A Novel Alternating Impedance Transceiver Coil for 7T MRI

James F. Stack, Jr. [1]

[1] *Remcom, Inc., State College, PA, United States*

INTRODUCTION: The small wavelength employed by 7T MRI leads to B_1^+ inhomogeneities in biological tissues. Microstrip transceiver arrays using microstrip resonators (MSR) demonstrate great potential to overcome many of the challenges facing 7T MRI (1, 2). Unfortunately, the conventional MSR yields an inhomogenous field along the coil axis with strong fields at the center of the microstrip and weak fields at the ends. Akgun et al. proposed using an alternating impedance MSR in (3). This approach placed square impedance elements along the MSR to control the magnetic field distribution. Later work determined that circular impedance elements could improve both the $E\,/\,B_1^+$ ratio and the B_1^+ homogeneity (4). Both of these methods use uniformly sized and spaced impedance elements. This work presents an alternating impedance MSR with non-uniformly sized and spaced circular impendance elements. This design is arrived at via particle swarm optimization (PSO) and finite difference time domain (FDTD) simulations.

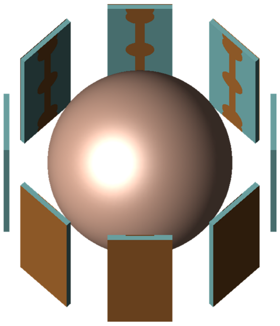


Fig 1: Eight element alternating impedance MSR coil and spherical phantom.

THEORY: The addition of alternating impedance elements to a conventional MSR can be used to reduce inhomogeneities of the B_1^+ field (3, 4). Previous work demonstrates that circular impedance elements yield better performance than rectangular elements (4). Permitting the impedance elements to employ non-uniform diameters and non-uniform spacing can allow greater control over the field distribution resulting in further reduction of B_1^+ inhomogeneities. For this work, PSO is used to design an optimal alternating impedance MSR where the radii of and spacing between individual elements can vary independently.

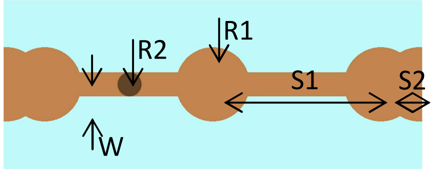


Fig 2: Optimized MSR geometry.

METHOD: An 8 channel 7T alternating impedance MSR is constructed with a diameter of 25.4 cm (Fig 1). Each MSR is built on low loss polytetrafluoroethylene (PTFE, ε_r=2.08, tanδ=0.004) substrate with dimensions of 2 x 6 x 15 cm. A particle swarm optimization is created where the width of the MSR is permitted to vary. Each MSR is also given the ability to employ up to 11 circular impedance elements in an effort to minimize B_1^+ variation over a spherical phantom of 17 cm in diameter (ε_r=78, σ=0.45 S/m). The impedance elements are distributed symmetrically about the axis of the MSR, and each pair of elements can vary its spacing and diameter independently. Pairs of current sources are used at the terminating ends of the MSR in order to generate an appropriate current distribution along the MSR. The fitness of each particle was evaluated by finding the minimum and maximum B_1^+ field values in the phantom and taking the ratio ($B_{1,max}^+$ - $B_{1,min}^+$)/ $B_{1,max}^+$. The optimization aims to minimize this ratio. The PSO was initialized with 36 particles and permitted to run for 600 generations. The optimization was performed using XF 7 (Remcom, Inc.).

RESULTS: Simulations were run on NVIDIA Tesla C2070 graphics processor units (GPU) using XF's XStream acceleration feature. This permitted a single generation to complete in an average time of 25.6 minutes. The finalized design included five circular elements with a radius of R1 = 1.32 cm, and one pair of circular elements which was optimized out by setting its radius, R2, to be less than the microstrip width W = 0.87 cm (Fig 2). The spacing between elements S1 and S2 are 6.02 cm and 1.36 cm respectively. The remaining elements were pushed beyond the bounds of the MSR. This indicates that the design would not benefit from the presence of additional impedance elements. Table 1 compares the results for a straight MSR, alternating impedance MSR with uniform circular elements and the optimized geometry.

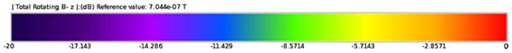
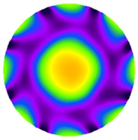
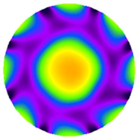
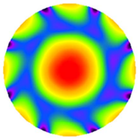
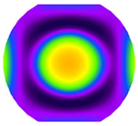
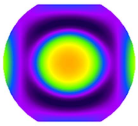
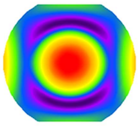
	Straight MSR	Uniform Elements	Optimized MSR
			
Axial B_1^+			
Sag. B_1^+			
Peak B_1^+	7.044e-7 T	7.098e-7 T	7.530e-7 T
Fitness	0.9596	0.9408	0.9111

Table 1: Comparison of optimized results to straight MSR and alternating impedance MSR with uniform circular elements. All results are normalized to 1W net input power.

CONCLUSION: This works demonstrates that B_1^+ field homogeneity of a 7T MSR coil can be improved through the use of non-uniformly distributed impedance elements. The peak B_1^+ field is also improved. Future work could build on this technique to gain even further improvements by experimenting with alternative shapes or fitness functions.

REFERENCES: 1. Adrianny et al., "Transmit and receive transmission line arrays for 7 Tesla parallel imaging," Magn. Reson. Med., vol. 53, no 2, pp. 434-445, Feb. 2005; 2. Zhang et al., "Microstrip RF surface coil design for extremely high-field MRI and spectroscopy," Magn. Reson. Med., vol. 46, no. 3, pp. 434-445, Sep. 2001; 3. Akgun et al., "Novel multi-channel transmission line coil for high field magnetic resonance imaging," 2009 IEEE MTT-S Int. Micro. Symp. Dig., pp1425-1428, 7-12 June 2009; 4. Elabyad et al., "An Investigation of Alternating Impedance Microstrip Transceiver Coil Arrays for MRI at 7T," 2011 IEEE MTT-S Int. Micro. Symp. Dig., 5-10 June 2011;