Extending the sensitivity of a transmit/receive radiofrequency coil with dielectric materials at 7 T

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TARGET AUDIENCE: Radiofrequency (RF) engineers and those interested in using dielectric materials at ultra high field.

PURPOSE: Receive arrays of small RF surface coils can provide high signal-to-noise ratio (SNR) over an extended field of view (FOV) [1]. High permittivity material (HPM) placed below an RF coil can increase transmit (Tx) efficiency, SNR and B_1 homogeneity [2]. Recently, it was shown that discs of HPM placed at a distance from an RF coil can shape the electromagnetic (EM) field distribution in the sample, improving Tx and receive (Rx) homogeneity, and broadening coil sensitivity over a larger FOV [3]. The use of HPM to extend the FOV covered by an RF coil could possibly increase the performance of Tx/Rx arrays, while reducing the number of coil elements and maintaining essential performance. However, noise susceptibility over a larger area may reduce the SNR as compared to a receive array with more elements covering an equivalent FOV. To investigate these relations, here we compared in simulations the SNR and the Tx efficiency for the following cases: a single large loop, a small loop with three discs of HPM and an array of three small loops. All three geometrical arrangements approximately covered the same region of the object (Fig. 1).

METHODS: We used a finite integration technique based method (CST studio suite 2013, Germany) to calculate the EM field in a uniform cylindrical phantom ($\varepsilon_r = 57.5$ $\sigma = 0.8$ S/m) for the three cases shown in figure 1. Voltage sources were used in all cases and the RF coils were tuned at 7T with S11 less than -20 dB. All EM fields were calculated at the proton frequency and analyzed for a transverse section through the center of the coil/array. The SNR was calculated using the Roemer-optimum method (1). Tx efficiency was calculated as the $|B_1+|$ field divided by the square root of the dissipated power within the entire phantom. HPM discs with $\varepsilon_r = 500$ and $\sigma = 0$ S/m were used for the case with a single small RF coil and three dielectric discs (Fig 1B). For the case with three loops, the phase of each Tx coil was adjusted to approximate circularly-polarized mode near the center of the transverse plane.

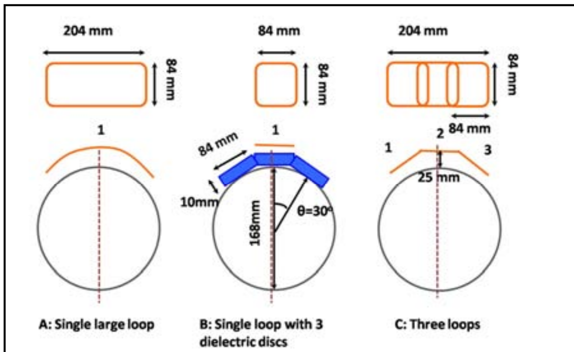

Fig. 1. Simulation set-up with a large surface coil (A), the combination of a small surface coil with three dielectric discs (B) and an array with three surface coils (C), all covering the same portion of the object. Top view of the coil conductors (orange) is shown on the first row. Dielectric discs are depicted in blue, whereas the gray circle indicates a transverse section of the phantom through the center of the coil/array. The length of the phantom was 400 mm. The distance of the coils from the phantom was 25 mm in all cases. Red dotted line indicates the line along which the profiles were measured (Fig3).

RESULTS: Extending the sensitivity of the small RF coil with HPM discs increased both overall SNR and Tx efficiency compared to the large RF coil covering an equivalent FOV (Fig 2). Tx and Rx homogeneity also improved considerably. Tx efficiency and SNR along a central profile (Fig. 3) were about 30% and 15% higher, respectively, for the array of three loops compared to the single coil with three dielectric discs. Tx efficiency and SNR were 60% and 75% lower for the large surface coil compared to the small loop with dielectrics, except near the center of the object where the large coil had a slightly better (~5-8%) performance.

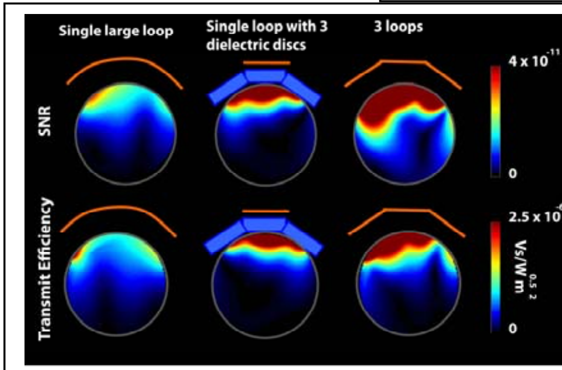

Fig. 2. SNR and transmit efficiency for the three coil configurations in the transverse section through the center of the coil/array.

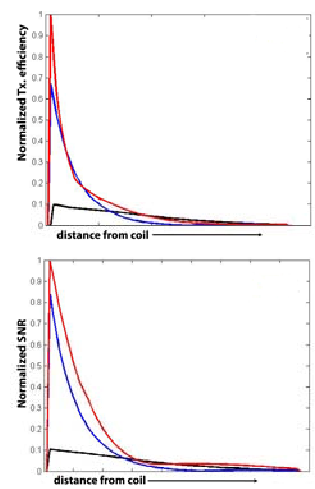

Fig 3: Profiles in the center of the transverse section. The performance of the 3-element array (red) is higher than that of a small loop with 3 dielectric discs (blue) and a large loop (black) with the same total dimensions. Values are normalized to the maximum in both plots.

DISCUSSION AND CONCLUSIONS: The magnetic field induced by the displacement currents within the dielectric discs contributes to the total B_1 field transmitted and received [2]. We showed that the presence of HPM extended the local Tx efficiency and SNR performance of a small loop over a larger FOV. The fact that the overall SNR and Tx efficiency were better than for a large surface coil suggests that the presence of HPM does more than extending the electrical length of the coil conductors. The performance of the large surface coil was slightly better in the center of the object, due to deeper penetration of the associated EM field. As expected, the performance of the three-element array was higher than for the single coil with the dielectric discs. However, the difference was small enough to suggest that the use of HPM could be a viable solution when, for example, only one or a few Tx/Rx channels are available. Although RF power can be split among multiple Tx coils, limitations on the output of the RF power amplifiers and safety considerations may still favor replacing some elements in a Tx array with discs of HPM. These advantages must be balanced with expectations that reducing the number of Tx coils would reduce flexibility for RF shimming and parallel Tx techniques, while broadening coil sensitivity could penalize the performance of parallel Rx techniques. Future work will include investigating the effect of adding HPM in Tx/Rx on the overall array performance.

REFERENCES: 1) Roemer et al., MRM 192-225 (1990) 2) Webb et al., C MR Part A, 38A(4) 148–184 (2011) 3) Vaidya et al., ISMRM p 4472 (2013)