How to Design a 1.5 kW 48 V/12 V Bi-Directional Power Module with AEC Qualified eGaN® FETs

Introduction

By 2025, one in every 10 vehicles sold worldwide, is projected to be a 48 V mild hybrid. 48 V systems boost fuel efficiency, deliver four times the power without increasing engine size, and reduce carbon-dioxide emissions without increasing system costs. These systems will require a 48V – 12V bidirectional converter, with power ranging from 1.5 kW to 6 kW. The design priorities for these systems are size, cost, and high reliability.

This application note discusses the design of a 1.5 kW, two-phase 48 V/12 V bi-directional converter using automotive qualified GaN FETs that operates with 95% efficiency. The heatsinking capability can be considered infinite since this will ultimately function inside a vehicle with the unit mounted to the chassis. The design of this converter is scalable to 3 kW by paralleling two converters.

Design of the Bi-directional DC-DC converter

A simplified schematic of the bi-directional DC-DC converter is shown in Figure. 1. Since the synchronous buck/boost converter is the simplest bi-directional converter, it is selected as the base topology. Other supporting circuitry includes current sensors, temperature sensor, digital controller and housekeeping power supply.

GaN FETs used in 48 V applications usually have a 4 times better figure of merit (die area ·R_{ON}) compared to similar MOSFETs [1]. For the same gate voltage of 5 V, GaN FETs have at least 5 times lower gate charge than MOSFETs. Other important advantages of GaN FETs include lower C_{oss}, faster voltage transition, zero reverse recovery and are physically smaller.

The AEC-Q101 qualified eGaN FET EPC2206 [2] is used in this design. With 2.2 mΩ R_{ON}, the rated peak DC current is 90 A. Therefore, the two-phase approach is selected so that the FET current requirement is reduced, i.e., at 12 V 1.5 kW output, the DC current in each phase is 62.5 A. This also reduces the current rating requirement for the inductors.

Vishay IHTH-1125KZ-5A series inductors [3] offer high current ratings for the inductance of 1 µH and 2.2 µH. In this design, the inductor values and switching frequency are determined using an analytical loss model so that the efficiency at 50% to full power is optimized. The 2.2 µH inductor and 250 kHz switching frequency is selected, resulting in 70 A peak inductor current.

To ensure accurate phase current balancing, current sensing using precision shunt resistor is preferred over inductor DCR current sensing. However, shunt resistors that are rated for above 70 A usually have large footprint, and therefore high parasitic inductance. This inductance can result in high noise that saturates the current sense amplifier and voids the measurement. A simple solution is to add an RC filter network with a matched time constant. MCP6C02 current sense amplifier is used in this design, with a maximum bandwidth of 500 kHz and 50 V/V gain. This results in 10 mV/A total current sensing gain for 0.2 mΩ shunt.

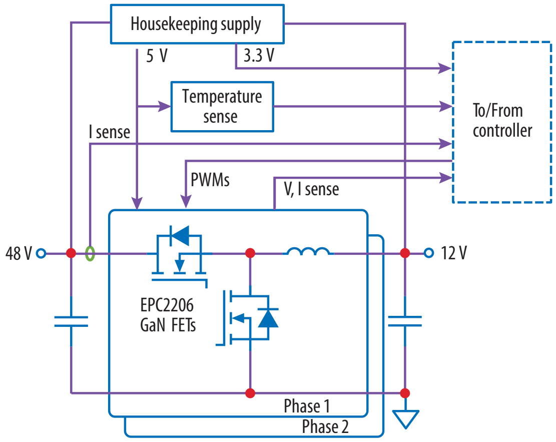


Figure 1. Simplified schematic diagram of the bi-directional converter.

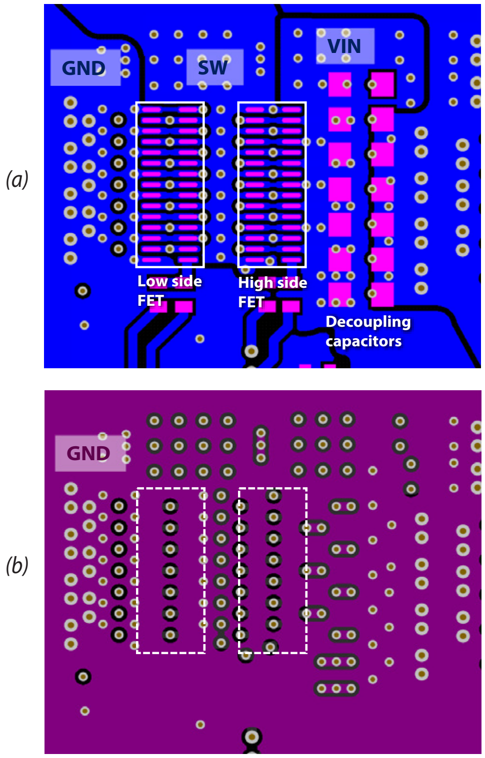


Figure 2. Example layout of the top two layers of the printed circuit board around GaN FETs: (a) top layer consisting of ground (GND), switching node (SW) and input (V_{IN}) nets, and (b) middle layer 1 of solid ground plane.

Symmetrical layout between the two phase is also critical in phase current balancing and minimizing other effects from mismatch, such as gate drive delay, switching transition speed, overshoot, etc. Figure 2 shows the layout example around the GaN FETs in this design, which utilizes the optimum layout technique [1] by placing the decoupling capacitors close the FETs with a solid ground plane underneath.

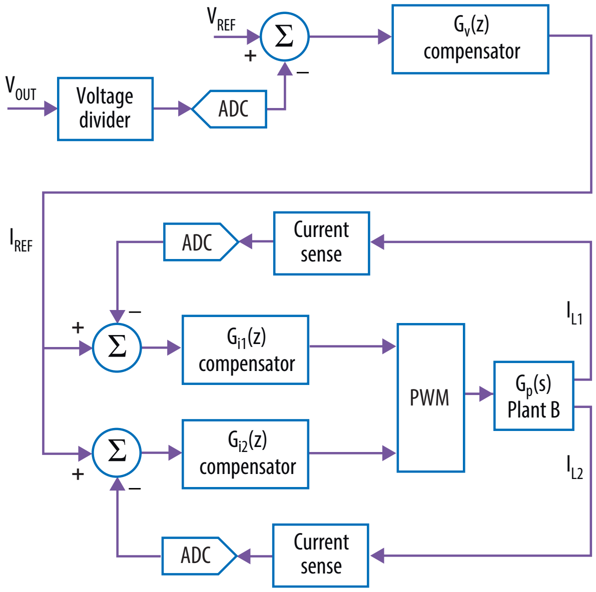


Figure 3. Digital average current mode control diagram.

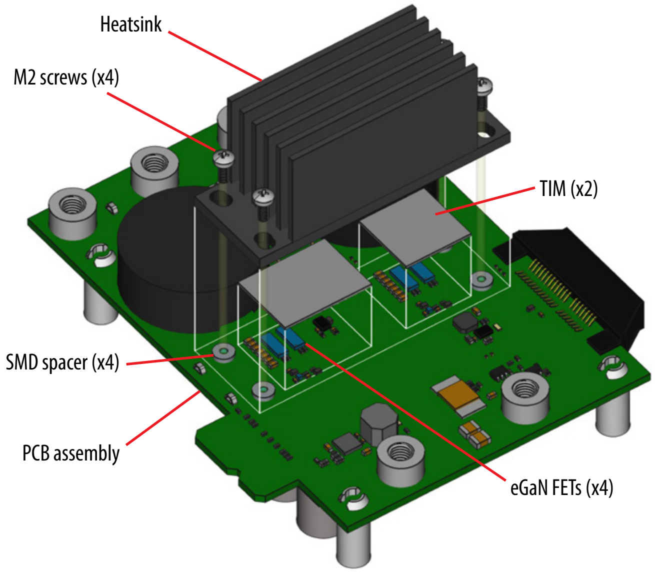


Figure 4. Heatsink installation view, showing the metal spacer, thermal interface material.

Digital control

A dsPIC33CK256MP503 [4] digital controller from Microchip is used. It is a 16-bit processor with a maximum CPU speed of 100 MIPS. The pulse- width modulation (PWM) module can be configured in high-resolution mode, resulting in 250 ps resolution in duty cycle and dead times, allowing accurate adjustment of dead times to fully exploit the high performance of GaN FETs.

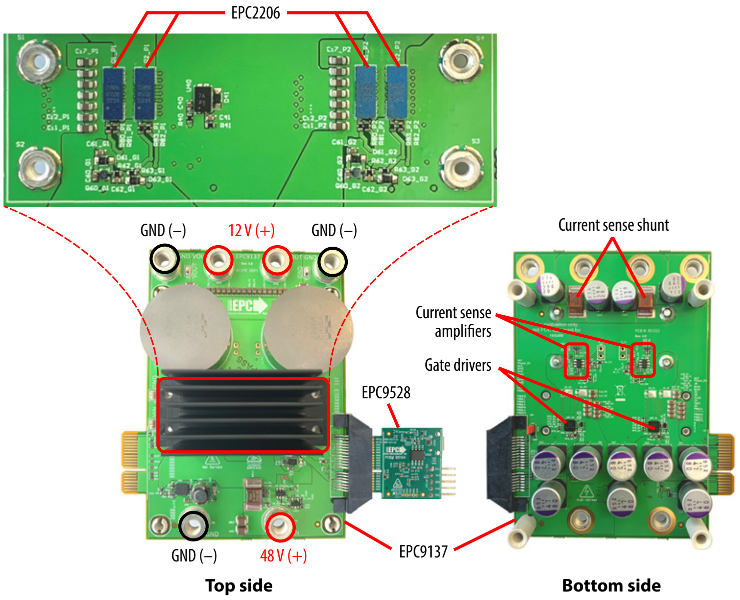
Digital average current mode control is implemented for both buck and boost modes. The current sensing circuitry consists of sense resistors and differential amplifiers. In this design, low loss 0.2 mΩ sense resistors and low-noise amplifiers MCP6C02 are used. The control block diagram is shown in Figure. 3. The same current reference I_{REF} is used for the two independent current loops. As a result, the current in both inductors will be regulated to the same value. The bandwidth of the two inner current loops are set to 6 kHz, and the outer voltage loop bandwidth is set to 800 Hz.

Thermal management

At full output power of 1.5 kW, a heatsink is required for the GaN FETs. A standard commercially available $^{1}/_{8}{}^{th}$ brick heatsink is used. Four metal spacers are installed on the PCB to provide the appropriate clearance for the heatsink mounting. A thermal interface material (TIM) is required between the FETs and heatsink. Usually, the material needs to have a) mechanical compliance due to compression, b) electrical insulation and c) good thermal conductivity. In this design, a TIM with 17.8 W/mK is used. Figure 4 shows the 3D heatsink installation view.

Experimental results

Figure 5 shows a photo of the EPC9137 [5] converter with and without the heatsink mounted. The dimensions are 4x2.8x1.6 inches (102x70x40 mm) excluding the edge connectors.



Top side **Bottom side**

Figure 5. Photo of the EPC9137 converter with the EPC9528 dsPIC33CK controller module attached.

With the heatsink installed and 1700 LFM airflow, the converter was operated at 48 V input, 13.8 V output and tested at both 250 kHz and 500 kHz, and the efficiency results are shown in Figure. 6. At 250 kHz, using a 2.2 µH inductor, the converter achieved a peak efficiency of 97%. When operated at 500 kHz, using a 1.0 µH inductor, the converter achieved a peak efficiency of 95.8%. The converter was also tested at 13.8 V input and 48 V output for boost mode operation, as shown in Figure. 7.

At full load, EPC eGaN FETs can operate with 96% efficiency at 250 kHz switching frequency, enabling 750 W/phase compared to silicon-based solutions, which are limited to 600 W/phase due to the limitation on the inductor current at 100 kHz maximum switching frequency.

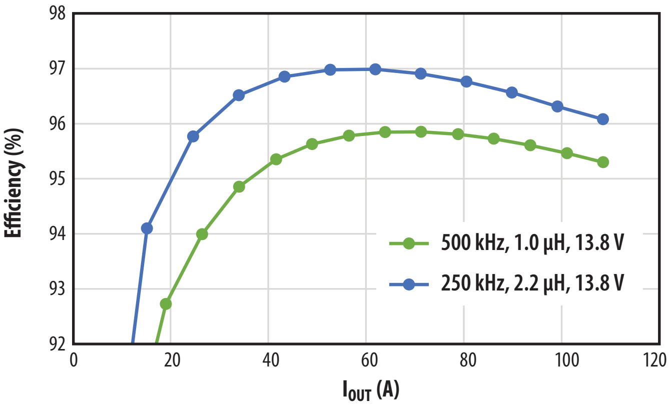


Figure 6. Measured converter efficiency at 250 kHz and 500 kHz, 48 V input and 13.8 V output.

Conclusion

This application note introduces a bi-directional high power EPC9137 converter for mild-hybrid cars and battery power backup units using four EPC2206 AEC-Q101 qualified eGaN FETs. When converting between 48 V and 13. 8 V, the efficiency is above 96% with 250 kHz switching frequency, and above 95% at 500 kHz.

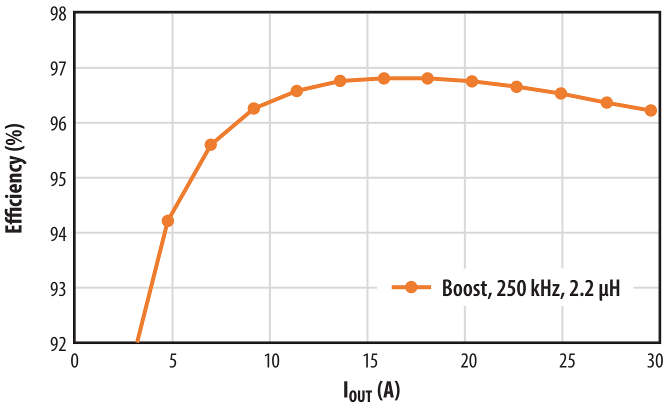


Figure 7. Measured converter efficiency at 250 kHz, 13.8 V input and 48 V output.

References

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