

Demonstration Board EPC9176 Quick Start Guide

*20 A_{RMS} 3-phase BLDC Motor Drive Inverter using
the EPC23102 ePower™ Stage IC*

Revision 1.0



DESCRIPTION

The EPC9176 demonstration board is a 3-phase BLDC motor drive inverter board featuring the **EPC23102 ePower Stage IC** 6.6 m Ω maximum $R_{DS(on)}$, 100 V maximum device voltage. The EPC9176 can deliver up to 28 Apk (20 A_{RMS}) steady state output current. The board can also be configured for multi-phase DC-DC conversion and the EPC23102 supports PWM switching frequencies up to 250 kHz in motor drive applications and 500 kHz in DC-DC applications. The EPC9176 contains all the necessary critical functions circuits to support a complete motor drive inverter including gate drivers, regulated auxiliary power rails for housekeeping supplies, voltage, and temperature sense, accurate current sense, and protection functions. The various functional blocks are shown in figure 1. The EPC9176 mates with an assortment of compatible controllers, supported by various manufacturers leveraging existing resources for quick development purposes, that can quickly be configured as a motor drive inverter or DC-DC converter.

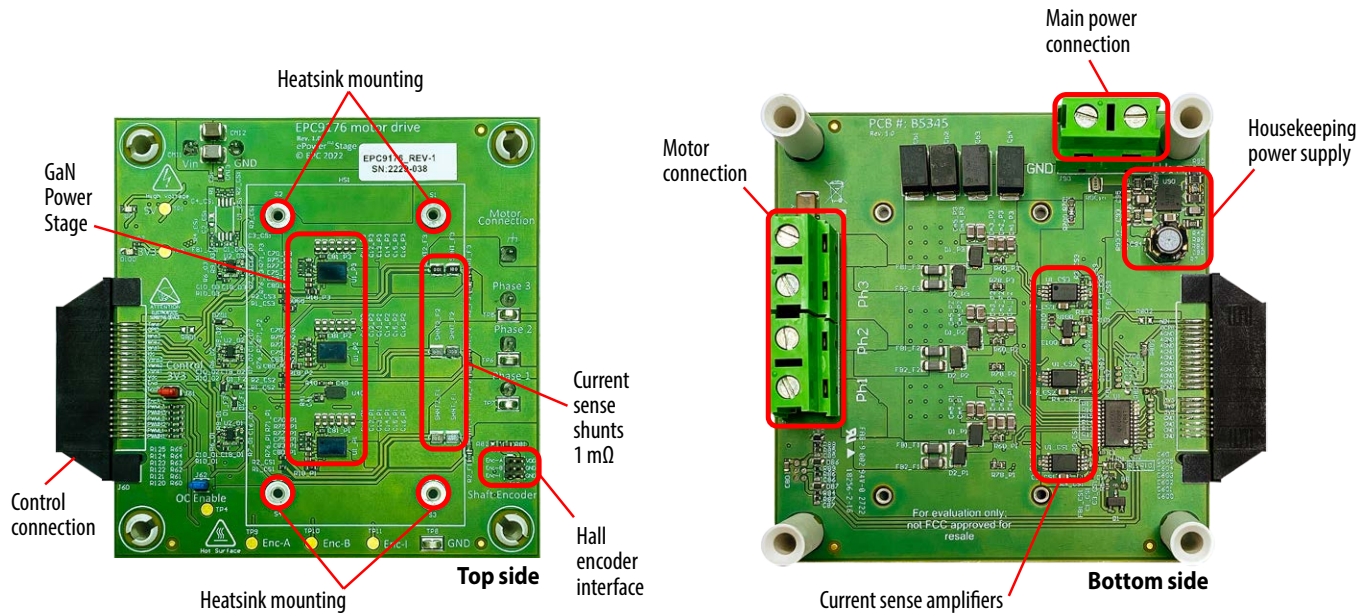


Figure 1: Photo overview of the EPC9176 board highlighting the main sections

A functional block diagram of the EPC9176 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.

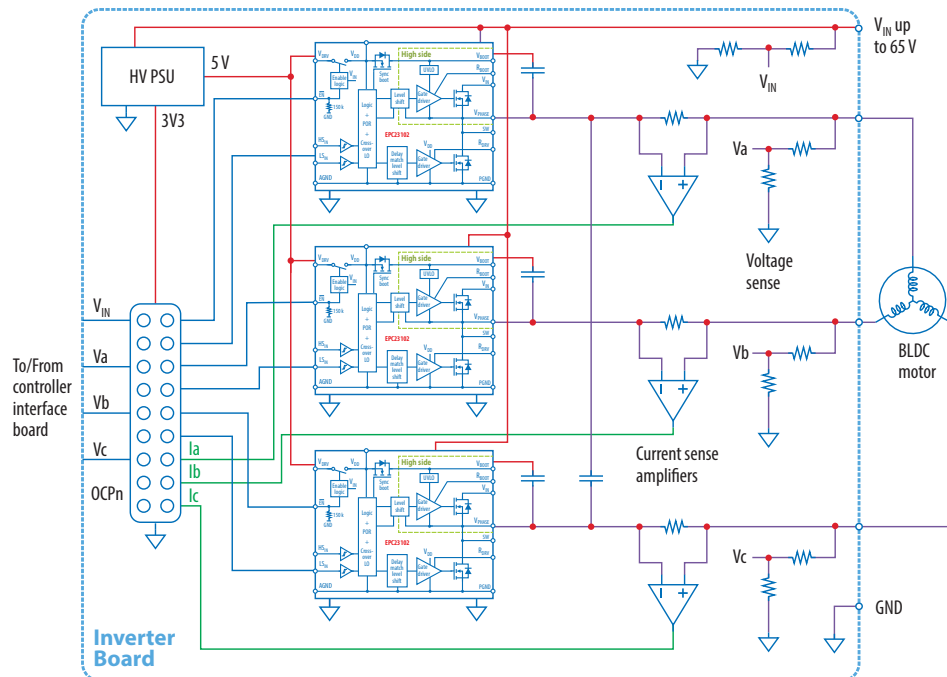


Figure 2. Block diagram of EPC9176 board in BLDC drive example application.

MAIN FEATURES

- 3-phase inverter based on EPC23102 eGaN IC with wide input DC voltage ranging from 14 V to 65 V
- Dimensions: L x W = 81 x 75 mm (including connector)
- Low distortion switching that keeps motor audio emission low and reduces torque ripple
- dv/dt optimized for motor drives less than 10 V/ns with option to increase dv/dt for DC-DC applications
- All current sense with high accuracy and bandwidth
- 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 EPC9176
- 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
- The board can also be configured to operate as a synchronous buck DC-DC converter.



EPC9176 Demonstration board with heatsink attached

RECOMMENDED OPERATING CONDITIONS

Table 1: Electrical Specifications ($T_A = 25^\circ\text{C}$) EPC9176

Symbol	Parameter	Conditions	Min	Nom	Max	Units
V_{IN}	Input supply voltage		14	48	65 ⁽⁵⁾	V
I_{Phase}	EPC9176 RMS Phase current ⁽¹⁾				20	A
f_{sw}	Switching frequency		20	100	250 ⁽⁴⁾	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		k Ω
t_{Prop_delay}	PWM input to Switch-node transition delay	High-side/Low-side on/off		20		ns
V_{Isns_range}	Phase current sense voltage dynamic range	– I_{max} to I_{max}	0		3.3	V
I_{sns_range}	Phase current sense dynamic range	Shunt = 1 m Ω , current sense amplifier gain = 50	-33		33	A
I_{ovc} ⁽²⁾	Positive over-current threshold	Over-current circuits detects both positive negative OVC		-32		
V_{Isns_offset}	Amplified current sense signal offset voltage	Shunt = 0.5 m Ω , current sense amplifier gain = 50, $I_{phase} = 0$ A		1.65		V
G_{Isns}	Amplified current sense gain	Shunt = 1 m Ω , current sense amplifier gain = 50. $V_{Isns} - V_{Isns_offset}$ is positive when current enters the inverter		50		mV/A
G_{Vsns}	Phase and DC voltage sense gain ⁽³⁾			29.2		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 [EPC23102 datasheet](#) for details.

(2) All phases over-current is monitored. Over-current signal is sent to the controller connector via R803. Insert J62 to automatically disable PWM when overcurrent is detected

(3) **Maximum dynamic voltage range is 0 V to 113.3 V which exceeds maximum recommended voltage for the capacitors and other circuits on the board.**

(4) Higher frequency operation up to 500 kHz in DC-DC mode is possible.

(5) Limited by capacitors

HIGHLIGHTED PARTS

Power Stage

The EPC9176 features a 3-phase inverter with EPC23102 eGaN ICs. For more information on the EPC23102 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 EPC9176 board includes logic and 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 jumper (J61).

Current and voltage sense

The EPC9176 inverter is equipped with voltage and current sense for all phases and voltage sense for the DC input.

Output current is measured in-line using a 1 mΩ shunt (SHNT and SHNT2) that is amplified using the INA240A2 (CSx_U1) bi-directional current sense amplifier that yields a total gain of 50 mV/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 shunt amplifiers 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 29.2 mV/V.

Temperature sensor

The EPC9176 board is equipped with a temperature sensor (U40 – AD590) that is centrally located on the top 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 EPC9176 board :

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

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 EPC9176 motor drive inverter. Table 2 gives the map (J60) for each signal.

LED indicators

The EPC9176 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	Idc (optional)	AGND	29
32	Isns1	AGND	31
34	Isns2	AGND	33
36	Isns3	AGND	35
38	N.C.	nOCerr/ ⁽²⁾	37
40	Tsns	nEN/	39

⁽¹⁾ 3.3 V is connected through the jumper J61 (installed by default)

⁽²⁾ nOCerr/ is connected through the resistor R803 (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.

Over-current protection

The EPC9176 includes an overcurrent detect circuit that triggers if any of the three phases current measurement exceeds -32 A. 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 (10 ms) of R5 + R8 and C17 and all PWM signals will be disconnected to the eGaN ICs if jumper J62 is installed. The OC detect signal can be passed on to the controller as nOCerr\ through R803 (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 EPC9176 is provided with two jumpers with functions given in table 3.

Table 3: Jumper settings function

Jumper	Installed	Open
J61	EPC9176 board supplies the control board with 3.3 V	EPC9176 board does not supply the control board with 3.3 V. In this case, the control board should be powered with an external supply.
J62	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 R803 must be mounted and the microcontroller must promptly react to over-current detection

Any combination of valid position settings may be selected.

Shaft Encoder / Hall Effect Sensors

Connector (J80) is used to connect a shaft sensor to the EPC9176 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 EPC9176 is given in table 4 for both Motor drive and DC-DC applications.

Table 4: Compatible controller interface and controller boards to the EPC9176

Controller Board Number	Controller Manufacturer	Controller	Target Application
EPC9147A - Rev. 2.1	Microchip - MA330031-2	dsPIC33EP256MC506	Motor Drive
EPC9147B ¹ - Rev. 1.0	Texas Instruments - LAUNCHXL-F28379D	TMS320F2837xD	Motor Drive
EPC9147C - Rev. 1.0	ST Microelectronics	NUCLEO-G431RB / NUCLEO-F401RE	Motor Drive
EPC9147E - Rev. 2.0	Generic Interface board	N/A	Motor Drive or DC-DC converter
EPC9528 - Rev. 3.0	Generic controller board	dsPIC33CK256MP503	DC-DC converter

¹Available soon

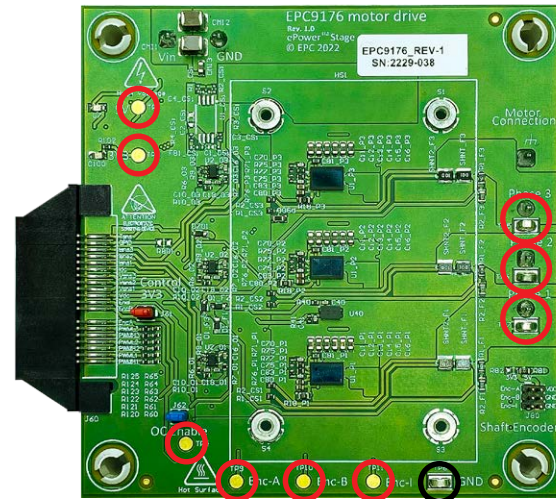


Figure 3: EPC9176 test point pad and hookup locations and designations. Black circle is the PGND reference point.

APPLICATION CONFIGURATIONS

The EPC9176 power board can be used for a number of different applications.

Motor Drive Inverter

A 3-phase BLDC motor drive inverter is the primary application case for which the EPC9176 board was designed for and can be used for either sensor-less or shaft encoder 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 4 shows the simplicity of connecting a controller and motor to the EPC9176. **In the default configuration, the EPC9176 is paired with the EPC9147A that is pre-programmed 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 orientated control with space vector pulse width modulation (SVPWM).**

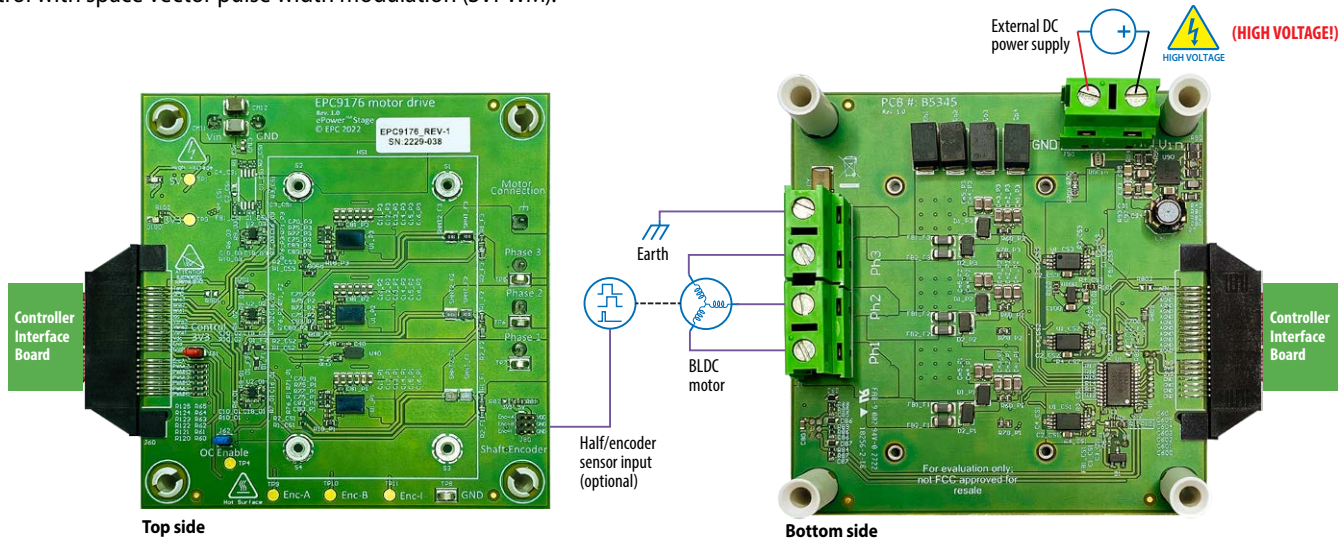


Figure 4: Connection diagram of the EPC9176 configured as a motor drive inverter

Multi-phase Synchronous Buck Converter

The EPC9176 can also be configured as multi-phase synchronous buck converter with either 2 or 3 phase options. When configured as a 2-phase converter, the user can choose any combination of output but should make use of the applicable on-board inductor pad allocations, with appropriate value for the inductor at the chosen operating frequency. **In this configuration it is important to remove the Y-capacitor (CY) and short out the pads with a conductor that can carry the full rated load current.** The earth connection then becomes the ground (GNDP) return as shown in figure 5. The output voltage can be measured using any of the phase voltage test points with respect to the ground (GNDP).

EPC9528 controller is best suited to control the EPC9176 as a DC-DC converter.

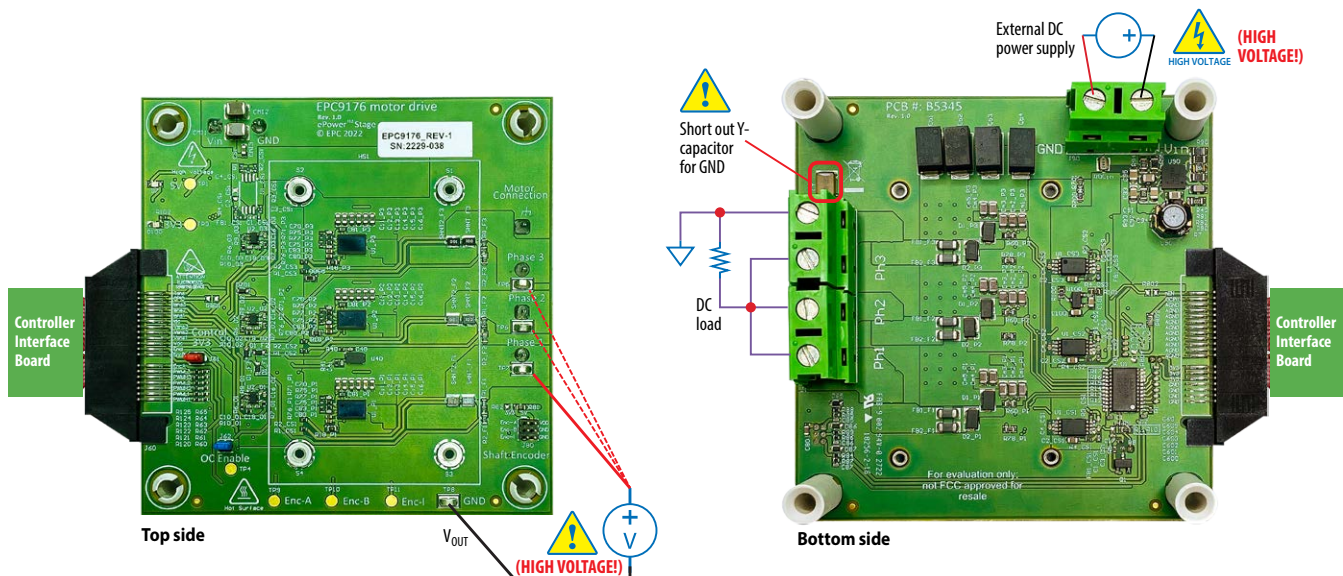


Figure 5: Connection diagram of the EPC9176 configured as a multi-phase converter

Full-Bridge Synchronous Buck Converter

The EPC9176 can also be configured as full bridge converter where any two of the three phases can be used. A full bridge connection example is shown in figure 6. Since the full-bridge converter is not specifically referenced to the ground (GNDP), the user must take appropriate measures to ensure the correct load connection. The output voltage can be measured using the applicable phase voltage test points. The user must ensure that the measurement system is isolated for this type of measurement. Alternatively the output voltage can also be measured using the same technique given in figure 4, using the common ground (GNDP) and subtracting the one signal from the other.

EPC9528 controller is best suited to control the EPC9176 as a DC-DC converter.

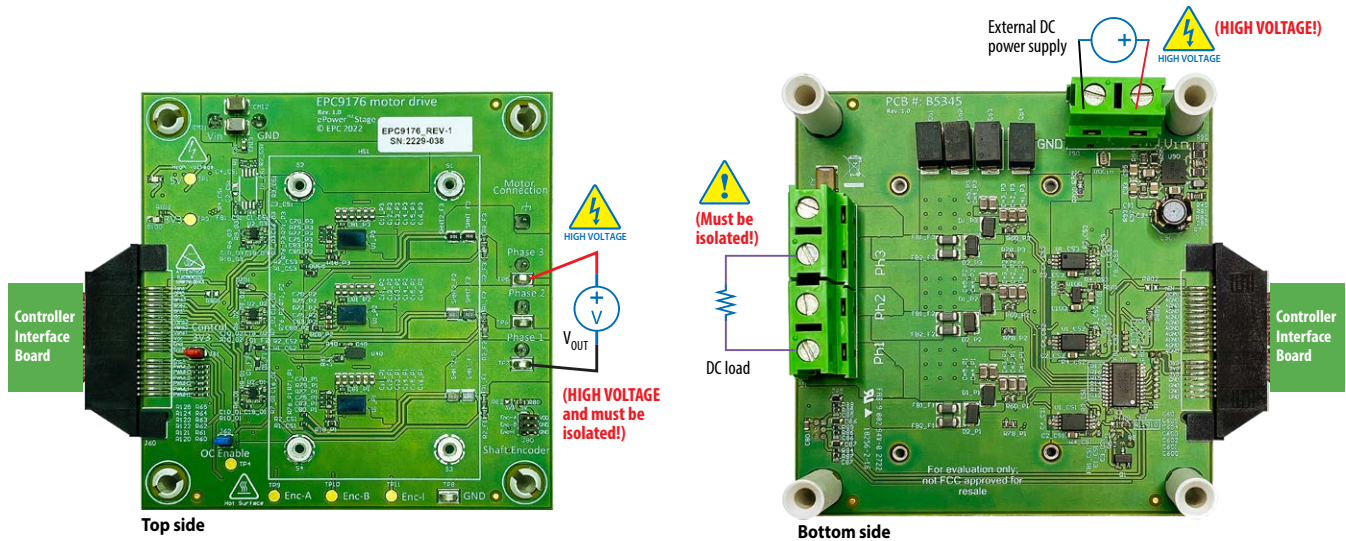


Figure 6: Connection diagram of the EPC9176 configured as a full bridge converter

QUICK START PROCEDURE

For this quick start procedure only the **motor drive application** using the [EPC9147A](#) controller is presented.

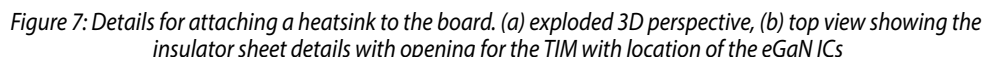
Follow the procedure below to operate the specific motor Teknic M-3411P-LN-08D with EPC9176 and controller board:

1. Mate the EPC9176 with an applicable controller interface board as given in table 4. Review the QSG of corresponding control interface board for detailed operating procedures. For this procedure, the EPC9147A is used.
2. Connect the correct motor, whose parameters are programmed into the controller, to the EPC9176 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. Adjust the speed and direction of the motor by pressing or adjusting the applicable button, knob or software setting.
Note that user interface (buttons and knob) are not isolated, so use appropriate precautions when dealing with high voltage. Please review the [EPC9147A QSG](#) for details.
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.

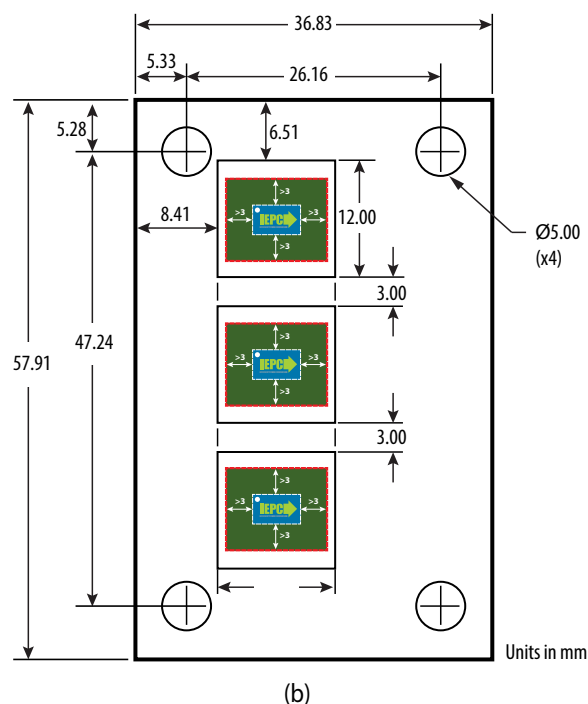
The EPC9176 is intended for bench evaluation at room ambient temperatures and under either natural convection or forced air cooling. The addition of a heatsink can significantly improve the heat dissipation from the eGaN ICs and increase the current capacity of these devices, while ensuring to not exceed the absolute maximum die temperature of 150°C.

The EPC9176 board is equipped with four mechanical spacers (S1, S2, S3, S4) that can be used to easily attach a heatsink as shown in figures 7 and 8 and only requires a thermal interface material (TIM), a heatsink, and 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.



When assembling the heatsink, it is 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 7 and 8. 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 ICs to be cooled with a minimum clearance of 3 mm on each side of the rectangle encompassing the ICs. 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 8. The insulator sheet material is made by Laird P/N A14692-30 Tgard K52 with thickness of 0.051 mm (0.0020”).



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 ICs. This volume compression exerts a force on the ICs. 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 ICs is connected to power ground (PGND).
- **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 default TIM used for the EPC9176 is made by t-Global Technology, measures 20 x 20 x 0.5 mm thick with P/N TG-A6200-20-20-0.5

The natural convection cooling heatsink used for the EPC9176 is Wakefield, model 547-95AB.

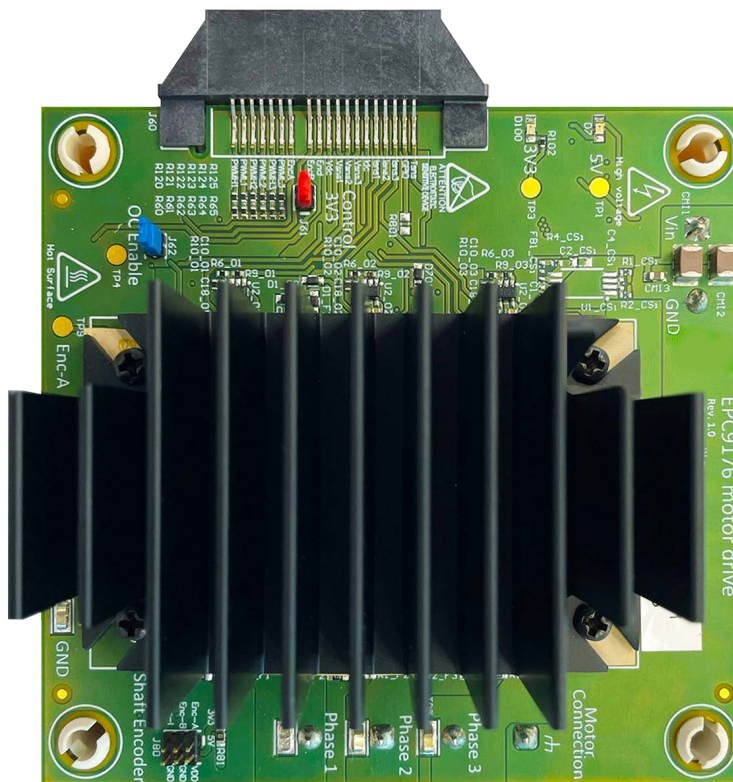


Figure 9: Natural convection cooling heatsink installed on the EPC9176 inverter board

The EPC Thermal Calculator provides quick estimates for the thermal performance parameters of PCB-mounted GaN devices subject to both board-side cooling through forced convection, and backside cooling through a thermal solution consisting of a heat spreader and heatsink. This calculator shows the excellent thermal properties of EPC's GaN FETs.

To simulate your thermal design please go to: <https://epc-co.com/epc/design-support/gan-power-bench/gan-fet-thermal-calculator>

EXPERIMENTAL VALIDATION EXAMPLE

The EPC9176 motor drive inverter, paired with EPC9147A interface controller, was operated from a 36 V_{DC} power supply voltage while switching at 100 kHz, 50 ns dead-time, powering a 500 W motor with sinusoidal modulation frequency of 5 Hz delivering to the motor a phase current of 15 A_{RMS} without a heatsink and natural convection cooling and 20 A_{RMS} with a heatsink and natural convection cooling.

MEASURED PHASE LEG WAVEFORMS

The measured waveforms of the motor phase current and temperature sensor voltage while the EPC9176 is delivering 20 A_{RMS} into each motor phase at 36 V_{DC} is shown in the figure 10.

The ambient temperature was measured using the temperature sensor of an unused board.

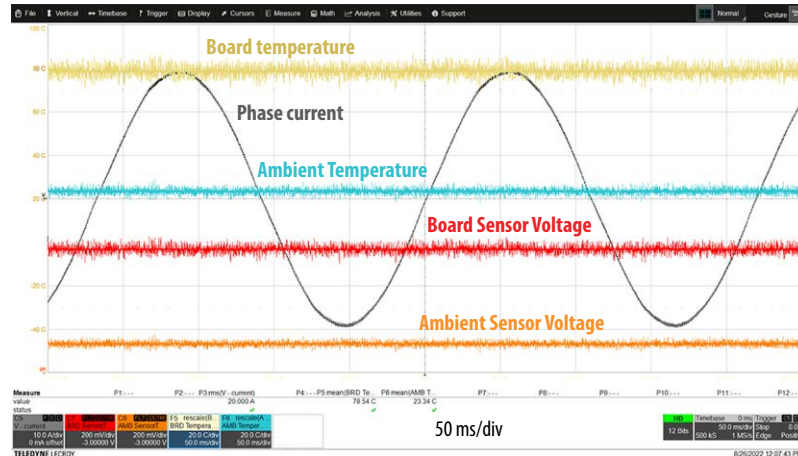


Figure 10. Phase 1 current and temperature sensor voltage

THERMAL PERFORMANCE

The thermal performance summary of the EPC9176 board is depicted in figure 11. When operated on a motor bench at ambient temperature of 25.5°C, with 36 V_{DC} supply and natural convection, the EPC9176 can deliver 13 A_{RMS} per phase without a heatsink and 18 A_{RMS} per phase with a heatsink attached with a temperature rise below 50°C from eGaN IC case to ambient. The temperature was recorded at steady state. EPC9176 can withstand short transients (less than 30 s) up to 20 A_{RMS}.

Motor drive operating points at PWM = 20, 50, and 100 kHz, deadtime = 50 ns, with and without heatsink at 25.5°C ambient temperature. Under natural convection.

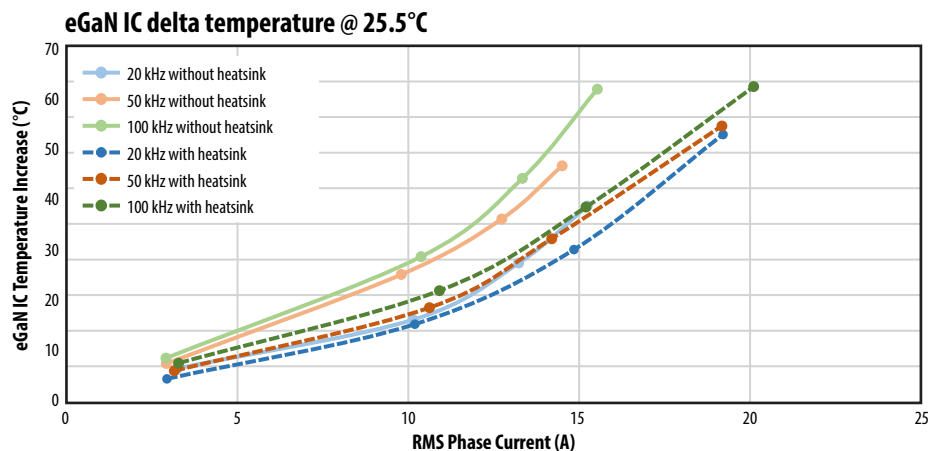


Figure 11: EPC9176 eGaN IC temperature (°C) increase vs. the ambient temperature (25.5°C). Measurements taken at various PWM frequencies.

(*) With heatsink, junction temperature has not measured directly. The indicated delta temperature with heatsink is measured with temperature sensor and derived from the sensor characterization.

The graph in Figure 12 shows the correlation between the measured temperature by the on-board temperature sensor on top side of the PCB and the infrared 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 top side of the PCB temperature.

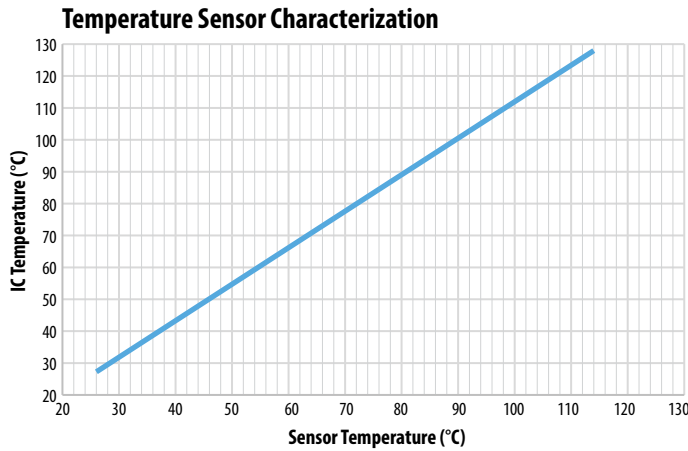


Figure 12: eGaN IC case temperature vs. temperature sensor placed on bottom of the PCB. Operation under natural convection without heatsink.

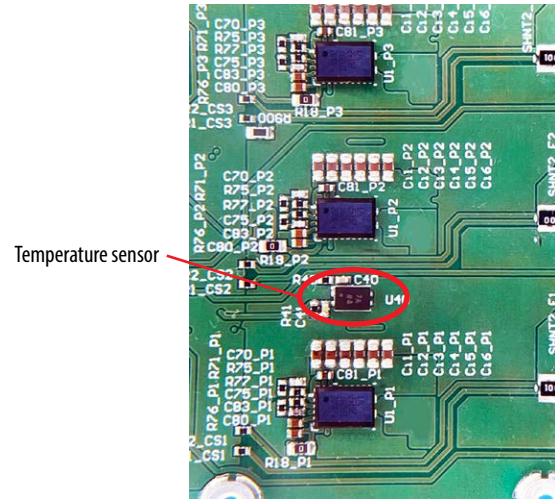


Figure 13: Temperature sensor location on the top side of the PCB

The board was also tested at higher DC bus voltage, 48 V and 54 V at 20 A_{RMS} phase current with a heatsink. Table 5 shows the IC temperature increase for several switching frequency values.

Table 5: EPC9176 thermal performance at 20 A_{RMS}

DCBUS voltage	Switching frequency	Ambient temperature	Sensor temperature	eGaN IC temperature*	eGaN IC temperature increase
48 V	20 kHz	26.3 °C	85.3 °C	94.5 °C	68.2 °C
	50 kHz	26.5 °C	92.9 °C	103.1 °C	76.6 °C
	100 kHz	26.0 °C	95.1 °C	105.6 °C	79.6 °C
54 V	20 kHz	26.8 °C	89.6 °C	99.4 °C	72.6 °C
	50 kHz	26.7 °C	95.4 °C	106.0 °C	79.3 °C
	100 kHz	26.5 °C	99.0 °C	110.1 °C	83.6 °C

* IC temperature was derived from the temperature sensor characterization in figure 12

For support files including schematic, Bill of Materials (BOM), and gerber files please visit the EPC9176 landing page at: <https://epc-co.com/epc/Products/DemoBoards/EPC9176.aspx>