Demonstration Board EPC9165 Quick Start Guide

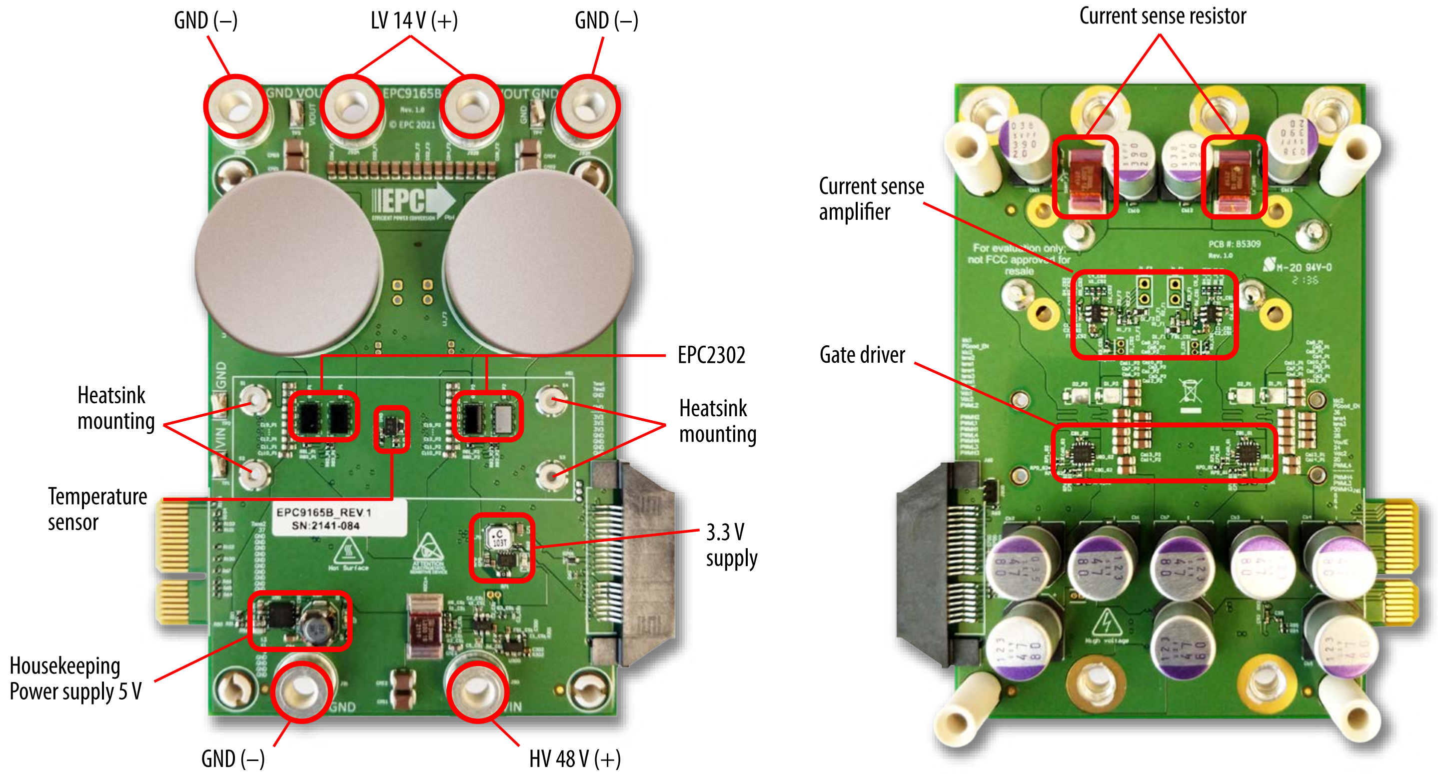
2 kW 48 V/14 V 140 A Bi-Directional Power Module Evaluation Board

Revision 1.0

EFFICIENT POWER CONVERSION

DESCRIPTION

The EPC9165 evaluation power module is designed for 48 V to/from 14 V DC-DC applications. It features the EPC2302 – 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.



Top view **Bottom view**

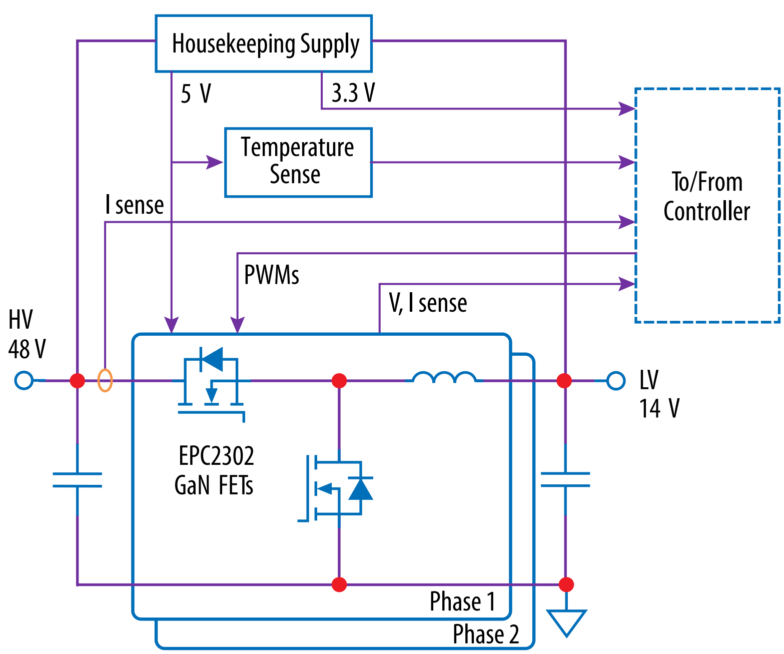
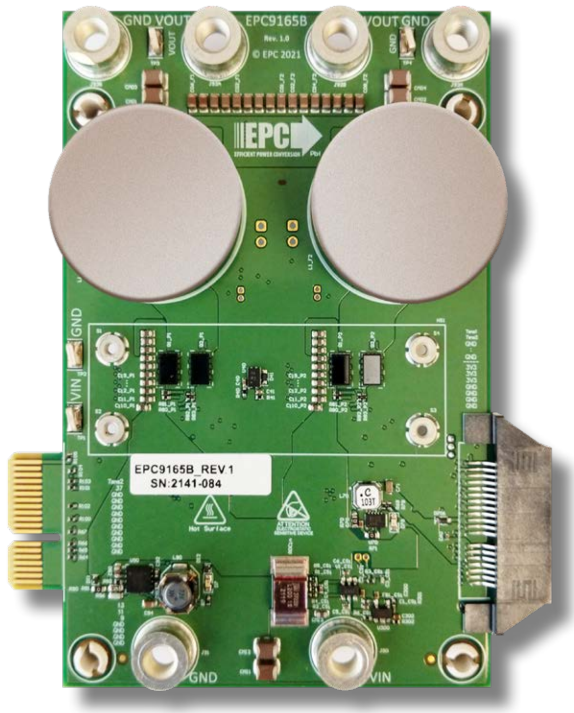


Figure 1: Functional block diagram overview of the EPC9165 board

MAIN FEATURES

- High efficiency: 96.1% @ 14.3 V/140 A output (buck)
- Dimension: 108 x 70 x 40 mm [4.3 x 2.8 x 1.6 in]
- Two-phase power stage with 100 V rated EPC2302
- Designed switching frequency: 500 kHz
- Re-programmable – Average current mode control (default)
- On board current sensor and temperature sensor
- Fault protection:
    - o Input undervoltage
    - o Input overvoltage
    - o Regulation error
    - o Inductor overcurrent
    - o Overtemperature



EPC9165 demonstration board

RECOMMENDED OPERATING CONDITIONS

Table 1: Electrical Specifications (T_A = 25°C) EPC9165

Symbol	Parameter	Conditions	Min	Nom	Max	Units
V_{IN}	Input Voltage	Buck	20	48	60	V
		Boost, during operation	11.3	14	16	
		Boost, start up	12.3			
$V_{IN,on}$	Input UVLO turn on voltage	Buck		20		
		Boost		12.3		
$V_{IN,off}$	Input UVLO turn off voltage	Buck		17.5		
		Boost		11.3		
V_{OUT}	Output Voltage	Buck	5	14.3	16	
		Boost	20	48	50	
$t_{OUT,rise}$	Output voltage rise time			100		ms
ΔV_{OUT}	Output voltage ripple	Buck, I_{OUT} = 21 A		40		mV
		Boost, I_{OUT} = 6 A		250		
$I_{OUT,BUCK}$	Buck Output Current	Buck	0		140	A
$I_{IN,BOOST}$	Boost Input Current	Boost	0		140	
I_{MAX}	Maximum current limit threshold	Buck, output current	145		150	
		Boost, input current	145		150	
T_{MAX}	Maximum temperature limit threshold	During operation	93		98	°C
$T_{Start,MAX}$	Maximum temperature to start converter	After over-temperature fault event			80	
f_S	Switching frequency			500		kHz

HIGHLIGHTED COMPONENTS AND FUNCTIONS

Power Stage

The EPC9165 features four 100 V, 1.8 mΩ EPC2302 GaN FETs. The datasheet should be read in conjunction with this quick start guide. For more information on EPC2302 please refer to the datasheet available from EPC at www.epc-co.com.

Housekeeping supply

The EPC9165 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 (100 k 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_0 [V] vs. temperature T [°C] follows the equation:

$$V_0 = \left(\frac{3.48}{1000}\right)T + 0.95$$

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 2.

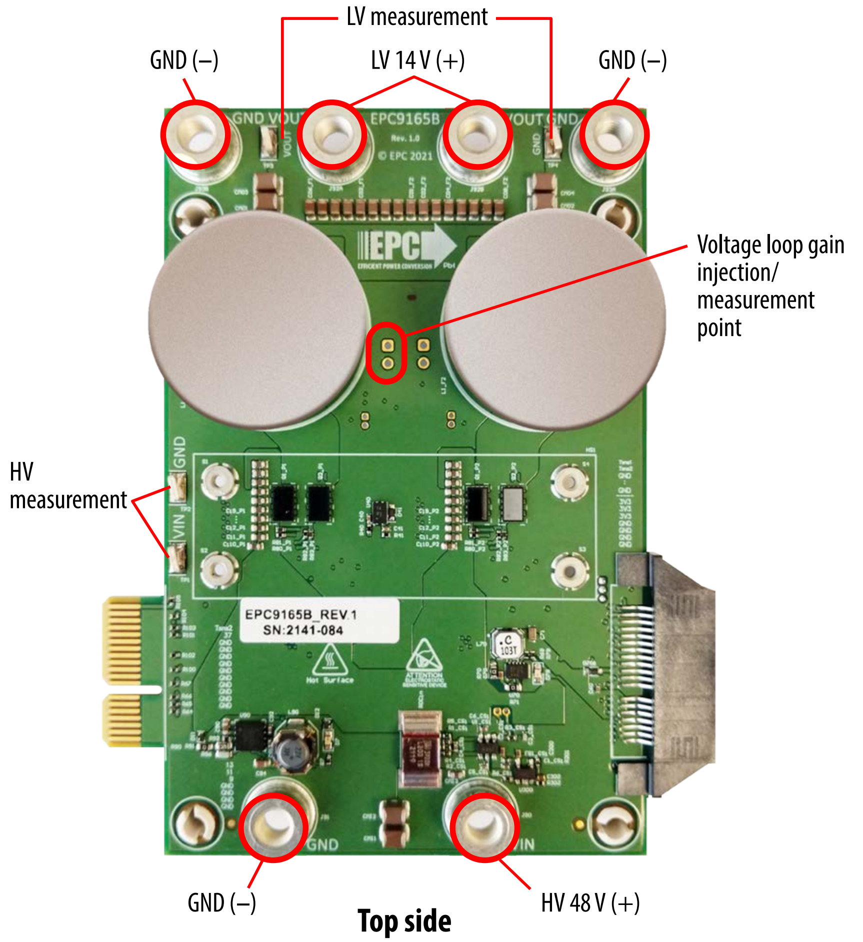


Figure 2: EPC9165 test point pad and hookup locations and designations

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 EPC9165 is given in table 2.

Table 2: Compatible controller interface and controller boards to the EPC9165

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 EPC9165.

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.**

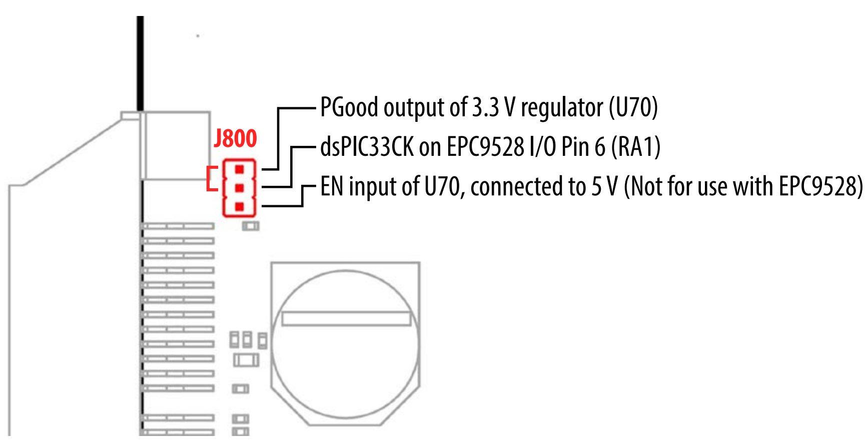


Figure 3: EPC9165 J800 jumper settings

MECHANICAL SPECIFICATIONS

Unit: mm [in]

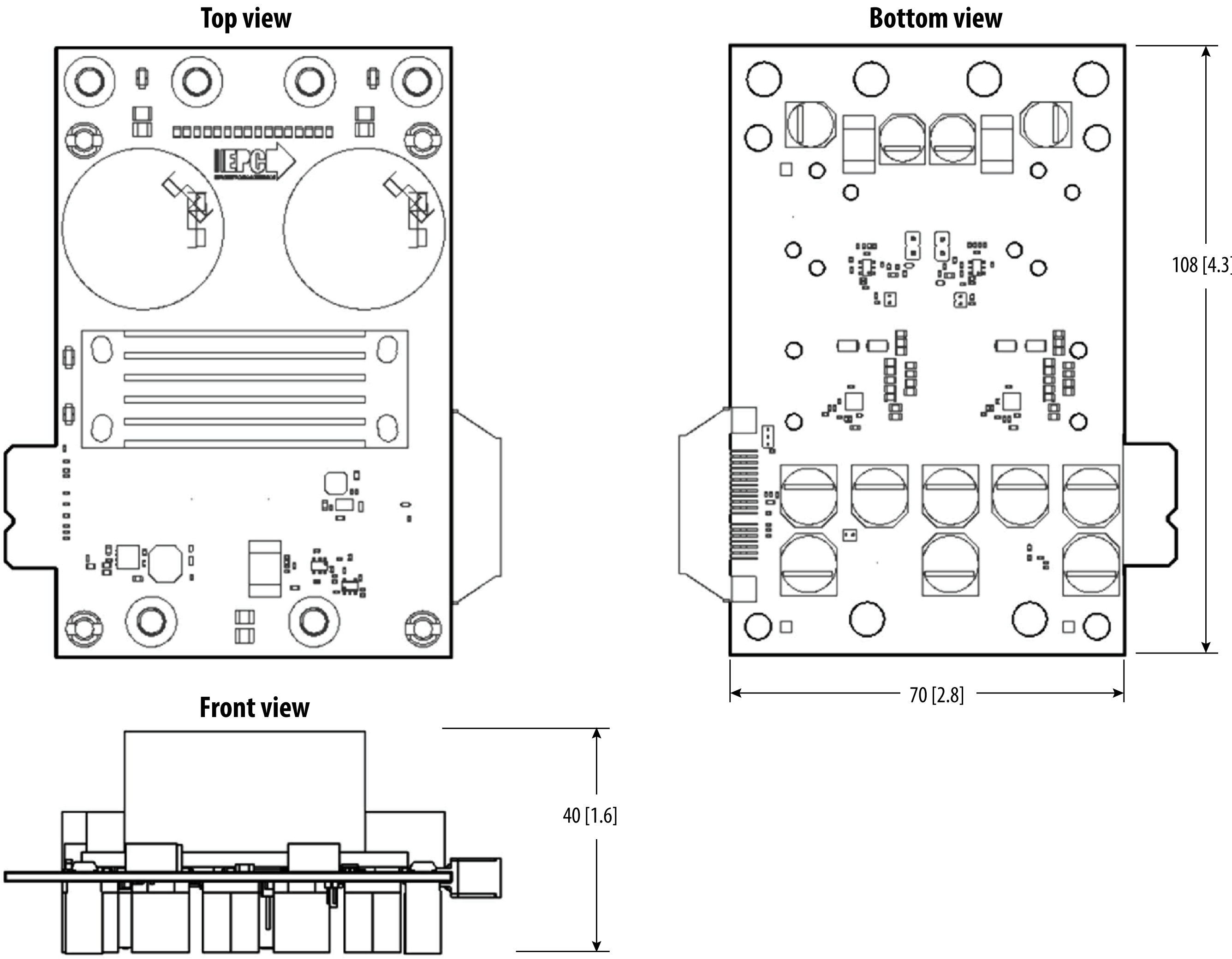


Figure 4: EPC9165 mechanical specifications

QUICK START PROCEDURE

Follow the procedure below to operate the EPC9165 as a buck/boost:

1. Program the correct firmware onto the EPC9528 controller
2. Insert the EPC9528 controller into the corresponding slot (J60) on EPC9165
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 (figure 5) are pre-installed and will provide adequate cooling for testing.

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 to higher junction temperatures.

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.

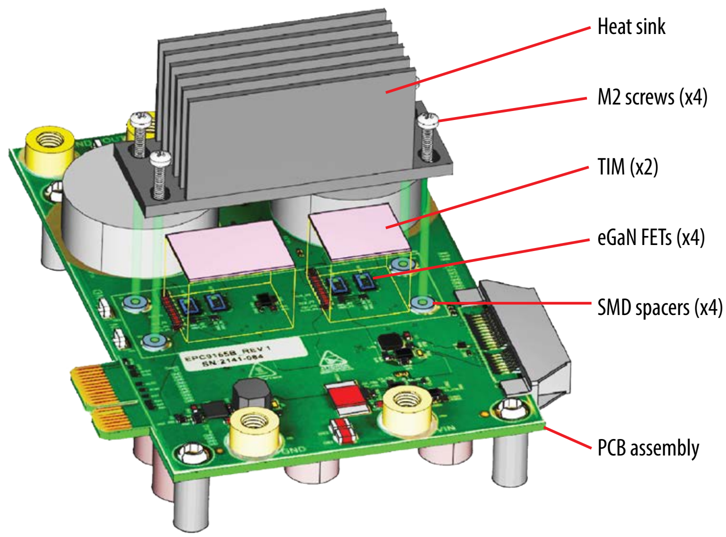


Figure 5. PCB 3D model showing TIM and heat sink installation

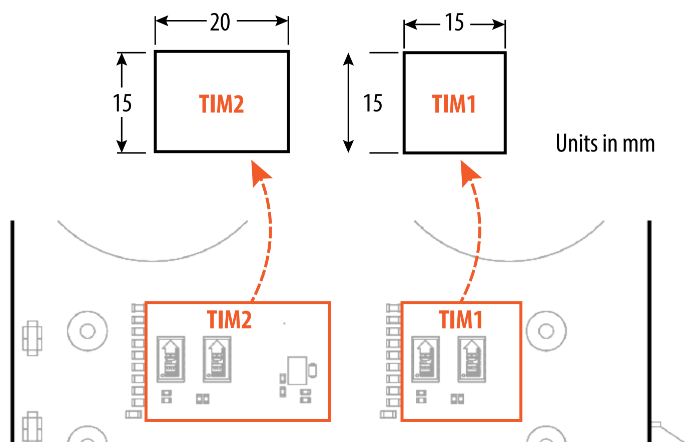


Figure 6. EPC9165 TIM specifications and location

EPC recommends the following thermal interface materials:

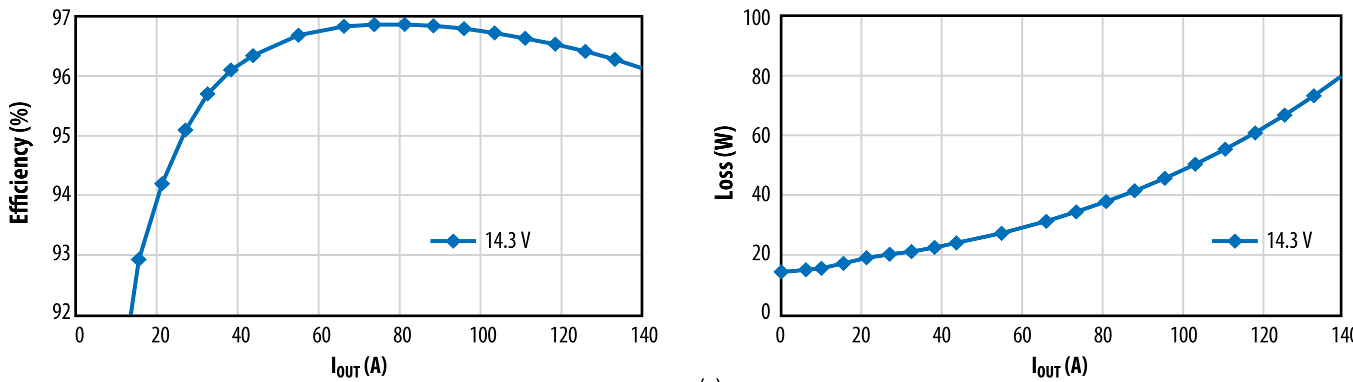
- **t-Global** P/N: TG-A1780 x 0.5 mm (highest conductivity of 17.8 W/m·K)
- **t-Global** P/N: TG-A6200 x 0.5 mm (moderate conductivity of 6.2 W/m·K)
- **Bergquist** P/N: GP5000-0.02 (~0.5 mm with conductivity of 5 W/m·K)
- **Bergquist** P/N: GPTGP7000ULM-0.020 (conductivity of 7 W/m·K)

The pre-installed TIM is TG-A1780 X 0.5 mm. The dimensions and positions of the TIM are shown in Figure 6.

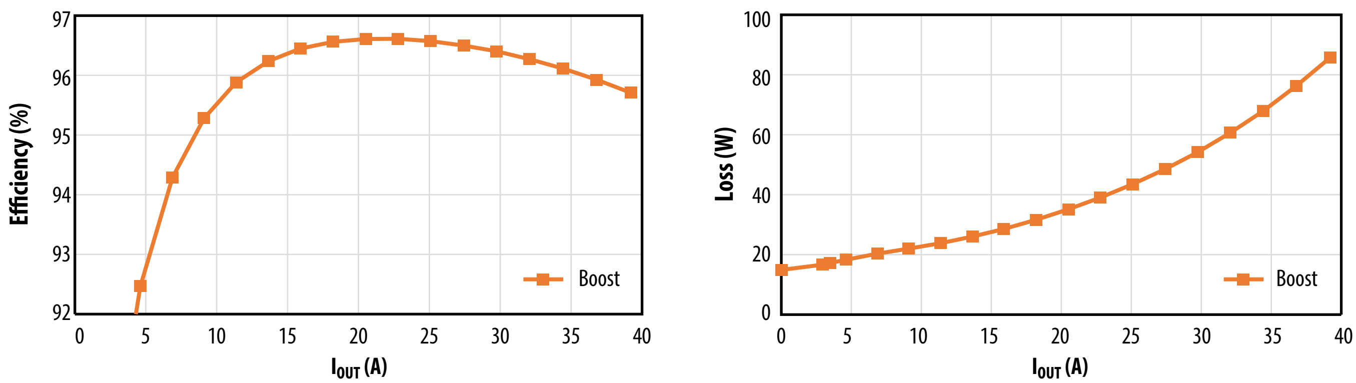
Thermal derating

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



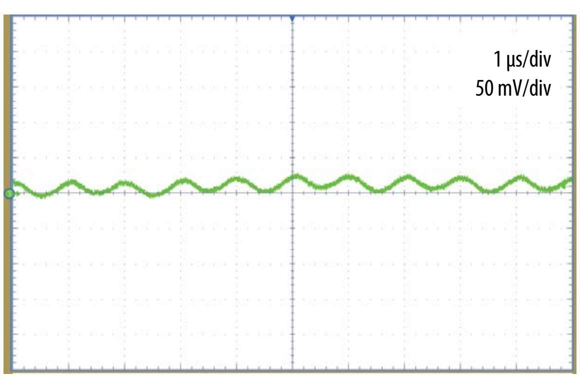
(a)



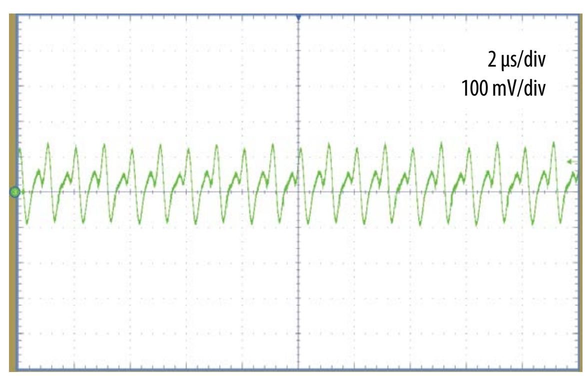
(b)

Figure 7: EPC9165 typical efficiency and power loss,
(a) buck V_{IN} = 48 V, (b) boost V_{IN} = 14.3 V, V_{OUT} = 48 V

Measurement Waveforms

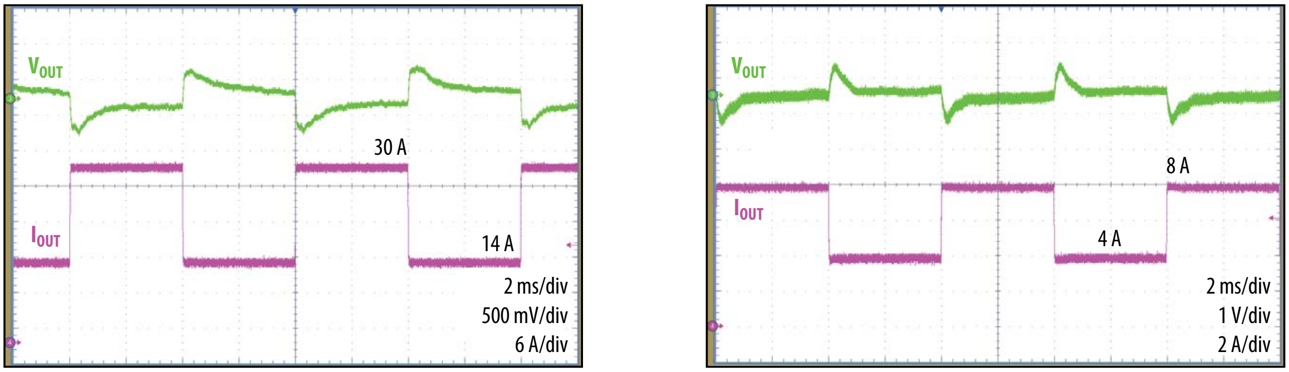


(a)



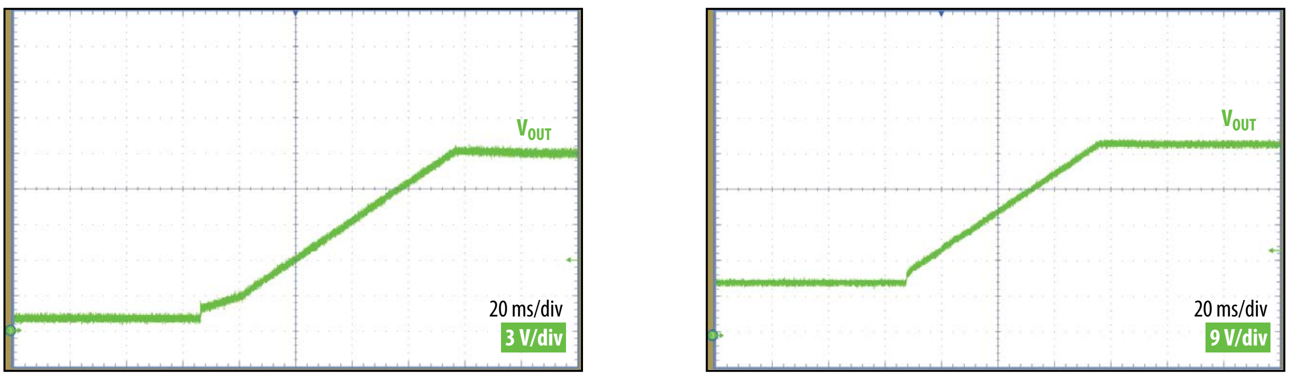
(b)

Figure 8: EPC9165 output voltage ripple
(a) buck Vin = 48V, V_{OUT} = 14.3V, I_{OUT} = 21 A; (b) boost V_{IN} = 14.3V, V_{OUT} = 48V, I_{OUT} = 6 A.



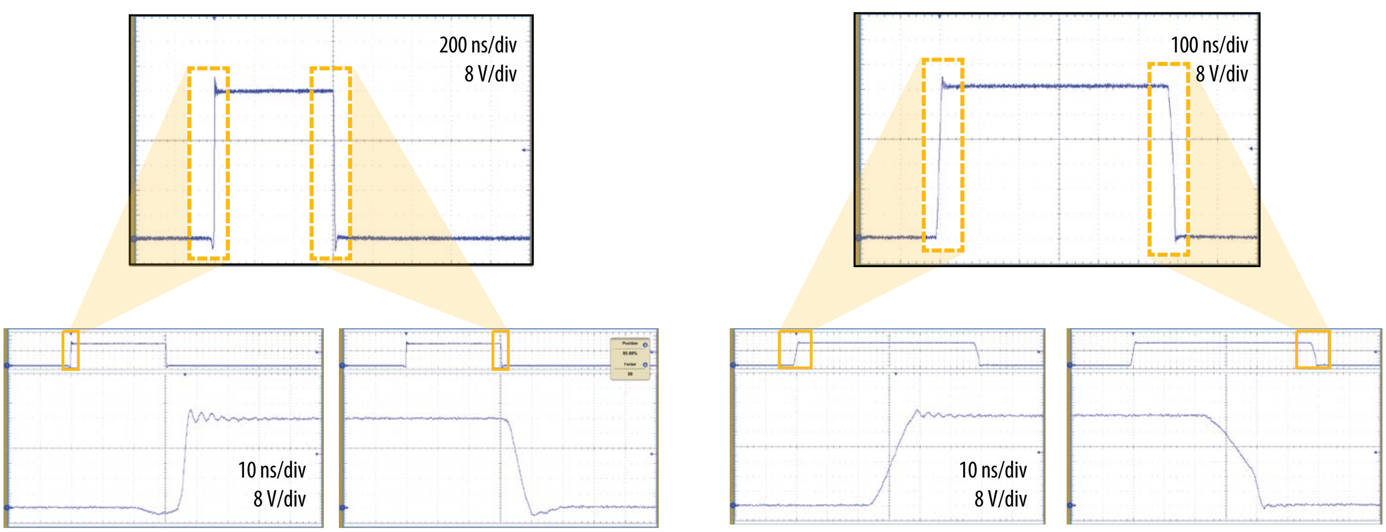
(a) (b)

Figure 9: EPC9165 transient response (a) buck V_{IN} = 48 V, V_{OUT} = 14.3 V; (b) boost V_{IN} = 14.3 V, V_{OUT} = 48 V.



(a) (b)

Figure 10: EPC9165 start up waveform, (a) buck V_{IN} = 48 V; (b) boost V_{IN} = 14.3 V



(a) (b)

Figure 11: EPC9165 switch node waveform
(a) buck V_{IN} = 48 V; (b) boost V_{IN} = 14.3 V

THERMAL PERFORMANCE

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 12.

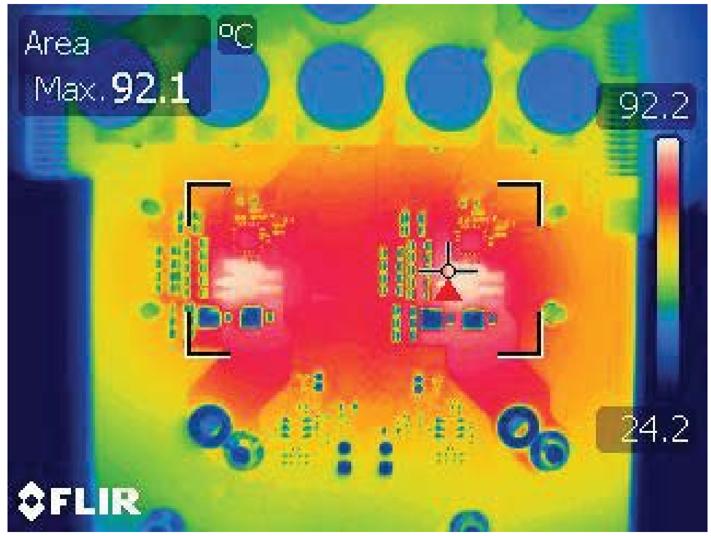


Figure 12. Thermal image showing FET region (back side of the board) temperature at full load with heatsink and 2000 LFM forced air cooling

Table 3: Bill of Materials

Item	Qty	Reference	Part Description	Manufacturer	Part #
1	7	C1_CS1, C1_CS2, C1_CSi, C40, C41, 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	3	C3_CS1, C3_CS2, C3_CSi	330 pF	TDK	C1005C0G1H331J050BA
5	3	C4_CS1, C4_CS2, C4_CSi	820 nF	Murata	GRM155R61A824KE15D
6	3	C5_CS1, C5_CS2, C5_CSi	33 pF	Samsung	CL05C330JB5NNNC
7	3	C6_CS1, C6_CS2, C6_CSi	10 nF	TDK	C1005X7S2A103M050BB
8	1	C60	1 µF, 25 V	Murata	GRM155R61E105MA12D
9	2	C60_G1, C60_G2	100 nF	TDK	C1005X7R1E104K050BB
10	1	C70	2.2 µF, 25 V	Murata	GRM155R61E225KE11D
11	1	C71	22 µF, 16 V	Samsung	CL10A226MO7JZNC
12	2	C80_G1, C80_G2	4.7 µF, 10 V	TDK	C1005X5R1A475K050BC
13	1	C90	0.22 µF, 100 V	Taiyo Yuden	HMK107C7224KAHTE
14	1	C91	1 µF, 16 V	TDK	C1005X6S1C105K050BC
15	1	C92	10 nF, 100 V	TDK	C1005X7S2A103K050BB
16	1	C93	3300 pF, 100 V	Murata	GRM155R72A332KA01D
17	1	C94	10 µF, 25 V	Murata	GRM188R61E106MA73D
18	1	C95	10 nF, 50 V	Murata	GRM155R71H103KA88D
19	8	Cb1, Cb2, Cb3, Cb4, Cb5, Cb6, Cb7, Cb8	47 µF 80 V	Panasonic	80SXV47M
20	4	Cb10, Cb11, Cb12, Cb13	390 µF 20 V	Panasonic	20SVPF390M
21	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
22	6	Ci8_P1, Ci8_P2, Ci9_P1, Ci9_P2, Ci10_P1, Ci10_P2	220 nF, 100 V	Taiyo Yuden	HMK107C7224
23	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
24	8	Cm11_P1, Cm11_P2, Cm12_P1, Cm12_P2, Cm13_P1, Cm13_P2, Cm14_P1, Cm14_P2	1 µF, 100 V	TDK	C2012X7S2A105M125AB
25	4	CMI1, CMI2, CMO1, CMO2	10 µF, 75 V	TDK	CGA6P1X7R1N106M250AC
26	2	CMO3, CMO4	10 µF, 75 V	TDK	CGA6P1X7R1N106M250AC
27	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
28	3	D1_F1, D1_F2, D701	40 V 30 mA	Diodes Inc.	SDM03U40
29	1	D7	LED 0603 **Orange**	Lite-On	LTST-C193KFKT-5A
30	1	D41	3V3 300 mW	Diodes Inc.	BZT52C3V3T-7
31	1	D78	LED 0603 **Yellow**	Lite-On	LTST-C193KSKT-5A
32	2	DI1, DI2	100 V 215 mA	Nexperia	BAS16LD,315
33	3	FB1_CS1, FB1_CS2, FB1_CSi	1.8 kΩ @ 100 MHz	TDK	MMZ1005Y182CTD25
34	1	HS1	8thB Heatsink 55 x 2 1 x 24 mm Horz. Fin	Wakefield	567-94AB
35	1	J60		Samtec	MEC1-120-02-F-D-EM2
36	6	J90, J91, J92A, J92B, J93A, J93B		Wurth	7466005R
37	1	J800	.05" Male Vert.	Sullins	GRPB031VWVN-RC
38	2	L1_F1, L1_F2	1.0 µH	Vishay	IHTH1125KZEB1R0M5A
39	1	L70	10 µH	Coilcraft	LPS4012
40	1	L90	220 µH 400 mA	Murata	MDH6045C-221MB=P3
41	4	Q1_P1, Q1_P2, Q2_P1, Q2_P2		EPC	EPC2302
42	6	R1_CS1, R1_CS2, R1_CSi, R2_CS1, R2_CS2, R2_CSi	10	Panasonic	ERJ-2RKF10R0X
43	3	R1_F1, R1_F2, R701	100 k	Panasonic	ERA-3AEB104V
44	3	R2_F1, R2_F2, R700	5.36 k	Panasonic	ERJ-2RKF5361X
45	6	R3_CS1, R3_CS2, R3_CSi, R3_F1, R3_F2, R702	20 Ω	Yageo	RT0402DRE0720RL

Table 4: Bill of Materials (continued)

Item	Qty	Reference	Part Description	Manufacturer	Part #
46	3	R6_CS1, R6_CS2, R6_CSi	1	Yageo	RC0402FR-071RL
47	1	R7	2.2 k	Panasonic	ERJ-2RKF2201X
48	1	R40	0 Ω	Vishay Dale	RCS04020000Z0ED
49	1	R41	3.48 k	Panasonic	ERA-2ARB3481X
50	9	R60, R61, R62, R63, R69, R71_G1, R71_G2, R76_G1, R76_G2	10 k	Yageo	RC0402FR-0710KL
51	10	R64, R65, R66, R67, R100, R101, R102, R103, R104, R105	1 M	Stackpole	RMCF0402FT1M00
52	1	R68	100 k	Panasonic	ERJ-2GEJ104X
53	5	R70, R71, R78_G1, R78_G2, R90	0 Ω	Panasonic	ERJ-3GEY0R00V
54	4	R70_G1, R70_G2, R75_G1, R75_G2	2.00 Ω+02	Panasonic	ERJ-2GEJ2R2X
55	1	R78	330 Ω	Panasonic	ERJ-2RKF3300X
56	4	R80_P1, R80_P2, R82_P1, R82_P2	1 Ω	Yageo	RC0402FR-071RL
57	4	R81_P1, R81_P2, R83_P1, R83_P2	0 Ω	Stackpole	RMCF0402ZT0R00
58	1	R91	43.2 k	Yageo	RC0603FR-0743K2L
59	1	R92	7.87 k	Yageo	RC0402FR-0714K7L
60	1	R93	51 k	Yageo	RC0402JR-0751KL
61	1	R94	11.3 k	Yageo	RC0402FR-0711K3L
62	1	R95	3.65 k	Yageo	RC0402FR-073K65L
63	1	R96	332 k	Vishay	MCT06030C3323FP500
64	2	R301, R302	3.3 k	Panasonic	ERA-2VRW3301X
65	3	RDCin, SHNT_F1, SHNT_F2	0.2 mΩ	Bournes	CSS2H-3920R-L200F
66	4	S1, S2, S3, S4	Standoff M2	Wurth	9774010243R
67	4	SO1, SO2, SO3, SO4		Keystone	8834
68	4	TP1, TP2, TP3, TP4		Keystone	5019
69	3	U1_CS1, U1_CS2, U1_CSi		MicroChip	MCP6C02T-50E/CHY
70	1	U40	Temperature Current Source	Analog	AD590JCPZ-R5
71	1	U70	IC REG BUCK 3.3 V	TI	TPS62177DQCR
72	2	U80_G1, U80_G2	GaN gate driver	MPS	MPQ1918
73	1	U90	Buck Regulator 100 V, 300 mA	Texas Instruments	LM5018SD/NOPB
74	1	U300		Texas Instruments	OPA365AIDBVR

Table 5: Optional Components

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

Table 6: Heatsink Kit

Item	Qty	Reference	Part Description	Manufacturer	Part #
1	1	HS1	Heatsink 55x21x24mm Horz. Fin	Wakefield	567-94AB
2	4	SC1, SC2, SC3, SC4	M2 6 mm screw	McMasterCarr	95836A107
3	1	TIM1	0.5 mm thick custom cut thermal interface material	t-Global	TG1780 0.5
4	1	TIM2	0.5 mm thick custom cut thermal interface material	t-Global	TG1780 0.5

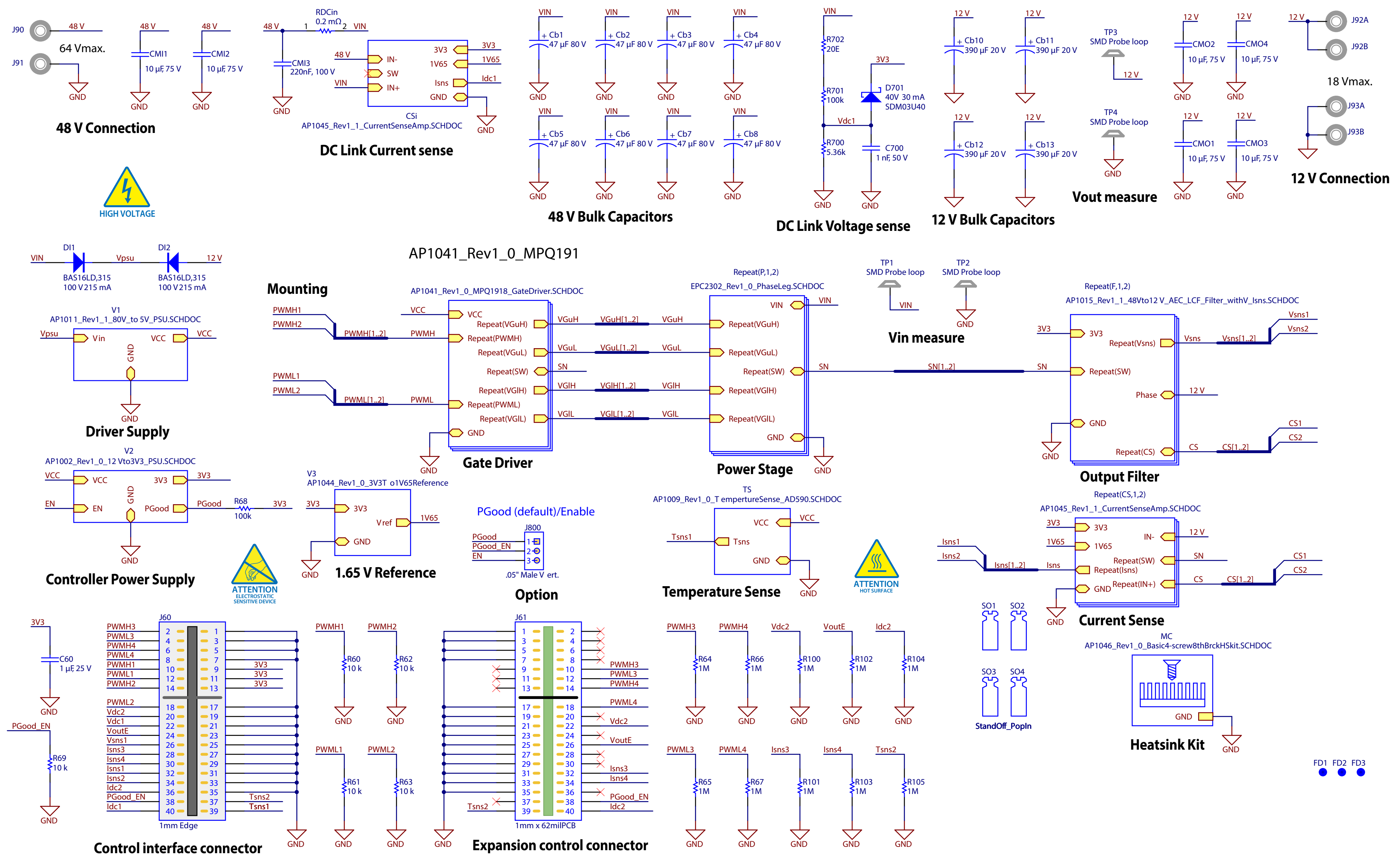


Figure 13: EPC9165 B5284 Rev1.0 main schematic

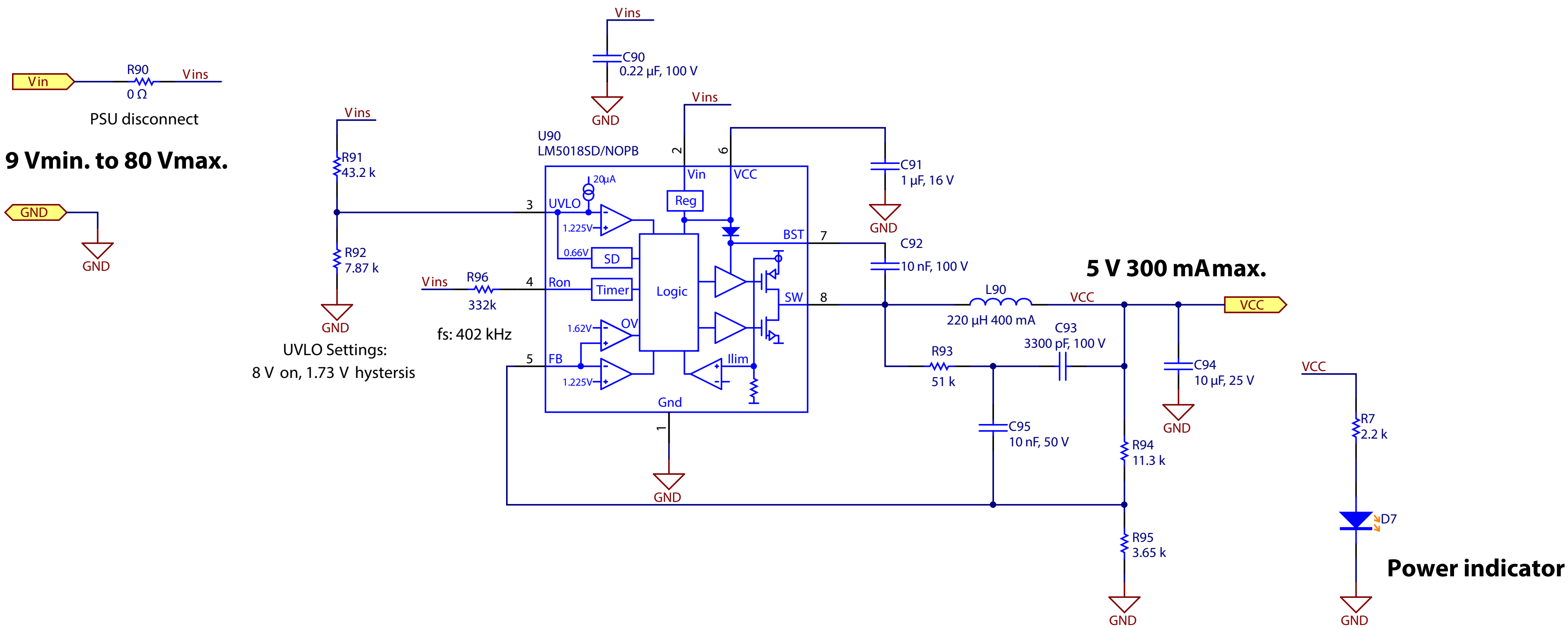


Figure 14: EPC9165 80 V to 5 V housekeeping power supply schematic

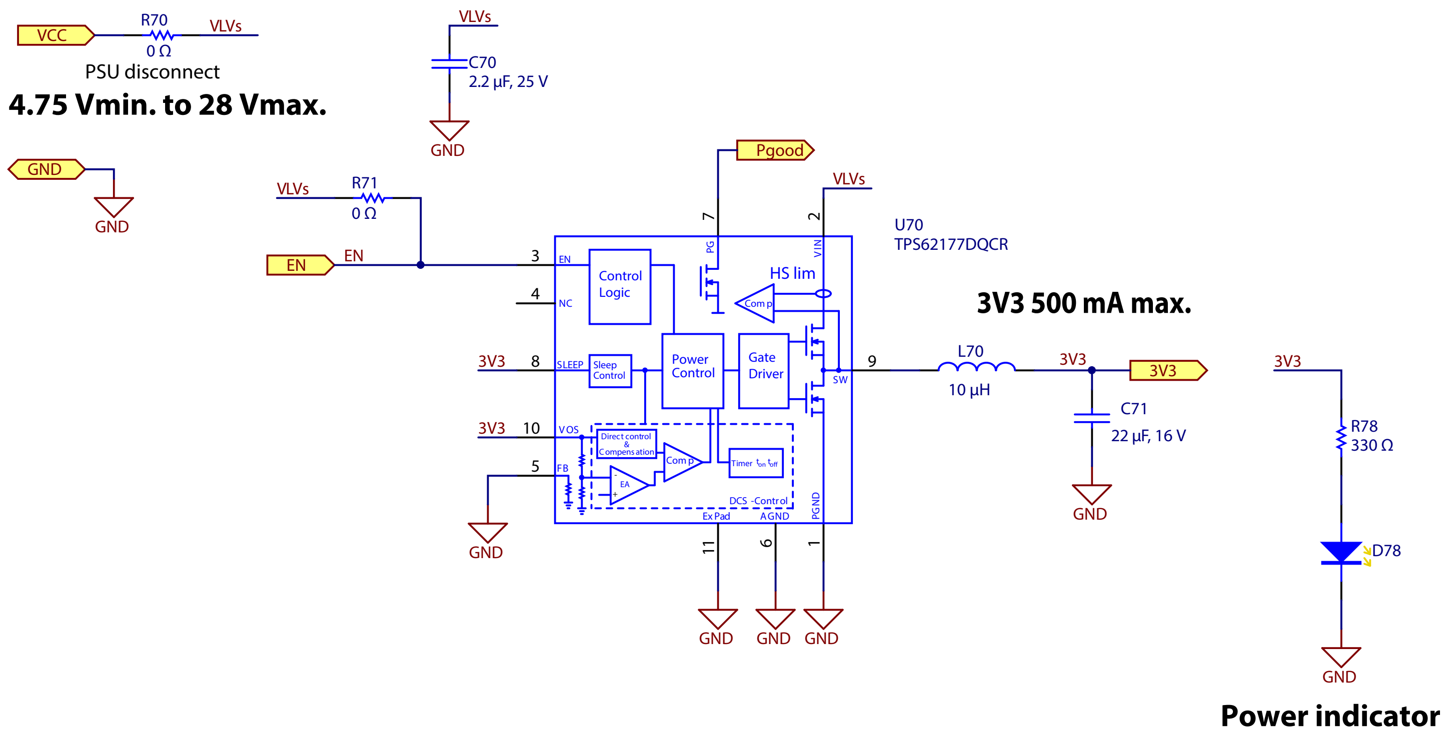


Figure 15: EPC9165 3.3 V housekeeping power supply schematic

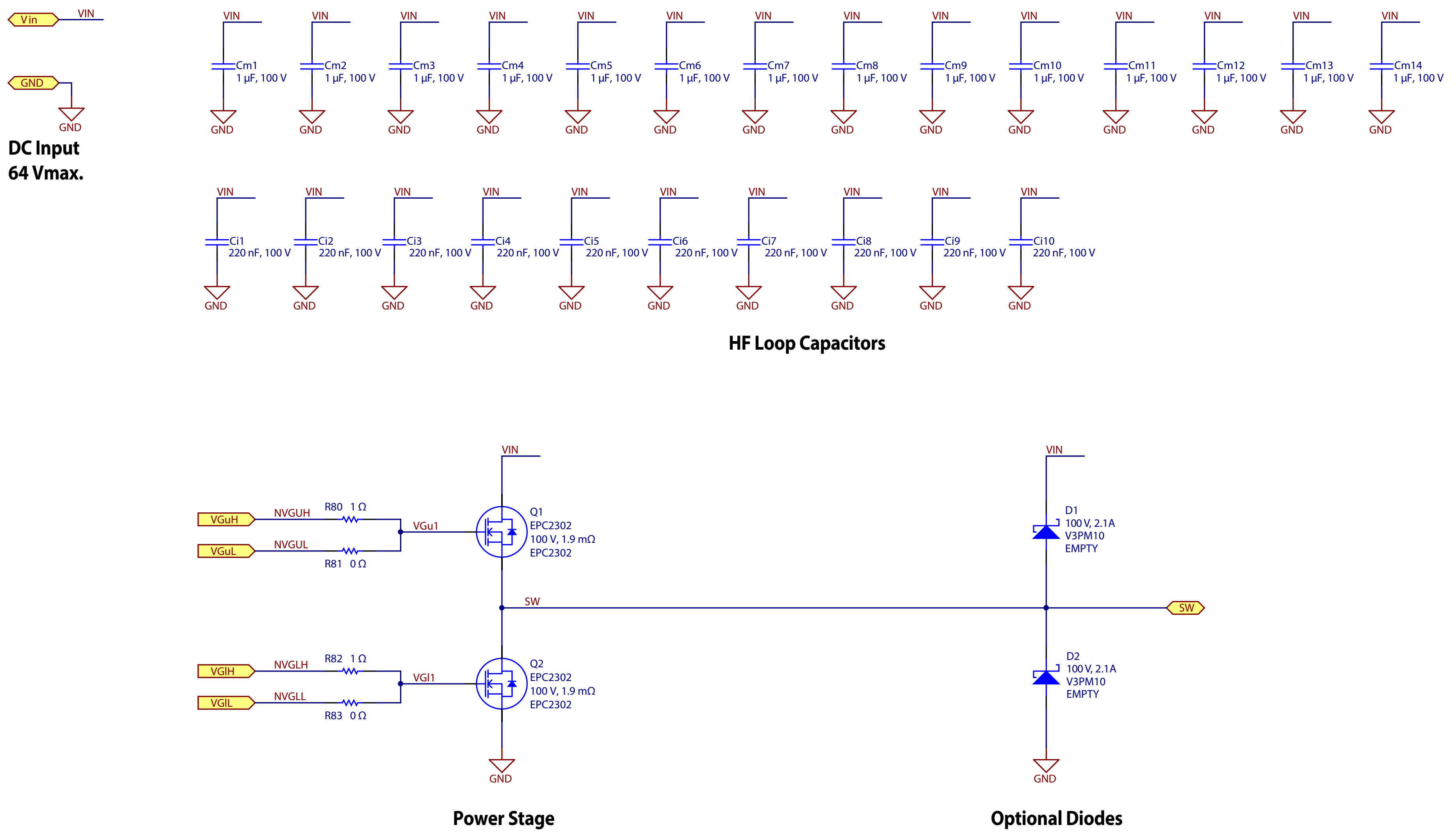


Figure 16: EPC2302 phase-leg schematic

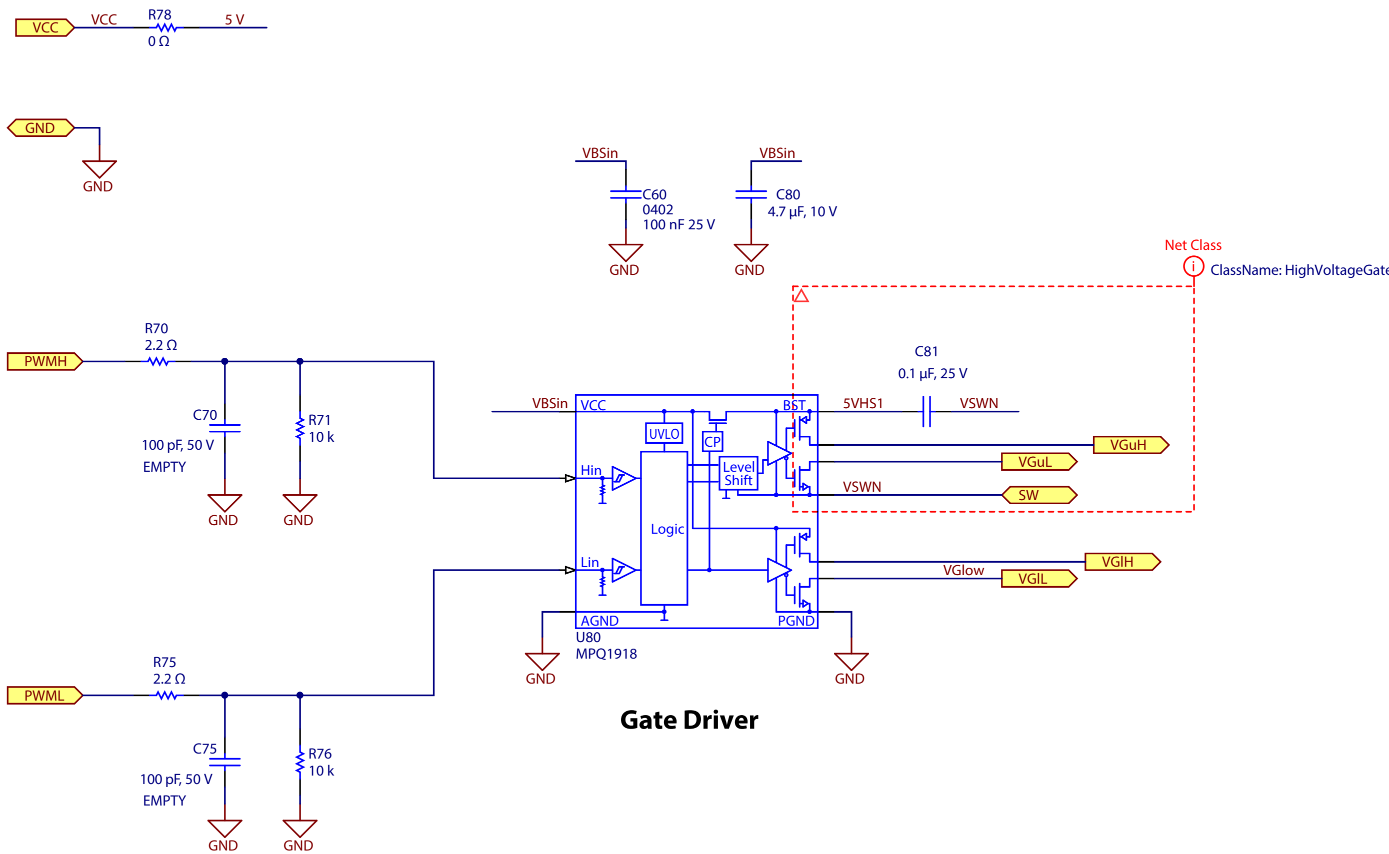


Figure 17: EEPC9165 100 V AEC gate driver schematic

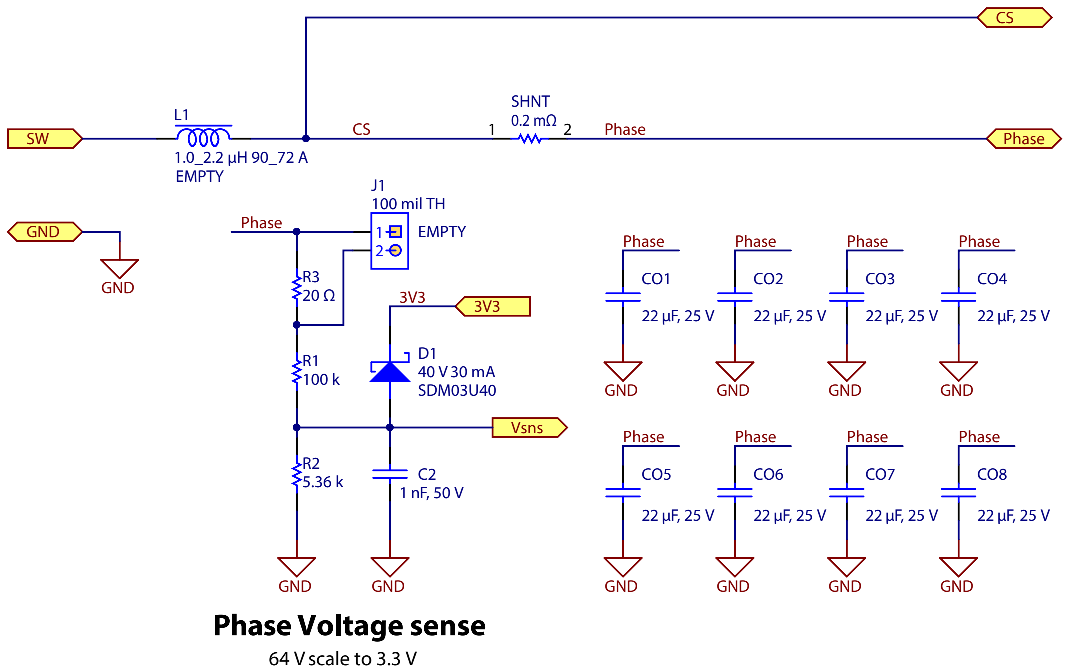


Figure 18: EPC9165 48 V to 12 V AEC high current filter schematic

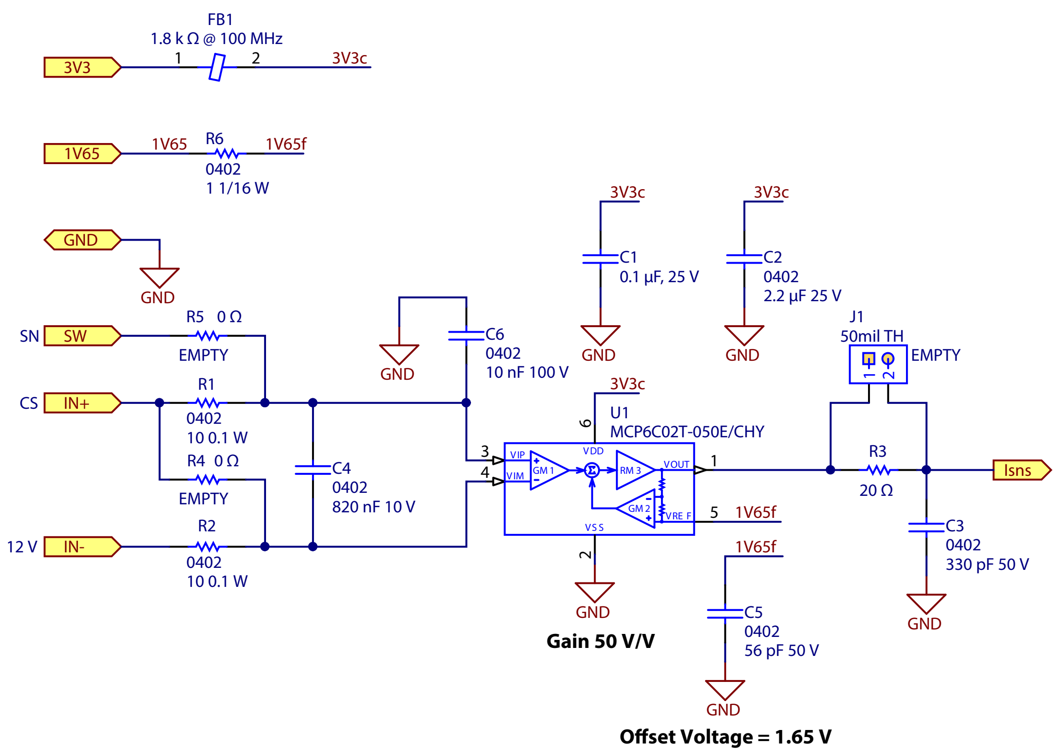


Figure 19: EPC9165 bi-directional current sense amplifier schematic

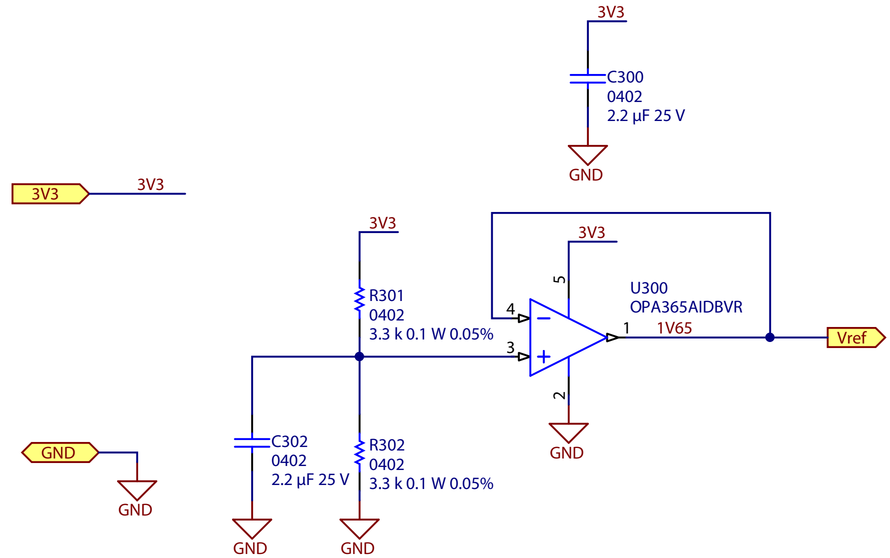


Figure 20: EPC9165 1.65 V reference schematic

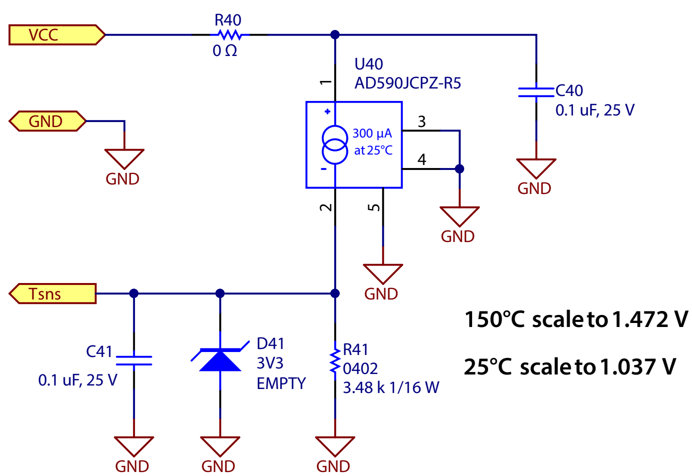


Figure 21: EPC9165 AD590 temperature sense schematic

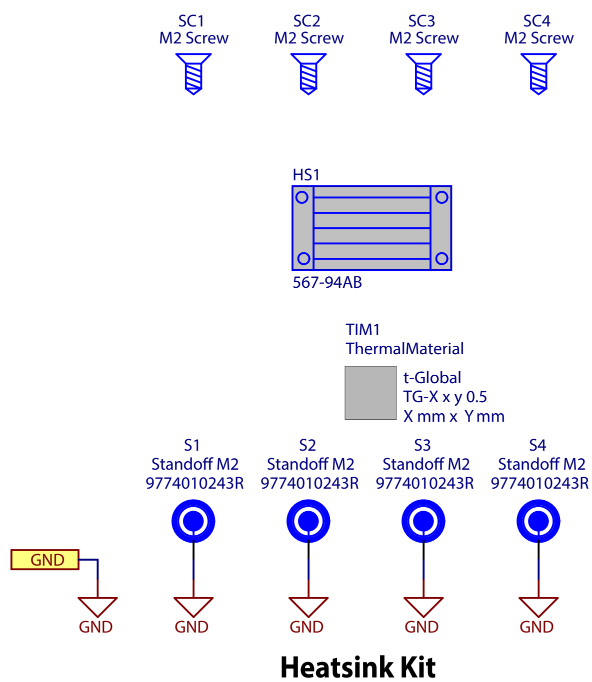


Figure 22: EPC9165 heatsink kit schematic

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EFFICIENT POWER CONVERSION

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