Maximized Local B1+ using Optimized Dielectric Pad at 7 T: Numerical Optimization and Experimental Validation

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Introduction: Recently, dielectric materials with high permittivity (ε_r) have been used to improve image homogeneity in high field MR images [1-3]. Since the high permittivity materials tend to enhance the RF magnetic field in the sample near the pad, minimizing the signal null is possible. On the other hand, dielectric pads are also used to enhance image quality by increasing image SNR near the pad [1-3]. It seems like higher permittivity enhances the local SNR, so very high permittivity material (barium titrate beads, $\varepsilon_r > 500$) has been successfully used at 3T [4]. However, for the best performance of dielectric pad, permittivity, geometry, dimension, and location of pads are subject to be optimized to maximize the effect of high dielectric materials. In this study, we report the permittivity optimization of dielectric pad to maximize the local B_1^+ in a phantom with electromagnetic field simulations at 7T. We also verify the optimized permittivity by comparing the flip angle (FA) mapping experiments at 7T when the dielectric pad is presented with different permittivity values.

Methods: For the permittivity optimization, we modeled cylindrical phantom, dielectric pad, and a single loop Tx/Rx coil using XFdtd (Remcom, Inc.) as shown in Figure 1a based on available experimental materials (Figure 1b). The square (80×80 mm^2) Tx/Rx coil was placed 5 mm above the phantom (diameter 168 mm, length 370 mm, σ 0.53 S/m, ε_r 78). The dielectric pad (diameter 84 mm, thickness 18 mm) was placed between the coil and the phantom. The conductivity and permittivity of the dielectric pad were variables for parameter sweeping in XFdtd. There were 10 values of pad relative permittivity (1, 80, 100, 150, 200, 250, 300, 350, 450, and 490) and 5 values of pad conductivity (0, 0.01, 0.1, 0.3, and 0.62 S/m). All 10 values of permittivity were repeated for each value of conductivity, so that 50 different simulations were performed at 297.2 MHz. The average magnitude of the B_1^+ field in the portion of the phantom within 84 mm of the coil center was quantified in each case. In the FA experiments at 7T (Siemens, Erlangen, Germany), two dielectric pads were prepared. One is barium titanate beads prepared in slurry with D_2O (σ 0.62 S/m, ε_r 490). The other one is slurry of D_2O and calcium titanate powder (σ 0.97 S/m, ε_r 319). Using FA mapping method (using pre-saturation pulses) [5], we acquired FA maps in the presence of a dielectric pad and/or without pad with imaging parameters of TR/TE=3000/2.56 ms, FOV=220×220 mm^2, matrix size=256×256, slice thickness=10 mm, and average=32. A rectangular saturation RF pulse with 2 ms duration of FA was utilized. Total acquisition time was 3 min 12 sec each. The 6-channel U-shaped Rx-array was placed under the phantom, so 7-channel Rx-array was used. We manually applied same reference voltage (30 V) to the RF power amplifier for each case to keep the same input power to the coil. The coil was tuned to 297.2MHz and matched to -30 dB or better for each case.

Results and Discussion: The average B_1^+ in the phantom near the dielectric pad is summarized in Figure 2. The averaging area in the phantom is within one radius of phantom at the coil location. In Figure 2, the maximum averaged-B_1^+ gradually decreased to the pad conductivity increased. However, the maximum averaged-B_1^+ was observed when the pad permittivity was about 300 for any conductivity. It means that the higher pad permittivity does not always promise the best local B_1^+ or sensitivity. In the simulations, we observed that the maximum local B_1^+ strength (close to pad location) was observed at the highest pad permittivity (Figures are not shown here). We verified our observations in simulations by comparing FA mapping experiments at 7 T in the cases of (1) without pad, (2) with pad having ε_r of 319, and (3) with pad having ε_r of 490 as shown in Figure 3. When the highest pad permittivity (ε_r 490) was used, a very high FA is observed at very near the pad, but in a very small region on the surface of phantom. When the pad ε_r was 319, the maximum FA was smaller than that for ε_r of 490 and higher than ε_r 1 (no pad), but the high FA values were much more evenly distributed than ε_r 490 case, leading to the highest average in the optimization region. The averaged FAs for (1) without pad, (2) with pad (ε_r 319), and (3) with pad (ε_r 490) were 36.8, 49.7, and 35.9 degrees, respectively. In this study, we only varied the pad permittivity. Better results could be expected if the pad geometry or dimension is also optimized.

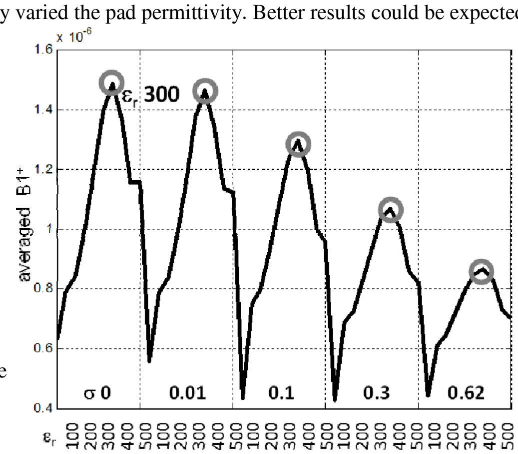

Figure 2. Averaged B_1^+ at each conductivity and permittivity combination. Circles indicate the maximum average B_1^+ and ε_r 300 position at each conductivity value.

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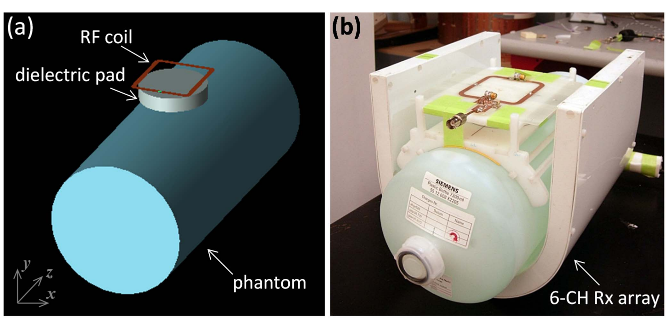

Figure 1. (a) EM field simulation setup in XFdtd. Teflon plates (top and bottom of dielectric pad) are removed for better visualization. (b) 7 T experiment setup. Cylindrical-shaped dielectric pad is placed between one-loop coil and phantom (not shown).

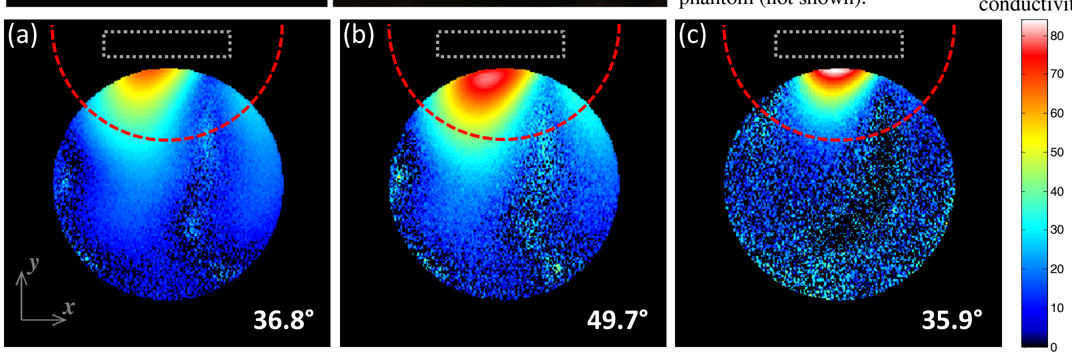

Figure 3. Flip angle maps (a) without pad, (b) with pad (ε_r=319), and (c) with pad (ε_r=490). The dielectric pad is located top of phantom (grey dotted line). Averaged FA values within the optimization region (red dotted line: 84 mm from coil center) are shown bottom right at each FA map.