GaN FETs Enable Large Area Wireless Power Transfer

To ensure widespread adoption, wireless power systems need to move beyond small charging pads and become active power sources over large surface areas. For magnetic resonant systems, this demands fundamental changes in coil technology, system architecture, and power amplifiers. Gallium nitride based amplifiers have proven capable of delivering 60 W with greater than 90 percent efficiency into the transmit coil over a wide load range [1]. **Yuanzhe Zhang, Applications Engineer and Michael A. de Rooij, V.P. Applications Engineering, Efficient Power Conversion Corporation, USA**

Today's 6.78 MHz highly resonant wireless power solutions are dominated by mobile device charging based on the AirFuel™ standard [2], which offers numerous discrete transmit power levels; for example 16 W [3] and 33 W [4]. These discrete power levels limit users to relatively small charging pads with areas less than 650 cm^2 (100 in^2). Large area wireless power systems have already demonstrated to be feasible with a small office desk by developed by Efficient Power Conversion Corporation, shown in Figure 1.

Large area wireless power system architecture

There are many architectures and configurations that can be employed to create a large area wireless power system – concepts from using a primary amplifier with repeaters, a smaller induction coil to a large resonant coil powered by a single high power amplifier, to using multiple coils each with its own amplifier which is the approach used in this article and shown in Figure 2.

Multiple coil systems scale in discrete steps but require precise synchronization among the amplifiers. This is needed to ensure that any device (load) large enough to couple to two or more coils receives power, in-phase, from each of the sources. The physical distance between the amplifiers however, makes it challenging to distribute the 6.78 MHz clock with low jitter and minimal timing distortion.

A negative aspect of the multiple coil architecture is that the coils cannot be located too close to each other as they will couple and energy from one amplifier can flow back into another. This problem can be reduced by using high output impedance amplifiers, such as the Class E. Coil separation with coupling lower than -17 dB yields the best performance but will have a power gap between the coils that may be deemed unacceptable.

Amplifiers for high power wireless power transfer

Large area wireless power coils are expected to power many devices simultaneously and therefore require higher power amplifiers with power ratings that increase proportionally to the surface area to be powered. The choice of wireless power architecture also affects the amplifier topology and configuration

Figure 1: Highly resonant wireless powered table with various devices

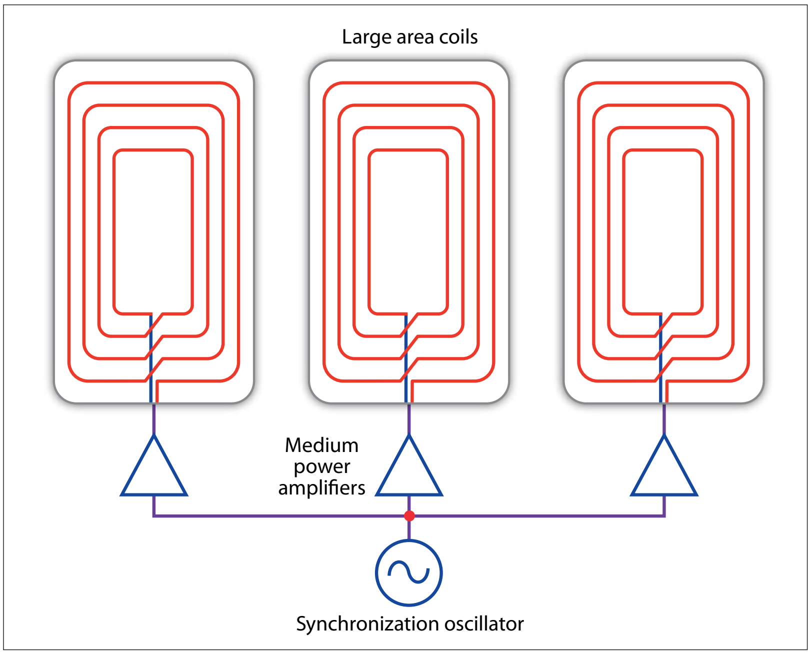


Figure 2: **Multiple coil and amplifier architecture for a large area wireless power system**

Device description	*Power*	*Function*
Laptop	25 W - 45 W	Power and charging
Monitor (< 27")	20 W - 40 W	Power
Tablets	13 W	Charging
Smartphone	5 W - 13 W	Charging
Lighting	5 W - 10 W	Power
Miscellaneous	5 W - 10 W	Power
Total Power Requirement	**73 - 131 W**	

Table 1: **List of devices with power requirements and function for a small office desk**

choices based on higher voltage or current drive requirements.

Power requirement is directly related to the targeted application. In the case discussed here, the target application is an office desk (about 5000 cm^2) that can accommodate multiple devices with various power requirements. Table 1 gives a list of typical devices that can be found on such an office desk with their respective power requirements and power function. Table 1 also shows that the maximum total power needed for this application is 131 W. Losses in the system also need to be accounted for when determining the power requirements for the source coil and amplifier. The larger the power surface area the higher the operating losses become and methods for efficiency improvement become increasingly important given this application will be subject to efficiency standards [6].

For the multiple-coil system, an increase in power capability for the amplifier can still be achieved using existing topologies [7]. High power amplifiers have higher operating voltage and current that increases the stress on the switching devices. eGaN FETs are excellent candidates due to their significantly lower parasitic capacitance and zero reverse recovery charge. A large area wireless power system for a small office desk [1] will require amplifier topologies capable of delivering 60 W.

Only the differential-mode versions of the class E [7, 8, 10] and ZVS class D [7, 8, 9, 10, 11] amplifiers will be considered for this example. The class E amplifier remains a popular choice, and due to its simplicity and the reduction in imaginary impedance shift from the large area coil due to external influences allows it remains a viable candidate for higher power. The choice of ZVS class D amplifier is based on its proven track record at higher power [8].

Evaluation of wireless power amplifiers

The circuits used to evaluate the multiple-coil large-area wireless power system suitable for an office desk is shown in Figures 3 and 4. The target power capability is 180W, sufficient to power the loads, including system losses, are described in Table1. The system is comprised of three wireless power coils, each with an area of 980 cm^2 (22.5 cm x 43.5 cm). The use case for the operating impedance range for each coil needs to be determined, as there is no AirFuel standard to reference for guidance.

The three coils are evenly spaced to cover a total area of 5000 cm^2 (100 cm x 50 cm). The separation between coils was experimentally determined that magnetic coupling needed to be lower than -17 dB in order to prevent impacting its neighbor. Each amplifier is required to deliver at least 60 W into the coil, which is double its previous capability [8, 10].

A differential-mode class E amplifier was designed based on the EPC2046 eGaN FETs [11] chosen for its low $R_{DS(on)}$ and low C_{OSS}. In particular, the low C_{OSS} made it possible to design this amplifier to be capable of delivering 60 W into the coil without the use of a heat sink for the reflected resistance range.

A differential-mode ZVS class D amplifier was designed using EPC2007C [12] FETs, which were chosen for their low $R_{DS(on)}$ and low C_{OSS}. This amplifier design has already

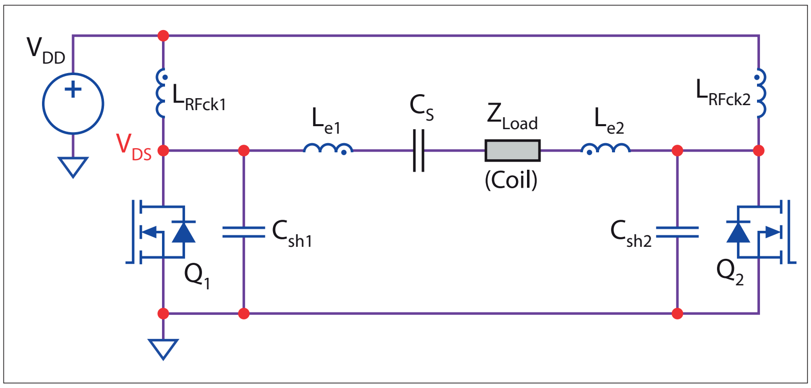


Figure 3: **Differential class E amplifier**

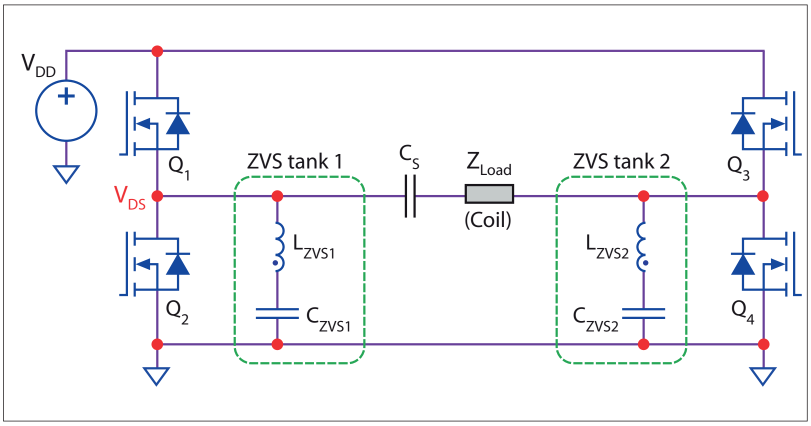


Figure 4: Differential zero-voltage switching (ZVS) class D amplifier

proven capable of delivering 100 W into the coil [13]. The design methodology is given in [7].

At the heart of the multiple coil architecture is the synchronization circuit to ensure that each amplifier operates in-phase. The details of the synchronization circuit are given in [1].

Experimental results

Both the class E and ZVS class D amplifiers were tested using a discrete programmable load. The tests performed were limited, based on either FET drain-source voltage reaching 80 % of rated or device temperature exceeding 100°C in an ambient of 25°C.

The efficiency performance of the class E amplifier is shown in Figure 5 and reveals that the amplifier efficiency largely exceeds 90 % when delivering 60 W full power across the reflected imaginary impedance range. At 60 W, the class E amplifier is capable of driving a relative imaginary impedance range of 35j Ω. Figure 6 shows the measured drain-source voltage across one of the FETs in the class E amplifier while delivering 60 W into a 15.5 + 0j Ω load. At this operating point, the load current is 2 A and the supply voltage to the differential-mode class E amplifier is 26.8 V.

Measured efficiency of the ZVS class D amplifier based on the EPC2007C eGaN FET was tested, with efficiency shown in Figure 7. Off-resonance operation has a large impact on this amplifier due to the C_{OSS} of the EPC2007C that requires energy to maintain ZVS and contributes to the ZVS transition time. This shows that an optimal FET with lower COSS than the EPC2007C will yield higher off resonance amplifier efficiency.

Figure 8 shows the measured drain-source voltage across one of the FETs in the EPC2007C based ZVS class D amplifier while delivering 60 W into a 15.5 + 0j Ω load. At this operating point, the load current is 2 A and the supply voltage to the differential-mode class E amplifier is 36.6 V.

The class E amplifier used a new EPC2046 fifth-generation eGaN FET, which has a lower $C_{OSS} \cdot R_{DS(on)}$ figure of merit than previous generations of eGaN FETs, such as those used in the ZVS class D amplifier. A 100 V fifth-generation eGaN FET with optimal $R_{DS(on)}$ suitable for this application will be tested once it becomes available.

Finally, a multiple coil large-area wireless power system was constructed that covers a total power surface area of 5000 cm^2. The system was made up of three ZVS class D amplifiers, three large area coils (each approximately 1000 cm^2), and the synchronization circuit. The measured timing mismatch between each of the four outputs of the synchronization circuit was less than 600 ps, thus ensuring precise phase alignment of each amplifier in the system. The large-area, multiple coil system was provided with various loads such as a laptop rated at 25 W, a 20" monitor rated at 21 W, office lamp rated at 6 W, and more. The operation of the large area system was discussed in [14].

Conclusions

The key to large area wireless power lies in both innovative coil technology and high power (> 60 W) amplifiers enabled by eGaN FETs. Large area wireless power coils have inherently different characteristics than traditional coils in that they have lower increase in inductance per increase in area, shorter magnetic field radiation, and are more immune to imaginary

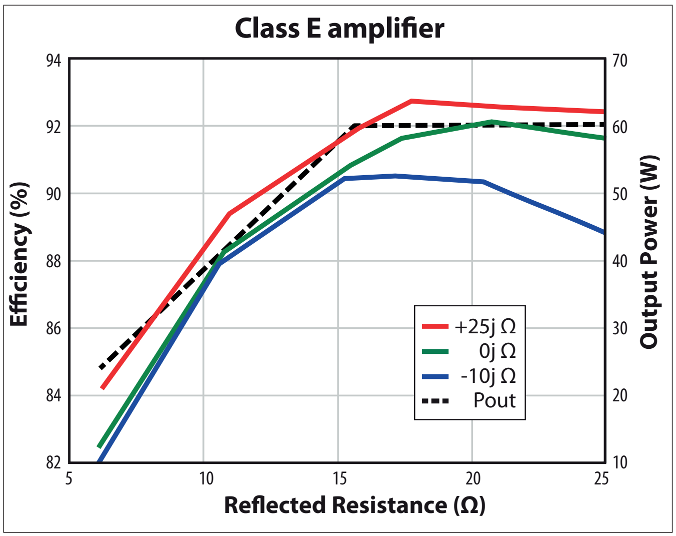


Figure 5: Measured efficiency and output power of the class E amplifier for a range of load impedance

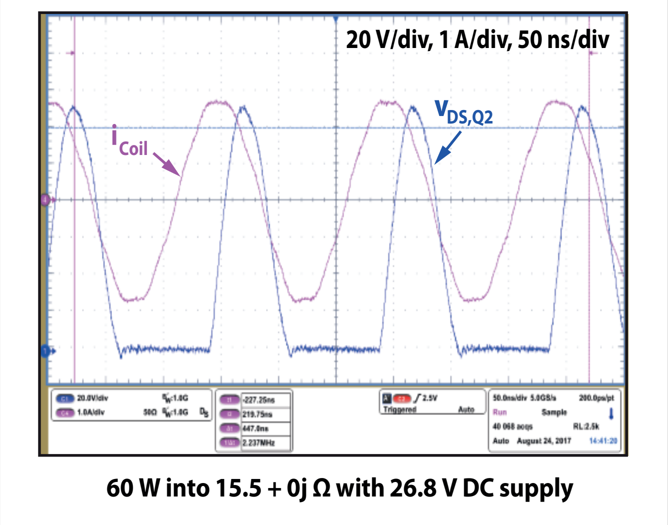


Figure 6: Measured drain-to-source voltage (V_{DS}) and output current (i_{Coil}) waveforms of the Class E amplifier delivering 60 W into 15.5 + 0j Ω with 26.8 V DC supply

impedance shifting.

A multi-coil, multi-amplifier approach using three eGaN FET-based, 60 W capable differential-mode amplifiers was constructed and tested. Both the class E amplifier and the ZVS class D exhibited greater than 90 % efficiency at full power. Further improvements can be expected from the ZVS class D when fitted with lower $R_{DS(on)}$ eGaN FETs. The work presented in this article underscores the challenges ahead for large area wireless power systems design to achieve high-efficiency with high-power amplifiers.

ZVS class D amplifier efficiency (EPC2007C)

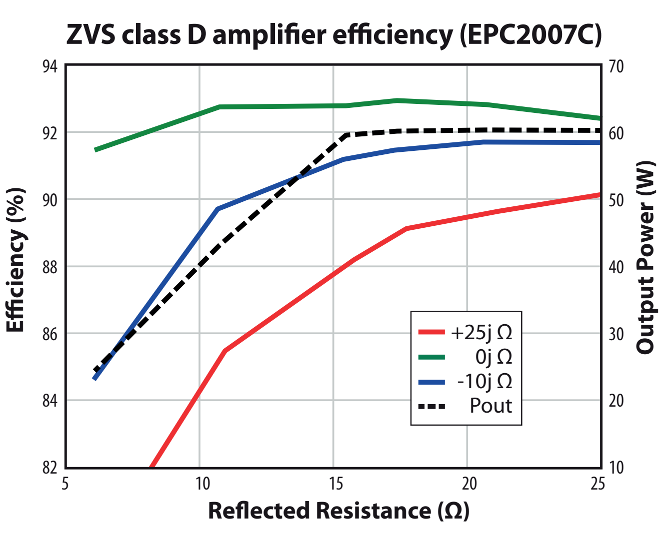
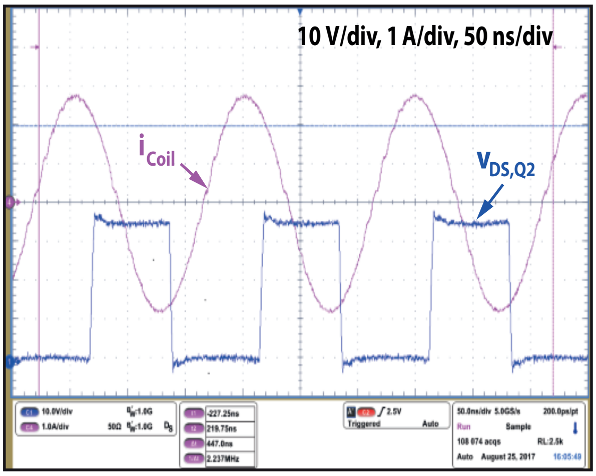


Figure 7: Measured efficiency and output power of the EPC2007C based ZVS class D amplifier for a range of load impedance



60 W into 15.5 + 0j Ω with 36 V DC supply, EPC8010

Figure 8: Measured drain-to-source voltage (V_{DS}) and output current (i_{Coil}) waveforms of the ZVS Class D amplifier delivering 60 W into 15.5 + 0j Ω with 36.6 V

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