Power GaN Opens New Applications

Efficient Power Conversion Corporation (EPC) has been in production with enhancement mode GaN-on-Silicon power transistors (eGaN® FETs) for over three years. Much progress has been made improving device performance and reliability. There have also been several new power management applications that have emerged. Two of these applications, RF Envelope Tracking and high frequency Wireless Power Transmission are beyond the fundamental capability for the aging power MOSFET due to the requirements of high voltage, high power, and high frequency. As a result, these are early growth markets for GaN on Silicon devices. eGaN FETs have also made inroads in several other applications that we will discuss along with the latest in device technology and future direction for both discrete and GaN ICs. **Alex Lidow, Johan Strydom, David Reusch, Michael de Rooij, Efficient Power Conversion Corp., El Segundo, USA**

For Silicon power devices, the gains in performance have slowed as the technology has matured and approached its theoretical limits. Gallium nitride (GaN) devices have emerged as a possible replacement for Silicon devices in various power conversion applications and as an enabler of new applications not previously possible. GaN devices are a high electron mobility transistor (HEMT) with a higher band gap, electron mobility, and electron velocity than Silicon and Silicon Carbide devices [1]. These material characteristics make the GaN device more suitable for higher frequencies and higher voltage operation.

The first commercially available enhancement mode Gallium Nitride on Silicon transistors (eGaN FETs) have a lateral structure with voltages ranging from 40-200 V. These devices operate similarly to the traditional Si MOSFETs and offer superior power conversion performance. As GaN technology matures, significant performance gains and higher blocking voltages are projected.

Wireless power application

Wireless power applications are gaining popularity in many applications such as mobile phone chargers, medical equipment, and defense electronics. Most of the wireless power solutions have focused on tight coupling with induction coil solutions at operating frequencies around 200 kHz, and Class E, F and S 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 GaN devices offer an alternative to MOSFETs as they can switch fast enough to be suited for such 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 (Figure 1). The experimental system was compared to a similar unit based on equivalent MOSFETs in the power converter stage.

Switching-based converters are required for wireless power applications because classic amplifiers do not have sufficient conversion efficiency to make them practical choices. This reduces the number of suitable converter choices for high efficiency wireless energy applications to Class D, Class E & F and Class S configurations. The amplifier selected was a Class D converter operating at a fixed frequency. The converter is operated above the resonant frequency to take advantage of zero-voltage switching (ZVS) and therefore obtain maximum power amplifier efficiency. The smallest 40 V eGaN FET, EPC2014, was chosen because it has a low on-state resistance and low C) which are factors that will ensure minimum losses.

A demonstration unit was designed and built to evaluate the performance of both the eGaN FET and the MOSFET. Using eGaN FETs in the power amplifier yields a 4 % amplifier efficiency improvement over the MOSFET version (a 24% reduction of power losses).

Envelope tracking application

The concept of envelope tracking (ET) for radio frequency (RF) amplifiers is not new. But with the ever increasing need for improved cell phone battery life, better base station energy efficiency, and more output power from very costly RF transmitters, the need for improving the RF Power Amplifier (PA) system efficiency through ET has become an intense topic of research and development.

The key to improve efficiency lies in the

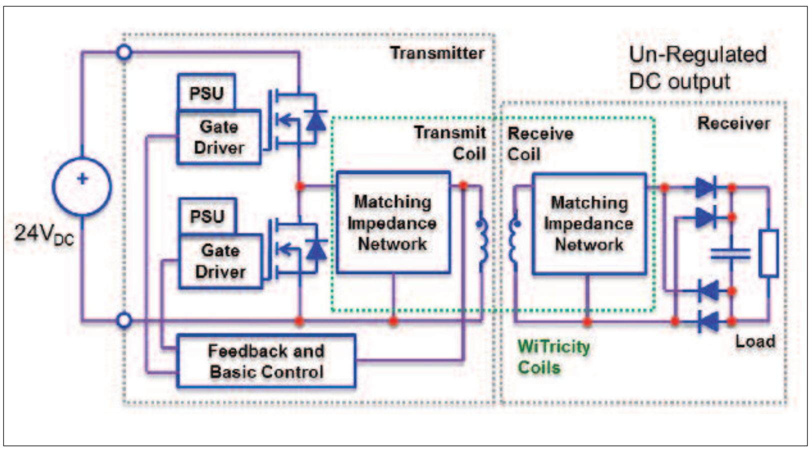

Figure 1: Schematic block diagram of the evaluated wireless energy system

PA's peak to average power (PAPR) requirements. As shown in Figure 2 it is possible to achieve peak PA efficiencies as high as 65 % with a fixed supply, but given PAPRs as high as 10 dB, the average efficiency is likely to be lower than 25 %. Through modulation of the PA supply voltage, this can be improved to over 50 % - essentially doubling the efficiency and reducing PA losses by two thirds. This not only reduces power consumption, but also lowers the cost of operation, cooling requirements, and size.

The high PAPR requirements that make ET possible also mean that average output voltage is typically between 30 – 50 % of the buck converter supply voltage, with short duration excursions below and above this average. Thus, for demonstration purposes a steady state buck converter running at a similar duty cycle can be used to demonstrate the efficiency and thermal requirements of a multi-phase ET buck converter. This can be further simplified by evaluating a single phase of a multi-phase system, as all phases are identical. Standard EPC9002 or EPC9006 development boards were used to generate all the results in this work.

Efficiency results for both converters are shown in Figure 3 and show that building a buck converter for high power envelope tracking applications is viable using eGaN FETs. The actual power level and number of phases required will depend on the power level and bandwidth requirements of the specific application. Over 97 % efficiency was achieved at 1 MHz and over 94 % efficiency was achieved at 4 MHz.

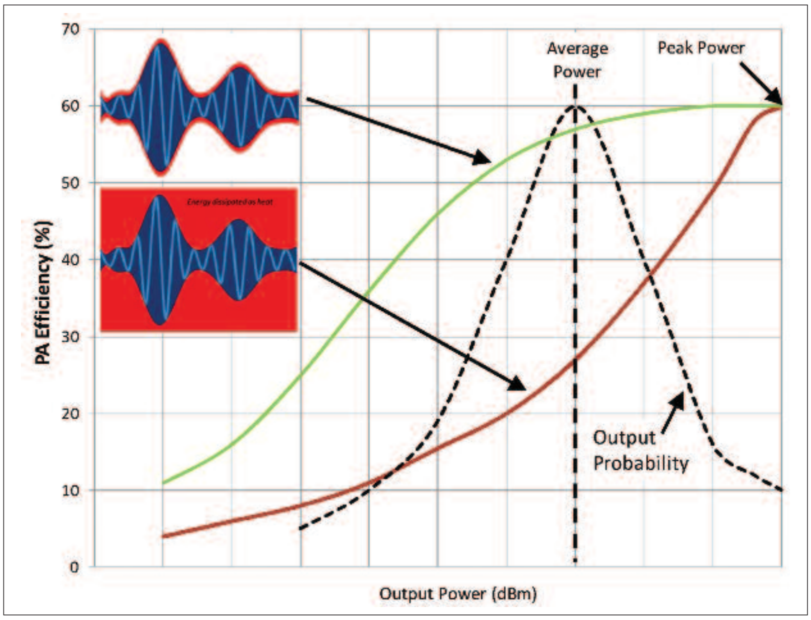

Figure 2: Conceptual PA efficiency vs. output power for fixed supply and ET operation

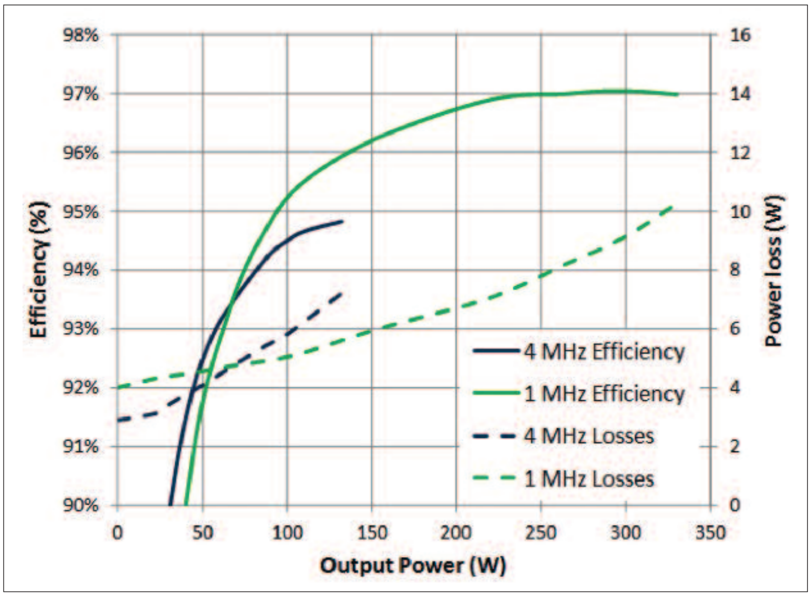

Figure 3: Efficiency results for EPC9006 and EPC9002 demonstration boards in ET application operating at 45 V input and 22 V output voltage

Resonant converter application

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 devices, we chose the topology as shown in Figure 4 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.

To obtain a direct comparison in performance between GaN devices 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 (FOM) 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's 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.

These FETs show significant improvements when compared to Si MOSFETs, with the gate drive FOM (QG x RDS(ON)) improved by a factor of approximately 4 and 3 for the 100 V and 40 V 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. They 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 land grid array (LGA) packaging has low parasitic package inductance as compared to the traditional Si MOSFET package (TSDSON-8, 5x6 mm). 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.

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. 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.

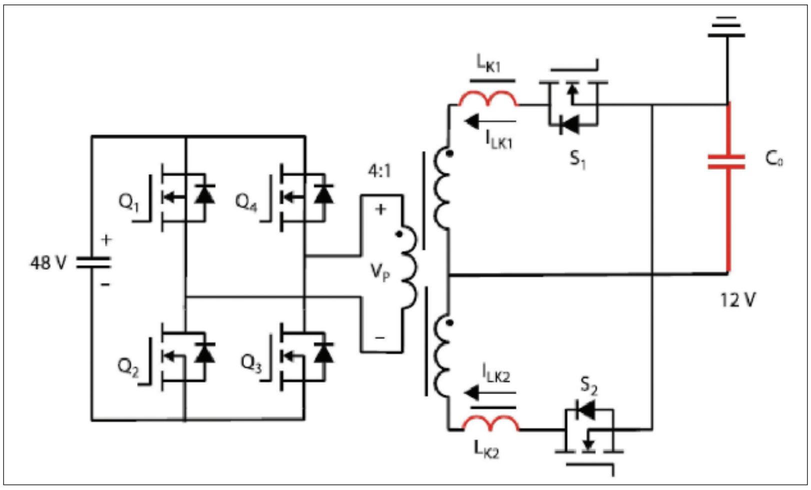

Figure 4: High frequency bus converter schematic

Radiation tolerance

Enhancement-mode FETs have also demonstrated their ability to operate reliably under harsh environmental conditions and high radiation conditions. Normal operation can be maintained after more than 1 MRad(Si) gamma radiation exposure and have also shown the ability to perform to data sheet specifications after substantial single event effects (SEE). As a result, both hard-switched and resonant topologies with very high efficiency, such as those discussed herein, can be used in satellites as well as other applications requiring these extreme conditions.

Conclusion

It has been previously shown that Gallium Nitride devices have a distinct advantage over Silicon MOSFETS in conventional applications, but little has been demonstrated about the impact of GaN devices in emerging applications such as envelope tracking and soft switching converters which are commonly used in wireless power and high frequency intermediate DC/DC bus converters. In this work, it is shown that eGaN FETs can also provide significant efficiency improvements over power MOSFETs in these emerging applications. Putting eGaN FETs to work in high frequency applications can help push the frequency without sacrificing converter performance, even in very demanding environments [2].

Literature

[1] "GaN Transistors for Efficient Power Conversion", Power Electronics April/May 2013, pages 38-40

[2] "GaN on Silicon Technology, Devices and Applications", PEE Special Session Power GaN for Highly Efficient Converters, PCIM Europe 2013, Nuremberg