A Numerical Comparison of Conservative E-field Shield Designs in a Solenoidal Coil

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INTRODUCTION: For high field microimaging in MRI, it is apparent that sample power loss can be a significant factor in SNR and sample heating (1), and the conservative electric field (E-field) can be a significant component in the total sample E-field (2). Based on previous research (2), we performed Full-Maxwell numerical calculations of the electromagnetic fields to evaluate the RF coil and sample power loss, and introduce a simple method to decrease sample power loss without changing RF magnetic field (B_1) distribution using passive pieces of conductive material to partially shield the sample from the conservative electric fields of the coil, making an "E_c shield." Our proposed E_c shield geometry involves a number of long, thin passive conductors oriented with the axis of the solenoid and spaced evenly about the surface of the sample.

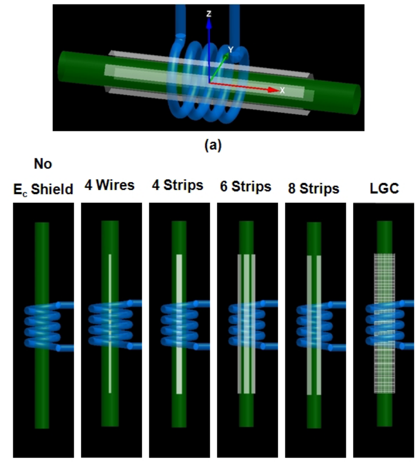

Figure 1 Geometry of solenoid coil (blue), sample (green) and copper strips (white) between coil and sample (a) and six different geometries for the numerical calculations (b).

METHOD: A solenoidal coil and enclosed sample were for high frequency microimaging were simulated at 600 MHz (14.1T). The solenoid had 4 turns of 0.35 mm-diameter round wire (d), with a coil diameter (d_{coil}) of 3.0 mm, and coil length (l_{coil}) of 3.47 mm. Copper wires (0.12mm diameter) or copper strips of (0.6 mm width and 10.8 mm length) were then oriented parallel to the axis of the coil and placed between the solenoid coil and the sample to decrease the sample power loss. The setup is shown in Figure 1. The weak saline sample (10 mM NaCl: σ = 0.2, ε_r= 78) had a 1.6 mm-diameter (d_{sample}) and 16mm-length (l_{sample}). E_c Shields, each with length 10.8 mm, and diameters 200 µm (4 wiress) and 600 µm (4, 6, and 8 strips) were modeled. In addition, the case without copper wires served as a control (No E_c Shield), and for comparison with a recently-published alternative (3), a loop-gap cylinder (LGC) with diameter 2.4 mm and length 10.8 mm was also modeled. In principle, with our design the strips will not significantly alter magnetic field penetration, but can partially shield the conservative E-fields due to electrical potential in the conductor along the length of the solenoid. All simulation work was performed using commercially available software (xFDTD; Remcom, Inc; State College, PA). And all results of electromagnetic fields were normalized so that B_x = 4mT at the coil center.

RESULT: Figure 2 shows magnitudes of conservative E-field (E_c), magnetically-induced E-field (E_i), and B_1 field in the coil and sample region for six different simulation conditions including no E_c shield, several variation of our design, and the LGC. Table 1 gives information regarding the B_1, E_c, E_{total}, and power loss in the sample for each simulation condition. The E_c and power loss within the sample were decreased significantly with the addition of the copper strips with minimal impact on B_1 (Figure 2 and Table 1).

DISCUSSION: The presence of copper strips resulted in decreased E_c (Figure 2, Table 1). Because E_c is the dominant factor in sample loss for this geometry, this results in a reduction in sample power loss of about 86% for 8 Strips. The scalar potential along the length of the solenoid induced a charge distribution along the strip that shielded the sample from the E_c with almost no effect on B_1 because of the orthogonal direction of currents in the solenoid to possible currents in the strips. A similar effect was reported for a solenoid containing a second RF coil (4). In comparison, the LGC also effectively shielded E_c, but had a greater effect on B_1 and required greater current in the solenoid to create the same B_1 field magnitude at the center of the sample.

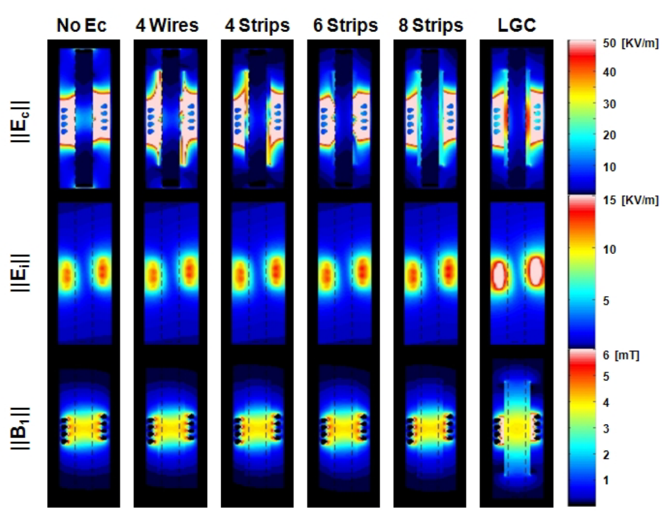

Figure 2 Approximate total magnitude of conservative electric field ($\|E_c\|$, first row), magnetically induced electric field ($\|E_i\|$, second row) and total RF magnetic field ($\|B_1\|$, third row) for six different conditions.

Table 1 Calculated electromagnetic field properties within the sample. Std. indicates standard deviation and PL indicates power loss.

E_c Shield	Mean $\|E_c\|$ [kV/m]	Mean $\|E_{Total}\|$ [kV/m]	Mean $\|B_1^+\|$ [mT]	Std. $\|B_1^+\|$ [mT]	Sample PL [mW]
No Ec Shield	12.64	11.57	1.82	0.73	119.15
4 Wires	8.84	7.38	1.82	0.73	49.79
4 Strips	7.30	5.44	1.82	0.73	28.77
6 Strips	6.26	3.98	1.83	0.74	17.48
8 Strips	6.20	3.80	1.83	0.73	16.89
LGC	8.12	4.00	1.87	0.75	26.72

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