How to Design a High-Efficiency 48 V, 1.2 kW LLC Resonant Converter in a $^{1}/_{8}{}^{th}$ Brick Size using eGaN® FETs

Motivation

To accommodate the increasing power requirement in the server applications, there is increasing demand on extracting more power from standard 48 V bus converters. This application note presents the design of a 1.2 kW, 4:1 conversion ratio, eGaN FET-based LLC resonant converter in the $^{1}/_{8}{}^{th}$ power brick size for the 48 V server applications. The EPC9174 [1] converter module achieves 97.3% peak efficiency and 96.3% full-load efficiency.

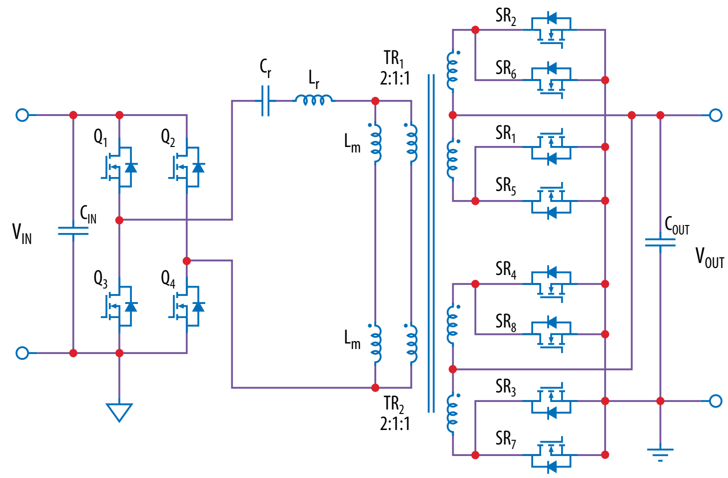


Figure 1. Power architecture schematic of the 48 V, 1.2 kW LLC resonant converter.

Design overview

The schematic of the LLC resonant topology adopted in this work is illustrated in Figure 1. It consists of a full-bridge primary side, a center-tapped secondary side with parallel-connected synchronous rectifiers to reduce the conduction loss. A series-connected 2 × 2:1:1 matrix transformer integrated in a single core is designed. The high output current is distributed among multiple secondary stages, ensuring low interconnect inductance between the transformer and the synchronous rectifiers, and reduces winding loss.

eGaN FET selection for the LLC resonant converter

eGaN FETs are well suited for the soft-switching LLC resonant converters [2]. Compared to Si MOSFETs of similar rating, their lower gate charge (Q_G) and the 5 V gate operation result in much lower gate power consumption. In addition, GaN FETs have much lower output capacitance and therefore need much less charge to achieve zero voltage switching (ZVS). This would either reduce the dead-time and increase the effective power delivering time, or reduce the required magnetizing current, circulating energy and conduction losses.

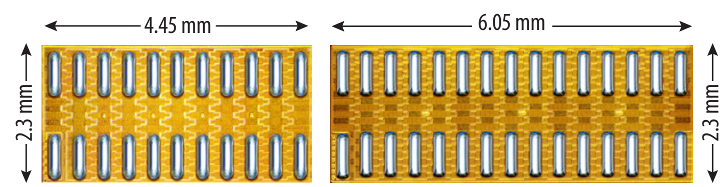


*Figure 2. Photo of the bump side of **EPC2071** (left) and **EPC2066** (right).*

The 100 V rated 2.2 mΩ **EPC2071**[3] and 40 V rated 1 mΩ **EPC2066**[4] as shown in Figure 2 are selected for the primary and secondary-side power devices respectively. Both eGaN FETs can operate at up to 150 °C junction temperature. The small form factor of GaN FETs makes it possible to fit in 8 FETs in the limited $^{1}/_{8}{}^{th}$ power brick size for the synchronous rectifiers.

The block diagram of the circuit design is shown in Figure 3. The design also includes on-board housekeeping power supply, digital controller, and input and output voltage sensing. The PWM signals are generated by the dsPIC controller dsPIC33CK32MP102-I/2N [5] from Microchip. On-board housekeeping power supply generates the 5 V for the gate drivers, and the 3.3 V for the controller.

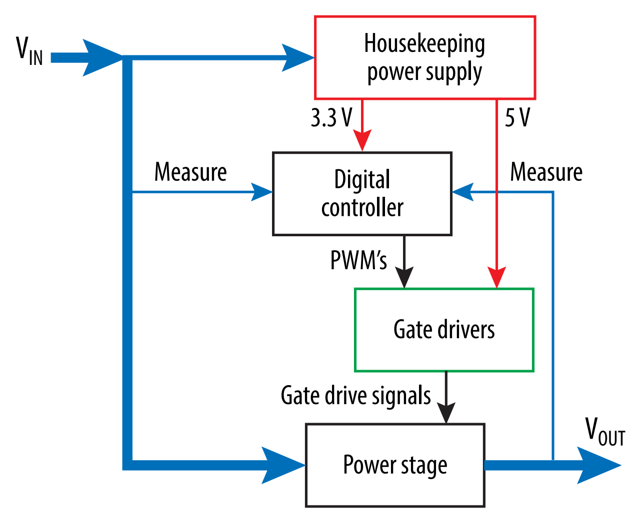


Figure 3. Block diagram of the LLC resonant converter.

Experimental validation

The EPC9174 1.2 kW, 4:1 ratio GaN FET-based LLC resonant converter shown in Figure 4 is built to verify the design.

The EPC9174 converter module is set up on a motherboard for evaluation. Figure 5 shows the motherboard and EPC9174 installed on it. The main input and output connections, measurement ports, bulk input and output capacitors, USB and communication port are located on the motherboard.

The overall power loss and efficiency at 48 V input and 12 V output including the housekeeping power consumption is given in Figure 6 with 97.3% peak efficiency and 96.3% full-load efficiency.

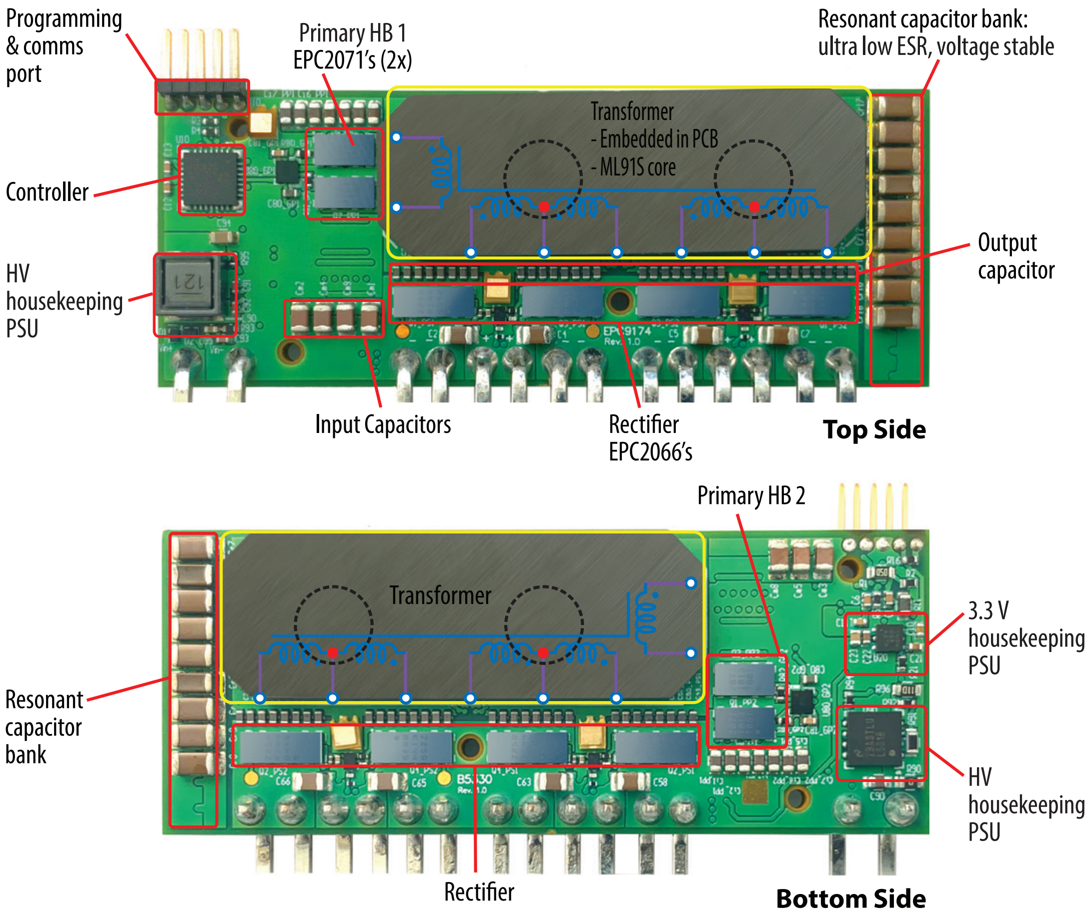


Figure 4. The 1.2 kW, 4:1 ratio, LLC resonant converter using ***EPC2071*** *and* ***EPC2066****.*

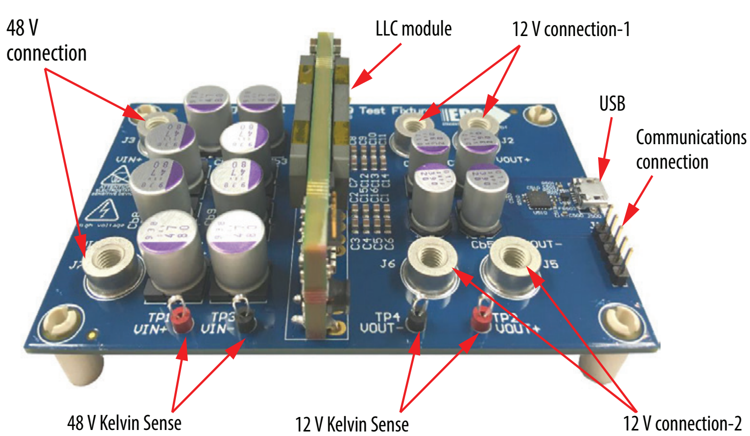


Figure 5. EPC9174 and motherboard assembly showing the input and output connections.

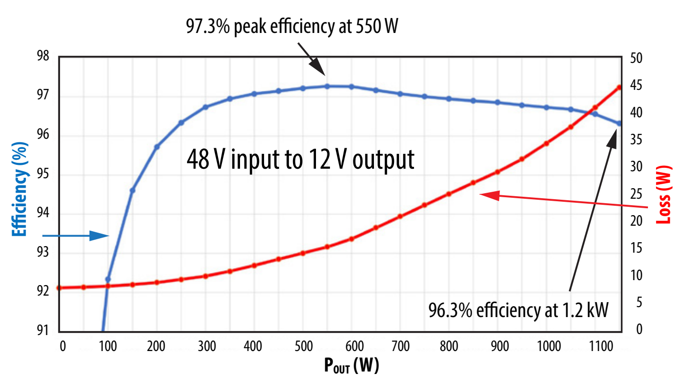
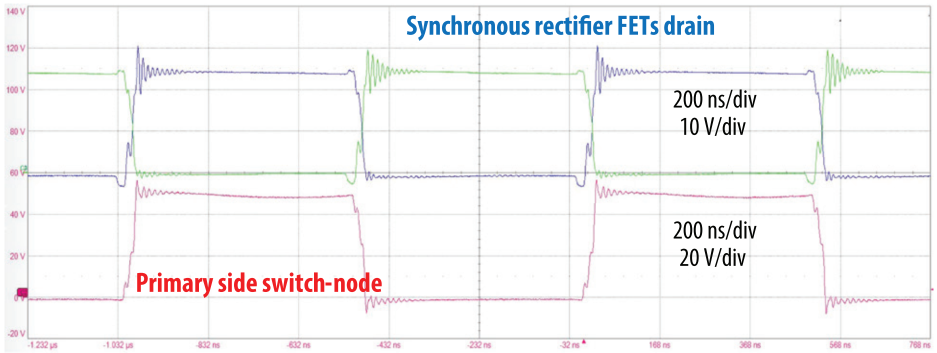


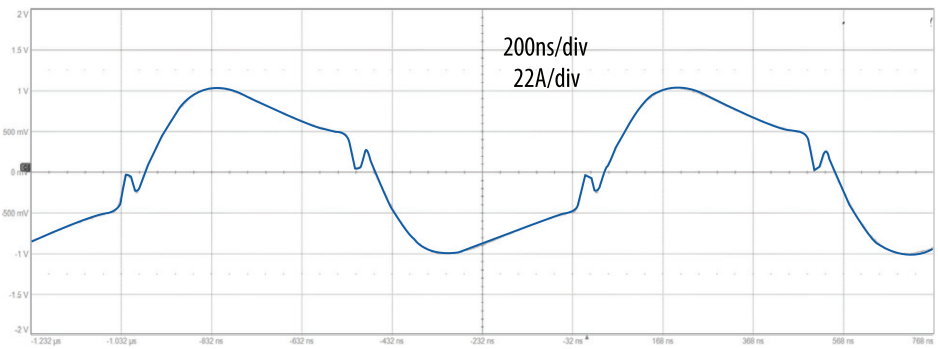
Figure 6. Power efficiency as function of output power at 48 V input voltage and 12 V output voltage.

The measured switching waveforms, at 48 V input, 12 V and 100 A output are shown in Figure 7(a). ZVS was achieved on the primary side devices as evident by the absence of overshoot and ringing. The resonant current flowing in the tank circuit is also shown in Figure 7(b). The circuit is tuned for operation above resonance to reduce conduction loss on the secondary side FETs.

A combination of custom shape heat spreaders and a finned heatsink for the top and bottom side of the EPC9174 board were designed. The thermal solution assembly is shown in Figure 8.



(a)



(b)

Figure 7. (a) Switching waveforms at 48 V input voltage and 1.2 kW load condition, (b) Resonant tank current waveform.

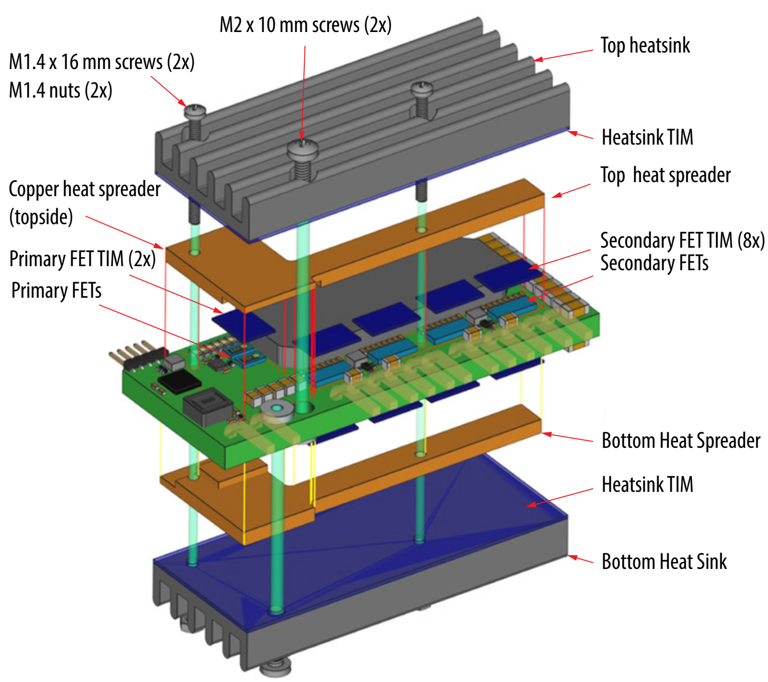


Figure 8. Thermal solution assembly process for the EPC9174 module.

Copper heat spreaders 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 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.

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. Figure 10 shows the thermal image of the module at steady state condition.

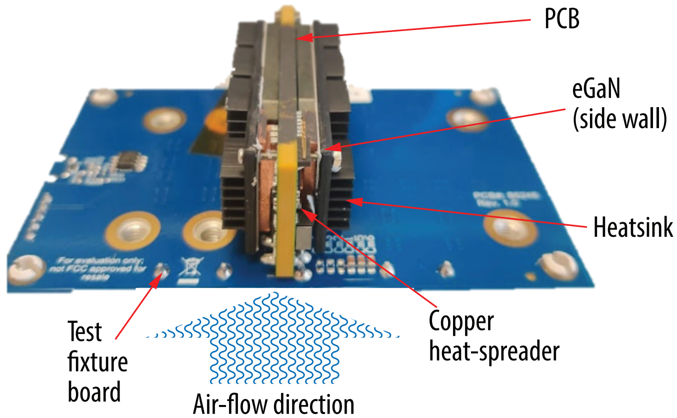


Figure 9. EPC9174 thermal measurement setup.

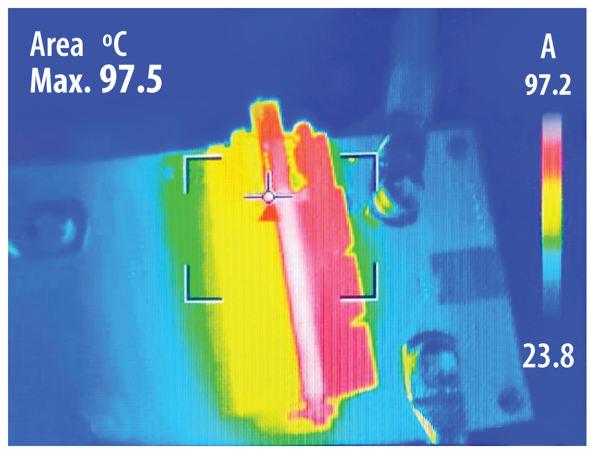


Figure 10. Thermal image of the EPC9174 operating at 48 V_{IN}, 12 V, 100 A output and 1000 LFM forced air cooling, thermal steady state reached after 10 minutes, highest board temperature.

Conclusion

The EPC9174 is a 48 V input, 1.2 kW output, 4:1 conversion ratio, LLC resonant converter in the $^1/_8{}^{th}$ power brick size built using eGaN FETs. Measured peak efficiency is 97.3% and full power efficiency is 96.3% including housekeeping power consumption. The low gate capacitance, output charge and on-resistance and the small form factor of the eGaN FETs are the key to achieving this at a power density exceeding 1472 W/in^3.

References

[1] EPC. (2022). “EPC9174 QSG,” [online]. Available: https://epc-co.com/epc/Portals/0/epc/documents/guides/epc9174_qsg.pdf

[2] A. Lidow, M. de Rooij, J. Strydom, D. Reusch, and J. Glaser, GaN Transistors for Efficient Power Conversion, 3rd ed. Wiley, 2019.

[3] EPC. (2022). “EPC2071 datasheet,” [online]. Available: https://epc-co.com/epc/Portals/0/epc/documents/datasheets/epc2071_datasheet.pdf

[4] EPC. (2022). “EPC2066 datasheet,” [online]. Available: https://epc-co.com/epc/Portals/0/epc/documents/datasheets/epc2066_datasheet.pdf

[5] Microchip. (2018-2020). [online]. Available: https://www.microchip.com/wwwproducts/en/dsPIC33CK32MP102