RF Safety Validation of High Permittivity Pads at 7 Tesla

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Target audience: Researchers with interest in RF shimming and RF safety at high fields

Purpose: RF shimming using dielectric pads has been shown to be useful by various authors, with an improved RF transmit field (B_1^+) fidelity [1,2]. Analyses of the specific absorption rate (SAR) in such configurations are typically based on electromagnetic (EM) simulations using approximate numerical methods and discretized body models [3]. The aim of this study is to further validate the accuracy of these methods inside a phantom configuration using RF near-field probes.

Methods: A homogeneous head and shoulders phantom was used to mimic the overall geometry of the human head and induce realistic coil loading. The phantom was filled with tissue simulating liquid which had a relative permittivity of $\varepsilon_r = 50$ and an electrical conductivity of $\sigma = 0.603$ S/m, as characterized using a dielectric probe kit (85070E, Agilent Technologies, Santa Clara, CA). Two sets of dielectric pads were constructed using aqueous suspensions of either $CaTiO_3$ ($\varepsilon_r = 118$, $\sigma = 0.14$ S/m) or $BaTiO_3$ ($\varepsilon_r = 288$, $\sigma = 0.38$ S/m), with dimensions of $18 \times 18 \times 1$ cm^3 and lateral position as used in previous work [1,2]. A 16-rung high-pass birdcage resonator was built using a cylindrical former with an inner/outer diameter of 30/35 cm and rung length of 17 cm. The coil was tuned to 300 MHz and the reflection and coupling coefficients were below -15 dB for all experiments.

RF near-field measurements were performed within the phantom liquid using RF probes (EASY4, SPEAG, Zurich, Switzerland), with and without the dielectric pads present. The RF frequency was set to 300 MHz not to interfere with MR acquisitions at 297 MHz. The accepted power at the coil input was recorded using a directional coupler and power detector to correct for losses up to the coil port. The electric field magnitude was recorded along two lines, as indicated by the dashed lines in Figure 1.

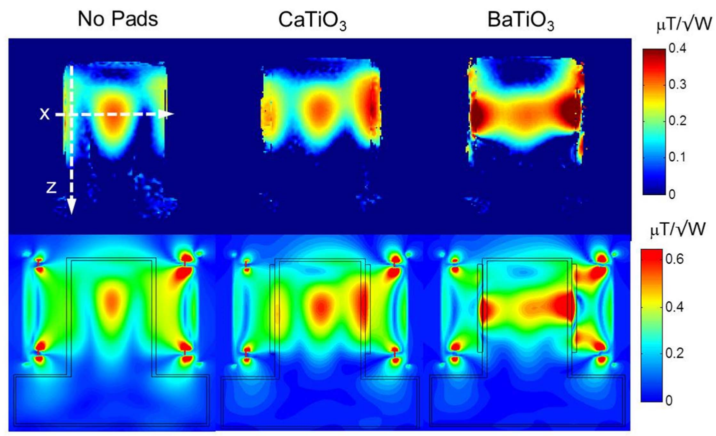

Fig. 1. Measured (top) and simulated (bottom) B_1^+ maps in the coronal view without and with pads. The dashed lines indicate the position of the line plots (cf. figure 2).

EM simulations were performed using the finite-integration time-domain method (CST Studio Suite, CST AG, Darmstadt, Germany) and circuit co-simulation to model the lumped elements. B_1^+ maps were acquired on a 7T system (Achieva, Philips Healthcare, Best, The Netherlands) using the double angle method [4], with nominal tip angles $\alpha_1/\alpha_2 = 60°/120°$, TR/TE = 5000/4.0 ms and a 500 ms saturation delay. The transmit efficiency was determined by normalizing B_1^+ to accepted power, which included losses in the RF chain during MR experiments.

Results: Figure 1 shows simulated and measured B_1^+ maps in the coronal plane, without and with dielectric pads. The offset between measured and simulated data here, is due to losses in the RF chain during the MR experiments. Line plots of the E-field magnitude are shown in Figure 2. The relative changes in electric fields are within ~10% agreement with simulated data.

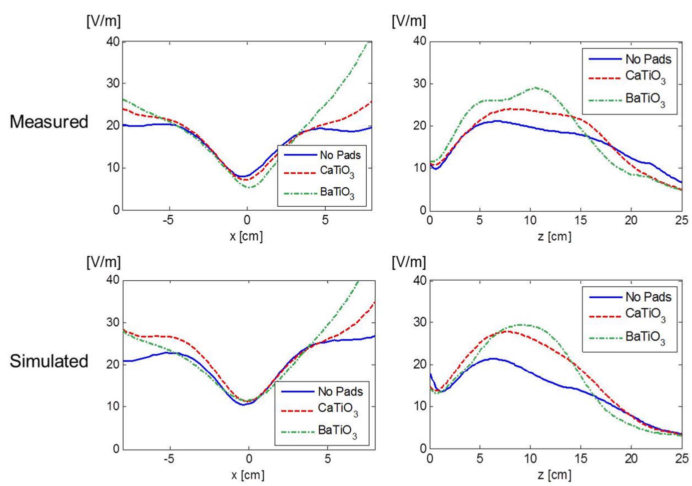

Fig. 2. Measured (top) and simulated (bottom) electric field magnitude without and with pads. The data were acquired along the dashed lines as shown in figure 1.

Discussion: Electric field measurements confirm that the electric fields within the phantom are affected by the dielectric pads. The largest E-field elevation is induced by the $BaTiO_3$ pads, which is in line with previous studies [2]. As can be appreciated from Figure 1, the B_1^+ 'focusing' induced by the $BaTiO_3$ pads leads to a local increase in transmit efficiency of up to ~300%. This can be of interest in localized applications such as MRS or high resolution imaging. The corresponding electric field data, which shows an increase in the order of 50-100%, indicates that the local SAR can be expected to remain in the same order of magnitude as when no pads are being used. The data presented here can only be indicative for the simulation error however; a realistic analysis of SAR requires the use of heterogeneous body models to relate these values to the in vivo case [3].

Conclusion: The data presented here indicate an agreement between simulations and measurements of electric and magnetic fields in the order of ~10%. This means that realistic scenarios can be evaluated with this error margin to provide SAR estimates for using pads in vivo.

References: [1] Teeuwisse et al., *MRM 2012*, 67:1285-93; [2] Brink et al., *Invest. Radiol. 2014*, 49:271-77; [3] Bitz et al., *Proc. ISMRM 2014*, 4892; [4] Cunningham et al., *MRM 2006*, 55:1326–33.