Multi-turn transmit coil to increase B1 efficiency in current source amplification

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Target Audience: Those interested in MRI transmit systems.

Purpose: There remain significant uncertainties about the configuration of an optimal parallel transmit (pTX) system. Reduced load sensitivity and simplified decoupling method have been possible through the design and implementation of current source amplifiers [1,2]. Here we take advantage of the constant current output of a Current-Mode Class-D (CMCD) amplifier with current amplitude feedback [2], and drive a multi-turn transmit surface coil to improve B_1 efficiency. This is shown to improve the system's performance by reducing heat dissipation on the amplifier board as well as allowing the use of lower current rated FETs.

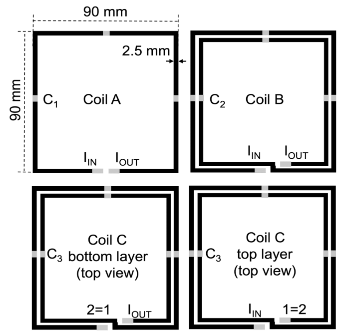

Figure 1: Coils layout

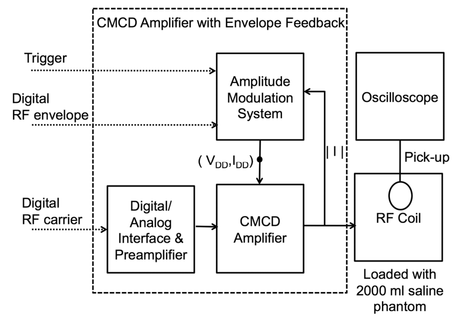

Figure 2: On-coil current source amplifier

Methods: Three coils were designed: a single-turn (coil A), two-turn coil (coil B) both printed on one-layer 1.6 mm thick FR-4 board and four-turn coil (coil C) printed on two-layer 1.6 mm thick FR-4 board (Fig. 1). Each coil was loaded with a 2000 ml saline phantom and connected to the same amplifier (Fig. 2). The input current to the CMCD stage (I_{DD}), as set by the controller, was estimated from a differential voltage reading across a 0.1-ohm (1%) shunt. B_1 at the center of the coil was indirectly measured from peak-to-peak voltage (V_{PP}) readings on a pick up coil using a conversion factor of 6.4 $\mu T/V_{PP}$ previously estimated from V_{PP} vs. I_{Coil} curves for this geometry. The temperature on the MOSFET's case was measured with a fiber optic temperature sensor (OpSens L804-0083-05, -40 to 125 °C, Canada) after 5-minute continuous operation. We replaced the setup with the 1-turn coil A driven by the high power MRF275G (M/A-COM semiconductor) by a setup with the 4-turn coil C driven by the lower power MRF6V2010NR1 (Freescale) and obtained B_1-I_{DD} curves and amplifier output impedances. In a 1.5 T scanner (Espree, Siemens) B_1 maps were obtained from gradient echo images (2 ms RF pulse, 10 ms TE, 3 s TR, 20 cm x 20 cm FOV) by transmitting RF with each coil at same RF envelope value (same current) and receiving signal with the body coil TX.

Results: B_1 was 1.7 higher for coil B than coil A, and 1.5 higher for coil C than coil B, resulting in a total gain in B_1 of approximately 2.6 from coil A to C when driving approximately 5 A to all coils [Fig. 3(a)] and without increasing heat dissipation [Fig. 3(b)]. Approximately three-fold reduction in current for same B_1 value was obtained with the MRF6V2010NR1 compared to the MRF275G [Fig. 4(a)]. In addition, the better port capacitances increased the amplifier output impedance across the whole range of drain voltages (V_{DD}) [Fig. 4 (b, c)]. Images of the saline phantom show that a signal inversion band was possible with coil C at same amplifier current as compared to the 1- and 2-turn cases [Fig. 5(a)]. Flip angle and B_1 estimations are shown for a 5-pixel ROI [Fig. 5(b,c)].

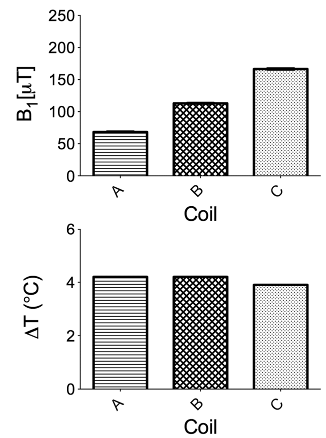

Figure 3: B1 field (a) and temperature at MOSFET's case (b) at 5 A

Discussion: Three-fold increase in B1 was possible by replacing a single turn coil with a 4-turn coil without increasing output current or dissipation in the power FET. This higher efficiency can allow either significantly increased effective power per amplifier, or the use of lower current/power rated FETs with reduced port capacitances. Even though the effective load was higher for the multi-turn coil design, the resulting higher voltage did not directly translate into an increase in power dissipated in the device as expected for a CM device and as confirmed by the temperature measurements.

Conclusion: We believe that a multi-turn coil driven by a CM amplifier is a promising approach to the design of pTX systems. The number and configuration of the turns provides additional degrees of freedom to increase the B_1 efficiency of an amplifier. Field shaping could be also possible through differential design of the multiple loops.

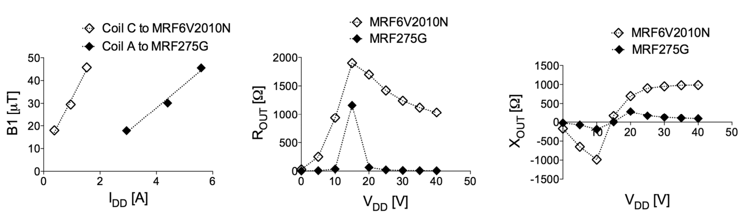

Figure 4: B1 field (a) and amplifier output impedance (b and c)

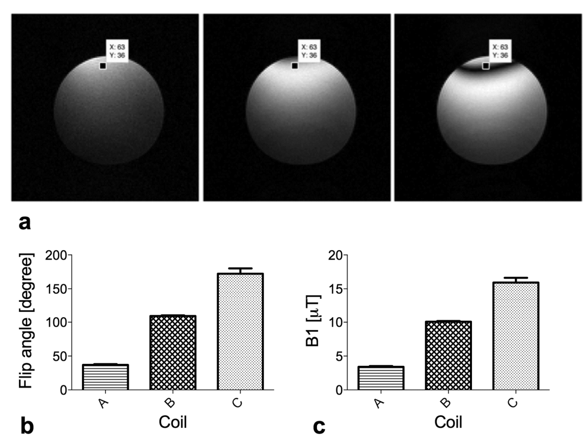

Figure 5: GRE Images of saline phantom acquired by transmitting RF with coil A, B and C (left to right) at same output current.

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References: 1- Kurpad KN, Wrigth SM, Boskamp EB. MRE 2006. 2- Gudino N, Heilman JA, Riffe MJ, et al. MRM 2012.