SAR Reduction in RF Shimming through the use of High Permittivity Materials: approach towards the Ultimate Intrinsic SAR

Gillian G Haemer[1,2], Manushka V Vaidya[1,2], Christopher M Collins[1,2], Daniel K Sodickson[1,2], Graham C Wiggins[1], and Riccardo Lattanzi[1,2]

[1]The Center for Advanced Imaging Innovation and Research, and the Center for Biomedical Imaging, Department of Radiology, New York University School of Medicine, New York, NY, United States, [2]The Sackler Institute of Graduate Biomedical Sciences, New York University School of Medicine, New York, NY, United States

Target Audience: RF coil engineers and anyone interested in using high-permittivity materials to improve RF coil performance.

Purpose: Transmit/receive coil designs are traditionally placed ≥1cm from the subject for safety. This space is available to be filled with high-permittivity, low-conductivity materials (HPMs), which can improve coil performance both in terms of signal-to-noise ratio (SNR)[1-3] and specific absorption rate (SAR)[1,2,4,5]. Utilizing a dyadic Green's function (DGF) framework for electrodynamic simulations in multi-layered spherical geometries[3,6], we investigated the effects of HPM on absolute RF shimming performance for transmit arrays at 7T.

Methods: Ultimate Intrinsic SAR (UISAR)[6] was calculated for excitation of a uniform flip angle (FA) distribution on a transverse plane through the center of a homogeneous 8.4cm radius sphere with the electrical properties of average brain tissue[7] (ε_R = 63, σ = 0.46), and an ideal current distribution defined at a 1 cm distance from the sphere surface (r_c = 9.4cm). The following three cases were simulated: the space between the currents and the object filled with air (ε_R = 1, σ = 0), filled with HPM (8.4cm≤r_{HPM} ≤ 9.4cm, ε_R variable, σ = 0), and half filled with HPM (8.4cm≤r_{HPM} ≤ 8.9cm, ε_R variable, σ = 0) (Fig 1b). We employed an RF shimming algorithm with regularization term (λ) adjusted to control the trade-off between profile fidelity and minimization of global SAR. The same algorithm was applied to closely packed transmit arrays with an increasing number of elements[8]. L-curves[9,10] showing the tradeoff between FA homogeneity and SAR were generated by plotting absolute array performance, defined as global SAR divided by UISAR, as a function of the root mean square error (RMSE) of the achieved excitation profile for various degrees of regularization. Relative permittivity of the HPM was varied to determine the optimal value for each coil setup, shown by the L-curve closest to the origin.

Results: In the absence of HPM, L-curves approached the optimal performance (dashed line) as the number of transmit elements was. increased (Figure 1). The effect of adding an HPM layer with different ε_R for the 48-element array is shown in Figure 2. Performance improved for ε_R ≤ 100 but degraded when ε_R was increased beyond this point. Optimal relative permittivity values for 24 and 32 coils were 175 and 150, respectively (Table 1), whereas optimal performance for a 64-element array was achieved for a range of permittivity values (50≤ε_R≤150). RF power requirements (rightmost column, Table 1), calculated by adding resistive losses in the coil conductors to global SAR[11] were considerably reduced by the use of the optimal HPM. By using HPM the 32 and 48 element arrays approached and exceeded, respectively, the performance of the 64-element array with no HPM (Figure 3). Furthermore, 24 elements with optimal HPM performed as well as 48 elements without HPM (not shown). When the coil-to-phantom space was half filled with HPM we found identical L-curves to the HPM-filled case (as in Figure 2), but the ε_R values required to obtain them were approximately twice as high.

Discussion: We have demonstrated that the DGF approach can be used to determine the ideal HPM for approaching UISAR with a given number of transmit channels. Adding a layer of HPM in the space between the coils and the object can improve performance considerably, especially when a limited number of transmit channels are available. For large arrays, e.g. 64 coils, the benefits of adding HPMs are smaller and less dependent on permittivity, suggesting that there is a limit at which the number of elements alone may saturate the ultimate performance. Relative permittivity values near the optimum resulted in similar performance, suggesting that high precision in achieving specific dielectric properties of the HPM in practice would not be necessary. As might be expected from equivalence principle arguments, and as we have confirmed in simulations, UISAR itself is not affected by the addition of zero-conductivity HPM, regardless of its permittivity. UISAR therefore serves as a useful reference. Further work would be required to determine the effects of conductivity in the HPM on UISAR and power requirements.

Conclusions: We showed that for finite arrays with a relatively small number of elements SAR could be substantially reduced for a given excitation fidelity in RF shimming with the use of integrated HPMs, likely due to a combination of mechanisms which will be explored in future work

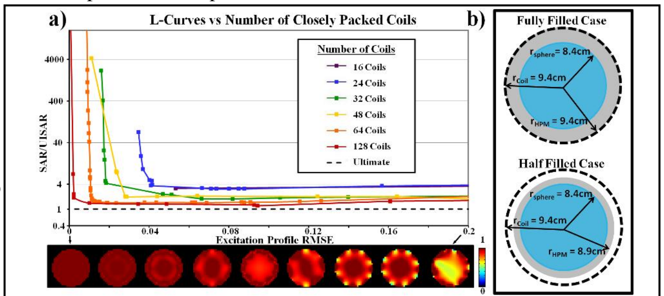

Figure 1: (a) L-curves for various transmit arrays in the absence of HPM. (b) Simulation setup for two HPM cases tested.

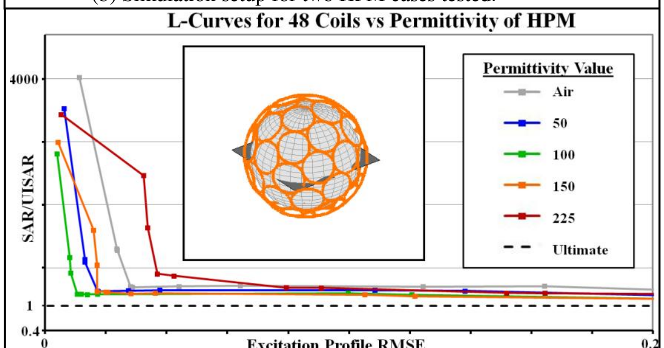

Figure 2: L-curves for 48 coils with varied relative permittivity with HPM (8.4≤r_{HPM} ≤ 9.4). HPMs initially improve performance (blue/green lines), but degrade performance when ε_R is too high (red/orange lines). Coil packing shown in inset including excitation plane

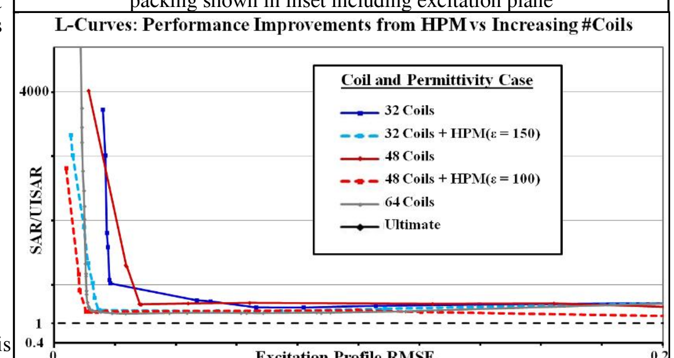

Figure 3: L-curve analysis comparing the performance improvements in 32 and 48 element arrays to the performance of 64 elements with no HPM.

Table 1: Quantitative differences with the addition of near optimum HPM.

#Coils	Permittivity	$RMSE_{HPM}/RMSE_{Air}$	SAR_{HPM}/SAR_{Air}	$Power_{HPM}/Power_{Air}$
24	175	0.5513	0.5510	0.5896
32	150	0.7846	0.5854	0.3853
48	100	0.3764	0.5525	0.4454
64	50-150	0.4605	0.6773	0.7547

References: [1] Webb. CMR 2011; 38A:148. [2] Yang et al. MRM 2011; 65:358. [3] Lattanzi et al. ISMRM 2014, p4818. [4] Brink et al. MRM 2014; 71:1632. [5] Collins et al. ISMRM 2014, p404. [6] Lattanzi et al. MRM 2009; 61:315. [7] Wiesinger et al. MRM 2004; 52:376. [8] Hardin. *Points on a Sphere*. 1994. [9] Guerin et al. MRM 2013; 71:1446 [10] Lawson and Hanson. *Solving Least Squares Problems*. New Jersey, 1974. [11] Deniz et al. ISMRM 2009, p4802.