Q-spoiling method using depletion mode Gallium Nitride (GaN) HEMT devices at 1.5T

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Introduction Development of low power receive chains is increasingly important as more electronics are integrated at the coil, and especially for future wireless receiver coils. We demonstrate a new Q-spoiling method with insignificant bias power using a 6 GHz depletion mode Gallium Nitride (GaN) HEMT FET device. Standard receive Q-spoiling uses a PIN diode [1], and requires 50-100 mA forward bias current. Recently, Q-spoiling was demonstrated with Enhancement mode GaN power switches [2], but these have high off-state capacitance (~40pF), a parasitic reverse diode, and require +ve voltage bias to conduct. Depletion mode GaN microwave FETs conduct at V_{gs} =0 and isolate with negative V_{gs} exceeding -4 V. Power microwave GaN FETs [3-4] handle the large 1-3A circulating currents within the high Q blocking circuit, have low on-resistance, and small output capacitance. This blocking circuit requires little power and Q-spoils even when unpowered, providing safety advantages, for example if cables disconnect.

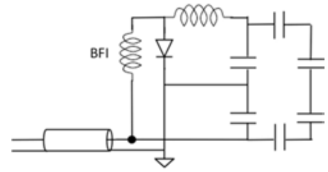

Fig 1. Q-spoiling circuit for using conventional PIN diode

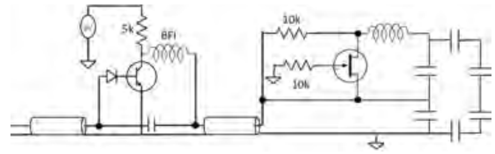

Fig 2. Q-spoiling circuit with GaN HEMT switch

Materials and Methods We constructed two 10.8cm by 14.5cm coils with different Q-spoiling circuits, and tuned them to ω_0=63.88 MHz (1.5T). Both Q-spoil networks switched ~130 nH inductance across ~43 pF capacitance. Our first coil and Q-spoiling circuit uses a nonmagnetic MAP7441F-1091 PIN diode (Fig1). The second coil used FET Q-spoiling (Fig 2) with a Cree CGH60015D GaN HEMT die, which is rated for 6 GHz, 15W, R_{on}<1Ω, C_{ds}=0.9pF, I_{sat}=3.5 A. Traditional GaAs RF switches have inadequate R_{on} for Q-spoiling. To avoid magnetic packaging, we acquired the HEMT in die form and gold wire bonded it to a PCB board. For potential shared preamp supplies, we set the gate to ground and instead impress a positive bias on the drain and source (Fig 2) to turn off the device. An added schottky diode-BJT circuit converted the scanner from PIN diode current bias to voltage bias. Using an HP network analyzer E5071C, we measured S11 to determine the blocking network impedances.

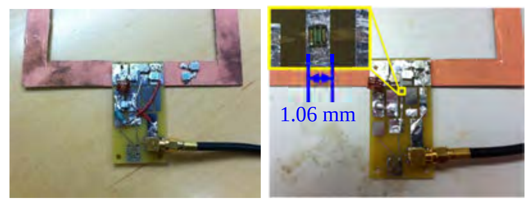

Fig 3. (left) Coil with PIN Diode Q-spoiling (right) Coil with FET switch Q-spoiling with blown up image of device in die form.

We tested the final coils in a General Electric 1.5T scanner. Each receive coil was tested individually on a GE $CuSO_4$ doped phantom with a gradient echo sequence (GRE) (FA=60°, TE=6.8 ms, TR=150ms, FOV=24cmx24cm). Coils were placed right against the phantom to enhance any Q-spoiling artifacts for easy observation. To examine the Q-spoiling ability of each circuit when powered off, we overlapped the coils and imaged with one coil connected while the other coil cable was disconnected. This would examine the inherent Q-spoiling of each coil for any form of power/cable disruption.

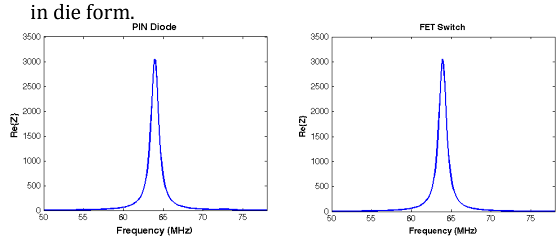

Fig 4. (left) PIN diode Q-spoil blocking impedance is 3 kΩ at 63.88 MHz and draws 23 mA current bias. (right) FET switch Q-spoil blocking impedance is 3.1 kΩ at 63.88 MHz.

Results and Discussion The HEMT switch is by default in a Q-spoiled state, which required no application of power and achieved a blocking impedance of 3.1kΩ when Q-spoiled. The PIN diode, in Q-spoiled state, achieved a blocking impedance of 3kΩ with 23 mA of bias current. Without power, the PIN diode circuit places the coil in resonance mode, but the FET switched coil is Q-spoiled. We first acquired our images using both the FET switch coil and the PIN diode coil individually and found comparable imaging results (PIN diode SNR=21.5dB, FET switch SNR=21.7dB). Next, when overlapping, we alternately placed one coil in receive mode while the other was disconnected. In Fig 6, the PIN-coil received image shows minimal artifacts with the FET coil disrupted (mostly conductor shielding). In contrast, the FET-coil received image shows major artifacts from the disrupted PIN diode coil. This is consistent with the GaN FET inherent Q-spoiling ability when unpowered – a superior feature.

Conclusion Depletion mode GaN FETs (unlike GaAs) perform well as receiver coil Q-spoil switches and achieve SNR comparable with conventional PIN diode Q-spoiling with insignificant bias power. In the case of cable/power disconnect, coils are in the Q-spoiled state, providing an important safety enhancement. GaN FET switches are ideal for low-voltage low-power receive arrays, and ultimately wireless array technology.

References [1] Pierret R, Addison Wes.1996 [2] Twieg M, ISMRM 2014 [3] Keller S, IEEE-T-ED 2001 [4] Mishra U, IEEE 2002

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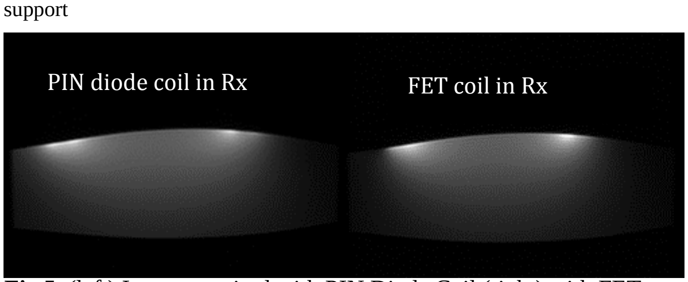

Fig 5. (left) Image acquired with PIN Diode Coil (right) with FET coil

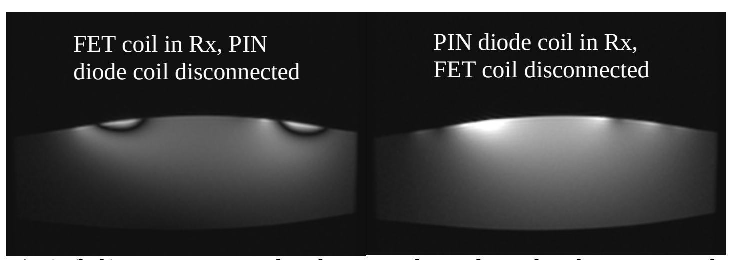

Fig 6. (left) Images acquired with FET coil, overlapped with unconnected PIN diode coil. (right) Image acquired with PIN diode coil, overlapped with unpowered FET coil.