# High-permittivity Materials can Improve Global Performance and Safety of Close-Fitting Arrays

Christopher M. Collins[1], Giuseppe Carluccio[1], Manushka V. Vaidya[1], Gillian G. Haemer[1], Wei Luo[2], Riccardo Lattanzi[1], Graham C. Wiggins[1], Daniel K. Sodickson[1], and Qing X. Yang[3]

*[1]Bernard and Irene Schwartz Center for Biomedical Imaging, Department of Radiology, New York University School of Medicine, New York, NY, United States, [2]Bioengineering, The Pennsylvania State University, PA, United States, [3]Radiology, The Pennsylvania State University, PA, United States*

**Audience:** All interested in improved performance and safety of MRI through engineering of RF Coils and Fields.

**Purpose:** Demonstrate the potential of high-permittivity materials (HPMs) combined with a close-fitting array to reduce SAR and improve SNR in the region encompassed by the array.

**Introduction:** In recent years, HPMs have shown great promise for improving SNR and reducing SAR in a number of applications at 3T and 7T (1, 2). While most work with HPMs has been focused on improving SNR or transmit efficiency for a relatively small region within a much larger coil or array, here we demonstrate that HPMs can also improve performance of small coils very near the subject, as well as arrays of such coils for the entire region of the anatomy they encompass. Here we introduce theoretical mechanisms for how this can occur before presenting numerical demonstrations that HPMs will, indeed, increase SNR within the entire cerebrum and reduce SAR for a specific close-fitting HPM/array combination at 7T.

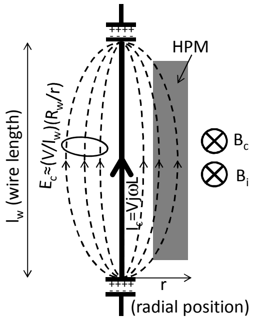

**Figure 1.** Schematic illustration of a conductive segment near a high permittivity material (HPM), the current in the coil $I_c$, conservative electric fields through space $E_c$, and magnetic fields produced by $I_c$ ($B_c$) and induced by $E_c$ ($B_i$).

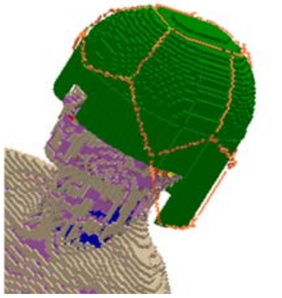

**Figure 2.** Geometry of transmit/receive array model based roughly on existing 7T array (7). For single-coil simulations, the coil most visible on the left side of the head is driven. Coil former (green) is alternately assigned properties of air or realistic HPM.

**Theory:** For a conductive segment of an RF coil near an HPM, it is possible (using inductance of the coil segment L, required voltage to drive a current I at frequency ω, and resulting near-field E and B) to calculate the displacement currents in the HPM and show that they will add to the magnetic fields within the nearby sample for a given coil current. For example, a 1cm-thick HPM with $\varepsilon_r$=300 positioned 5mm from a 1-cm diameter conductive tube at 3T will cause more than a 15% higher magnetic field in the sample adjacent the HPM than would the conductive current alone. Additionally, in the near field of the conductive segment (having a different E/H ratio than the far field) it can be shown that the optimal materials for impedance matching typically have a higher permittivity than those of human tissues (3). Both the displacement current and matching mechanisms lead to directionality in field propagation preferentially towards the sample from the coil, or into the region of the sample encompassed by an array of coils. Additionally, because the displacement currents are, by nature, more distributed than the conductive currents, the result is safer (inducing lower peak local SAR) than if the conductors were simply moved closer to the subject. The net result is stronger coupling to the region of interest (ROI) relative to the rest of the body, and thus higher SNR in reception and lower SAR in transmission.

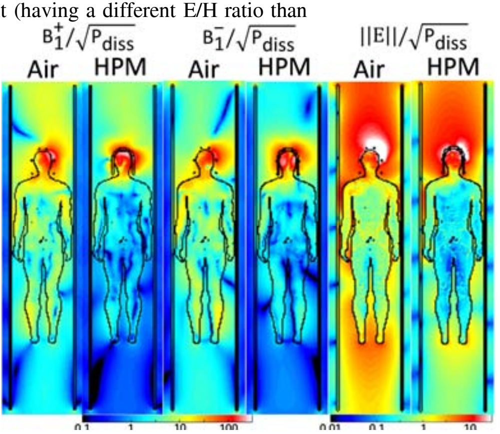

**Figure 3.** Transmit efficiency (nT/√W), receive efficiency (nT/√W), and normalized E fields (V/m/√W) throughout the subject and bore for a single surface coil adjacent the head with and without the presence of an HPM coil former (green in Fig. 3). All fields are stronger in the ROI (head region) and lower elsewhere in the body, indicating better sensitivity to signal in the ROI and less sensitivity to noise from the rest of the body (better SNR), as well as less total subject heating during transmission, when the HPM former is used.

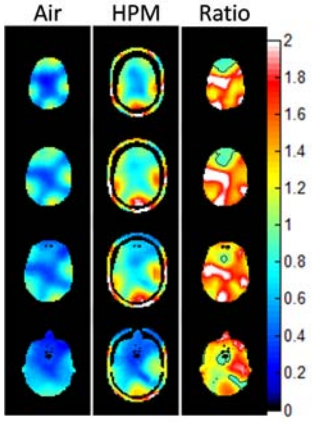

**Figure 4.** SNR for 8-channel Rx array of Fig. 1 without (left) and with (center) the HPM coil former present, and the ratio of SNR with the HPM to that without it on four transverse slices through the head spaced 2.5cm apart, covering the brain. SNR plots (left and middle) are on the same linear scale (arbitrary units). Numbers on colorscale correspond to ratios (right column).

**Methods and Results:** An 8-element, 7T, transceive array was simulated on a 5mm-thick helmet-shaped former about the head of a numerical model of the human body ("Duke") within a conductive magnet bore, as shown in Figure 2. The former was alternately assigned dielectric properties of air or a slurry of Barium titanate powder and water (4). When a single coil is driven, it is seen that use of the HPM increases transmit and receive efficiency to the ROI surrounded by the HPM while reducing coupling (E and B fields) to the rest of the body. When SNR for the entire array is calculated with appropriate consideration of fields and noise resistance matrix throughout the subject and former (5), it is seen that many regions of the brain experience more than a 2-fold enhancement in SNR (Fig. 4), with an average improvement throughout the cerebrum of 48%. It is also shown that the presence of the HPM does not reduce efficacy of RF shimming during transmission (Fig. 5), but in fact increases transmit efficiency (resulting in reduced SAR for a desired $B_1$ strength) for the entire array (Fig. 5, Table 1), just as it does for individual coils (Fig. 3).

**Table1:** Percent *reduction* in SAR levels when shimming the array of Fig. 1 for maximum transmit efficiency to the center of brain with the HPM coil former compared to shimming for maximum transmit efficiency without it. In each case, the coil is driven to produce the same average transmit $B_1$ field strength on center axial slice through the brain.

| Whole Body Ave. SAR reduction | Head Average SAR reduction | Max 10g SAR reduction |
|---|---|---|
| 69.1% | 65.3% | 69.5% |

**Discussion:** Strategic use of high-permittivity materials in MRI has the potential to improve SNR and simultaneously reduce SAR. The mechanisms involved are in addition to (and not in competition with) those of field strength (which results in both increased SNR and increased SAR) and multi-channel transmission or reception. It has also been shown recently that a coil former similar to that simulated here can improve transmit efficiency (reduce SAR) for a large (body-size) encircling array or a patch antenna. These results coupled with previous ones (1-4, 6) indicate that HPMs can improve MRI at a given field strength significantly, and should be pursued and developed further.

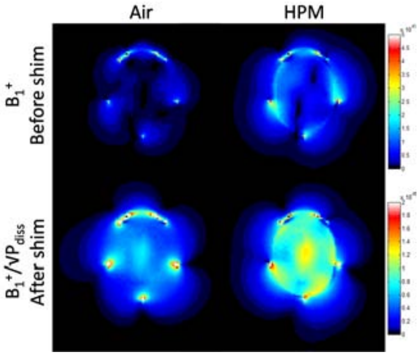

**Figure 5.** Simulated $B_1^+$ for equal current in all coils (top) and transmit efficiency for shim to produce circular polarization at the center of brain (bottom) without (left) and with (right) HPM coil former for the array of Fig. 1. As for any one coil, transmit efficiency is much better for the transmit array when the HPM former is present.

## References:

1. Yang QX *et al*. MRM 2011;65:358-362
2. Webb AG. Concepts in MR 2011;38A:148-84
3. Carluccio G *et al*., 2013 ISMRM, p. 4374
4. Luo W *et al*., MRM 2013;70:269-275
5. Roemer PB *et al*. MRM 1990;16:192-225
6. Collins CM *et al*., 2013 ISMRM, p. 2797
7. G Haemer *et al.,* 2013 ISMRM, p. 2749