Drastic Enhancement and Manipulation of RF Field with Ultra High Dielectric Constant (uHDC) Material at 3T

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Introduction: Recent experiments utilizing high dielectric constant (HDC) pads have shown improved efficiency of both transmission (B_1^+) and reception (B_1^-) fields at 3 T and 7 T [1~5]. The HDC materials used in the previous studies were water (ε_r = 70), water based slurry (ε_r = 100) or beads (ε_r = 515). In this study, we explored the effect of ultra-high dielectric constant (uHDC) monolithic materials with ε_r up to 1200 on RF fields at 3 T. We demonstrated that the RF field can be greatly enhanced with UHDC material, leading to as much as 27-fold reduction of transmission power for a given sample.

Method: The experiments were carried out with monolithic blocks (101 mm x 77 mm x 14 mm) with ε_r = 800 and ε_r = 1200, respectively. A rectangular bottle filled with gadolinium-doped distilled water was covered with five uHDC blocks as shown in Fig. 1. All images were acquired on a Siemens 3T Tim Trio System using a 12-element head array in the same position for all three conditions indicated in Fig, 2 and 3. B_1^+ maps were acquired using the AFI technique [6] with RF gradient spoiling [7] and non-selective hard pulses applied. To calculate receive sensitivities, non-selective 3D GRE scans with TR = 100 ms, low flip angle (FA), RF and gradient spoiling [8], and matrix size identical to the AFI scan were acquired. The transmit factor ($\frac{1-E_1*\sin(FA)}{1-E_1*\cos(FA)}$) was computed with the flip angle map obtained from the AFI scan and subsequently divided out of the GRE images, yielding a B_1^- weighted image. An additional noise scan was acquired with the RF transmission disabled. SNR scaled images [9] were computed from the 3D GRE scans and the noise covariance matrix calculated from the noise scan. The SNR scaled images were normalized to the case with no UHDC material present.

Results: As shown in Fig. 3. uHDC materials drastically changed the RF field distribution. The RF field was intensely "*focused*" into the region covered by the uHDC material. B1+ is increased 100% by 800-permittivity block and more 500% with permittivity-1200 block. The enhancement of B_1^+ resulted in a 3, respectively 27-fold transmission power reduction (see table 1). The B_1^- from the receive array coil exhibited the same trend of enhancement with a smaller magnitude, leading to images SNRs increase by more than 40% on average in the given ROI (Fig. 2).

Discussion: The drastic RF field changes with UHDC material demonstrated here can have a profound impact on RF field engineering. Most interestingly, the transmission field produced by the body coil was was focused in the region enclosed by the UHDC material, resulting a *several-fold* reduction in transmission power, and subsequently, the SAR. In most MRI studies, the local imaging of body parts is subject to whole-body RF SAR restriction. With uHDC material, RF exposures to the human body can be greatly reduced. This experiment was conducted based on the available uHDC material. It is likely the current condition is suboptimal. More improvement can be achieved with even higher relative permittivity, considering the drastic SNR increase in the regions near the blocks at ε_r = 1200 in Figure 2.

Conclusion: Our experimental results at 3T showed that utilization of uHDC materials can potentially achieve several-fold improvements in RF transmission and reception efficiencies with standard hardware. Particularly, the drastic reduction of transmission power will greatly improve imaging acquisition speed while maintaining patient safety. The strong capability of of uHDC material in enhancing and manipulating RF field shown here opens a new avenue for RF field engineering.

	ε_r=1200	ε_r=800
$\frac{P_\varepsilon}{P_{no\ block}}$	0.036	0.277

Table 1: Transmission power reduction: Power with uHDC divided by no block case normalized to 60˚ FA (up to 27 fold less power)

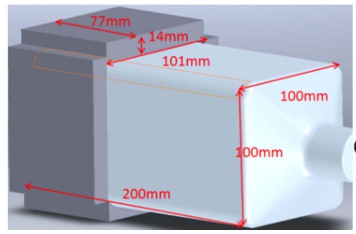

Fig. 1: The phantom (white), placed parallel to the z axis and four identical dielectric blocks (grey) of the same permittivity positioned around the bottle.

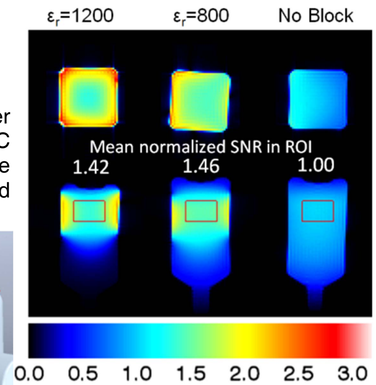

Fig. 2: Signal to noise ratio (SNR) maps for the transverse (upper row) and sagittal (lower row) slices of all three configurations with mean normalized SNR in ROI's. The transverse slice is perpendicular to the ROI centerline in the coronal slice.

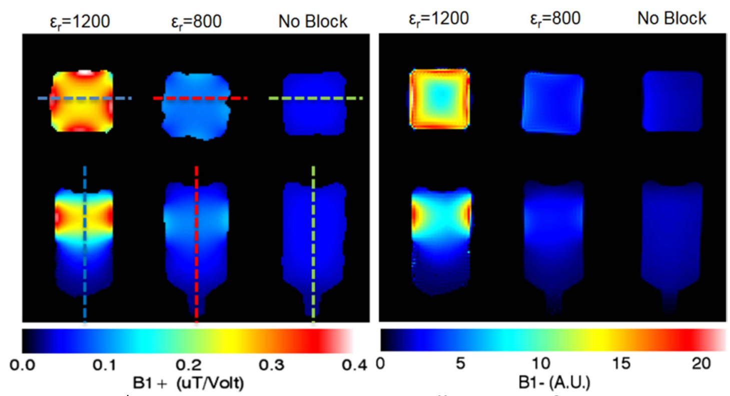

Fig. 3a: B_1^+ and B_1^- maps obtained with different uHDC blocks and no-block case. B_1^+ maps are normalized to a transmit voltage of 1V..B_1^- in arbitrary units (AU).

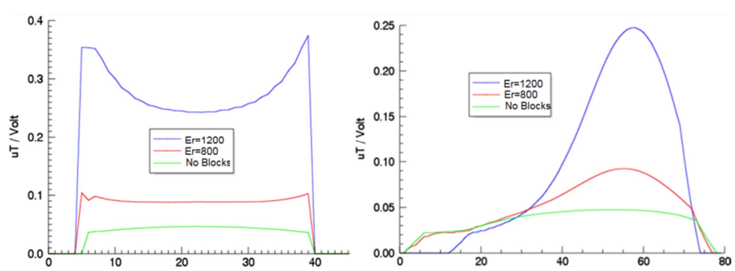

Fig. 3b: Profile plots of all three cases in B_1^+ as shown in 2a: from left to right through the center of the axial slice (left) and bottom up through the coronal slice (right).

References: [1] Yang *et al.*, JMRI 2006. [2] Yang *et al.*, MRM 2010. [3] Teeuwisse *et al.*, MRM 2011. [4] Teeuwisse *et al.*, MRM 2012. [5] Luo *et al.*, MRM 2011. [6] Yarnykh, MRM 2007 [7] Nehrke, MRM 2009 [8] Yarnkyh, MRM 2010 [9] Kellman et al., MRM 2005

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