Electromagnetic simulations of high dielectric materials at 7 Tesla

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Introduction. The use of high dielectric constant materials is a simple approach to tailor the RF field distribution for high field MR imaging and spectroscopy [1,2]. Mixtures of different compounds can be used to produce a wide range of dielectric values. To date there has been little systematic study of how the geometry and distribution of such materials affect the distribution of the RF field, and how different configurations are optimal for different applications. Here we present a series of electromagnetic simulations exploring the general behaviour of such dielectric material.
Methods. Electromagnetic simulations were performed for 7 Tesla MRI ((298.1 MHz) using a discretized model of the human head and shoulders with a finite-difference time-domain (FDTD) method using commercially-available software (xFDTD, Remcom Inc, State College, PA, USA). All dielectric materials were modelled as having a loss tangent of 0.05 [1]. To enable direct comparison of simulation results with experimental results a model of theNova Medical transmit/receive birdcage head coil was used.
Results. Figure 1 shows illustrative results from a number of different dielectric geometries which have been approximated in practise [1,2]. Figure 1(a) provides a reference with no dielectric material. In (b), adding a dielectric cylinder with ε_r=80 smooths out the B_1^+ distribution and makes it much stronger in the neck region (useful for ASL labeling below the cerebrum). Increasing ε_r to much larger values (c) introduces severe non-uniformities into the image which arise because of wave behaviour from the displacement currents present in the dielectric. A more practical implementation is to use rectangular pads. Two placed on either side of the head (d) improve the B_1+ homogeneity over the brain, and increase the field significantly in the temporal lobes [2]. If the pads are made shorter, then the local gain in B_1^+ is larger, but there are non-uniformities introduced at the ends of the pads. In (f) a pad with a large ε_r placed only on one side increases the local field significantly, but also causes a large decrease in the field at locations deeper within the brain. One way to avoid wave behaviour in the dielectric is to split it into separate pieces. In (g, sagittal view) and (h, coronal view) a single large dielectric pad with high ε_r is placed at the back of the head, resulting in significant wave behaviour, especially within the pad. This can be reduced by using an equivalently sized pad split into twelve equally sized compartments, as shown in (I,, sagittal view) and (j, coronal view).

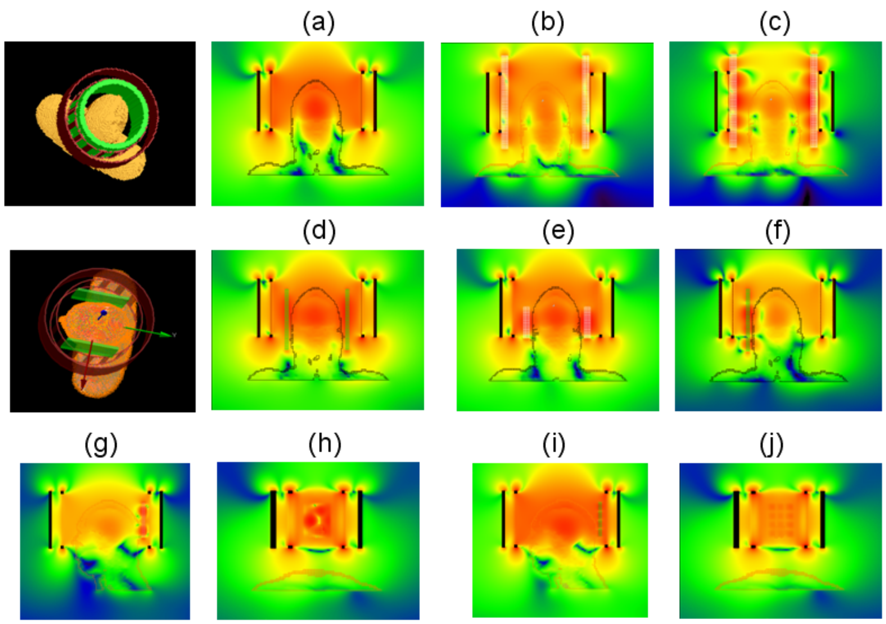

Figure 1. Rotating B_1^+ fields. (a) RF coil with no dielectric insert. (b) Dielectric cylinder, ε_r=80. (c) Cylinder, ε_r=150. (d) Two long dielectric pads, ε_r=100. (e) Two short pads, ε_r=100. (f) One dielectric pad, ε_r=150. (g) and (h) One large dielectric pad at pack of head, ε_r=300. (i) and (j) Equivalent pad split into twelve equal sized pads, ε_r=300.

Discussion. High-dielectric suspensions of metal titanates can be used to tailor the RF field distribution at high static magnetic field strengths. The field distributions can be optimized for maximum global homogeneity or local intensity by varying the geometry, size, position and number of dielectric elements. This work gives some general insights for specific applications.
References. [1] K.Haines, N.B.Smith and A.G.Webb, J.Magn.Reson., 203, 323, 2010. [2] J.M.Snaar et al. NMR in Biomedicine, in press, 2010.