Demonstration Board EPC9186 Quick Start Guide

5 kW, 3-phase BLDC Motor Drive Inverter using the EPC2302 eGaN® FET

Revision 1.1

EFFICIENT POWER CONVERSION

DESCRIPTION

The EPC9186 demonstration board is a 3-phase BLDC motor drive inverter board featuring the EPC2302 eGaN FET, rated at 100 V with 1.8 mΩ $R_{DS(on\_max)}$. The EPC9186 uses four paralleled GaN FETs per switch position and can deliver up to 212 A_{pk} (150 A_{RMS}) maximum output current. The board supports PWM switching frequencies up to 100 kHz in motor drive applications. The EPC9186 contains all the necessary critical functions circuits to support a complete motor drive inverter including gate drivers, regulated auxiliary housekeeping power supplies, voltage, and temperature sense, accurate current sense, and protection functions. The main sections are shown in Figure 1. The EPC9186 mates with an assortment of compatible controllers, supported by various manufacturers leveraging existing resources for quick development purposes.

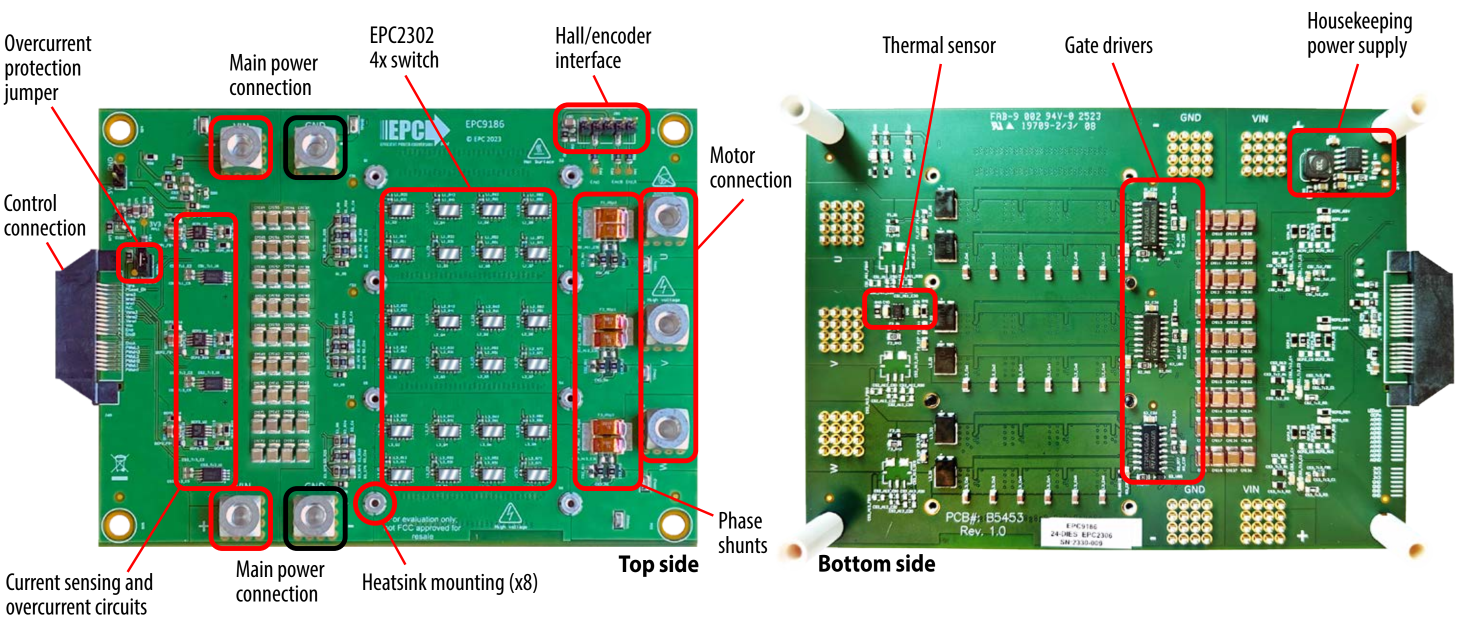


Figure 1: Photo overview of the EPC9186 board highlighting the main sections

A functional block diagram of the EPC9186 demonstration board is shown in figure 2 that details the phase current sense, phase and DC voltage sense, the half-bridge power stages, housekeeping power supply and controller interface connection.

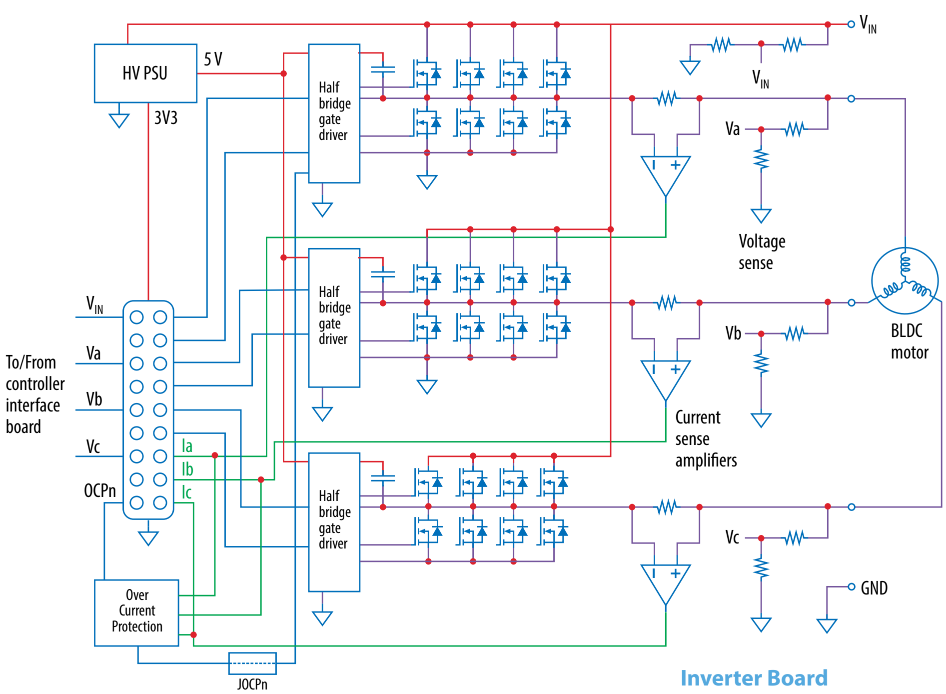


Figure 2. Block diagram of EPC9186 board in BLDC drive example application. EPC9186 has four EPC2302 in parallel per each switch.

MAIN FEATURES

- 3-phase inverter based on EPC2302 eGaN FET with wide input DC voltage ranging from 14 V to 60 V
- Dimensions: L x W = 135 x 100 mm (including connector)
- Low distortion switching that keeps motor audio emission low and reduces torque ripple
- dv/dt optimized for motor drives in the range of 6 V/ns
- All current sense with high accuracy and bandwidth (option to choose between TI INA and Allegro current sensor ICs)
- All phases voltage sense
- Voltage sense for the DC supply to the drive
- Housekeeping power for the various circuits and external controller derived from the main power supply to the EPC9186
- Temperature monitoring circuit
- Protection features including: over-current and input supply under voltage lockout
- Shaft encoder/Hall sensors interface connector for motor drive application with two voltage levels selection option

EPC9186 Demonstration board with heatsink attached

RECOMMENDED OPERATING CONDITIONS

Table 1: Electrical Specifications (T_A = 25°C) EPC9186

Symbol	Parameter	Conditions	Min	Nom	Max	Units
V_{IN}	Input supply voltage		14	48	60	V
I_{Phase}	EPC9186 Phase current[(1)]	TI INA240 Current sensing option (inverting)		70	150	A_{RMS}
		Allegro IC current sensing option (non inverting)		70	130	
f_{sw}	Switching frequency		20	100	120	kHz
V_{IN_uvlo}	Input undervoltage lockout voltage			14		V
$V_{IN\_uvlo\_hys}$	Input undervoltage lockout voltage hysteresis			1.64		
V_{IH}	PWM high-level logic threshold	PWM rising edge	2.4			
V_{IL}	PWM low-level logic threshold	PWM falling edge			0.8	
V_{IHyst}		V_{IH} Rising – V_{IL} Falling		0.5		
R_{in}	PWM input pulldown resistance			150		kΩ
PW_{min}	Minimum input pulse -width	50% level to 50% level – based on gate driver specs		120		ns
t_{Prop_delay}	PWM input to Switch-node transition delay	High-side/Low-side on/off		50		
V_{Isns_range}	Phase current sense voltage dynamic range	–Imax to Imax	0		3.3	V
I_{sns_range}	Phase current sense dynamic range	TI INA Shunt = 100 μΩ, current sense amplifier gain= 50 inverting	-330		330	A
		Allegro IC insertion = 200 μΩ gain = 33 non inverting	-250		250	
I_{ovc}[(2)]	Over-current threshold	TI option Over-current (positive and negative OVC threshold)		$\lvert 233 \rvert$		
		Allegro option Over-current		$\lvert 194 \rvert$		
V_{Isns_offset}	Amplified current sense signal offset voltage	Valid for both TI option and Allegro options		1.65		V
G_{Isns}	Amplified current sense gain	TI option - Shunt = 100 μΩ,current gain = 50. V_{1sns} - V_{1sns_offset} is positive when current enters the inverter		5		mV/A
		Allegro option - insertion = 200 μΩ, current gain = 33. V_{1sns} - V_{1sns_offset} is negative when current enters the inverter		6.6		
G_{ysns}	Phase and DC voltage sense gain	112.93 V scales to 3.3 V		29.22		mV/V

(1) Maximum current depends on die temperature – actual maximum current is affected by switching frequency, bus voltage and thermal cooling. Refer to thermal performance section in this guide and to EPC2302 data sheet for details.

(2) All phases over-current is monitored. Over-current signal is sent to the controller connector via R60. Insert JOCPn to disable PWM when over-current is detected. Over-current comparator time constant (10 μs) may be too slow for short circuit conditions.

HIGHLIGHTED PARTS

Power Stage

The EPC9186 features a 3-phase inverter with EPC2302 eGaN FET in parallel per switch and gate drivers. For more information on the EPC2302 please refer to the datasheet available from EPC at www.epc-co.com. The datasheet should be read in conjunction with this quick start guide.

Onboard power supply

The EPC9186 board includes logic and gate driver house-keeping power supplies that are powered from the main input supply voltage to the inverter board. The 3.3 V controller supply voltage is also provided to the controller connector (J60) and can be disconnected by removing a resistor (R803).

Current and voltage sense

The EPC9186 inverter is equipped with voltage and current sense for all phases and voltage sense for the DC input. The EPC9186 is equipped with two motor phase current sensor options; 1) A shunt with INA240 amplifier combination (default), 2) integrated IC current sensor.

Shunt with INA240 amplifier (default)

In the TI INA240A2 version, the output current is measured in-line using a 100µΩ shunt (RSpx) that is amplified using the INA240A2 bi-directional current sense amplifier that yields a total gain of 5m V/A. The bandwidth of the current sense amplifier is 400 kHz which is adequate for accurate motor control operation at 100 kHz switching frequency. The amplifier is **inverting**, hence current going from inverter to motor is mapped to voltage values lower than the 1.65 V offset.

Integrated current sensor option

In the Allegro IC version, the output current can be measured using Allegro ACS72981 bi-directional current sense IC (insertion resistance of 200 µΩ) with a total gain of 6.6 mV/A and an offset of 1.65 V. The Allegro IC is **non inverting**, hence current going from inverter to motor is mapped to voltage values higher than the 1.65 V offset. The reference design is populated either with the TI INA240A2 or with the ACS72981. In all configurations, the current sensing ICs are bi-directional ensuring the full four quadrant operation is covered.

The main input DC supply voltage and each phase voltage are measured using a resistor divider network that yields a total gain of 29.22 mV/V.

Temperature sensor

The EPC9186 board is equipped with a temperature sensor (U40 – AD590) that is centrally located on the bottom of the board that reports an analog voltage reading proportional to the measured temperature using the following equation that was confirmed through characterization of the EPC9186 board :

$$T = \left(\frac{V \cdot 1000}{7.87}\right) - 273.16 \ \ [°C]$$

Connection and controller mate options

A 40 pin connector is used to interface power, PWM signals and analog feedback signals between the interface control board and the EPC9186 motor drive inverter. Table 2 gives the map (J60) for each signal.

LED indicators

The EPC9186 has a number of LED indicators indicating the presence of the various supply voltages as follows:

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

Table 2: Controller interface connection (J60) pin assignment map

Pin #	Pin name		Pin #
2	PWMH1	GND	1
4	PWML1	GND	3
6	PWMH2	GND	5
8	PWML2	GND	7
10	PWMH3	3V3 [1]	9
12	PWML3	3V3 [1]	11
14	EncA	3V3 [1]	13
Index Slot			
18	EncB	AGND	17
20	EncI	AGND	19
22	Vdc	AGND	21
24	Vsns1	AGND	23
26	Vsns2	AGND	25
28	Vsns3	AGND	27
30	N.C.	AGND	29
32	Isns1	AGND	31
34	Isns2	AGND	33
36	Isns3	AGND	35
38	EN/Pgood	OC_FLT/ [2]	37
40	Tsns	LEDact	39

[1] 3.3 V is connected through the resistor R803 (installed by default)

[1] OC_FLT/ is connected through the resistor R60 (installed by default)

Test Points

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

- Touch-point pad for the 5 V supply
- Touch-point pad for the 3.3 V supply
- Touch-point pad for the Over-current detect
- A SMD hookup for each phase voltage
- Touch-point pad for the shaft encoder A or Hall_A signal
- Touch-point pad for the shaft encoder B or Hall_B signal
- Touch-point pad for the shaft encoder Index or Hall_C signal

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

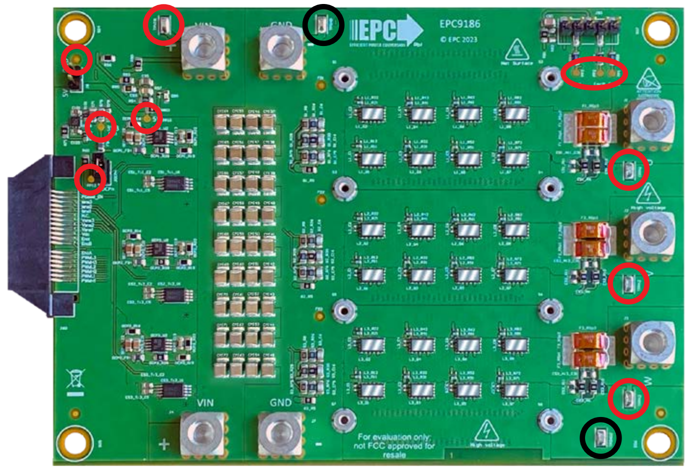


Figure 3: EPC9186 test point pad and hookup locations and designations. In black the PGND reference points.

Over-current protection

The EPC9186 includes and overcurrent detect circuit that triggers if any of the three phases current measurement exceeds a threshold that depends on the current sense option (233 A_{pk} for TI version and 194 A_{pk} for Allegro version). Once an over-current is triggered, the active low OC signal will remain low for a short period of time, determined by the RC time constant (3.6 µs) of R29 and C16 and all PWM signals will be disconnected to the gate drivers if jumper JOCPn is installed. The OC detect signal can be passed on to the controller as OC_FLT\ through R60 (installed by default). The OC signal should not be loaded by the controller and a high input impedance circuit must be used to read the status. Loading the OC signal will affect the reset time or could place the inverter in permanent over-current state.

Jumper Settings

The EPC9186 is provided with one jumper with functions given in table 3.

Table 3: Jumper settings function

Jumper	Installed	Open
JOCPn	The over-current detection circuit disables the PWM signals independently from microcontroller	The over-current detection circuit does not disable the PWM signals independently from microcontroller. In this case R60 must be mounted and the microcontroller must promptly react to over-current detection

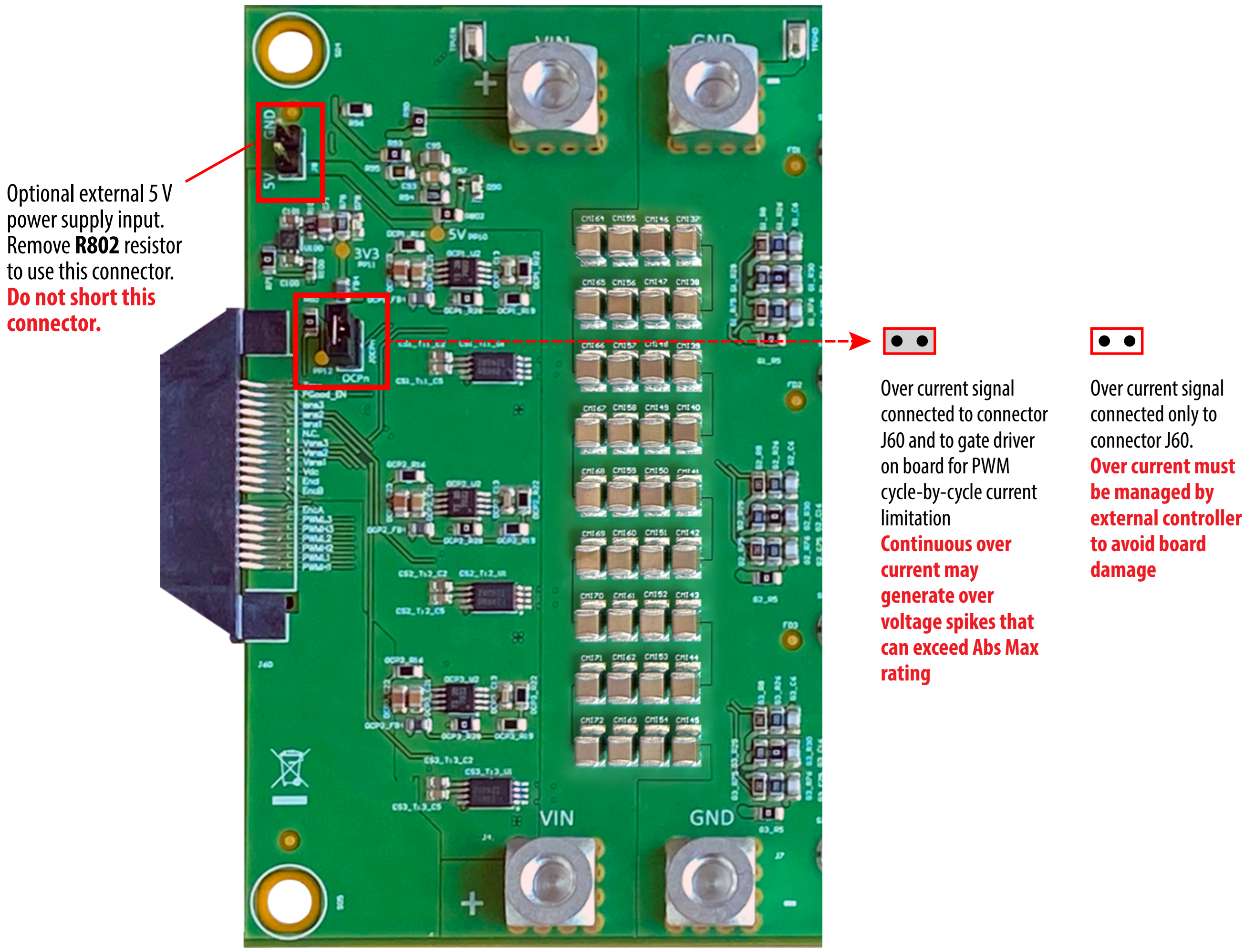


Figure 4: Over-current jumper settings and external 5 V optional power supply input

Shaft Encoder / Hall effect sensors

Connector (J80) is used to connect a shaft sensor to the EPC9186 motor drive inverter that is compatible with optical quadrature encoders or hall effect sensors and provides supply voltage for the encoder. The available voltage selections can be made by installing the applicable resistors as follows: 5 V using R81 (default), and 3.3 V using R82. The filtered signals are then provided to the controller connector (J60).

Compatible Controllers

A list of compatible controllers for the EPC9186 is given in table 4 for motor drive applications.

Table 4: Compatible controller interface and controller boards to the EPC9186

Controller Board Number	Controller Manufacturer	Controller	Target Application
EPC9147A - Rev. 2.1	Microchip - MA330031-2	dsPIC33EP256MC506	Motor Drive
EPC9147B - Rev. 1.0	Texas Instruments - LAUNCHXL-F28379D	TMS320F2837XD	Motor Drive
	Texas Instruments - LAUNCHXL-F28069M	TMS320F28069M	
EPC9147C - Rev. 1.0	ST Microelectronics	NUCLEO-G431RB / NUCLEO-G474RE	Motor Drive
EPC9147E - Rev. 2.0	Generic Interface board	N/A	Motor Drive or DC–DC converter

APPLICATION CONFIGURATIONS

The EPC9186 power board has been designed for high current motor drive applications.

Motor Drive Inverter

The EPC9186 board can be used for either sensor-less or shaft encoder or hall sensor configurations .The motor drive controller options are given in table 4 giving the user various mainstream choices that leverage existing resources to simplify and speed up development and evaluation. Figure 5 shows the simplicity of connecting a controller and motor to the EPC9186. **In the default configuration, the EPC9186 is paired with the EPC9147C (not shown) that is pre-programed to power and control a NEMA 34 size motor from Teknic M-3411P-LN-08D**, with DC supply voltage of 48 V using sensor-less field oriented control with space vector pulse width modulation (SVPWM).

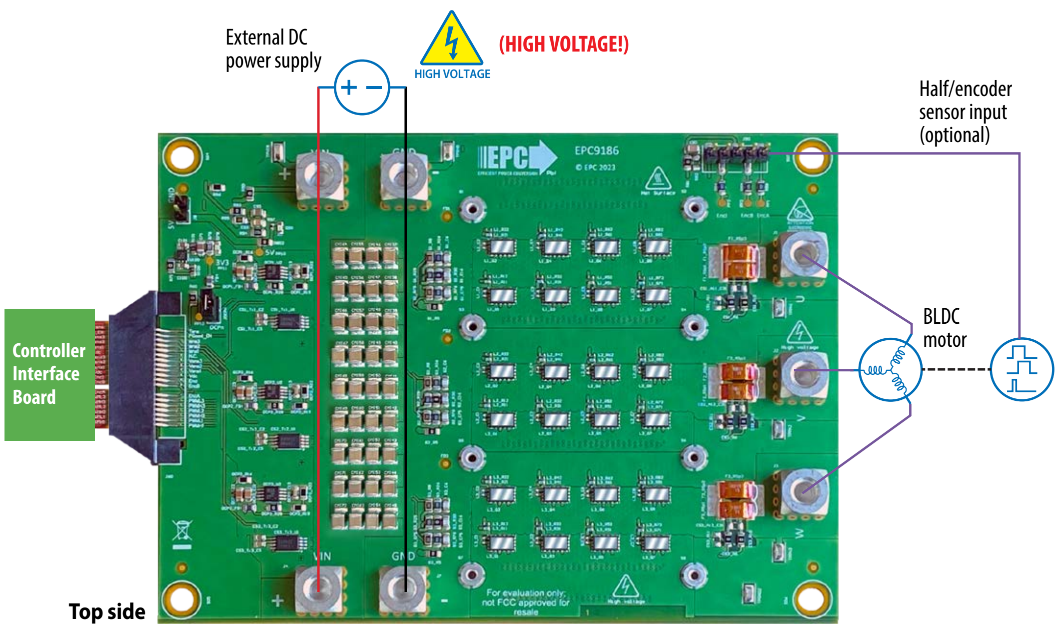


Figure 5: Connection diagram of the EPC9186 configured as a motor drive inverter

QUICK START PROCEDURE

For this quick start procedure, only the **motor drive application** using the EPC9147C controller is presented. The operating process is similar when using alternative controller options.

Follow the procedure below to operate the specific motor Teknic M-3411P-LN-08D with EPC9186 and controller board:

1. Mate the EPC9186 with an applicable controller interface board as given in table 4. Review the QSG of corresponding control interface board for detailed operating procedures.
2. Connect the correct motor, whose parameters are programmed into the controller, to the EPC9186 at connector J1 and the DC power supply at connectors J5 and J6 (**Observe correct polarity, there is no inverse polarity protection on board**) and shown in figure 5.
3. Preset the main supply voltage to the operating voltage and turn on and observe the power LEDs illuminate. Press the Start/Stop button to start the motor spinning. Additional controls are available using ST Microelectronics motor control software. Please review the **EPC9147C QSG** for details. Similarly for the alternative controllers. Firmware for the standard motor and controllers listed in table 4 are available on **GitHub**.
4. Once operational, make the necessary measurements.
5. For shutdown, press the Start/Stop button to stop the motor spinning, then turn OFF the main DC power supply.

THERMAL CONSIDERATIONS

The EPC9186 is intended for bench evaluation at room ambient temperatures and under either natural convection or forced air cooling. The addition of a heatsink can significantly improve the heat dissipation from the eGaN FETs and increase the current capacity of these devices, while ensuring to not exceed the absolute maximum die temperature of 150°C.

The EPC9186 board is equipped with eight mechanical spacers (S1 to S8) that can be used to easily attach a specific heatsink as shown in figures 8 and 9, and only requires a thermal interface material (TIM), a heatsink, and M2 screws.

The 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.

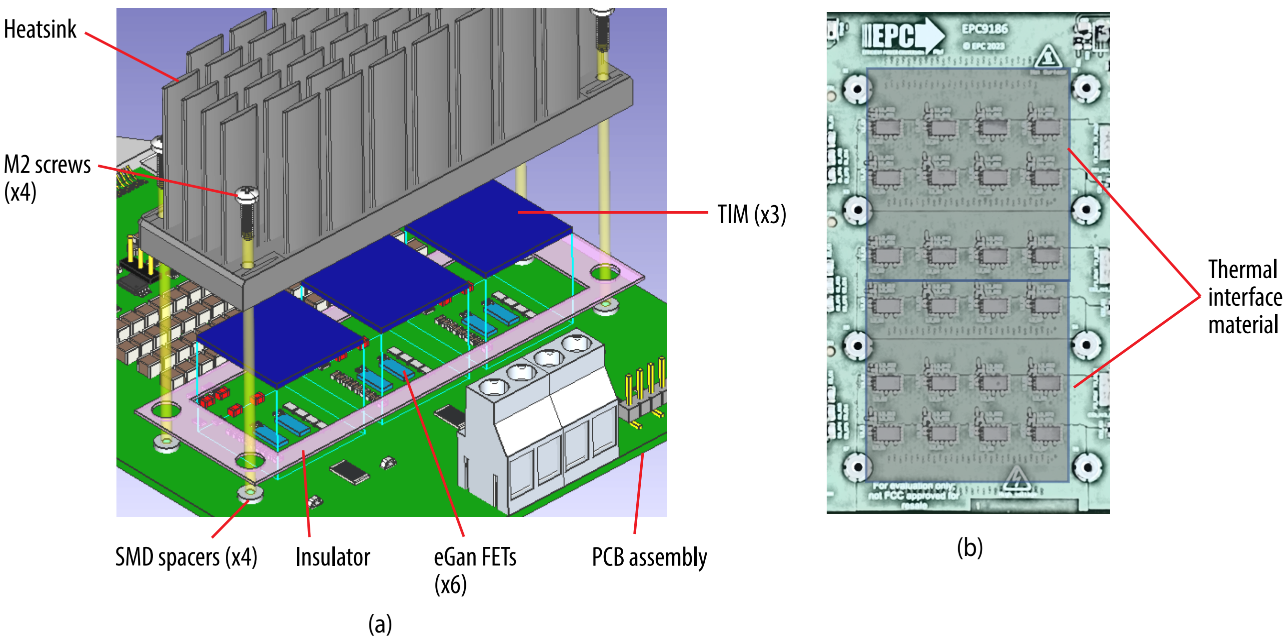


Figure 6: Details for attaching a heatsink to the board. (a) exploded 3D perspective, (b) top view showing the insulator sheet details with opening for the TIM with location of the eGaN FETs

When assembling the heatsink, it may be necessary to add a thin insulating 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 and 7. Note that the heatsink is ground connected. A rectangular opening in the insulator must be provided to allow the TIM to be placed over the FETs to be cooled with a minimum 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 by the red dashed outline in figure 7. The EPC9186 was designed to use only a TIM material without an insulator.

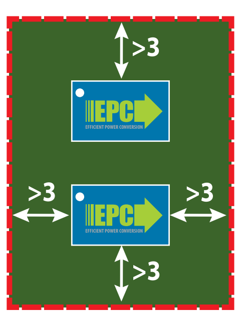
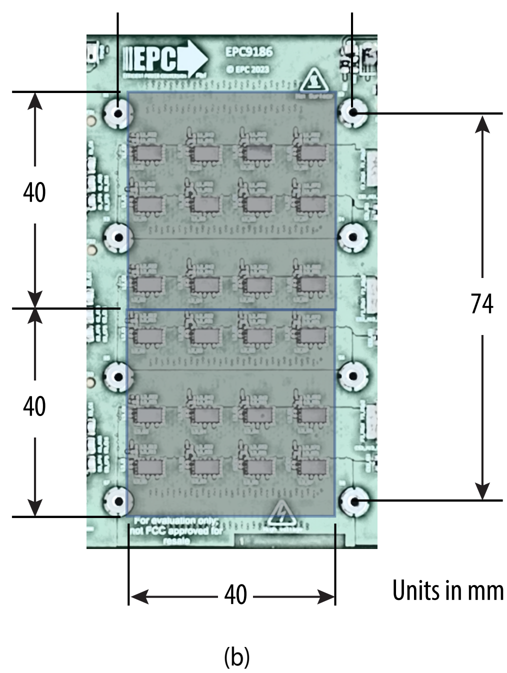


Figure 7: (a) minimum TIM coverage area



A TIM is added to improve the interface thermal conductance between the GaN ICs and the attached heatsink. The choice of TIM needs to consider the following characteristics:

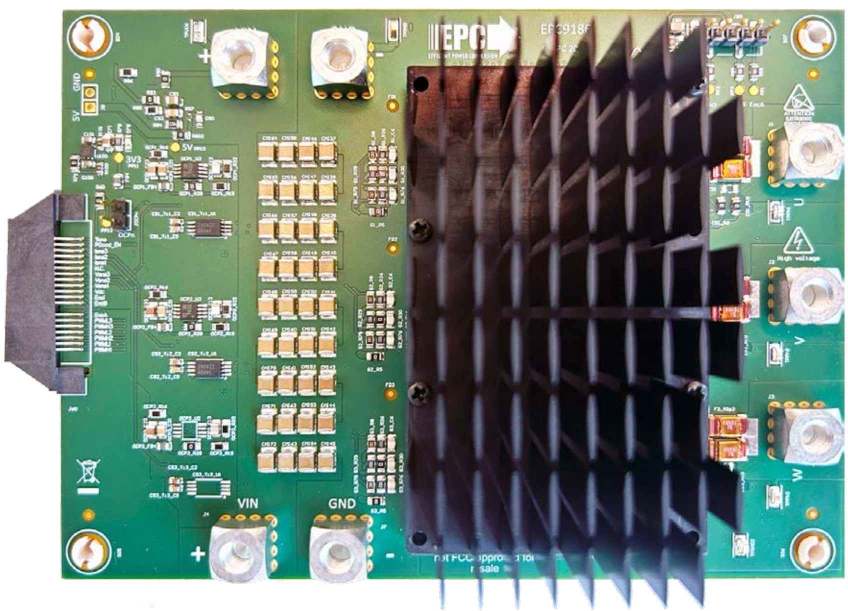
- **Mechanical compliance** – During the attachment of the heat spreader, the TIM underneath is compressed from its original thickness to the vertical gap distance between the spacers and the FETs. This volume compression exerts a force on the FETs. A maximum compression of 2:1 is recommended for maximum 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)

The default TIM used for the EPC9186 is made by t-Global Technology, measures 40 x 40 x 0.5 mm thick with P/N TG-A1780-40-40-0.5

The heat sink provided with the EPC9186 reference board is made by Alpha Novatech and it is model # LPD4980-30BM-E48 (default heatsink shown in figure 8). All tests up to 70 A_{RMS} phase current have been executed at room temperature without air convection. To reach 150 A_{RMS} phase current in steady state, it is necessary to have 400 LFM forced air convection.



Natural Convection Cooling

Figure 8: Natural convection cooling and force air cooling heatsink options installed on the EPC9186 inverter board.

EXPERIMENTAL VALIDATION EXAMPLE

The EPC9186 motor drive inverter, paired with the EPC9147C interface controller, was operated from a 48 V_{DC} supply voltage while switching at 100 kHz, 50 ns dead-time setting, powering a 5 kW motor with a sinusoidal modulation frequency of 5 Hz and delivering to the motor a phase current of 35 A_{RMS} without heat sink and under natural convection, 50 A_{RMS} with heat sink and natural convection, and 120 A_{RMS} with heat sink and 400 LFM forced air convection. In all these conditions the temperature rise vs. ambient temperature was 50°C.

MEASURED PHASE LEG WAVEFORMS

The measured waveforms of the motor phase currents while the EPC9186 operating at 100 kHz, is delivering 93 A_{RMS} into each motor phase at 60 V_{DC} Bus is shown in figure 9.

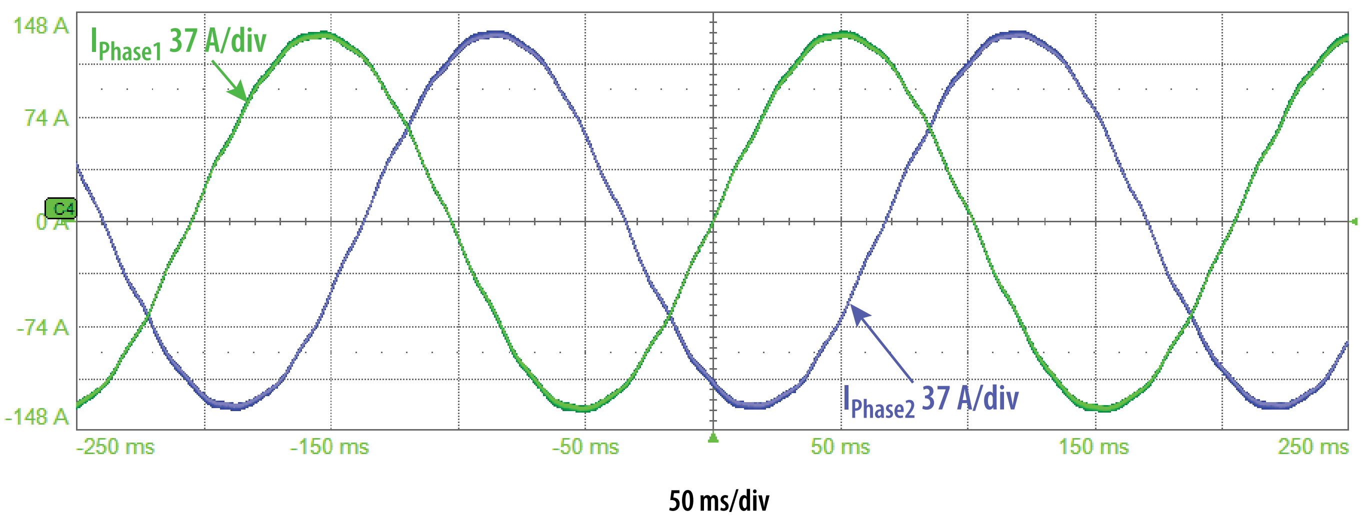


Figure 9. Phase 1 and Phase 2 current (93 A_{RMS}) at 100 kHz PWM and 60 V_{DC} bus

Figure 10 shows all four possible dv/dt slope combinations. The DC Bus voltage is set at 60 V, and the PWM frequency is set at 100 kHz, while the inverter feeds 150 A_{pk} to the motor phase. Figures 10a) and b) show the rising and falling phase voltage when the phase current flows from the inverter to the motor. Figures 10c) and d) show the rising and falling phase voltage when the phase current flows from the motor to the inverter. It is possible to observe that the dv/dt commanded by the inverter (Fig 10a and Fig 10d) is less than 10 V/ns. In the other two cases (b) and (c), the dv/dt depends on the phase current, the inverter output capacitance, and the motor inter winding capacitance. It is in any case limited below 10 V/ns.

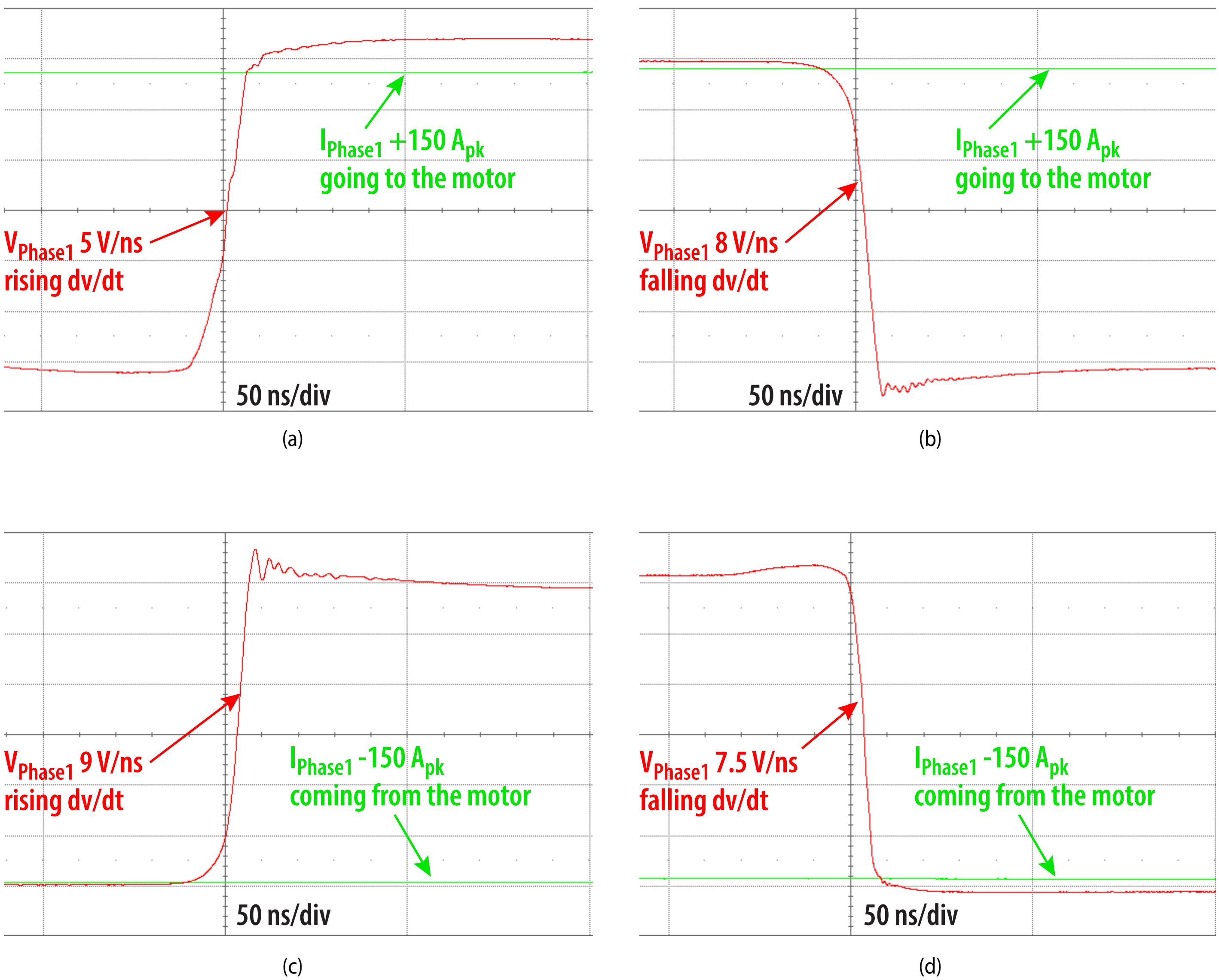


Figure 10. Phase voltage rising and falling edges when current is 150 A peak. Both positive and negative current cases are shown.

THERMAL PERFORMANCE

The thermal performance summary of the EPC9186 board is depicted in figures 11a-11c. When operated on a motor bench at an ambient temperature of 25.5°C, with 48 V_{DC} supply and natural convection, the EPC9186 can deliver 30 A_{RMS} per phase without a heatsink and 60 A_{RMS} per phase with a heatsink attached with a temperature rise below 50°C from eGaN FET case to ambient. If 400 LFM forced air convection is used, the EPC9186 can deliver respectively 60 A_{RMS} and 150 A_{RMS} under same conditions. The temperature was recorded at steady state.

Motor drive operating points at PWM = 20, 50, and 100 kHz, dead time = 50 ns, with and without heatsink at 25.5°C ambient temperature. Under natural convection and with 400 LFM forced air flow.

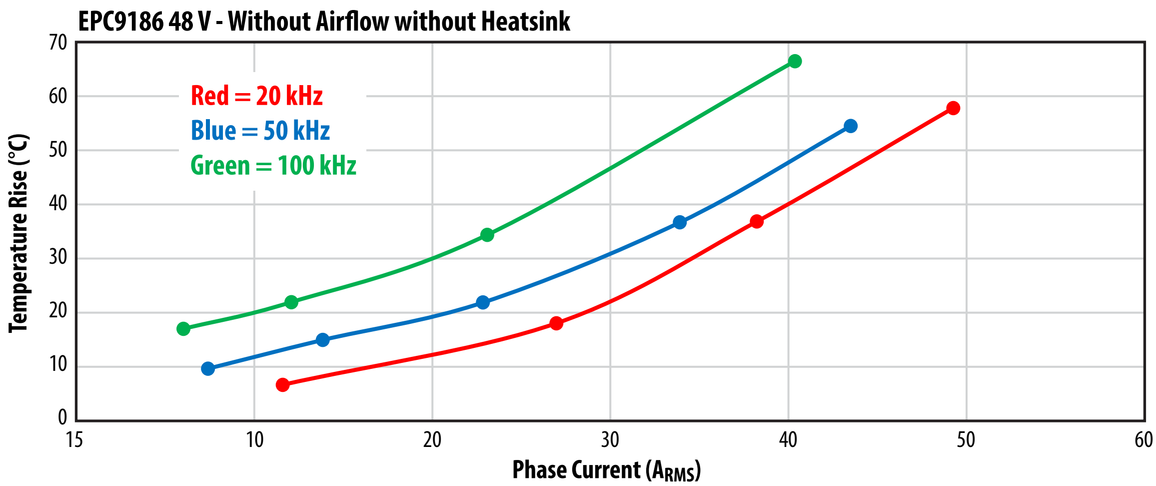


Figure 11a: EPC9186 GaN FET temperature increase vs. the ambient temperature (25.5°C). Measurements were taken at various PWM frequencies without heatsink and without forced convection.

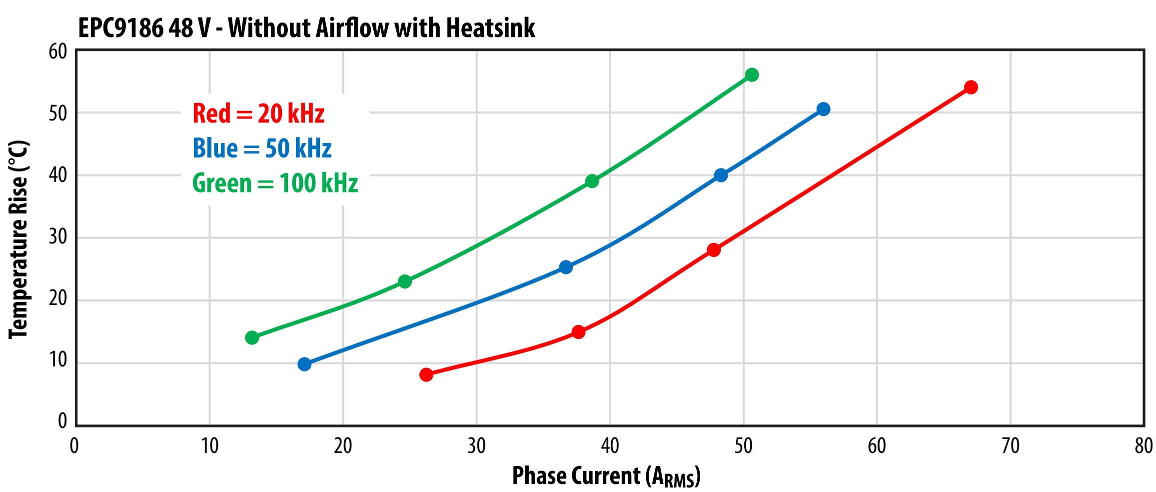


Figure 11b: EPC9186 GaN FET temperature increase (*) vs. the ambient temperature (25.5°C). Measurements were taken at various PWM frequencies with heatsink and without forced convection.

(*) With heatsink, junction temperature has not measured directly. The indicated delta temperature with heatsink is measured using the thermal sensor on the bottom of the PCB.

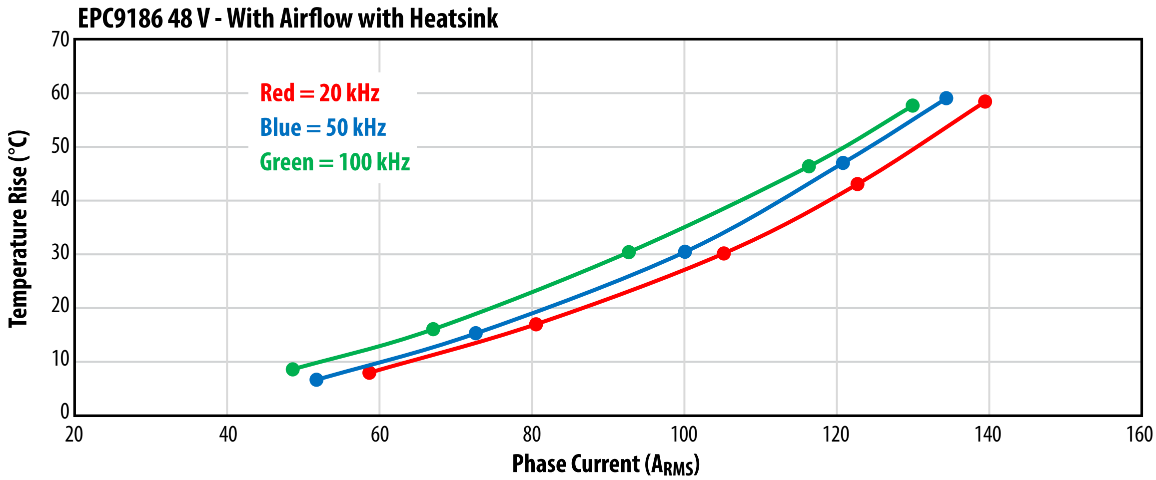


Figure 11c: EPC9186 GaN FET temperature increase (*) vs. the ambient temperature (25.5°C). Measurements were taken at various PWM frequencies with heatsink and without forced convection.

(*) With heatsink, junction temperature has not measured directly. The indicated delta temperature with heatsink is measured using the thermal sensor on the bottom of the PCB.

The graph in Figure 12 shows the correlation between the measured temperature by the on-board temperature sensor placed beneath the phase-2 eGaN FETs on the bottom side of the PCB and the infra-red camera die case temperature for same eGaN IC that is measured without a heatsink and with only natural convection cooling. Figure 13 shows the location of the temperature sensor used to measure the bottom side of the PCB temperature.

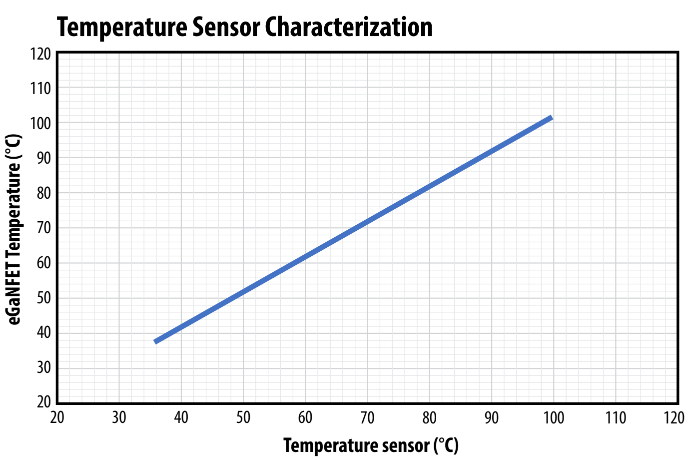


Figure 12: eGaN FET case temperature vs. temperature sensor placed on bottom of the PCB. Operation under natural convection without heatsink.

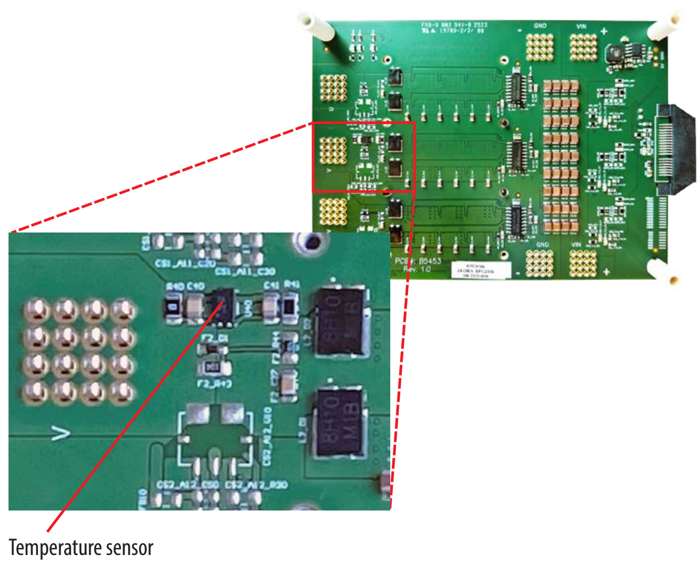


Figure 13: Temperature sensor location on the bottom side of the PCB

For support files including schematic, Bill of Materials (BOM), and gerber files please visit the EPC9186 landing page at: https://epc-co.com/epc/Products/Demo-Boards/EPC9186

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EFFICIENT POWER CONVERSION

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