EPC9174: 40–60 V Input, 10–15 V, 100 A Output Fixed Conversion Ratio 1.2 kW LLC, <sup>1</sup>/<sub>8</sub><sup>th</sup> Brick Size Module Quick Start Guide

*EPC2071 and EPC2066* 

**Revision 1.0** 



## EPC9174 1.2 kW LLC <sup>1</sup>/8<sup>th</sup> Brick Module

### **QUICK START GUIDE**

## DESCRIPTION

The EPC9174 demonstration 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<sup>3</sup> (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<sub>a</sub> = 25 °C unless specified otherwise)

Symbol	Parameter	Conditions	Min	Тур	Max	Units
V <sub>IN</sub>	Input Voltage		40	48	60	
V <sub>OUT</sub>	Output Voltage	Fixed ratio of 4:1 based on $V_{IN}$		12		
I <sub>OUT</sub>	Output Current Continuous*		0		100	Α
f <sub>s</sub>	Switching Frequency			1		MHz
T <sub>rise</sub>	Temperature Rise	$V_{IN} = 48 \text{ V}$ , $I_{OUT} = 100 \text{ A}$ , thermal system installed, 400 LFM forced air, measured at heat-spreader		72.5		°C
V <sub>IN,on</sub>	Input UVLO turn on voltage			7.5		
V <sub>IN,off</sub>	Input UVLO turn off voltage			5.5		
t <sub>OUT,rise</sub>	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**



## EPC9174 1.2 kW LLC <sup>1</sup>/8<sup>th</sup> Brick Module

### **QUICK START GUIDE**

### 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  $V_{\text{OUT+}}$  and  $V_{\text{OUT-}}$  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 m $\Omega$  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.



## **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<sub>IN</sub>, 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

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## 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







M1.4 screws

M2 screw

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- 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



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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

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### **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:

MPLAB X IPE v5.25

#### File Settings View Tools Window Help

Ор		Advanced Mode	
D	$\checkmark$	Verify Device ID before program	
	$\checkmark$	Erase All before program	
F		Auto Download Firmwara	

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

Device and T	ool Selection		
Family:	All Families	•	
Device:	dsPIC33CK32MP102	-	Apply
Tool:	Select Tool	•	Connect

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

Family:	All Families	•		
Device:	dsPIC33CK32MP102	•	•	Apply
Tool	ICD 4 S.No ; BUR193075983	•	1	Connect

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

		1				-
		😨 Oper	Ŭ.			×
			Look in: 📒 production	n	< 🗈 💣 💷 •	
		¥	EPC9174-	REV1.X.production.hex		
WIPLAB X IF	2E V5.25	Recent	Items			
File Settings	View Tools Window	wН				
Export >	Operate	Desk	top			
Import >	Environment	alect	3			
Exit	Hex	Docun	File name:			Open
Operate	Multiple Hex		Files of type:	HexFile	~	Cancel

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



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

(2) F	rogram	1 Erase				
2	Program	Erase	Read	Verify	Blank	Check
lex File:	C:\Users\					Clear sele.
SQTP File:	Click on browse to select a SQTP file					Clear sele

#### 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<sup>2</sup>C instead of UART, the EPC9533 needs to be modified as follows:

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

Note: Once configured to use I<sup>2</sup>C, programming of the device is not possible.

### THERMAL MECHANICAL DRAWINGS

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

ltem	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



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ltem	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)



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/DemoBoards/EPC9174.aspx



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Microchip Technology Incorporated is a leading provider of smart, connected and secure embedded control solutions. Its easy-to-use development tools and comprehensive product portfolio enable customers to create optimal designs, which reduce risk while lowering total system cost and time to market. The company's solutions serve customers across the industrial, automotive, consumer, aerospace and defense, communications and computing markets.

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.