Evaluation Board EPC91104 Quick Start Guide

14 A_{RMS}, 20 A peak 3-Phase
BLDC Motor Drive Inverter Board

January 6, 2025

Revision 1.0

EFFICIENT POWER CONVERSION

DESCRIPTION

The EPC91104 evaluation board is a 3-phase BLDC motor drive inverter board featuring the **EPC23104 ePower Stage IC** 11 mΩ maximum RDS(on), 100 V maximum device voltage. The EPC91104 can deliver up to 10 Apk (7 ARMS) steady-state output current and up to 20 Apk (14 ARMS) pulsed output current (tpulse= 300 ms at 5%, 10%, and 20% of the total period).The EPC91104 contains all the necessary critical function 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 EPC91104 mates with an assortment of compatible controllers, supported by multiple manufacturers leveraging existing resources for quick development purposes.

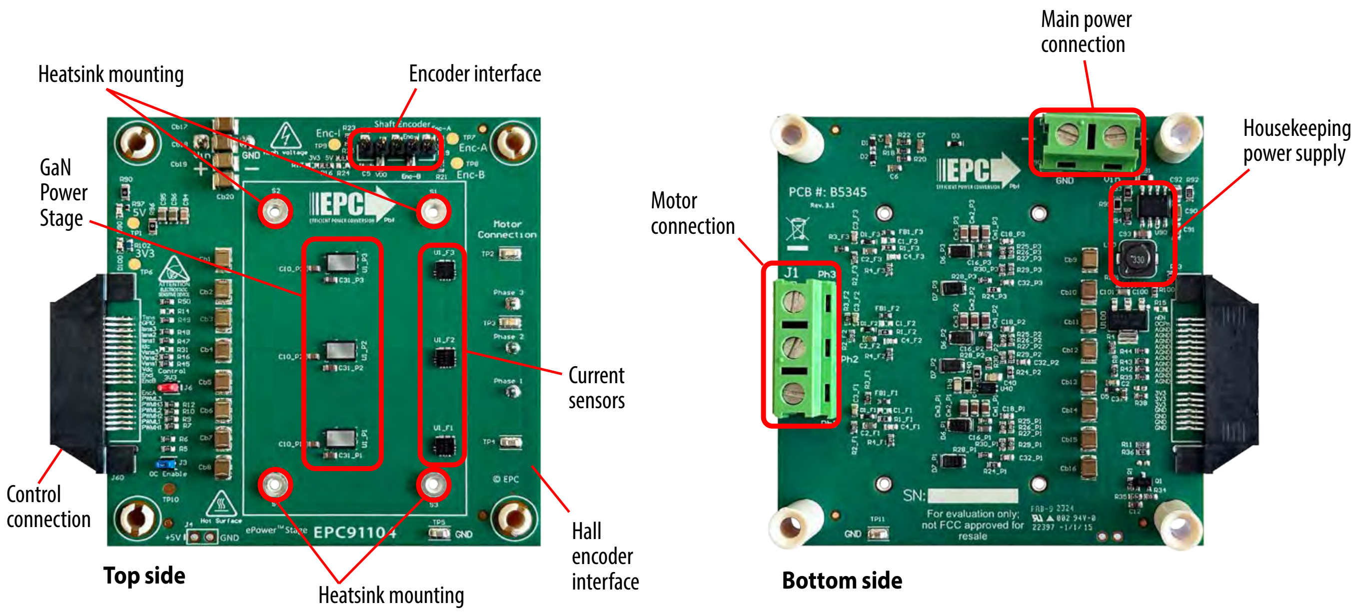


Figure 1: Photo overview of the EPC91104 board highlighting the main sections

Figure 2 shows the functional block diagram of the EPC91104 reference design board that details the phase current sense, phase and DC voltage sense, the half-bridge power stages, housekeeping power supply, and controller interface connection.

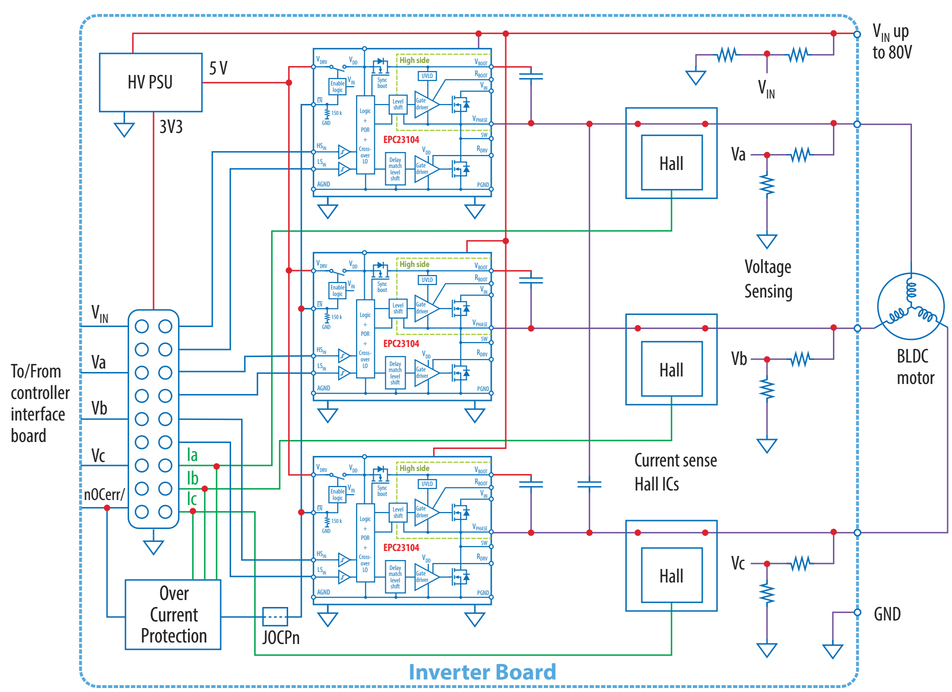
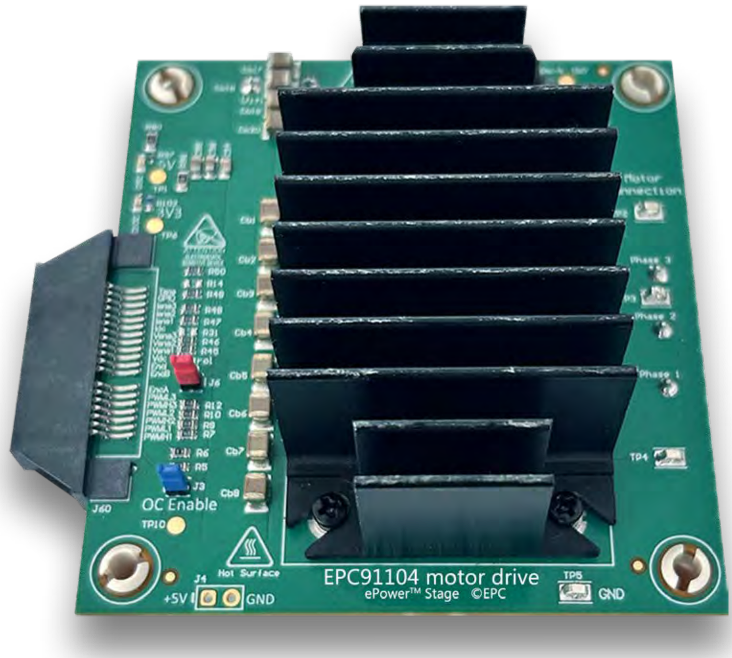


Figure 2. Block diagram of EPC91104 board in BLDC drive example application.

MAIN FEATURES

- 3-phase inverter based on EPC23104 eGaN IC with wide input DC voltage ranging from 14 V to 80 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 the option to increase or decrease dv/dt by changing a resistor
- All current sense with 120 kHz 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 EPC91104
- Temperature monitoring
- 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 options



EPC91104 Evaluation board with heatsink attached

RECOMMENDED OPERATING CONDITIONS

Table 1: Electrical Specifications (T_A = 25°C) EPC91104

Symbol	Parameter	Conditions	Min	Nom	Max	Units
V_{IN}	Input supply voltage		14	48	80	V
I_{Phase}	RMS Phase current[1]				10	A
f_{sw}	Switching frequency		20	100	150	kHz
t_{dt}	Dead Time		25	50	100[4]	ns
V_{IN_uvlo}	Input undervoltage lockout voltage			14		V
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}	Input logic threshold hysteresis	V_{IH} Rising – V_{IL} Falling		0.5		
V_{ENC}	Encoder supply voltage[5]		3.3		5.2	
R_{in}	PWM input pulldown resistance			150		kΩ
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	–Imax to Imax	0		3.3	V
I_{sns_range}	Phase current sense dynamic range		–30		30	A
I_{ovc}[2]	Over-current threshold	Over-current circuits detect both positive and negative OVC		30		
G_{Isns}	Amplified current sense gain			44		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 EPC23104 datasheet for details.

(2) All phases over-current is monitored. Over-current signal is sent to the controller connector via R1. Insert J3 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) Diodes are mounted to protect the board when the maximum dead time value is exceeded. If the dead time is kept within the specified range in the table, the diodes can be removed.

(5) The available voltage selections can be made by installing the applicable resistors: 5.2 V using R16 (default) and 3.3 V using R17.

HIGHLIGHTED PARTS

Power Stage

The EPC91104 features a 3-phase inverter with EPC23104 eGaN ICs. For more information on the EPC23104 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 EPC91104 board includes logic and housekeeping power supplies 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 (J6).

Current and voltage sense

The EPC91104 inverter is equipped with voltage and current sense for all phases and voltage sense for the DC input.

Phase current is measured using a Hall current sensor IC on each phase. The sensor's current range is ± 30 A.

The current sensors are bi-directional, ensuring the full four-quadrant operation.

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 EPC91104 board is equipped with a temperature sensor (U40–AD590) that is centrally located on the bottom of the board and reports an analog voltage reading proportional to the measured temperature using the following equation:

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

Connection and controller mate options

A 40-pin connector interfaces power, PWM signals, and analog feedback signals between the interface control board and the EPC91104 motor drive inverter. Table 2 gives the signal map of J60.

LED indicators

The EPC91104 has a number of LEDs indicating the presence of the various supply voltages as follows:

- 5.2 V LED (**green**) – indicates the 5.2 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	N.C.	nOCerr/ (2)	37
40	Tsns	nEN/	39

(1) 3.3 V is connected through the jumper J6 (installed by default)

(1) nOCerr/ is connected through the resistor R1 (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 5.2 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 the digital ground (GND) using a SMD hookup. Figure 3 shows all test point locations.

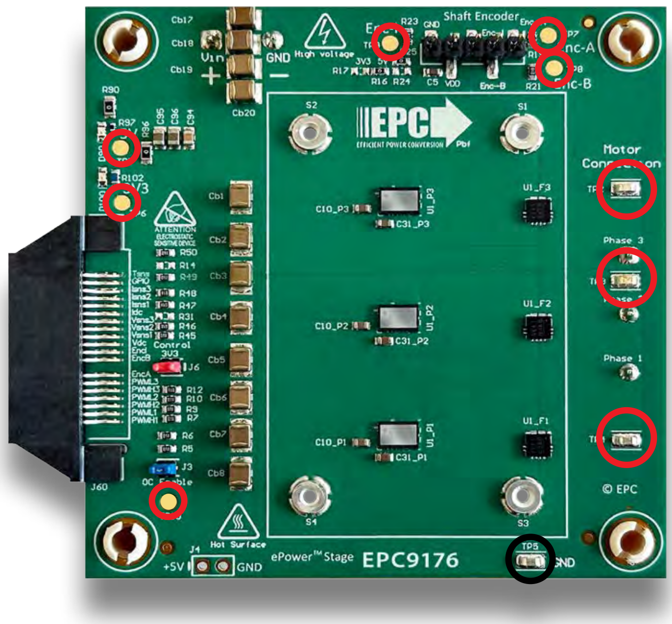


Figure 3: EPC91104 test point pad and hookup locations and designations. Black circle is the PGND reference point

Over-current (OVC) protection

The EPC91104 current sensors include an overcurrent detector that triggers if the current measurement exceeds 50 A. Once an over- current is triggered, the active low OC signal will remain low for a short period, determined by the RC time constant (10 ms) of R34 + R35 and C12, and the enable signal will be removed from the eGaN ICs if jumper J3 is installed. The OVC detect signal is sent to the controller as nOCerr\ through R1 (installed by default).

Note: The Enable pin doesn't disable the PWM signals. The controller must disable the PWM signals when an OVC event occurs.

Jumper Settings

The EPC91104 is provided with two jumpers with functions described in Table 3.

Table 3: Jumper settings function

Jumper	Installed	Open
J6	EPC91104 board supplies the control board with 3.3 V	EPC91104 board does not supply the control board with 3.3 V. In this case, the control board should be powered with an external supply.
J3	The over-current signal is sent to the micro-controller AND to the power stage EPC23104 IC standby input. Refer to EPC23104 data sheet for the standby function description.	The over-current detection circuit does not disable the PWM signals independently from microcontroller. In this case R1 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

The connector (J7) connects a shaft sensor to the EPC91104 motor drive inverter, which is compatible with optical quadrature encoders or hall effect sensors and provides a supply voltage for the encoder. The available voltage selections can be made by installing the applicable resistors: 5.2 V using R16 (default) and 3.3 V using R17. The pull-up voltage selections can be made by mounting the resistors: R25 for 3.3 V (default) and R24 for 5.2 V. The filtered signals are then provided to the controller connector (J60).

Compatible Controllers

A list of compatible controllers for the EPC91104 is given in Table 4 for Motor drive applications.

Table 4: Compatible controller interface and controller boards to the EPC91104

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
EPC9147C - Rev. 1.0	ST Microelectronics	NUCLEO-G431RB / NUCLEO-F401RE	Motor Drive
EPC9147D- Rev 1.1	Renesas-RTK0EMA270C00000BJ	RA6T2	Motor Drive
EPC9147E - Rev. 2.0	Generic Interface board	N/A	Motor Drive

APPLICATION CONFIGURATIONS

Motor Drive Inverter

A 3-phase BLDC motor drive inverter is the primary application for which the EPC91104 board was designed for and can be used for 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 EPC91104. I**n the default configuration, the EPC91104 is paired 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).

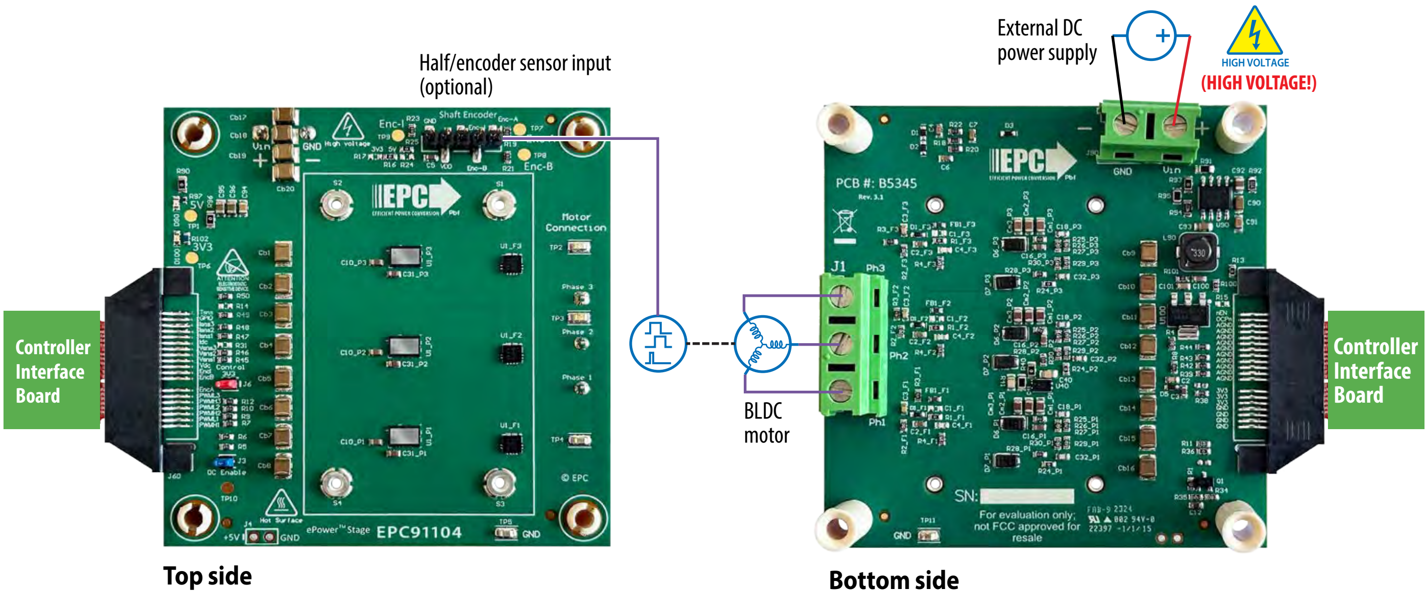


Figure 4: Connection diagram of the EPC91104 configured as a motor drive inverter

QUICK START PROCEDURE

Follow the procedure below to operate the specific motor Teknic M-3411P-LN-08D with EPC91104 and controller interface board:

Mate the EPC91104 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 as an example.

1. Connect the correct motor, whose parameters are programmed into the controller, to the EPC91104 at connector J1 and the DC power supply at connector J90 (**Observe the correct polarity; there is no reverse polarity protection on board**) and shown in figure 4.
2. 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 the user interface (buttons and knob) is not isolated, so use appropriate precautions when dealing with high voltage.** Please review the **EPC9147A QSG** for details.
3. Once operational, make the necessary measurements.
4. For shutdown, press the Start/Stop button to stop the motor spinning, then turn off the main DC power supply.

THERMAL CONSIDERATIONS

The EPC91104 is intended for bench evaluation at room ambient temperatures and under natural convection or forced air cooling. Adding 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 EPC91104 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.

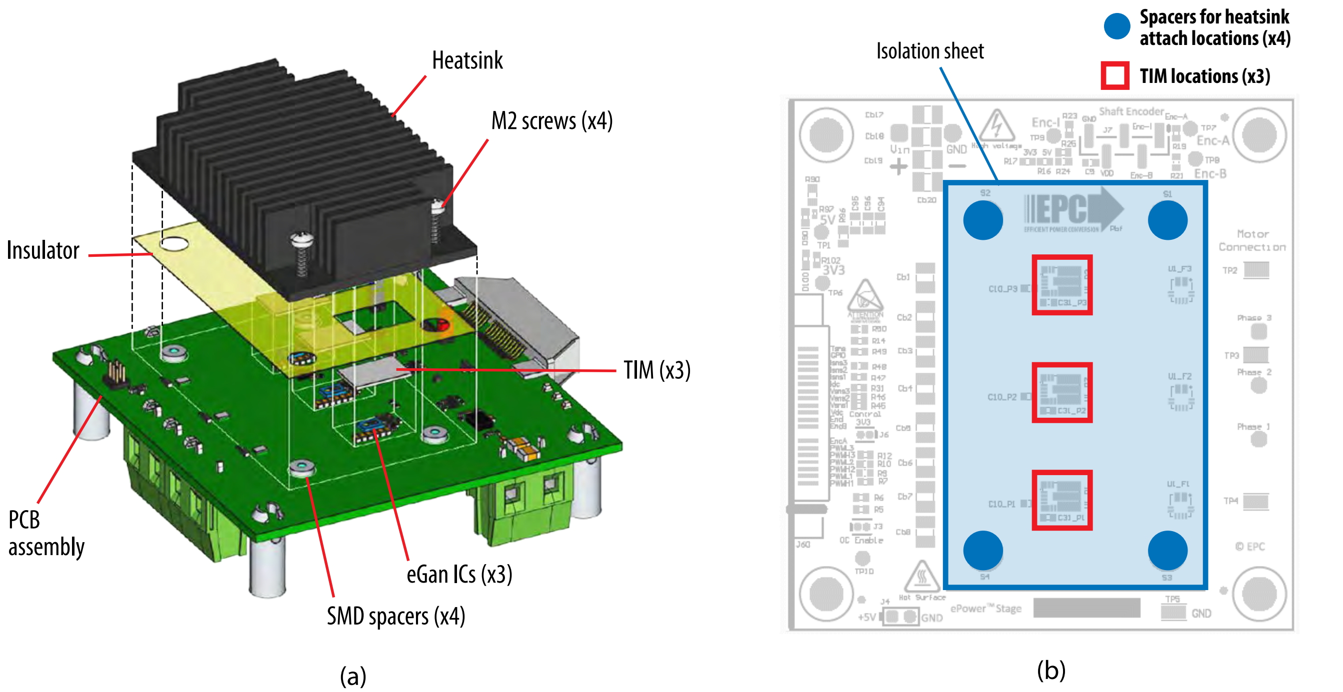
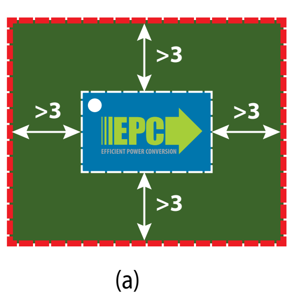


Figure 5: Details for attaching a heatsink to the board. (a) exploded 3D perspective, (b) top view showing the insulator sheet details with opening for the TIM with location of the eGaN ICs

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 5 and 6. 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 6. The insulator sheet material is made by Laird P/N A14692-30 Tgard K52 with thickness of 0.051 mm (0.0020").



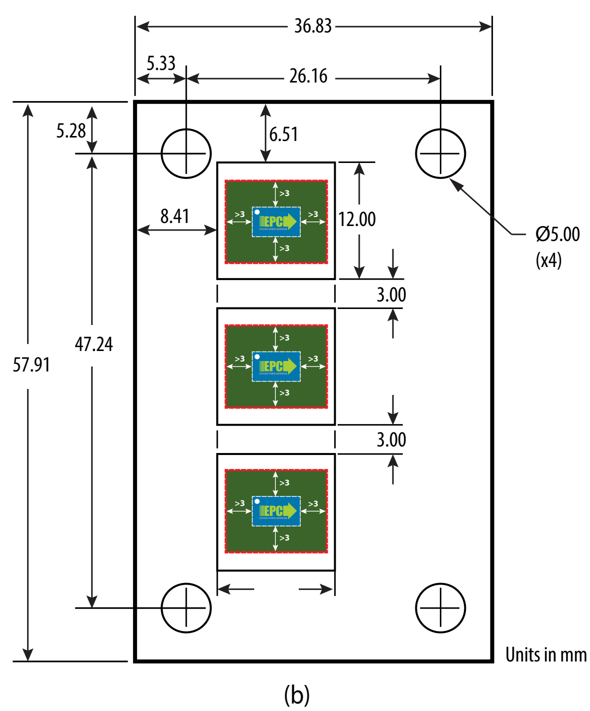


Figure 6: (a) minimum TIM coverage area (b) Insulator sheet details

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 EPC91104 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 EPC91104 is Wakefield, model 547-95AB.

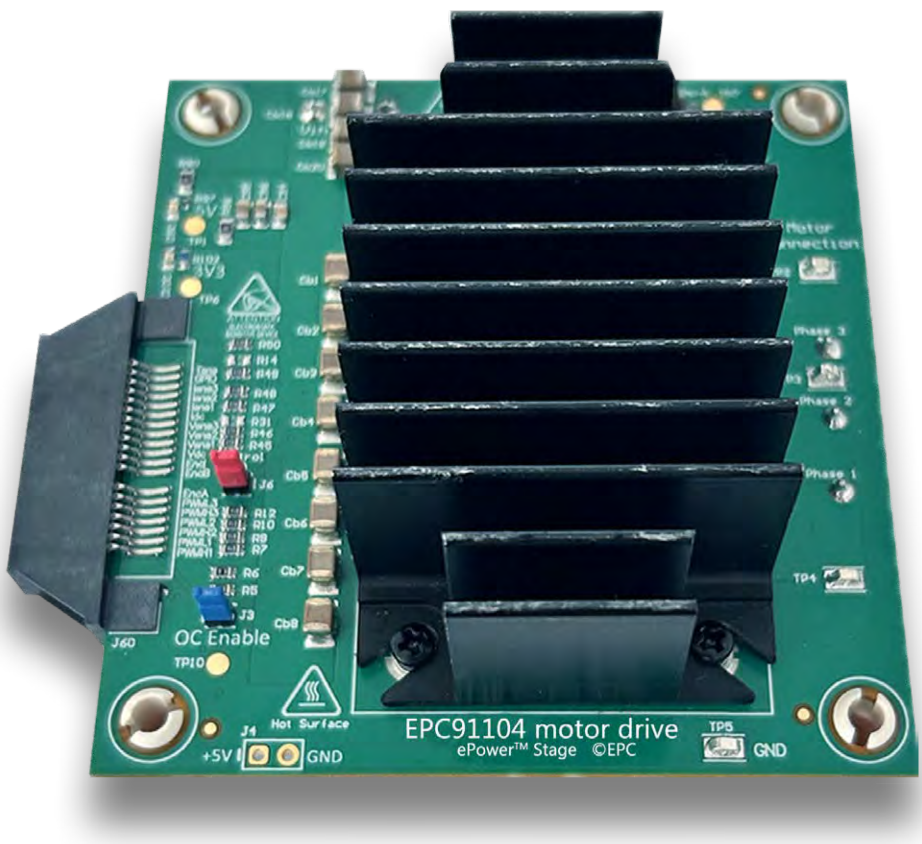


Figure 7: Natural convection cooling heatsink installed on the EPC91104 inverter board

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 EPC91104 motor drive inverter, paired with EPC9147C interface controller, was operated from a 48 V_{DC} power supply voltage while switching at 100 kHz, 50 ns dead-time, powering a 3 kW motor delivering to the motor a steady state phase current of 15 A_{RMS} without a heatsink and natural convection cooling and 20 A_{RMS} with a heatsink and natural convection cooling and an impulsive current up to 26.5 A_{RMS} with and without heatsink.

MEASURED PHASE LEG WAVEFORMS

The measured waveforms of the motor phase current while the EPC91104 delivers 20 A_{RMS} into each motor phase at 48 V_{DC}, PWM 50 kHz, and 50 ns dead time are shown in Figure 8.

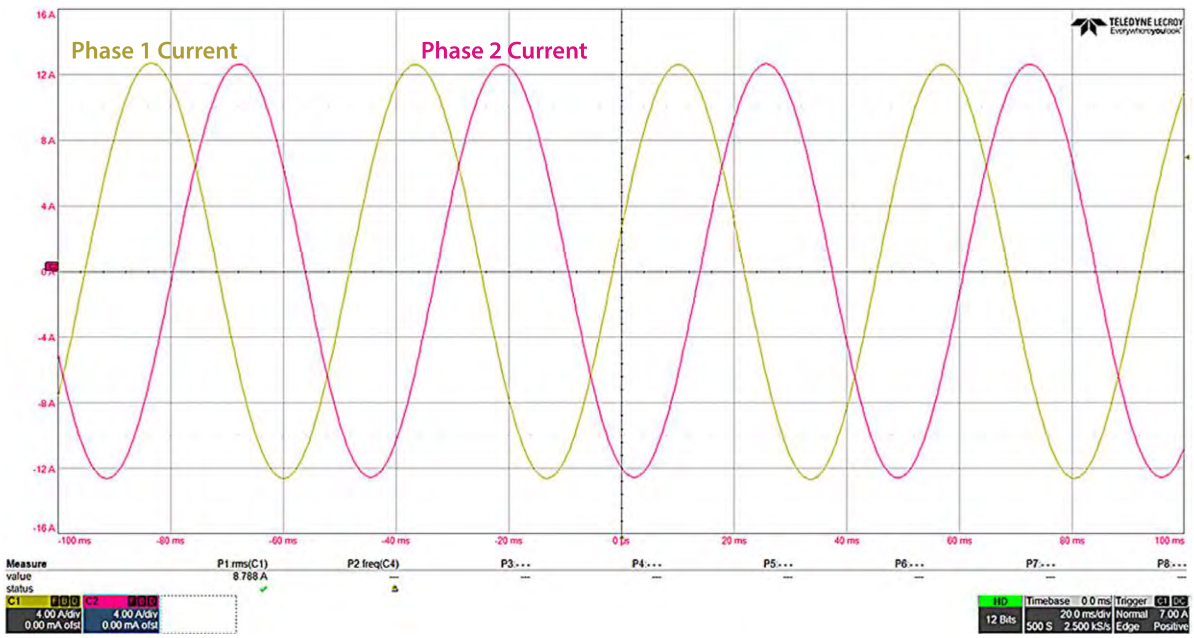


Figure 8. Phase 1 and phase 2 current at 48 V_{DC}

THERMAL PERFORMANCE

In the thermal analyses, a thermocouple placed on the top side of the central device relating to phase 2 is used, as described in Figure 9. There are two different thermal tests:

1) Steady-state thermal analysis
2) Pulsed torque thermal analysis

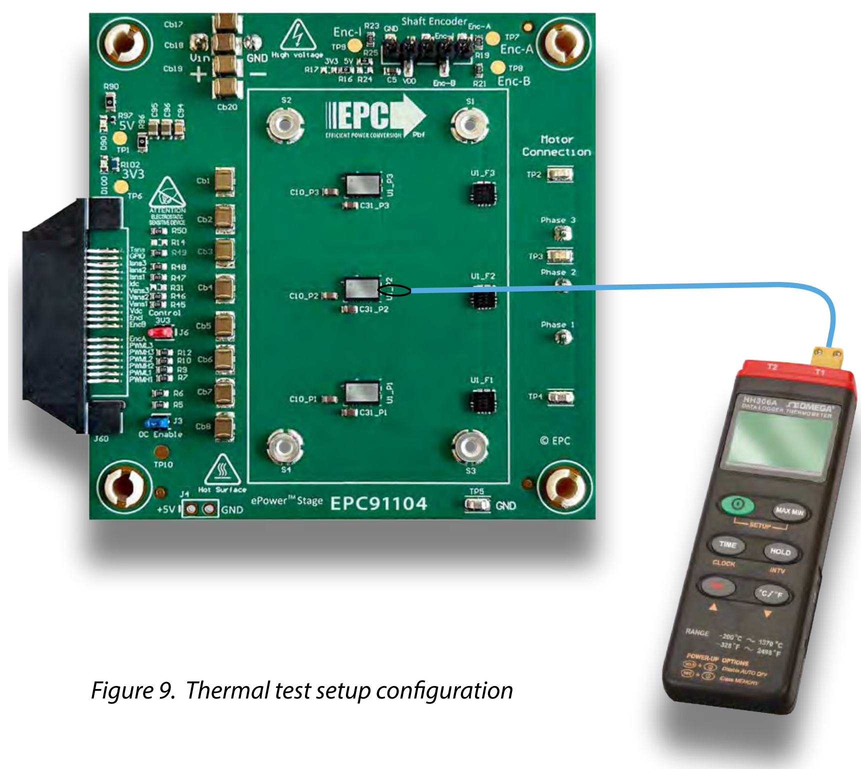


Figure 9. Thermal test setup configuration

STEADY STATE ANALYSIS

Figure 10 depicts the steady-state thermal performance summary of the EPC91104 board. When operated on a motor bench at an ambient temperature of 22°C, with a 48 V_{DC} supply and natural convection, the EPC91104 can deliver 15 A_{RMS} per phase without a heatsink and 20 A_{RMS} per phase with a heatsink attached, with a temperature rise below 75°C from the eGaN IC case to ambient.

Motor drive operating points at PWM = 20, 50, and 100 kHz, deadtime = 50 ns, with and without heatsink at 22°C ambient temperature, under natural convection.

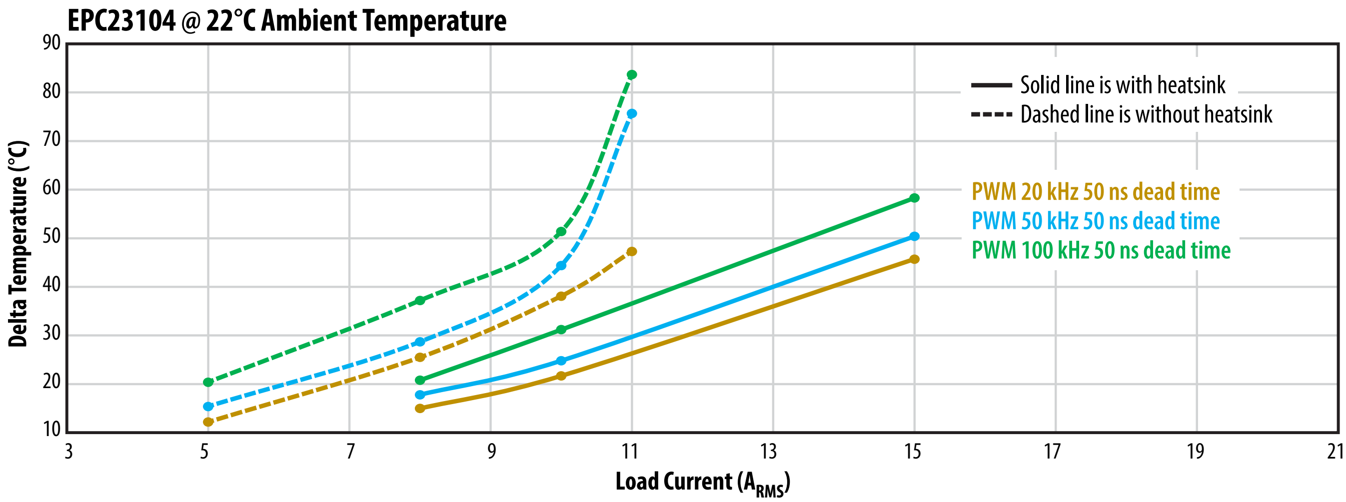


Figure 10: EPC91104 eGaN IC temperature (*) increase vs. the ambient temperature (22°C). Measurements taken at various PWM frequencies

PULSED TORQUE ANALYSIS

The pulsed torque thermal analysis describes the performance of EPC91104 for applications subject to a dynamic operation. The tests were done using a system with an hysteresis brake controlled by current pulses. Figure 11 shows a schematic model of the analysis setup. As in the example in Figure 12, the motor braking generates an impulse with a total current of 14 A_{RMS} for 300 ms (10% of the total period), which returns in the no-load conditions after brake-off.

Figure 13 summarizes the thermal performance of EPC91104 under pulsed torque. The tests were done with a 48 V_{DC} supply, 100 kHz PWM frequency, and 50 ns dead time at 24°C ambient temperature with and without a heatsink. The curve shows the temperature increase of the EPC91104 considering total RMS current and different pulse duties, such as 5%, 10%, and 20% of the total period.

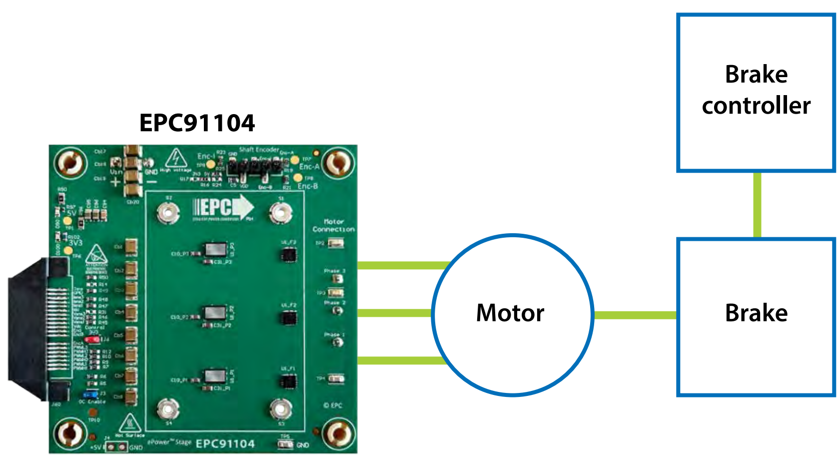


Figure 11: Pulsed torque test set up schematic

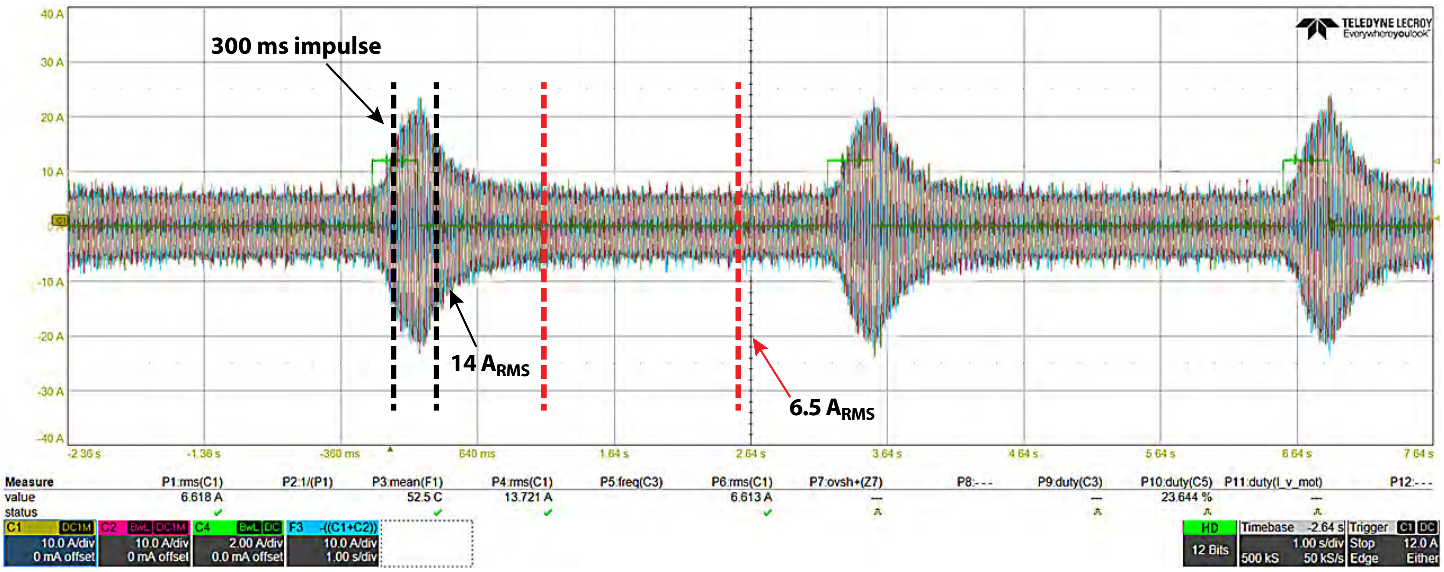


Figure 12: Pulsed torque test at 10% duty

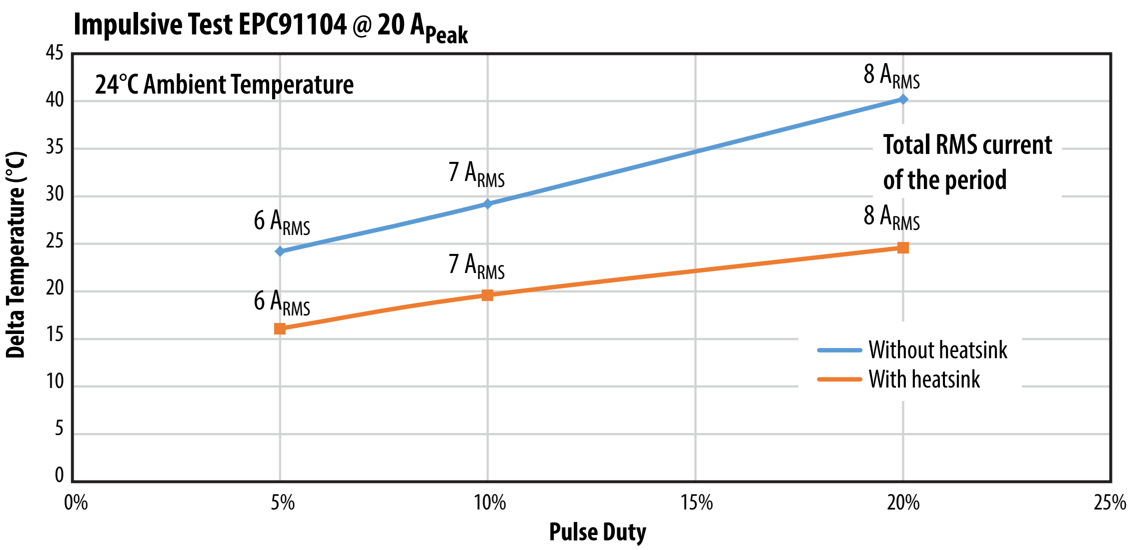


Figure 13: EPC91104 eGaN IC temperature increase vs. ambient temperature (22°C).
Measurements were taken at various pulse duties. In the point labels indicate the total RMS current.

The graph in Figure 14 shows the correlation between the measured temperature by the on-board temperature sensor on bottom side of the PCB and the thermocouple die case temperature for same eGaN IC with only natural convection cooling. Figure 15 shows the location of the temperature sensor used to measure the top side of the PCB temperature.

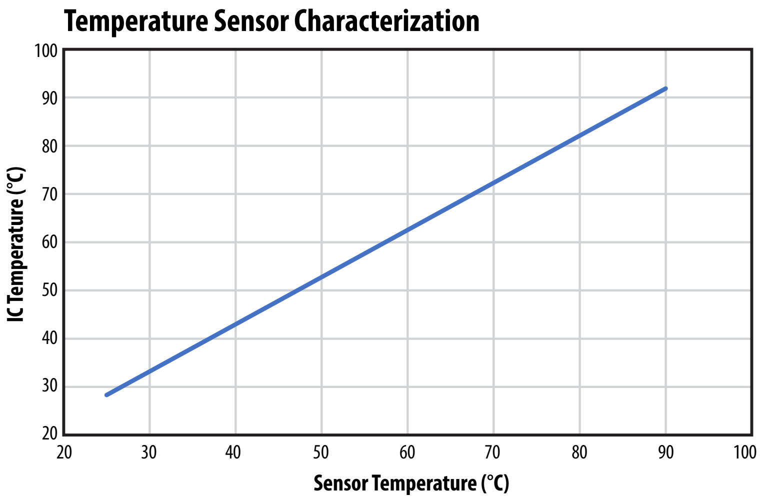


Figure 14: eGaN IC case temperature vs. temperature sensor placed on bottom of the PCB. Operation under natural convection without heatsink.

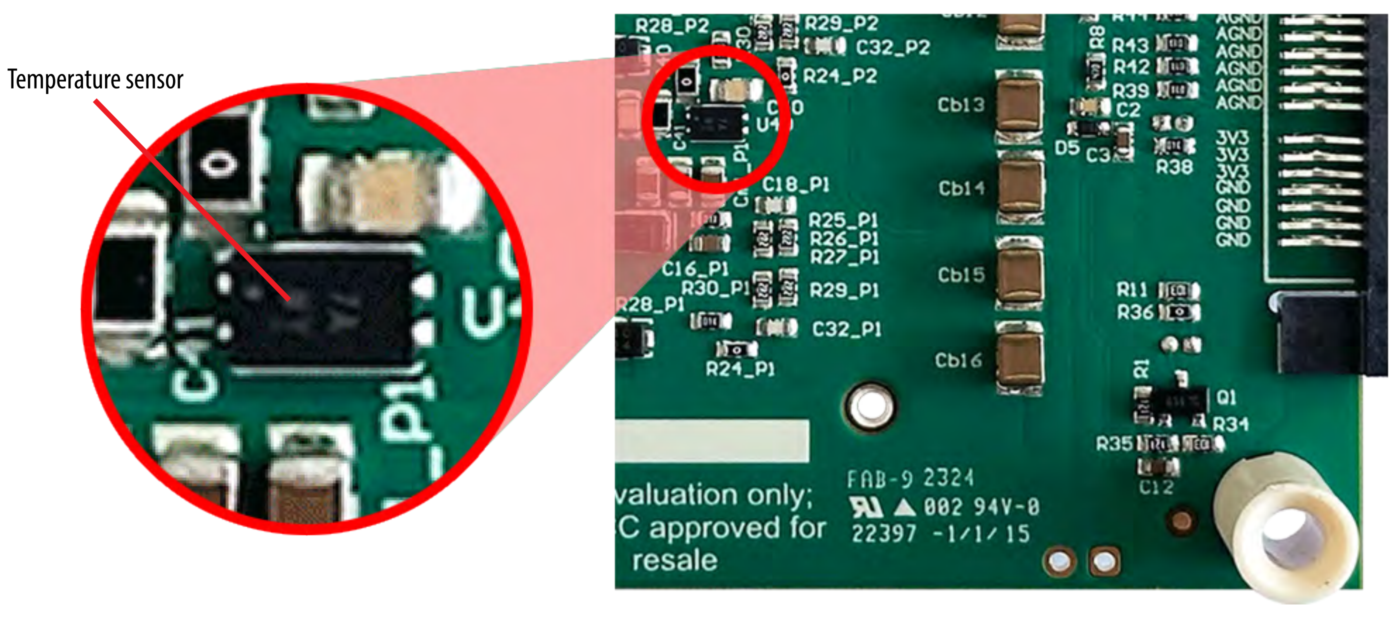


Figure 15: Temperature sensor location on the top side of the PCB

For support files including schematic, Bill of Materials (BOM), and gerber files please visit the EPC91104 landing page at: https://epc-co.com/epc/products/evaluation-boards/EPC91104

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