Enhancement Mode GaN (eGaN) FETs for On-Coil MRI Transmit Amplifiers

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Target audience: This work is relevant to those interested in parallel transmit arrays and transmit amplifiers.

Purpose: Recent developments in RF transmit systems have trended towards increasing number of independent elements for the purpose of correcting B_1 inhomogeneity and reducing SAR at high field strength. However, the design and implementation of such arrays presents challenges due to inter-element coupling, cabling restrictions, and overall system cost. Past research has addressed some of these issues by placing the transmit amplifier on-coil and using high efficiency amplifier topologies[1,2]. However, putting the amplifiers on-coil creates significant restrictions on amplifier size and heat dissipation. Here we propose the use of enhancement mode Gallium Nitride FETs (eGaN FETs) for use in high efficiency, low cost, miniature RF amplifiers for parallel transmit arrays. This preliminary work shows the potential for significant cost savings and miniaturization when compared to the more typical LDMOS RF FET technology.

Methods: ***eGaN FETs:*** For this work we used eGaN FETs manufactured by Efficient Power Conversion Corporation. GaN's superior material properties result in devices much smaller than Si FETs with equivalent on state resistance and breakdown voltage. Additionally, the eGaN's lateral HEMT structure provides low junction capacitances (approximately 250pF for the EPC2012) and high frequency operation approaching that found in power LDMOS FETs[3]. Fig 1 shows a size and typical cost[4] comparison of eGaN FETs vs. LDMOS Si FETs. While eGaN FETs were originally aimed at DC-DC power conversion applications, we have found them suitable for use in switch mode RF amplifiers at frequencies typical of MRI scanners. ***CMCD transmit amplifier:*** For this work we utilized EPC2012 eGaN FETs in the current mode class D (CMCD) topology[5,2] operating at 63.6MHz. The drain outputs of the CMCD stage can either be connected directly to an RF coil, or fed to a 50 Ω load via a balun. ***Amplifier module:*** In addition to the CMCD amplifier itself, we constructed a complete transmit module utilizing envelope elimination and restoration (EER), allowing it to replicate shaped RF pulses produced from the scanner. The coil current is detected and regulated using a small current transformer. The output current is modulated by varying the supply voltage to the CMCD stage with a class S amplifier[6]. The class S amp also benefits significantly from using eGaN FETs (EPC2014) in place of Si MOSFETs. The complete module measures 10.4cm long, 4.2cm wide, and 2.4cm high, and is constructed using only negligible amounts of ferrous material, allowing it to be placed fully within the bore, next to the coil. ***Benchtop measurements:*** To measure the power efficiency of the CMCD stage, and the overall module, the output was fed to a signal analyzer via a 1:4 balun and a 50 Ω attenuator. When driving a coil, we used a Pearson 2877 current monitor to measure output current. ***Imaging experiment:*** We performed an imaging experiment using the module to directly drive a 10 cm diameter three-turn surface coil[7] placed 16 mm from the surface of a 6 L saline phantom in a Siemens Espree 1.5T scanner. A photograph of the experimental setup is shown in fig 2. The module was powered from a benchtop DC power supply providing +5VDC and +16VDC, while the body coil was used for reception. A GRE sequence with TR=1s and a 1.1KHz Gaussian excitation pulse was used to acquire images with varying excitation flip angles, and the results were used to derive maps of flip angle and B_1[8]. To observe the impact of the module's presence on image SNR, we also acquired noise images with the module's power supply enabled and disabled.

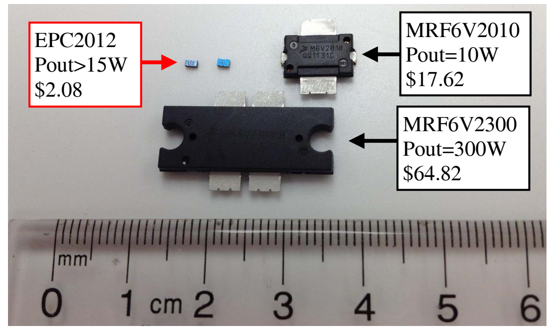

Figure 1: Size, power, and cost comparison of eGaN FETs vs. example Si LDMOS FETs. Power ratings are continuous (per FET) and cost is for quantities of 100 pieces (in USD)[4].

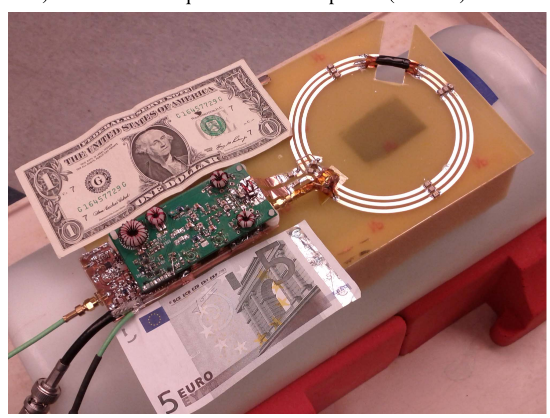

Figure 2: Photograph of module, coil, and phantom.

Results: ***Benchtop measurements:*** The drain efficiency and power added efficiency (PAE) of the CMCD stage when driving a 50 Ω load at full power were measured at 87% and 85% respectively, with much of that loss coming from the output balun. The efficiency of the class S stage was measured at full load to be 94%, giving an overall power added efficiency of 80%. We found that when driving RF coils, the CMCD stage was cable of delivering RF currents in excess of 3 A rms. ***Imaging results:*** The results of the imaging experiment were used to derive a B_1 sensitivity map for the module. Fig 3 shows the B_1 map for a pulse with amplitude of 3.2 A peak. No change in the noise floor was observed in the noise images when power was applied to the module.

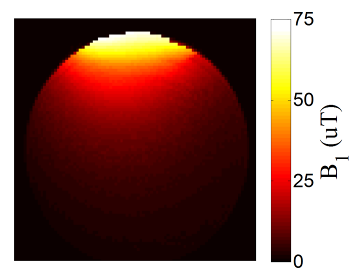

Figure 3: B_1 map for the module

Discussion and conclusion: These results demonstrate that eGaN FETs provide tremendous performance relative to their size and cost, and thus should provide a significant motivation to rethink the way parallel transmit systems are constructed in the future. We have demonstrated that we can reliably control over 3A of RF current with a device occupying less than 2 mm^2 of circuit board area. Thus despite being in its infancy, eGaN technology already holds a clear advantage over existing Si LDMOS in terms of power density and cost, which are both critical limitations in large arrays. Future work in this area will focus on translating this performance to higher field strengths and to higher density arrays.

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References: [1] Kurpad K et al, CMR, vol. 29B, pp. 75–83, 2006. [2] Gudino N et al, MRM. [3] Lidow A et al, Power Conversion Publications, 2012. [4] DigiKey Corporation - Electronic Component Distributor [Online]. [5] Kobayashi H et al, IEEE Tran Microwaves Theory and Techniques, vol. 49, no. 12, pp. 2480–2485, 2001. [6] Raab F H et al, 19th ISMRM, 2011. [7] Gudino N et al, MRM *in press*. [8] Insko E K et al, JMR, vol. 103, no. 1, pp. 82–85, 1993.