Manipulating B₁ spatial distribution at 7 Tesla with dielectric pads at a distance from a transmit surface coil

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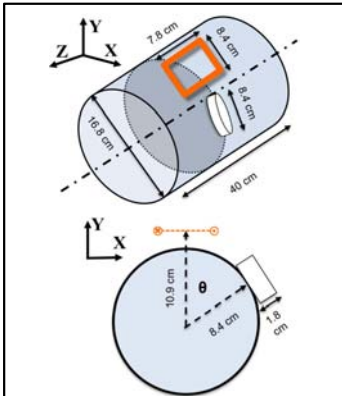
Fig. 1. Experimental set-up showing the cylindrical phantom, surface coil and dielectric pad (white disk).

INTRODUCTION: The distinctive asymmetry of the B_1+ and B_1- fields at ultra-high-field (UHF) strength [1] makes it difficult to achieve homogenous magnetic resonance (MR) excitation and reception with surface coils. While radiofrequency (RF) inhomogeneities can be reduced through parallel MR transmission [2] and specialized RF pulse design [3], practical implementation remains complex, preventing widespread clinical use. It has been shown that dielectric pads can improve RF homogeneity, transmit efficiency, and signal-to-noise ratio (SNR) and can reduce specific absorption rate (SAR) in MR applications [4]. In previous studies, dielectric pads were placed either between a volume coil and its shield [5], or between the coil and the sample [6,7]. In this work, we demonstrate how dielectric pads placed on the sample at a distance from a surface coil can change the spatial distribution of B_1 inside the sample.

METHODS: We used XFDTD (Remcom, State College, PA, USA) to calculate the electromagnetic field generated in a uniform cylindrical phantom ($\varepsilon_r = 90$, $\sigma = 0.6$ S/m) by a rectangular surface coil. Fig. 1 shows the simulation set-up with relevant dimensions and parameters. All simulations were performed using the proton frequency at 7T, for a transverse plane centered with the coil. We investigated the effect of the position of the dielectric pad ($\varepsilon_r = 300$, $\sigma = 0$ S/m), relative to the coil, on the spatial distribution of B_1+ inside the phantom. We repeated the simulations after adding copper shielding to the dielectric pad, either while keeping its relative permittivity at $\varepsilon_r = 300$ or changing it to $\varepsilon_r = 1$.

RESULTS AND DISCUSSION: In Figs 2-4, the circle marks the edge of the phantom, the dotted line indicates the position of the coil, and the rectangle indicates the position of the dielectric pad. B_1 maps were normalized by the square root of the total power dissipated (P_{diss}) in the transverse section of the cylinder and scaled to the same minimum and maximum values. Fig. 2 shows the change in spatial distribution of $|B_1+|$ in response to the position of 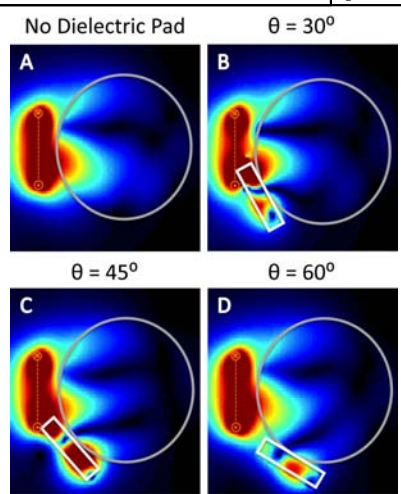the dielectric pad. Displacement currents induced within the dielectric pad increase the amplitude of the transmit field locally. In Fig. 2 the transmit field couples directly to the dielectric pad outside the phantom, reducing the $|B_1+|$ created by the RF coil inside the phantom. Fig. 3B shows that after shielding the dielectric pad except for the surface in contact with the phantom, the presence of the dielectric pad mostly affects the $|B_1+|$ pattern inside the phantom. In addition to the induced displacement currents within the dielectric pad, conduction currents are generated in the copper shield, which also contribute to the overall shape of $|B_1+|$ in the phantom (Fig. 3B). Almost no change in $|B_1+|$ is observed in response to a shielded dielectric pad with $\varepsilon_r = 1$ (Fig 3B vs. Fig 3C and Fig 2A vs. Fig 3C). This is likely due to the reduced displacement currents within the dielectric pad. If $\varepsilon_r = 1$ is used and only the lateral surface is shielded (Fig. 3D), the pad, which is now effectively a passive coil, becomes transparent to the $|B_1+|$ distribution. Fig. 4 shows that by using three unshielded dielectric pads, it is possible to improve transmit efficiency (i.e., mean $|B_1+|/\sqrt{P_{diss}}$) by 20.5% compared to the case with a single dielectric pad under the coil. Transmit homogeneity also improves, as qualitatively shown by the disappearance of null in the $|B_1+|$ spatial distribution near the coil.

SUMMARY AND CONCLUSIONS: At high frequencies, the spatial distribution of the transmit RF field inside a sample can be manipulated by placing a high-permittivity dielectric pad outside the sample at a distance from the coil. We simulated various configurations for the dielectric pad and showed the corresponding changes in $|B_1+|$ maps. This method for modifying B_1 inside the imaging object has significant potential applications in high-field MRI. For example, it could widen the range of applications of RF coil arrays just by the addition, removal or re-positioning of dielectric pads. This preliminary study also suggests that it may be possible to achieve homogenous MR excitations over large body regions at UHF with a surface coil array using external dielectric pads to shim B_1+. In the future, this may reduce the number of transmit elements needed for effective parallel excitation, and help translate the technique into clinical use. As future work, we plan to explore optimal permittivity, size and position for the dielectric pad, and simulate B_1 spatial distribution for different sample/coil/dielectric pad configurations, including arrays of surface coils and realistic body models.

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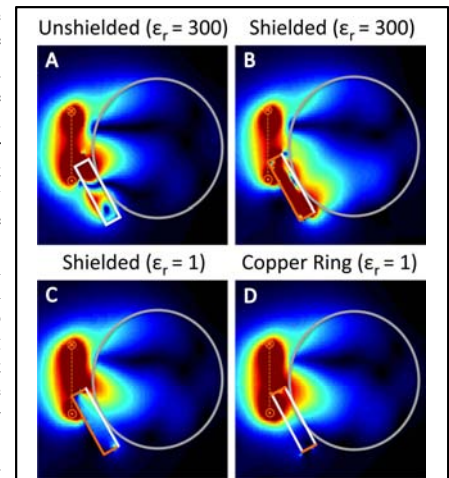
Fig. 2. $|B_1+|/\sqrt{P_{diss}}$ of the surface coil in the absence (A) and presence (B-D) of a high-permittivity dielectric pad ($\varepsilon_r = 300$) at various positions.

Fig. 3. $|B_1+|/\sqrt{P_{diss}}$ for different types of dielectric pads at $\theta = 45^o$. In A the pad is uniform, in B and C is shielded (orange sides) with the exception of the surface touching the sample. For large permittivity (B), the shielded pad substantially modifies the $|B_1+|$ distribution within the sample. The pad in D is effectively a passive coil and does not perturb the transmit field (compare to Fig. 2a).
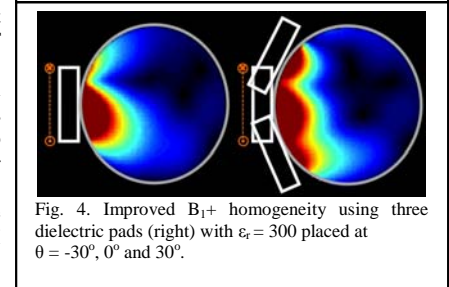

Fig. 4. Improved B_1+ homogeneity using three dielectric pads (right) with $\varepsilon_r = 300$ placed at $\theta = -30^o$, 0° and 30°.