# EPC9174: 40–60 V Input, 10–15 V, 100 A Output Fixed Conversion Ratio 1.2 kW LLC, $^{1}/_{8}^{th}$ Brick Size Module Quick Start Guide

*EPC2071 and EPC2066*

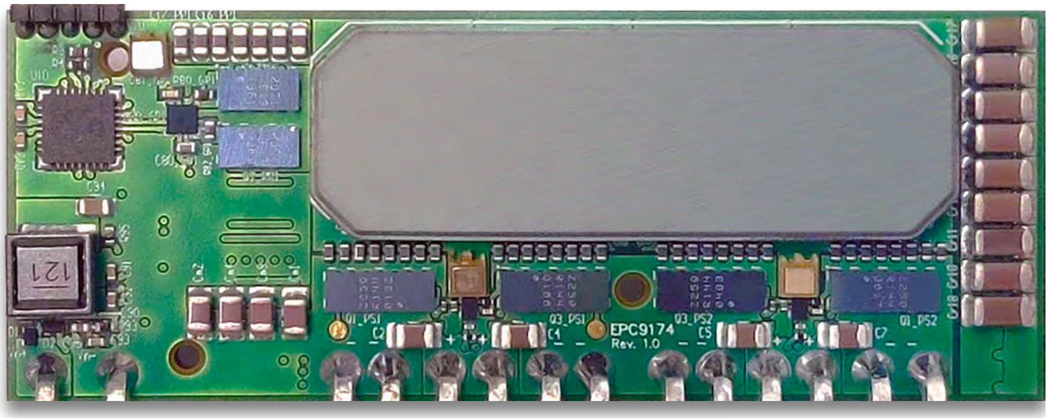
November 15, 2022

Version 1.0

## DESCRIPTION

The EPC9174 evaluation board is a 1.2 kW, 48 V input to 12 V output LLC converter that operates as a DC transformer with fixed conversion ratio of 4:1. The simplified schematic diagram is shown in Figure 1. It features the 100 V rated EPC2071 and 40 V rated EPC2066 GaN FETs, the uP1966A and LMG1020 gate drivers as well as the Microchip dsPIC33CK32MP102 16-bit digital controller. Other features include:

- Peak efficiency: 97.3 % at 550 W
- Full-load efficiency: 96.3% @ 12 V delivering 100 A output
- 22.9 × 58.4 mm (0.90 × 2.30 inches)
- Low profile: 10 mm total converter thickness without heatsink
- Temperature rise: 72.5°C @ 12 V with 100 A output (with heatsink kit installed)
- Fixed switching frequency: 1 MHz
- Soft startup into full resistive load
- High power density: 1472 W/in$^3$ (excluding pins)




*EPC9174 board*

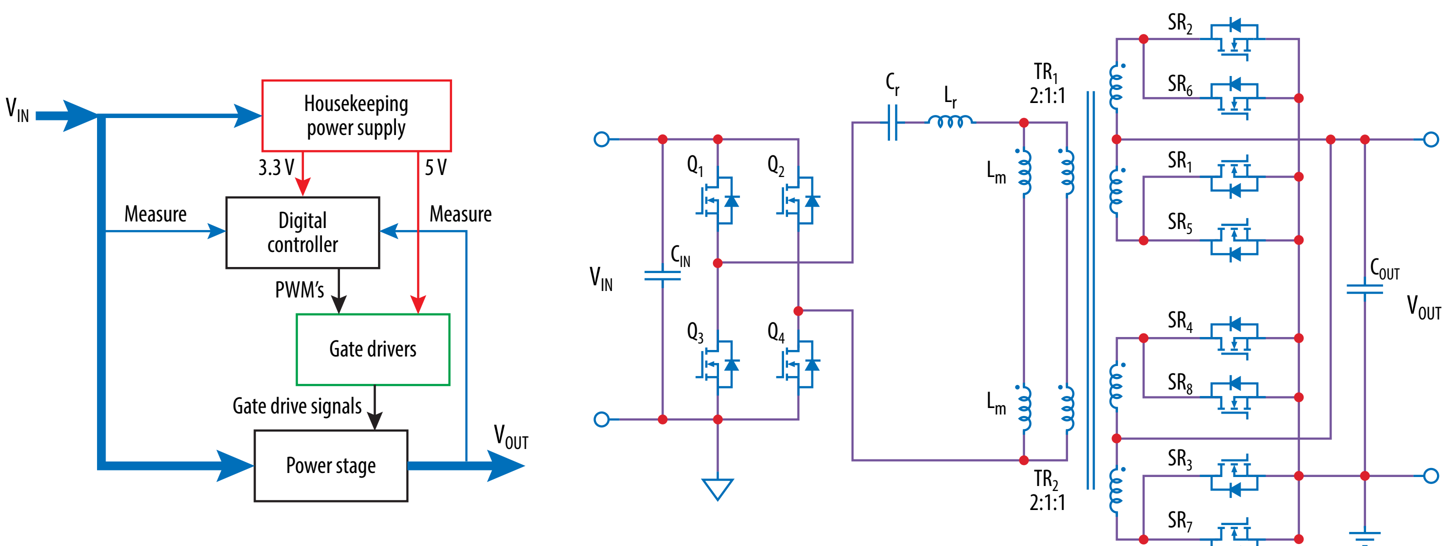



*Figure 1: Simplified schematic diagram of the EPC9174 LLC Module*

## REGULATORY INFORMATION

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

## FIRMWARE UPDATES

Every effort has been made to ensure all control features function as specified. It may be necessary to provide updates to the firmware. Please check the EPC website for the latest firmware updates.

**Table 1: Electrical Characteristics ($T_a$ = 25 °C unless specified otherwise)**

| Symbol | Parameter | Conditions | Min | Typ | Max | Units |
|---|---|---|---|---|---|---|
| $V_{IN}$ | Input Voltage | | 40 | 48 | 60 | V |
| $V_{OUT}$ | Output Voltage | Fixed ratio of 4:1 based on $V_{IN}$ | | 12 | | |
| $I_{OUT}$ | Output Current | Continuous* | 0 | | 100 | A |
| $f_S$ | Switching Frequency | | | 1 | | MHz |
| $T_{rise}$ | Temperature Rise | $V_{IN}$ = 48 V, $I_{OUT}$ = 100 A, thermal system installed, 400 LFM forced air, measured at heat-spreader | | 72.5 | | °C |
| $V_{IN,on}$ | Input UVLO turn on voltage | | | 7.5 | | V |
| $V_{IN,off}$ | Input UVLO turn off voltage | | | 5.5 | | |
| $t_{OUT,rise}$ | Output voltage rise time | | | 3 | | ms |

** Requires adequate cooling*

## HIGHLIGHTED PARTS

The EPC9174 features a primary side full bridge and a dual secondary side center tapped half bridge configuration based on EPC2071 and EPC2066 eGaN® fets. For more information on the **EPC2071** and **EPC2066** please refer to the datasheet available from EPC at **www.epc-co.com**.

### Onboard power supply

The EPC9174 board includes logic and gate driver house-keeping power supplies that are powered from the main input supply voltage to the LLC board.

### Input and output voltage sense

Input and output voltages are measured by resistor dividers and fed back to the microcontroller to be used for control purposes.

### Transformer core

This module uses a customized transformer core with ML91S material from Hitachi metals (part number: U-36-4.57-12.2) which offers low core loss at high frequency operation. The drawing and dimensions of this core is shown in Figure 14. Two half core sections are inserted from top and bottom side of the board as shown in Figure 2 below. Proper spacers are also added in between to achieve the required magnetizing inductance.

## MECHANICAL SPECIFICATIONS

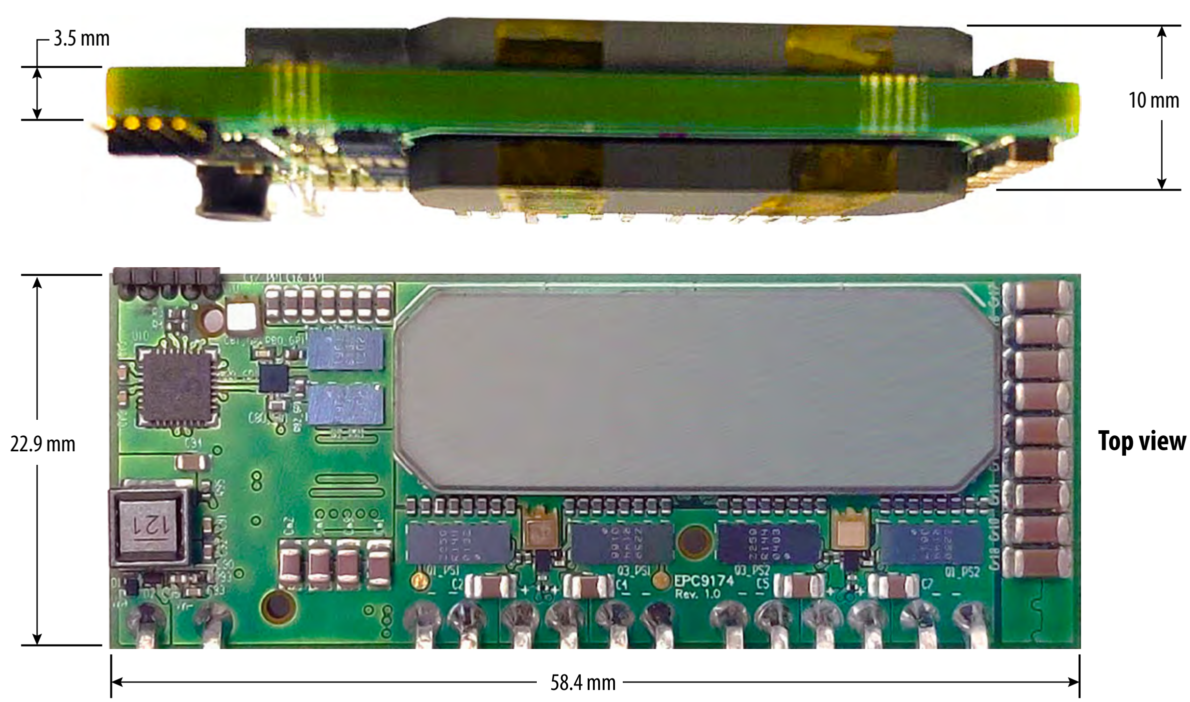



*Figure 2: EPC9174 mechanical dimensions*

## QUICK START PROCEDURE

The EPC9174 LLC converter module is easy to set up for evaluation. Refer to Figures 3-4 and follow the procedure below for proper connection and measurement setup:

1. EPC9533 is the motherboard for EPC9174 where the main input and output power connections are located.
2. Attach the standoffs for EPC9533.
3. With power off, connect the input power supply to $V_{IN+}$ and $V_{IN-}$ as shown in Figure 3.
4. With power off, connect the load to $V_{OUT+}$ and $V_{OUT-}$ as shown in Figure 3.
5. Connect the input and output kelvin connections shown in Figure 3 to the measurement devices.
6. Apply the input voltage and once operational, adjust the load within the operating range and observe the efficiency, temperature and other characteristics.
7. For shutdown, please follow the above steps in reverse. (**The input supply can be turned off as well**)

In order to measure the input and output currents, proper shunts can be connected in series with the corresponding connections. (input supply and load, respectively)

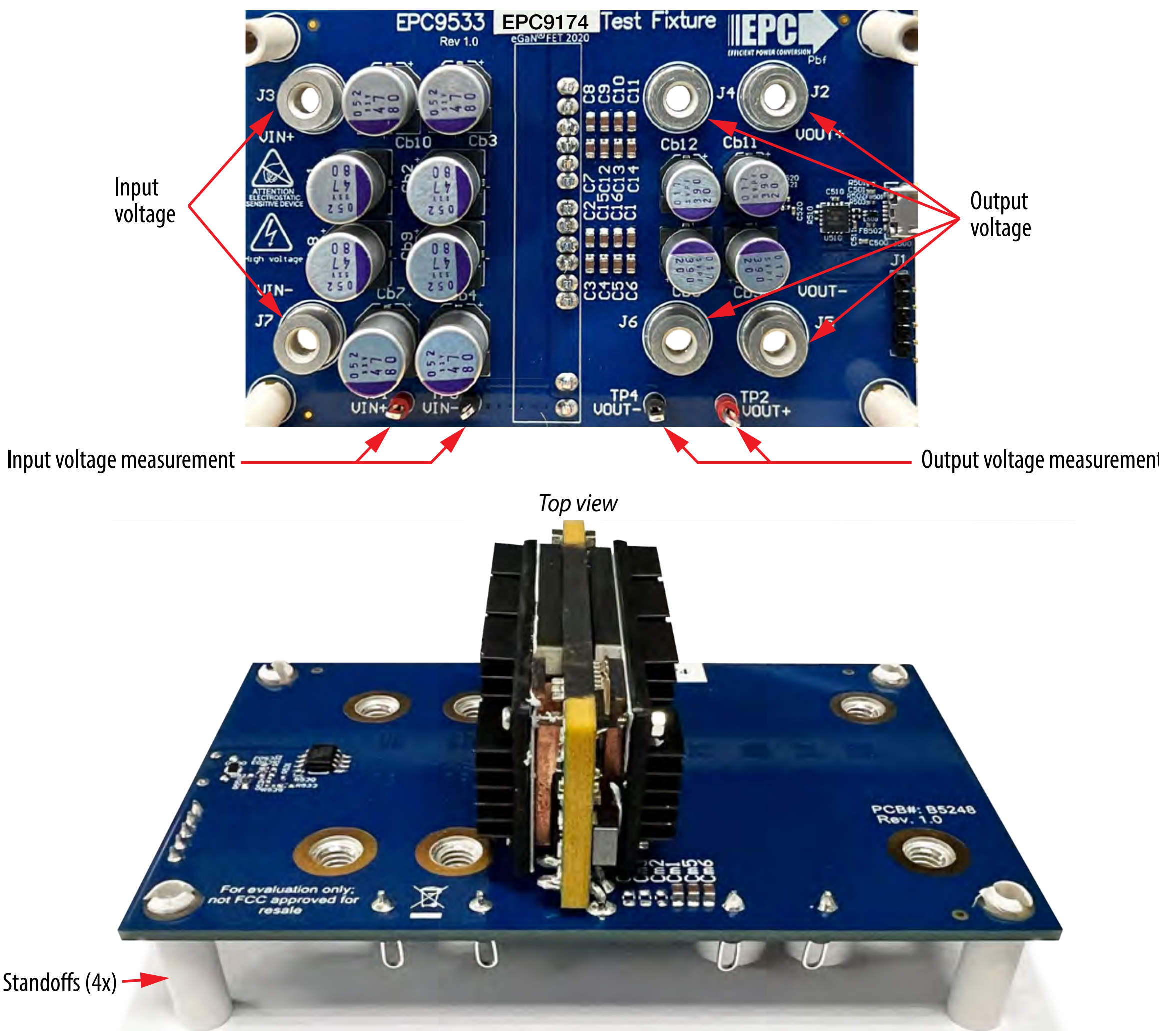



*Figure 3: EPC9174 and motherboard assembly showing the input and output connections*

## ELECTRICAL and THERMAL PERFORMANCE

### Typical efficiency and power loss

The module provides maximum efficiency of 97.3% and full load efficiency of 96.3%.

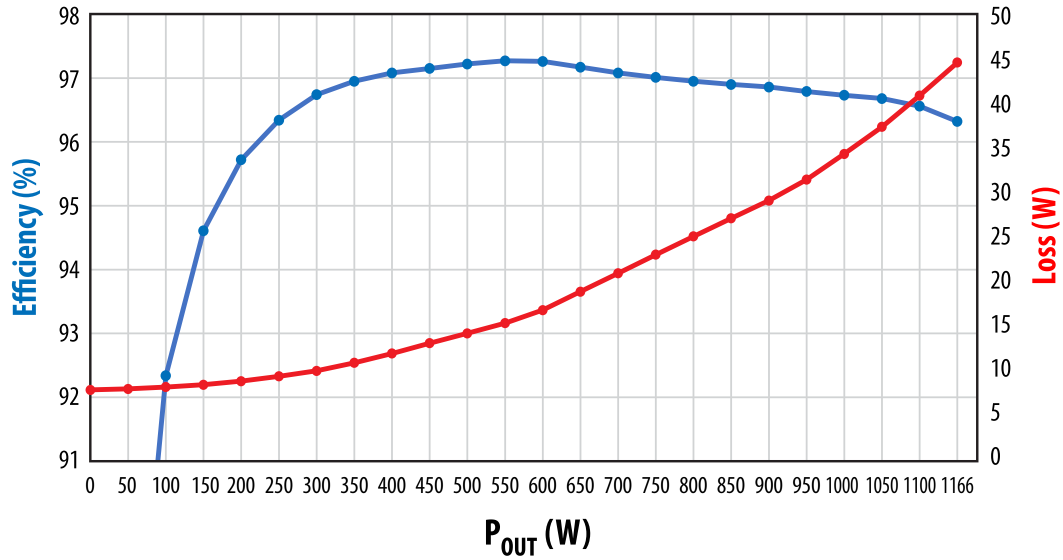



*Figure 4: Total system efficiency and loss @ 12 V output, 48 V input voltage, 400 LFM forced air cooling.*

### Soft start-up

The start-up of the EPC9174 output voltage is programmed to be a soft start-up: Once the input voltage passes the UVLO of the bias supply IC, the output voltage rises monotonously from 0 to its final value in less than 5 ms (Figure 5).

The start up waveform is measured while the scope is triggered on the output voltage rise and the module is turned on into the constant resistive load of 120 mΩ that results in 1.2 kW load at 12 V output voltage. Both primary and secondary FETs are commanded with a minimum pulse width and the duty cycle is slowly ramped up as the output voltage increases to avoid excessive current and voltage stresses during startup.

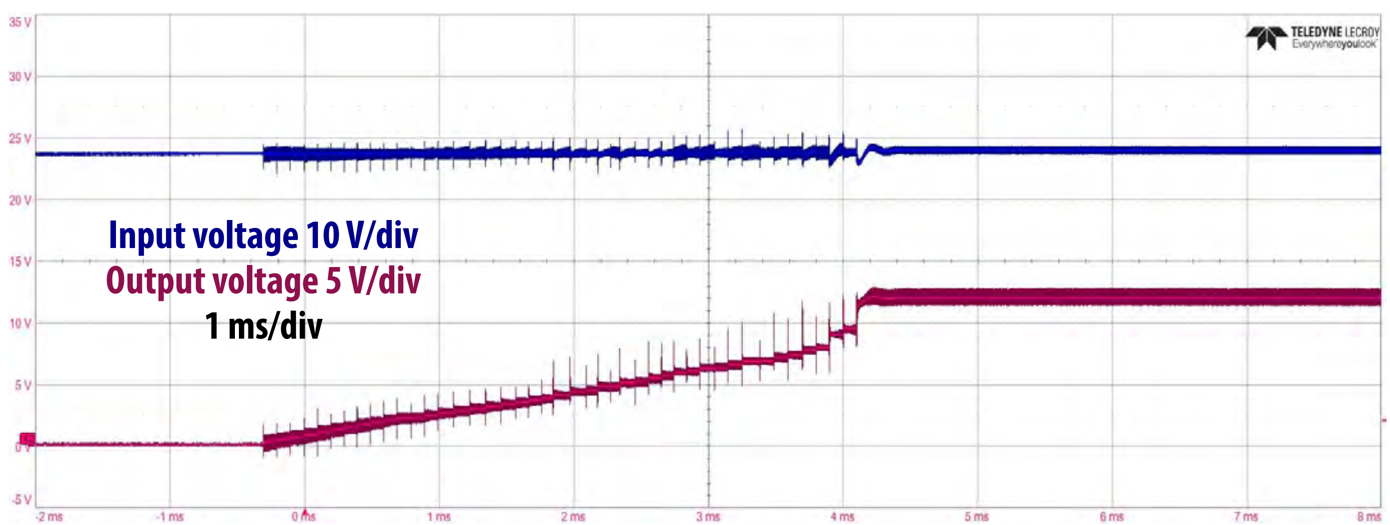



*Figure 5: Startup waveform (larger time scale on top and zoomed in version on the bottom)*

## Output voltage droop

This converter operates in open loop meaning that output voltage is not regulated at various line and load conditions. Therefore, output voltage droops when higher loads are applied to the module. Figure 6 shows the output voltage droop as function of load current at nominal 48 V input voltage. In DC transformer applications, the lowest possible deviation of the voltage conversion ratio between the input and output across the entire load is desired.

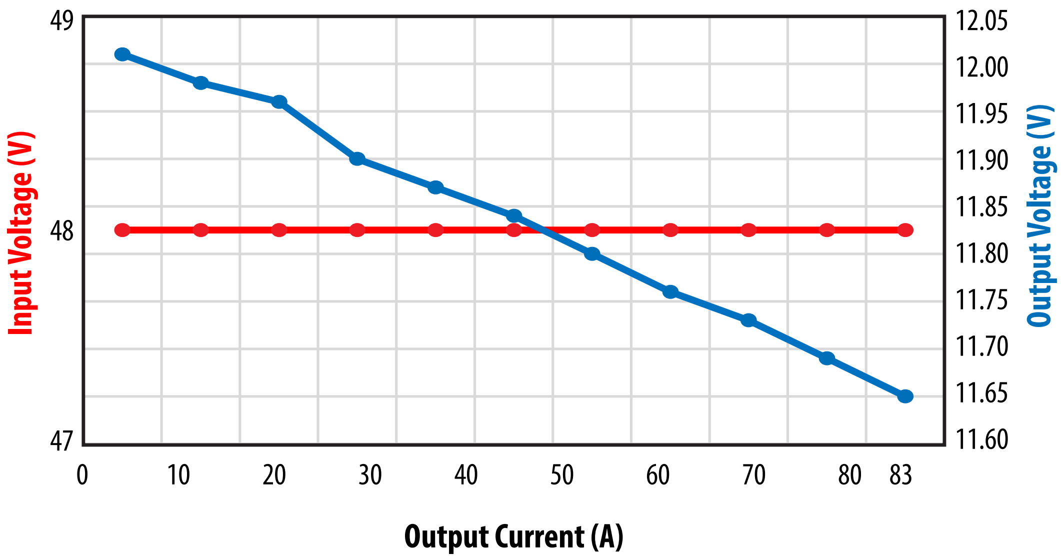
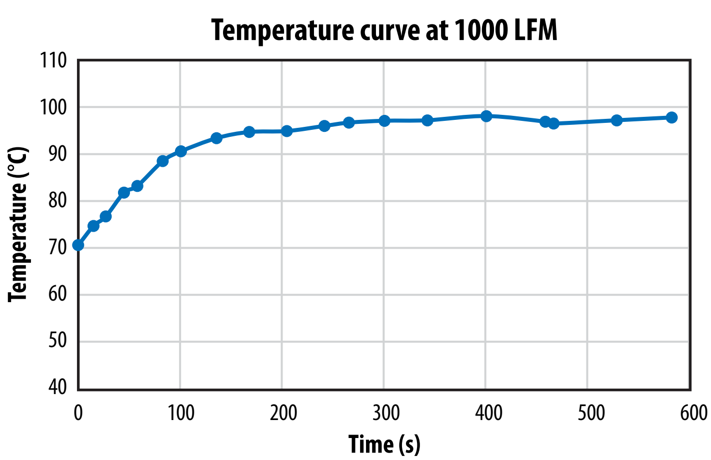



*Figure 6: Output voltage droop vs output current*

## Thermal performance

As shown in Figure 7, the EPC9174 board with the heat-spreader installed measures a temperature rise of 72.5°C at full load operation with 1000 LFM forced air.



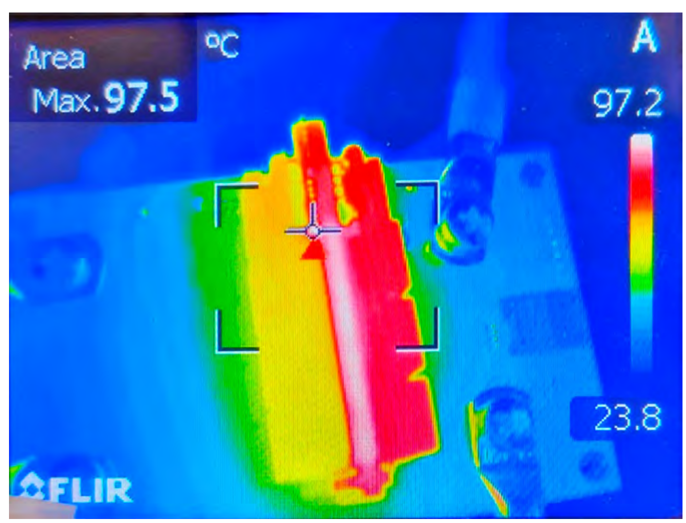




*Figure 7 Thermal image of the EPC9174 operating at 48 $V_{IN}$, 12 V and 100 A output, thermal steady state reached after 10 minutes, Top: primary FET junction temperature and Bottom: highest board temperature (ambient temperature at 25°C).*

## THERMAL DERATING

Without sufficient thermal management, the output current capability is reduced. If the user decides to uninstall the heatsink, the module temperature should be monitored to ensure the maximum temperature does not exceed the rating.

## THERMAL MANAGEMENT

Thermal management is very important to ensure proper and reliable operation. The EPC9174 is intended for bench evaluation at normal ambient temperature. The addition of a heat-spreader or heatsink and forced air cooling can significantly increase the current rating of the power devices, but care must be taken to not exceed the absolute maximum die temperature of 150°C.

A combination of custom shape heat spreaders and a finned heatsink for the top and bottom side of the EPC9174 board are designed. The thermal solution assembly is shown in Figure 8. Copper heat spreaders (item 1 and 3) are placed on top of both primary and secondary side FETs to spread their heat to the outer structure. Two 1 mm height copper shims (item 2) are used to fill the gaps and help with cooling the board surface. It only requires a gap filler TIM to be added underneath of the heat spreader pieces to provide insulation and high thermal conductivity between the components and the metal surface of heat spreaders. Several mechanical shims help mounting the heat spreader on the PCB surface and maintaining required clearance between the heat spreader and component surfaces. Mechanical screws are inserted on the board to hold the entire mechanical structure together.

A step-by-step assembly guideline are presented. The needed parts are listed below.

- 2x heatsinks for top and bottom side (not identical)
- 2x Copper (Cu) heat spreaders for primary FETs (item #1)
- 2x Cu spacers/seats for primary FETs (item #2)
- 2x Cu heat spreaders for secondary FETs (item #3)
- 2x M1.4 16 mm screws
- 2x M1.4 nuts
- 2x M2 10 mm screws
- TIM pads TG-A1780 0.5 mm
- TIM pads TG-A6300 0.5 mm
- TIM gap filler Bergquist GF4000

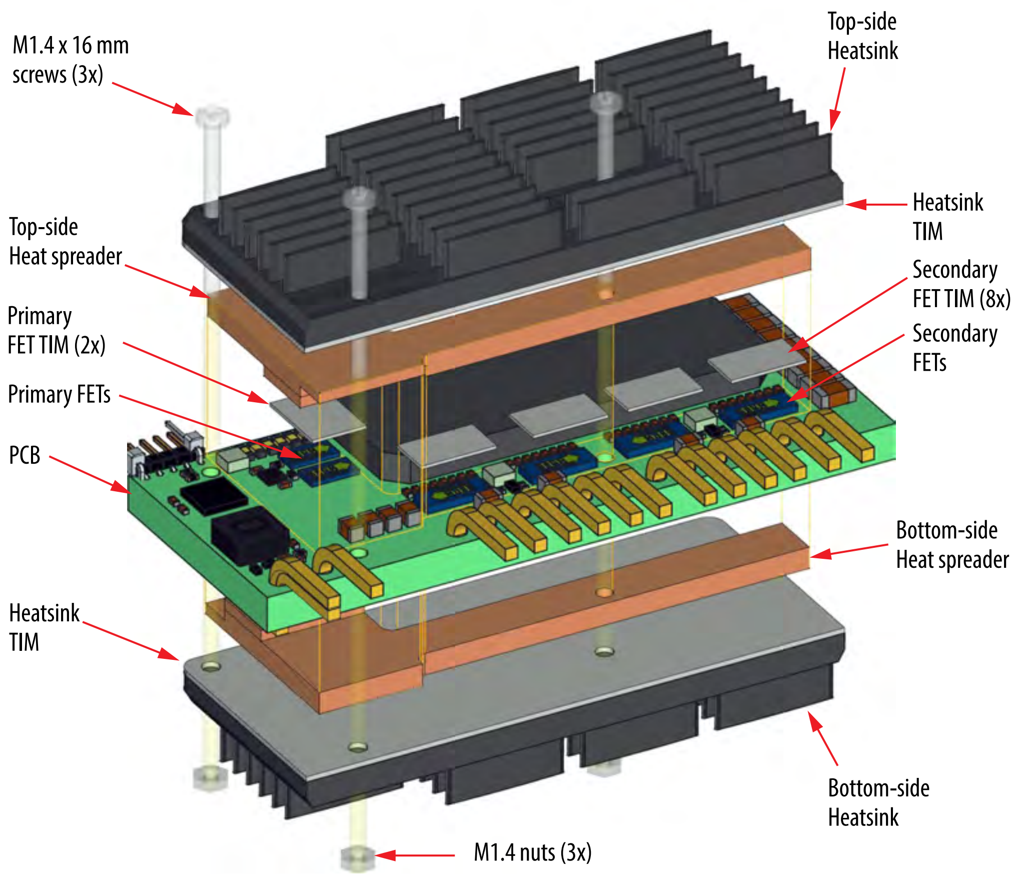
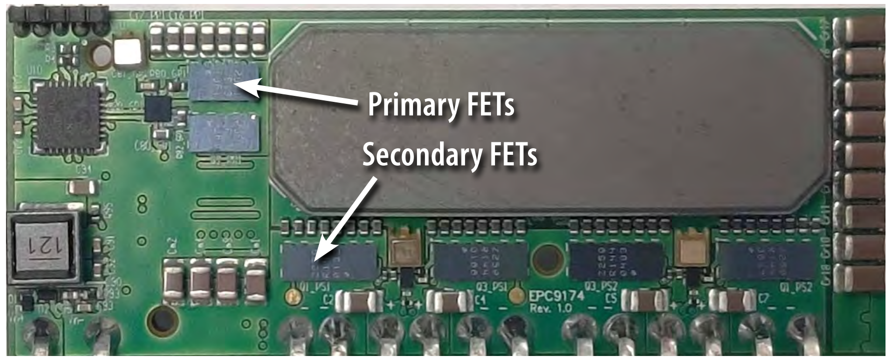



*Figure 8: Thermal solution assembly process for the EPC9174 module*

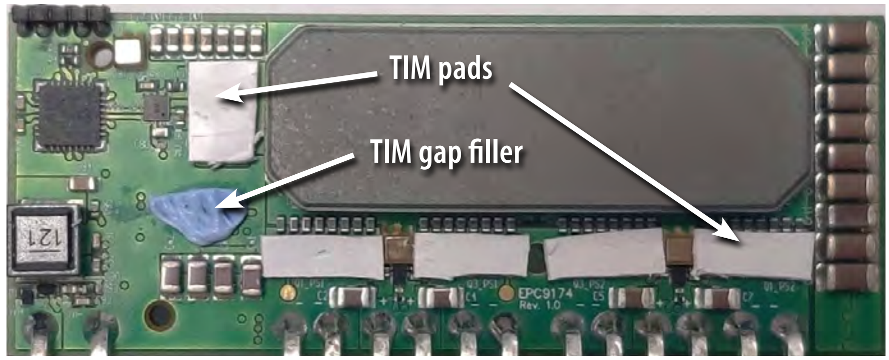
## THERMAL SOLUTION ASSEMBLY GUIDELINES

1. Beginning at the top face of the PCB, note the position of the primary and secondary FETs



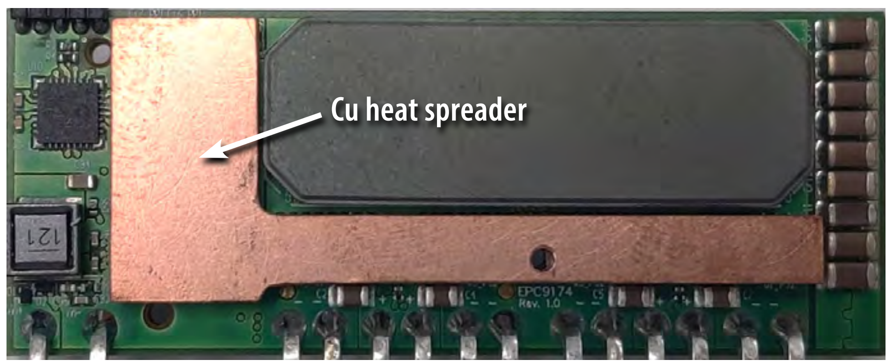

2. Add a small amount of **TIM gap filler** (Bergquist GF4000) on PCB next to Primary FETs

3. Place **TIM pads** (TG-A1780) on the primary and secondary FETs



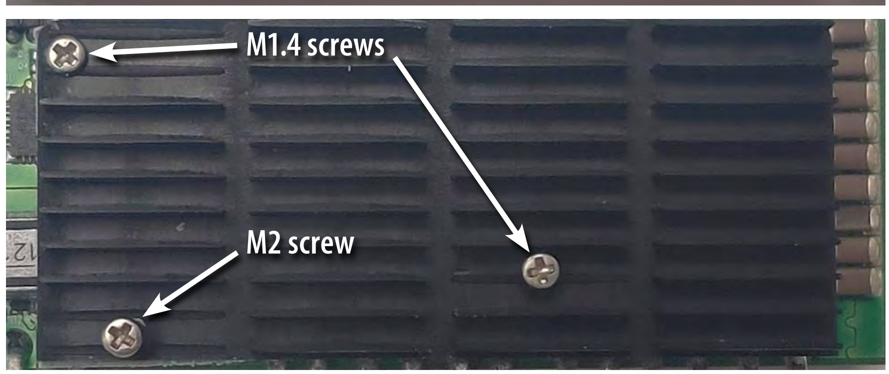

4. Place **heat spreaders** on the FETs, making sure the holes align with the drill holes on the PCB

**Note**: The two Cu heat spreaders for top and bottom sides are not identical

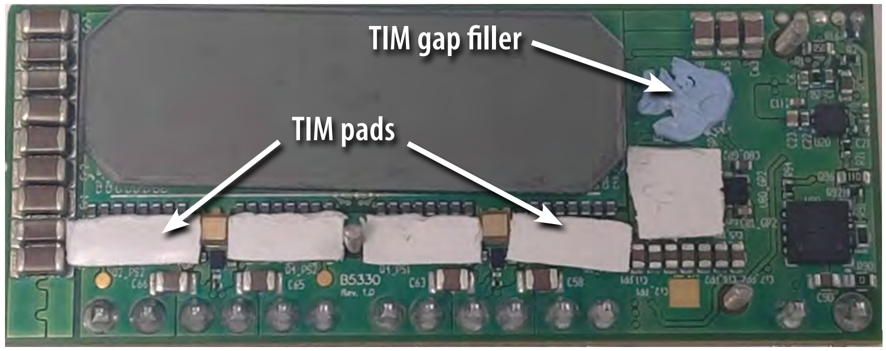



5. Place **TIM pad** (TG-A6200) on the backside of the heatsink (flat side) and align it to PCB holes


6. Use **M1.4** and **M2 screws** for assembly as shown in schematic; M2 is connected to threaded flange on PCB, do not fully tighten the M2 screw yet

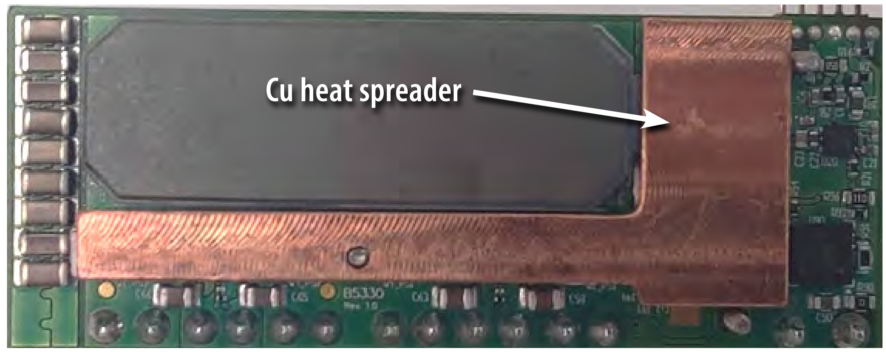


7. Repeat similar procedure for PCB backside: Add a small amount of **TIM gap filler** (Bergquist GF4000) next to Primary FETs
8. Place **TIM pad** (TG-A1780) cutouts to cover primary and secondary FETs



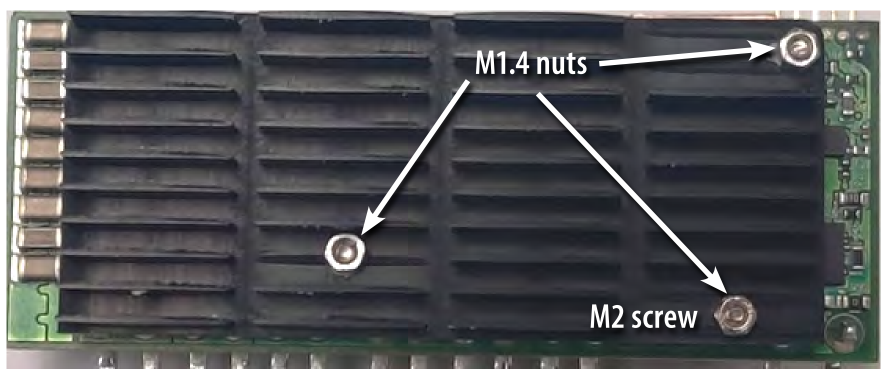

9. Place copper heat spreader on FETs, holes must align with PCB holes and the M1.4 screws

**Note**: The two Cu heat spreaders for top and bottom sides are not identical

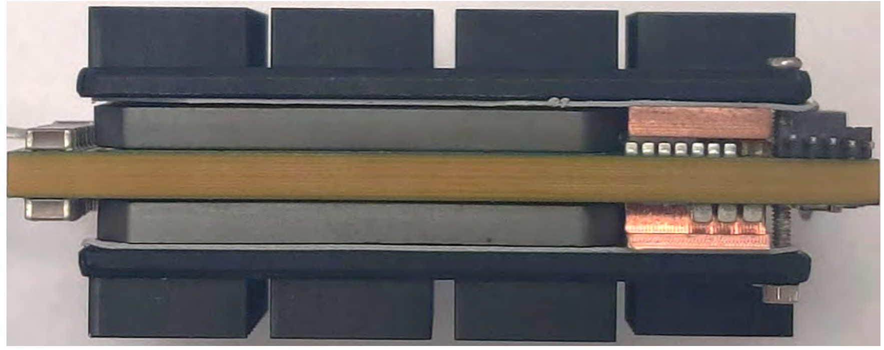


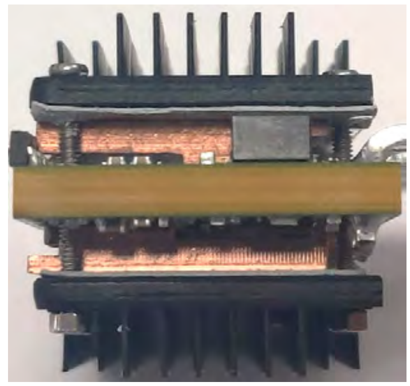

10. Place TIM (TG-A6200) on backside of heatsink and align it to screw holes


11. Use **M1.4 nuts** and an **M2 screw** to assemble heatsink to the PCB as shown; M2 can be connected to threaded flange on PCB



12. Tighten screws in sequence while keeping heatsink parallel to PCB





The choice of TIM needs to consider the following characteristics:

- **Mechanical compliance** – The TIM becomes compressed during heatsink attachment and exerts a force on the FETs. A maximum compression of 2:1 is recommended for maximum thermal performance and to constrain the mechanical force that maximizes thermal mechanical reliability.
- **Electrical insulation** – The backside of the eGaN FETs are substrate that are connected to source and the upper FET will thus be connected to the switch-node. The TIM must therefore provide insulation to prevent short-circuiting the upper FET to the ground.
- **Thermal performance** – The choice of thermal material will affect the thermal performance. Higher thermal conductivity materials will result in higher thermal performance.

EPC recommends T-Global: A1780- 500 µm for the thermal interface material between FETs and heat spreaders and T-Global: A6200 for heatsinks. The gap filler TIM recommended is Bergquist GF4000.

## CONTROLLER

The EPC9174 LLC power module features a Microchip dsPIC33CK32MP102 Digital Signal Controller DSC. This 100 MHz single core device is equipped with dedicated peripheral modules for Switched-Mode Power Supply (SMPS) applications, such as a feature-rich 4-channel (8x output), 250 ps resolution pulse width modulation (PWM) logic, three 3.5 Msps Analog-To-Digital Converters (ADC), three 15 ns propagation delay analog comparators with integrated Digital-To-Analog Converters (DAC) supporting ramp signal generation, three operational amplifiers as well as Digital Signal Processing (DSP) core with tightly coupled data paths for high performance real-time control applications. The device used is the smallest derivative of the dsPIC33CK single core and dsPIC33CH dual core DSC families. The device used in this design comes in a 28 pin 4x4 mm UQFN package, specified for ambient temperatures from -40 to +125° C.

The dsPIC33CK device is used to drive the converter in a fully digital fashion. Input voltage and output voltage measurements are fed back to the dsPIC and read using two independent core ADCs.

## PROGRAMMING

The Microchip dsPIC33CK controller can be re-programmed using the MPLAB ICD4 or other Microchip programmer tools and through the 5-pin header on EPC9174 board shown below. RJ11 to ICSP adapter 02-10310-R1 from microchip is used to interface programmer and the main board (Fig. 11(b)). (Please refer to www.microchip.com for available options)

EPC9997 board is designed to be specifically used as an ICSP adapter as shown in Fig. 9(a) as well.

**Please make sure the programming is performed only when the module is not running and no input voltage is applied.**

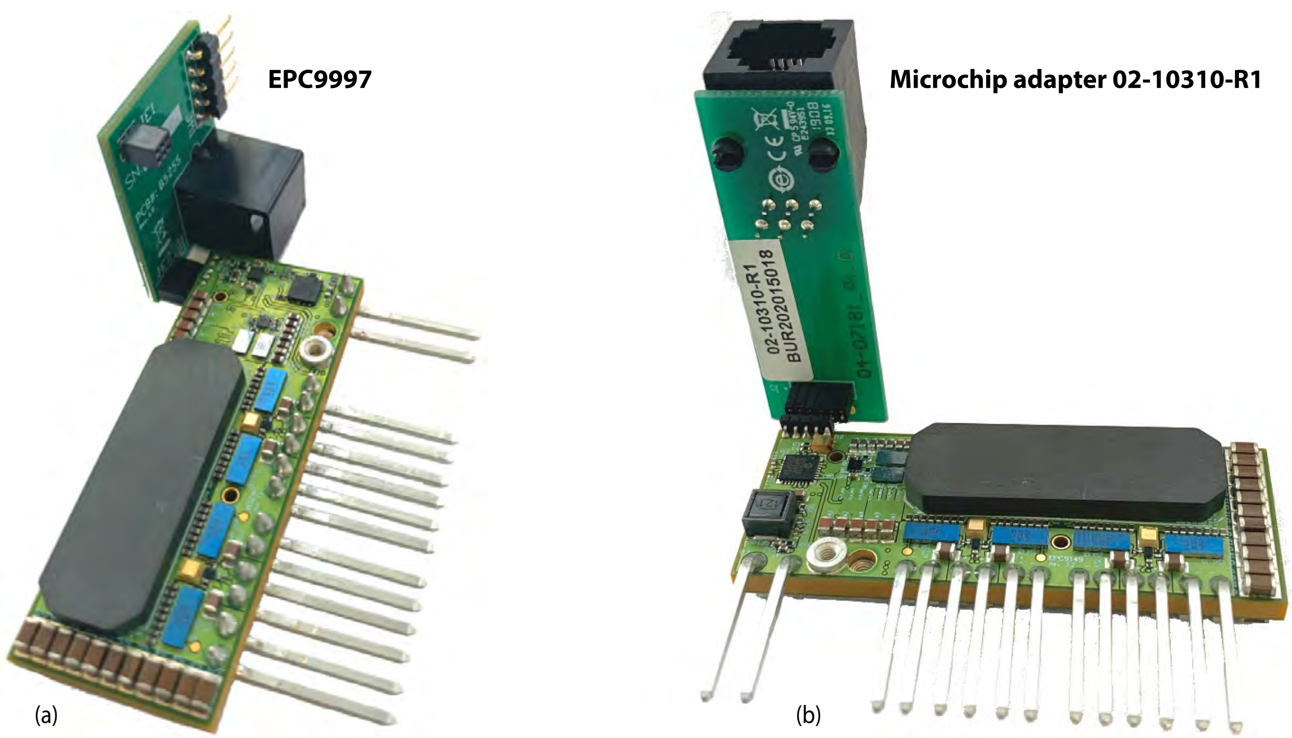


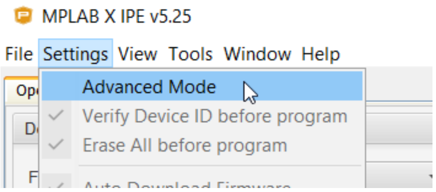

*Figure 9: Programming connection options*

## Programming with HEX file

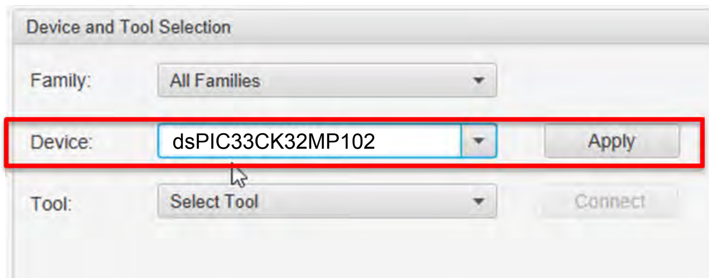
Download the latest MPLAB® X IPE from Microchip website and follow the five steps below:

https://www.microchip.com/mplab/mplab-integrated-programming-environment

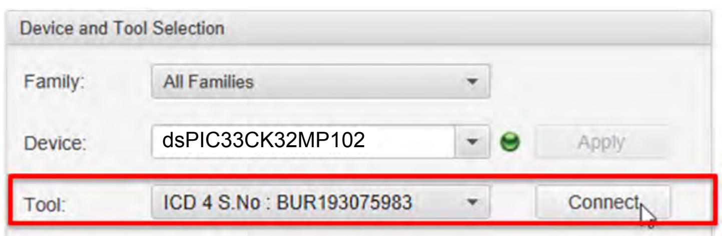
**1. Enable Advanced Mode:**



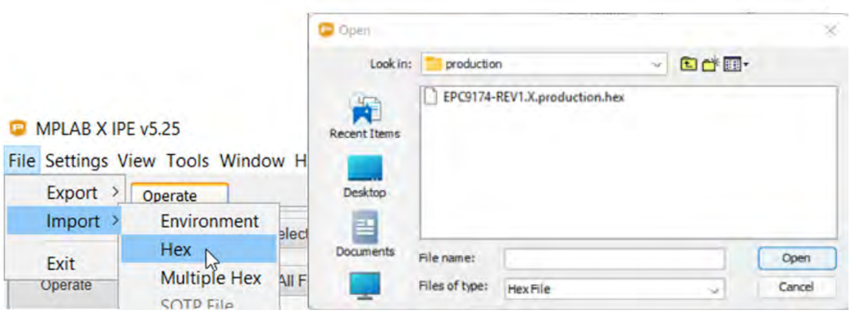

**2. Select Device: dsPIC33CK32MP102 and then apply:**



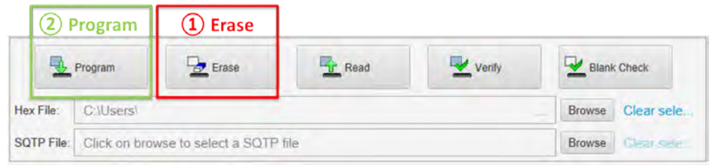

**3. Select programming tool and then connect:**



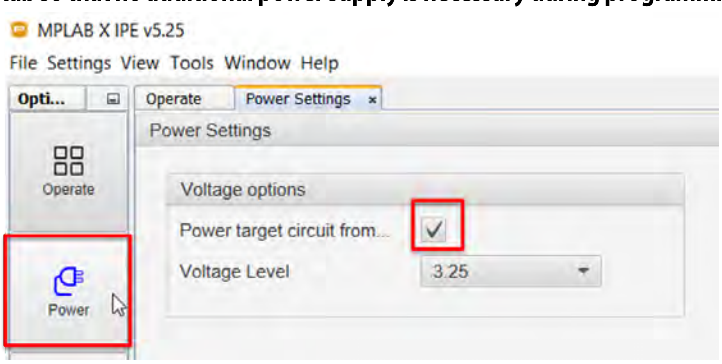

**4. Click 'Browse' to select the provided .hex file:**




**5. Erase device, and then program device:**




**Optional: Enable 'Power target circuit from programming tool' from left panel 'Power' tab so that no additional power supply is necessary during programming:**



**Communication**

The built-in USB to UART adaptor on the EPC9533 motherboard uses MCP2221A, and is connected to the same PGD and PGC pins as in J10 (see Figure 10).

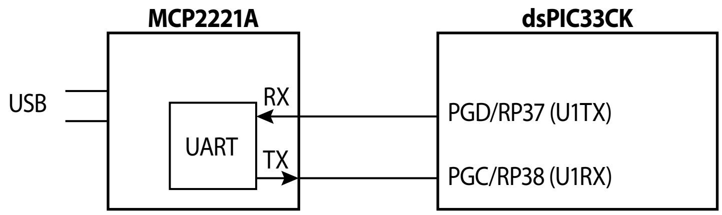



*Figure 10: RX and TX pin map of the USB to UART adaptor*

The 5 V from the USB port does not provide power for 3.3 V.

To use $I^2C$ instead of UART, the EPC9533 needs to be modified as follows:

- Remove resistors R530 and R531 (size 0402, 0 Ω)
- Install resistors R532 and R533 (size 0603, 0 Ω)

**Note:** Once configured to use $I^2C$, programming of the device is not possible.

## THERMAL MECHANICAL DRAWINGS

**Table 2: Bill of Materials - Thermal-Mechanical components**

| Item | Qty | Part Description | Manufacturer | Part # |
|---|---|---|---|---|
| 1 | 1 | Heatsink (Top) | Alpha Novatech | S08EHS0E |
| 2 | 1 | Heatsink (Bottom) | Alpha Novatech | S08EHS0D |
| 3 | 1 | Integrated Heat Spreader (Top) | N/A | N/A |
| 4 | 1 | Integrated Heat Spreader (Bottom) | N/A | N/A |
| 5 | 2 | Primary FET TIM Pad (5 mm x 7 mm) | T-Global | TG-A1780x0.5mm |
| 6 | 8 | Secondary FET TIM Pad (4.5 mm x 7.5 mm) | T-Global | TG-A1780x0.5mm |
| 7 | 2 | Heatsink TIM Pad (18 mm x 48 mm) | T-Global | TG-A6200x0.3mm |
| 8 | 3 | M1.4x16 mm Screws | Metric Screws US | 21856 |
| 9 | 3 | M1.4 Hex Nuts | Metric Screws US | 20680 |

| Item | Qty | Part Description | Manufacturer | Part # |
|---|---|---|---|---|
| 1 | 1 | Heatsink (Top) | Alpha Novatech | S08EHS0E |
| 2 | 1 | Heatsink (Bottom) | Alpha Novatech | S08EHS0D |

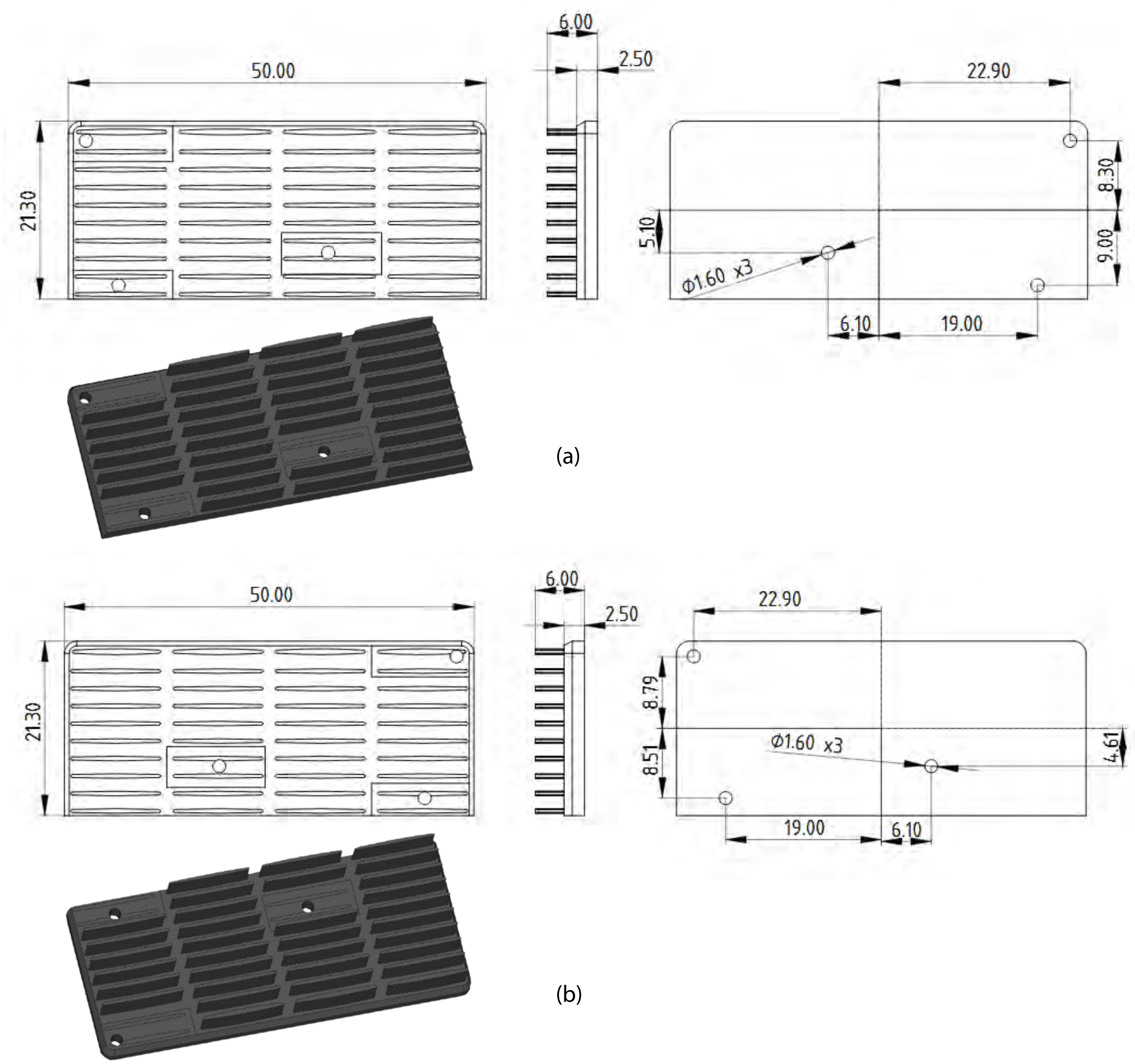
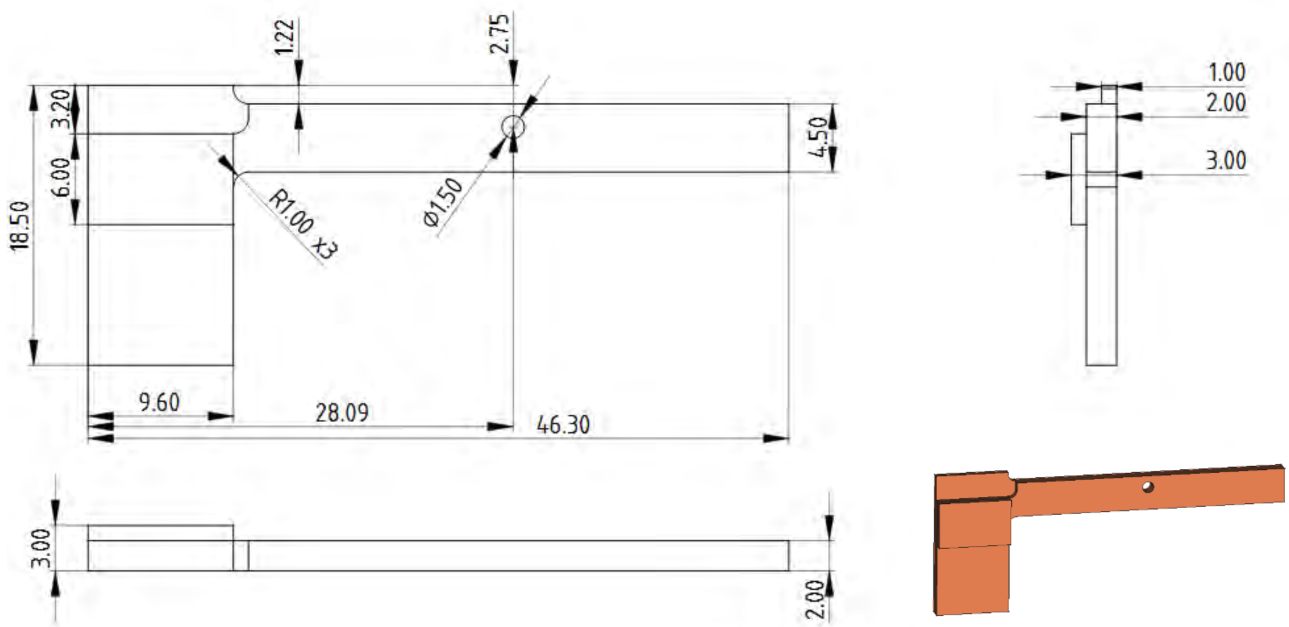
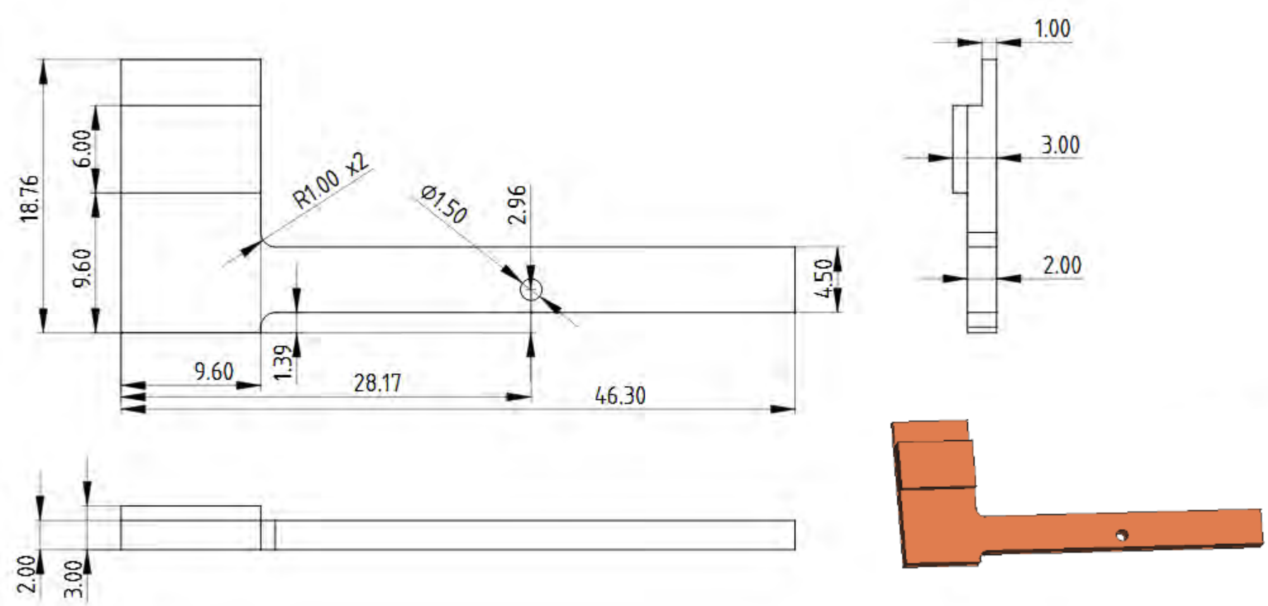



*Figure 11: Top side and (b) bottom side heatsink drawing. Units in mm.*
*Heatsink Drawing based on Alpha Novatech part UB2150-6BM-147, drawing S08EHS0D and S08EHS0E*

| Item | Qty | Part Description | Manufacturer | Part # |
|---|---|---|---|---|
| 3 | 1 | Integrated Heat Spreader (Bottom) | N/A | N/A |
| 4 | 1 | Integrated Heat Spreader (Top) | N/A | N/A |




(a)




(b)

All units in mm

*Figure 12. (a) Top side copper heat-spreader, (b) Bottom side copper heat-spreader*

## CORE DRAWING AND DIMENSIONS

All units in mm

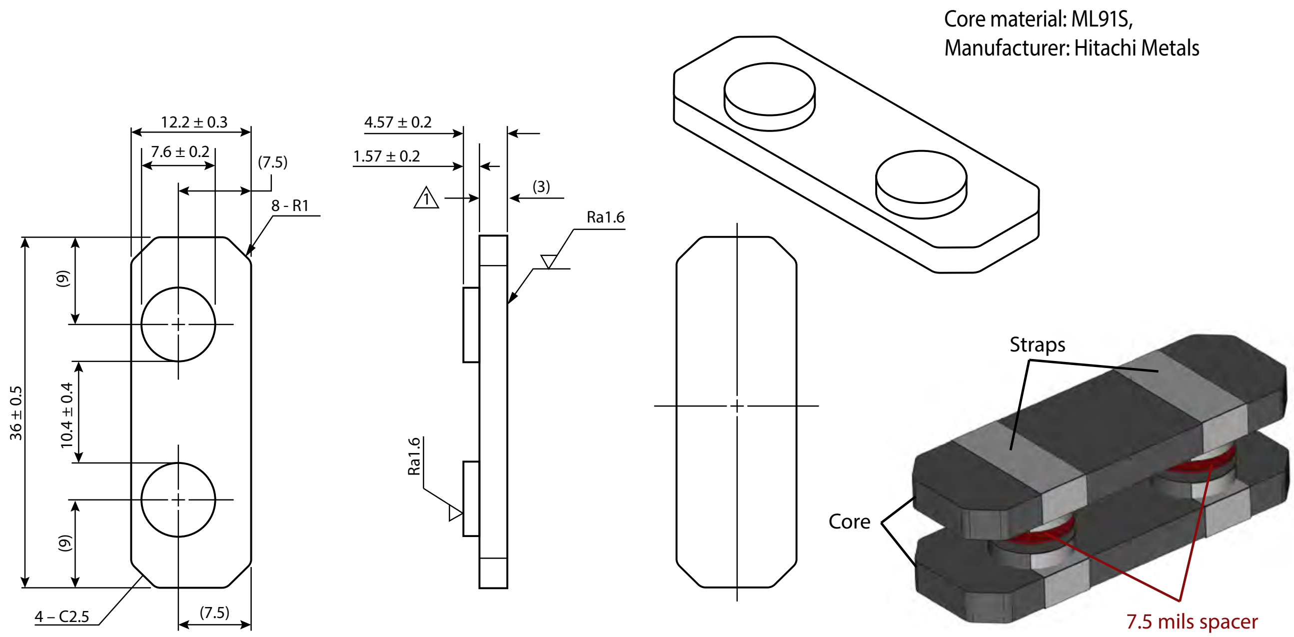



*Figure 13: Drawing with dimensions of the transformer core*

**For support files including schematic, Bill of Materials (BOM), and gerber files please visit the EPC9174 landing page at: https://epc-co.com/epc/products/demo-boards/epc9174**

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

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The EPC9174 system features the **dsPIC33CK32MP102** 16-Bit Digital Signal Controller with High-Speed ADC, Op Amps, Comparators and High-Resolution PWM. Learn more at **www.microchip.com**.

## For More Information:

Please contact **info@epc-co.com**
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EFFICIENT POWER CONVERSION



**Evaluation Board Notification**

**The EPC9174 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.

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