Changes in neighbor and next-nearest-neighbor coupling of transmit/receive arrays in the presence of close-fitting high permittivity materials

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Target Audience: RF coil engineers interested in improving tight fitting transmit arrays by incorporating high permittivity materials.

Introduction: Previous work has shown that the use of high permittivity materials (HPMs) can improve coil performance at ultra high field[1-3]. Much recent experimental work performed with HPMs has been done with prefabricated coils and/or standardized clinical coils, built without the use of dielectric materials in mind[4-6]. Much of the initial work performed with HPMs was under the guidelines of a large transmit coil and close-fitting HPM pads. However, recent experimental work has shown that close-fitting transmit coils may benefit in both transmit efficiency and homogeneity with the addition of HPM placed between the coil and the subject[7]. Close-fitting transmit arrays are, naturally, closer in proximity to the HPM, and therefore more at risk of interacting closely with the HPM. Here we explore how HPM proximal to a set of three geometrically decoupled coils affects their performance and decoupling. Additionally, we explore how this affect may influence results obtained with tight fitting arrays when the coil coupling is not adjusted for the presence of HPMs.

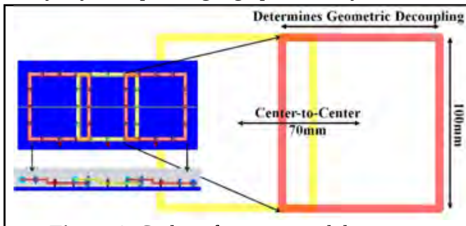

Figure 1: Coil configuration and dimensions

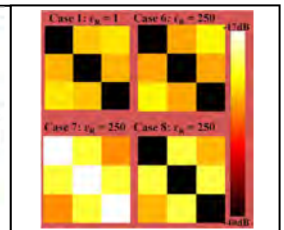

Figure 2: Coupling matrices

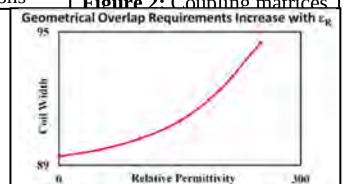

Figure 3: Geometrical Decoupling

Methods: Simulations were performed using Microwave Studio (CST 2013, Darmstadt, Germany). Three square coils were placed on top of a large square HPM pad (400x400x5mm, ε_R variable, $\sigma = 0$ S/m) and a large rectangular block loading phantom (400x400x150mm, $\varepsilon_R = 57.5$, $\sigma = 0.8$ S/m). A 5mm gap was placed both between the phantom and the HPM, and between the HPM and the coil. The coils were given a defined length (10cm) and spaced 7cm apart, and the center-to-center distance was held constant. Their widths were then adjusted for each case to vary coil overlap and find the ideal geometric decoupling. A 3mm gap was set as the overlap spacing, with each coil bent to allow equal phantom loading for all coils (Figure 1). Six cases of relative permittivity for the HPM were analyzed for coupling parameters, and defined as cases 1-6 (Table 1): $\varepsilon_R = 1$ (air), 50, 100, 150, 200, and 250. These cases were tuned and matched at the proton frequency for 7T, and for all cases the conductivity of the HPM was set to zero. Two additional cases were also analyzed for $\varepsilon_R = 250$. In case 7 the coil array from the $\varepsilon_R = 1$ case was simulated overthe HPM ($\varepsilon_R = 250$), with no tuning, matching, or decoupling adjustments. Case 8 uses the $\varepsilon_R = 1$ overlap condition, and therefore is not optimized for decoupling, but was adequately tuned and matched. Once the ideal overlap was determined, each case was analyzed for transmit efficiency with two separate metrics: $B_1^+/\sqrt{SAR_{10gPeak}}$ and $B_1^+/\sqrt{Power_{Accepted}}$. Coils were combined such that their B_1^+ added constructively at an ROI at a 3cm depth from the surface at the center of the phantom. Each port was given a 1V input voltage.

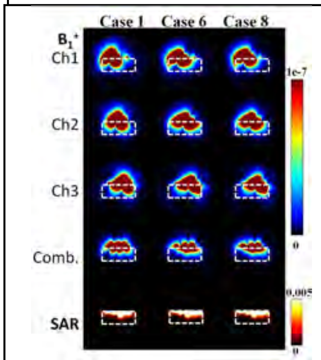

Figure 4: Individual coil B1+(Vs/m[2]), and Coil Combined 10g SAR(W/kg) maps.

Results: Figure 3 shows geometric overlap required to minimize coil coupling, and resulting coupling parameters are listed in Table 1. Coils exhibited increased coupling in the presence of the HPM, requiring a larger overlap to create minimal coupling. All coils were tuned and matched to -40dB in simulation, and all coils optimized for the HPM showed $S_{12} \leq$-23dB. In Figure 2 we see that with geometric coupling optimized the coupling matrices for large variations in relative permittivity are comparable. However, we also see that for case 7, tuned and matched for air, the S_{11} values were severely degraded with the addition of the HPM with $\varepsilon_R = 250$, and it appears that the addition of the HPM substantially changes the match of the coil. When examining the coils' output impedance of each HPM case prior to matching there is a dramatic shift in the presence of HPM, moving further away from 50Ω with higher relative permittivity values. When case 7 was re-matched in the presence of the HPM the S_{11} performance is recovered, and an adequate comparison of the effect of the diminished geometric decoupling can be seen (case 8). Figure 4 shows individual channel and channels combined B_1^+, as well as the 10g Specific Absorption Rate (SAR) maps for the combined case through the coil array center. Transmit efficiency is shown in Figure 5, where a clear benefit is seen by adding HPM with ε_R=250. This benefit is seen with (Case 6) and without (Case 8) correcting for changes in coupling in the coils. However, optimizing the geometric decoupling for the presence of the HPM allows for improved benefit over the non-optimized case.

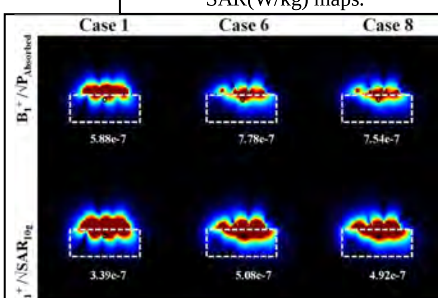

Figure 5: Transmit efficiency maps ($B_1^+/\sqrt{SAR_{10g}}$ or $B_1^+/\sqrt{}$ (Power absorbed in phantom) through coil array center for cases 1, 6, and 8. White numbers indicate transmit efficiency for point of interest.

Discussion and Conclusions: The required geometric overlap for ideal decoupling was found to increase with increasing relative permittivity. For a transmit/receive coil array, the presence of close-fitting HPM can significantly alter the coil performance, especially if the coil is not is re-tuned and re-matched in the presence of the HPM. Coil coupling will also be affected by the introduction of close-fitting HPM, but if this is not corrected for it will provide a much smaller loss to the system. Coupling does appear, however, to be correlated in a more-than-linear way to relative permittivity of the close-fitting HPM, so coupling could become a critical issue for high relative permittivities. We hypothesize that the presence of conductivity within HPMs will also have an effect on the coil interactions, and will be explored in future work. It should be noted that the coils matched in the presence of a HPM required a larger compensation in the match circuit, correlating with increasing permittivity. This suggests that the HPM close to the coil may be interacting capacitively with the drive point, which will also be explored further in future work.

Table 1: Coil cases and corresponding dimensional data. Width in mm.

Case #	Relative Permittivity	Width	Overlap %	S_{12} (nearest nieghbor)	S_{13} (next-nearest neighbor)
1	1	89.4	21.7%	-24.76dB	-23.68dB
2	50	89.7	22.0%	-24.34dB	-23.74dB
3	100	90.2	22.4%	-23.79dB	-23.64dB
4	150	91	23.1%	-23.36dB	-23.17dB
5	200	92.4	24.2%	-23.37dB	-23.51dB
6	250	94.5	25.9%	-25.72dB	-23.17dB
7	250	89.4	21.7%	-21.50dB	-26.69dB
8	250	89.4	21.7%	-21.38dB	-25.25dB

References: [1]Webb. C MR 2011; 38A:148.[2]Yang et al. MRM 2011; 65:358. [3]de Heer. MRM 2012; 68:1317.[4]Rupprecht et al. ISMRM 2014; p403. [5]Sica et al. ISMRM 2014, p405; [6]Wezel et al. ISMRM 2014; p1450. [7] Collins et al. ISMRM 2013; p404.