EPC9149: 36 - 60 V Input, 9 - 15 V, 83 A Output Fixed Conversion Ratio 1 kW LLC, $^{1}/_{8}{}^{th}$ Brick Size Module Quick Start Guide

EPC2218 and EPC2024

Revised January 5, 2023

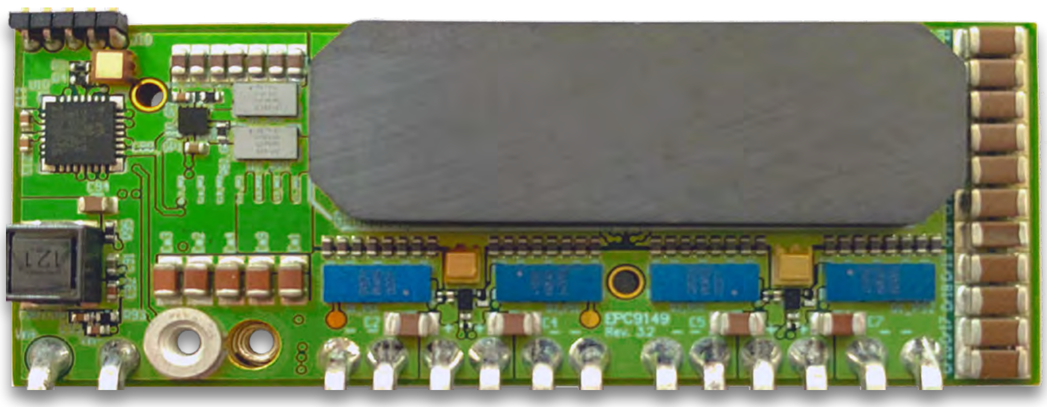
Version 3.2

EFFICIENT POWER CONVERSION

DESCRIPTION

The EPC9149 demonstration board is a 1 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 **EPC2218** and 40 V rated **EPC2024** GaN FETs, the uP1966E and LMG1020 gate drivers as well as the Microchip dsPIC33CK32MP102 16-bit digital controller. Other features include:

- Peak efficiency: 97.5 % at 400 W
- High full-load efficiency: 96.7% @ 12 V delivering 83.3 A output
- 22.9 × 58.4 mm (0.90 × 2.30 inches)
- Low profile: 10 mm total converter thickness without heatsink
- Temperature rise: 70°C @ 12 V with 83.3 A output (with heatsink kit installed)
- Fixed switching frequency: 1 MHz
- Soft startup into full resistive load
- High power density: 1227 W/in^3 (excluding pins)



EPC9149 board

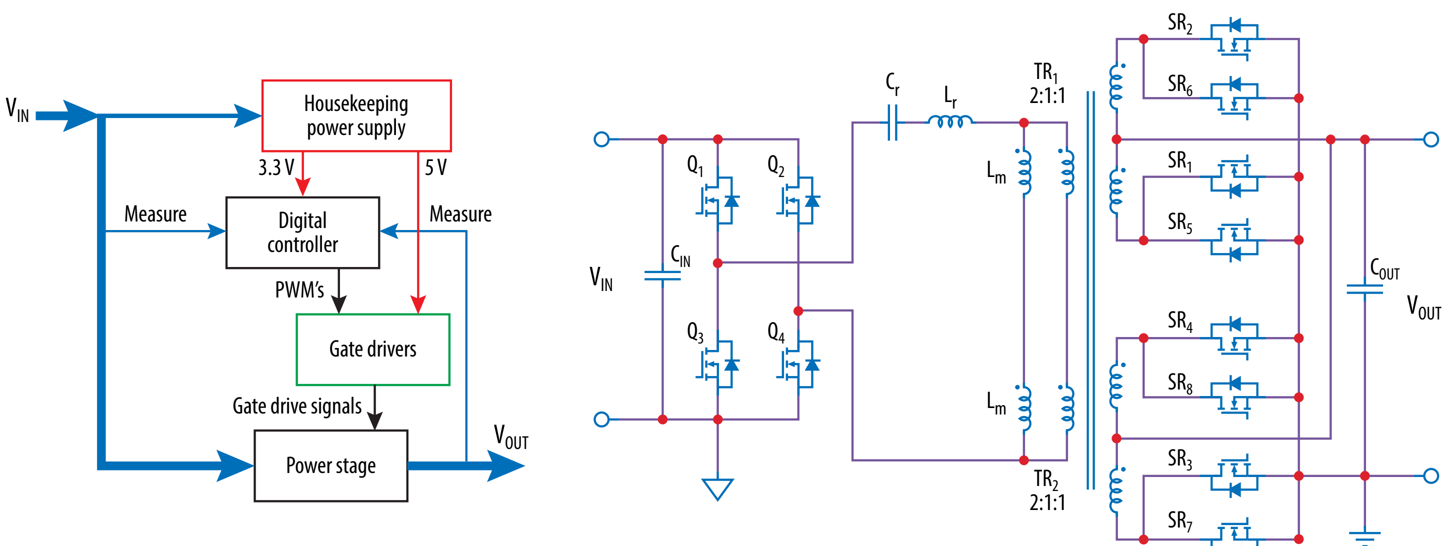


Figure 1: Simplified schematic diagram of the EPC9149 LLC Module

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		36	48	60	V
V_{OUT}	Output Voltage	Fixed ratio of 4:1 based on V_{IN}		12		
I_{OUT}	Output Current	Continuous*	0		83.3	A
f_S	Switching Frequency			1		MHz
T_{rise}	Temperature Rise	V_{IN} = 48 V, I_{OUT} = 83.3 A, thermal system installed, 400 LFM forced air, measured at heat-spreader		70		°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

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.

Power Stage

The EPC9149 features a primary side full bridge and a dual secondary side center tapped half bridge configuration based on EPC2218 and EPC2024 eGaN fets. Available from EPC's website (**epc-co.com**) are **EPC2218's datasheet** and **EPC2024's datasheet**.

Onboard power supply

The EPC9149 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 12. 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.

Three layers of 2.5mils Kapton tap adding up to 7.5mils total thickness was used as spacer on each center pillar as shown in Figure 12. Very thin straps help to wrap the cores tightly together.

MECHANICAL SPECIFICATIONS

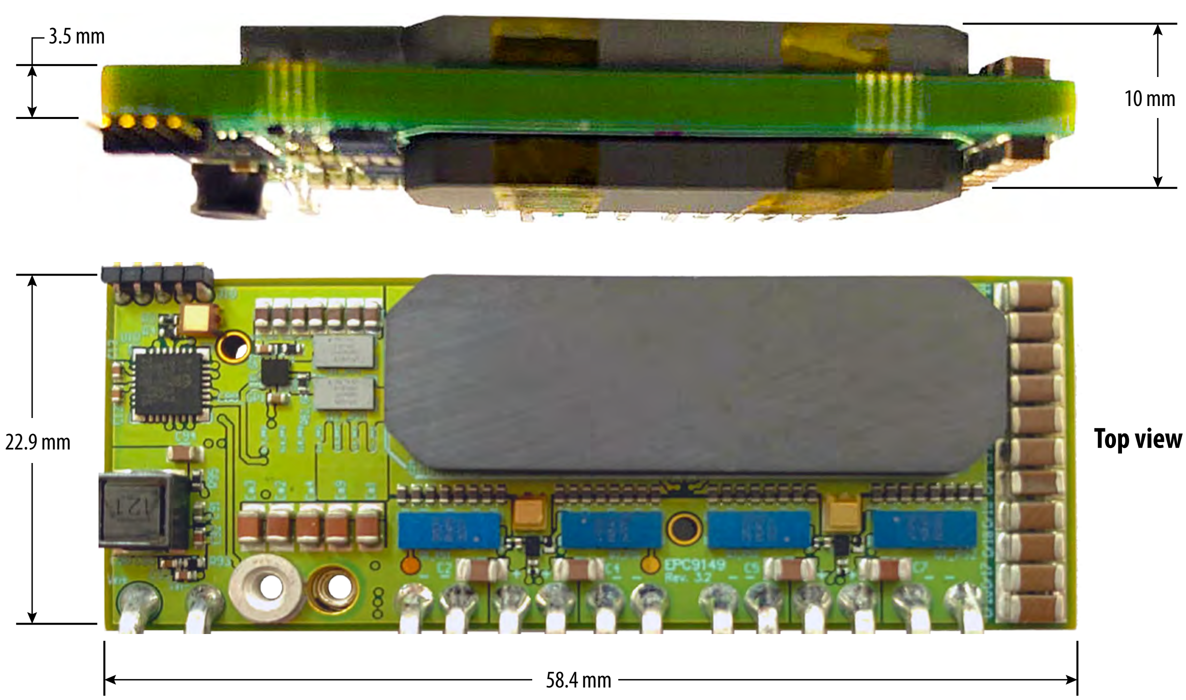


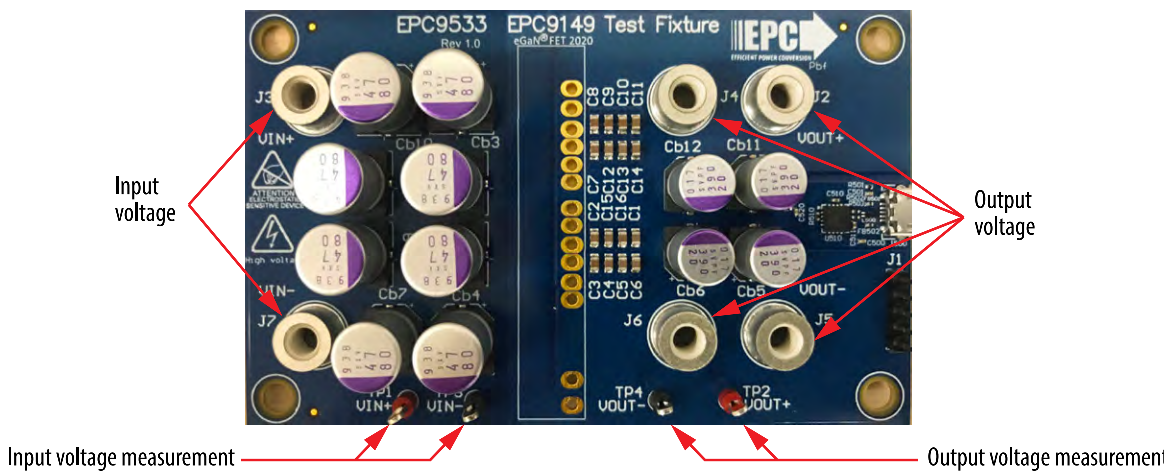
Figure 2: EPC9149 mechanical dimensions

QUICK START PROCEDURE

The EPC9149 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 EPC9149 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 respective measurement instruments.
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)



Top view

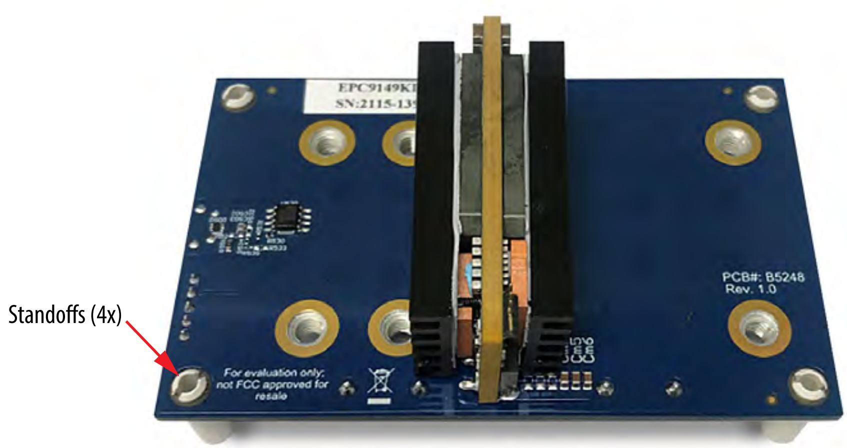


Figure 3: EPC9149 and motherboard assembly showing the input and output connections

ELECTRICAL and THERMAL PERFORMANCE

The module provides maximum efficiency of 97.5% and full load efficiency of 96.7%.

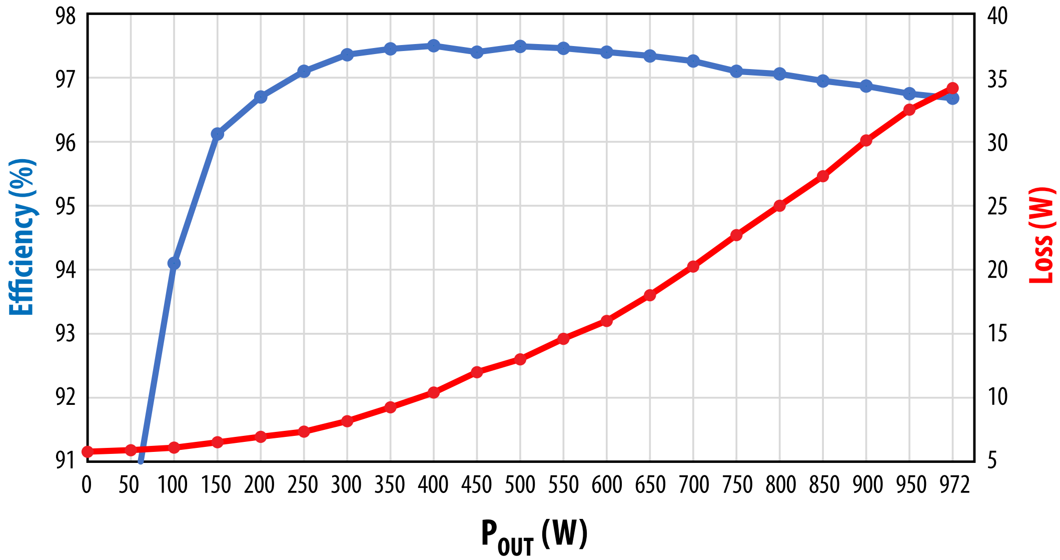
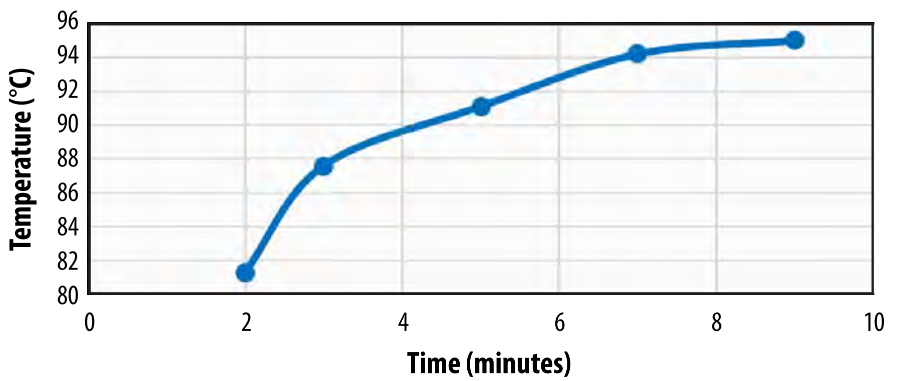


Figure 4: Total system efficiency and loss @ 12V output, 48V input voltage, 400LFM forced air cooling.

Thermal performance

The measured thermal performance of the EPC9149 is shown in Figure 7, with the heatsink kit installed. The temperature rise for the hottest portion of the board is 70 °C when operating at full load with 400 LFM forced air cooling.



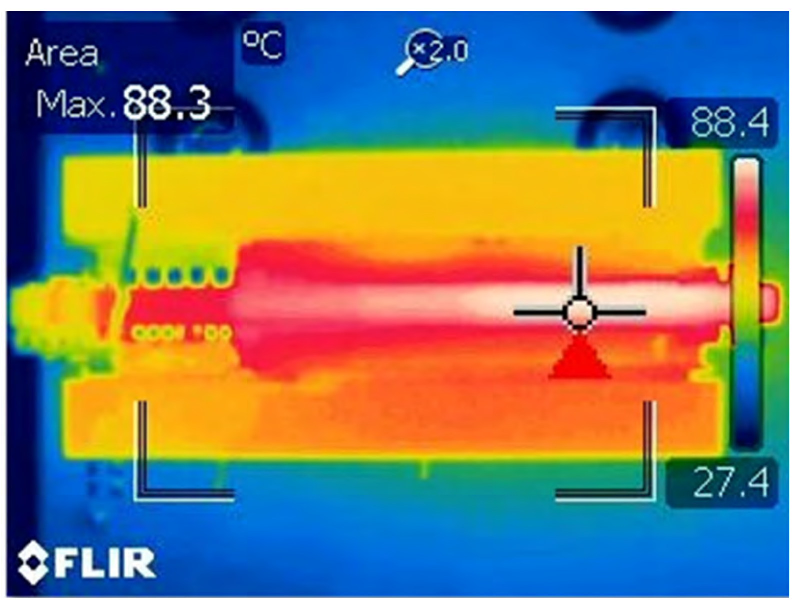


Figure 5: Thermal image of the EPC9149 operating at 48 V_{IN}, 12 V and 83.3 A output, thermal steady state reached after 10 minutes, Top: primary FET junction temperature and Bottom: highest board temperature.

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 EPC9149 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 EPC9149 board are designed. The thermal solution assembly is shown in Figure 6. 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 M1.4 16 mm screws and 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

Drawings and dimensions of these parts are provided in the Mechanical Bill of Materials (BOM) and in Figures 10, 11 and 12.

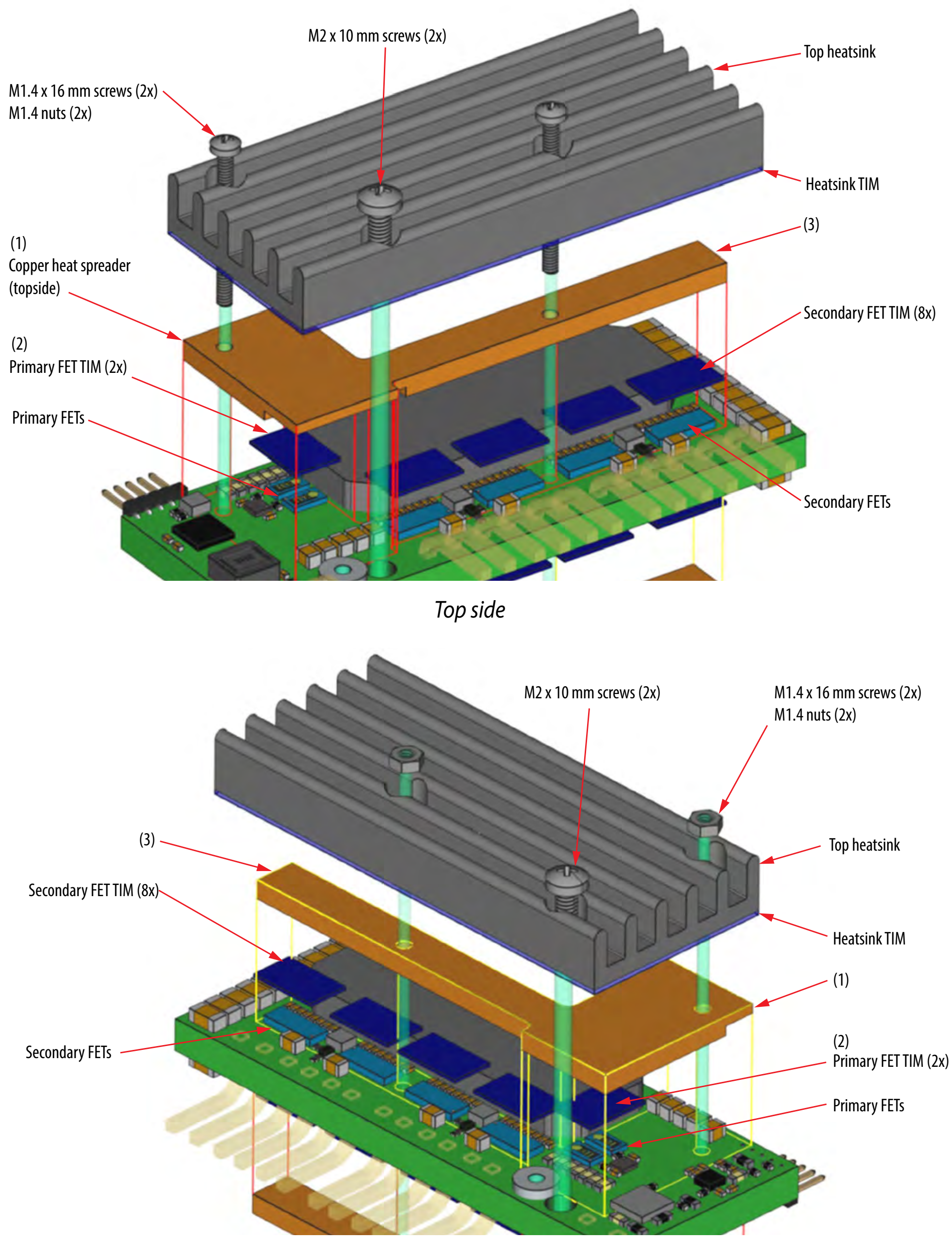
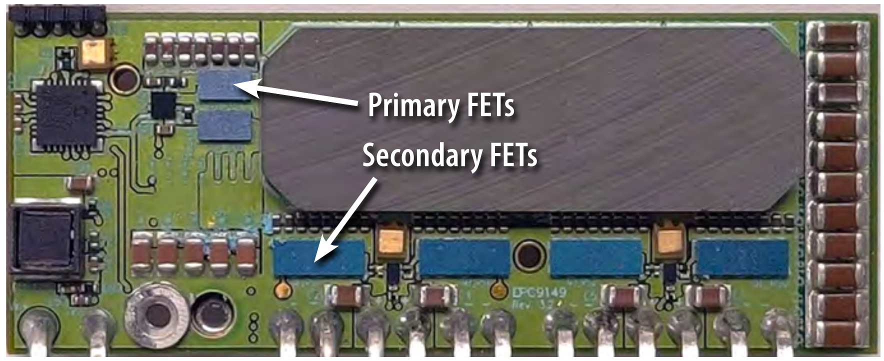


Figure 6: Thermal solution assembly process for the EPC9149 module

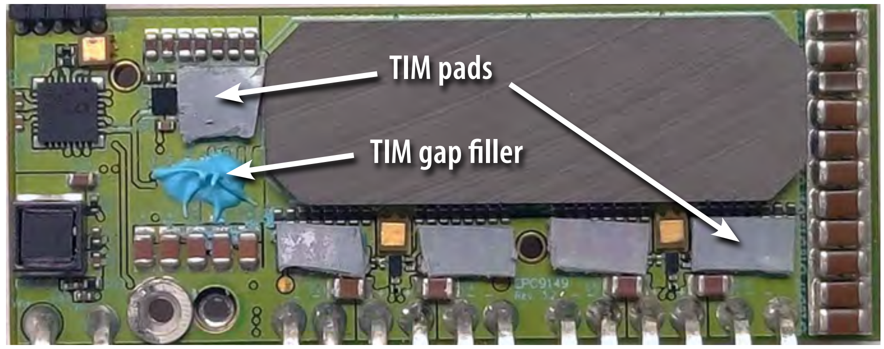
THERMAL SOLUTION ASSEMBLY GUIDELINES

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



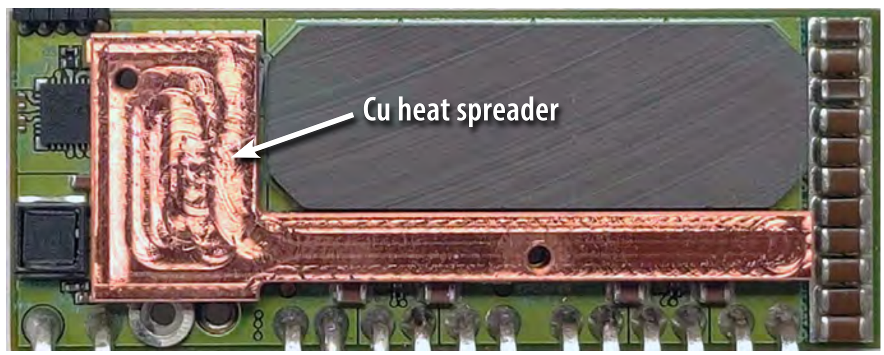
2. Add a small amount of **TIM gap filler** (Bergquist GF4000) on PCB next to Primary FETs

3. Place **TIM pads** (TG-A1780) on the primary and secondary FETs (Figure 12)

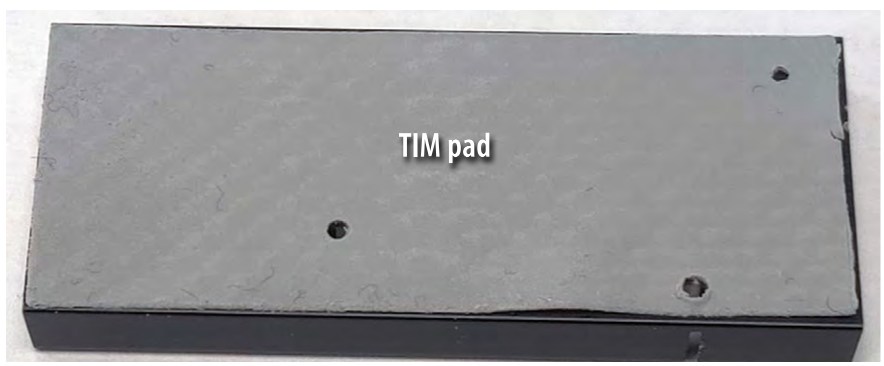


4. Place **heat spreaders** on the FETs, making sure the holes align with the drill holes on the PCB

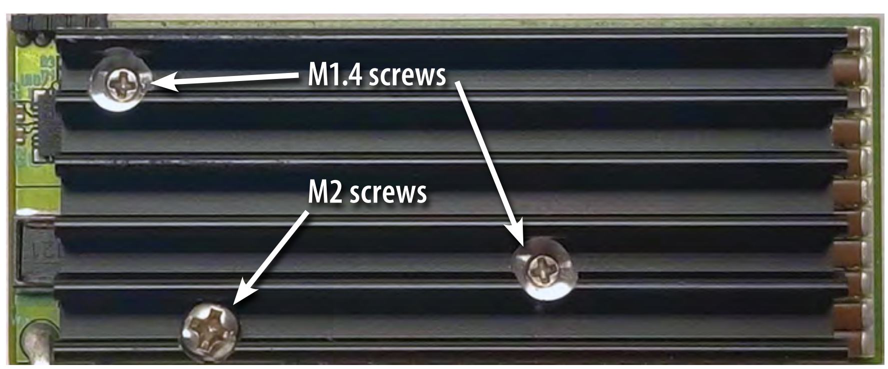
Note: The two Cu heat spreaders for top and bottom sides are not identical (Figure 11)



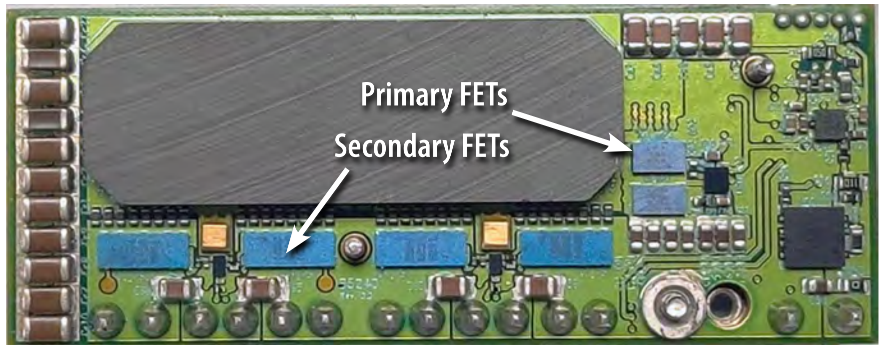
5. Place **TIM pad** (TG-A6200) on the backside of the heatsink (flat side) and align it to PCB holes (Figure 12)



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. Turn the PCB to the backside and note the placement of the FETs

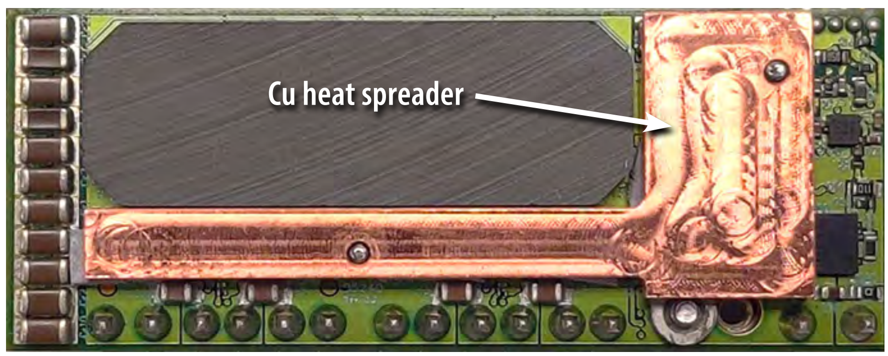


8. Add a small amount of **TIM gap filler** (Bergquist GF4000) next to Primary FETs

9. Place **TIM pad** (TG-A1780) cutouts to cover primary and secondary FETs (Figure 12)

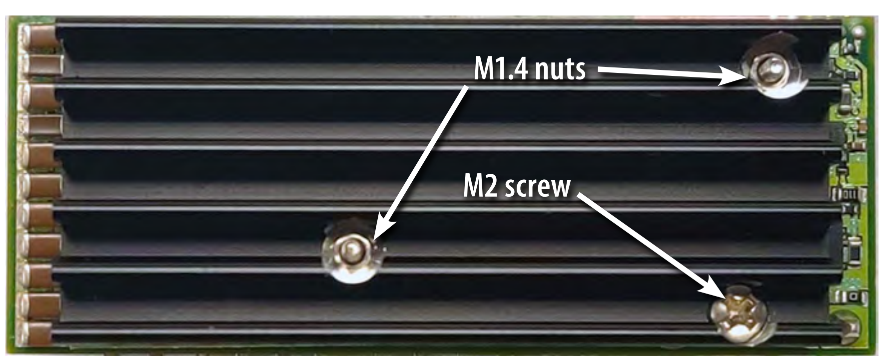
10. Place copper heat spreader on FETs, holes must align with PCB holes and the M1.4 screws

Note: The two Cu heat spreaders for top and bottom sides are not identical (Figure 11)

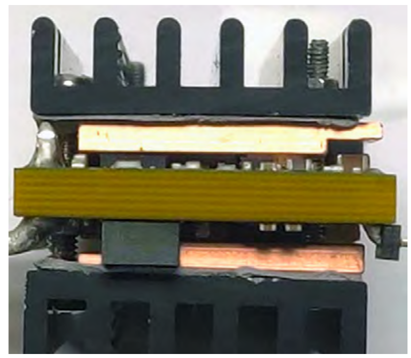


11. Place TIM (TG-A6200) on backside of heatsink and align it to screw holes (Figure 12)

12. 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



13. 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 EPC9149 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 EPC9149 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.

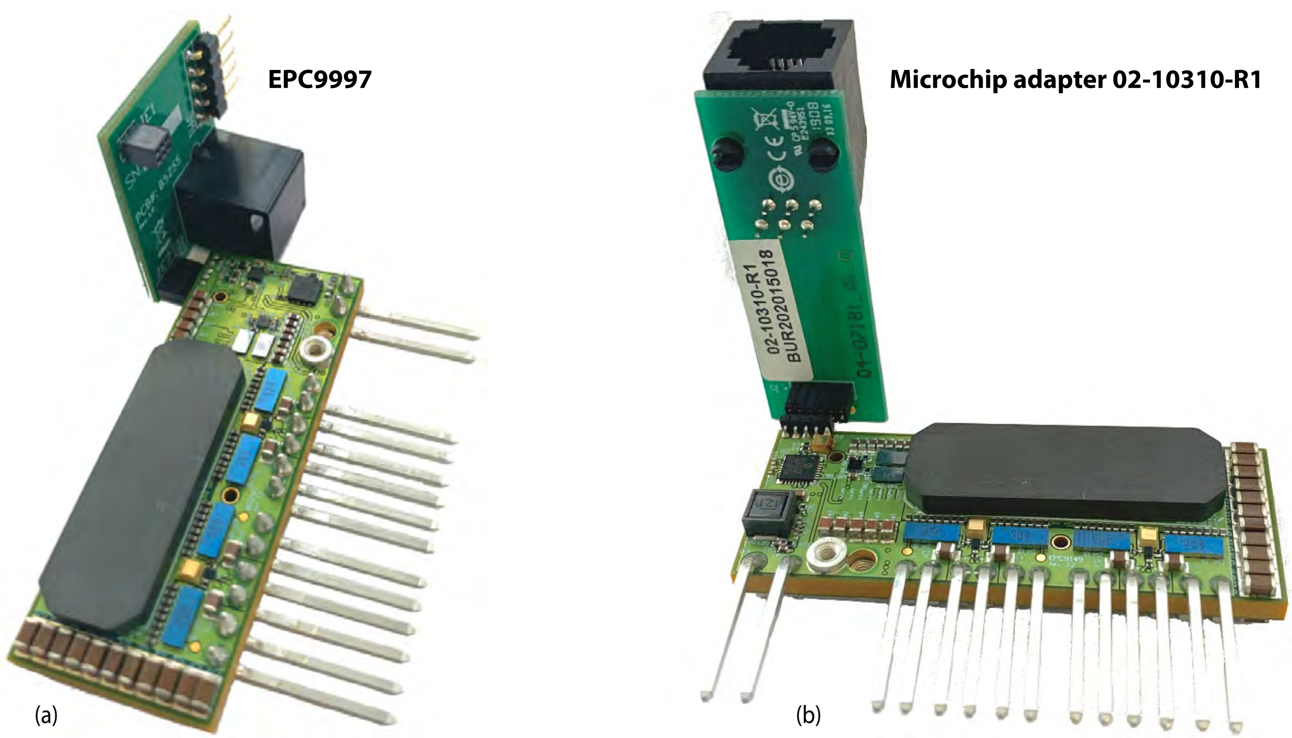


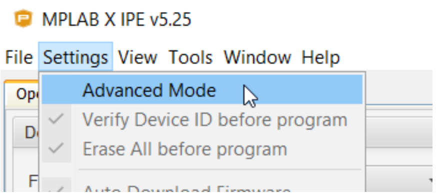
Figure 9: Programming connection options

Programming with HEX file

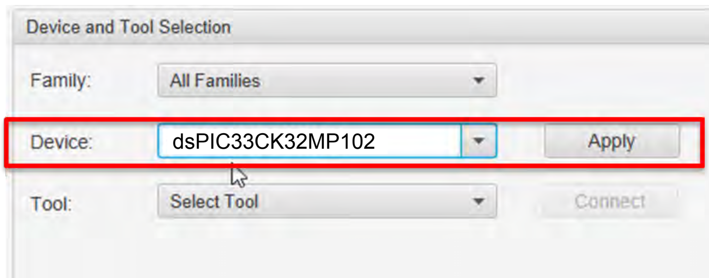
Download the latest MPLAB® X IPE from Microchip website and follow the five steps below:

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

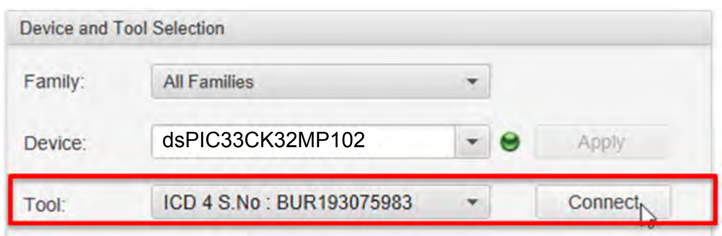
1. Enable Advanced Mode:



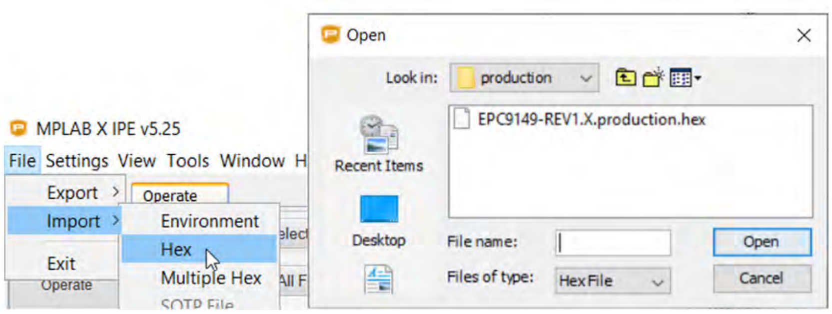
2. Select Device: dsPIC33CK32MP102 and then apply:



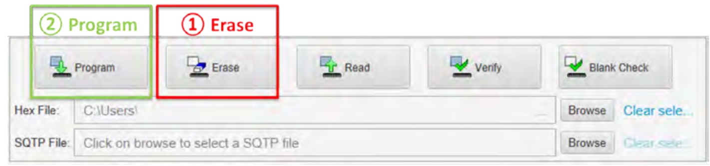
3. Select programming tool and then connect:



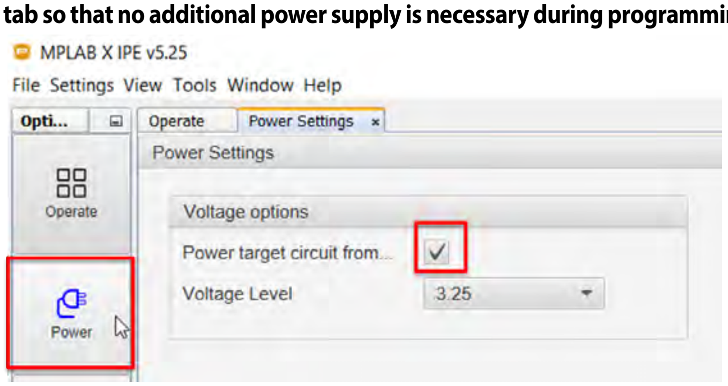
4. Click 'Browse' to select the provided .hex file:



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:

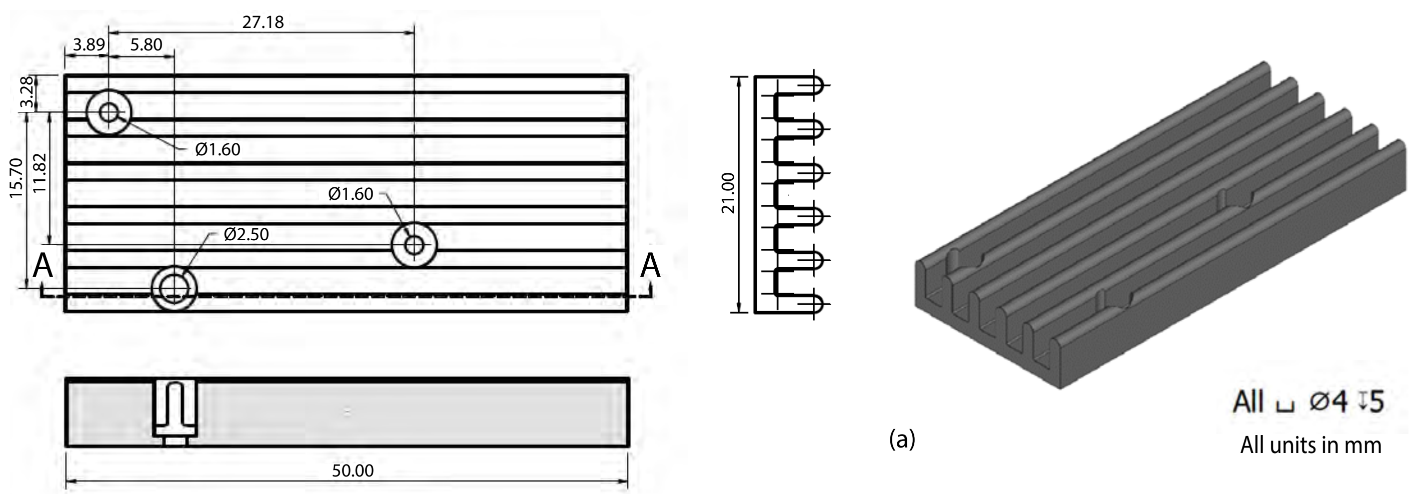


THERMAL MECHANICAL DRAWINGS

Table 2: Bill of Materials - Thermal-Mechanical components

Item	Qty	Part Description	Manufacturer	Part #
1	1	Heat Sink Top Side	Fischer Elektrik	SK 476 50 SA
2	1	Heat Sink Bottom Side	Fischer Elektrik	SK 476 50 SA
3	1	Integrated Heat Spreader (Top)	Prototype-Shortrun	Custom part
4	1	Integrated Heat Spreader (Bottom)	Prototype-Shortrun	Custom part
5	2	Primary TIM pad	T-Global	TG-A1780 X 0.5 mm
6	8	Secondary TIM pad	T-Global	TG-A1780 X 0.5 mm
7	2	Heat Sink TIM pad	T-Global	TG-A6200 X 0.5 mm
8	2	M2-0.40x10mm Screws	Metric Screws US	10047
9	2	M1.4x16mm Screws	Metric Screws US	21856
10	2	M1.4 Hex Nuts	Metric Screws US	20680

Item	Qty	Part Description	Manufacturer	Part #
1	1	Heat Sink Top Side	Fischer Elektrik	SK 476 50 SA



Item	Qty	Part Description	Manufacturer	Part #
2	1	Heat Sink Bottom Side	Fischer Elektrik	SK 476 50 SA

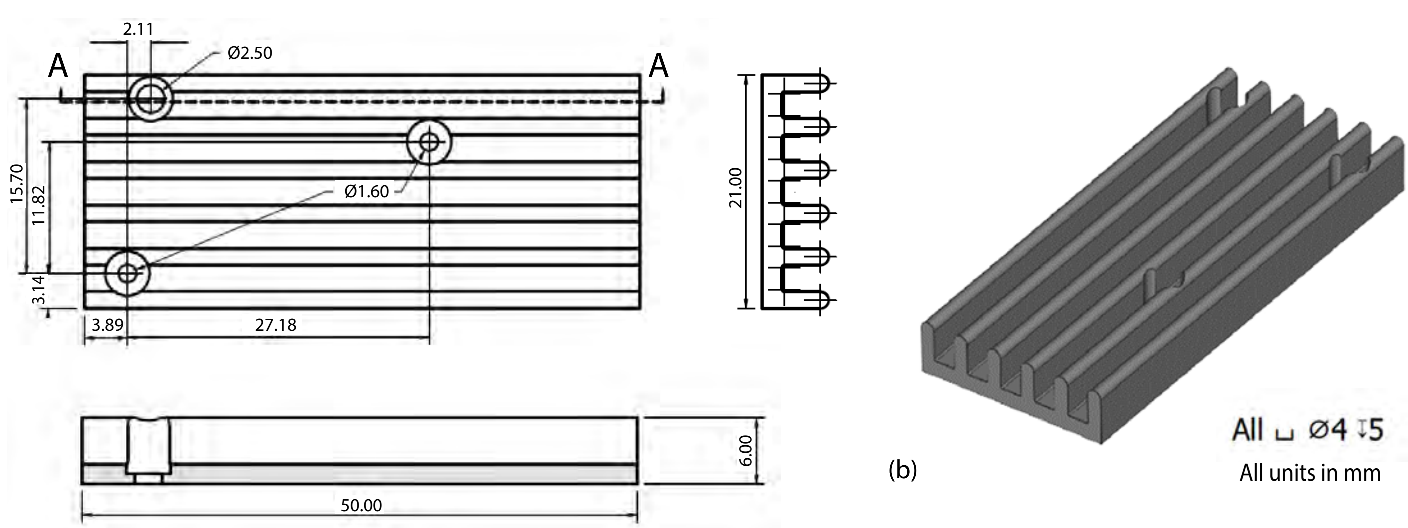
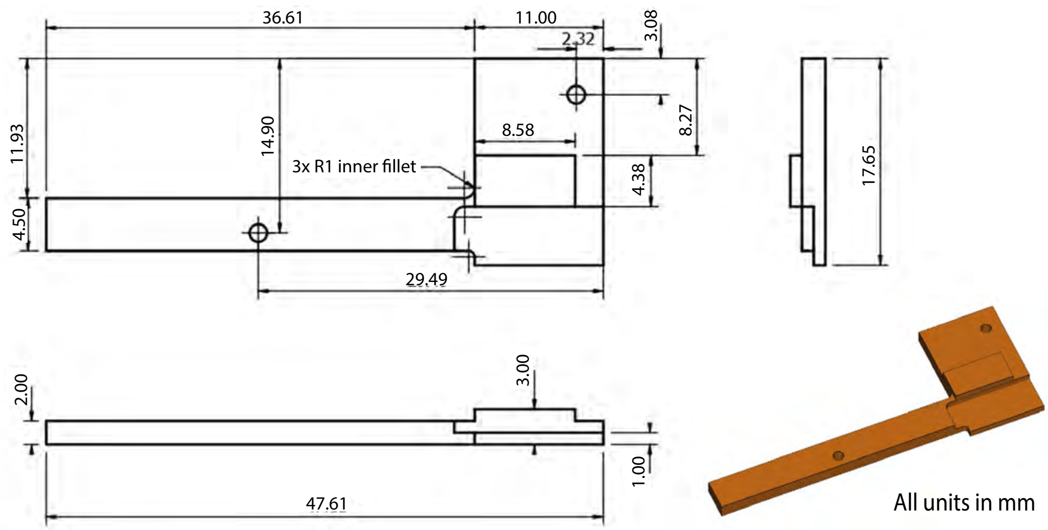


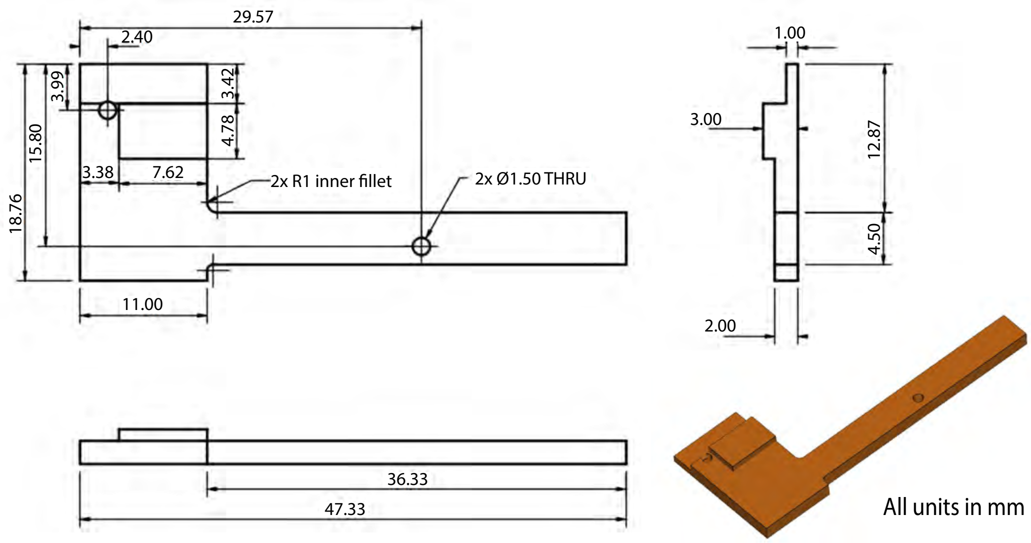
Figure 10: (a) Top side heatsink drawing, (b) Bottom side heatsink

Item	Qty	Part Description	Part #
3	1	Integrated Heat Spreader (Top)	Custom part



(a)

Item	Qty	Part Description	Part #
4	1	Integrated Heat Spreader (Bottom)	Custom part



(b)

Figure 11. Integrated heat spreader drawing for (a) top-side and (b) bottom-side

Item	Qty	Part Description	Manufacturer	Part #
5	2	Primary TIM pad	T-Global	TG-A1780 X 0.5 mm
6	8	Secondary TIM pad	T-Global	TG-A1780 X 0.5 mm
7	2	Heat Sink TIM pad	T-Global	TG-A6200 X 0.5 mm

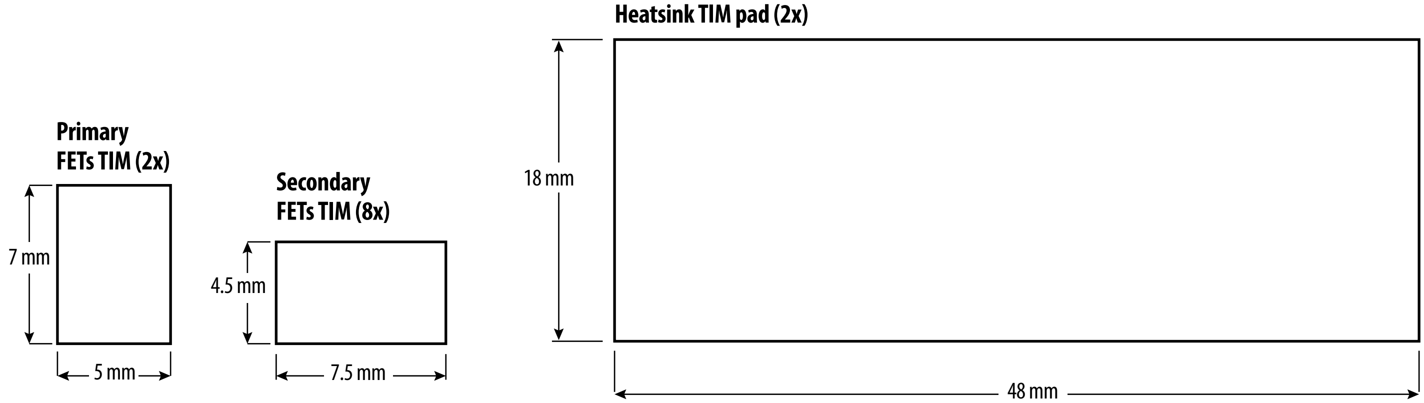


Figure 12: Drawings and dimensions of TIM pad cutouts for primary FETs, secondary FETs and heatsinks.

Item	Qty	Part Description	Manufacturer	Part #
8	2	M2-0.40x10mm Screws	Metric Screws US	10047
9	2	M1.4x16mm Screws	Metric Screws US	21856
10	2	M1.4 Hex Nuts	Metric Screws US	20680

CORE DRAWING AND DIMENSIONS

All units in mm

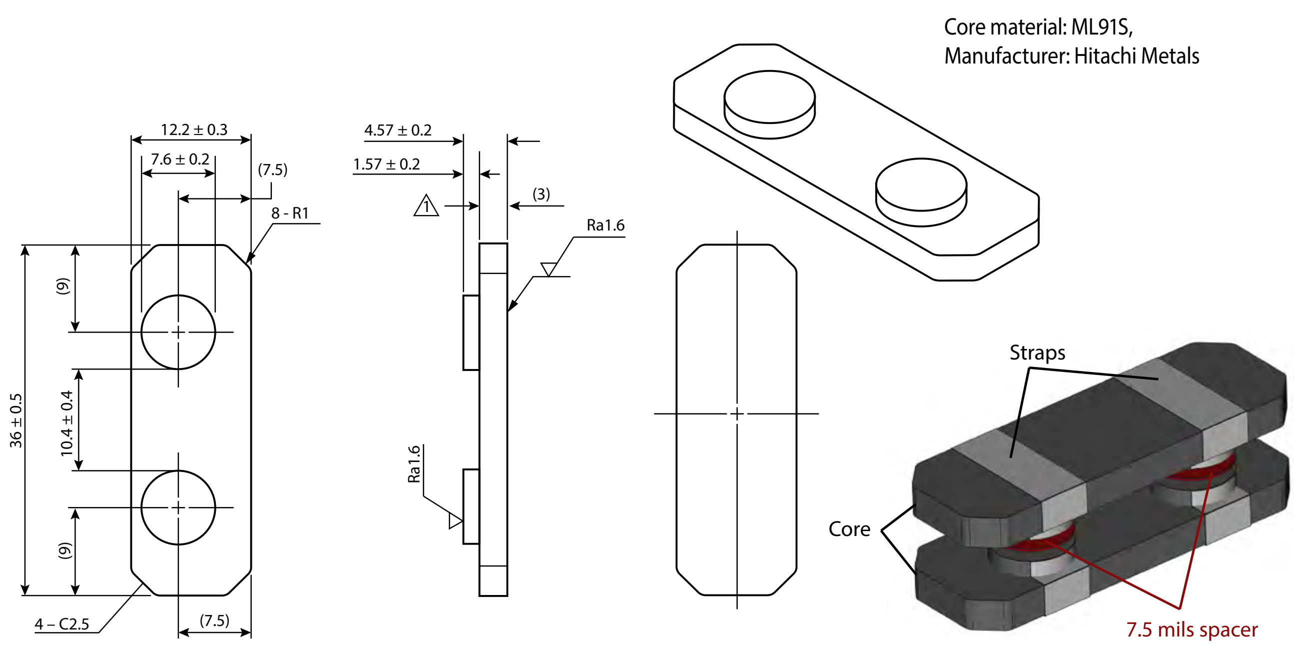


Figure 13: Drawing with dimensions of the transformer core

For support files including schematic, Bill of Materials (BOM), and gerber files please visit the EPC9149 landing page at: https://epc-co.com/epc/products/demo-boards/epc9149

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

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The EPC9149 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**
or your local sales representative

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EFFICIENT POWER CONVERSION

Demonstration Board Notification

The EPC9149 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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