

Using GaN FETs to Burst Through 5 kW/in³ in a 48 V to 12 V LLC Converter

The latest generation of eGaN[®] FETs from EPC enable exceeding 5 kW/in³ power density in a LLC resonant converter capable of delivering 1 kW at 12 V from a 48 V bus.

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The rapid demand growth of digital services and internet traffic, the surge in artificial intelligence systems and the continuous increase in computational power are driving significant technological improvements in power management solutions for data centers and server racks. Energy distribution at 48 V reduces losses significantly but requires very efficient and high-power-dense converters to be located as close as possible to the loads.

LLC resonant converters have emerged as the preferred topology for an intermediate 48 V to 12 V conversion due to their high efficiency, high power density and good dynamic response. The outstanding performance resulting from the combination of this topology with GaN transistors has been demonstrated in the past [1-4]. This article presents how the newest generation of GaN devices, such as those from EPC, continues to push the envelope even further.

EPC has recently released the EPC9159KIT [5], a continuation of a previous 48 V to 12 V LLC converter module from [1], that has been updated to achieve more than 5 kW/in³ of power density when assembled into a module. Peak efficiency of more than 97.5% and full load efficiency over 95.5% when delivering 1 kW into a 12 V load are realized using a partial power technique [6, 7].

Converter Overview

The LLC resonant converter featured in EPC9159KIT is based on primary full bridge, with a 3:1 transformer and center tapped full-wave synchronous rectifier. Four EPC2619 [8] eGaN transistors are used in the primary and six EPC2067 [9] eGaN FET transistors are used in the secondary. The resonant tank is tuned to approximately

1.8 MHz using the transformer leakage inductance and two additional external inductors as shown in Figure 1.

In addition, the EPC9159KIT takes advantage of the inherent electrical isolation of the LLC topology to implement a partial power technique [6, 7] and enable higher efficiency and higher current capability. When configured in Partial Power Mode, the converter has an input-to-output voltage ratio of 4:1, and it can process up to 1 kW into a 12 V load from a 48 V supply. In this mode, the return of the primary full-bridge (OVHV) floats above the output voltage (VLV), and the transformer only processes 75% of the output power. The EPC9159KIT can also be configured in Through Power Mode, with a 3:1 input-to-output voltage ratio, and a max. power rating of 750 W into a 12 V load from a 36 V supply. In this mode the transformer processes 100% of the output power. The LLC converter in the EPC9159KIT is implemented using a modular approach comprising four components, as shown in Figure 2. A card labeled as EPC9556P containing the primary full bridge, the transformer module with the resonant tank and synchronous rectifier identified as EPC9551T, the EPC9528 controller card, and the EPC9536 motherboard. The motherboard serves as the platform to connect all the pieces together and contains auxiliary power supplies, measurement points, additional input/output bus capacitance and input/output terminals.

Power Transistors, Gate Drivers and Controller

The primary full bridge features four 100 V rated 3.3 mΩ EPC2619 [8] used in conjunction with two uP1966E [10], a half-bridge gate driver IC. For the secondary, a total of six 40 V rated 1.55 mΩ

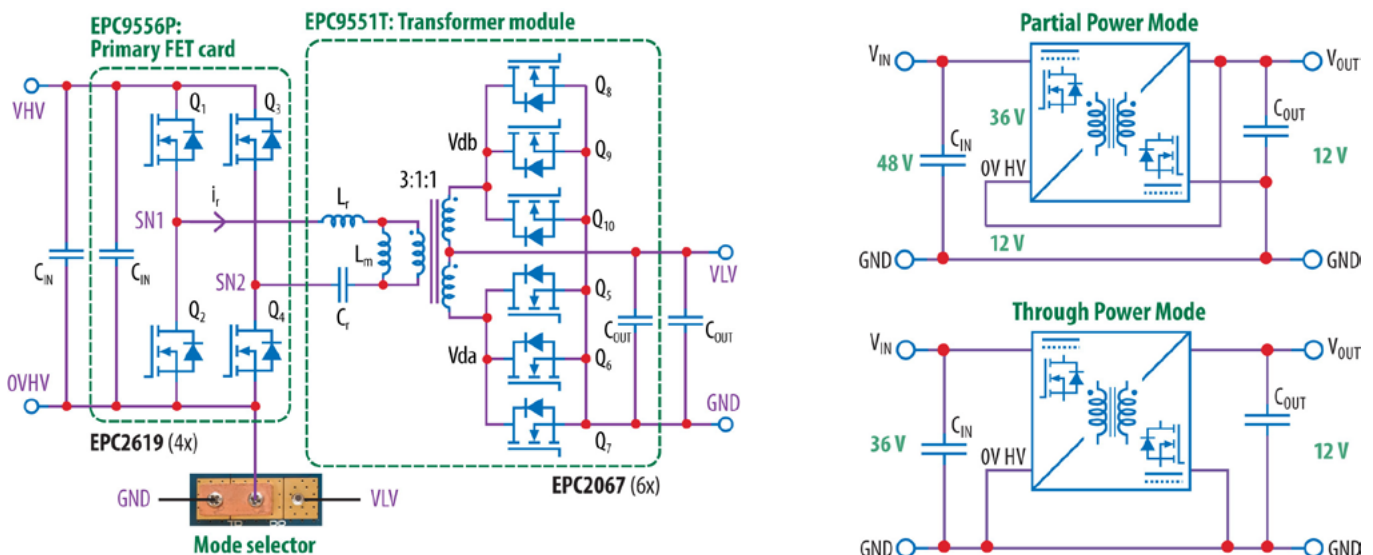


Figure 1: (left) Topology of the LLC converter, (right-top) connection diagram for partial power mode, (right-bottom) connection diagram for through power mode.

EPC2067 [9] are used as synchronous rectifiers. These six transistors are divided into two branches, with an LMG1020 [11] low side gate driver for each branch. All power transistors and gate drivers are in CSP (chip scale package) format for minimum size.

GaN transistors, and specifically the EPC2619, offer the lowest $R_{DS(on)} * C_{OSS}$ figure of merit available in the market for a > 80 V rated FET. Low $R_{DS(on)}$ is needed to minimize conduction losses, and a small C_{OSS} helps in reducing the transition times required to maintain ZVS in the primary while keeping the magnetizing current as low as possible. A die size of only 2.5 x 1.5 mm² is also a key feature to realize the desired power density.

A total of 6 independent PWM signals are generated using a Microchip dsPIC33CK256MP503 controller to compensate propagation delay mismatches in gate drivers and achieve near-perfect synchronization between the primary transistors and the synchronous rectifiers. This is done with a time resolution of 250 ps in a very compact size with a 5x5 mm QFN package. A 4-channel digital isolator is also included to level-shift the four PWM signals for the primary when operating in Partial Power mode.

found to have a significant impact on efficiency in previous work [4]. The center post goes through both PCBs with two plates at the ends that provide a magnetic path for the flux to return through four small satellite posts. The geometry of the end plates was optimized for uniform and adequate flux density while freeing enough board space for the resonant capacitors and secondary synchronous rectifier FETs. The transformer core is split into two identical halves, top and bottom, and manufactured using ML915 material from Proterial [12]. Two layers of 3.5 mil polyimide tape separate each half to set the magnetizing inductance to approximately 1.8 µH. This, combined with the Coss of EPC2619 results in a transition time of ~23 ns when the voltage across the primary is 36 V.

The resonant tank is also integrated into the transformer module, and it is tuned at approximately 1.8 MHz. The resonant capacitance consists of fourteen 22 nF ceramic capacitors in parallel. These capacitors were carefully selected to use U2J dielectric for minimum ESR, high stability over temperature and voltage, and high capacitance compared to C0G [13]. The resonant inductance of ~26 nH is comprised of the transformer leakage inductance of ~1.6 nH, and two external inductors of ~12.2 nH each. These inductors are built

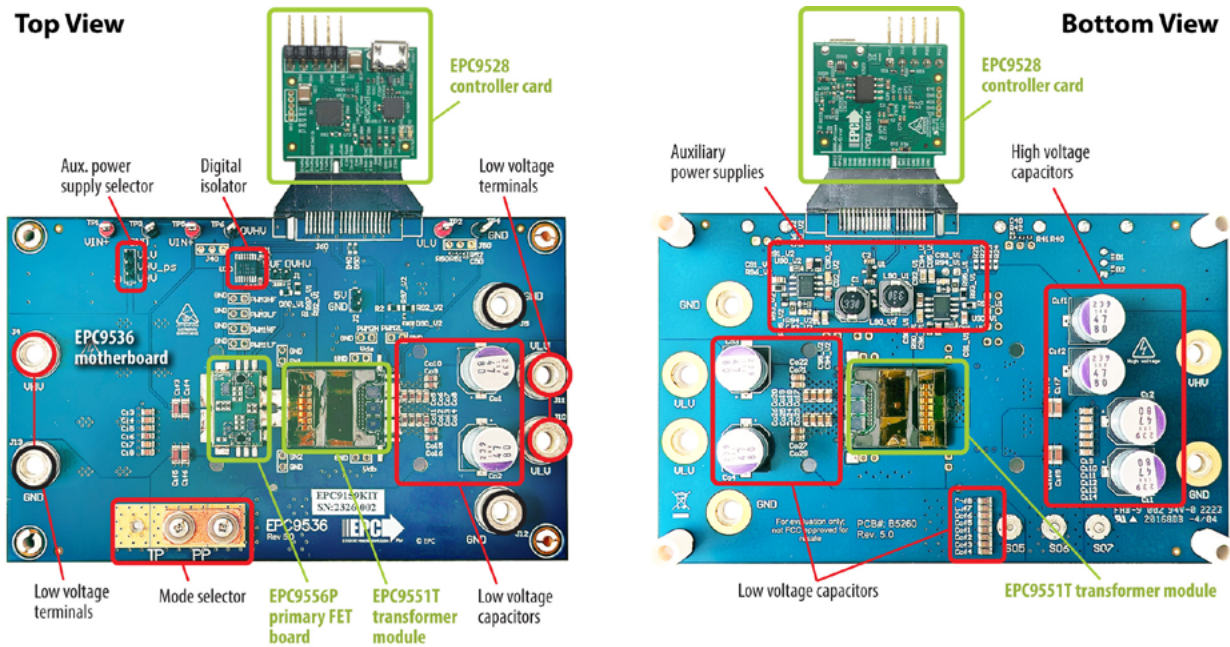


Figure 2: Top and bottom views of the EPC9159KIT with the main components highlighted.

Transformer Module: Transformer Core, Resonant Tank, and PCB

The core of the EPC9159KIT is the EPC9551T transformer module shown in detail in Figure 3. In it, the transformer windings and resonant tank are built into two 12-layer PCBs with a 17.5 mm x 23 mm footprint. This provides a total of 20 layers in 2 oz. of Cu thickness for the transformer windings, with the remaining four layers dedicated to routing and connections to components. Both primary and secondary windings form concentric turns around the transformer core's center post. Examples of both are also provided in Figure 3. The layers used for the three primary turns and the single secondary turn of the transformer are interleaved to minimize proximity losses by alternating the magnetomotive force. And the rectifier FETs are integrated into the transformer windings to minimize leakage inductance, which was

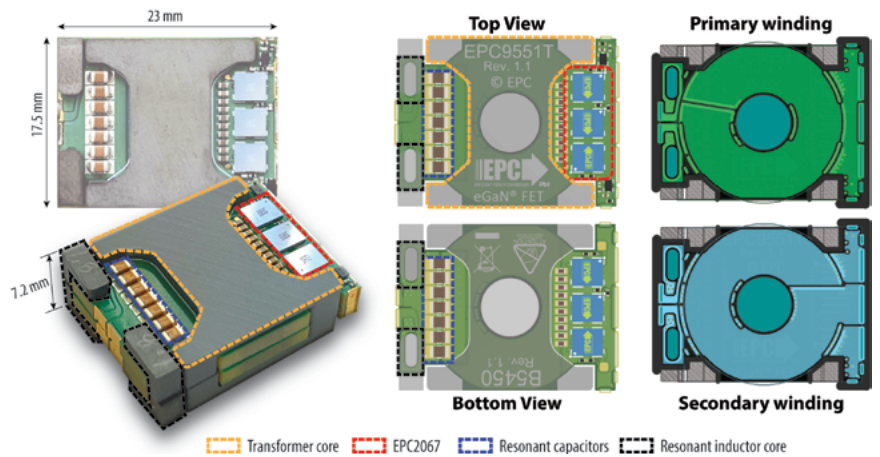


Figure 3: (left) Photo of the EPC9551T transformer module, (center) top and bottom views of the module, (right) example layers for one of the primary turns of the transformer and example layer for one of the secondary turns.

into the PCB using a total of 22 layers and a custom magnetic core in ML95S material from Proterial [14].

Testing Results

Figure 4 shows waveforms of the converter operating in Partial Power Mode and Through Power Mode at various currents. The switching frequency is set to slightly above 1.6 MHz for operation at resonance, considering the transition times of ~23 ns and resonant frequency of ~1.8 MHz. At no load, the resonant current is just the magnetizing current, and it has a triangular shape. As the load increases, the resonant current becomes closer to a sinusoid.

It is important to note that the value of the resonant current at the beginning and end of the transition times is the same regardless of the load current, this indicates operation at resonance. In addition, the shape of the resonant current and the secondary drain voltages are independent of the operating mode. It is not the case for the primary switch nodes (SN1 and SN2), where in Partial Power Mode with a 48 V supply, they have a trapezoidal shape between 48 V and 12 V (VOUT), and in Through Power Mode a trapezoidal shape between 36 V and 0 V. The waveforms in Figure 4 are labeled according to the node designators shown in Figure 1.

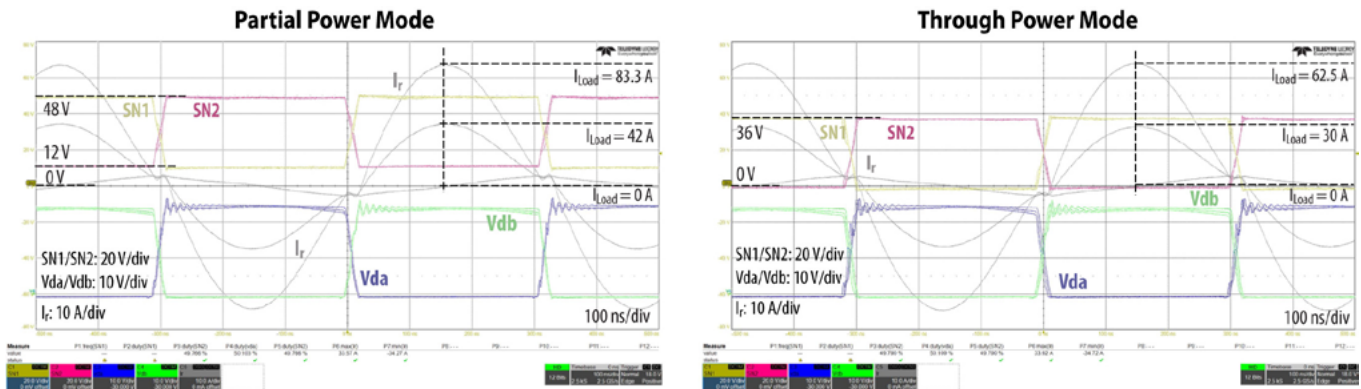


Figure 4: (left) Measured waveforms in Partial Power Mode, (right) measured waveforms in Through Power Mode.

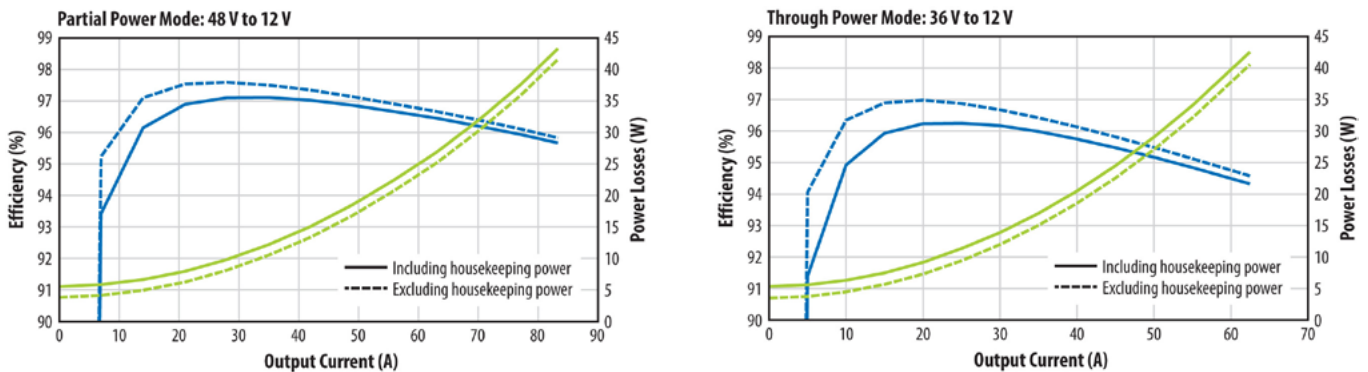


Figure 5: (left) Measured efficiency and power loss in Partial Power Mode, (right) measured efficiency and power loss in Through Power Mode.



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Moreover, figure 5 provides efficiency and power loss curves for the EPC9159KIT operating in both modes up to the maximum load. In Partial Power Mode, excluding housekeeping power supplies, peak efficiency surpasses 97.5% at 25 A load and is 95.8% at full load (1 kW). Similarly, in Through Power Mode, peak efficiency reaches 97% at 20 A and is 94.5% at a full load (750 W). As mentioned previously, the power processed by the converter is the same in both modes relative to their full load. Consequently, the power losses relative to the full load are also the same, which can be observed in Figure 5.

To reach full load continuously the kit must be operated with a thermal kit and forced air of 400 LFM. Details of the thermal kit, including the TIMs and heatsinks are provided in [5]. Without the heatsink kit and high air flow, the converter can reach full load for a duration of up to 3 seconds. Under these conditions a peak temperature of approximately 90 °C is reached in the vicinity of the secondary rectifiers. Alternatively, the converter without a heatsink kit, can be operated continuously with 400 LFM of airflow up to 64% of the full load.

Conclusions

The work presented in this article demonstrates how to achieve 48 V to 12 V power conversion with a power density beyond 5 kW/in³ using GaN transistors. The latest technology of eGaN FETs from EPC offers the lowest relevant figure of merit for LLC converters, enabling outstanding performance. EPC2619, a 100V-rated eGaN FET in a CSP package of 2.5 mm x 1.5 mm in size, offers more than 4 times lower $R_{DS(on)}$ per unit area than an equivalent 100V-rated Si MOSFET. Similarly, EPC2067, a 40V-rated eGaN FET in a CSP package of 2.85 mm x 3.25 mm in size, offers similar $R_{DS(on)}$ per unit area of an equivalent 40V-rated Si MOSFET with less than half the gate charge.

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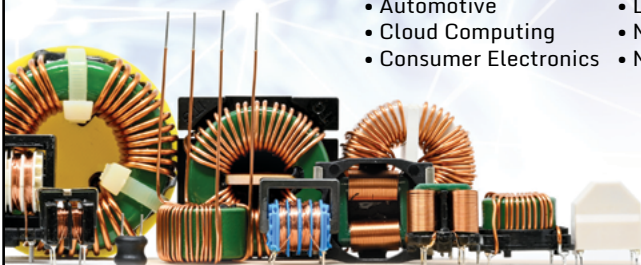
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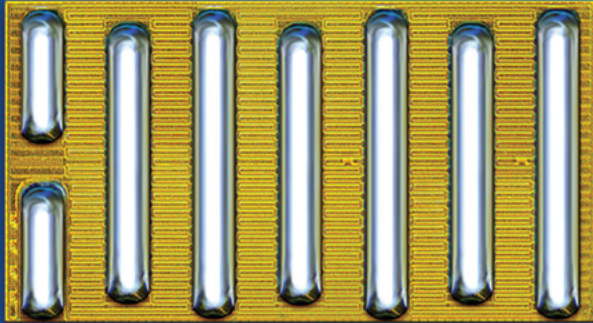


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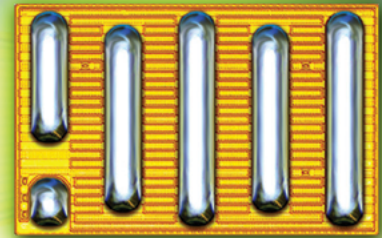
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