

Maximizing RF efficiency and minimizing eddy current artifacts using RF and eddy current simulations

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Introduction: A novel RF coil shielding should be transparent to low time varying gradient field and accommodating/supporting for high frequency RF field. The RF coil shielding should be designed to suppress gradient field induced eddy currents without sacrifice of the RF signal. The design of RF coil shielding is most critical for 7T MRI EPI and parallel transmission (PTX) applications since most of the PTX trajectories are using spiral or EPI type gradient waveforms. These gradient waveforms are changing very fast inducing intensive eddy currents that can distort the image quality. Effective RF coil shielding slots design was reported [1, 2] in order to reduce eddy currents. Multiple thin copper layers were also discussed and their performance could ideally be transparent for the MR gradient fields and efficiently blocking high frequency electromagnetic emission [3]. In this work, we present a new and an elaborate dual-optimization method that maintains RF-coil RF characteristics and simultaneously reduces low frequency magnetic field distortions due to eddy currents. The optimization is guided by full wave electromagnetic simulation combined with eddy current simulation. The designs were successfully tested on a 7T human scanner using phantoms and 4 in-vivo subjects.

Methods: Simulation: Finite-difference time-domain (FDTD) method with an accurate transmission-line feed model mechanism was implemented to model the RF magnetic field inside a 4-channel transmit coil, in order to calculate the RF current densities on the coil shielding at 297 MHz. The current density distribution on the coil shielding was examined for multiple types of RF excitations (varying phases and amplitudes) resembling RF (B1) shimming. Fig.1 shows the RF current distribution associated with four different combinations of excitation pulses. Eddy current simulations were performed based on particular slotting patterns that maintain RF current density distributions (obtained using RF simulations) and minimize low frequency magnetic fields induced due to eddy currents. **Coil and Experiments:** A 4-element Tic-Tac-Toe transmit coil was built and five RF shielding sides were designed in a way that copper shielding could be easily changed to different copper patterns. Five different kinds RF copper shielding were tested: single 18 μ m (half oz) copper layer sheet, single 18 μ m copper layer with slots, 4 μ m (0.114 oz) single copper layer sheet, double 4 μ m copper layer sheet, double 4 μ m copper layer with slot pattern. The 4 μ m double layer copper slots pattern is based on the FDTD simulation results (Fig. 1) and are shown in Fig 2. Coil tuning was checked before and after copper cut into slot pattern. Reflection, coupling and B1+ mapping are shown in Figure 3 which demonstrates that the slotting patterns (shown in Fig. 2) does not alter the RF-coil RF performance.

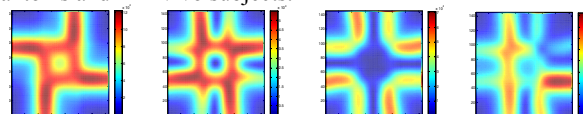


Fig1 Full wave simulation of RF current density distribution



Fig2 Copper slots pattern

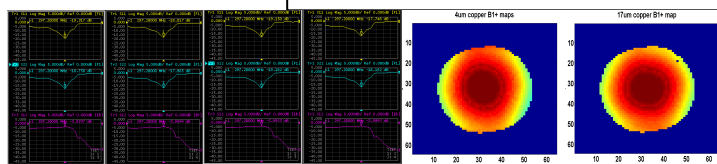
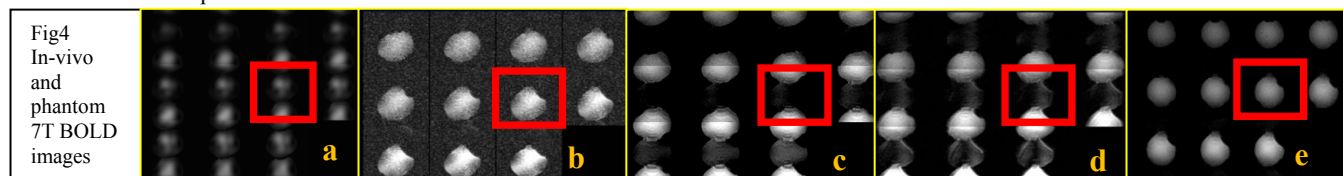


Fig3 S parameters and B1+ maps



Results and Discussion: Fig. 1 shows that the locations that exhibit relatively high-intensity RF current densities are changing with different excitation mechanisms. However areas on the coil shielding with minimal RF current densities are consistent. Based on these current distribution patterns, the 4 μ m double layer copper shielding was cut into different slotting patterns which are shown in Fig. 2. The inner sides copper layers (facing the human subject) are all connected and are slotted in order to maintain the main RF current density pathways. Based on eddy current simulations, the outside copper layers (facing the magnet) were cut along the B0 direction and cap shielding was cut horizontally. Five phantom BOLD images are shown in Fig. 4 (a),(b),(c),(d),(e). In every image, there are 11 slices at adjacent positions along B0 direction and one image is in one red frame box. Images (a) are for the half oz copper layer. Because of the eddy current distortion, it is hard to tell where the phantom image is and where the artificial ghosting is. Images (b) are for half oz single layer slots copper. Obviously the eddy currents were suppressed, however this was achieved at the sacrifice of the RF-coil RF efficiency. In 4 μ m single layer and double layers copper shielding images (c and d), the eddy current is less than the 18 μ m case. However, the phantom images were shifted by half of the slice due to the eddy current. The 4 μ m double layer particularly patterned shielding (images (e)) was highly effective in almost negating all of the eddy current artifacts and maintaining the RF-coil RF characteristics (as shown in Fig. 3.) In-vivo images with 18 μ m copper shielding and with 4 μ m double layer copper slots shielding patterns are also shown in (f) and (g). In every image, there are 22 slices covering the whole human head. Because of eddy currents artifacts, brain images were overlapped in almost every slice in the 18 μ m copper case (f). In the particularly slotted copper case (g), images were intact (except near the absolute top of the human head.) The eddy current artifacts of this particularly slotted coil were comparable to other commercial and in-house made 7T RF-coils that contain no RF shielding. **Acknowledgements:** This work was supported by NIH. **References:** [1]J.T. Vaughan, et al, MRM, 47:990-1000, 2002;[2]G. C. Wiggins, et al, MRM, 54: 235-240, 2005;[3] D. Truhn, et al, ISMRM 2011 #1838