A reliable method for calculating RF coil performance

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Introduction: Electromagnetic (EM) simulation is a valuable tool for predicting and evaluating the radiofrequency (RF) field inside the human head during an MRI experiment. At high field strength, knowledge of coil performance, defined as B1+ field magnitude per RF voltage applied to coil input, is vital for reliable definition of SAR, monitoring of SAR, and coil optimization. Experimental confirmation of coil performance simulations is essential, using well-characterized and relatively realistic phantoms. Earlier studies [1, 2, 3] have used textbook values for phantom EM properties, and have generally assumed the phantom dimensions. They also compared only scaled B1+ profiles, normalizing the maximum amplitude of simulated and experimental data. For reliable prediction of transmit coil performance, additional factors must be considered. These include the exact position and shape of the phantom within the coil, precise values for the actual phantom EM properties, full details of the RF pulse shape used in experimental B1+ profiling, and measured losses between the coil input and the point where the RF pulse amplitude is monitored by the scanner hardware.

Method: The simulations were performed in CST Studio Suite 2008. The coil 3-D EM model includes all construction details for the resonance elements, simulated with realistic dimensions and material electrical properties. The shape of the phantom was obtained using a 3D TurboFLASH scan. The MRI data was segmented with MatLab and exported in an appropriate format. To determine the position of the phantom inside the coil, gel markers were attached to the coil. With the help of these markers, the translation vector from the scanner coordinate system to that of the coil was determined. The phantom tissue EM properties were measured using the reflection technique with the Agilent network analyzer, HB8510 [5]. The simulated $B1^{+}_{sim}$ field magnitude was calculated for a voltage V_{sim}= 20 V applied to the coil input, and coil performance was estimated as $C_{p\_sim}= B1^{+}_{sim}/ V_{sim}$. The magnitude of B1+ was mapped experimentally by applying rectangular RF pulses with amplitude V_{tales}=33.3 V (measured at the Transmit Antenna Level Sensor (TALES)) and pulse length τ =2.56 ms. Insko's double angle method [6] was employed, for which $B1^{+}_{exp} = \varphi / \gamma\tau$, where φ is the flip angle, and γ is the gyromagnetic ratio. There is a measured loss of about 2.8 db in total (i.e. attenuation factor K_{loss}=1.38) between the TALES and the coil input (Fig.1). Including this loss, the actual coil performance could be estimated as $C_{p\_exp}= B1^{+}_{exp}/ (V_{tales}/K_{loss})$.

Results and Discussion: The experiments were performed using a Siemens 7T whole body scanner with a commercially available multi-channel coil. One comparison was performed for a 2 litre bottle filled with a saline solution (ε = 80 and conductivity σ = 0.41 S/m) (Fig.2). This gave the following values at the RF coil's isocentre: $B1^{+}$sim=1.9 mT, $B1^{+}$exp=2.3 mT. Once scaled for the differing RF voltages applied, this result shows a very precise agreement between actual and simulated coil performance, where C_{p_sim}=0.095 mT/V, C_{p_exp}=0.0953 mT/V. Fig. 3 shows the comparison between $B1^{+}_{sim}$, appropriately scaled by $(V_{tales}/K_{loss})/ V_{sim}$, and $B1^{+}$exp, for a transverse slice of the phantom.

Fig. 4 shows the comparison for a more complicated phantom, a plastic model of a human skull filled with gel of appropriate EM properties.

The advantage of the B1+ mapping method used here is that $B1^{+}$exp has a simple relation to the amplitude and duration of a single rectangular RF pulse. The drawback is that it delivers noisy results for regions with low $B1^{+}$exp field magnitude. In such regions the deviation between experiment and simulation is higher. This can be circumvented using additional scans with higher flip angle. If the phantom is too large to fit within a feasible 3D scan FOV, it can of course be approximated by an appropriate analytic model.

Conclusion: The results show that precise predictions of coil performance and B1+ profile are achievable by EM simulation in any complex configuration, when geometry, electromagnetic properties and RF losses are taken fully into account.

[1] Collins et al. MRM 47:1026-1028 (2002) [2] van de Moortele et al. MRM 54:1503-1518 (2005) [3] Ibrahim NMR Biomed. 20:58-68 (2007)
[5] S. Takashima et al. Biophys. J. 49:1003-1008 (1986) [6] E.K. Insko et al. JMR 103 :82-85 (1993)

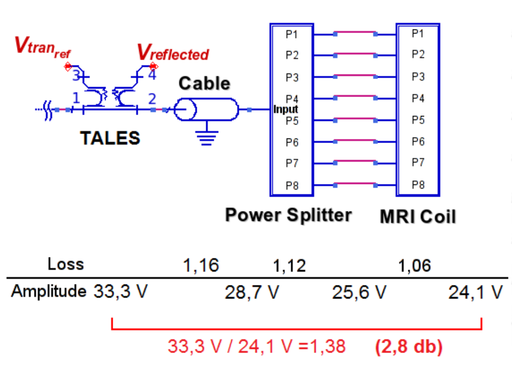

Fig. 1. Circuit between TALES and MRI coil input

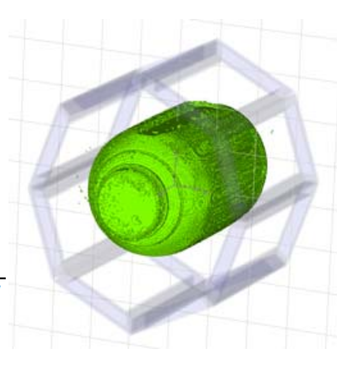

Fig. 2. Simulated voxel-based model

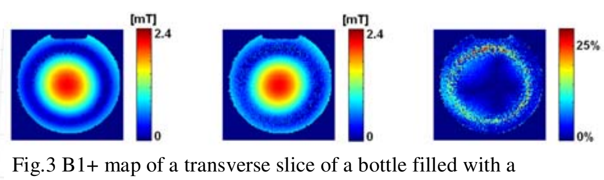

Fig.3 B1+ map of a transverse slice of a bottle filled with a saline solution. Left: Simulation. Middle: Experiment, Right: relative difference between Simulation and Experiment

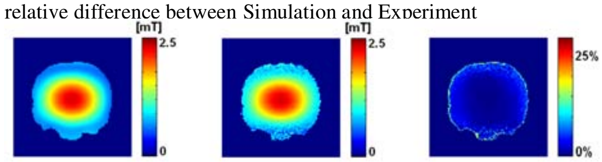

Fig.4 B1+ map of a coronal slice of a skull filled with gel. Left: Simulation, Middle: Experiment, Right: relative difference between Simulation and Experiment Simulation