

Demonstration Board EPC9163 Quick Start Guide

*2 kW 48 V/14 V 140 A Bi-Directional Power Module
Evaluation Board*

Revision 1.0



DESCRIPTION

The EPC9163 evaluation power module is designed for 48 V to/from 14 V DC-DC applications. It features the EPC2218 – enhancement mode eGaN® field effect transistors (FETs). The compatible controller module (EPC9528) includes the Microchip dsPIC33CK256MP503 16-bit digital controller. The various functional blocks are shown in figure 1.

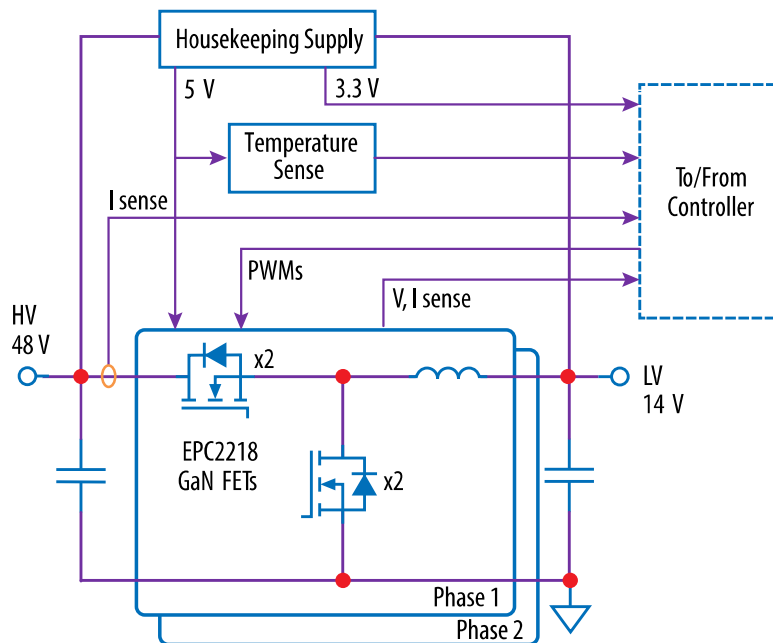
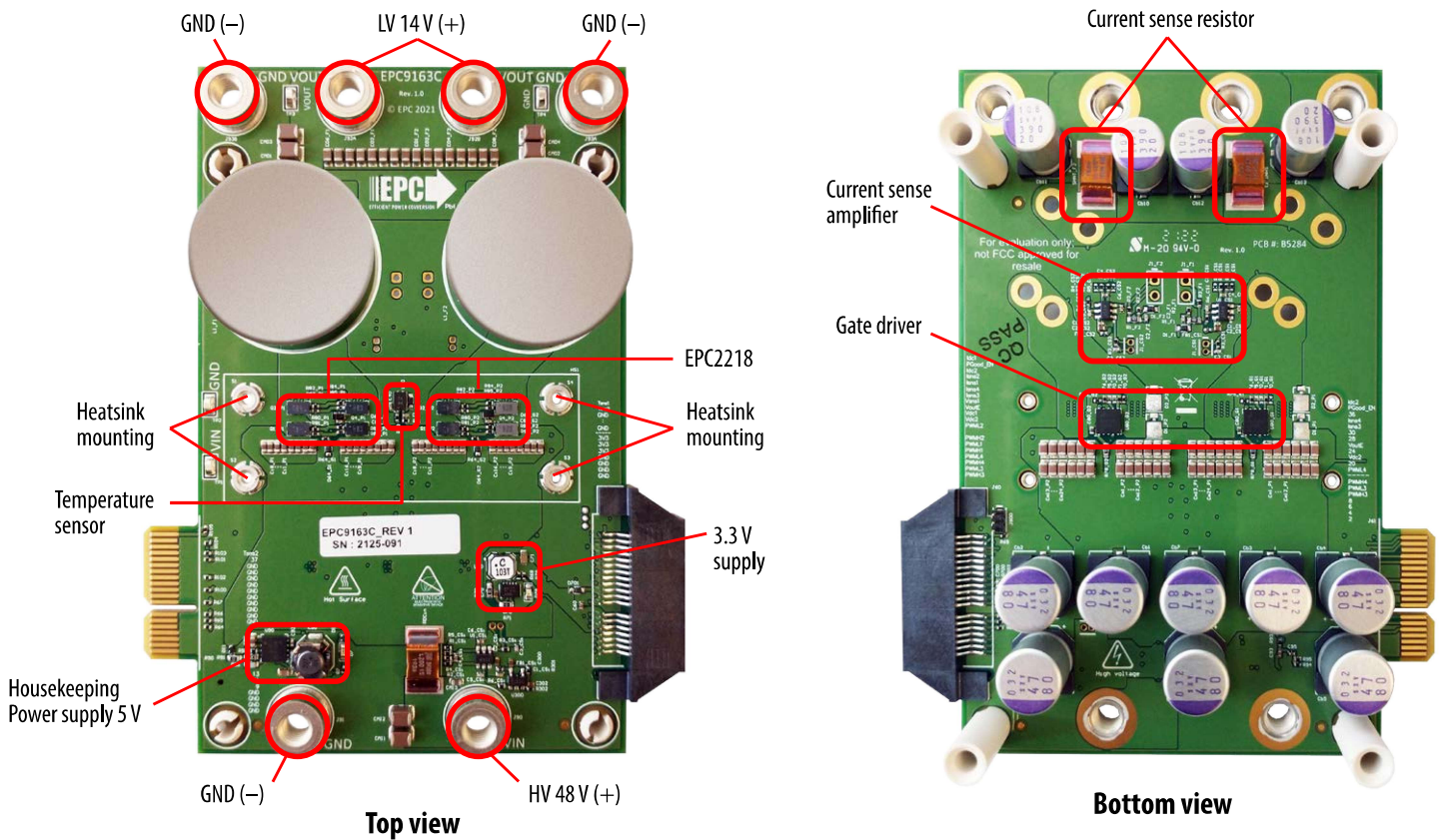
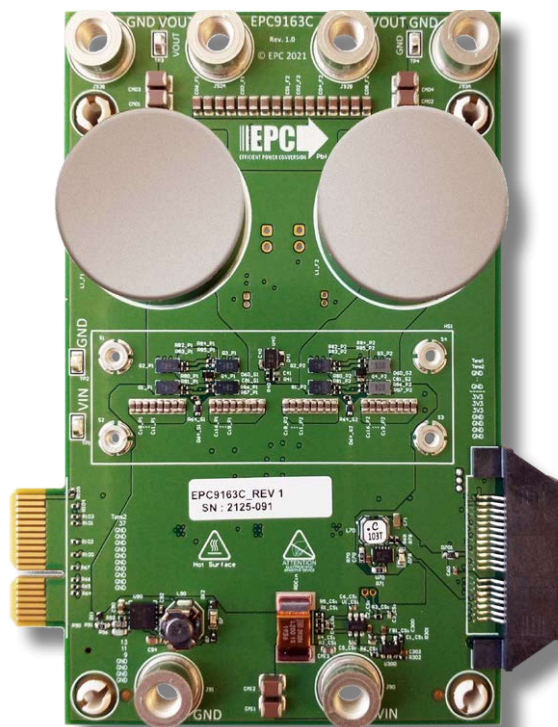


Figure 1: Functional block diagram overview of the EPC9163 board

MAIN FEATURES

- High efficiency: 95.8% @ 14.3 V/140 A output (buck)
- Dimension: 112 x 70 x 40 mm [4.4 x 2.8 x 1.6 in]
- Two-phase power stage with 100 V rated EPC2218
- Designed switching frequency: 500 kHz
- Re-programmable – Average current mode control (default)
- On board current sensor and temperature sensor
- Fault protection:
 - Input undervoltage
 - Input overvoltage
 - Regulation error
 - Inductor overcurrent
 - Overtemperature



EPC9163 demonstration board

RECOMMENDED OPERATING CONDITIONS

Table 1: Electrical Specifications ($T_A = 25^\circ\text{C}$) EPC9163

Symbol	Parameter	Conditions	Min	Nom	Max	Units
V_{IN}	Input Voltage	Buck	20	48	60	V
		Boost, during operation	11.3	14	16	v
		Boost, start up	12.3			V
$V_{IN,on}$	Input UVLO turn on voltage	Buck		20		V
		Boost		12.3		V
$V_{IN,off}$	Input UVLO turn off voltage	Buck		17.5		V
		Boost		11.3		V
V_{OUT}	Output Voltage	Buck	5	14.3	16	V
		Boost	20	48	50	V
$t_{OUT,rise}$	Output voltage rise time			100		ms
ΔV_{OUT}	Output voltage ripple	Buck, $I_{OUT} = 23\text{ A}$		50		mV
		Boost				mV
$I_{OUT,BUCK}$	Buck Output Current	Buck	0		140	A
$I_{IN,BOOST}$	Boost Input Current	Boost Input Current	0		140	A
I_{MAX}	Maximum current limit threshold	Buck, output current	145		150	A
		Boost, input current	145		150	A
T_{MAX}	Maximum temperature limit threshold	During operation	93		98	$^\circ\text{C}$
$T_{Start,MAX}$	Maximum temperature to start converter	After over-temperature fault event			80	$^\circ\text{C}$
f_s	Switching frequency			500		kHz

HIGHLIGHTED PARTS

Power Stage

The EPC9163 features four 100 V, 3.2mΩ EPC2218 GaN FETs. The datasheet should be read in conjunction with this quick start guide. For more information on EPC2218 please refer to the datasheet available from EPC at www.epc-co.com.

Housekeeping supply

The EPC9163 includes logic power supplies for 5 V and 3.3 V. It also supplies power to the controller card through the edge connector J60.

Current and voltage sense

The output inductor current and input current are all measured using 0.2 mΩ sensing resistor and 50 V/V amplifier. Therefore, the current sense gain is 0.01 V/A. Input and output voltages are measured using resistor divider network (100k and 5.36 k), the gain is 0.05087.

Temperature sensor

An AD590 temperature sensor is located under the heatsink. It has a 3.48 k load resistor, therefore the output voltage V_o [V] vs. temperature T [°C] follows the equation:

$$V_o = \left(\frac{3.48}{1000} \right) T + 0.95$$

LED indicators

There are two LEDs indicating the status of the housekeeping supply:

- 5 V LED (**orange**) – indicates the 5 V supply is operational
- 3.3 V LED (**yellow**) – indicates the 3.3 V supply is operational

Test points and measurement setup

A number of test points are available for easy measurement of various nodes as follows:

- SMD hookup for high voltage (HV) terminals TP1 and TP2
- SMD hookup for low voltage (LV) terminals TP3 and TP4
- Voltage loop gain injection/measurement point J1_F1
- Current loop gain injection/measurement point J1_CS1 and J1_CS2

All signals are measured with respect to ground (GND). All the test point locations are shown in figure 3.

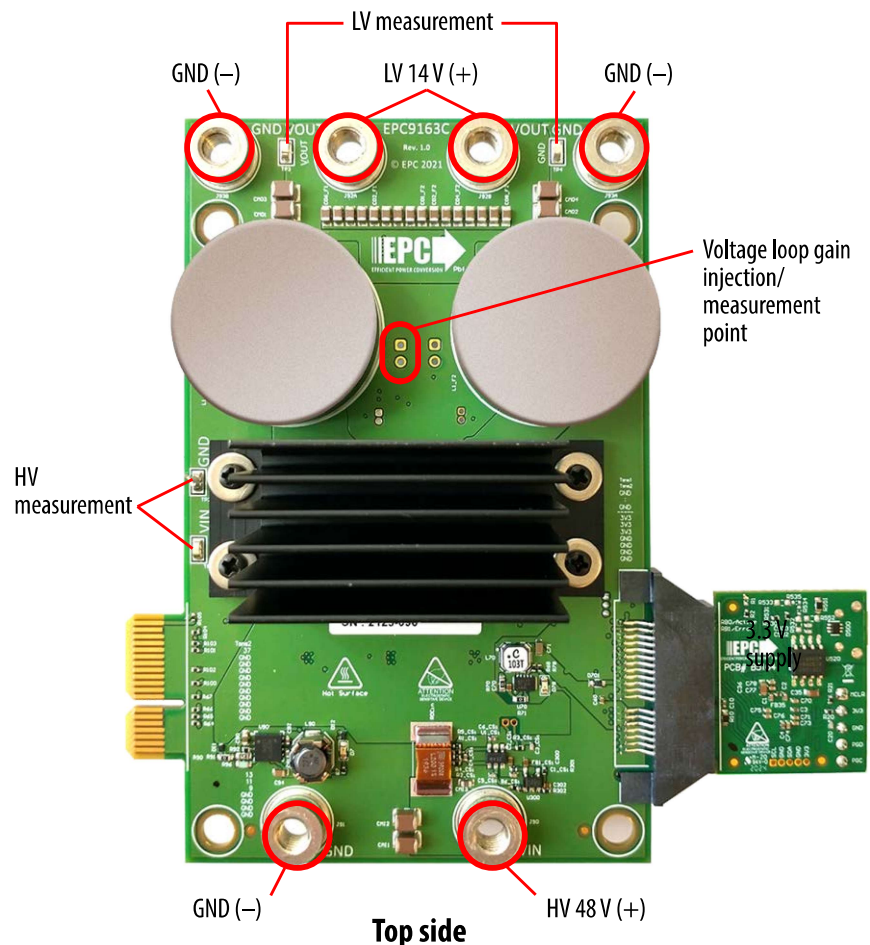


Figure 2: EPC9163 test point pad and hookup locations and designations

OPERATING CONSIDERATIONS

Buck/Boost Modes

The module is programmed with Buck mode by default. To operate as a boost converter, please download the firmware for boost mode and re-program the control module.

Over-current protection

If the load current exceeds a pre-determined maximum setpoint, this condition will be regarded as a fault condition and the converter will shut down. The converter will then attempt to restart after 2 seconds. This shut down and restart cycle will continue until the over-current condition clears.

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.

Compatible Controllers

A list of compatible controllers for the EPC9163 is given in table 2.

Table 2: Compatible controller interface and controller boards to the EPC9163

Controller Board Number	Controller Manufacturer	Controller	Target Application
EPC9528 Rev. 3.0	Generic controller board	dsPIC33CK256MP503	DC-to-DC converter

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 EPC9163.

Jumper J800

The jumper J800 is located next to the EPC9528 edge connector. The default setting is left floating. It is possible to route the output of power good (PGood) signal of the 3.3 V regulator to the controller by connecting top two pins together, as shown in figure 3. While not implemented, this can be used as the enable signal for the controller.

The other jumper position routes 5 V DC to the controller. **Do not use this setting with the EPC9528 controller.**

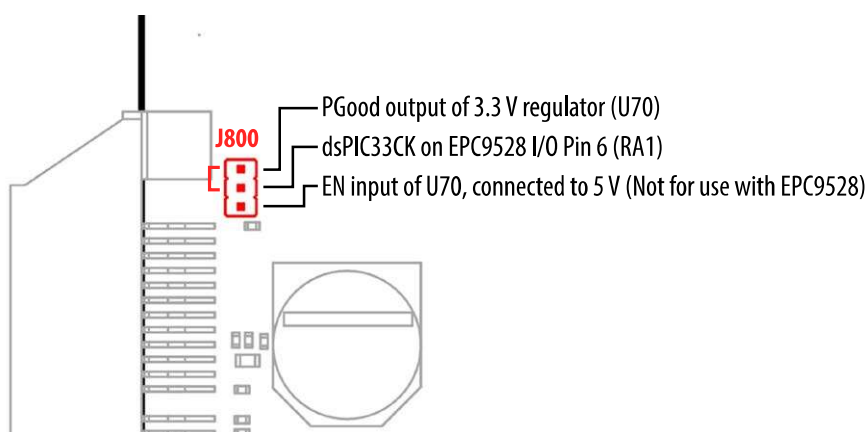


Figure 3: EPC9163 J800 jumper settings

MECHANICAL SPECIFICATIONS

Unit: mm [in]

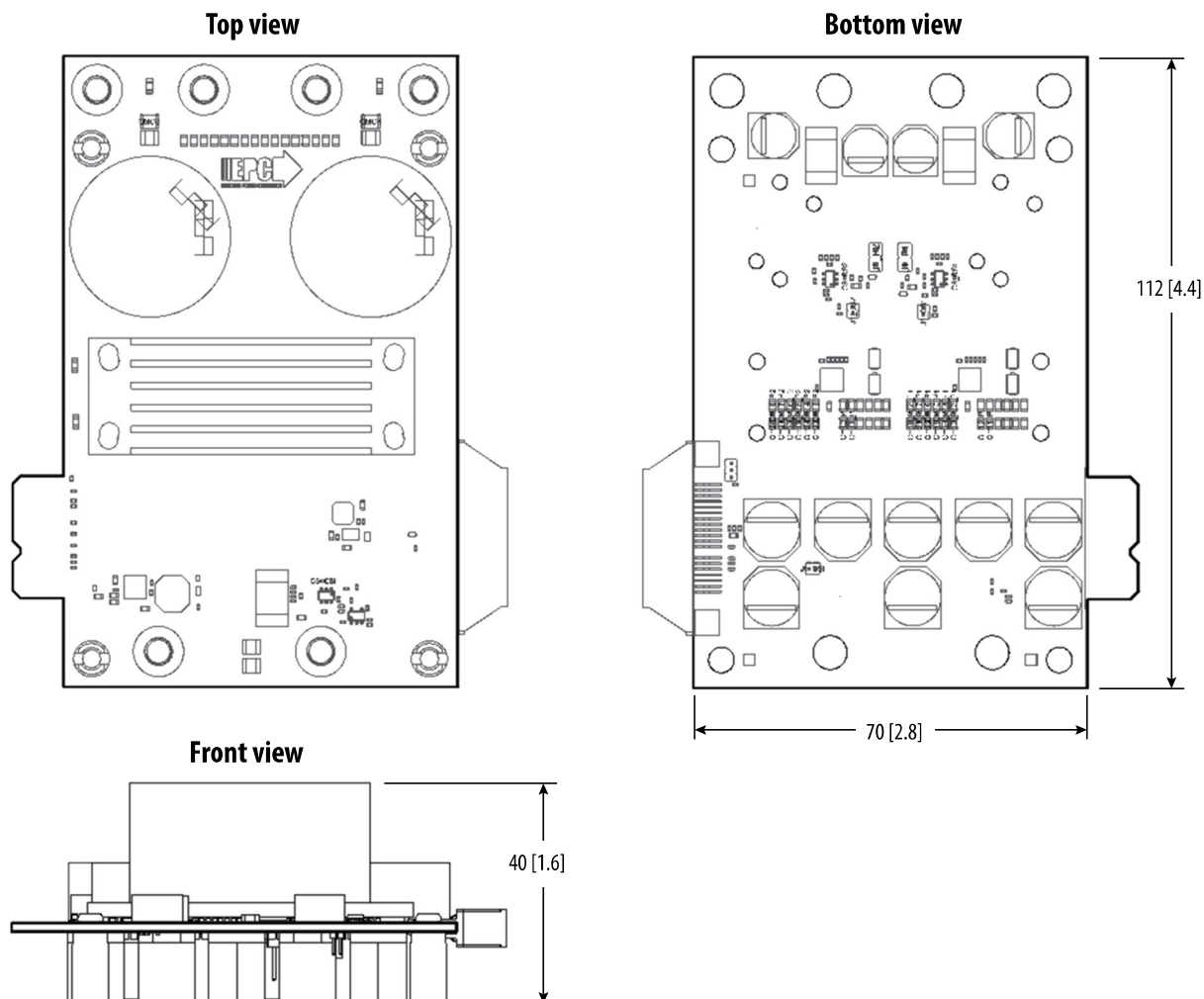


Figure 4: EPC9163 mechanical specifications

QUICK START PROCEDURE

Follow the procedure below to operate the EPC9163 as a buck/boost:

1. Program the correct firmware onto the EPC9528 controller
2. Insert the EPC9528 controller into the corresponding slot (J60) on EPC9163
3. With power off, connect input and output terminals (M5 screws) to power supply and load

Buck mode: power supply connects to HV 48V (+) and GND (-); load connects to LV 14V (+) and GND (-), as shown in figure 2.

Boost mode: power supply connects to LV 14V (+) and GND (-); load connects to HV 48V (+) and GND (-), as shown in figure 2.

4. Turn on the power supply and load, and ensure voltages and currents are within specifications of table 1.
5. For shutdown, please follow the above steps in reverse.

THERMAL MANAGEMENT

Thermal management is very important to ensure proper and reliable operation. Sufficient cooling is required for this module to operate in the full specified output current range, even with heatsink installed.

Heatsink Installation

A mounted heatsink is required for effectively dissipating the generated heat to ambient. The heatsink from Wakefield 567-94AB can be mounted to the SMD threaded (M2) spacers on the board, which are 1 mm tall, leaving around 0.3 mm gap between the FETs and heatsink. High thermal conductivity TIM materials T-Global A1780 of thickness 0.5 mm provides good thermal conductance across the 0.3 mm gap. The heatsink and TIM materials are pre-installed and will provide adequate cooling for testing.

Specification testing is performed using forced air of 2000 LFM due to the small size of the heatsink. Thermal tests reaching 1 kW per phase indicate that the operating temperature is within thermal limits with the recommended heatsink and TIM installed and with the applied forced air-cooling conditions as shown in Figure 5.

Configurations with higher TIM thicknesses and lower thermal conductivity degrade thermal performance and increase the thermal resistance between the FETs and the sink surface ($R_{th,JS}$). This directly translates to higher temperature rise across the TIM material which can lead the junction temperature to exceed reliability limits according to the equation: $T_J = T_S + R_{th,JS} \times P$. Additional gap fill (GF) TIM material can be added to conduct heat from the sides of the FETs and from the top conductor surface of the PCB to the sink.

Operating temperature can be further reduced by reducing the sink temperature (T_S). Air-cooled heatsinks provide a sink to ambient resistance $R_{th,SA}$ on the order of 1 °C/W, which results in an elevated T_S for high heat dissipation rates according to the equation $T_S = T_{amb} + R_{th,SA} \times P_{total}$. A liquid-cooled heatsink (i.e., cold-plate) offers a low $R_{th,SA}$ (on the order of 0.1°C/W) and thus reduces heatsink surface and FET temperature rise by up to 50°C (assuming heatsink dissipating >50 W) as shown by simulations.



Figure 5. Thermal image showing FET region (back side of the board) temperature at full load with heatsink and 2000 LFM forced air cooling

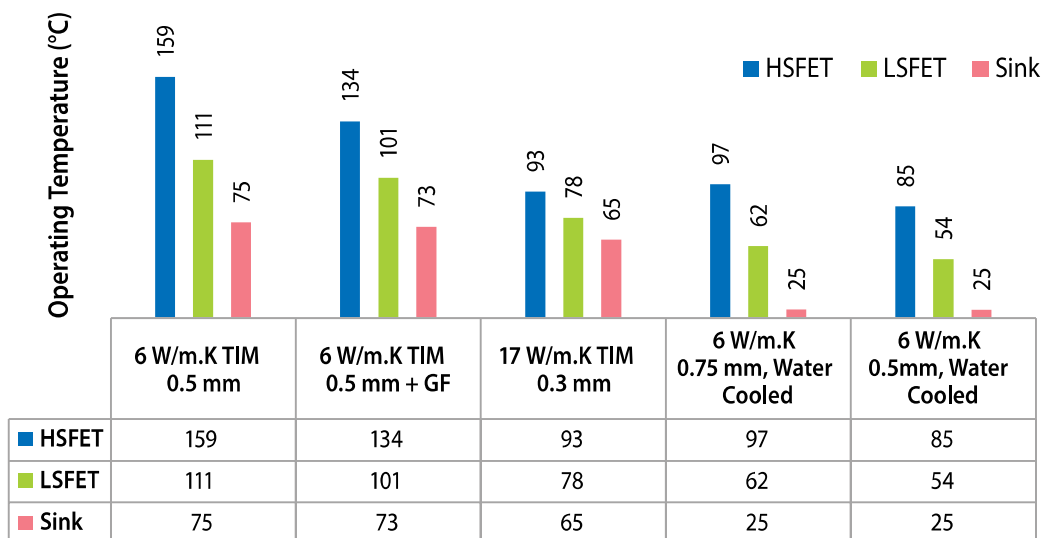


Figure 6: Chart showing simulated operating temperatures for high-side FET (HSFET) and low-side FET (LSFET) comparing forced air-cooled and water cooled heatsinks when operating the converter at full load (48 V_{IN}, 14.3 V_{OUT}, 140 A)

The choice of TIM needs to also 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-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)

The pre-installed TIM is TG-A1780 X 0.5 mm. The dimensions and positions of the TIM are shown in Figure 7.

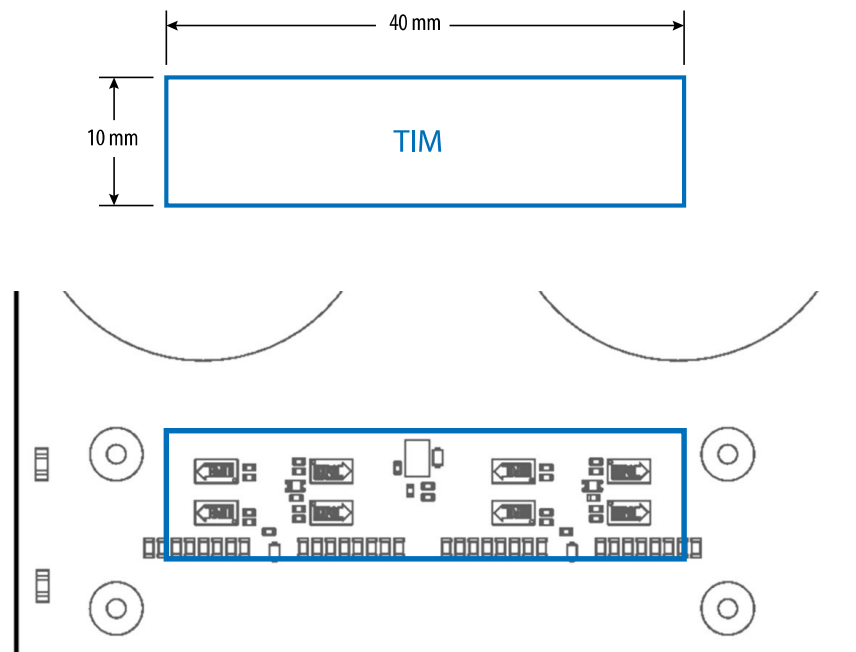


Figure 7: EPC9163 TIM specifications and location

When assembling the heatsink, it may be necessary add a thin insulation layer to prevent the heatsink from electrically contacting with components that have exposed conductors such as capacitors and resistors and increases the clearance voltage between those conductor surfaces. In this design, an insulation layer is not included.

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 maximum junction specified in the datasheet.

EXPERIMENTAL VALIDATION EXAMPLE

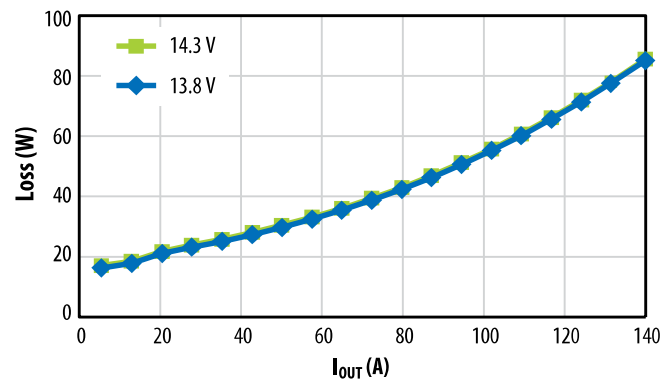
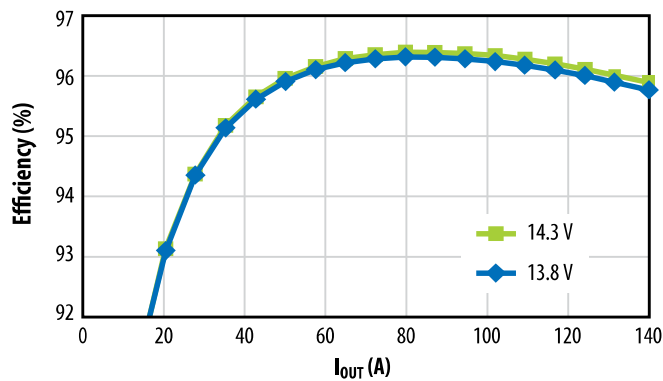


Figure 8: EPC9163 typical efficiency and power loss, buck $V_{IN} = 48\text{ V}$

Measurement Waveforms

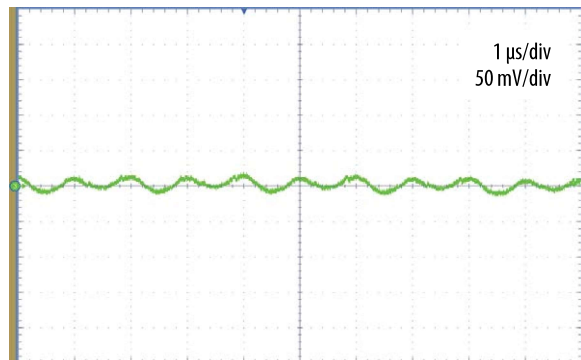


Figure 9: EPC9163 output voltage ripple, buck $V_{IN} = 48\text{ V}$, $V_{OUT} = 14.3\text{ V}$, $I_{OUT} = 23\text{ A}$

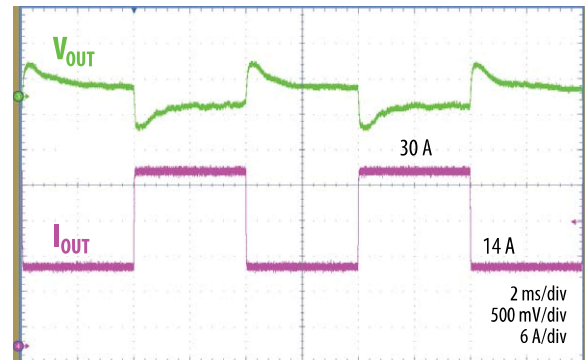


Figure 10: EPC9163 transient response, buck $V_{IN} = 48\text{ V}$, $V_{OUT} = 14.3\text{ V}$

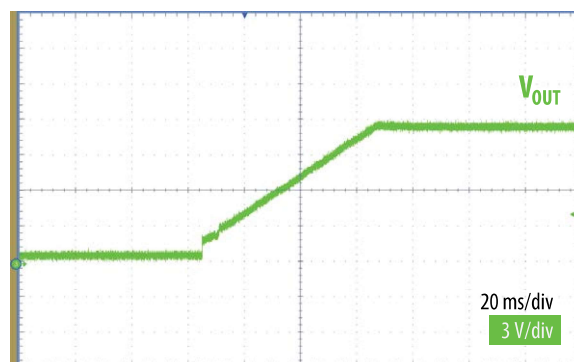


Figure 11: EPC9163 start up waveform, buck $V_{IN} = 48\text{ V}$

Table 3: Bill of Materials

Item	Qty	Reference	Part Description	Manufacturer	Part #
1	8	Cb1, Cb2, Cb3, Cb4, Cb5, Cb6, Cb7, Cb8	47 μ F 80 V	Panasonic	80SXV47M
2	4	Cb10, Cb11, Cb12, Cb13	390 μ F 20 V	Panasonic	20SVPF390M
3	6	CM11, CM12, CMO1, CMO2, CMO3, CMO4	10 μ F, 75 V	TDK	CGA6P1X7R1N106M250AC
4	48	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, Cm11_P1, Cm11_P2, Cm12_P1, Cm12_P2, Cm13_P1, Cm13_P2, Cm14_P1, Cm14_P2, Cm15_P1, Cm15_P2, Cm16_P1, Cm16_P2, Cm17_P1, Cm17_P2, Cm18_P1, Cm18_P2, Cm19_P1, Cm19_P2, Cm20_P1, Cm20_P2, Cm21_P1, Cm21_P2, Cm22_P1, Cm22_P2, Cm23_P1, Cm23_P2, Cm24_P1, Cm24_P2	1 μ F, 100 V	TDK	C2012X7S2A105M125AB
5	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 μ F, 25 V	TDK	C2012X5R1E226M125AC
6	1	C71	22 μ F, 16 V	Samsung	CL10A226M07JZNC
7	1	C94	10 μ F, 25 V	Murata	GRM188R61E106MA73D
8	35	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, Ci8_P1, Ci8_P2, Ci9_P1, Ci9_P2, Ci10_P1, Ci10_P2, Ci11_P1, Ci11_P2, Ci12_P1, Ci12_P2, Ci13_P1, Ci13_P2, Ci14_P1, Ci14_P2, Ci15_P1, Ci15_P2, Ci16_P1, Ci16_P2, C90, CM13	220 nF, 100 V	Taiyo Yuden	HMK107C7224
9	7	C1_CS1, C1_CS2, C1_CSi, C40, C41, C81_G1, C81_G2	0.1 μ F, 25 V	Yageo	CC0402KRX7R8BB104
10	5	C2_CS1, C2_CS2, C2_CSi, C300, C302	2.2 μ F	Murata	GRM155R61E225ME15D
11	3	C2_F1, C2_F2, C700	1 nF, 50 V	Kemet	C0402C102J5GACAU0
12	3	C3_CS1, C3_CS2, C3_CSi	330 pF	TDK	C1005C0G1H331J050BA
13	3	C5_CS1, C5_CS2, C5_CSi	56 pF	TDK	C1005C0G1H560J050BA
14	3	C4_CS1, C4_CS2, C4_CSi	820 nF	Murata	GRM155R61A824KE15D
15	3	C6_CS1, C6_CS2, C6_CSi	10 nF	TDK	C1005X7S2A103M050BB
16	1	C60	1 μ F, 25 V	Murata	GRM155R61E105MA12D
17	1	C70	2.2 μ F, 25 V	Murata	GRM155R61E225KE11D
18	2	C80_G1, C80_G2	4.7 μ F, 10 V	TDK	C1005X5R1A475K050BC
19	1	C91	1 μ F, 16 V	TDK	C1005X6S1C105K050BC
20	1	C92	10 nF, 100 V	TDK	C1005X7S2A103K050BB
21	1	C93	3300 pF, 100 V	Murata	GRM155R72A332KA01D
22	1	C95	10 nF, 50 V	Murata	GRM155R71H103KA88D
23	3	FB1_CS1, FB1_CS2, FB1_CSi	1.8k Ω @ 100MHz	TDK	MMZ1005Y182CTD25
24	8	Q1_P1, Q1_P2, Q2_P1, Q2_P2, Q3_P1, Q3_P2, Q4_P1, Q4_P2	100 V, 3.2 m Ω	EPC	EPC2218
25	3	RDCin, SHNT_F1, SHNT_F2	0.2 m Ω	Bournes	CSS2H-3920R-L200F
26	3	R1_F1, R1_F2, R701	100 k	Panasonic	ERA-3AEB104V
27	5	R70, R71, R78_G1, R78_G2, R90	0 Ω	Panasonic	ERJ-3GEY0R00V
28	1	R91	43.2 k	Yageo	RC0603FR-0743K2L
29	1	R96	332 k	Vishay	MCT06030C3323FP500
30	6	R1_CS1, R1_CS2, R1_CSi, R2_CS1, R2_CS2, R2_CSi	10	Panasonic	ERJ-2RKF10R0X
31	3	R2_F1, R2_F2, R700	5.36 k	Panasonic	ERJ-2RKF5361X
32	6	R3_CS1, R3_CS2, R3_CSi, R3_F1, R3_F2, R702	20 Ω	Yageo	RT0402DRE0720RL
33	11	R6_CS1, R6_CS2, R6_CSi, R84_P1, R84_P2, R86_P1, R86_P2, R80_P1, R80_P2, R82_P1, R82_P2	1 Ω	Yageo	RC0402FR-071RL
34	1	R7	2.2 k	Panasonic	ERJ-2RKF2201X
35	1	R40	0 Ω	Vishay Dale	RCS04020000Z0ED
36	1	R41	3.48 k	Panasonic	ERA-2ARB3481X
37	9	R60, R61, R62, R63, R69, R71_G1, R71_G2, R76_G1, R76_G2	10 k	Yageo	RC0402FR-0710KL
38	10	R64, R65, R66, R67, R100, R101, R102, R103, R104, R105	1 M	Stackpole	RMCF0402FT1M00
39	2	R64_G1, R64_G2	20 Ω	Stackpole	RMCF0402JT20R0
40	1	R68	100 k	Panasonic	ERJ-2GEJ104X
41	4	R70_G1, R70_G2, R75_G1, R75_G2	2.00 Ω +02	Panasonic	ERJ-2GEJ2R2X
42	1	R78	330 Ω	Panasonic	ERJ-2RKF3300X
43	8	R81_P1, R81_P2, R83_P1, R83_P2, R85_P1, R85_P2, R87_P1, R87_P2	0 Ω	Stackpole	RMCF0402ZT0R00
44	1	R92	7.87 k	Yageo	RC0402FR-0714K7L
45	1	R93	51 k	Yageo	RC0402JR-0751KL

Table 4: Bill of Materials (continued)

Item	Qty	Reference	Part Description	Manufacturer	Part #
46	1	R94	11.3 k	Yageo	RC0402FR-0711K3L
47	1	R95	3.65 k	Yageo	RC0402FR-073K65L
48	2	R301, R302	3.3 k	Panasonic	ERA-2VRW3301X
49	3	D1_F1, D1_F2, D701	40 V 30 mA	Diodes Inc.	SDM03U40
50	1	D7	LED 0603 Orange	Lite-On	LTST-C193KFKT-5A
51	1	D41	3V3 300 mW	Diodes Inc.	BZT52C3V3T-7
52	2	D60_G1, D60_G2	5V1, 150 mW	Bournes	CD0603-Z5V1
53	2	D64_G1, D64_G2	100V 200 mA	ST	BAT41KFILM
54	1	D78	LED 0603 Yellow	Lite-On	LTST-C193KSKT-5A
55	2	DI1, DI2	100V 215 mA	Nexperia	BAS16LD,315
56	1	J60		Samtec	MEC1-120-02-F-D-EM2
57	6	J90, J91, J92A, J92B, J93A, J93B	Terminal M5	Würth	7466005R
58	1	J800	.05" Male Vert.	Sullins	GRPB031VWVN-RC
59	2	L1_F1, L1_F2	1.0 μ H	Vishay	IHTH1125KZEB1R0M5A
60	1	L70	10 μ H	Coilcraft	LPS4012
61	1	L90	220 μ H 400 mA	Murata	MDH6045C-221MB=P3
62	4	S1, S2, S3, S4	Standoff M2	Würth	9774010243R
63	4	SO1, SO2, SO3, SO4	Nylon Standoff	Keystone	8834
64	4	TP1, TP2, TP3, TP4	Test point	Keystone	5015
65	3	U1_Cs1, U1_Cs2, U1_Csi	Current sensor	MicroChip	MCP6C02T-050E/CHY
66	1	U40	Temperature Current Source	Analog	AD590JCPZ-R5
67	1	U70	IC REG BUCK 3.3 V	TI	TPS62177DQCR
68	2	U80_G1, U80_G2	100V eGaN Driver	Texas Instruments	LM5113-Q1
69	1	U90	Buck Regulator 100 V, 300 mA	Texas Instruments	LM5018SD/NOPB
70	1	U300	Op-amp	Texas Instruments	OPA365AIDBVR

Table 5: Optional Components

Item	Qty	Reference	Part Description	Manufacturer	Part #
1	4	C70_G1, C70_G2, C75_G1, C75_G2	100 pF, 50 V	Yageo	CC0402KRX7R9BB101
2	4	D1_P1, D1_P2, D2_P1, D2_P2	100 V, 2.1 A	Vishay	V3PM10

Table 6: Heatsink Kit

Item	Qty	Reference	Part Description	Manufacturer	Part #
1	1	HS1	Heatsink 55 x 21 x 24 mm Horz. Fin	Wakefield	567-94AB
2	4	SC1, SC2, SC3, SC4	M2 6 mm screw	McMaster Carr	95836A107
3	1	TIM1	0.5 mm thick custom cut thermal interface material	t-Global	TG1780 0.5

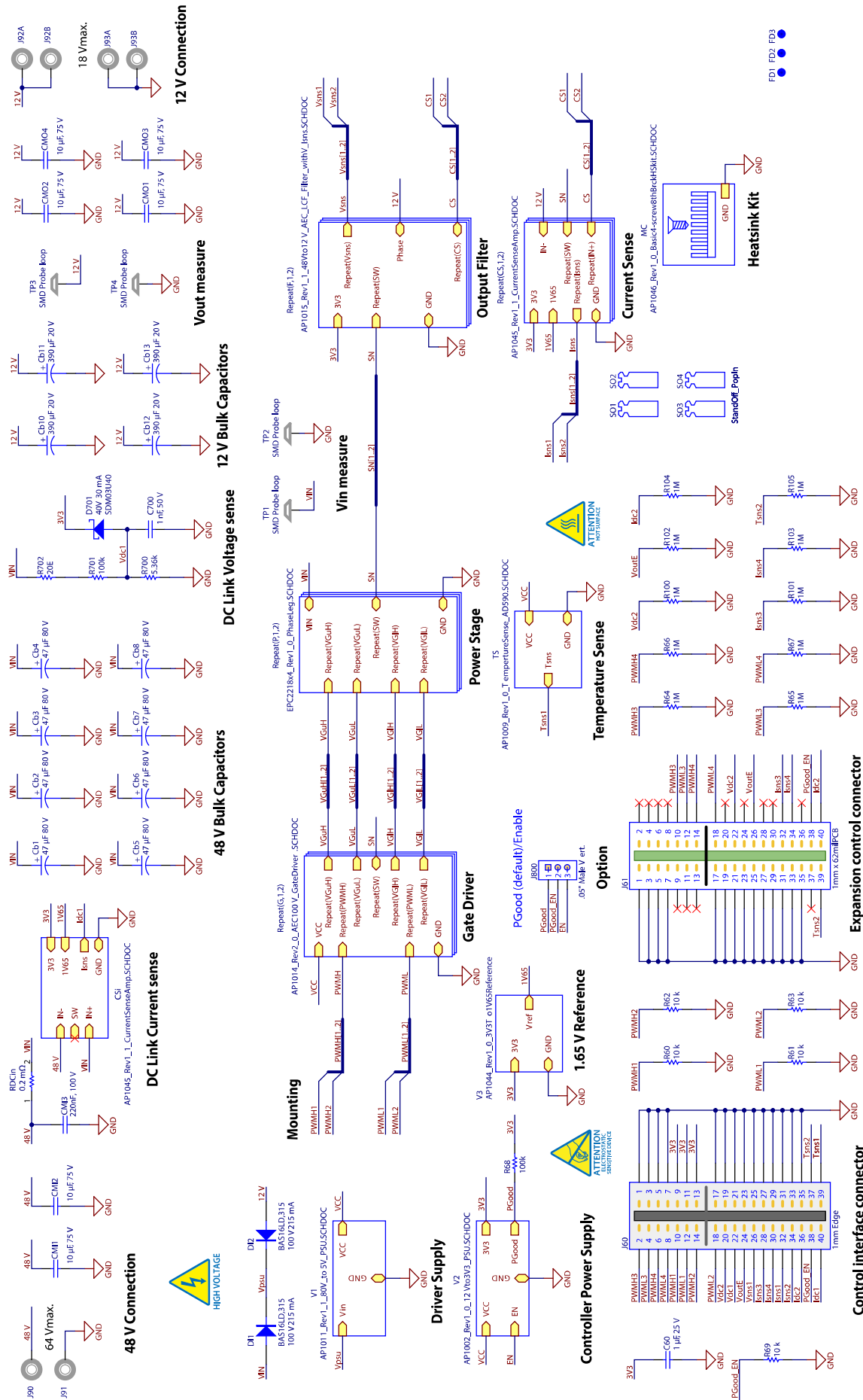


Figure 12: EPC9163C Rev1.0 main schematic

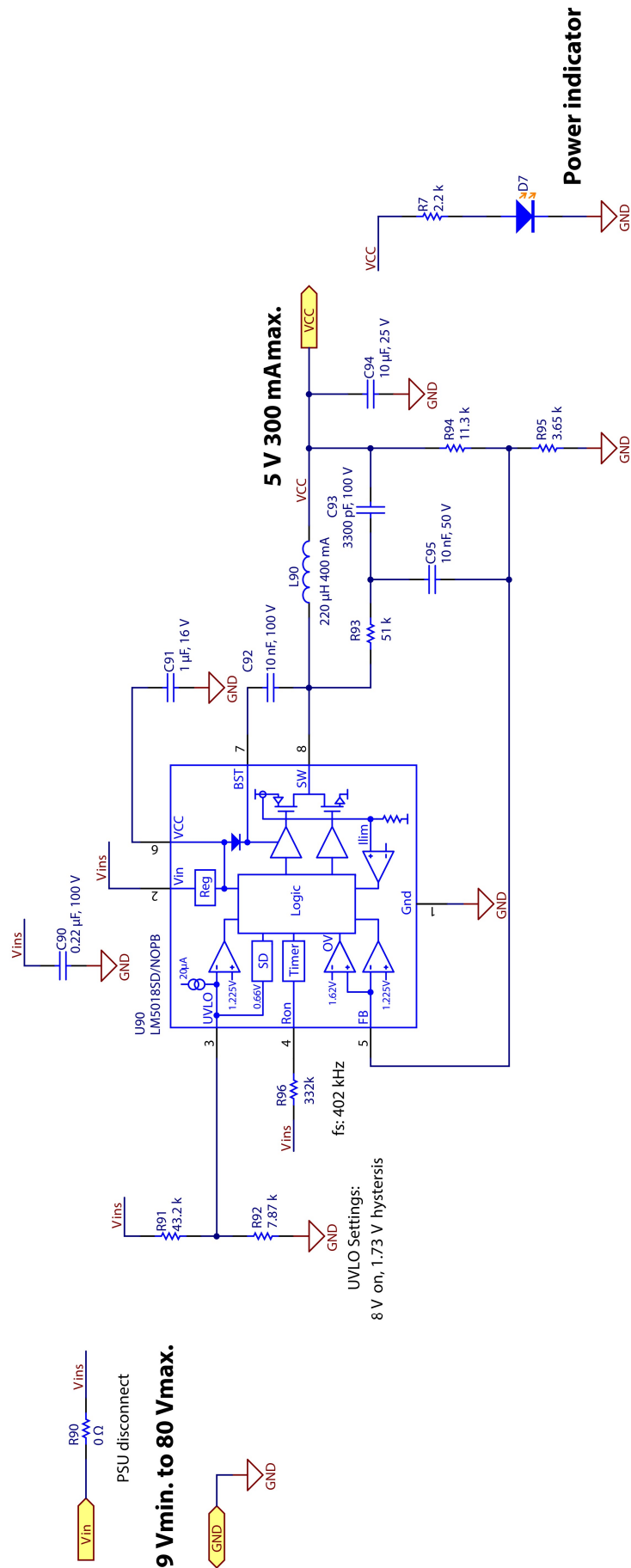


Figure 13: EPC9163 80 V to 5 V housekeeping power supply schematic



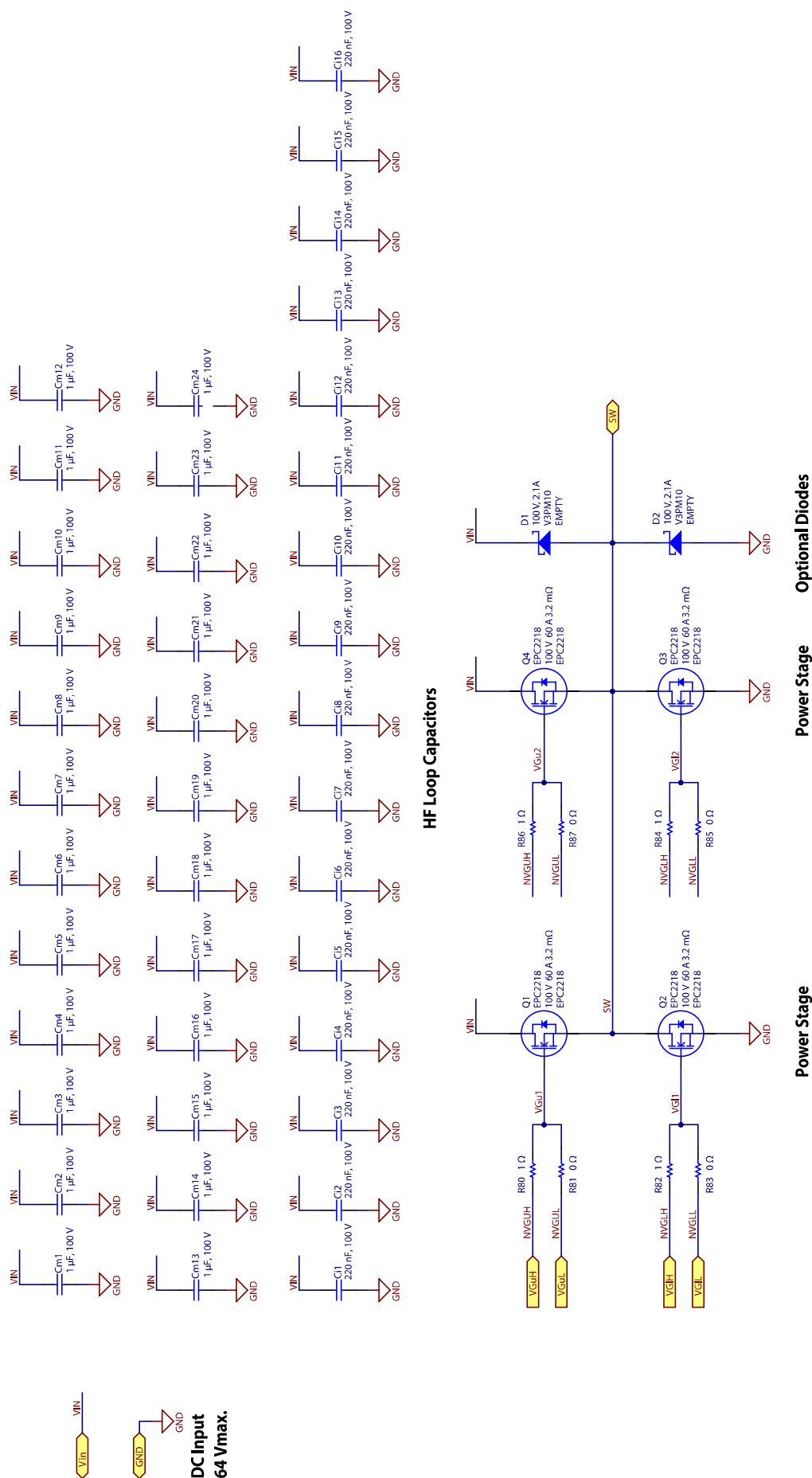
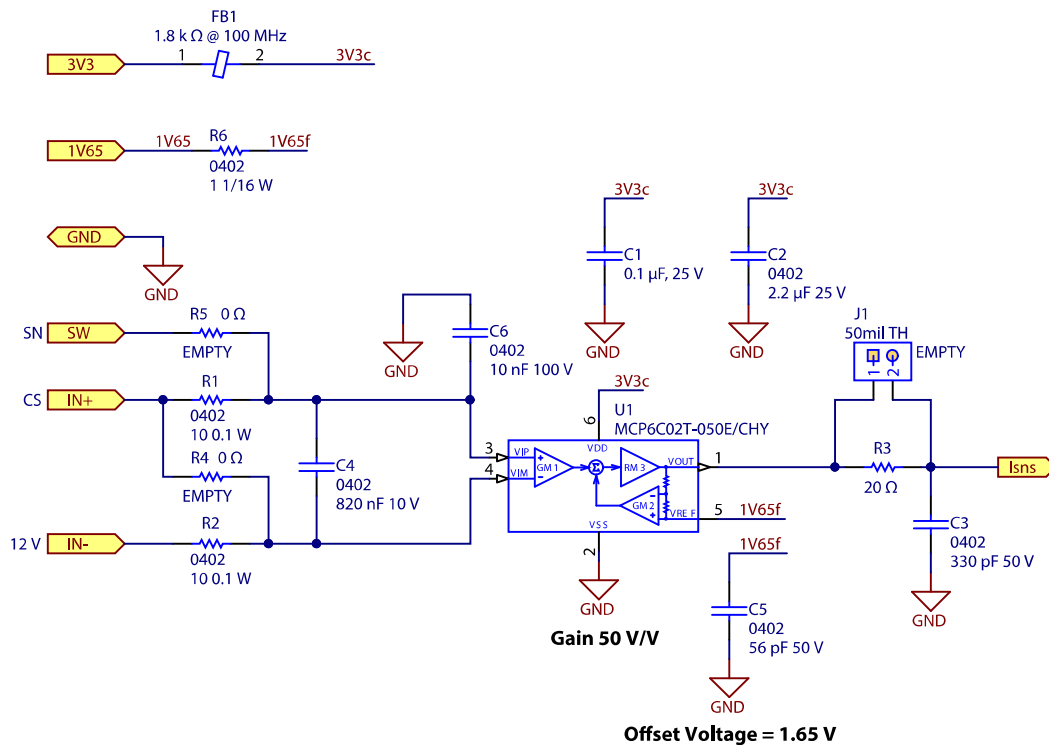
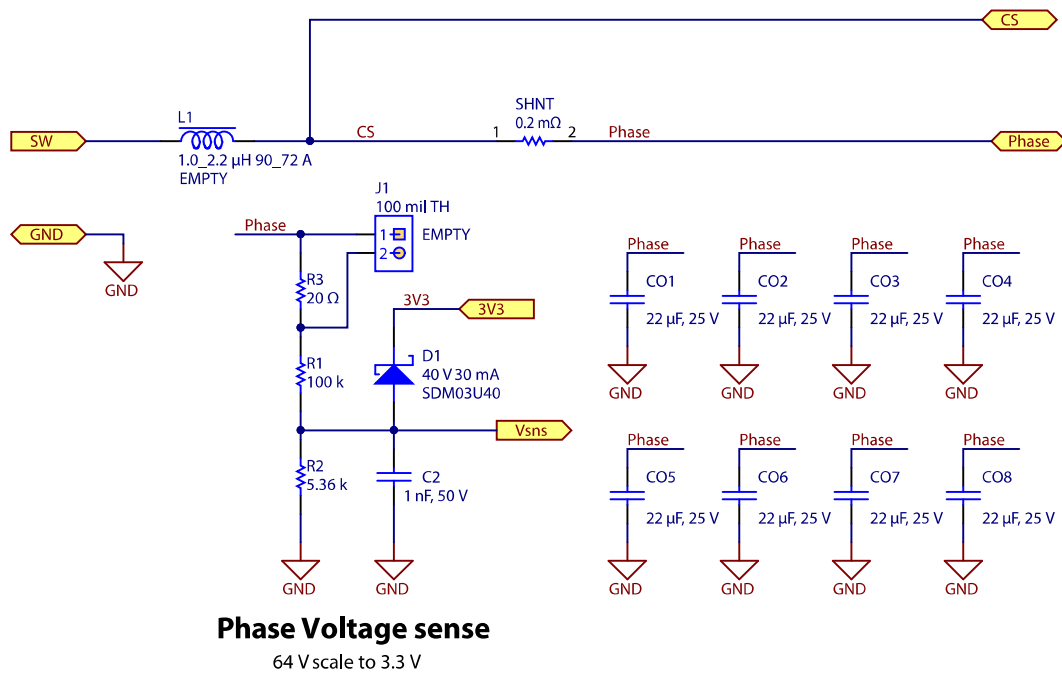


Figure 15: EPC2218 phase-leg schematic



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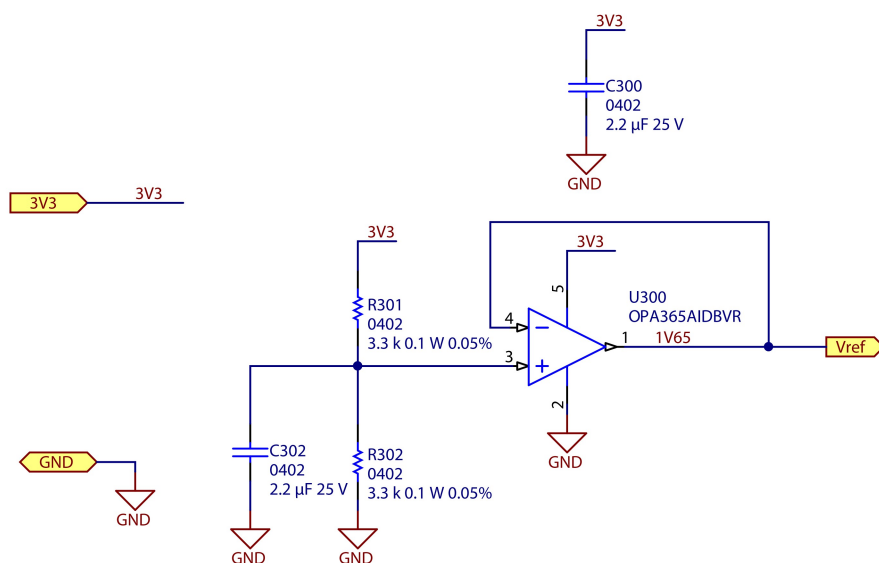


Figure 19: EPC9163 1.65 V reference schematic

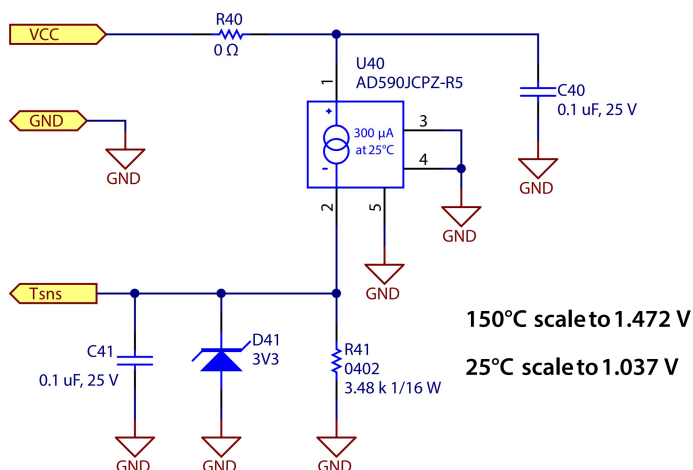
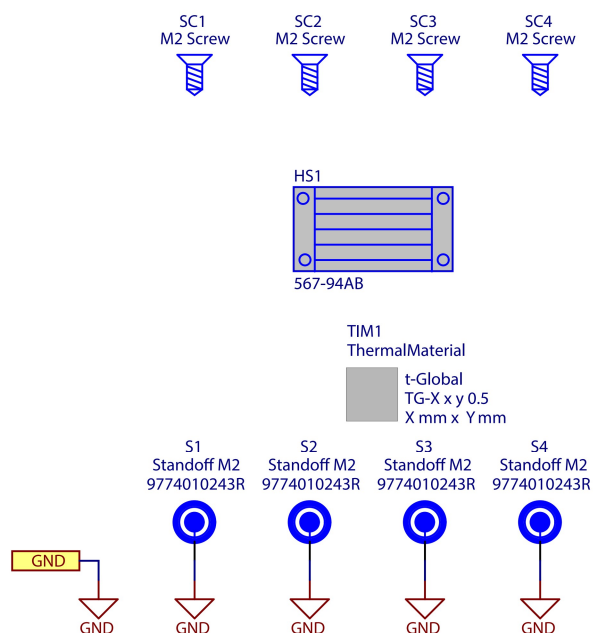


Figure 20: EPC9163 AD590 temperature sense schematic



Heatsink Kit

Figure 21: EPC9163 heatsink kit schematic

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