Design and Decoupling of a Parallel Transmit Head Coil at 7T Using Magnetic Walls

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Purpose: Ultra High-field MRI (≥ 7 Tesla), require radio-frequency coils to operate in an electromagnetic spectrum where the effective wavelength of the RF field approaches the patient dimensions, leading to inhomogeneities in the transmit RF fields. To address this, multi-channel transmit and transcieve coils, driven in parallel to produce a combined magnetic field, have been developed to increase the field uniformity and facilitate parallel imaging. However, inside compact RF coils, the closely packed transmit channels significantly interact, resulting in mutually coupled elements. We have previously demonstrated the ability of a metamaterial inspired frequency selective surface (FSS) - or 'magnetic wall' - to effectively decouple transmit elements (1). However, the design required miniaturization and was not implemented in a full transmit-array. **Methods:** By virtue of the distributed inductance and capacitance located in the conductor windings, the magnetic wall design is highly resonant (see Fig. 1a,b). Values for the inductance and capacitance of the magnetic walls were designed based on a quasi-static circuit model (Fig. 1c). (2) To test the efficacy of magnetic wall decoupling in high field RF coils, we implement the miniaturized magnetic wall inside a 10-channel transmit coil designed for neuroimaging at 7 T, in combination with a 31-channel receive array. The optimized magnetic walls included 27 resonant elements in a linear array, laid on a Rogers 4350B dielectric substrate. To achieve maximum decoupling, the magnetic walls are made from three strips stacked and aligned atop each other. The efficiency of the magnetic wall-decoupled 10-channel transmit coil was compared to a conventionally decoupled 15-channel transmit coil. The 15-channel coil had overlapped nearest-neighbours and capacitively decoupled next-nearest neighbours with a mean S_{12} of -23 dB over the whole array. Both coils were built on the same former. **Results:** Adjacent elements had a maximum (worst case) and mean S_{12} value of -18 dB and -22 ± 5 dB, respectively. Next-nearest neighbours had a minimum and mean isolation of -24 dB and -33 ± 9 dB, respectively. The mean S_{12} value across the full S-parameter matrix was -28 ± 8 dB. Relative flip-angle maps on individual elements of the 10-channel array (Fig. 2) demonstrate high isolation and limited coupling artifacts between individual elements. Peak splitting about the Larmor frequency was eliminated in all S_{11} spectra: coil elements achieved a mean S_{11} value of -38 ± 11 dB. A single transmit element in isolation had a Q-ratio of 4.0 (Q_U/Q_L: 135/34) without magnetic walls present. When magnetic walls were placed on either side of the element, the Q-ratio decreased to 3.4 (Q_U/Q_L: 129/38) at the Larmor frequency. This represents a 15% decrease in the Q-ratio due to the presence of the magnetic walls. In the completed array, Q-ratios for the nine elements located on the transmit former ranging between 2.0 and 2.2. The tenth transmit element located on the receive former had a Q-ratio of 1.6. The measured transmit efficiency of a single element in isolation decreased by only 16% (0.63 dB) after MWs were placed on either side of the coil. The 10-channel MW coil required 38.7 W of total RF power at the coil input to perform a 90° flip in the sample with a 6000 μs hard pulse. In the same sample, the 15-channel overlapped/capacitively-decoupled coil required 55.2 W of total RF power at the coil input to perform a 90° flip with a 6000 μs hard pulse. The transmit field homogeneity across the entire head is demonstrated with flip angle maps in Fig. 3. The transmit field uniformity over the axial, sagittal, and coronal planes of the whole-brain shim solution was 17%, 10%, and 11%, respectively. The transmit field uniformity over the whole brain (to the inferior-most extent of the cerebellum) was 24%. **Discussion:** The high decoupling between next-nearest neighbours (-33 ± 9 dB) is a major benefit to this decoupling scheme (this is compared to -7.4 dB for next-nearest neighbours with no MWs present). The achieved mean S_{12} value between next-nearest neighbours is on the order of what low-input-impedance preamplifier decoupling can provide in receive coils (the current gold-standard for decoupling). When comparing a single transmit element with adjacent magnetic walls to the same transmit element in isolation, there is a small 15% reduction in the normalized Q-ratio and a commensurate 16% decrease in transmit efficiency. Low coupling between coil elements also provides a modest improvement in transmit efficiency due to a decreases in the power loss in adjacent elements and the potential for destructive interference between B_1^+ fields of coupled elements. Altogether, a higher transmit efficiency was measured for the MW coil in comparison to a conventional overlapped/capacitively-decoupled coil. With RF shimming, the deviation in flip angle was 24% across the whole brain, with a moderate reduction in flip angle in the inferior aspect of the brain (i.e., the cerebellum), as noted in Fig. 3. **Conclusion:** This study establishes the efficacy of the 'magnetic-wall' in decoupling multi-channel transmit arrays. The MW decoupling technique attains high decoupling values between adjacent elements and is capable of efficiently decoupling next-nearest (and further) neighbours to a level comparable to that achieved by receive-only coils using low-input-impedance preamplifiers—a feat not permitted by conventional transmit-array decoupling techniques. This provides exciting opportunities to acquire images with highly decoupled transmit channels and high transmit efficiency.

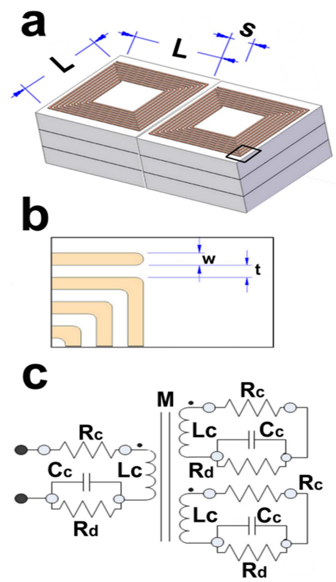

Fig. 1: **(a)** Dimensions: L = 7 mm; s = 1.58 mm, **(b)** Dimensions: w = 0.127 mm; t = 0.127 mm, **(c)** Equivalent circuit.

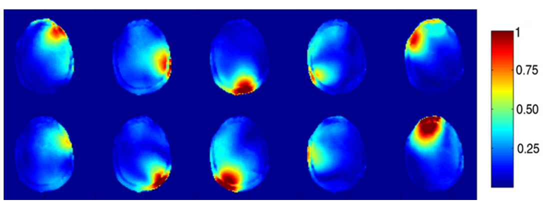

Fig. 2: Relative flip-angle maps acquired from each

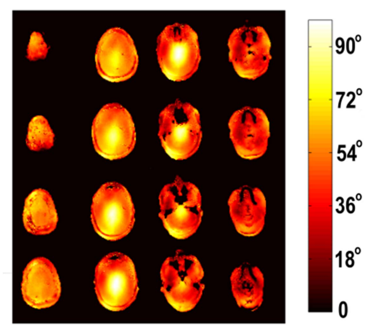

Fig. 3: Flip-angle map acquired across the entire sample.

1. Abou-Khousa M et. al. Magnetic Walls for RF Coil Elements Decoupling. 21st Proc of the ISMRM. Salt Lake City, Utah; 2013. p 724. **2.** Bilotti F, Toscano A, et al. Equivalent-circuit models for the design of metamaterials based on artificial magnetic inclusions. IEEE Trans Microw Theory Tchn 2007;55(12):2865-2873.