

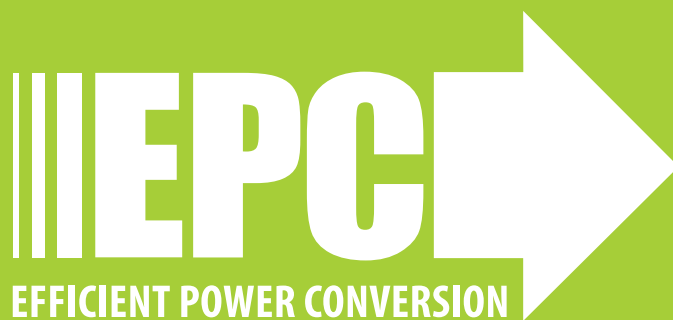
EPC9137

1.5 kW 48 V/12 V Bi-Directional Power Module Evaluation Board Quick Start Guide

20–60 V Input, 12 V 125 A Output (Buck)

12–16 V Input, 48 V 29 A Output (Boost)

Revision 4.0



DESCRIPTION

The EPC9137 evaluation power module is designed for 48 V to/from 12 V DC-to-DC applications. It features the EPC2206 – enhancement mode eGaN® field effect transistors (FETs) with AEC-Q101 qualification. The EPC9137 is controlled using the EPC9528 controller module that includes the Microchip dsPIC33CK256MP503 16-bit digital controller. Other features include:

- High efficiency: >95.7% @ 12 V/125 A output (buck)
>95.2% @ 48 V/29 A output (boost)
- Preset switching frequency: 250 kHz
- Re-programmable – Average current mode control (default)
- Fault protection:
 - o Input undervoltage
 - o Input overvoltage
 - o Regulation error
 - o Input undervoltage
 - o Inductor overcurrent
 - o Overtemperature

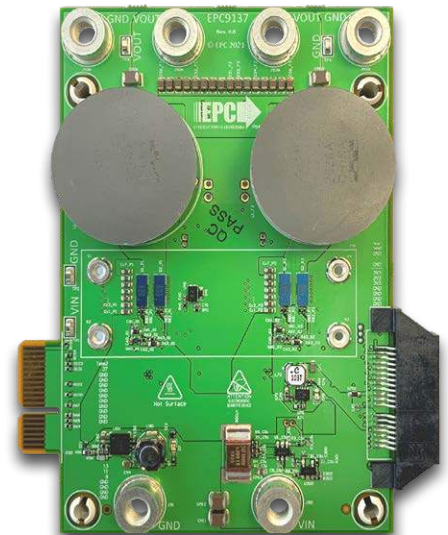
REGULATORY INFORMATION

This power module is for evaluation purposes only. It is not a full-featured power module and cannot be used in final products. No EMI test was conducted. It is not FCC approved.

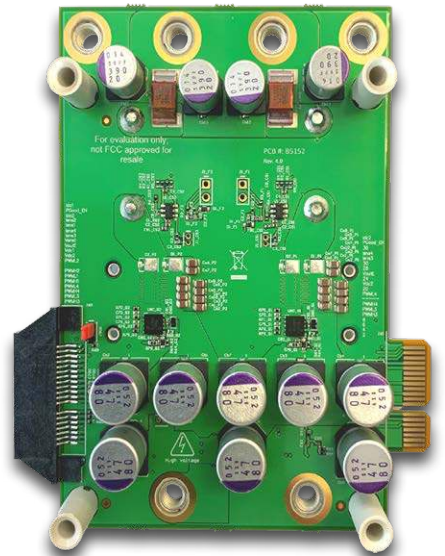
FIRMWARE UPDATES

The EPC9528 module is programmed as a Buck converter by default. To change to Boost converter, please re-program the module with the boost firmware available at the [EPC website](#). Using the incorrect firmware could result in damage.

Every effort has been made to ensure all control features function as specified. It may be necessary to provide updates to the firmware. Please check the EPC and Microchip websites for the latest firmware updates.



EPC9137 top view



EPC9137 bottom view

Table 1: Absolute Maximum Ratings

Symbol	Parameter	Conditions	Min	Max	Units
V_{IN}	Input voltage	Buck		64	V
		Boost		17	
I_{OUT}	Output current	Buck ⁽¹⁾		125	A
		Boost ⁽¹⁾		29	
$T_{C,MAX}$		Measured at heatsink base		95	°C

⁽¹⁾ with 1700 LFM airflow

Table 2: Electrical Characteristics

Symbol	Parameter	Conditions	Min	Typ	Max	Units
V_{IN}	Input voltage	Buck	20	48	60	V
		Boost, during operation	11.3	12	16	
		Boost, start up	12.3			
$V_{IN,on}$	Input UVLO turn on voltage	Buck		20		V
		Boost		12.3		
$V_{IN,off}$	Input UVLO turn off voltage	Buck		17.5		V
		Boost		11.3		
V_{OUT}	Output Voltage	Buck	5	12	16	V
		Boost	20	48	50	
$t_{OUT,rise}$	Output voltage rise time			100		ms
ΔV_{OUT}	Output voltage ripple	Buck, $I_{OUT} = 30$ A		80		mV
		Boost		-		
I_{OUT}	Output Current	Buck	0		125	A
		Boost	0		29	
I_{MAX}	Maximum current limit threshold	Buck, output current	130		145	A
		Boost, input current	130		145	
T_{MAX}	Maximum temperature limit threshold	During operation	93		98	°C
$T_{start,MAX}$	Maximum temperature to start converter	Before startup, after over-temperature fault event			80	°C
f_{sw}	Switching frequency			250		kHz

ELECTRICAL PERFORMANCE

Typical efficiency and power loss

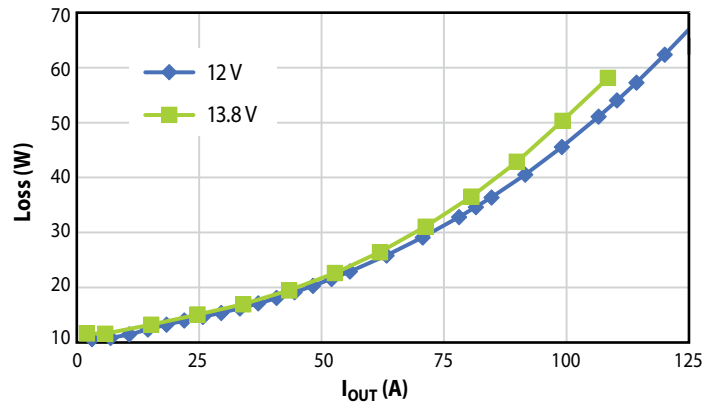
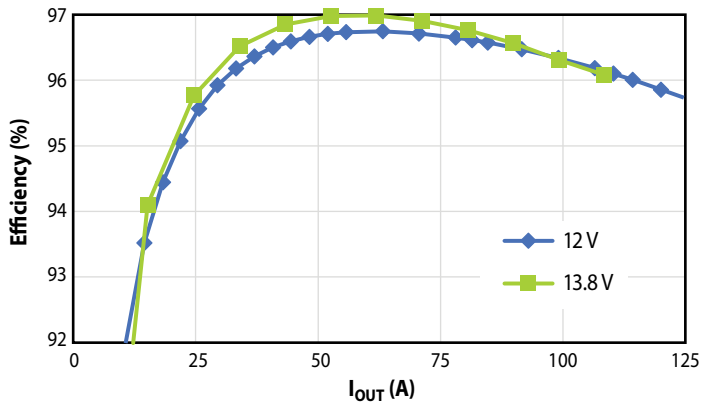


Figure 1. Measured buck converter efficiency and power loss at 12 V and 13.8 V load voltage up to 1.5 kW load power

Typical output voltage ripple

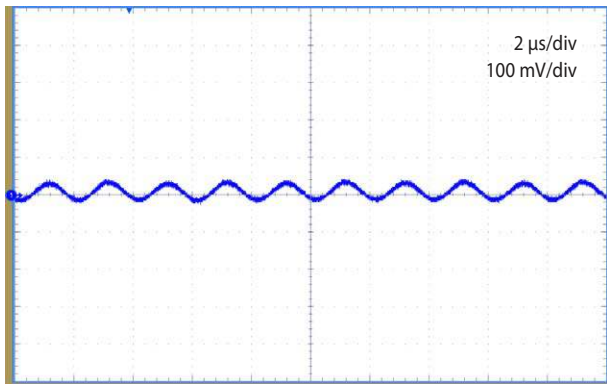


Figure 2: Measured buck converter output voltage ripple with $V_{IN} = 48$ V, $V_{OUT} = 12$ V, $I_{OUT} = 30$ A

Typical transient response

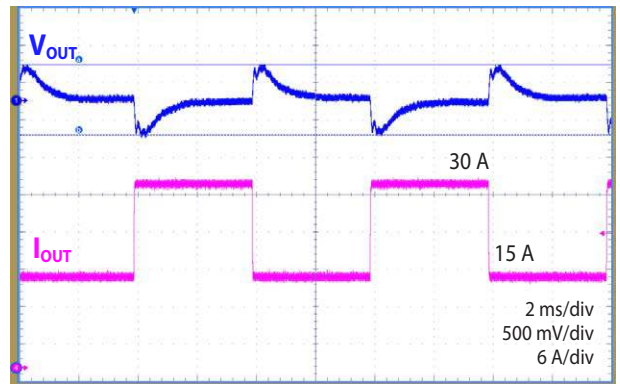
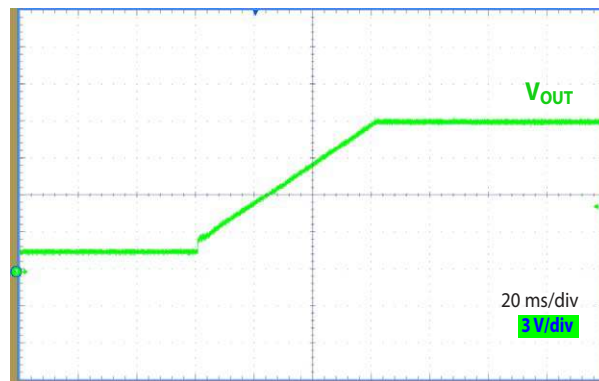


Figure 3: Measured transient response with $V_{IN} = 48$ V, $V_{OUT} = 12$ V, output 15 A to 30 A 125 Hz transitions (Buck)

Startup waveform



48 V input, 12 V output (buck)

Figure 4. Buck converter output voltage start up response

OPERATING CONSIDERATIONS

Buck/Boost Modes

The module is programmed with Buck mode by default. To operate as a Boost converter, please download the firmware available at the [EPC website](#) for Boost mode and re-program the control module.

Over-current protection

This module supports conventional average current mode control (ACMC).

Over-temperature protection

During operation, if the heatsink base temperature (sensed by AD590) exceeds 95°C, the over-temperature fault condition will be set, and the converter will shut down. After the temperature drops to below 80°C, the converter will be able to restart.

CONTROLLER

Please refer to [EPC9528 Quick Start Guide](#) for more information about the control module with Microchip dsPIC33CK256MP503.

The average current mode control (ACMC) is used for EPC9137.

Conventional, Robust Average Current Mode Control (ACMC) (figure 5): With this firmware the power converter is controlled by one outer voltage loop providing a shared reference to two independent inner average current loops controlling the phase current of each converter phase. This conventional approach ensures proper current balancing between both phases of this interleaved converter, operating 180° out of phase to minimize the input current ripple and filtering. The inner current loops are adjusted to average cross-over frequencies of 10 kHz. To balance the current reference perturbation of the inner current loops, the outer voltage loop has been adjusted to an average cross-over frequency of 2 kHz, which determines the overall response time of the converter.

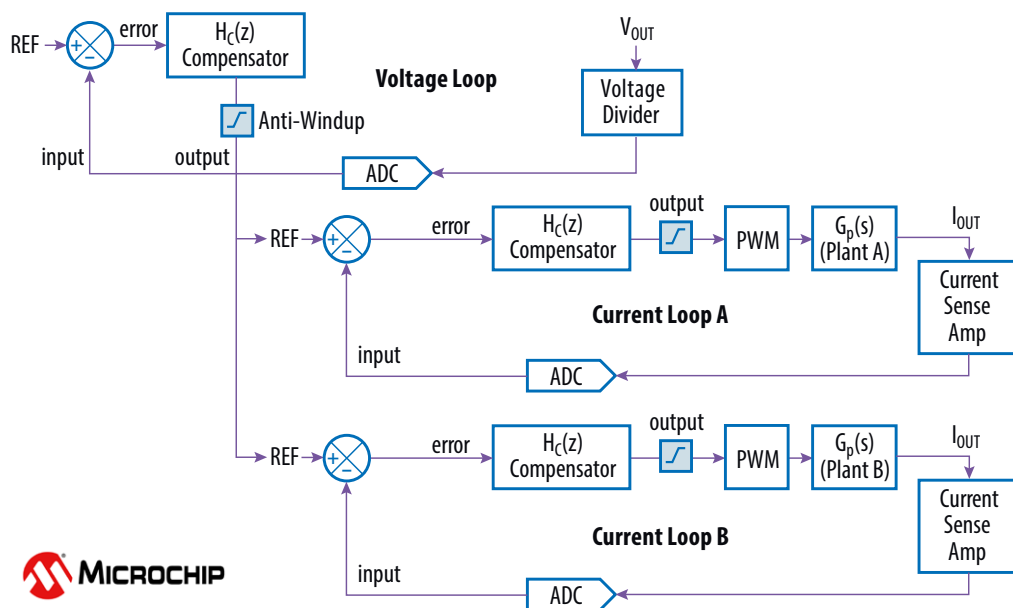


Figure 5. Interleaved buck converter average current mode control

TWO-BOARD (FOUR-PHASE) PARALLEL OPERATION

Two of the EPC9137s can be connected in parallel and controlled by one single EPC9528 controller for four-phase operation, as shown in Figure 6. The correct firmware (see next section: **Programming with Hex file**) needs to be programmed to the EPC9528 controller. The measured efficiency and loss at 48 V input, 12 V output is shown in Figure 7.

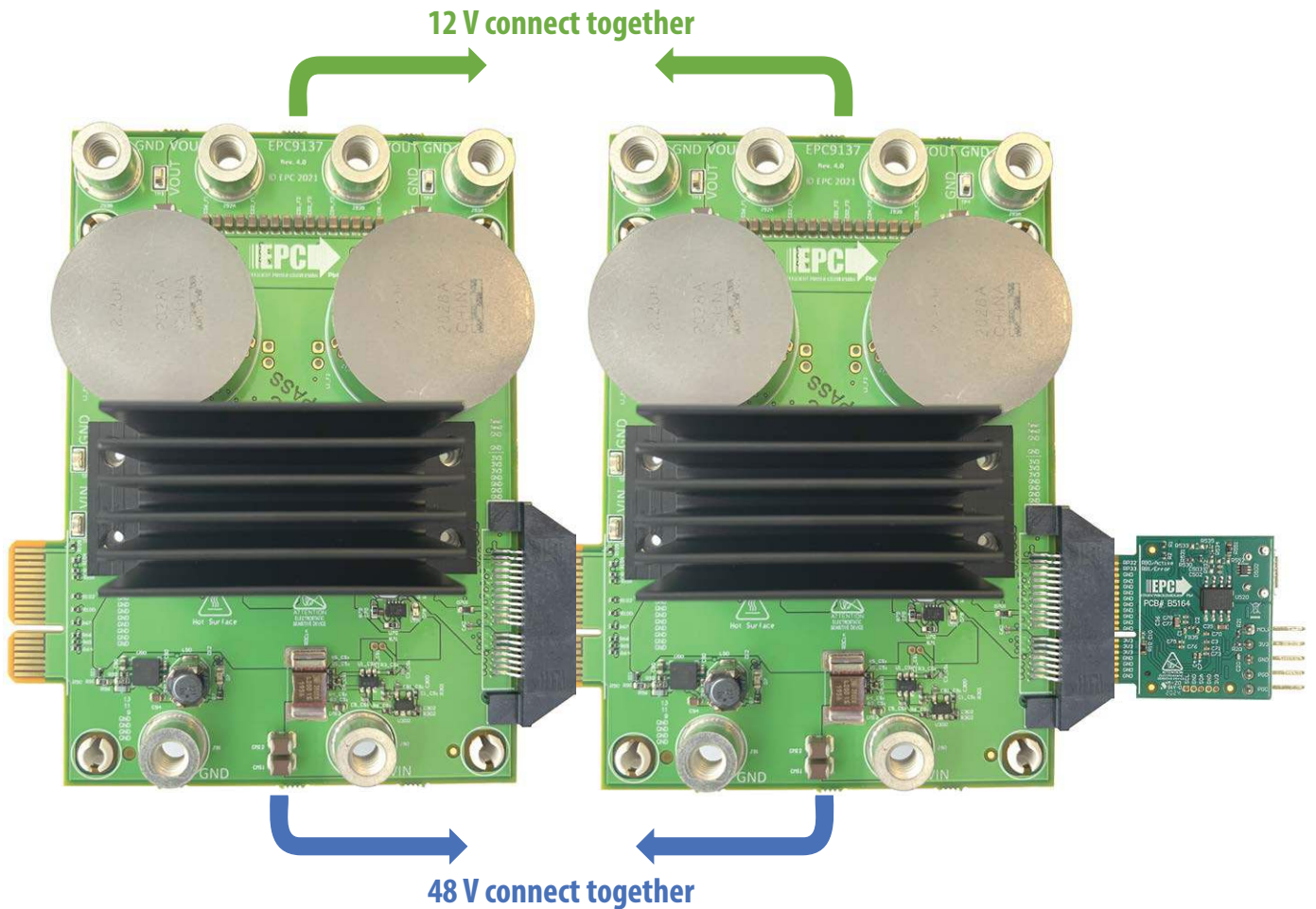


Figure 6. Two EPC9137s connected in parallel to achieve 3 kW (four-phase) using one EPC9528 controller

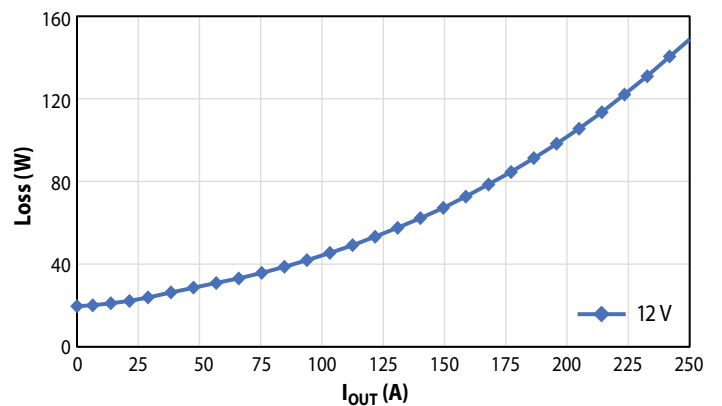
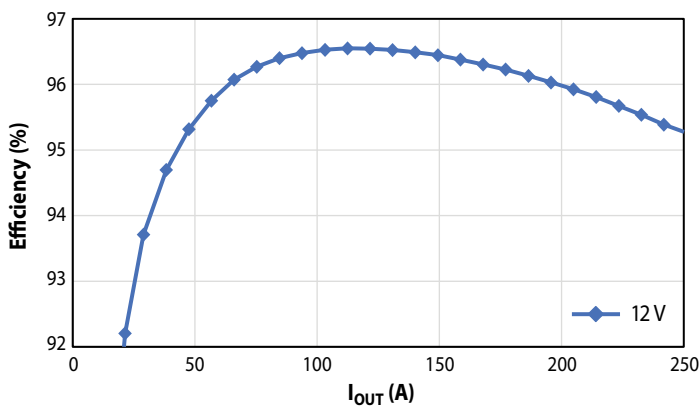


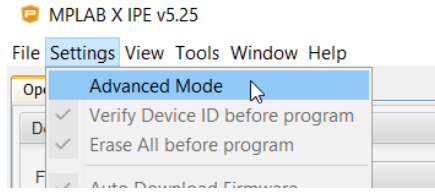
Figure 7. Measured four-phase (2xEPC9137) buck converter efficiency and power loss at 12 V load voltage up to 3 kW load power

Programming with HEX file

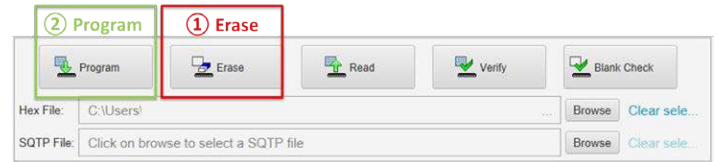
Download the latest MPLAB® X IPE from Microchip website and follow the five steps below:

<https://www.microchip.com/mplab/mplab-integrated-programming-environment>

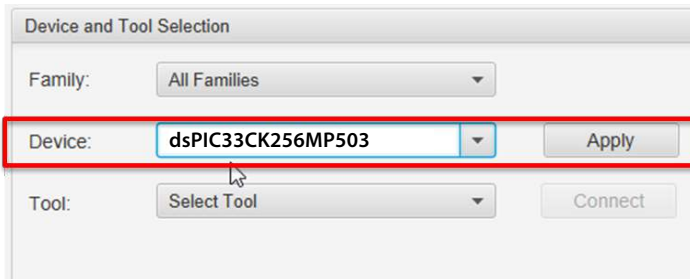
1. Enable Advanced Mode:



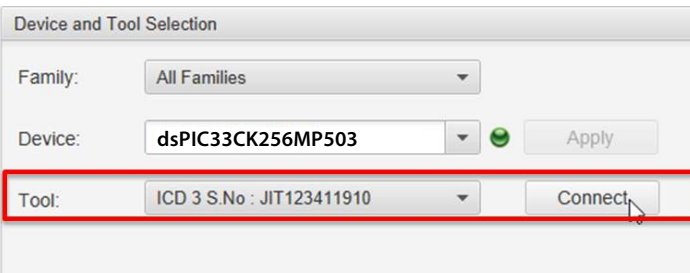
5. Erase device, and then program device:



2. Select Device: dsPIC33CK256MP503 and then apply:



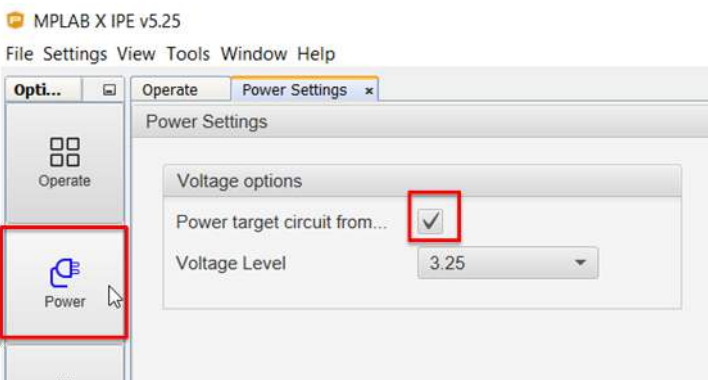
3. Select programming tool and then connect:



4. Click 'Browse' to select the provided .hex file:



Optional:



MECHANICAL SPECIFICATIONS

Unit: mm [in]

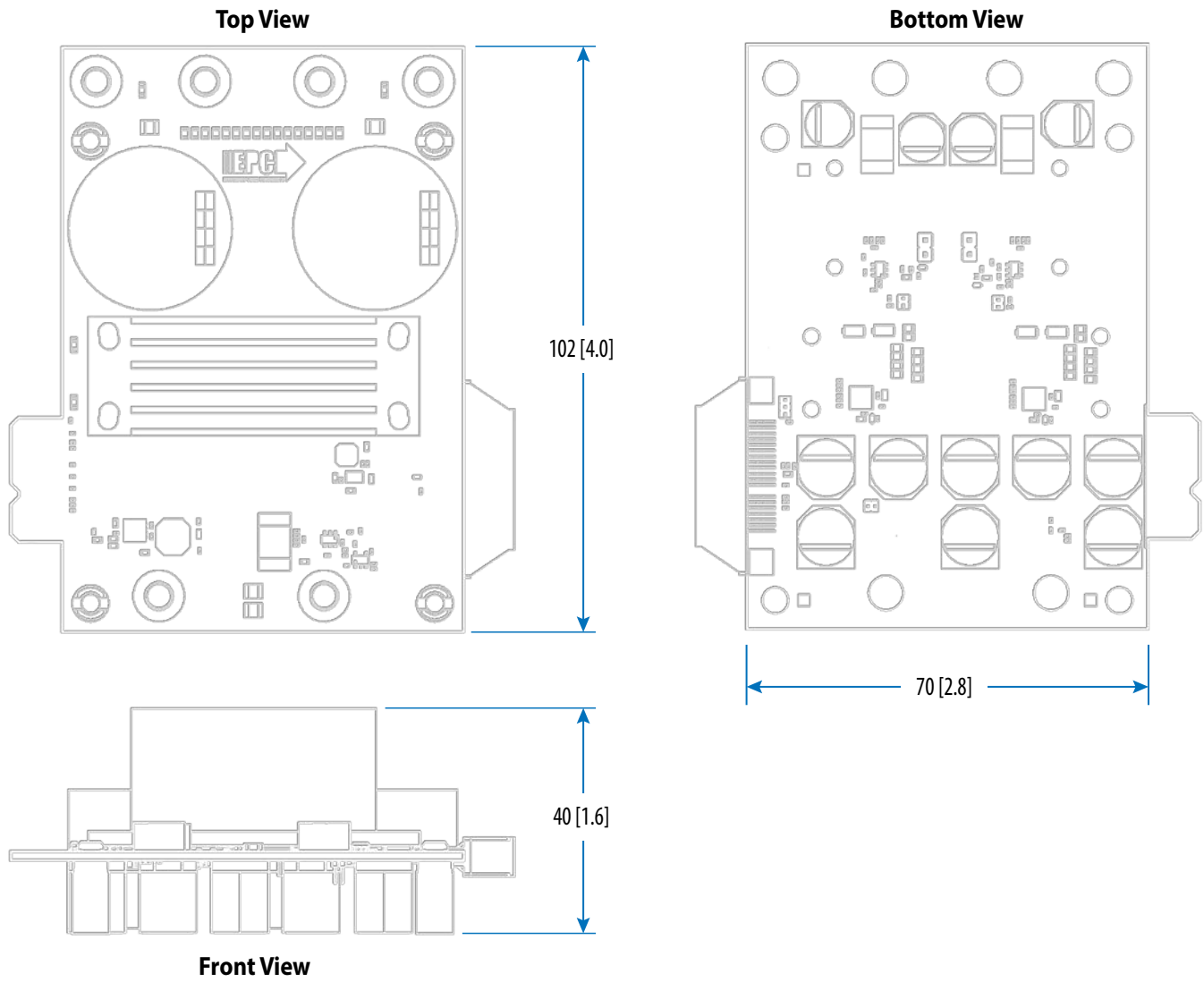


Figure 8: Mechanical dimensions of the EPC9137 board

THERMAL MANAGEMENT

The EPC9137 is intended for bench evaluation at room ambient temperatures and under forced air cooling. The addition of a heatsink can significantly improve the heat dissipation from the eGaN IC's and increase the current capacity of these devices, while ensuring to not exceed the absolute maximum die temperature of 150°C.

The EPC9137 board is equipped with four mechanical spacers (S1, S2, S3, S4) that can be used to easily attach a standard eighth-brick converter heatsink as shown in figure 9, and only requires a thermal interface material (TIM), a heatsink, and screws.

The pre-installed heatsink is held in place using screws that fasten to the mechanical spacers which will accept 6 mm long M2 x 0.4 mm thread screws such as McMasterCarr 95836A109.

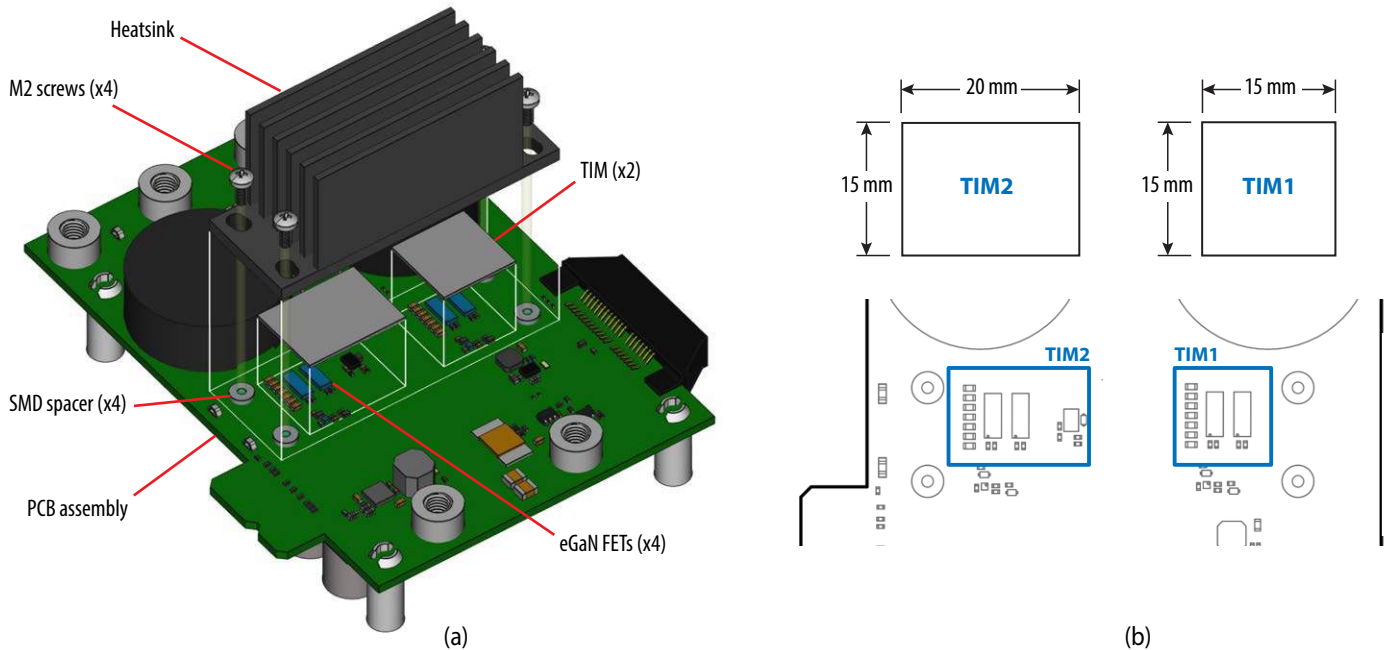


Figure 9: Details for attaching a heatsink to the board. (a) exploded 3D perspective, (b) top view showing the TIM location with respect to the eGaN FETs

A TIM is required between the FETs and the heatsink. 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** – The backside of the eGaN FET is a silicon substrate that is connected to source and thus the upper FET in a half-bridge configuration is connected to the switch-node. To prevent short-circuiting the switch-node to the grounded thermal solution, 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.

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-A620 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)

The default TIM used for the EPC9137 is made by t-Global Technology, with P/N TG-A1780 and it 0.5 mm thick.

Thermal derating

Without sufficient cooling, the output current capability is reduced. The module temperature should be monitored to ensure the maximum temperature does not exceed the rating. Especially when the input voltage is higher than 48 V, the maximum output current is reduced.

Table 3: Bill of Materials

Item	Qty	Reference	Part Description	Manufacturer	Part #
1	11	C1_CS1, C1_CS2, C1_CSi, C40, C41, C60_G1, C60_G2, C61_G1, C61_G2, C81_G1, C81_G2	0.1 µF, 25 V	Yageo	CC0402KRX7R8BB104
2	5	C2_CS1, C2_CS2, C2_CSi, C300, C302	2.2 µF	Murata	GRM155R61E225ME15D
3	3	C2_F1, C2_F2, C700	1 nF, 50 V	Kemet	C0402C102J5GACAUTO
4	6	C3_CS1, C3_CS2, C3_CSi, C5_CS1, C5_CS2, C5_CSi	330 pF	TDK	C1005C0G1H331J050BA
5	3	C4_CS1, C4_CS2, C4_CSi	820 nF	Yageo	CC0402KRX5R6BB824
6	1	C60	1 µF, 25 V	Murata	GRM155R61E105MA12D
7	2	C62_G1, C62_G2	22 nF, 25 V	TDK	C1005X7R1E223K050BB
8	1	C70	2.2 µF, 25 V	Murata	GRM155R61E225KE11D
9	1	C71	22 µF, 16 V	Samsung	CL10A226M07JZNC
10	2	C80_G1, C80_G2	4.7 µF, 10 V	TDK	C1005X5R1A475K050BC
11	1	C90	0.22 µF, 100 V	Taiyo Yuden	HMK107C7224KAHTE
12	1	C91	1 µF, 16 V	TDK	C1005X6S1C105K050BC
13	1	C92	10 nF, 100 V	TDK	C1005X7S2A103K050BB
14	1	C93	3300 pF, 100 V	Murata	GRM155R72A332KA01D
15	1	C94	10 µF, 25 V	Murata	GRM188R61E106MA73D
16	1	C95	10 nF, 50 V	Murata	GRM155R71H103KA88D
17	8	Cb1, Cb2, Cb3, Cb4, Cb5, Cb6, Cb7, Cb8	47 µF 80 V	Panasonic	80SXV47M
18	4	Cb10, Cb11, Cb12, Cb13	390 µF 20 V	Panasonic	20SVPF390M
19	15	Ci1_P1, Ci1_P2, Ci2_P1, Ci2_P2, Ci3_P1, Ci3_P2, Ci4_P1, Ci4_P2, Ci5_P1, Ci5_P2, Ci6_P1, Ci6_P2, Ci7_P1, Ci7_P2, CMI3	220 nF, 100 V	Taiyo Yuden	HMK107C7224
20	20	Cm1_P1, Cm1_P2, Cm2_P1, Cm2_P2, Cm3_P1, Cm3_P2, Cm4_P1, Cm4_P2, Cm5_P1, Cm5_P2, Cm6_P1, Cm6_P2, Cm7_P1, Cm7_P2, Cm8_P1, Cm8_P2, Cm9_P1, Cm9_P2, Cm10_P1, Cm10_P2	1 µF, 100 V	TDK	C2012X7S2A105M125AB
21	4	CMI1, CMI2, CMO1, CMO2	10 µF, 75V	TDK	CGA6P1X7R1N106M250AC
22	16	CO1_F1, CO1_F2, CO2_F1, CO2_F2, CO3_F1, CO3_F2, CO4_F1, CO4_F2, CO5_F1, CO5_F2, CO6_F1, CO6_F2, CO7_F1, CO7_F2, CO8_F1, CO8_F2	22 µF, 25 V	TDK	C2012X5R1E226M125AC
23	3	D1_F1, D1_F2, D701	40 V 30 mA	Diodes Inc.	SDM03U40
24	1	D7	LED 0603 Orange	Lite-On	LTST-C193KFKT-5A
25	1	D41	3V3 300 mW	Diodes Inc.	BZT52C3V3T-7
26	2	D60_G1, D60_G2	5V1, 150 mW	Bournes	CD0603-Z5V1
27	4	D61_G1, D61_G2, D63_G1, D63_G2	40 V 30 mA	Diodes Inc.	SDM03U40
28	2	D64_G1, D64_G2	100 V 200 mA	ST	BAT41KFILM
29	1	D78	LED 0603 Yellow	Lite-On	LTST-C193KSKT-5A
30	2	DI1, DI2	100 V 215 mA	Nexperia	BAS16LD,315
31	3	FB1_CS1, FB1_CS2, FB1_CSi	1.8 kΩ @ 100MHz	TDK	MMZ1005Y182CTD25
32	1	J60	1.0 mm micro edge card connector	Samtec	MEC1-120-02-F-D-EM2
33	6	J90, J91, J92A, J92B, J93A, J93B	M5 high current SMD terminal	Würth	7466005R
34	2	L1_F1, L1_F2	2.2 µH, 0.74 mΩ	Vishay	IHTH1125KZEB2R2M5A
35	1	L70	10 µH	Coilcraft	LPS4012
36	1	L90	220 µH 400 mA	Murata	MDH6045C-221MB=P3
37	4	Q1_P1, Q1_P2, Q2_P1, Q2_P2	80 V 90 A 2.2 mΩ	EPC	EPC2206
38	2	Q60_G1, Q60_G2	100 V 2800 mΩ	EPC	EPC2038
39	6	R1_CS1, R1_CS2, R1_CSi, R2_CS1, R2_CS2, R2_CSi	10 Ω	Panasonic	ERJ-2RKF10R0X
40	3	R1_F1, R1_F2, R701	100 k	Panasonic	ERA-3AEB104V

Table 3: Bill of Materials (continued)

Item	Qty	Reference	Part Description	Manufacturer	Part #
41	3	R2_F1, R2_F2, R700	5.36 k	Panasonic	ERJ-2RKF5361X
42	6	R3_CS1, R3_CS2, R3_CSi, R3_F1, R3_F2, R702	20 Ω	Yageo	RT0402DRE0720RL
43	3	R6_CS1, R6_CS2, R6_CSi	1 Ω	Yageo	RC0402FR-071RL
44	1	R7	2.2 k	Panasonic	ERJ-2RKF2201X
45	1	R40	0 Ω	Vishay Dale	RCS04020000Z0ED
46	1	R41	3.48 k	Panasonic	ERA-2ARB3481X
47	9	R60, R61, R62, R63, R69, R71_G1, R71_G2, R76_G1, R76_G2	10 k	Yageo	RC0402FR-0710KRL
48	2	R62_G1, R62_G2	27 k	Panasonic	ERJ-2GEJ273X
49	4	R63_G1, R63_G2, R64_G1, R64_G2	20 Ω	Stackpole	RMCF0402JT20R0
50	10	R64, R65, R66, R67, R100, R101, R102, R103, R104, R105	1 M	Stackpole	RMCF0402FT1M00
51	1	R68	100 k	Panasonic	ERJ-2GEJ104X
52	5	R70, R71, R78_G1, R78_G2, R90	0 Ω	Panasonic	ERJ-3GEY0R00V
53	4	R70_G1, R70_G2, R75_G1, R75_G2	200 Ω	Panasonic	ERJ-2GEJ2R2X
54	1	R78	330 Ω	Panasonic	ERJ-2RKF3300X
55	4	R80_P1, R80_P2, R82_P1, R82_P2	1 Ω	Yageo	RC0402FR-071RL
56	4	R81_P1, R81_P2, R83_P1, R83_P2	0 Ω	Stackpole	RMCF0402ZT0R00
57	1	R91	43.2 k	Yageo	RC0603FR-0743K2L
58	1	R92	7.87 k	Yageo	RC0402FR-0714K7L
59	1	R93	51 k	Yageo	RC0402JR-0751KL
60	1	R94	11.3 k	Yageo	RC0402FR-0711K3L
61	1	R95	3.65 k	Yageo	RC0402FR-073K65L
62	1	R96	332 k	Vishay	MCT06030C3323FP500
63	2	R301, R302	3.3 k	Panasonic	ERA-2VRW3301X
64	3	RDCin, SHNT_F1, SHNT_F2	0.2 mΩ	Bournes	CSS2H-3920R-L200F
65	4	S1, S2, S3, S4	Standoff M2	Würth	9774010243R
66	4	SO1, SO2, SO3, SO4	Nylon standoff	Keystone	8834
67	4	TP1, TP2, TP3, TP4	Test point	Keystone	5015
68	3	U1_CS1, U1_CS2, U1_CSi	Current sensor	MicroChip	MCP6C02T-50E/CHY
69	1	U40	Temperature sensor	Analog	AD590JCPZ-R5
70	1	U70	IC REG BUCK 3.3 V	TI	TPS62177DQCR
71	2	U80_G1, U80_G2	100 V eGaN Driver	Texas Instruments	LM5113-Q1
72	1	U90	Buck Regulator 100 V, 300 mA	Texas Instruments	LM5018SD/NOPB
73	1	U300	Op-amp	Texas Instruments	OPA365AIDBVR

Table 4: Optional Components

Item	Qty	Reference	Part Description	Manufacturer	Part #
1	4	C70_G1, C70_G2, C75_G1, C75_G2	100 pF, 50 V	Yegeo	CC0402KRX7R9BB101
2	4	D1_P1, D1_P2, D2_P1, D2_P2	100 V, 2.1A	Vishay	V3PM10
3	1	J800	.05" Male Vert.	Sullins	GRPB031VWVN-RC
4	1	JP800	50 mil +Handle Red	Harwin Inc	M50-2020005

Table 5: Heatsink Kit

Item	Qty	Reference	Part Description	Manufacturer	Part #
1	4	SC1, SC2, SC3, SC4	M2 6 mm screw	McMasterCarr	95836A109
2	1	HS1	Heatsink 55x21x24mm Horz. Fin	Wakefield	567-94AB
3	1	TIM1, TIM2	0.5 mm thick custom cut Thermal interface material	t-Global	TG1780 0.5

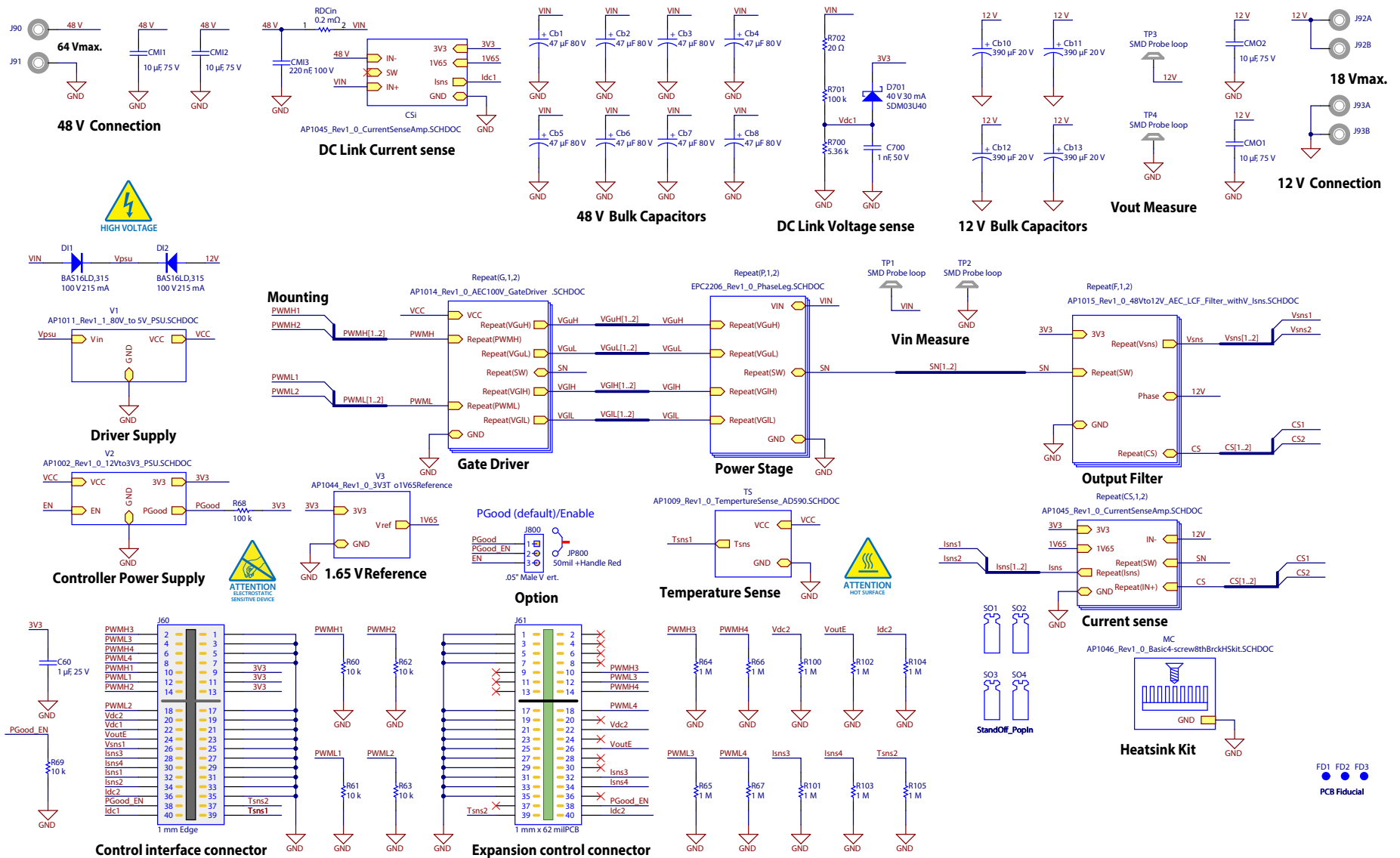


Figure 10: EPC9137 Rev 4.0 main schematic

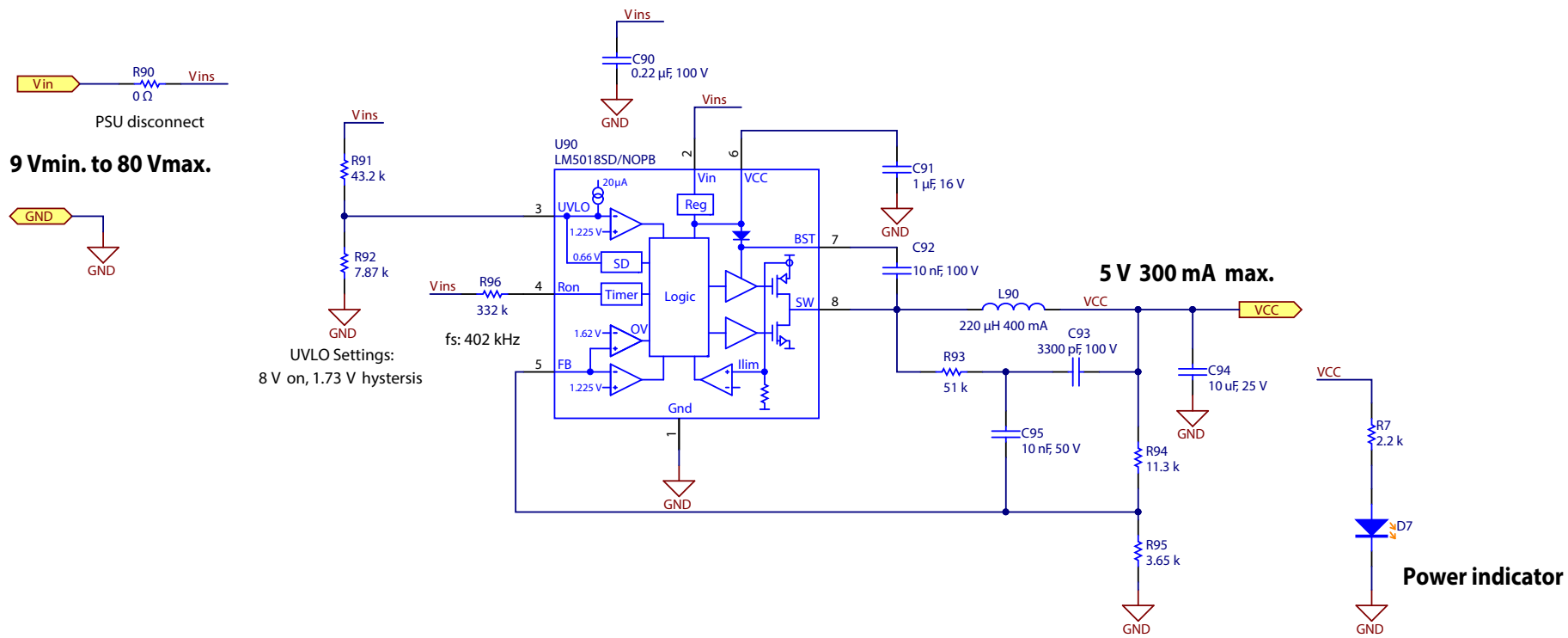


Figure 11: EPC9137 80 V to 5 V housekeeping power supply

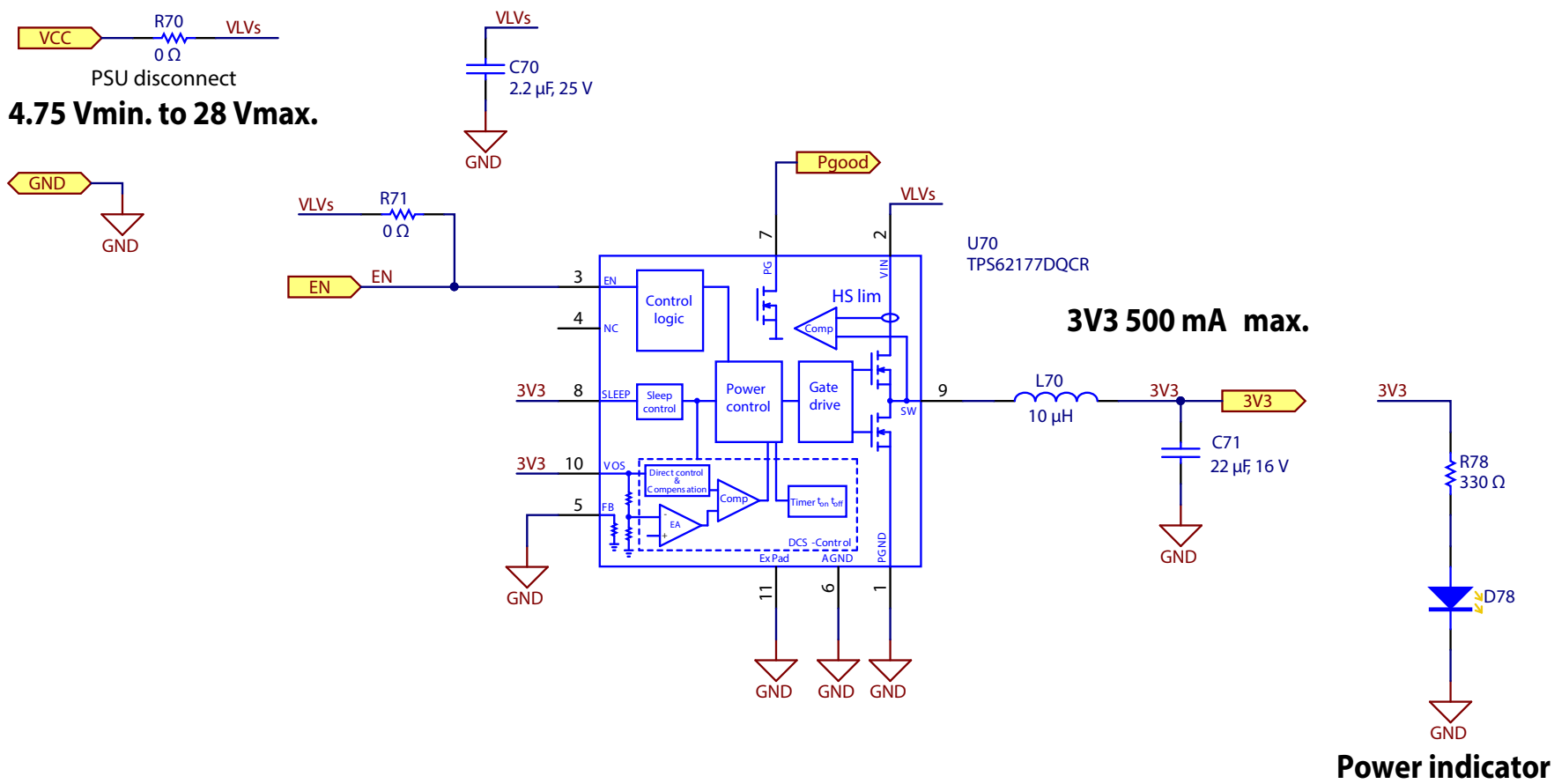


Figure 12: EPC9137 3V3 housekeeping power supply

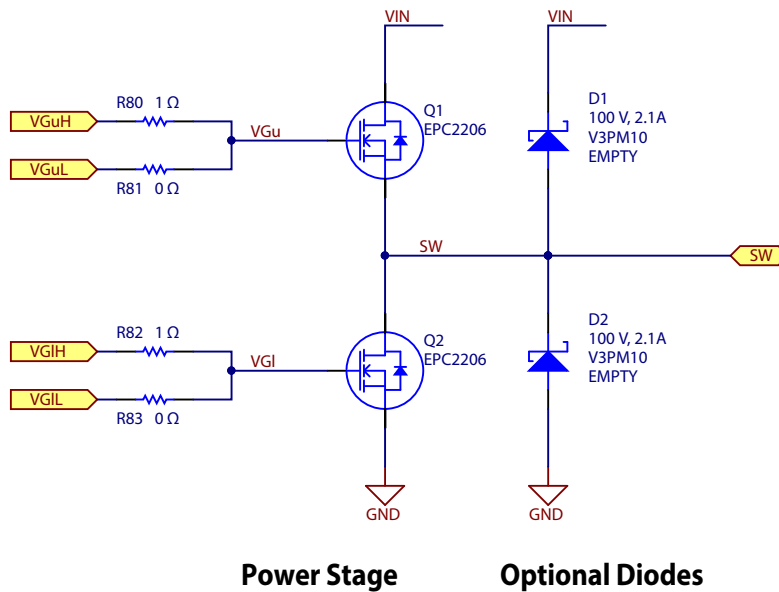
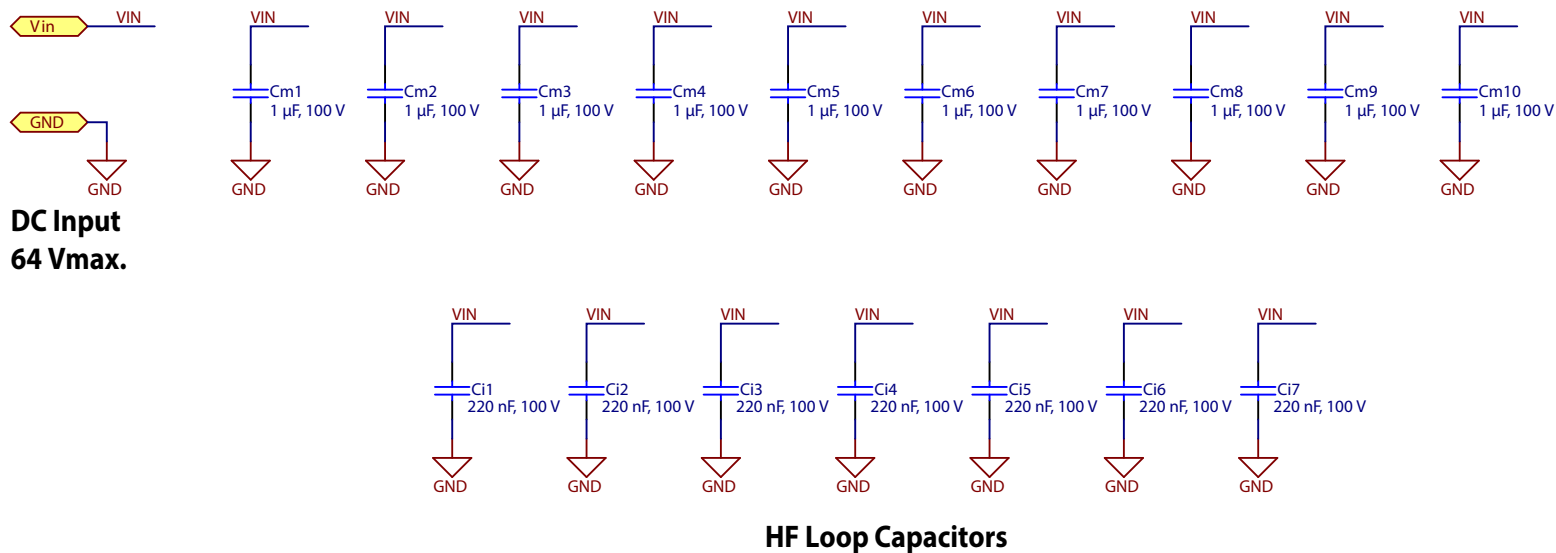


Figure 13: EPC2206 phase leg

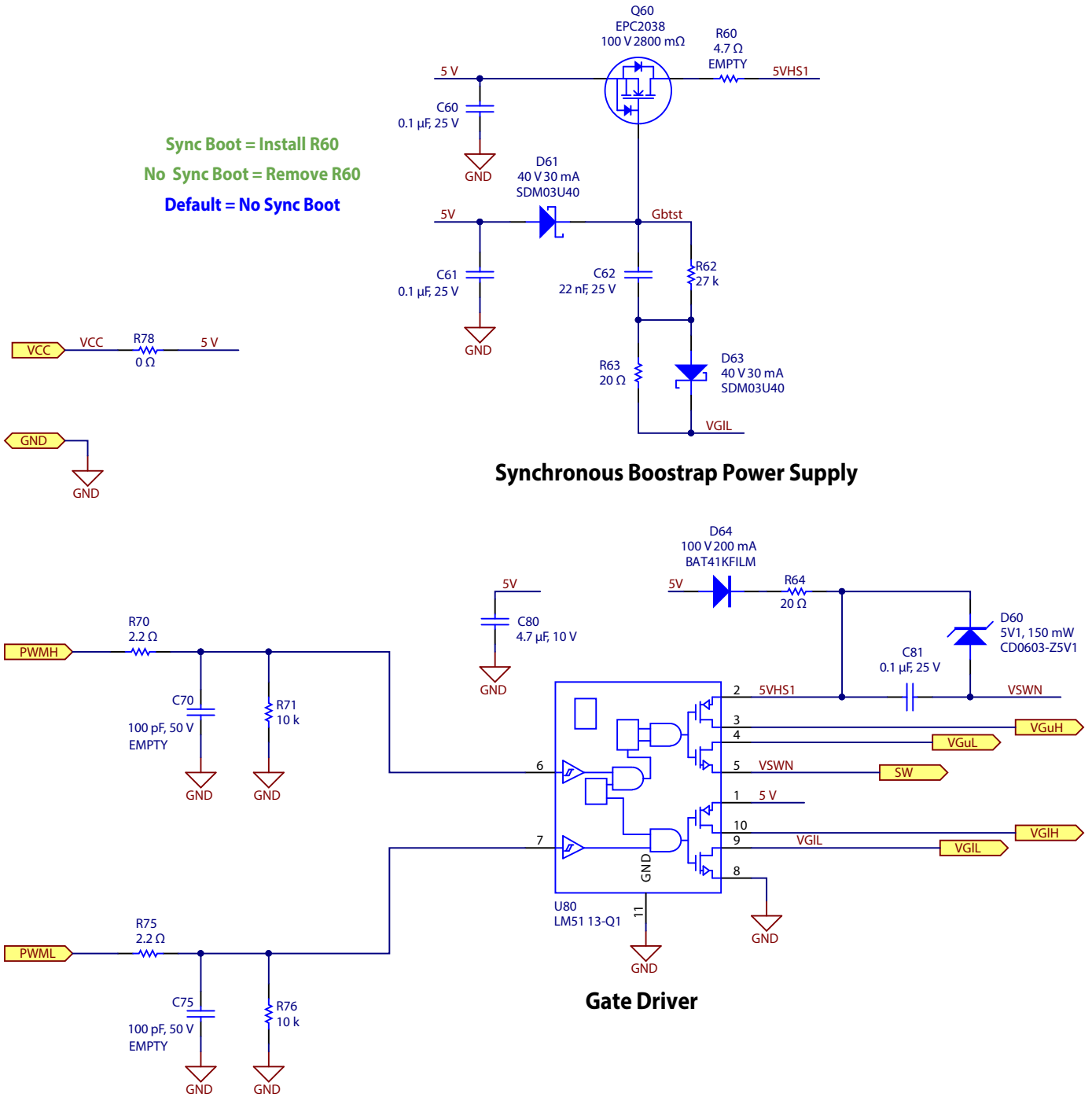


Figure 14: EPC9137 100V AEC gate driver

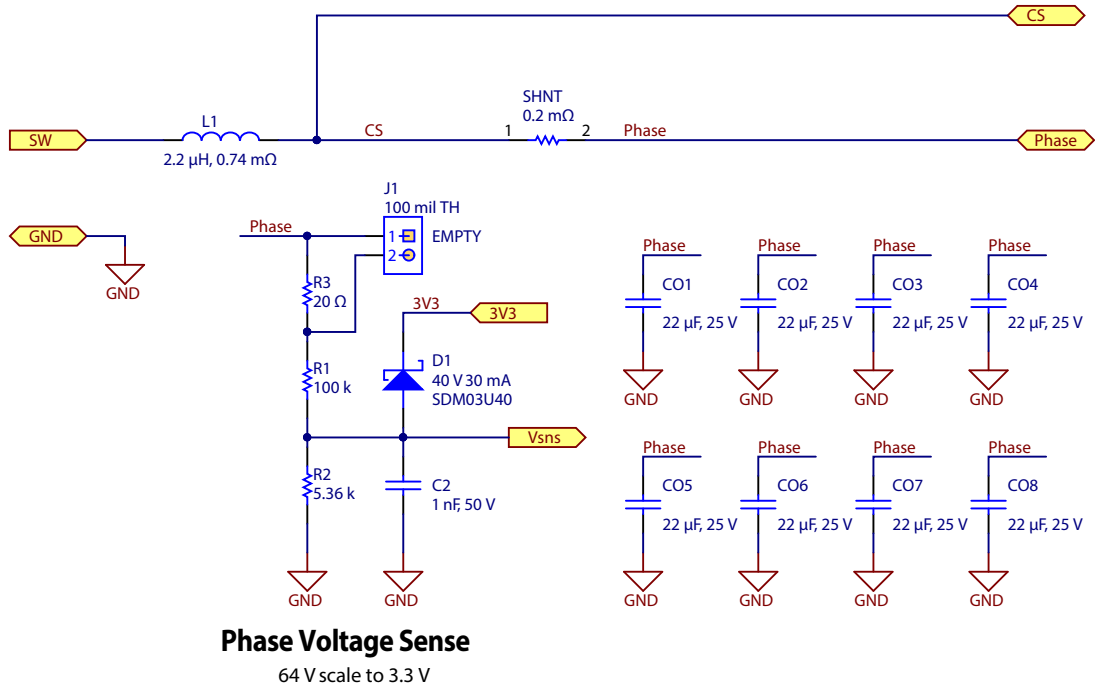


Figure 15: EPC9137 48 V to 12 V AEC high current filter

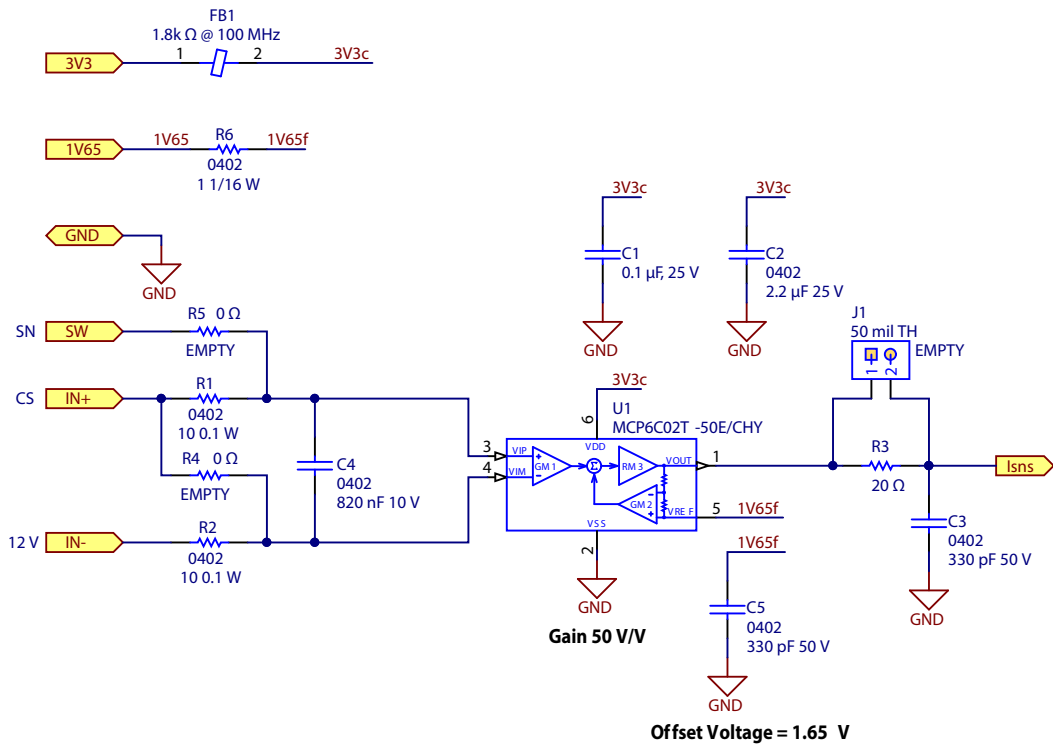


Figure 16: EPC9137 bi-directional current sense amplifier

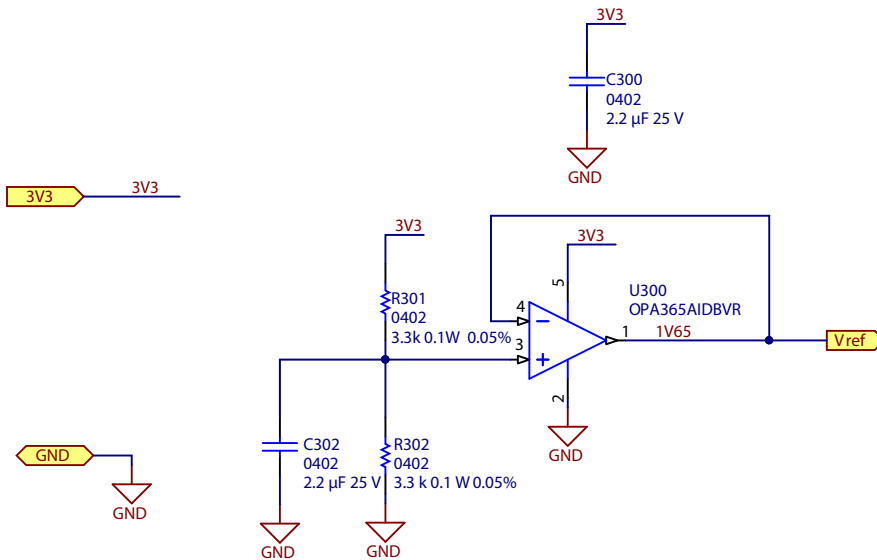


Figure 17: EPC9137 1.65 V reference

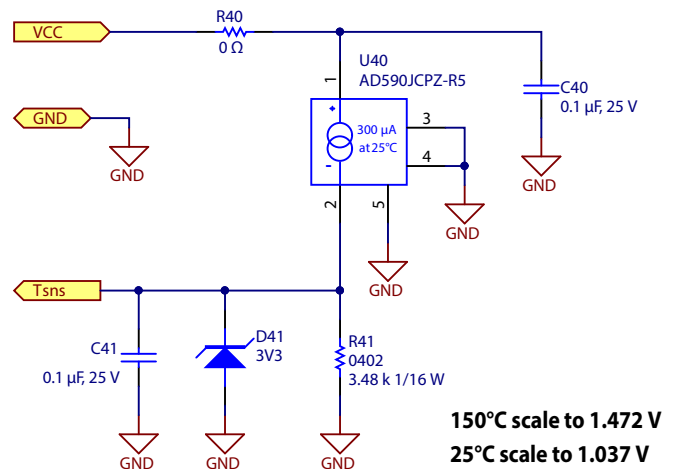


Figure 18: EPC9137 AD590 temperature sense

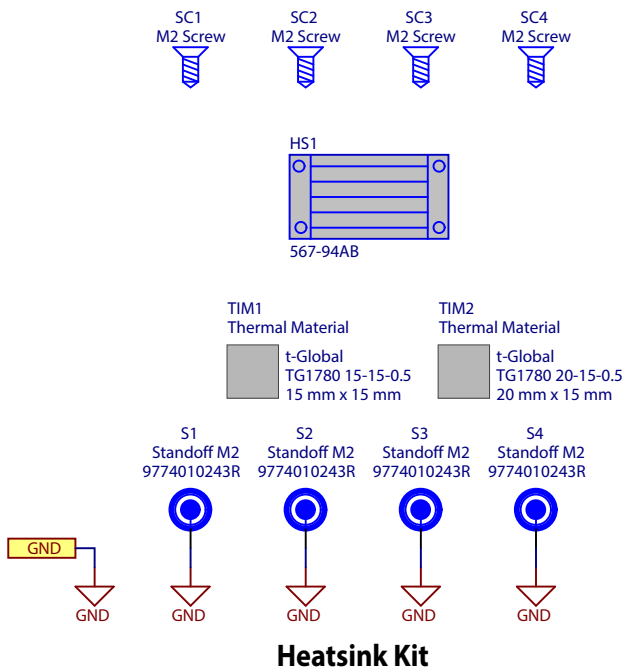


Figure 19: EPC9137 basic 4 screw heatsink kit



EPC would like to acknowledge Microchip Technology Inc. (www.microchip.com) for their support of this project.

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The EPC9137 system features the [dsPIC33CK256MP503](http://www.microchip.com) 16-Bit Digital Signal Controller with High-Speed ADC, Op Amps, Comparators and High-Resolution PWM. Learn more at www.microchip.com.

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