Enhancement Mode GaN Making Wireless Power Transmission More Efficient

In this article we show that enhancement mode GaN transistors enable significant efficiency improvements in resonant topologies and demonstrate a practical example of a wireless power transmission system operating in the 6.78 MHz range.

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Resonant Converters

To achieve improved efficiency at higher switching frequencies, resonant topologies may be considered. Resonant topologies are particularly beneficial in DC/DC transformer applications due to the removal of the regulation requirements, allowing the converter to always operate at the resonant frequency. To demonstrate the opportunities enabled by converting from silicon-based power MOSFETs to enhancement mode GaN transistors, we chose the topology as shown in Figure 1 that employed a resonant technique utilizing the transformer's magnetizing inductance (L_M) and resonance of the leakage inductance (L_K), together with a small output capacitance (C_O), to achieve zero voltage switching (ZVS), limit turn-off current, and eliminate body diode conduction [1].

To obtain a direct comparison in performance between GaN transistors and Si MOSFETs in a high-frequency resonant bus converter application, devices with similar on-resistance were selected, the same circuit topology was used, and a similar layout was maintained for both designs. The Figures of Merit (FOMs) of importance in this work are Q_G x $R_{DS(ON)}$ and Q_{OSS} x $R_{DS(ON)}$ due to the soft switching topology that reduces the switching related losses, thereby rendering the FET gate drive and conduction being the major loss contributors. The device output charge has a direct impact on the energy required to achieve ZVS. A reduction in energy required to achieve ZVS can result in reduced dead time, providing a larger power delivery period and lower RMS currents in a high-frequency resonant converter. eGaN® FETs [2] show significant improvements when compared to Si MOSFETs, with the gate drive FOM (Q_G x $R_{DS(ON)}$) having been improved by a factor of approximately 4 and 3 for the 100 V [3] and 40 V [4] devices respectively, while the output charge FOM (Q_{OSS} x $R_{DS(ON)}$) is improved around a factor of 1.6 and 2 for the primary and secondary devices respectively. The eGaN FETs also provide performance improvements in the form of reduced Miller charge that reduces the turn-off switching losses in the primary devices. As a further advantage, the LGA packaging of the eGaN FET has low parasitic package inductance as compared to the traditional Si MOSFET package (SuperSO8). When putting all these benefits together, multi-MHz switching frequencies can be obtained through the use of advanced topologies combined with low-loss eGaN FETs [5].

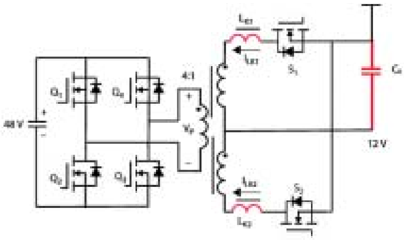

Figure 1: High frequency bus converter schematic.

The experimental switching waveforms for the designs at 1.2 MHz are shown in Figure 2. Both designs have the same magnetizing inductance, built into the transformer via an air gap, to achieve zero-voltage switching during the device off state. Due to almost a factor of 2 decrease in output charge (Q_{OSS}) provided by the primary and secondary eGaN FETs, the ZVS transition is achieved in a proportionally shorter period, increasing the effective duty cycle and improving the overall converter performance. For the Si MOSFET design, the dead time required for ZVS was measured to be 87 ns and the effective duty cycle for each device was limited to 34%. With the faster switching eGaN FETs, the dead time was reduced to 42 ns resulting in a 42% duty cycle for each device while allowing for an extended power delivery period. From the switching waveforms, it can also be seen that the gate drive speed for the eGaN FET is significantly faster than the Si MOSFET counterpart even when driven with a lower gate drive voltage, providing both faster switching speed and reduced gate losses.

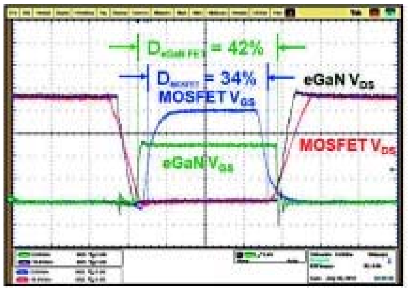

Figure 2: Switching waveforms showing effective duty cycle for primary side eGaN FET and Si MOSFET designs at F_S = 1.2MHz, V_{IN} = 48 V, and I_{OUT} = 26 A.

The comparison in efficiency and power loss between the two designs operating at 1.2MHz is shown in Figure 3. The eGaN FET-based converter offers a one-percentage point improvement in peak efficiency over its Si MOSFET counterpart, resulting in about 25% less power loss. Since products based on this type of design are thermally limited, the reduction in power loss translates directly into higher output power handling capability. In this case, the eGaN FET converter can increase the output power capability by up to 65 W (14W maximum power loss) while maintaining the same total converter loss when compared to the benchmark SiMOSFET design. Assuming an approximate 12 W maximum power loss for both designs, the output power of the eGaN FET-based converter can be increased from 270W to 325W.

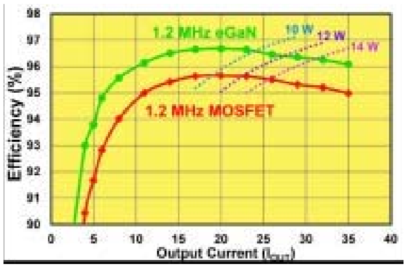

Figure 3: Experimental comparison between eGaN FET and Si MOSFET based V_{IN} = 48 V, V_{OUT} = 12 V, F_S = 1.2 MHz resonant bus converters.

Wireless Power

Wireless power applications are gaining popularity in many commodity products such as mobile phones chargers. Most of the wireless power solutions have focused on tight coupling with induction coil solutions at operating frequencies around 200 kHz, and Class E [6], F and S amplifier converter topologies. Recently, however, there has been a push for operation in the restricted and unlicensed lower ISM band at 6.78 MHz where traditional MOSFET technology is approaching its capability limit. Enhancement mode gallium nitride transistors offer an alternative to MOSFETs as they can switch fast enough to be ideal for wireless power applications. To illustrate the opportunity to improve efficiency, an experimental evaluation was performed for an induction coil wireless energy system using eGaN FETs in a half-bridge topology operating at 6.78 MHz designed to be suitable for multiple 5 W USB-based charging loads. The experimental system was compared to a similar unit based on equivalent MOSFETs in the power converter stage.

The amplifier selected was a Class D converter operating at a fixed frequency. The converter is operated above resonance to take advantage of zero voltage switching (ZVS) and therefore obtain maximum power amplifier efficiency. The smallest 40 V eGaN FET, EPC2014 [7], was chosen because it has a low on-state resistance and low C_{OSS} which are factors that will ensure minimum losses. Figure 4 shows a block diagram of the wireless system.

To show what benefits eGaN FETs can bring to wireless energy, it is necessary to compare the performance of the circuit when fitted with an equivalent MOSFET. The MOSFET selected is a BSZ130N03LS_G [8] and is available in a PG-TSDSON-8 (3 mm x 3 mm) package. It has a very similar RDS(ON) compared to EPC2014 but is only rated to 30 V where the eGaN FET is rated to 40 V.

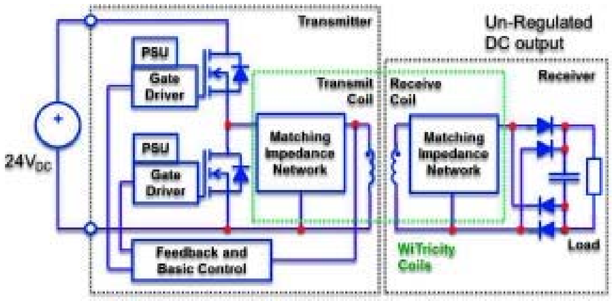

Figure 4: Schematic block diagram of the proposed wireless energy system.

A demonstration unit was designed and built to evaluate the performance of both the eGaN FET and the MOSFET [10]. The efficiency as a function of output power for both the eGaN FET solution and the MOSFET solution are shown in Figure 5. This graph shows that using eGaN FETs in the power amplifier yields a 4% amplifier efficiency improvement over the MOSFET version (a 24% reduction of power losses) [10].

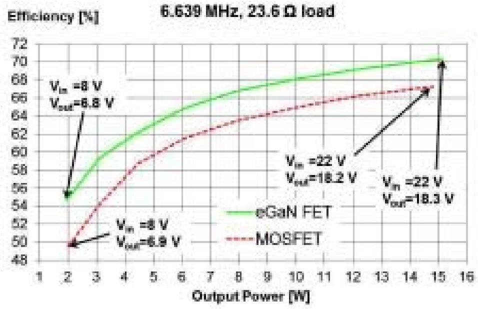

Figure 5: DC in to DC out efficiency (including gate driver power consumption) comparison between eGaN FET and MOSFET wireless boards as a function of output power for a fixed load resistance.

Summary

It has been previously shown that gallium nitride transistors have a distinct advantage over silicon MOSFETS in hard-switched applications [11], but little has been demonstrated about the impact in soft switching converters. In this article, it is shown that eGaN FETs can also provide significant efficiency improvements over power MOSFETs in soft switching resonant converters such as being used in intermediate bus DC-DC converters and wireless power transmission.

References:

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