Enhancement Mode GaN (eGaN® FETs) for Coil Detuning

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Target audience: This work is relevant to those interested in RF coil design and patient safety.

Purpose: Coil detuning in RF coils is necessary for patient safety and RF field homogeneity. Decoupling is typically achieved using PIN diodes, which function as switches to permit or restrict the flow of RF current on coil elements. However, a major drawback to PIN diodes is that they require large DC bias current in order to achieve a conducting state[1]. DC bias current on a coil presents a potential problem due to the resulting static B_0 inhomogeneity and power dissipation, which may be especially problematic in dense receive arrays. In this work we demonstrate the use of Enhancement-Mode Gallium Nitride FETs (eGaN FETs) from Efficient Power Conversion Corporation as a replacement for PIN diodes in active detuning circuits. The performance of eGaN FETs allows for effective RF switches without the need for large DC bias currents, thus eliminating B_0 inhomogeneity and static dissipation from the switch.

Methods: *eGaN FETs:* An effective coil detuning network relies on a switching device whose impedance changes greatly between its on and off states. For example, a MA4P7470F-1072T PIN diode from MACOM Technologies has a resistance near 0.5 Ω while forward biased with 100 mA, while when reverse biased with 10 V its impedance increases to near 20 kΩ with less than 1 pF of parallel capacitance. It has been previously suggested[2] that field effect transistors (FETs) be used as an alternative to PIN diodes for coil detuning, but the performance of FETs suffers since achieving a comparably low on-state resistance also requires a large parasitic output capacitance C_{OSS}, which causes a lowered off-state impedance. However, recent advances in eGaN FETs have yielded devices with on-state resistances less than 0.125 Ω with C_{OSS} of just 40 pF[3], making them potentially competitive. *eGaN FET RF switch:* The schematic of the fundamental eGaN FET switch is shown in fig 1a. A pair of common source devices is used so that the switch can operate in all four quadrants. When biased in the off state, the switch still has significant parallel capacitance due to C_{OSS}. The off-state impedance of the switch is increased by adding a resonant inductor L_1 in parallel. When in the off state, coil current is allowed to flow normally through coil capacitor C_C. When biased in the on state, inductor L_2 is shunted in parallel with C_C, forming a high impedance at f_0 and blocking coil current. This is analogous to the operation of the typical PIN diode detuning circuit shown in fig 1b. The gate biasing network consists of two inductors selected for self-resonance at f_0, as well as a TVS diode D_1 and a pull down resistor to protect the gates. The control signal would ideally be a 0-5 V logic signal with only milliamps of current capacity.

Performance characterization: The performance of the eGaN FET method (fig 1a) was compared with a typical PIN diode method (fig 1b). A 10 cm square surface coil was constructed and tuned for 63.6MHz. A C_C value of 53 pF was used in both detuning circuits. The coil was designed to allow for different detuning networks to be interchanged easily while minimizing effects on the coil itself (see fig 2). PIN diode networks were made using the MA4P7470F-1072T, while eGaN circuits were made using the EPC8004 from EPC. A benchtop experiment using decoupled RF pickup loops in fixed locations was performed to measure the performance of the detuning circuits in the detuned state. The S_{21} between the two pickup loops was measured, and the difference in S_{21} at f_0 between the tuned and detuned states was observed. Imaging experiments were performed with each detuning circuit to quantify their effect on signal dynamic range (DR) and image SNR[4]. A GRE sequence (TE=10 ms, TR=100 ms, FA=20°, 256x256, N_{AVG}=1) was performed using a Siemens Espree 1.5 T scanner. All experiments were performed with the coil placed 15 mm above a flat 5.3 L saline phantom (2.4 g/L NaCl, 1.0 g/L CuSO$_4$), with the coil impedance matched to 50 Ω (S_{11}<-45 dB). When using the eGaN FET switch, an external circuit was used to convert the normal bias signal from the scanner into a 0-5V logic signal.
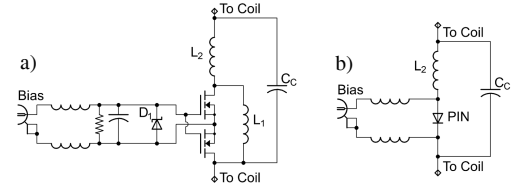

Fig 1: Schematics of the a) eGaN switch and b) PIN diode switch for RF receive coils.
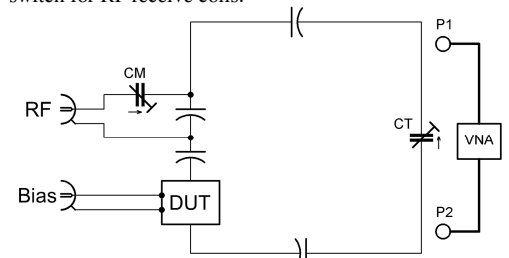

Fig 2: Schematic of test coil with interchangeable detuning circuits. Pickup loops P1 and P2 are used to quantify detuning.

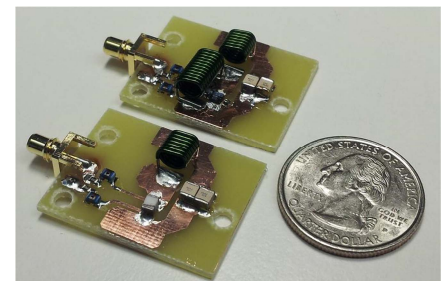|	Detuning (dB)	DR (dB)	SNR (dB)
PIN diode	-47.0	48.48	27.81
eGaN FETs	-53.8	48.35	27.69
Change	-6.8	-0.07	-0.12

Table 1: Results summary for coil performance

Figure 3: Photograph of the eGaN detuning circuit (top) and PIN diode detuning circuit (bottom).

Results: Table 1 summarizes the results of the imaging and benchtop experiments described above. The detuning measurement showed a -6.8 dB improvement from the eGaN FET switch vs. the PIN diode switch. The imaging experiments showed a 0.07 dB drop in signal DR and a 0.12 dB drop in image SNR with the eGaN FET switch. The measured current draw of the eGaN switch was 75 µA. Fig 3 shows photos of the two switch networks used in the measurements.

Discussion and conclusion: These results suggest that eGaN FETs have several advantages over PIN diode switches for detuning networks in receive coils. The eGaN FET switch had a lower on state resistance than typical PIN diodes, giving higher detuning performance and power handling. We observed a 0.12 dB decrease in image SNR, though this loss may be further mitigated by increasing the value of C_C. The eGaN FET switch required <100 µA of control current, and the eGaN devices have been previously shown to have negligible susceptibility[5], thus eliminating B_0 inhomogeneity concerns from coil detuning. Given the high current capability of eGaN FETs, it is expected that they would also be suitable for use in transmit coil detuning, and possibly transmit/receive switches. This work also suggests that current eGaN FETs would be effective for operation at 128 MHz (^{1}H at 3T), and that passive and active detuning functionality may also be realizable within the same switch element, further improving overall system safety. The relative cost of eGaN FETs is expected to be comparable, once the next-generation eGaN FETs reach mass production.

References: [1] Haase H et al, CMR, vol. 12-6, pp. 361-388, 2000. [2] Reykowski A, Patent WO2012160518 A1, 2012. [3] EPC Corporation, 2013 [Online]. [4] Riffe M et al, MRM 2013, doi: 10.1002/mrm.24613. [5] Twieg M et al, ISMRM 2013.