Experimental Verification of Numerical EM Field Simulations for Ultra-High Field Travelling Wave MRI

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Introduction: UHF MRI suffers from increased spatial inhomogeneity of the B1 excitation field, particularly when using resonant coil designs. Travelling wave MRI has recently been suggested as an alternative to conventional excitation and reception coils [1]. The performance of a custom-built patch antenna [2] for travelling wave excitation at 9.4T was quantified to validate the results obtained from simulations using the antenna setup with B1 mapping methodology.

Methods: The antenna was used for measurements in a Magnetom 9.4T human MRI scanner (Siemens Healthcare, Erlangen, Germany). The gradient system, which has a clear bore of 60cm, is capable of a maximum slew rate of 200 mT/(m*ms) and maximum gradient amplitude of 40 mT/m. Measurements were performed on a cylindrical calibration phantom (375 mm length, 160 mm diameter, 7 litre volume) filled with $NiSO_4$ and NaCl positioned in the isocentre (x, y, z = 0mm) of the magnet. Using a commercially available conductivity meter the conductivity of the phantom fluid was determined to be 5.73 mS/m. The centre of the patch antenna was placed on the z-axis of the magnet with the phantom at the isocentre allowing a distance of 610 mm (beginning of the RF-screen) between the patch antenna and the isocentre. B1 maps of the measurement setup were acquired with a 3D-AFI sequence [3] with adapted RF spoiling [4] and the following protocol parameters: FOV: 202*202*410 mm^3, resolution: 1.8mm^3 isotropic, TR: 110ms, TE: 2.5ms, n: 5. A non-selective excitation pulse of 700us and a nominal transmitter voltage of 93 volts were applied. The antenna was also used for signal reception.

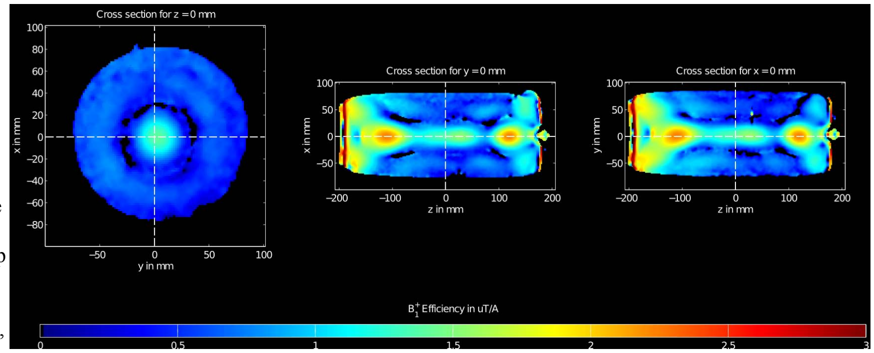

Figure 1: Measurement results. White dashed lines indicate the line profiles seen in Fig.3

The acquired raw data were processed offline using the real part of the signals to cover a higher dynamic range. The flip angle maps were smoothed with a median filter with a 3x3x3 voxel kernel to suppress artefacts. Subsequently, B_1 maps were derived from the data by exploiting the linear relationship between flip angle, B_1^+ and pulse duration for non-selective excitations. The B_1^+ maps were normalised to per unit current to allow a better comparison with the simulation results. The same measurement setup was simulated using the FIM method implemented in CST Microwave Studio (CST GmbH, Germany). The model consisted of the antenna and the phantom placed at one end of the RF screen with low-density polyethylene (PE-LD) as the flask material. A relative dielectric permittivity of 78 was assumed for the phantom fluid.

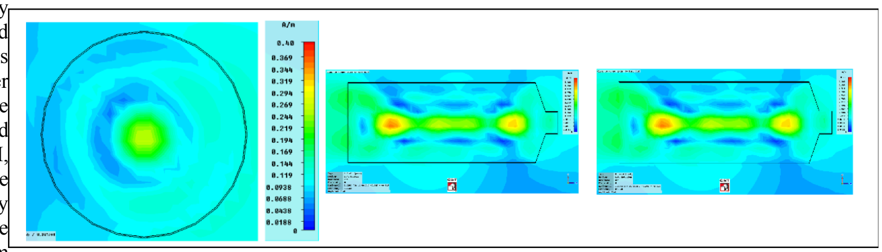

Figure 2: H1+ simulation results

Results: Figure 1 shows three orthogonal cross sections of the acquired B_1^+ maps. Figure 2 displays the simulated distribution of the H_1^+ field using the CST software suite. The positive z-axis runs from the patient end to the service end of the scanner. Qualitative comparison by visual inspection reveals a clear agreement between the measured and simulated shapes of the B_1^+ and the H_1^+ fields. Figure 3 shows two selected line profiles (x-profile: y=0mm, z=0mm and z-profile: x=0mm, y=0mm) for a detailed comparison of simulation and experiment. The simulated H fields were converted to B fields in these plots for ease of comparison. A slight shift of the line profiles (approximately 1cm along z direction) is evident which may be the result of inexact placement during the experimental setup. Comparison of the central peak of the x profiles discloses a relative deviation of 21.6% with the simulation overestimating the actual B_1^+ field strength. Comparison of the other peaks visible in the z-profile shows a significantly lower deviation between simulation and experiment.

Conclusion: We have been able to verify our EM simulations with phantom measurements using a travelling wave antenna at 9.4T. The good agreement between simulation and experimental data supports the use of EM field simulations as a means to predict the B_1^+ field distribution at UHF [5]. Exact simulation of B_1^+ field distribution will also allow realistic SAR predictions due to the fundamental relationship between magnetic and electric fields.

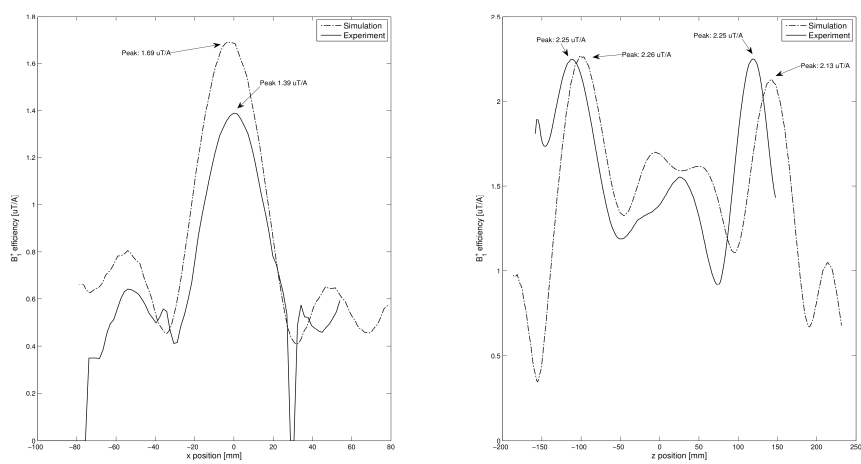

Figure 3: Line profiles for x and z taken from Fig.1 and 2.

References:

[1] Brunner et al. Nature 457:994-998(2009) [2] Geschewski et al Proc. ISMRM p.1478 (2010) [3] Yarnykh MRM 57:192-200(2007) [4] Nehrke MRM 61:84-92(2009) [5] Yang et al. MRM 47:982-989(2002)