Improving central transmit efficiency and homogeneity using interleaved shielded dielectric discs and coil elements in a 4-element transmit/receive array at 7 T

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TARGET AUDIENCE: Radiofrequency (RF) engineers and those interested in the use of dielectric materials

PURPOSE: Magnetic resonance (MR) imaging of deep anatomical structures at 7T is challenging, because of B_1 field inhomogeneities and safety limitations on RF power. Placing an RF shield above the coil elements of an array can increase transmit (Tx) and receive (Rx) efficiency near the surface of the object, but reduces field efficiency in deeper regions[1]. Parallel Tx techniques improve efficiency for deep structures[2], but cost and complexity currently prevent their widespread use. High permittivity materials, placed between an RF coil and the sample, can improve Tx efficiency, signal-to-noise ratio (SNR), and RF homogeneity in various MR applications[3,4]. However, the benefits reported in previous studies are limited to regions near the dielectric materials. A recent simulation study showed that placing dielectric discs covered with passive conductive shields at various positions on the surface of the sample could shape the B_1 field of a Tx coil[5] in a favorable manner. Here we show, in both simulation and experiment, the advantage of interleaving shielded dielectrics with RF coils in a four-element Tx/Rx array.

METHODS: Simulations: We used a finite integration technique (CST Studio Suite 2013) to calculate the electromagnetic (EM) field in a tissue-equivalent cylindrical phantom (ε_r = 57.5 σ=0.8 S/m) generated by a four-element loop array driven in quadrature (i.e. in a four-port circularly-polarized mode) with various configurations of external dielectric materials and shields, one of which is illustrated in Fig 1. Six cases were evaluated: 1) coils alone (Figs 2A & 4 col. 1), 2) coils and passive conductive shields alone (Figs 2B, 4 col. 2) or 3) covering dielectric discs between adjacent coils (Figs 3A, 4 col. 3), 4) dielectric discs alone (Fig 3B), 5) flat 80 mm diameter circular shields placed 25mm above each coil (Fig 2C), and 6) a single continuous cylindrical shield surrounding all four coils, at 25mm offset (Fig 2D). Voltage sources were used and the coils were tuned for 7T (S11< -25dB) for all configurations. The Tx efficiency was calculated for a transverse plane through the center of the coils by dividing the $|B_1+|$ by the square root of the dissipated power within the entire phantom. B_1+ homogeneity (calculated as 1 – (st.dev./mean) of the Tx efficiency), Tx efficiency at the center and its mean were evaluated. **Experiments:** Geometry matched simulation set up (Fig 1). Dielectric discs were made with copper-covered petri dishes filled with a gelatin and water mixture of measured (85070E Dielectric Probe Kit, Agilent Technologies) electrical properties: ε_r=76.16 and σ=0.198 S/m. RF coils were tuned for 7T (S11 < -25 dB), and a quadrature excitation was obtained using a power splitter with cable lengths chosen for a 90-degree phase shift between adjacent channels. On a 7T whole-body scanner (MAGNETOM, Siemens), B_1+ maps were obtained by fitting a series of images with incremented nominal flip angles/voltages to a cosine curve. SNR was calculated from the raw data[6], obtained using a GRE sequence, and normalized to the sine of the actual flip angle.

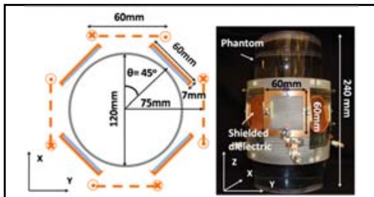
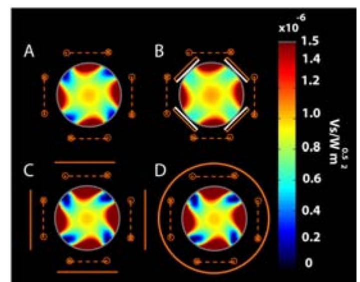


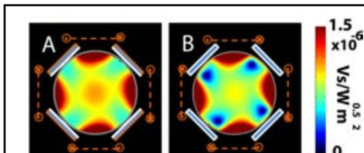
Fig. 1 Simulation and Experimental set-up. RF coils (dotted orange lines, 15 mm from phantom surface) and dielectric discs (blue) covered by a shield (solid orange lines, 3 mm from phantom surface) symmetrically surround the phantom (gray).



% change w.r.t to A	B	C	D
Homogeneity	+27.74	-41.71	-45.23
Mean Tx efficiency	+3.73	+21.26	+27.75
Tx efficiency at center	+4.89	-0.59	-0.87

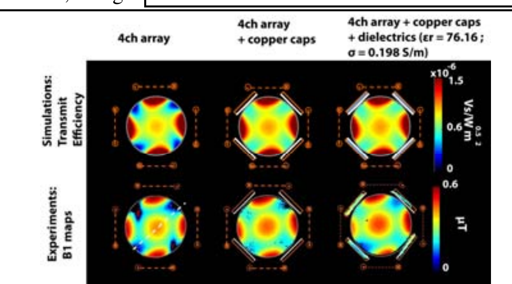
Fig 2: Shields (no dielectrics; ε_r = 1,σ = 0 S/m) placed at 45 degrees from RF coil (B) perform better than shields (solid orange line) placed above coil elements (C, D).

RESULTS: A shield between adjacent coils increased Tx efficiency at the center, improved B_1+ homogeneity and limited the size of signal drops between the coils (Fig 2B vs. Fig 2A). By contrast, shields above the Tx coils, reduced Tx efficiency at the center and B_1+ homogeneity, with a prominent increase in the nulls between the coil elements (Fig 2C-D vs. 2A). Shielded dielectric discs between coils further improved results (Fig 3A vs. 2B). Performance decreased if the shield was removed completely from the dielectric discs (Fig 3B vs. 3A), but the performance was similar if removed only from the lateral surfaces (results not shown). Positioning the shielded dielectric discs directly against the phantom reduced the efficiency at the center by 14.7% compared to Fig. 2A (data not shown). In experiments, using shielded discs alone between adjacent coils improved Tx efficiency at the center (Fig. 4 col. 2 vs. col. 1). Adding dielectrics provided an additional 6% benefit to the $|B_1+|$ at the center (Fig 4 col. 3 vs. col. 2). Normalized experimental SNR maps (not shown) showed a trend similar to the simulated Tx efficiency maps (Fig 4 row 1), with an SNR increase at the center of 5% for both the cases of shielded dielectrics and shields alone, compared to the case with only coils. The profiles (Fig. 4) show that $|B_1+|$ increases for a larger area at the center (Fig. 4 col. 2,3 vs. col.1).



% change w.r.t to Fig 2A	A	B
Homogeneity	+27.30	-11.45
Mean Tx Efficiency	+4.35	+1.66
Tx efficiency at center	+5.62	-8.32

Fig 3: Shielded dielectric discs (A) perform better than unshielded dielectric discs (B) (ε_r = 500, σ = 0 S/m).



% change w.r.t to column (Col) 1	Col 2	Col 3
Sim: Tx efficiency at center	+4.89	+5.23
Exp: $|B1+|$ (center)	+5.19	+10.9

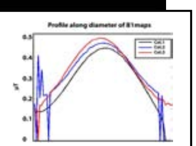


Fig 4: Simulations and experimental results show an increase in Tx efficiency and |B1+| at the center of the sample. Profiles were taken along the white dotted diagonal line shown.

DISCUSSION AND CONCLUSIONS: Our experimental results showed that placing shielded dielectrics between adjacent coil elements of a Tx/Rx array improves overall B_1+ homogeneity and SNR at the center. Simulation results showed that Tx efficiency in the center also improves. The magnetic field induced by the displacement and conduction currents within the shielded dielectric contributes to the EM field at the center of the object, whereas the presence of a shield helps direct the field inside the sample (Fig. 3B vs. Fig 3A). When a shield is placed above the Tx coils, the coils induce opposing mirror currents in the shields, which reduce the $|B_1+|$ intensity at the center of the sample. While doubling the number of coils may seem like a feasible alternative, practical limits on maximum power per channel and number of elements would eventually limit the achievable Tx performance. Increasing coil size so that adjacent coils overlap would increase the field of view (FOV) covered by each coil, but at the expense of SNR, as each element will receive noise from a larger FOV. Future work will focus on optimizing the geometry (height of dielectrics and distance from object) and in-vivo experiments. **REFERENCES**: 1) Haemer et al., ISMRM p 4406 (2013) 2) Metzger et al., MRM (2008) 3) Webb et al., C MR Part A (2011) 4) Yang et al., JMRI (2013) 5) Vaidya et al., ISMRM p 4472 (2013) 6) Kellman et al. MRM (2005)