EPC9178

Bidirectional Capable Buck–Boost DC-DC Converter Quick Start Guide

Featuring the EPC2306 ePower™ Stage, Optimized for PV Optimizers

Revision 4.0

EFFICIENT POWER CONVERSION

DESCRIPTION

The EPC9178 is a high efficiency four switch buck-boost converter demonstration board , specifically designed for PV optimizers, that employs the LM5177 controller and features the 100 V rated EPC2306 GaN field effect transistor (FET). The EPC9178 operates at a fixed frequency of 450 kHz with an input voltage range from 30 V through 60 V. The output voltage is fixed but can be selected from three options: 30 V, 45 V and 60 V. The board is also equipped with two DC current sense resistors, monitoring both the input and output current on a cycle-by-cycle basis. Both input and output current limits are set to 15 A for a maximum output power of 675 W at 45 V_{DC}. A block diagram overview of the functional blocks of the EPC9178 converter is shown in Figure 1.

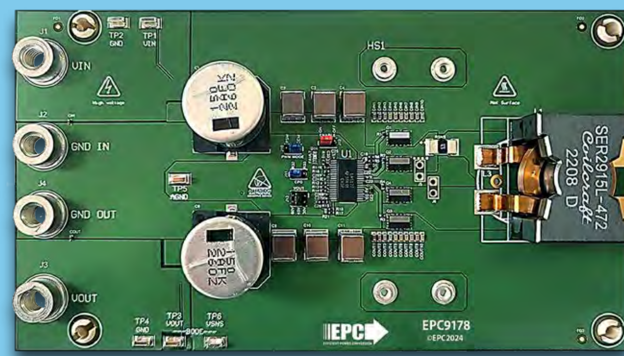
REGULATORY INFORMATION

This evaluation 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.

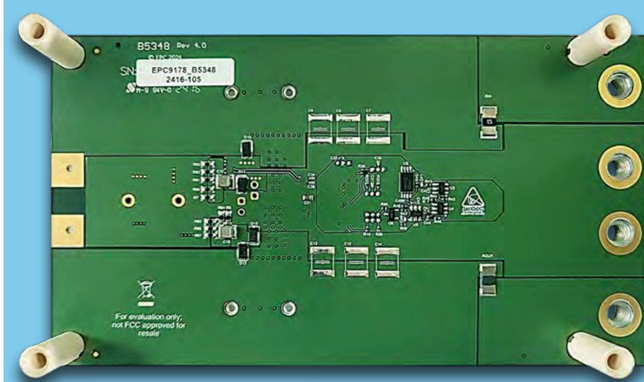
KEY FEATURES OF THE EPC9178 EVALUATION BOARD

- Wide input voltage range of 30 V to 60 V
- Selectable output voltages that match most common solar panel bus voltages
- Employs four low conduction and switching loss EPC2306 GaN FETs in back-to-back converter configuration
- Simple, low component count, high power-density circuit design within a compact 50 x 60 mm footprint (excluding inductor)
- Smooth transition from step up to step down or from step down to step up output voltage
- Supports multiple inductor footprints, allowing customizing the inductor
- Supports adding additional ceramic capacitors to input and output
- Programmable configuration controller

EPC9178 Evaluation Board



Top view



Bottom view

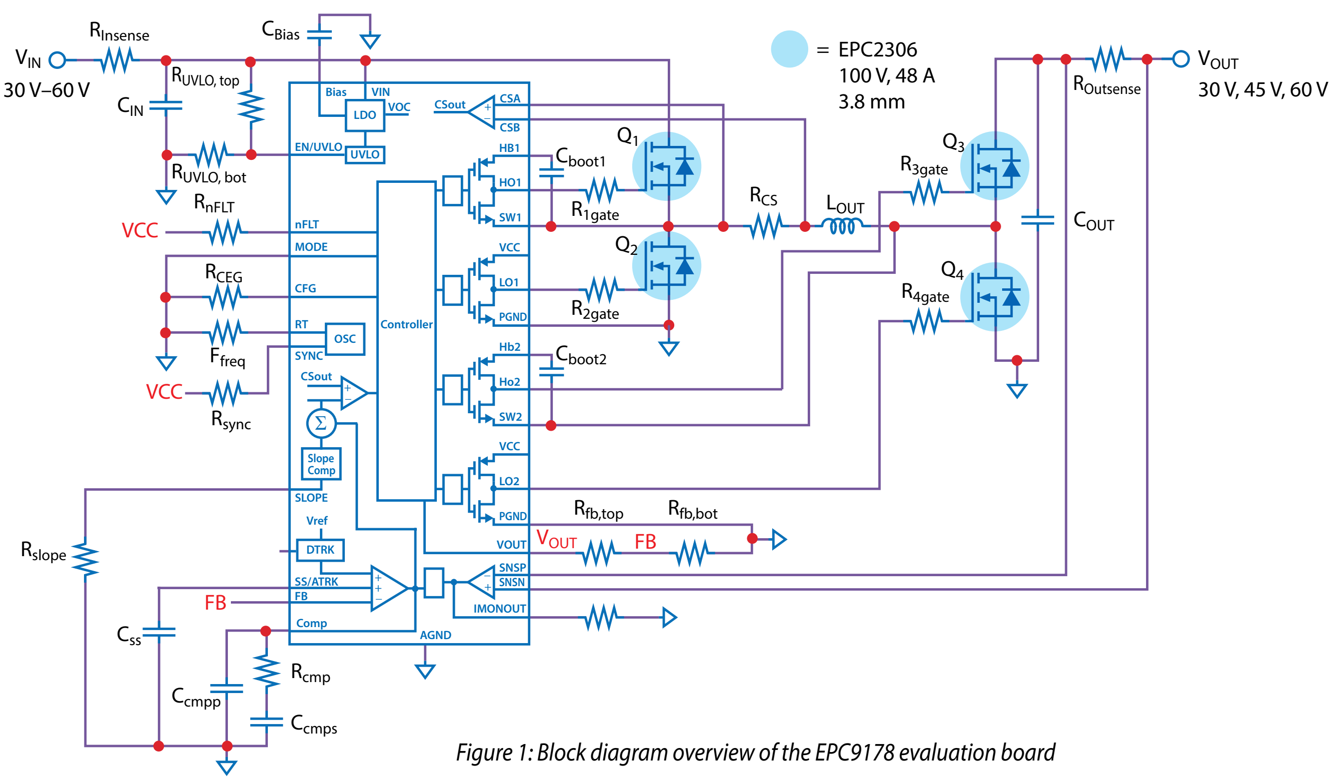
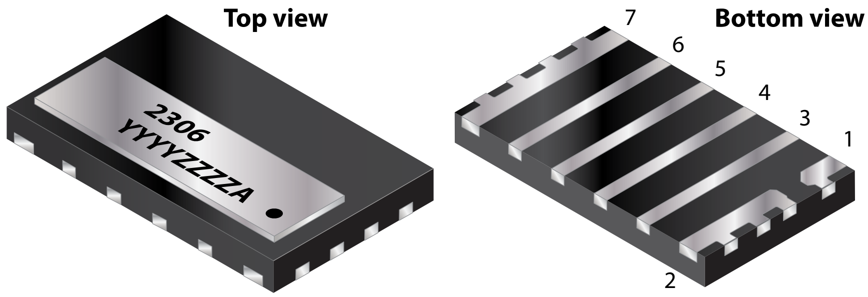


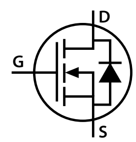
Figure 1: Block diagram overview of the EPC9178 evaluation board

FEATURED eGaN FET

The EPC9178 demonstration board features four 100 V rated, 3.8 mΩ $R_{DS(on)}$ EPC2306 GaN FETs in a 4-switch buck-boost configuration. The symbol of GaN FET and photo with pin assignment are shown in figure 2.



V_{DS}	**100 V**
$R_{DS(on)}$	**3.8 mΩ**
I_D	**48 A**



Pin	Description
1	Gate
2, 4, 6	Source
3, 5, 7	Drain

Figure 2: Detailed block diagram symbol and photo with pin assignment of the EPC2306

Refer to the **EPC2306 datasheet** for additional details.

OVERVIEW OF THE EPC9178 EVALUATION BOARD

Figure 3 shows an image of both sides of the EPC9178 evaluation board with the location of the various functional circuits highlighted.

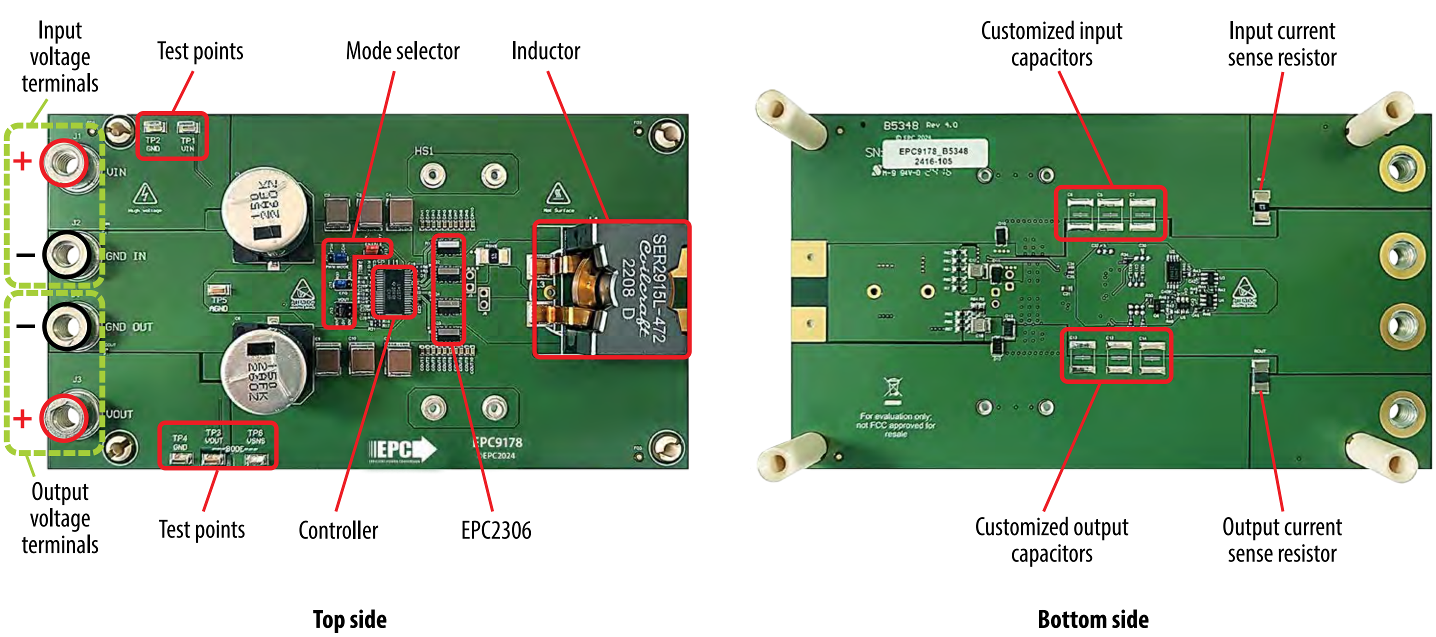


Figure 3: Photo overview of the EPC9178 evaluation board with various functional blocks highlighted

Figure 4 presents a close-up view of both sides of the application circuit. Excluding the inductor, the circuit area is confined to a compact 50 x 60 mm footprint.

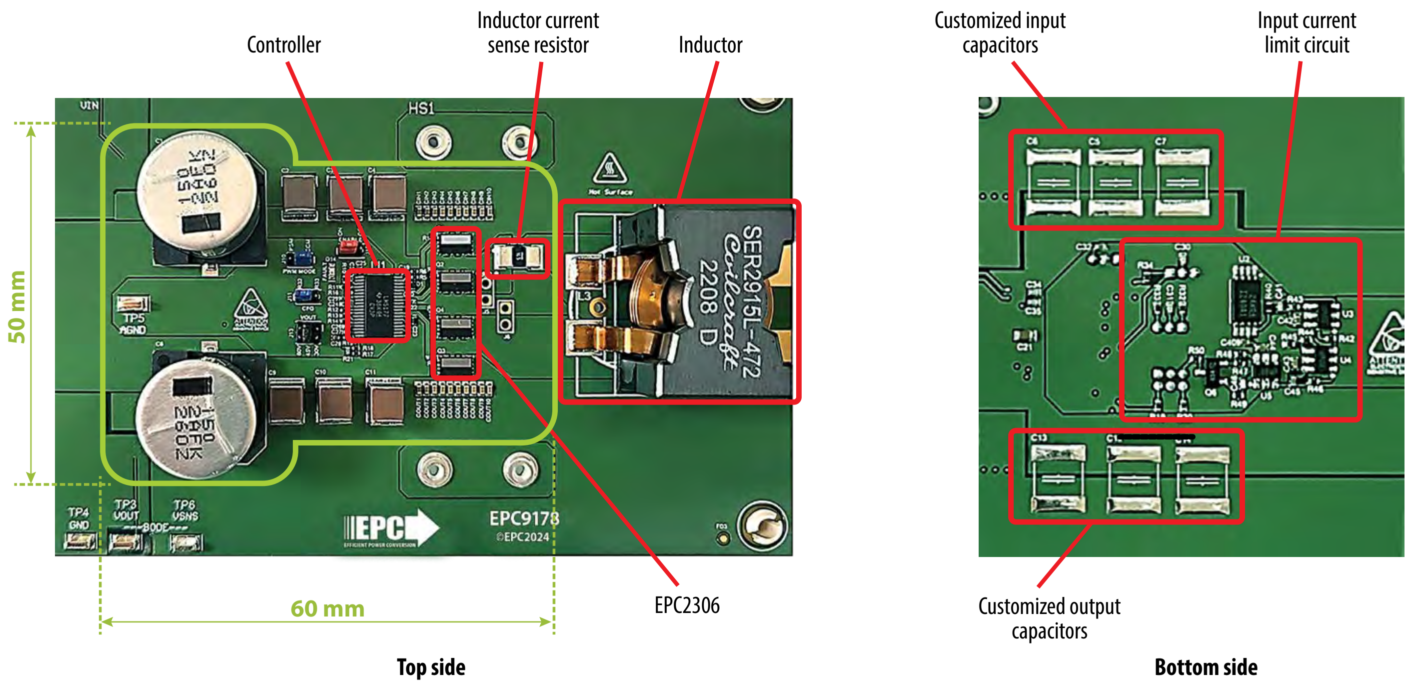


Figure 4: Zoomed-in photo details of the EPC9178 evaluation board with power circuit highlighted

RECOMMENDED OPERATING CONDITIONS

Table 1: Performance Summary (T_A = 25°C) EPC9178

Symbol	Parameter	Conditions	Min	Nominal	Max	Units
V_{IN}	Input voltage port (V_{IN})	Max I_{IN} = 15A	30	45	60[1]	V
V_{OUT}	Output voltage port (V_{OUT})	V_{IN} = 30 V, 45 V or 60 V, user selectable	30	45	60	
I_{OUT}	Output current	At V_{OUT} = 30 V with no heatsink & 400 LFM airflow			15[2,3]	A
f_{SW}	Nominal switching frequency			450[4]		kHz

[1] *Maximum voltage limited by maximum input voltage of LM5177 controller.*

[2] *Maximum current is limited by the input and output current limiting circuit.*

[3] *Maximum current capability is lower than stated in EPC2306 datasheet as it is dependent on thermal conditions and die temperature, and on component choice and board design – actual maximum current is affected by switching frequency, bus voltage, inductor current and thermal limits, and thermal cooling. Refer to **thermal performance section** in this guide and to **EPC2306 datasheet** for details.*

[4] *LM5177 controller can operate from 100 kHz through 600 kHz switching frequency. EPC9178 is set to operate at a fixed switching frequency of 450 kHz.*

HIGHLIGHTED PARTS OF THE EPC9178 CIRCUIT

Refer to figures 1 and 4 for the main blocks and components that comprise the EPC9178 evaluation board.

Power Stage

The EPC9178 features dual half-bridge converters using the EPC2306 eGaN FET configured in a back-to-back topology. For more information on EPC2306, 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.

Controller

The power circuit of the EPC9178 demonstration board is controlled using the LM5177 synchronous 4-switch buck-boost controller from Texas Instruments and is configured to operate with a fixed frequency and in peak current mode control. The functions of the LM5177 controller can be adjusted using the appropriate jumper setting. For information on configuring the controller, please refer to the jumper section. Refer to the **LM5177 datasheet** for additional details.

Current and Voltage Sense

The EPC9178 demonstration board is equipped with voltage and current sense for feedback control. A simple resistor divider network feeds the error amplifier within the controller, measured output voltage. A Fault LED (D14) illuminates when the output voltage deviates from the regulated value by approximately 10% due to any reasons, including over temperature and short circuit occurring.

Inductor current is monitored using a 1.5 mΩ shunt resistor (**R7**), providing accurate inductor current limiting for the controller during normal operation. Both input and output DC current are also monitored using **RIN** and **ROUT** respectively, providing the input and output current limit of 15 A. The input current is amplified using a INA240A1PWR high common-mode IC from Texas Instruments along with other signal processing circuits, connecting to the input voltage divider. When the input current reaches this limit, the input current limit circuit will force the output voltage to reduce proportionally to maintain power output.

Note: The fault LED will illuminate when the current input limit is reached, because the output voltage falls out of regulation proportional to the power output.

CONNECTIONS, MEASUREMENT TEST POINTS & JUMPERS

Power Connections

To operate the EPC9178, connect the input supply and the load as shown in figure 5.

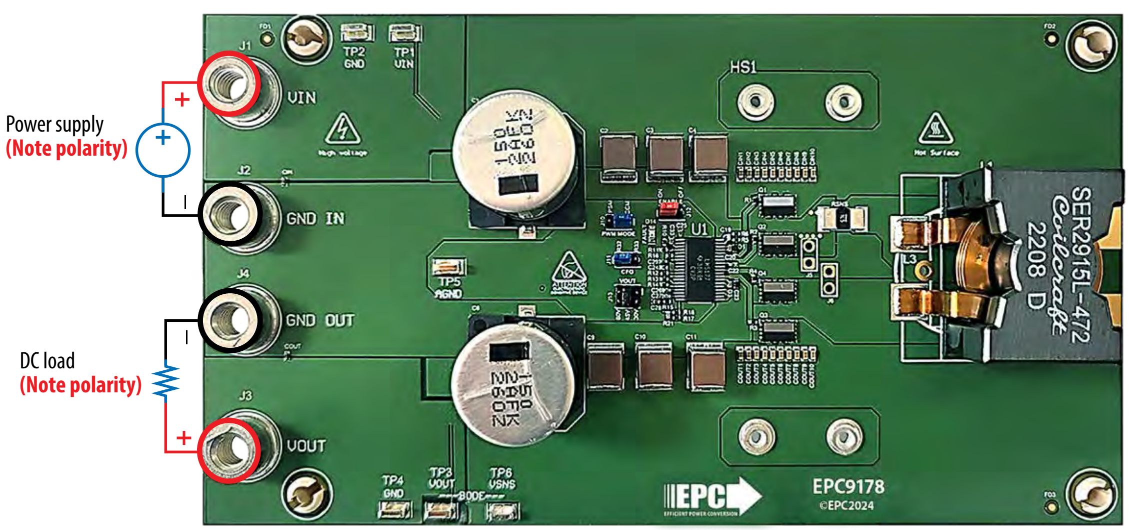


Figure 5: Power connections to the EPC9178 demonstration

Test Points and Measurement Setup

Figures 6 and 7 show the various measurement connections of the EPC9178 evaluation board.

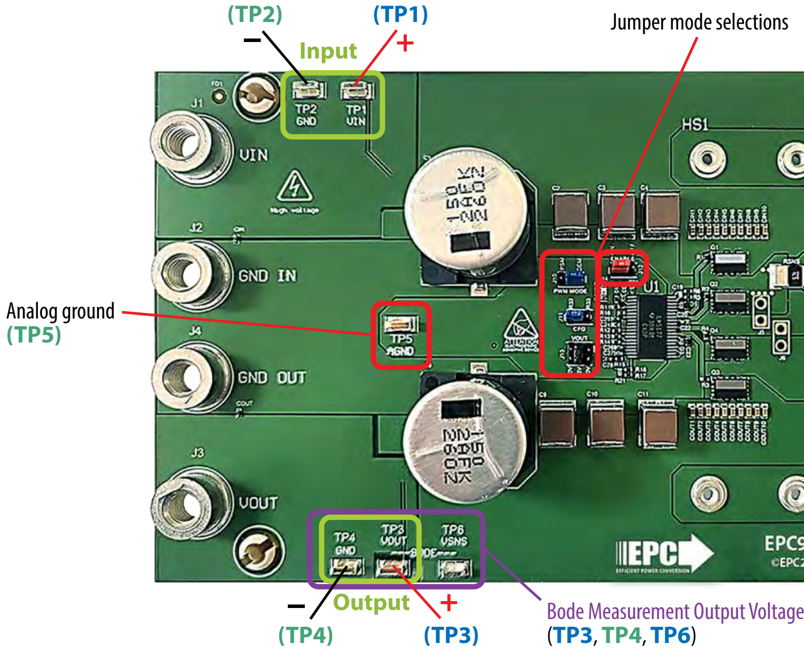


Figure 6: EPC9178 test point pad and hookup locations and designations.

The available measurement nodes with their respective reference are:

- **VIN**-**GND**: Input voltage (**TP1** & **TP2**)
- **VOUT-GND: Output voltage (TP3 & TP4),**
- **VLOAD-VSNS-GND: Output voltage bode measurement (TP3, TP6 & TP4),**
- **AGND: Analog Ground (TP5)**

Note: Exercise caution when using the bode measurements to ensure proper connection to the instrument.

Switch-nodes Measurement

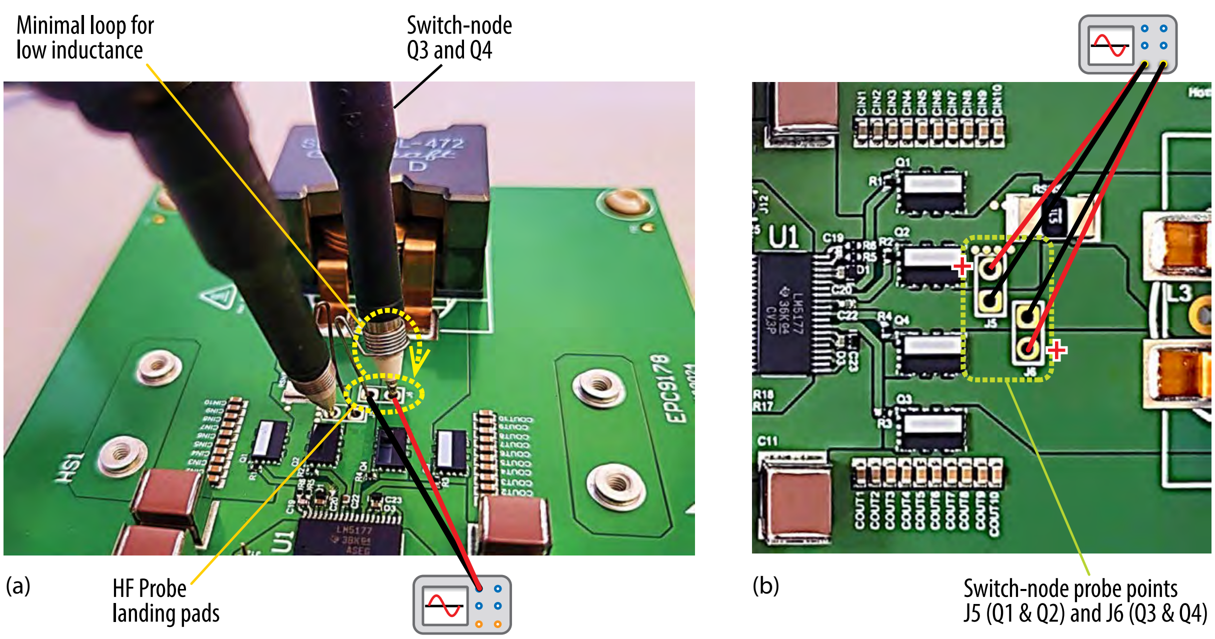


Figure 7: (a) Recommended method to measure the switch- node measurement voltage waveform.
(b) Zoomed in view of the switch-node probe points

Jumper Settings

Note: A jumper must be inserted to select a mode at each jumper header.

Output voltage settings

The EPC9178 offers three selectable output voltage settings: 1) 30 V, 2) 45 V and 3) 60 V. The desired output voltage can be selected by inserting a jumper into the appropriate position on J13 with position 1-2 for 30 V, position 3-4 for 45 V (default) and position 5-6 for 60 V. Details are shown in Figure 8.

Mode Configuration Selection

The EPC9178 offers two mode configuration settings: 1) enable 15 A output current limit and 2) disabled output current limit. Insert a jumper into J11 (CFG) to select the desired configuration mode. Inserting a jumper into position 1-2 (R32) (default) to enable the 15 A output current limit and inserting the jumper into position 2-3 (R33) disables the output current limit. Refer to figure 8 for the location of the CFG mode.

PWM Settings

The EPC9178 has two PWM setting options for light load operation; 1) continuous current mode (CCM) and 2) Power save mode (PSM). The desired setting can be selected by inserting a jumper into the appropriate position in J10 with position 1-2 for CCM and position 3-4 for PSM (default). See Figure 9 for the location of the PWM jumper settings.

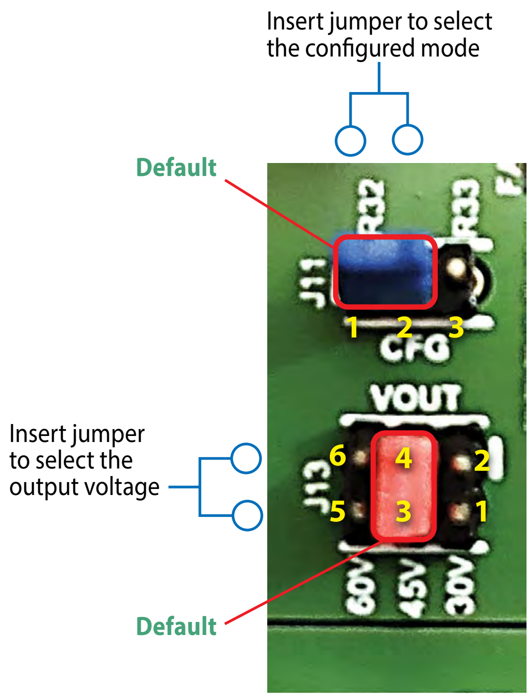


Figure 8: EPC9178 selector point locations and designations for output voltage adjustment and configuration mode (CFG – J11).

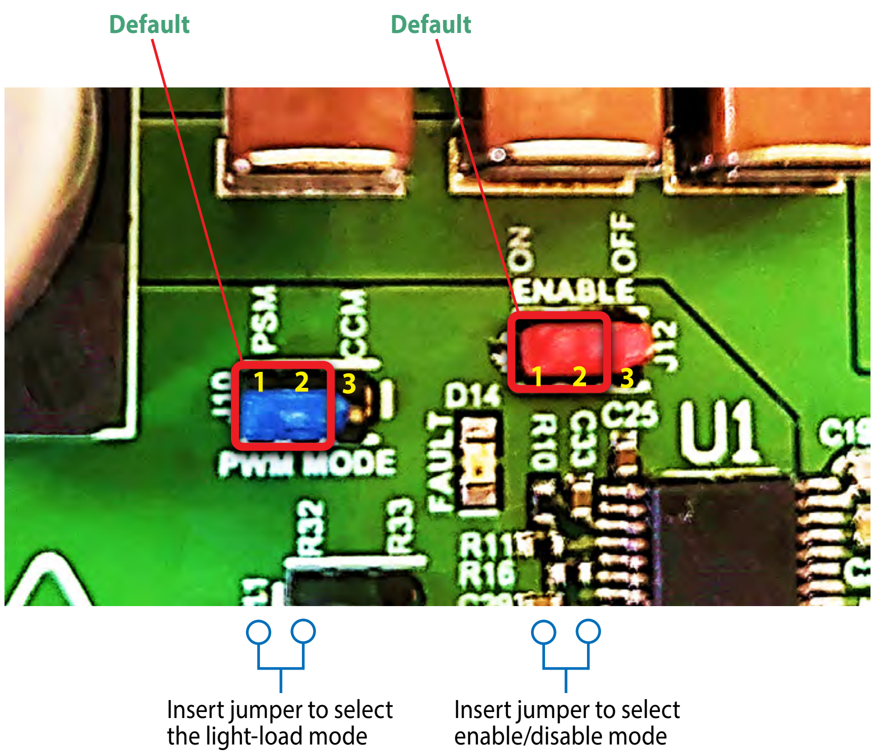


Figure 9: EPC9178 selector point locations and designations for the PWM Mode (J10) and ENABLE mode (J12) settings.

QUICK START PROCEDURE

The EPC9178 demonstration board is easy to set up to evaluate the performance of the EPC2306 GaN FETs. Refer to figures 5, 6, 7, 8, & 9 for proper connection and measurement setup and follow the procedure below to operate the board:

1. With power off, connect the input power supply between VIN (J1) and GND (J2). Pay careful attention to the polarity of the supply as shown in figure 5. A shunt can be inserted in series with the positive supply to measure the input current.
2. Ensure the jumpers settings of J10, J11, J12 and J13 are in the default positions.
3. With power off, connect a suitable load between VOUT (J3) and GND (J4). Pay careful attention to the polarity as shown in figure 5.
4. With power off, connect the various measurement probes as shown in Figure 6 and 7.
5. Keeping the load off, turn on the main power supply. Observe that the output voltage is 45 V.
6. Adjust the load current within the current capability of the EPC9178 per table 1. Observe the temperature of the GaN FET and ensure that it does not exceed the maximum value given in the EPC2306 datasheet.
7. Collect the data measurements while adjusting the supply voltage and load current. Ensure that all operating parameters remain within the specifications provided in table 1.
8. To shut down the EPC9178 demonstration board, decrease the main power supply to 0 V before turning off.

The operating instructions in this document do not cover how to perform bode measurements. Please refer to the equipment manufacturer for those instructions.

THERMAL MANAGEMENT (Optional)

EPC9178 is intended for bench evaluation at room ambient temperatures and under moderate forced air convection cooling. The addition of heatsink along with forced air cooling is not required but can increase the power dissipation capability of the active devices. The devices are cooled from the top side of the device through applicable thermal interface material (TIM) and takes advantage of the very low thermal resistance from junction to case of the eGaN FETs, see the EPC2306 datasheet for additional details.

Figure 10 shows an exploded 3D view of the simple cooling system employed on the EPC9178 demonstration board that comprises just 3 elements; 1) a heatsink (P/N: 567-94AB), 2) a 21 mm x 31 mm TIM, and 3) 1mm Heatsink standoff (P/N: 9774010243R), all shown in figure 10 with details of the TIM shown in figure 11.

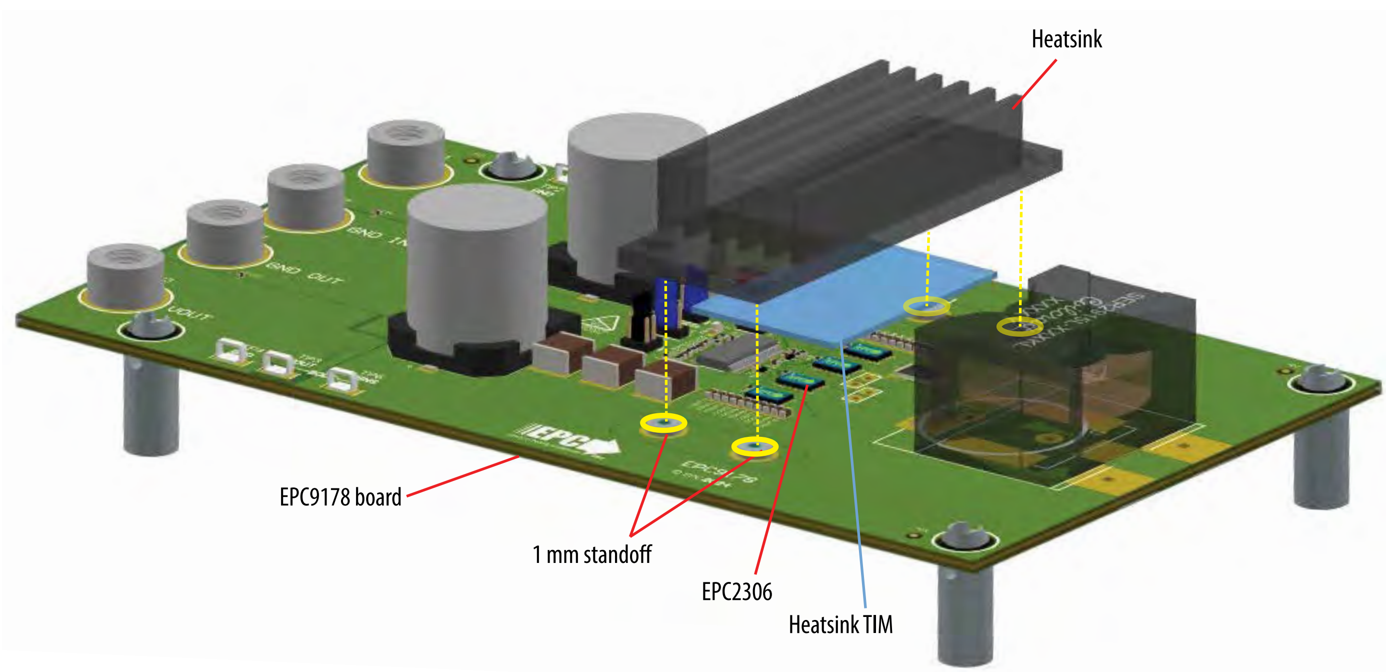


Figure 10: Exploded 3D view of the EPC9178 heatsink assembly

It is important that the TIM properly covers all four eGaN FETs and the bus capacitors to electrically isolate these components from the heat sink. The heatsink is then carefully placed on top and secured in place using the M2 x0.4 thread size screws in the designated standoff holes on the EPC9178 PCB.

The choice of TIM for the eGaN IC 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 eGaN FET/IC. 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/IC is a silicon substrate that is connected to ground. Electrical insulation is not required but is still recommended to isolate the GaN IC from the thermal solution.
- **Thermal performance** – The choice of thermal interface material will affect the thermal performance of the thermal solution. Higher thermal conductivity materials are preferred to provide higher thermal conductance at the interface.

EPC recommends the t-Global Part Number: TG-A1780 for the eGaN FETs TIM as it has a high thermal conductivity of 17.8 W/m·K.

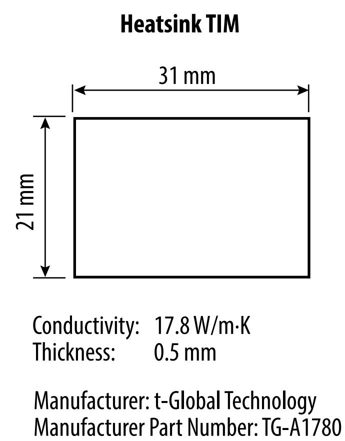


Figure 11: Details of the recommended TIM's used on the EPC9178 demonstration boar.

Errata

Silk screen error. See figure 12 for correct silk screen information.

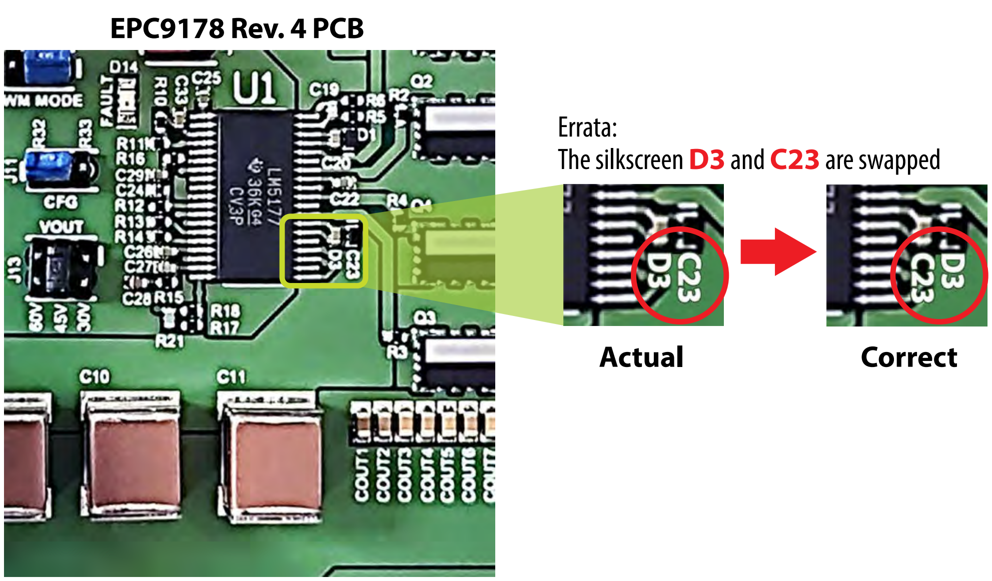


Figure 12: Silkscreen error with correction

EXPERIMENTAL VALIDATION

The target applications for the EPC9178 demonstration board are a PV panel optimizer and low voltage battery chargers. The board is configured using the default jumper settings and operated from a supply ranging from 30 V through 60 V.

Power Performance

The measured efficiency and power loss of the EPC9178 operating with various supply voltages are shown in Figures 13 through Figure 15. The maximum operating currents are limited by the input and output current limits setting and thermal limit setting of the controller IC. The tests were conducted with 400 LFM airflow and without a heatsink installed.

Experimental Results

Output Voltage: 30 V

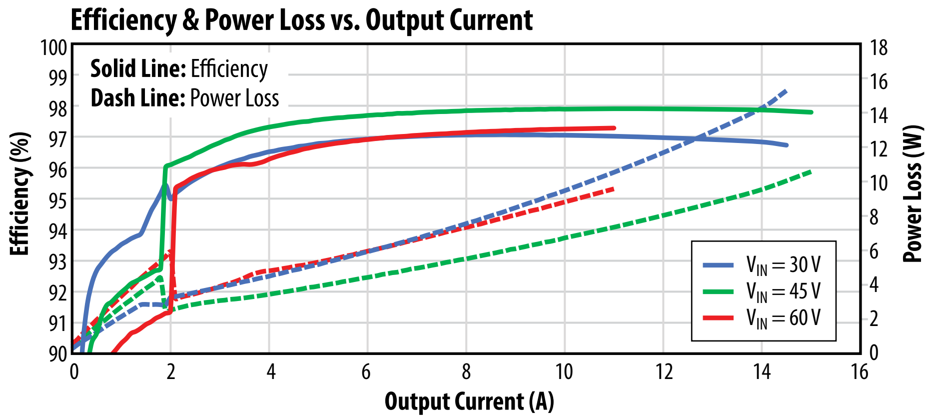


Figure 13: Measured the efficiency and power loss of the EPC9178 board for multiple input voltages and V_{OUT} = 30 V, 400 LFM airflow and without a heatsink installed.

Output Voltage: 45 V

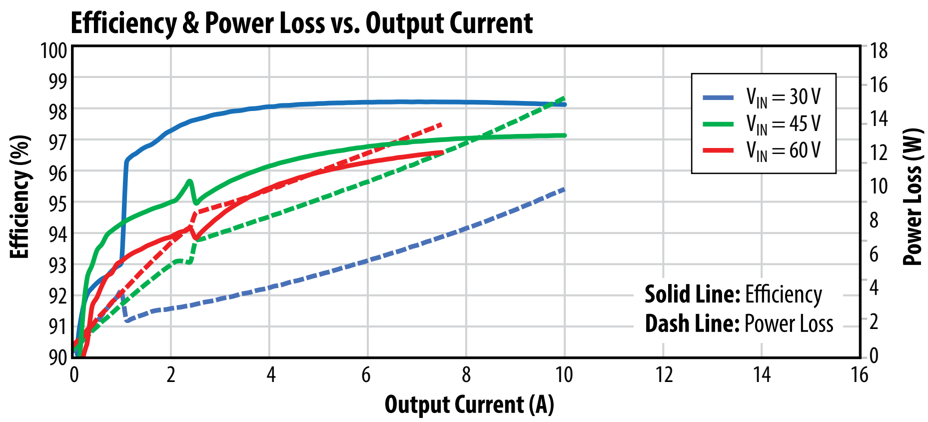


Figure 14: Measured the efficiency and power loss of the EPC9178 board for multiple input voltages and V_{OUT} = 45 V, 400 LFM airflow and without a heatsink installed.

Output Voltage: 60 V

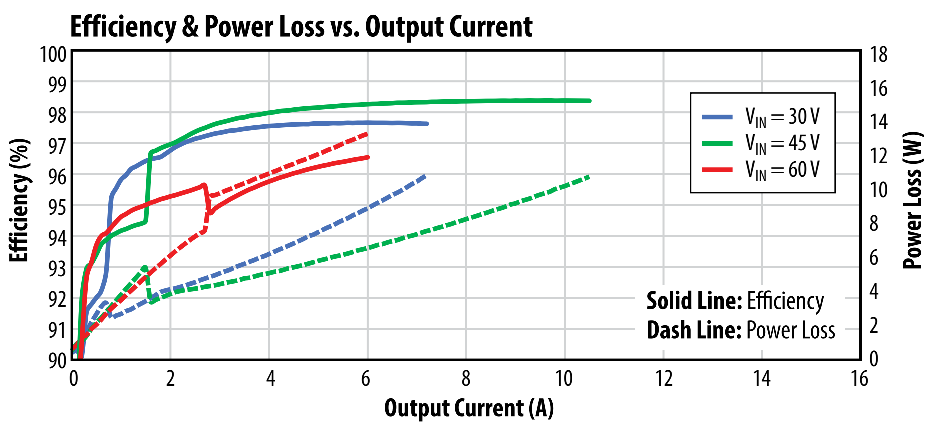


Figure 15: Measured the efficiency and power loss of the EPC9178 board for multiple input voltages and V_{OUT} = 60 V, 400 LFM airflow and without a heatsink installed.

Waveforms

Figure 16 shows the measured switch-node waveforms taken with EPC9178 operating with 30 V input, 45 V output (boost mode) and delivering 5 A into the load. Figure 17 shows the measured switch-node waveforms taken with the EPC9178 operating with 45 V input, 45 V output (buck-boost mode) and delivering 5 A into the load.

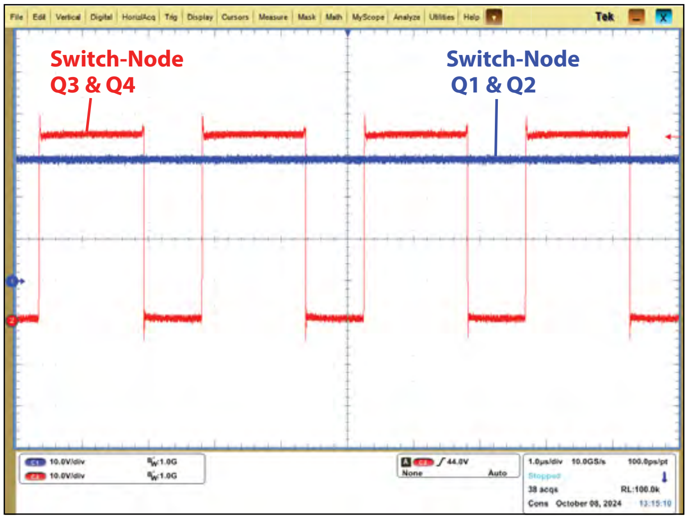


Figure 16: Measured switch-node voltage waveform of the EPC9178 operating with 30 V input, 45 V output and delivering 5 A into the load

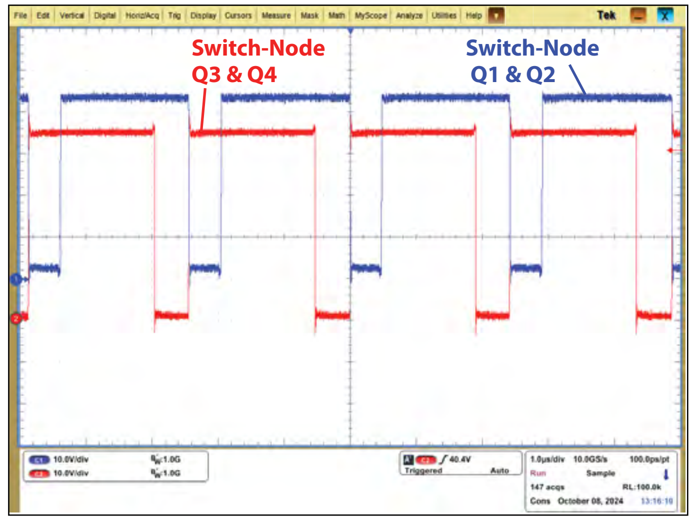


Figure 17: Measured switch-node voltage waveform of the EPC9178 operating with 45 V input, 45 V output and delivering 5 A into the load

Figure 18 shows the measured switch-node waveforms taken with the EPC9178 operating with 60 V input, 45 V output (buck mode) and delivering 5 A into the load. Figure 19 shows the measured output ripple voltage taken with the EPC9178 operating with 45 V input, 45 V output and delivering 5 A into the load.

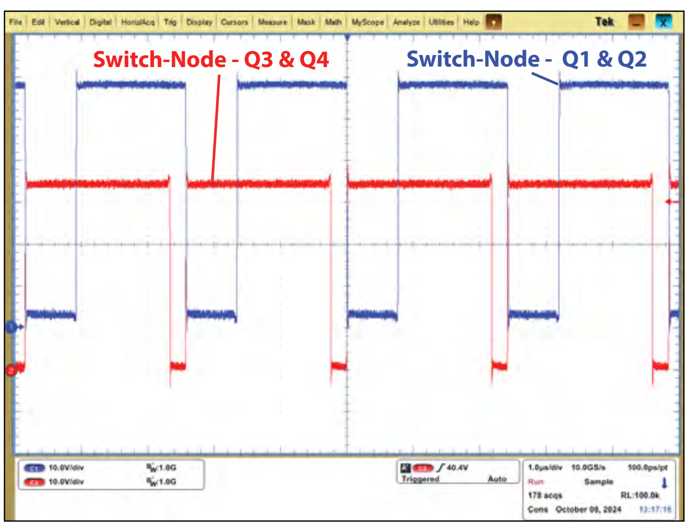


Figure 18: Measured switch-node voltage waveform of the EPC9178 operating with 60 V input, 45 V output and delivering 5 A into the load

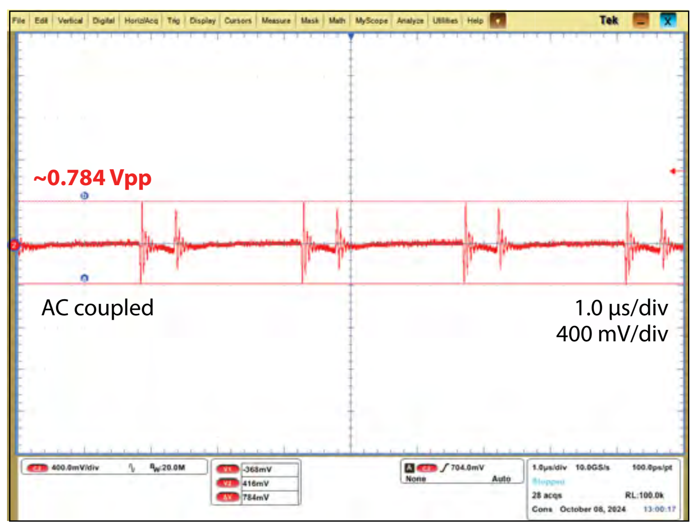


Figure 19: Measured ripple output voltage waveform of the EPC9178 operating with 45 V input, 45 V output and delivering 5 A into the load

Transient Response

Figure 20 shows the measured transient response taken with the EPC9178 operating with 45 V input, 30 V output with a load step change of 10% to 90% and 90% to 10% of 15 A output.

Voltage Regulation Performance

Figures 21 to 23 illustrate the measured output voltage regulation of the EPC9178 in pulse skipping light load mode. The device was tested with input voltages of 30 V, 45 V, and 60 V while delivering 30 V, 45 V, and 60 V to the load function of load current.

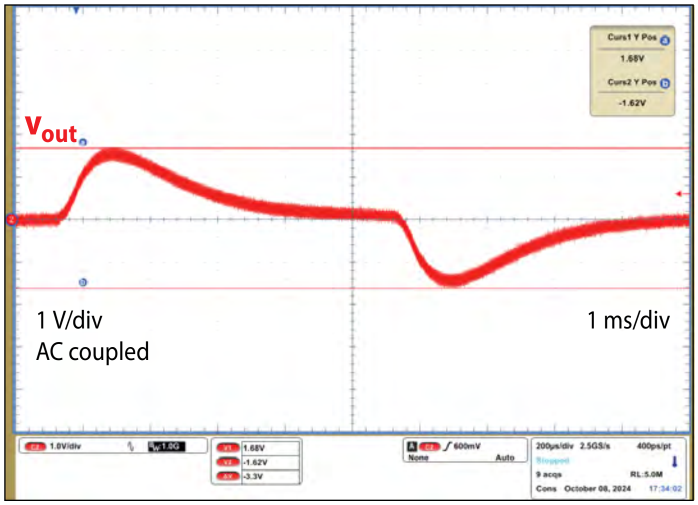


Figure 20: measured transient waveform of the EPC9178 operating with 45 V input, 30 V output and with a load step change of 10% to 90% and 90% to 10% of 15 A.

Output Voltage: 30 V

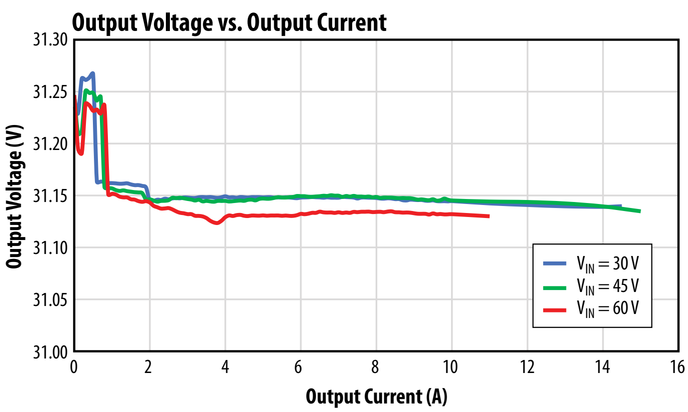


Figure 21: Measured output voltage regulation of the EPC9178 operating with input voltages of 30 V, 45 V and 60 V. The voltage was set to 30 V as function of load current.

Output Voltage: 45 V

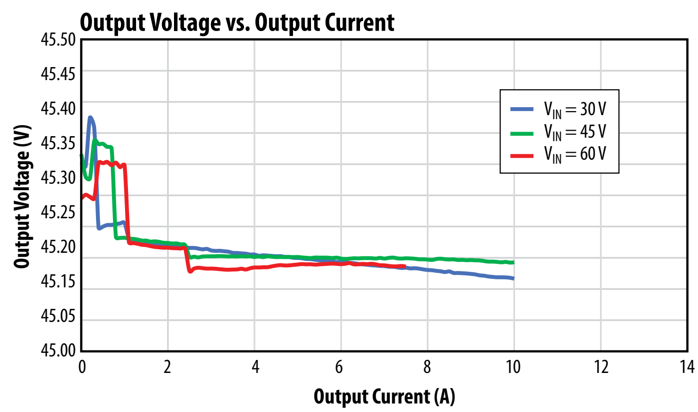


Figure 22: Measured output voltage regulation of the EPC9178 operating with input voltages of 30 V, 45 V and 60 V. The voltage was set to 45 V as function of load current.

Output Voltage: 60 V

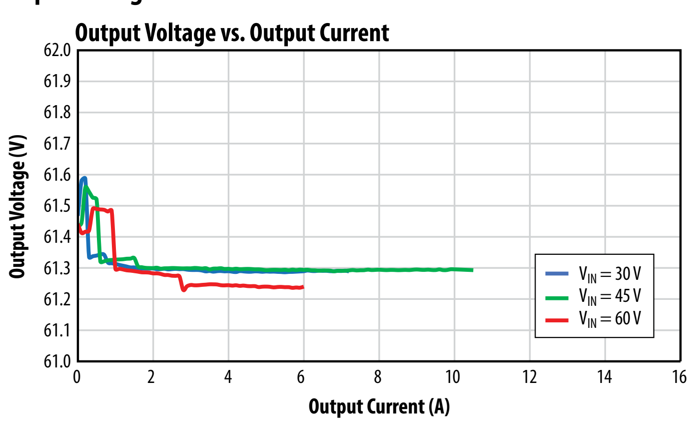


Figure 23: Measured output voltage regulation of the EPC9178 operating with input voltages of 30 V, 45 V and 60 V. The voltage was set to 60 V as function of load current.

Thermal Performance

Figures 24 through 26 shows the measured thermal performance taken with the EPC9178 operating with 30 V, 45 V, and 60 V input respectively. The output was set to 45 V, 60 V, and 30 V respectively. The EPC9178 delivered 10 A, 10.5 A and 11 A into the load respectively, with no heatsink installed and with 400 LFM airflow.

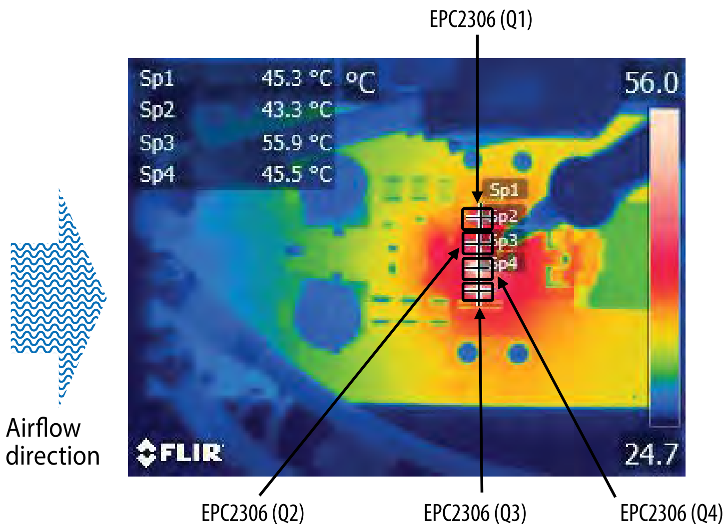


Figure 24: Steady state measured thermal image of the EPC9178 operating with 30 V input, 45 V output and delivering 10 A into the load, 400 LFM airflow and no heatsink attached.

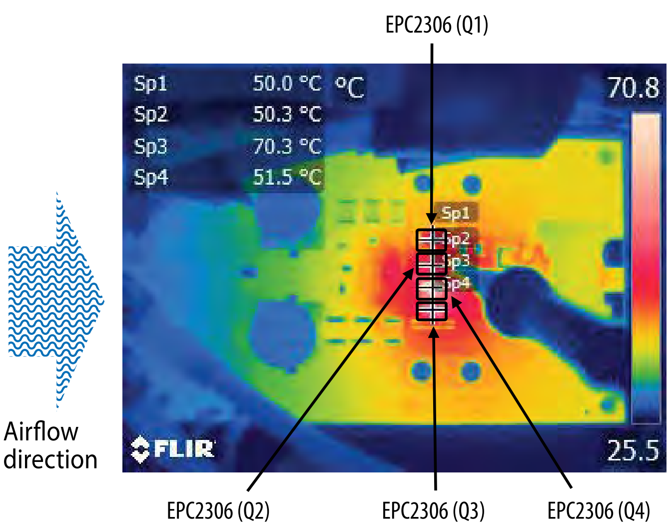


Figure 25: Steady state measured thermal image of the EPC9178 operating with 45 V input, 60 V output and delivering 10.5 A into the load, 400 LFM airflow and no heatsink attached.

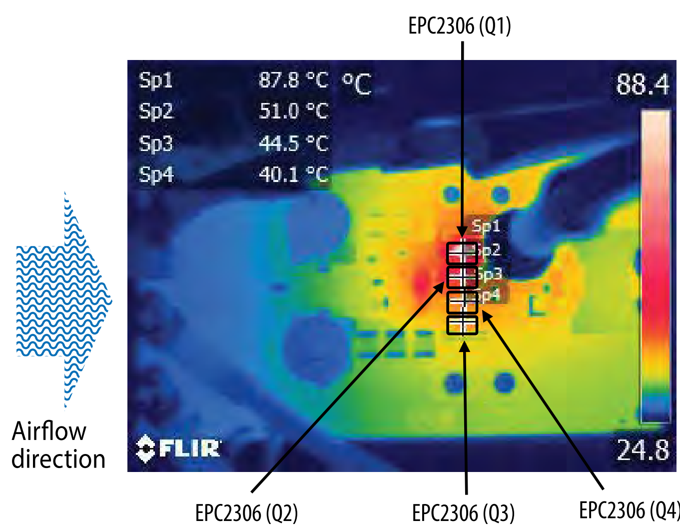


Figure 26: Steady state measured thermal image of the EPC9178 operating with 60 V input, 30 V output and delivering 11 A into the load, 400 LFM airflow and no heatsink attached.

For support files including schematic, Bill of Materials (BOM), and gerber files please visit the EPC9178 landing page at:
https://epc-co.com/epc/products/evaluation-boards/EPC9178

ACKNOWLEDGEMENTS

EPC would like to acknowledge Texas Instruments Incorporated (**www.ti.com**) for their support of this project. Texas Instruments Incorporated (TI) is a global semiconductor design and manufacturing company that develops analog ICs and embedded processors. By employing the world's brightest minds, TI creates innovations that shape the future of technology. TI is helping more than 100,000 customers transform the future, today.

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Evaluation Board Notification

The EPC9178 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 evaluation 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.