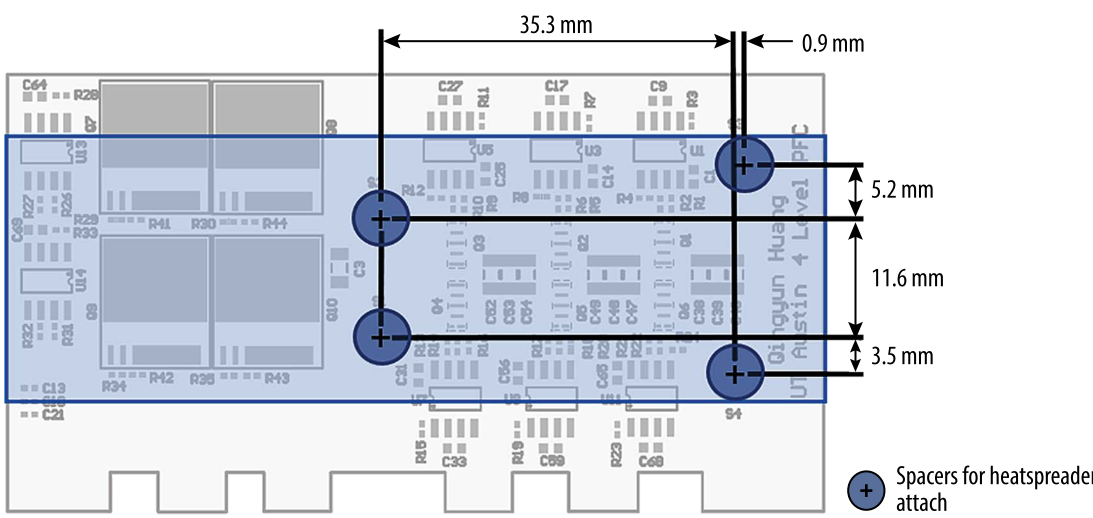


Figure 14: Heatsink Measurements

The design of the heat-spreader is shown in figure 15 and can be made using aluminum or tellurium copper for higher performance.

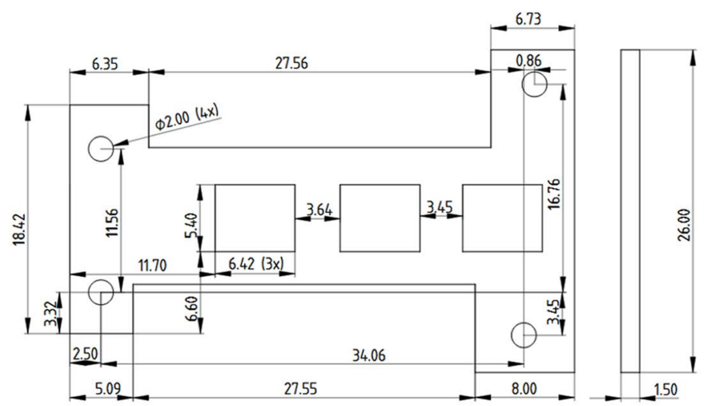
The heat-spreader is held in place using countersunk screws that fasten to the mechanical spacers which will accept M2 x 0.4 mm thread screws such as McMasterCarr 91294A002.

When assembling the heatsink, it may be necessary add a thin insulation layer to prevent the heat-spreader from short circuiting with components that have exposed conductors such as capacitors and resistors, as shown in figure 6. Note that the heat-spreader is ground connected by the lower most mounting post. A rectangular opening in the insulator must be provided to allow the TIM to be placed over the FETs to be cooled with sufficient clearance of 3 mm on each side of the rectangle encompassing the FETs. The TIM will then be similar in size or slightly smaller than the opening in the insulator shown in figure 16.

EPC recommends Laird P/N: A14692-30, Tgard™ K52 with thickness of 0.051 mm the for the insulating material.

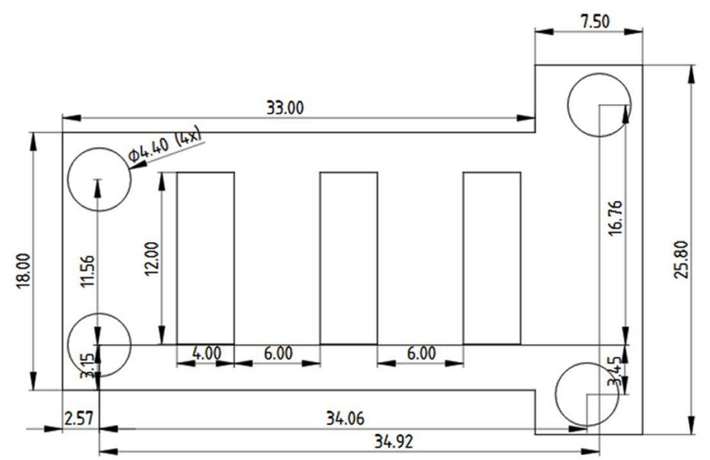
A TIM is added to improve the interface thermal conductance between the FETs and the attached heat exchanger. The choice of TIM needs to consider the following characteristics:

- **Mechanical compliance** – During the attachment of the heat spreader, the TIM underneath is compressed from its original thickness to the vertical gap distance between the spacers and the FETs. This volume compression exerts a force on the FETs. A maximum compression of 2:1 is recommended for maximum thermal performance and to constrain the mechanical force which maximizes thermal mechanical reliability.
- **Electrical insulation** – To prevent short-circuits, the TIM must be of high dielectric strength to provide adequate electrical insulation in addition to its thermal properties.
- **Thermal performance** – The choice of thermal interface material will affect the thermal performance of the thermal solution. Higher thermal conductivity materials is preferred to provide higher thermal conductance at the interface.



All units in mm

Figure 15: Heatspreader Measurements



All units in mm

Figure 16: Insulator Cutout

EPC recommends the following thermal interface materials:

- **t-Global** P/N: TG-A1780 x 0.5 mm (highest conductivity of 17.8 W/m·K)
- **t-Global** P/N: TG-A6200 x 0.5 mm (moderate conductivity of 6.2 W/m·K)
- **Bergquist** P/N: GP5000-0.02 (~0.5 mm with conductivity of 5 W/m·K)
- **Bergquist** P/N: GPTGP7000ULM-0.020 (conductivity of 7 W/m·K)

NOTE. The PFC board does not have any thermal protection on board. For more information regarding the thermal performance of EPC eGaN FETs, please consult: D. Reusch and J. Glaser, DC-DC Converter Handbook, a supplement to GaN Transistors for Efficient Power Conversion, First Edition, Power Conversion Publications, 2015.

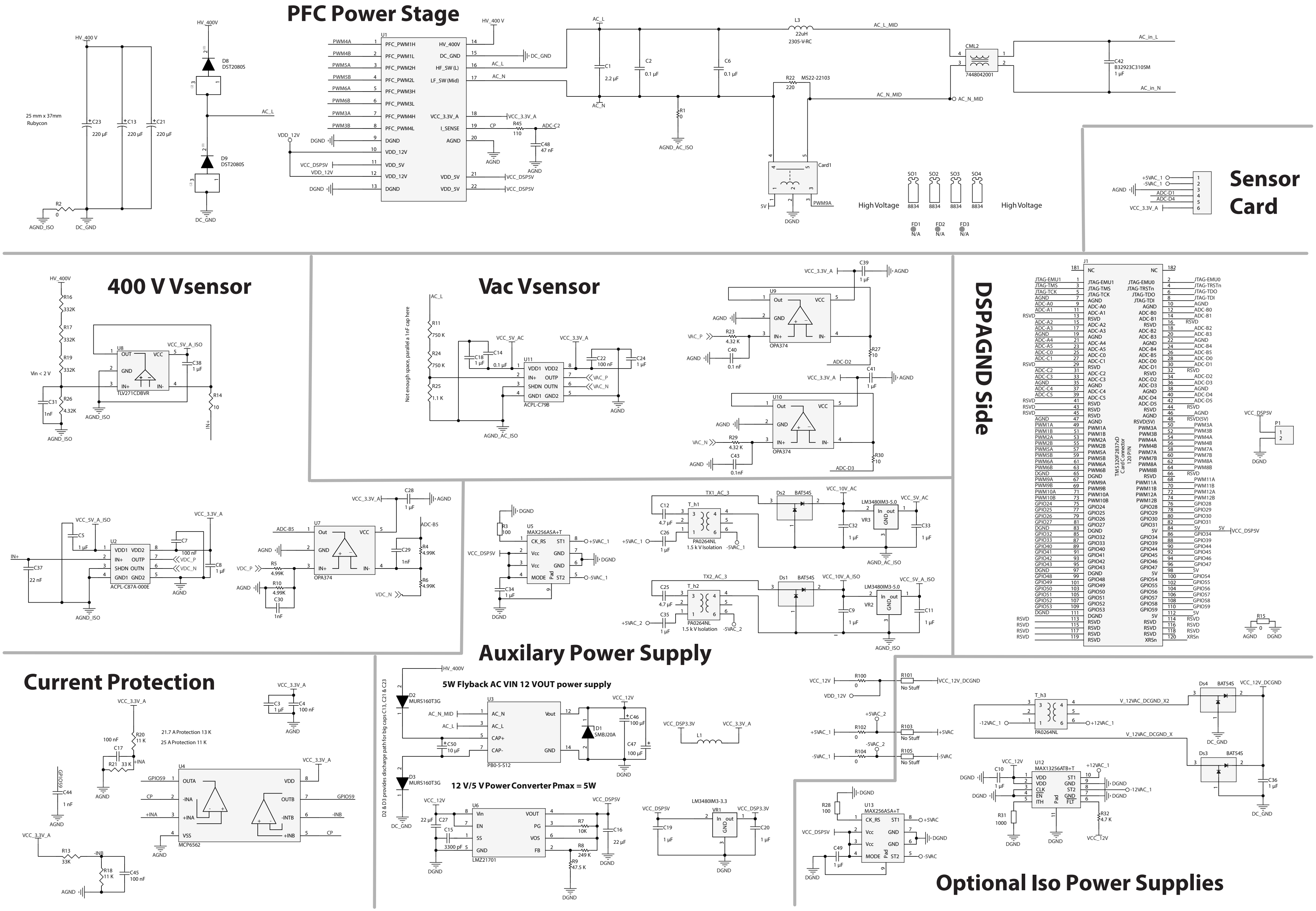


Figure 17: EPC9164 main board schematic

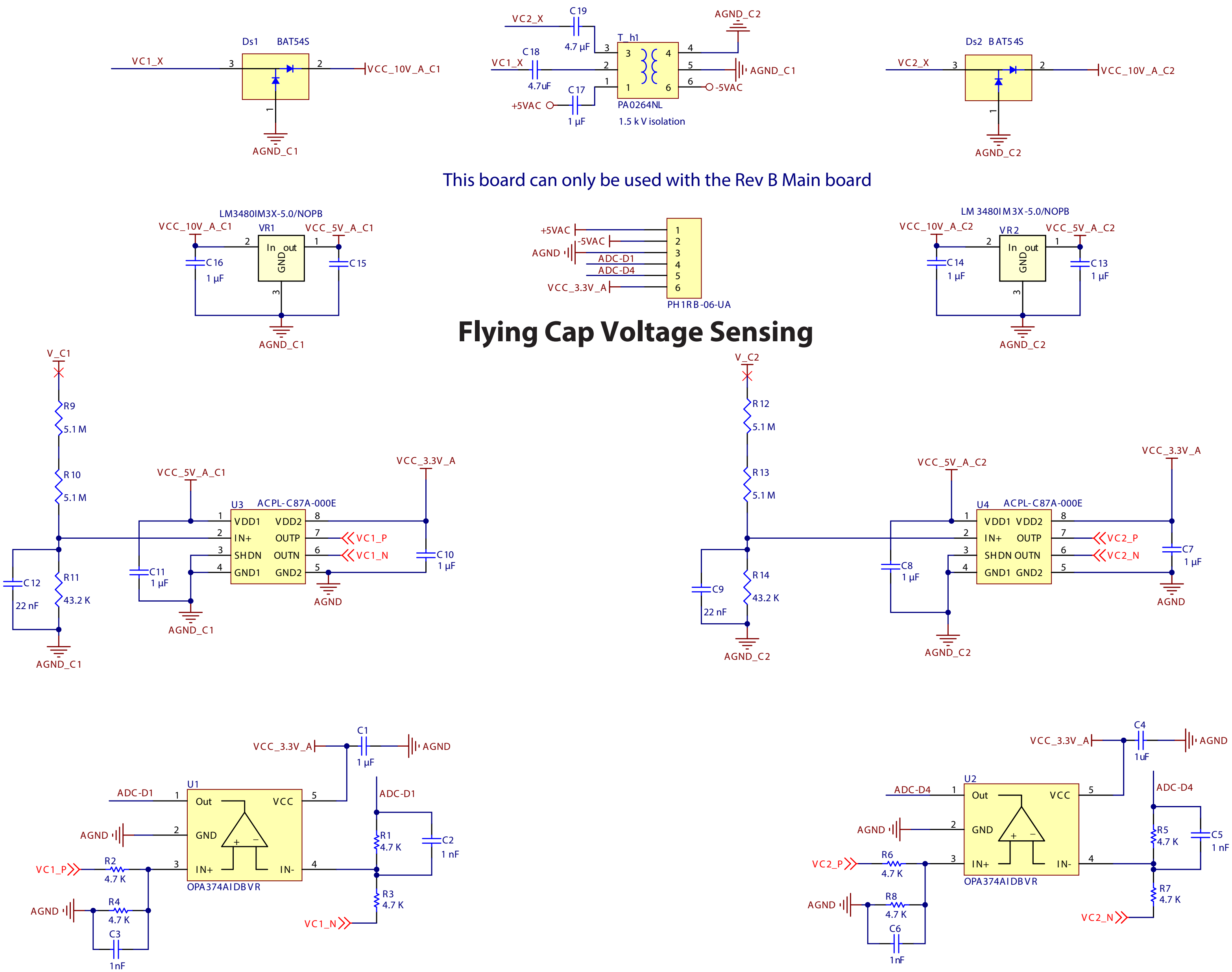


Figure 18: Schematic of the sensor card for the flying capacitor voltage measurement

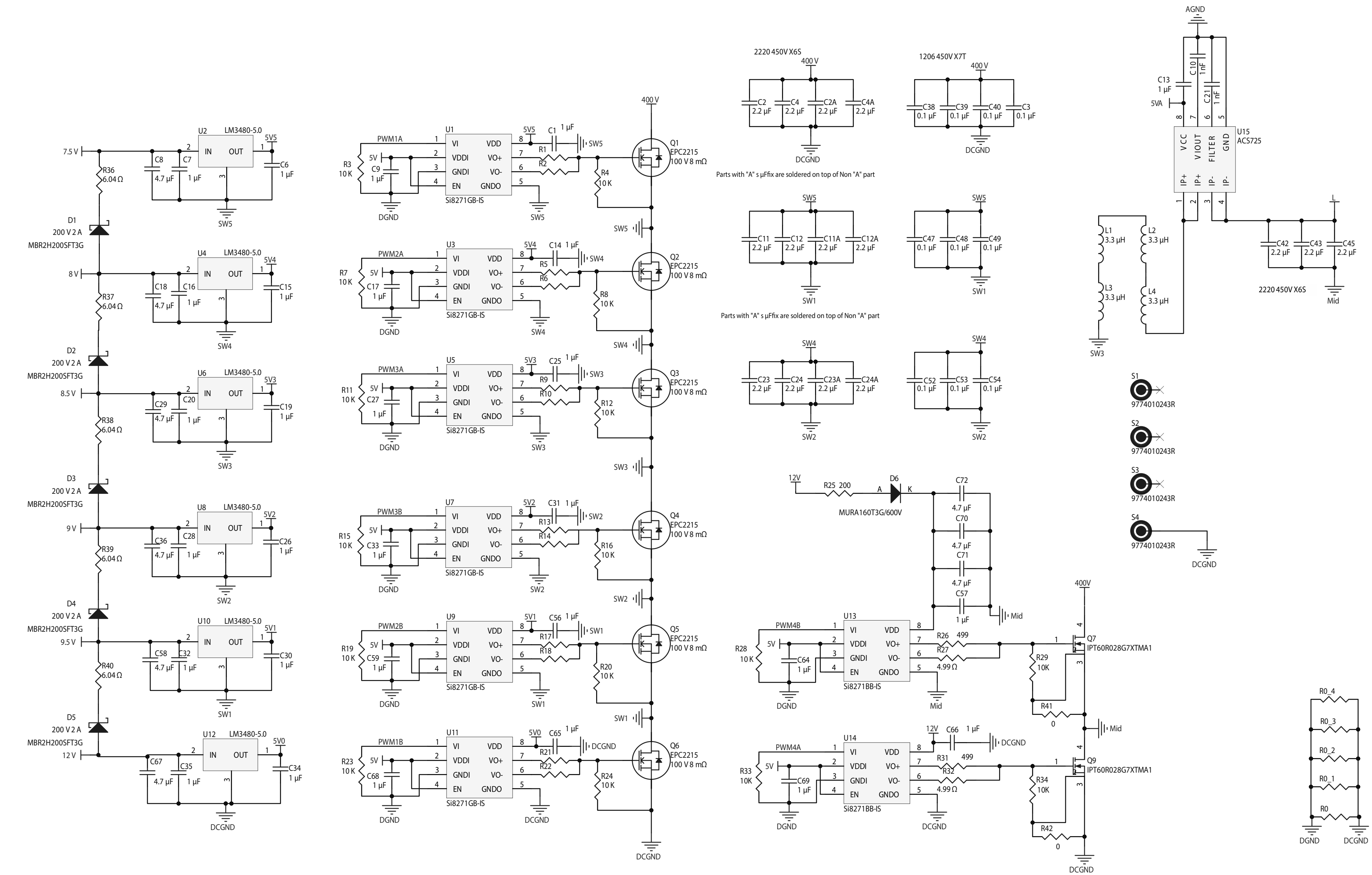


Figure 19: Schematic of the GaN Card featuring the EPC2215 eGaN FETs and includes the main inductor and gate drivers

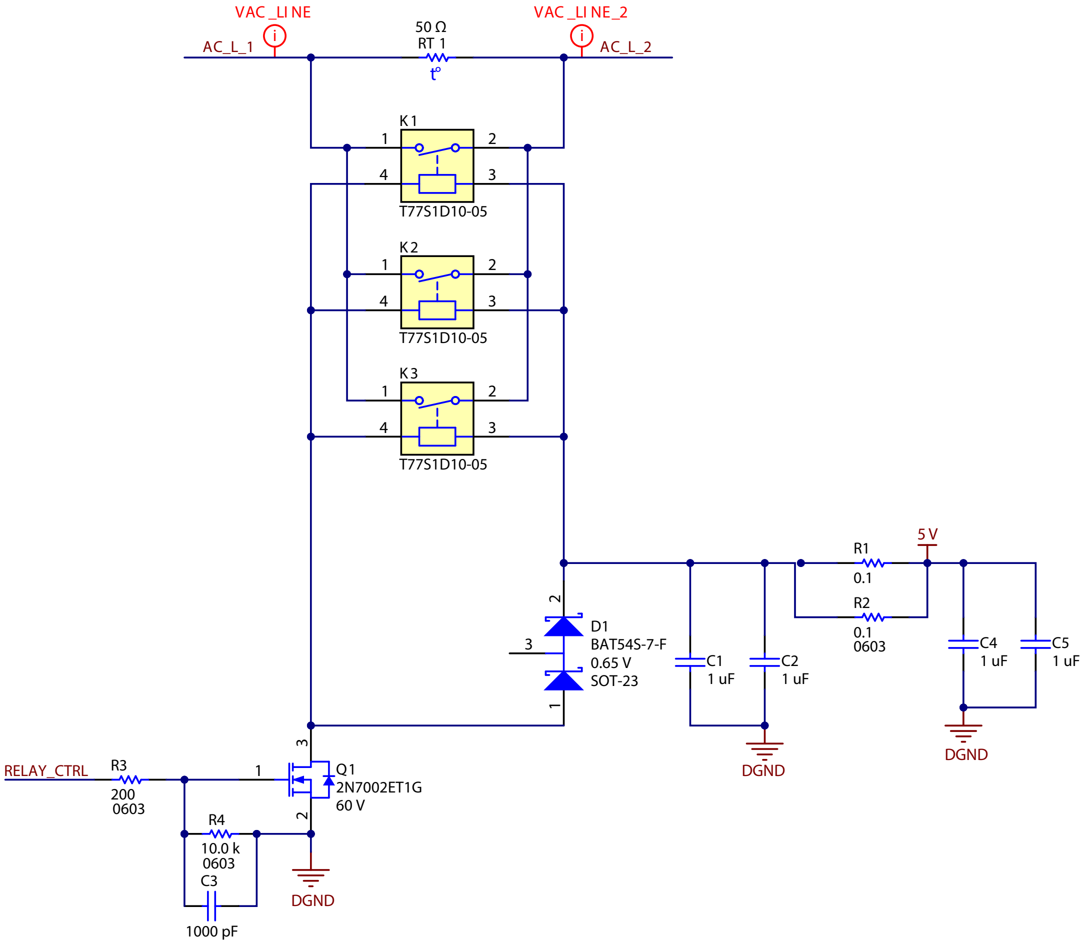


Figure 20: Schematic of the In-rush current limiting relay card.

For More Information:

Please contact **info@epc-co.com**
or your local sales representative

Visit our website:
www.epc-co.com

Sign-up to receive
EPC updates at
bit.ly/EPCupdates
or text "EPC" to 22828

EFFICIENT POWER CONVERSION

Demonstration Board Notification

The EPC9164 board is intended for product evaluation purposes only. They are not intended for commercial use nor are they FCC approved for resale. Replace components on the Evaluation Board only with those parts shown on the parts list (or Bill of Materials) in the Quick Start Guide. Contact an authorized EPC representative with any questions. This board is intended to be used by certified professionals, in a lab environment, following proper safety procedures. Use at your own risk.

As an evaluation tool, this board is not designed for compliance with the European Union directive on electromagnetic compatibility or any other such directives or regulations. As board builds are at times subject to product availability, it is possible that boards may contain components or assembly materials that are not RoHS compliant. Efficient Power Conversion Corporation (EPC) makes no guarantee that the purchased board is 100% RoHS compliant.

The Evaluation board (or kit) is for demonstration purposes only and neither the Board nor this Quick Start Guide constitute a sales contract or create any kind of warranty, whether express or implied, as to the applications or products involved.

Disclaimer: EPC reserves the right at any time, without notice, to make changes to any products described herein to improve reliability, function, or design. EPC does not assume any liability arising out of the application or use of any product or circuit described herein; neither does it convey any license under its patent rights, or other intellectual property whatsoever, nor the rights of others.