Demonstration Kit EPC9159KIT Quick Start Guide

High-Efficiency and High-Power-Density LLC Converter

Revision 1.0

EFFICIENT POWER CONVERSION

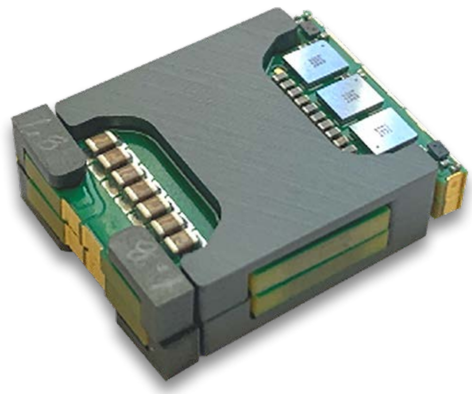
DESCRIPTION

The EPC9159KIT features a high-efficiency and high-power-density LLC converter capable of delivering up to 1 kW continuous output power into a 12 V load, powered from a 48 V supply. The kit comprises 4 main components: 1) EPC9536 Rev. 5.0 motherboard, 2) EPC9528 controller, 3) EPC9556P primary side FET card and, 4) EPC9551T transformer module with synchronous rectifier. The EPC9536 motherboard connects the primary FET card and transformer module in a LLC topology and provides power and measurement ports. The EPC9536 can be configured in either Through Power Mode or Partial Power Mode for a high efficiency solution. The EPC9159KIT uses a microcontroller located in the EPC9528 card, which has its own corresponding **Quick Start Guide** for reference.

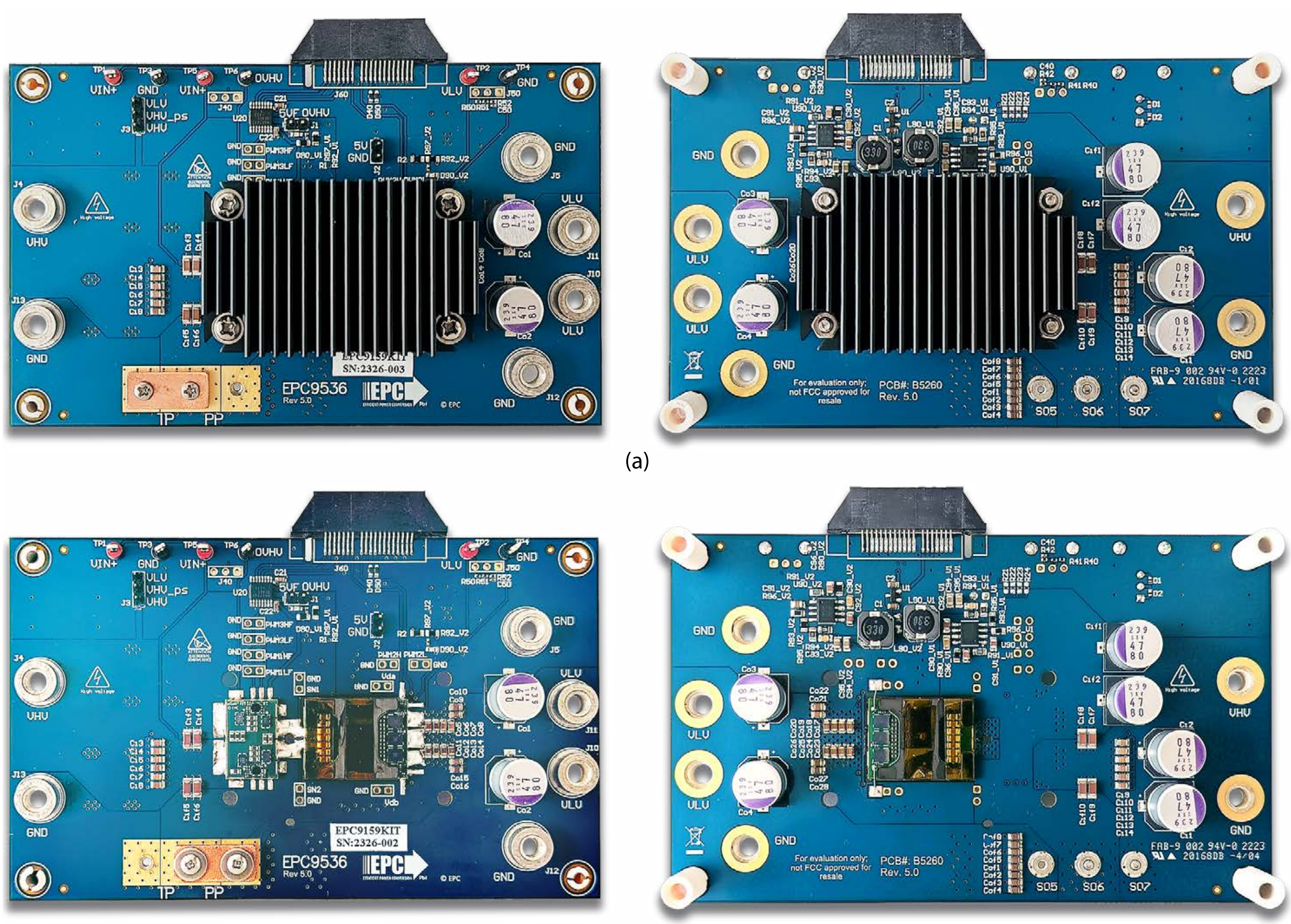
Figure 1 shows photographs of top and bottom views of the kit, with and without the heatsinks installed, and figure 2 shows a functional block diagram and a simplified schematic of the main power stage topology.

The key target applications for EPC9159 include, but is not limited to, computing power supplies, DC power distribution systems, and transportation.*

**Demonstration board is not automotive qualified. Contact EPC should this be a requirement.*



EPC9159KIT transformer module, size 22.8 x 17.5 x 7.2 mm



(a)

(b)

Top view ***Bottom view***

Figure 1: Photos of the EPC9159KIT demonstration kit with transformer module mounted on motherboard: (a) with heatsink installed, (b) without heatsink

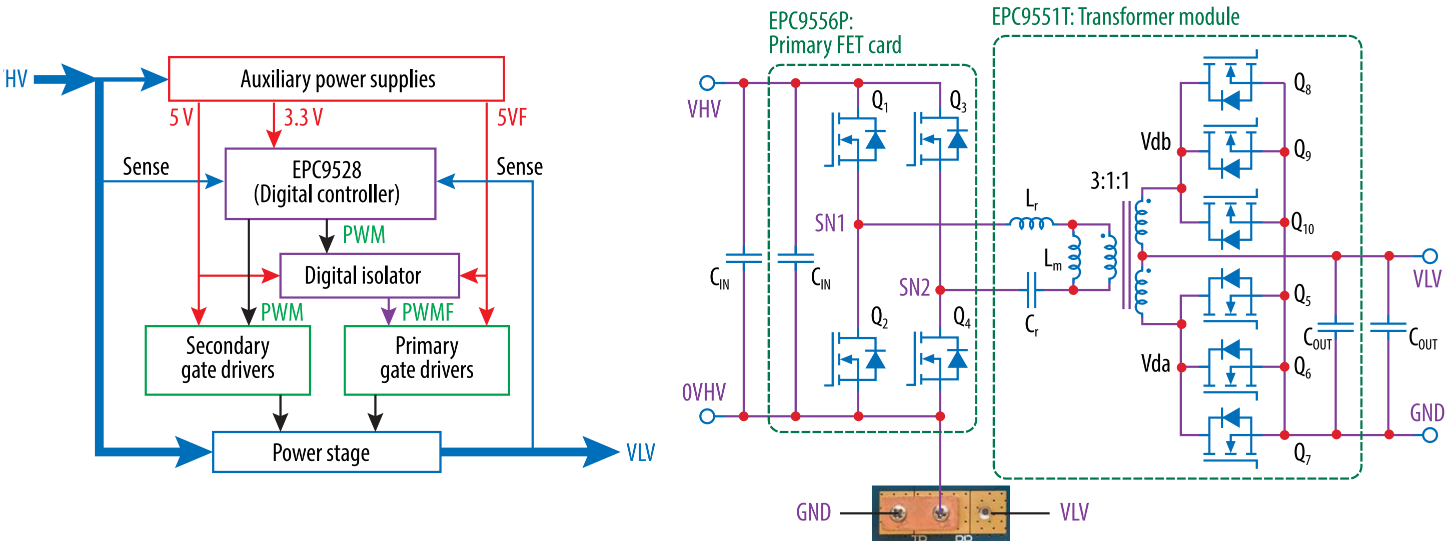


Figure 2: (left) Functional blocks of the board, (right) simplified schematic of the power stage of the converter

REGULATORY INFORMATION

This demonstration board is for evaluation purposes only. It is not a full-featured unit and cannot be used in final products. No EMI test was conducted. It is not FCC approved.

KEY FEATURES OF THE EPC9159KIT DEMO BOARD

- Peak efficiency > 97.5%, for the power stage
- Full-load efficiency > 95.5% delivering 83 A into 12 V load when configured in Partial Power Mode
- Designed to exceed 5 kW/in^3 (325 W/cm^3) once assembled into a module and configured in Partial Power Mode
- Kelvin test points for accurate performance measurement

FEATURED eGaN FETs

The EPC9159KIT demonstration kit features eGaN® FET transistors in the primary and secondary sides of the transformer. The primary full bridge uses four **EPC2619**, 80 V-rated 3.3 mΩ eGaN® transistor, and the secondary uses six **EPC2067** 40 V-rated 1.3 mΩ transistors. For more details of each product, please refer to their datasheet available at **www.ep-co.com**.

DESCRIPTION OF THE EPC9159KIT DEMO KIT

The converter selected for the EPC9159KIT is based on the LLC topology. The implemented LLC consists of a primary side full bridge, a fixed ratio 3:1 planar transformer, and a center tab synchronous rectifier for the secondary side. The primary comprises four EPC2619 GaN FETs, and the secondary uses a total of six EPC2067 GaN FETs. The converter is realized with a planar transformer design with custom magnetic cores. In addition, the board can be easily configured in Partial Power Mode for an input-to-output conversion ratio of 4:1, or through power for a 3:1 ratio. Contact EPC at www.epc-co.com for further information on the converter design, board layout, or components used.

Figure 3 shows photographs of both sides of the EPC9159KIT with the location of the main elements and components highlighted.

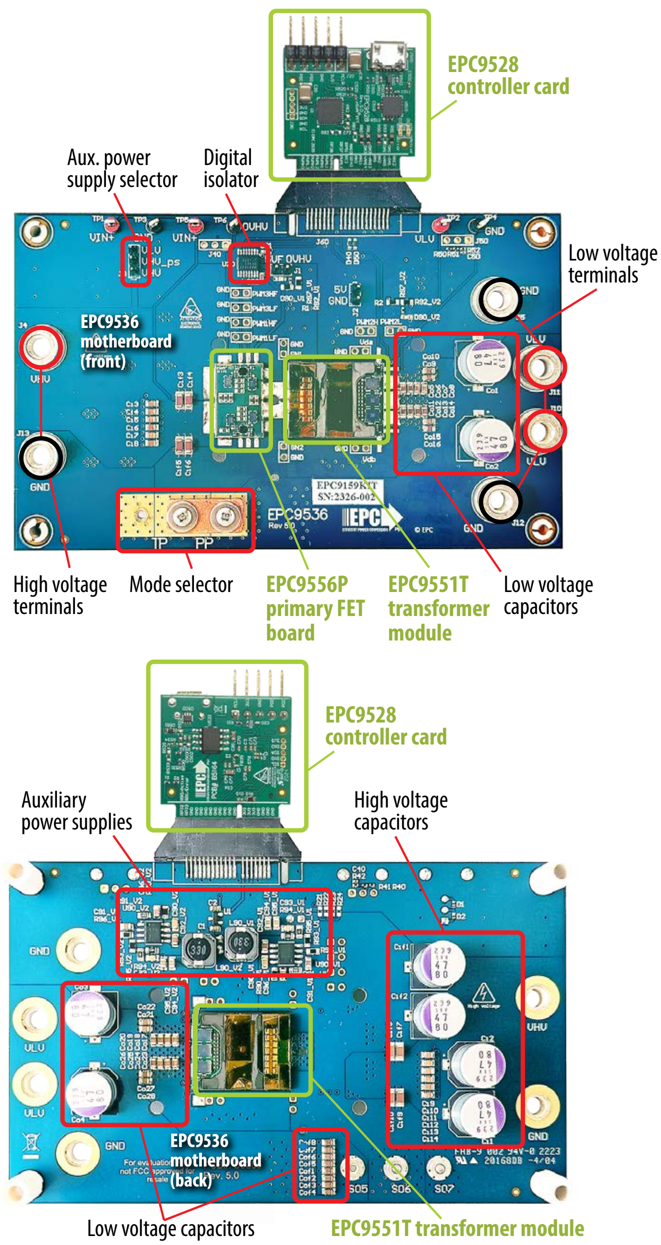


Figure 3: EPC9159KIT demo board with various components highlighted

Figure 4 shows a zoomed-in view of the EPC9556P primary side FET card configured as a full bridge using four EPC2619 eGaN transistors, two uP1966E half-bridge gate drivers, and some ceramic bypass capacitors.

Figure 5 shows a more detailed view of both sides of the transformer board (EPC9551T) with the custom magnetic cores installed. The resonant inductor, resonant capacitor and, transformer windings are built into the transformer board. Two groups of three EPC2067 eGaN transistors connected in parallel and controlled by the LMG1020 low-side gate driver are used for synchronous rectification in a center tap configuration. The synchronous rectifier was integrated into the secondary winding of the transformer to minimize leakage inductance and thus maximize the transformer efficiency. The transformer board is installed in a cutout on the motherboard, using castellated edges for connections. The transformer board also contains resonant capacitors, as well as some ceramic filter capacitors for the output DC bus. Soft-switching is achieved by properly tunning the frequency and duty cycle of the primary FETs and rectifier FETs with respect to the converter resonant frequency. This solution does not use zero current detection for that purpose.

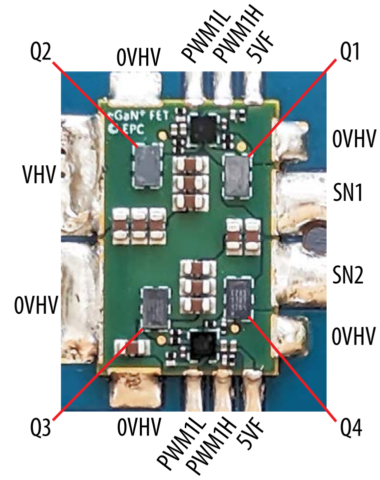


Figure 4: Zoomed-in photo of the EPC9556P primary side FET card

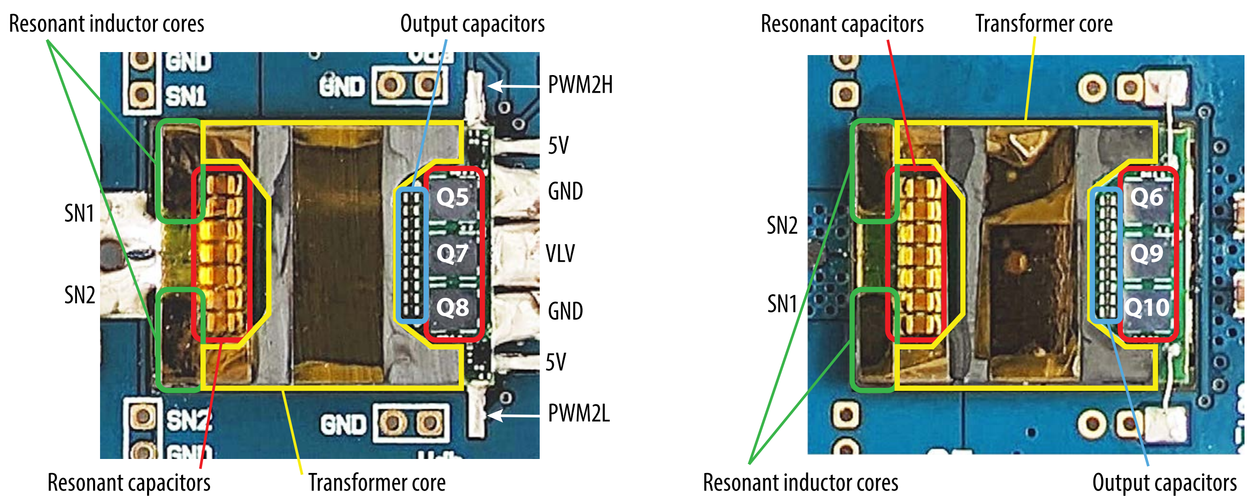


Figure 5: Zoomed-in photo of the EPC9551T transformer module with various components highlighted

Table 1: Electrical Operating Specifications (T_{Amb} = 25°C) EPC9159KIT

Symbol	Parameter	Conditions	Min	Typ	Max	Units
V_{HV}	High Voltage[1] Port (V_{IN})	Partial Power (PP)	12	48	52	V
		Through Power (TP)	9	36	40	
V_{LV}	Low Voltage[2] Port (V_{OUT})			12		
I_{HV}	High Voltage Port Current	With heatsink & 400 LFM airflow			21[3]	A
I_{LV}	Low Voltage Port Current	With heatsink & 400 LFM in PP			83[3]	
		With heatsink & 400 LFM in TP			62.5[3]	
f_{SW}	Switching Frequency			1.6		MHz

1 Maximum input voltage is limited by the rating of the eGaN FETs used in the primary (EPC2619), the rating of the primary gate drivers (up1966E), and the V·s across the primary winding of the transformer. See device datasheets for additional information.

2 There is a fixed ratio between the voltages in the High Voltage Port and Low Voltage Port. This ratio is 4:1 in Partial Power Mode, and 3:1 in Through Power Mode.

3 Maximum current capability is dependent on thermal limitations, maximum die temperature, and saturation of the resonant inductor core material. See material datasheet for further information and refer to thermal performance section in this guide for thermal management details.

CONNECTIONS

Power Connections

The EPC9159 kit is configured to operate as a step-down converter with a fixed input to output ratio. The ratio is set to 4:1 (Partial Power Mode) or 3:1 (Through Power Mode), depending on the position of the copper bar along the lower edge of the board.

Partial Power Mode (default)

By default, the EPC9159KIT is configured to operate in Partial Power Mode with a 4:1 ratio, to output 12 V when sourced with 48 V. In this configuration, the converter can process up to 1 kW of power.

Note the position of the copper bar in the lower left of the board shown in figure 6. It connects the two exposed copper pads above the "PP" label. The right exposed pad is the VLV net (Output voltage) and the left pad, the 0VHV net. This configuration causes the 0VHV node to float above GND, hence the need for a floating 5V auxiliary supply (5VF), and a digital isolator to level shift the PWM signals coming from the controller card, which is referenced to GND.

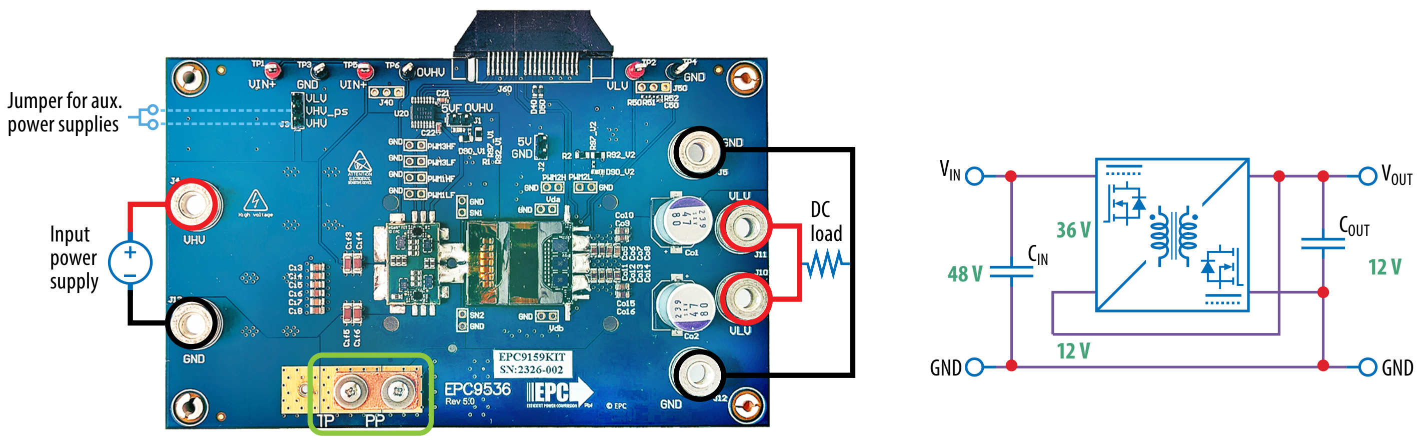


Figure 6: Left: Power connections and configuration for operation in Partial Power Mode. Right: Block diagram of the converter in Partial Power Mode.

Through Power Mode (alternative)

Alternatively, the EPC9159KIT can be configured in Through Power Mode, which changes the input to output voltage ratio to 3:1. In this mode, the converter can process up to 750 W into 12 V output from a 36 V supply.

To operate in Through Power Mode the position of the copper bar needs to be adjusted to connect the two exposed copper pads above the "TP" label, as shown in figure 7. In this configuration, the 0VHV net is connected to GND.

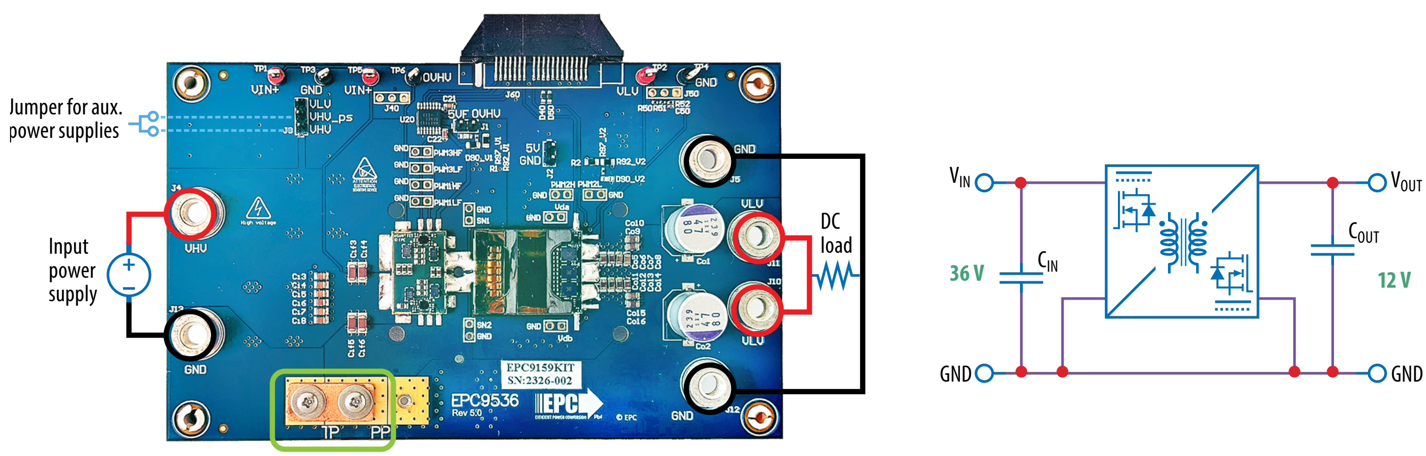


Figure 7: Left: Power connections and configuration for operation in Through Power Mode. Right: Block diagram of the converter in Through Power Mode.

Test Points and Measurement Setup

Figure 8 shows the various measurement connections of the EPC9159KIT demonstration kit. The motherboard is equipped with Kelvin sense points for DC voltage measurements of input and output voltages, needed for accurate converter efficiency measurements.

In addition, there are multiple oscilloscope probe points for all the relevant PWM signals, the two primary switch nodes (SN1 and SN2), and secondary drains (Vda and Vdb). All these signals can be measured using **single-ended probes** referenced to GND. This means that in Partial Power Mode the primary PWM signals (PWMxyF) appear as square waveforms switching between 0VHV and 0VHV + 5 V, with 0VHV = VLV (Output voltage). The same applies to SN1 and SN2. Figure 9 (left) shows the recommended method to measure these signals.

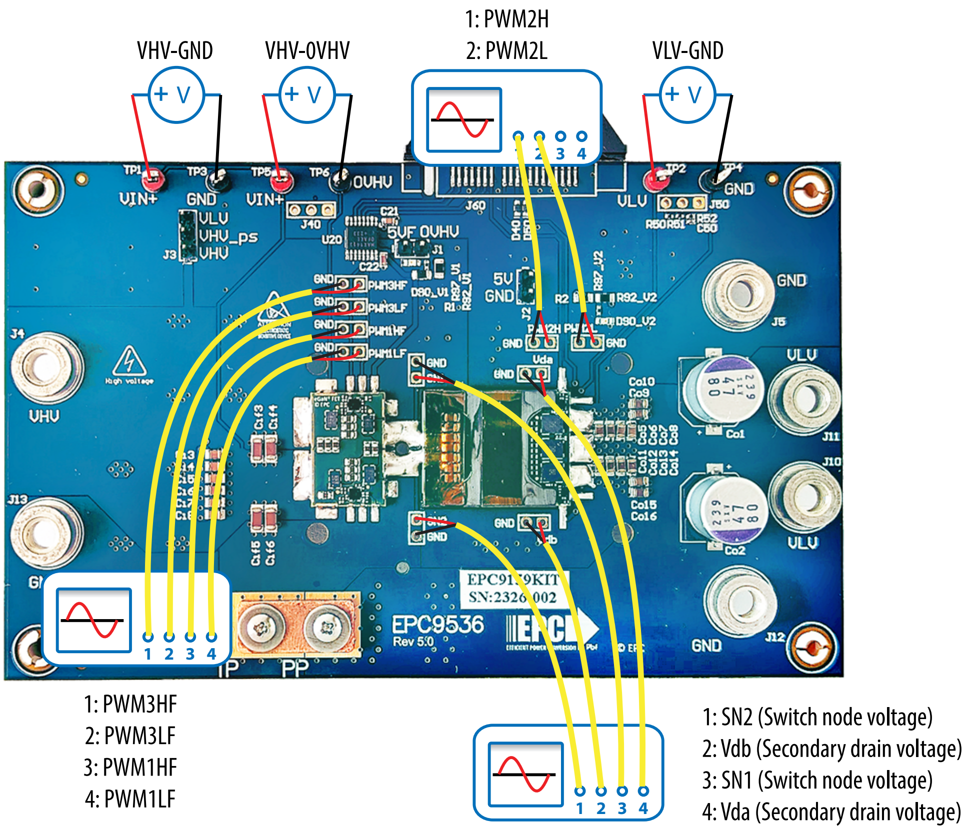


Figure 8: EPC9159KIT hookup locations for DC measurements and oscilloscope probe points for waveform measurements

Description of measurement ports:

DC measurements

- **VHV-GND**: DC Kelvin sense points for input voltage supply referenced to GND.
- **VHV-0VHV**: DC Kelvin sense points for input voltage supply referenced to 0VHV. In Through Power Mode 0VHV = GND, in Partial Power Mode 0VHV = VLV (Output voltage).
- **VLV-GND**: DC Kelvin sense points for the output voltage referenced to GND.

Oscilloscope measurements

- **SN1**: Primary Switch Node voltage between Q1 and Q2 referenced to GND, so single ended scope probes referenced to GND can be used. Note that the actual SN1 signal is referenced to 0VHV, which in Partial Power Mode 0VHV = VLV (Output voltage), and in Through Power Mode 0VHV = GND. The difference in these signals for both modes can be observed in Figures 15 and 16 respectively.
- **SN2**: Primary Switch Node voltage between Q3 and Q4 referenced to GND. Same comments mentioned above for SN1 apply.
- **Vda**: Secondary drain voltage of Q5/6/7 referenced to GND.
- **Vdb**: Secondary drain voltage of Q8/9/10 referenced to GND.
- **PWM2H/PWM2L**: PWM signals for the secondary rectifier eGaN FETs, from the controller card to the gate drivers, referenced to GND.
- **PWM1H/PWM1L/PWM3H/PWM3L**: PWM signals for the eGaN FETs in the primary, from the digital isolator to the gate drivers, referenced to GND. Similar to SN1 and SN2, the actual signals are referenced to 0VHV for operation in Partial Power Mode, but the probe points are referenced to GND so single ended probes can be used.

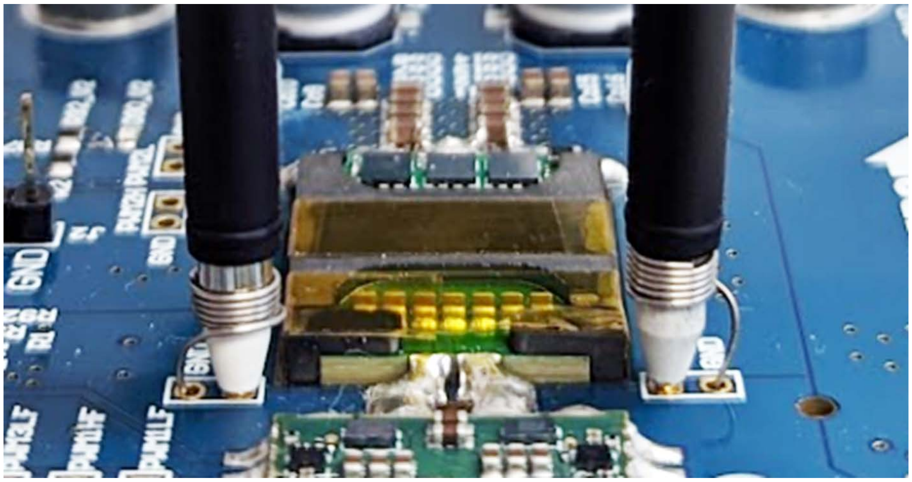


Figure 9: Recommended method for measuring switch-node voltages in the primary (SN1, SN2) and Drain voltages in the secondary (Vda, Vdb)

QUICK START PROCEDURE

The EPC9159KIT demonstration kit was designed to easily evaluate the performance of EPC2619 and EPC2067 in a high efficiency high-power-density LLC converter. Refer to figures 6 or 7, 8 & 9 for proper power connections and measurement setup, and follow the procedure below to operate the board:

1. Make sure the Auxiliary Power Supply Selector is installed between VHV and VHV_ps (see figures 6 or 7 for its location). In this position, the input for the auxiliary power supplies is connected to VHV.
2. Make sure the EPC9528 controller card is installed in the edge card connector J60.
3. Make sure the copper bar for the mode selector is installed properly. The default configuration is Partial Power Mode and is shown in figure 6.
4. With power off, connect a power supply as shown in figure 6 or 7. A shunt resistor can be inserted in series with the positive supply to measure the DC input current to the board.
5. With power off, connect a suitable load as shown in figure 6 or 7.
6. With power off, connect the various measurement probes as shown in figure 8.
7. With setting at 0V, Turn on the input power supply.
8. **Keeping the load off**, turn up the source power supply. The converter will not start up until the minimum input voltage for the auxiliary power supplies, approximately 7 V, has exceeded. As the input supply voltage increases, note that the converter operates with a fixed ratio, so the output is not regulated and increases with the input.
9. Engage the load and adjust the load current within the current capability of the EPC9159KIT per table 1.
10. Collect the various measurements while adjusting the supply voltage and load current while observing that all operating parameters remain within the specifications provided in table 1.
11. For shutdown, please follow steps in reverse.

THERMAL MANAGEMENT

The EPC9159KIT is fitted with a heatsink kit installed. This kit includes thermal interface pads and a low profile heatsink on both sides of the board, as shown in the exploded 3D view of figure 10. This thermal solution is required to reach the maximum power listed in Table 1 in steady state with 400 LFM of forced air and 25°C ambient temperature.

These are the main components of the thermal solution:

- Thermal interfaces for the eGaN FETs (t-Global Part Number: TG-A1780), see figure 11 for details
- Thermal interfaces for the inductor and transformer cores (t-Global Part Number: TG-A1780), see figure 11 for details
- Low profile heatsinks from Wakefield-Vette; Part Number: 547-45AB

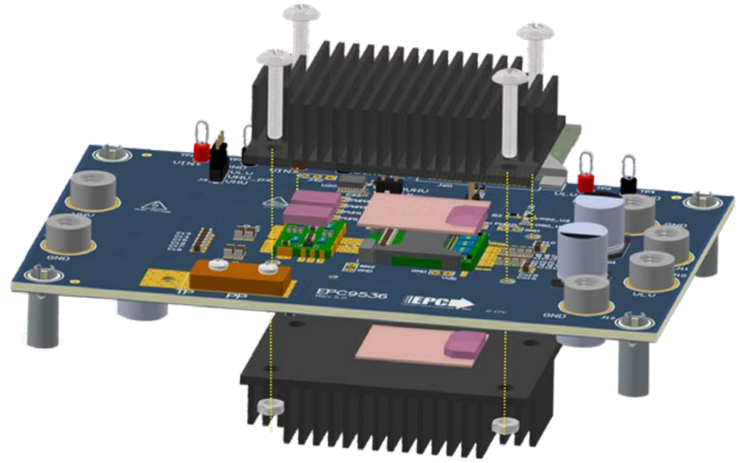


Figure 10: Exploded view of the cooling system assembly with location of the various TIM's

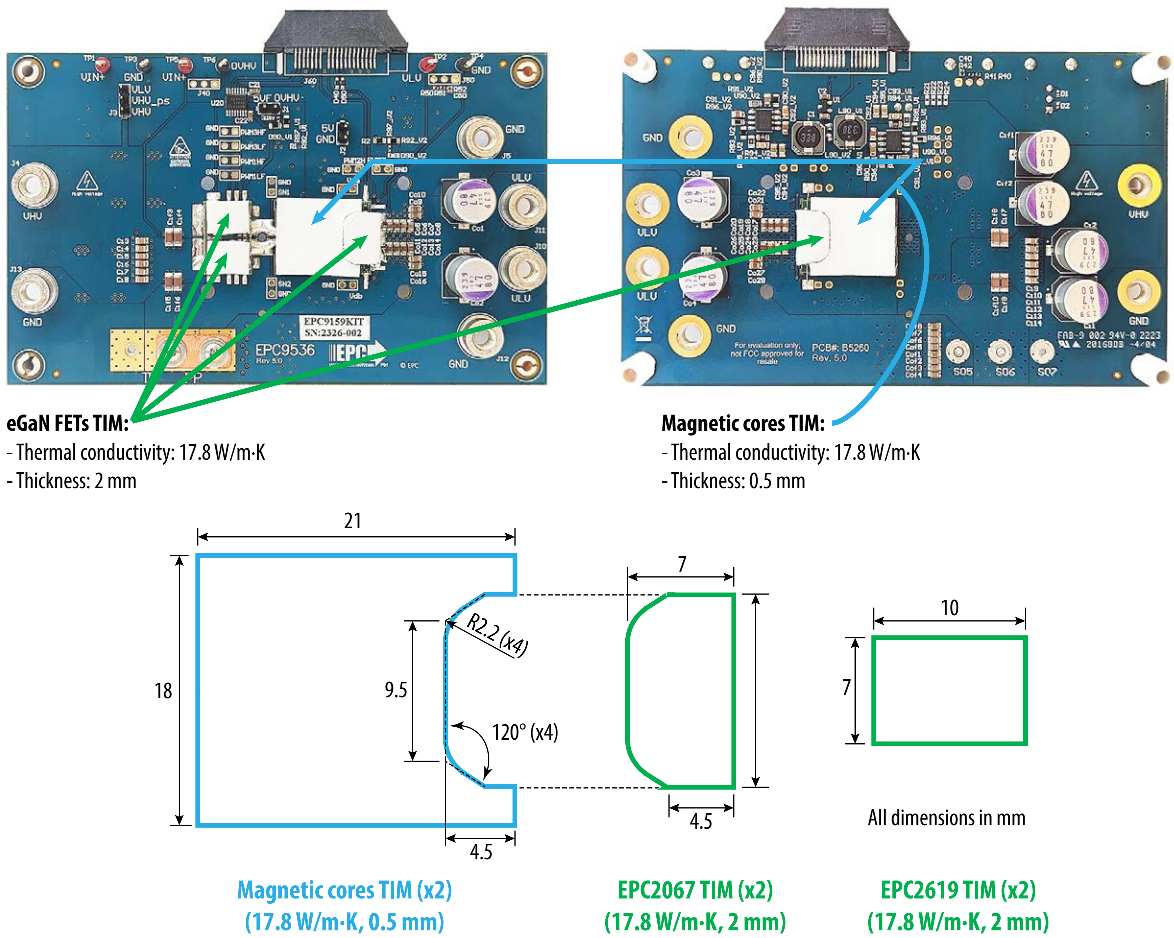


Figure 11: Location and details of the thermal interface materials used in the EPC9159KIT

NOTE. The EPC9159KIT Demonstration Kit does not have any over-current or thermal protection on board. For more information regarding the thermal performance of EPC eGaN FETs and ICs, please consult:

D. Reusch and J. Glaser, *DC-DC Converter Handbook, a supplement to GaN Transistors for Efficient Power Conversion*, First Edition, Power Conversion Publications, 2015.

EXPERIMENTAL VALIDATION

Experimental results for EPC9159KIT demonstration kit operating in both modes are included in this guide. In either mode, Partial Power at 1 kW with a 48 V supply or Through Power at 750W with a 36 V supply, the power processed through the LLC converter is the same, and so are the power losses.

The tests results shown in this section were obtained with an ambient temperature of 25°C and different forced airflows, as indicated below. The cooling system described previously in the Thermal Management section of this Quick Start Guide is required to maintain full power in thermal steady state conditions.

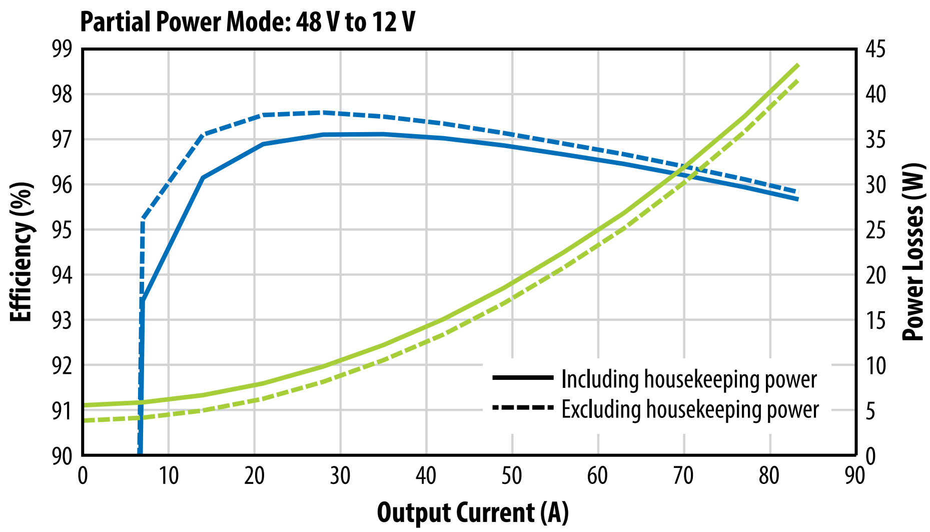


Figure 12: Measured efficiency and power loss curves for the EPC9159KIT with the heatsink installed in Partial Power Mode

Partial Power Mode Results

In Partial Power Mode with a 48 V supply and a fixed step-down ration of 4:1, the EPC9159KIT can process up to 1 kW of power into a 12 V load.

Efficiency and Power Loss Results

The measured power loss and efficiency of the EPC9159KIT operating in Partial Power Mode with 400 LFM forced airflow and heatsink installed is shown in figure 12. Input and output DC voltages were measured using the Kelvin connections shown in figure 8. Input DC current was measured using a shunt resistor between the output of power supply and the VHV terminal of the kit, and output current was controlled and measured using a controllable electronic load. Two cases, one that includes housekeeping power (solid lines) and the other excluding it (dashed lines) are provided.

Waveforms

Figure 13 shows the measured switch-node waveforms, secondary Drain voltages, and resonant current at various output currents when operating from 48 V input. In Partial Power Mode, the switch-node waveforms (SN1 and SN2) have a trapezoidal shape between 48 V and 12 V.

All the voltage waveforms were captured using single ended probes referenced to ground (GND) and a Rogowski coil for the resonant current. Please refer to the Test Points and Measurement Setup section of this Quick Start Guide for details.

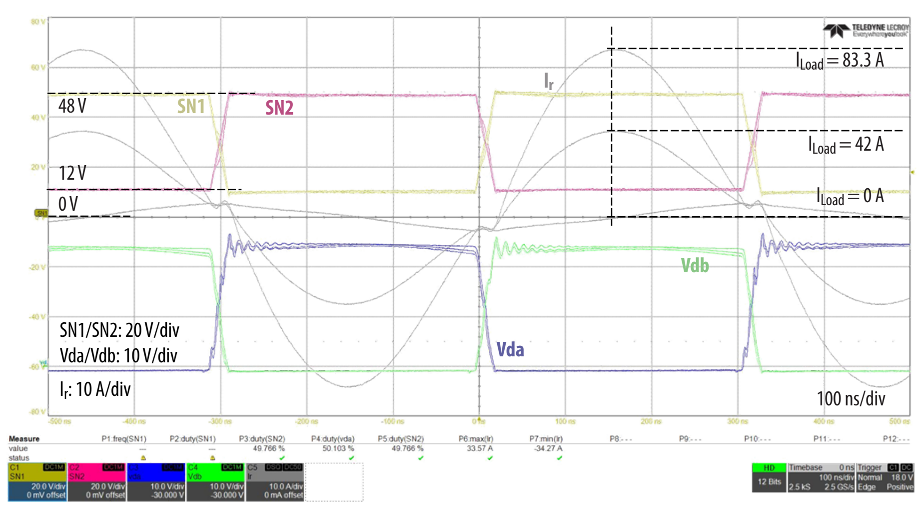


Figure 13: Measured waveforms of the EPC9159 kit operating in Partial Power Mode with 48 V input, 12 V output and various load currents.

Through Power Mode Results

In Through Power Mode, the step-down ratio is 3:1, so the same output voltage can be achieved with a 36 V supply. In this mode, the converter can process up to 750 W.

Efficiency and Power Loss Results

The measured power loss and efficiency of the EPC9159KIT operating in Through Power Mode with 400 LFM forced airflow and heatsink installed is shown in figure 14. Input and output DC voltages were measured using the Kelvin connections shown in figure 8. Input DC current was measured using a shunt resistor between the output of power supply and the VHV terminal of the kit, and output current was controlled and measured using a controllable electronic load. Two cases, one that includes housekeeping power (solid lines) and the other excluding it (dashed lines) are provided.

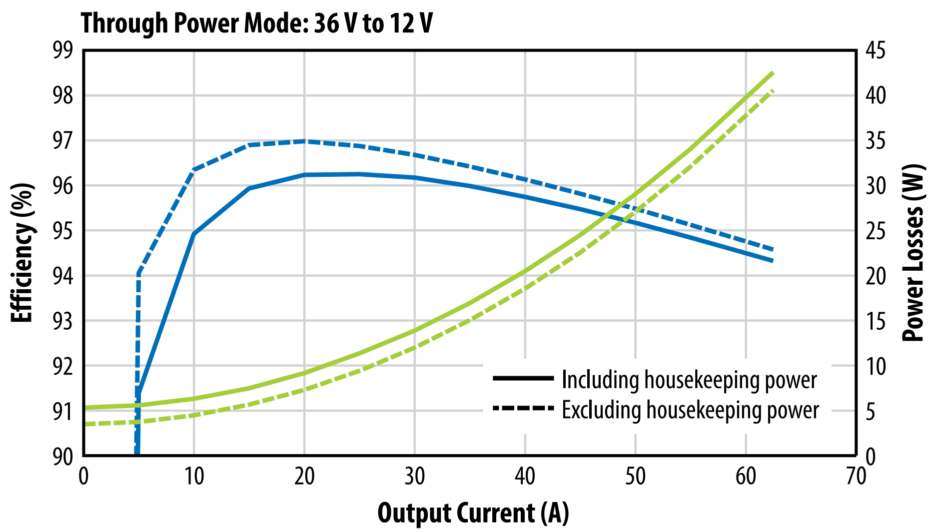


Figure 14: Measured efficiency and power loss curves for the EPC9159KIT with the heatsink installed operating in Through Power Mode with 400 LFM forced airflow

Waveforms

Figure 15 shows the measured switch-node waveforms, secondary Drain voltages, and resonant current at various output currents when operating from a 36 V supply. In Through Power Mode, the switch-node waveforms (SN1 and SN2) have a trapezoidal shape between 36 V and 0 V. All the voltage waveforms were captured using single ended probes referenced to ground (GND) and a Rogowski coil for the resonant current. Please refer to the Test Points and Measurement Setup section of this Quick Start Guide for details.

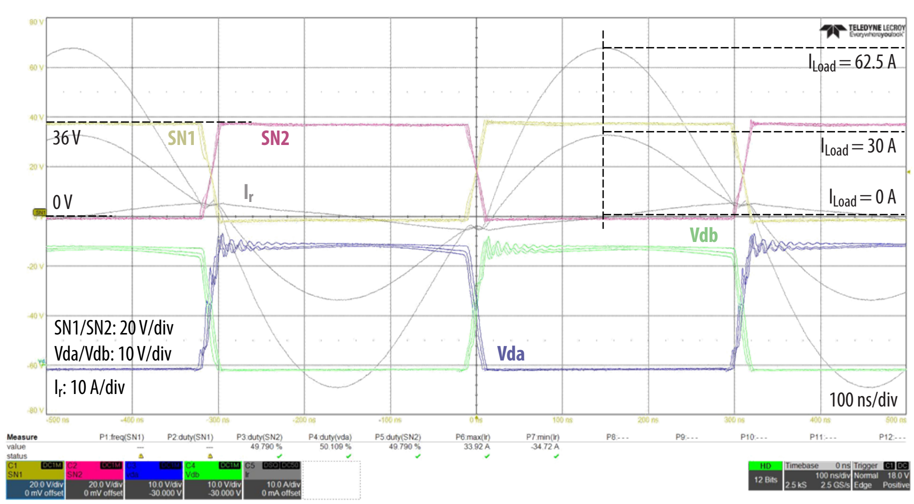


Figure 15: Measured waveforms of the EPC9159 kit operating in Through Power Mode with 36 V input, 12 V output and various load currents

THERMAL PERFORMANCE

As mentioned previously, the power flowing through the converter module when operating in Partial Power Mode at 1 kW is the same as in the Through Power Mode at 750 W. This means thermal performance can be measured in either mode with the same result. Therefore, for the remainder of this section, with 12 V output voltage, "maximum power" is defined as 750 W in Through Power Mode and 1 kW in Partial Power Mode.

Figure 16 shows a thermal image of the EPC9159KIT with the heatsink kit installed in thermal steady state with 25°C ambient temperature and 400 LFM of forced air. The converter was operating in Through Power Mode from a 36 V supply at maximum power. The same performance would result from operating in Partial Power Mode from a 48 V supply at 1 kW load. As shown in figure 16, the heatsink surface temperature settles at approximately 60–65°C while the eGaN FETs, both the EPC2619 in the primary and the EPC2067 in the secondary, approaches 80–85°C.

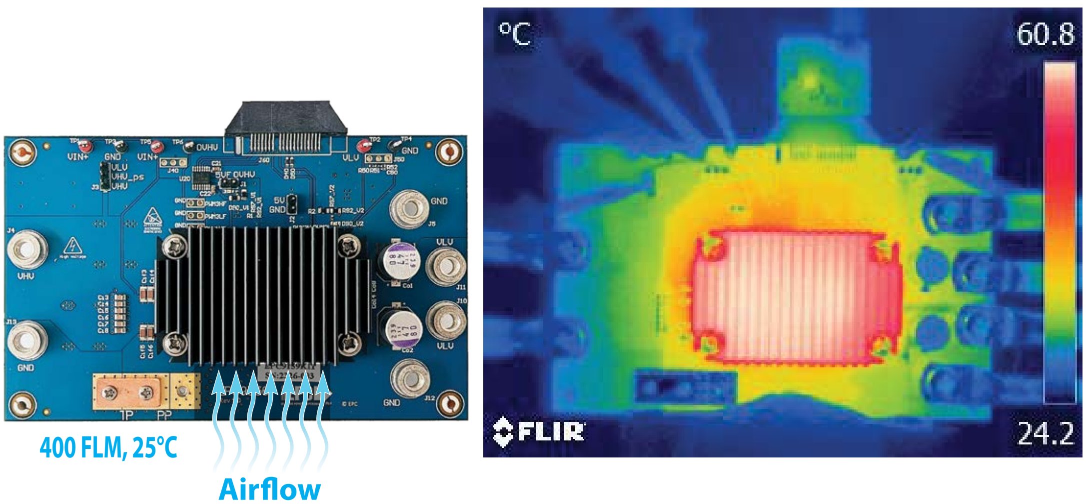


Figure 16: Thermal steady state image of the EPC9159KIT with the heatsink kit installed, in Through Power Mode, while processing maximum power from a 36 V supply. Forced air of 400 LFM and 25°C ambient temperature.

The EPC9159KIT can also operate without the heatsink and thermal interface materials. However, the operating temperatures of the eGaN FETs will increase rapidly unless the output power is limited or the time operating at maximum load is reduced.

Figure 17 shows the kit operating without a heatsink and **high air flow**, while delivering maximum power into a 12 V load, for a **duration limited to 3 seconds**. On the top-left corner of the thermal image four different spot temperatures are provided. "Sp1" shows the temperature of the hottest EPC2619 in the primary full bridge, "Sp2" the temperature of the core of the resonant inductor, "Sp3" the winding temperature under the transformer core, and "Sp4" the winding temperature in the proximity of one of the EPC2067 in the secondary rectifier.

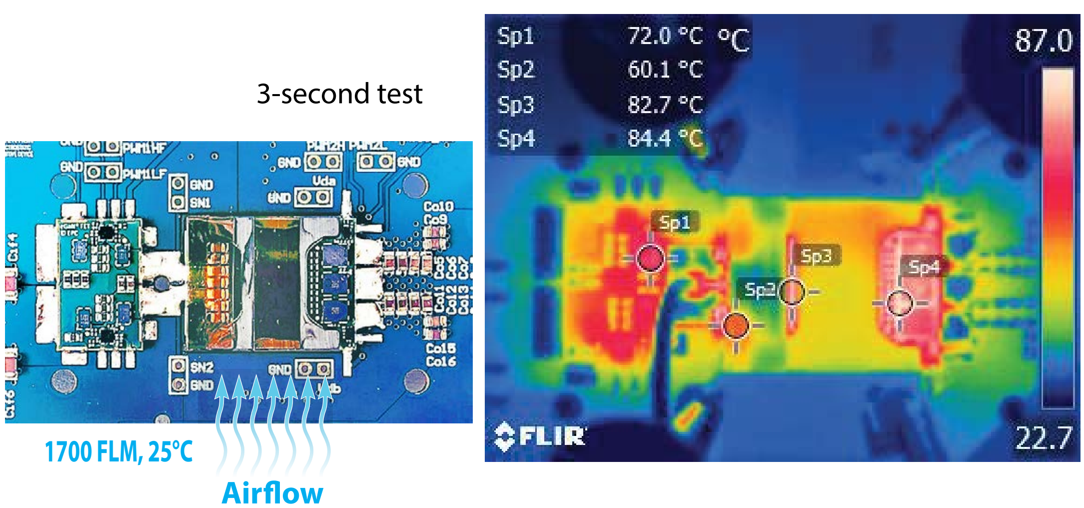


Figure 17: Thermal image of the EPC9159KIT in Partial Power Mode, without the heatsink kit installed and high airflow, while delivering 1 kW into a 12 V load from a 48 V supply.

Similarly, the EPC9159KIT can operate without a heatsink in thermal steady state and moderate airflow (400 LFM) and under power derating. For a maximum operating temperature of approximately 85°C, the converter can deliver up to 64% of the maximum power with a heatsink and 400 LFM. For a 12 V load, this means 640 W in Partial Power Mode and 480 W in Through Power Mode. Figure 18 shows the temperatures of the various components in the converter in thermal steady state without a heatsink and 400 LFM.

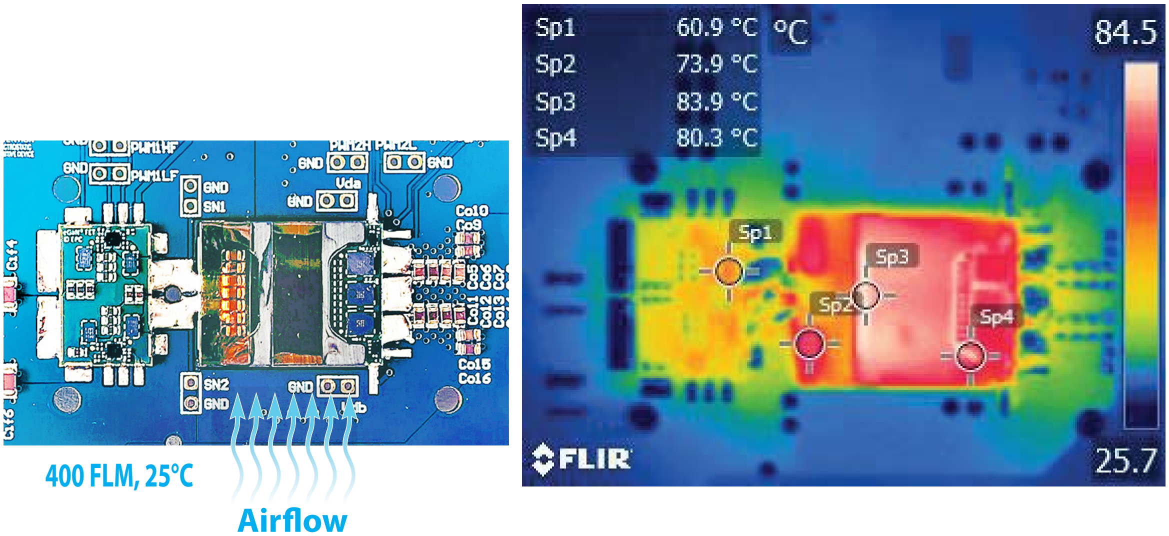


Figure 18: Thermal steady state image of the EPC9159KIT without the heatsink kit installed while processing 640 W into a 12 V load from a 48 V supply, in Partial Power Mode.

PROGRAMMING

The EPC9159KIT comes with a pre-programmed EPC9528 controller board. Refer to the **EPC9528 Quick Start Guide** for more information about the controller (Microchip dsPIC33CK256MP503) and instructions on how to program the board. Please contact EPC for the HEX file and instructions to properly tune the board if needed.

For support files including schematic, Bill of Materials (BOM), and gerber files please visit the EPC9159 landing page at: https://epc-co.com/epc/Products/Demo-Boards/EPC9159

ACKNOWLEDGEMENTS

Proterial – Magnetic Cores

PROTERIAL

EPC would like to acknowledge Proterial, Ltd. (**https://www.proterial.com/e/**) for their support with the custom inductor and transformer cores.

Microchip – Digital Controller

MICROCHIP

EPC would like to acknowledge Microchip Technology Inc. (**www.microchip.com**) for their support of this project.

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EFFICIENT POWER CONVERSION

Demonstration Board Notification

The EPC9159 board is intended for product evaluation purposes only. It is not intended for commercial use nor is it FCC approved for resale. Replace components on the Evaluation Board only with those parts shown on the parts list (or Bill of Materials) in the Quick Start Guide. Contact an authorized EPC representative with any questions. This board is intended to be used by certified professionals, in a lab environment, following proper safety procedures. Use at your own risk.

As an evaluation tool, this board is not designed for compliance with the European Union directive on electromagnetic compatibility or any other such directives or regulations. As board builds are at times subject to product availability, it is possible that boards may contain components or assembly materials that are not RoHS compliant. Efficient Power Conversion Corporation (EPC) makes no guarantee that the purchased board is 100% RoHS compliant.

The Evaluation board (or kit) is for demonstration purposes only and neither the Board nor this Quick Start Guide constitute a sales contract or create any kind of warranty, whether express or implied, as to the applications or products involved.

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