13 Scientific Session - Preclinical Studies & Basic Science
1:50 pm - 3:20 pm *Lecture Room 11*

Frontiers in RF

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Numerical EM field simulations and B1 mapping for multi-mode travelling wave MRI at 9.4T

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Introduction: Travelling waves have been introduced as an alternative excitation technique for MRI [1]. Recently the extension to multi-channel excitation has been presented at 7T [2] using dielectric material the magnet bore. At 9.4T (~400MHz) it is possible to excite multiple modes without the necessity of such dielectric fillers. This work investigates the efficiency of a multi-mode antenna and verifies numerical EM-field simulations of the setup.
Methods: The multi-mode antenna is based on the design of a previously developed patch antenna [3] with an additional monopole connected at the middle of the patch. Both patch ports and the monopole were fed independently by the pTX system of a 9.4T MR scanner (Siemens Healthcare, Erlangen, Germany). Measurements were performed on a cylindrical calibration phantom (375 mm length, 160 mm diameter, 7 litre volume) filled with aqueous $NiSO_4$/NaCl solution positioned in the isocentre (x, y, z = 0mm) of the magnet. B_1 maps of the measurement setup were acquired with a 3D-AFI sequence [4] with adapted RF spoiling [5] and the following protocol parameters: FOV: 202*202*410 mm^3, resolution: 1.8mm^3 isotropic, TR: 110ms, TE: 2.5ms, n: 5, non-selective excitation pulse (700us duration). The measurement was repeated for all three ports of the antenna. The resulting 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.
Results: Figure 1 shows the acquired B_1^+ maps (three cross-sections per channel). Figure 2 displays the simulated distribution of the B_1^+ fields (identical scale). Good quantitative agreement between simulation and experiment is evident.

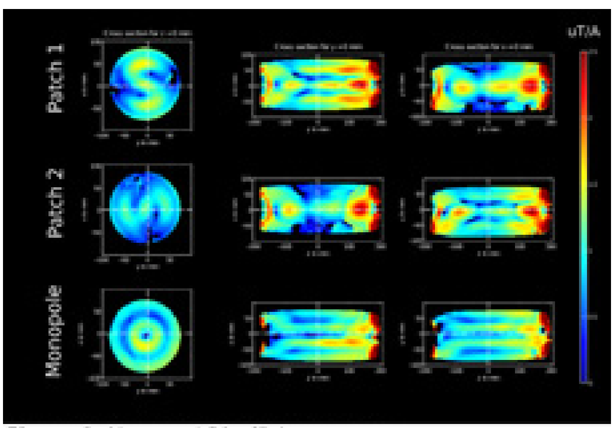

Figure 1: Measured B1 efficiency maps

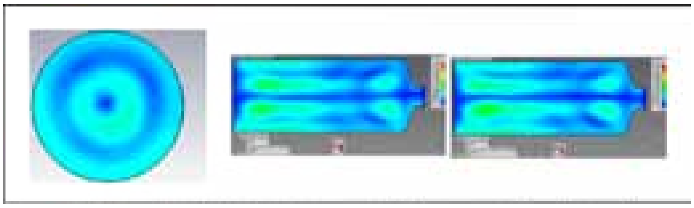

Figure 2: Simulated B1 efficiency maps of the monopole channel. Identical color scale as Figure 1.

Conclusion: In analogy to previous work [6] we could validate EM field simulations with B1 measurements for a multi-mode excitation antenna for 9.4T MRI. The distinct field patterns and acceptable efficiency hold promises for RF shimming and accelerated selective excitation with good homogeneity over a large FOV.

References:
[1] Brunner et al. Nature 457:994-998 (2009)
[2] Brunner et al. MRM; *Ahead of print* (2011)
[3] Geschewski et al. Proc. ISMRM p.1478 (2010)
[4] Yarnykh MRM 57:192-200 (2007)
[5] Nehrke MRM 61:84-92 (2009)
[6] Brenner et al. Proc. ISMRM p.1907 (2011)

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MetaBore - a fully adaptive RF field control scheme based on conformal metamaterial ring antennas for high-field traveling-wave MRI

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Purpose/Introduction: In their seminal publication Brunner et al. [1] have pioneered the distribution of the RF B_1-field using the propagation of traveling waves within the bore of the 7 T MRI scanner. A common feature of most traveling-wave approaches is a waveguide mode excitation that relies on a closed-end antenna system at the bore end. We therefore propose an adaptive RF antenna system for the excitation (and control) of the fundamental circular waveguide mode (TE_{11}), consisting of multiple «flat» composite right-/left-handed (CRLH) metamaterial ring antennas [cf. Fig.1(a)] that fully conforms to the inner surface of the MRI bore [2], and therefore yields no drawbacks in terms of patient's comfort.
Subjects and Methods: The use of CRLH metamaterials [3] is mainly due to its inherent dispersion engineering capabilities, which is needed when designing ring structures at full-wave resonance that mimic the surface current distribution of the TE_{11}-mode [cf. Fig.1(a)] for any predefined diameter operating at the given Larmor frequency (298 MHz). Fig.1(b) depicts the working principle of the RF antenna system, where pairs of subsequently spaced and correspondingly current-fed ring antennas are used for the unidirectional excitation (antenna 1), amplification (antennas 2 and 3) and dumping (antenna 4) of propagating, circularly polarized B_1 mode fields.

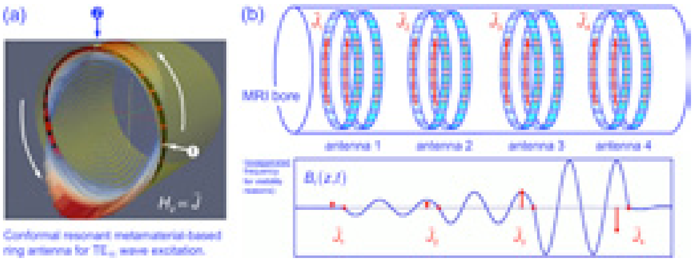

Figure_1

Results: Given these functionalities one can setup a compound scheme [i.e. periodically arranged multiple antenna pairs as sketched in Fig.1(a)] - termed as "MetaBore" - that is capable to provide e.g. a tailored RF power distribution [cf. Fig.2(b)] as well as full wave reflection compensation [cf. Fig.2(c)] virtually at any desired location along the loaded bore. A first proof-of-concept is given in Fig.3(a) showing a full-wave simulation of the "MetaBore" consisting of 15 CRLH ring antennas each with 32 unit cells. From the E_r-component of the propagating TE_{11}-mode, unidirectional wave excitation is visible at the rear end, whereas "active wave dumping" is effective at the front-end of the bore.

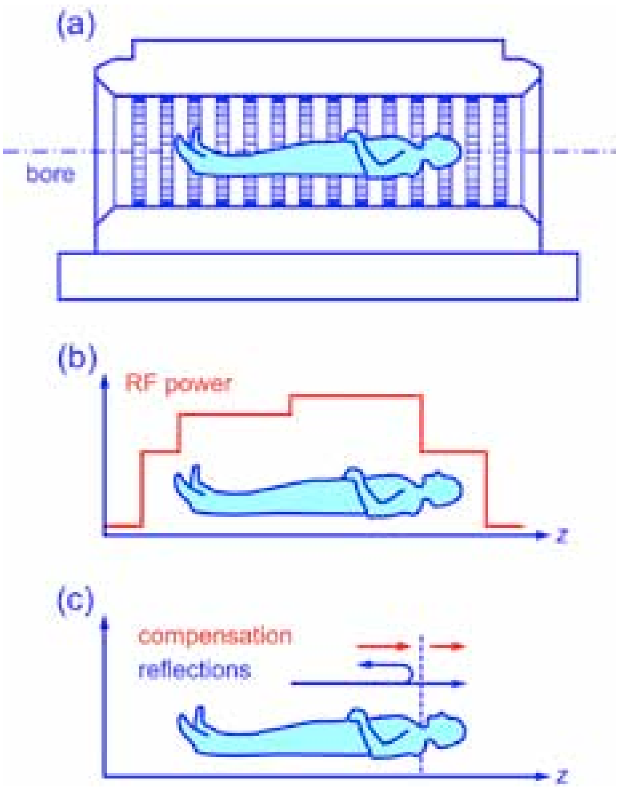

Figure_2

Discussion/Conclusion: We are currently investigating the inverse problem, where the in-phase and quadrature current excitations of all 15 ring antennas are subject to ultra-fast optimization, in order to achieve a desired longitudinal B_1-field distribution in the loaded bore [cf. Fig.3(b)], rendering the "MetaBore" a holistic approach to future multi-functional traveling-wave MRI.

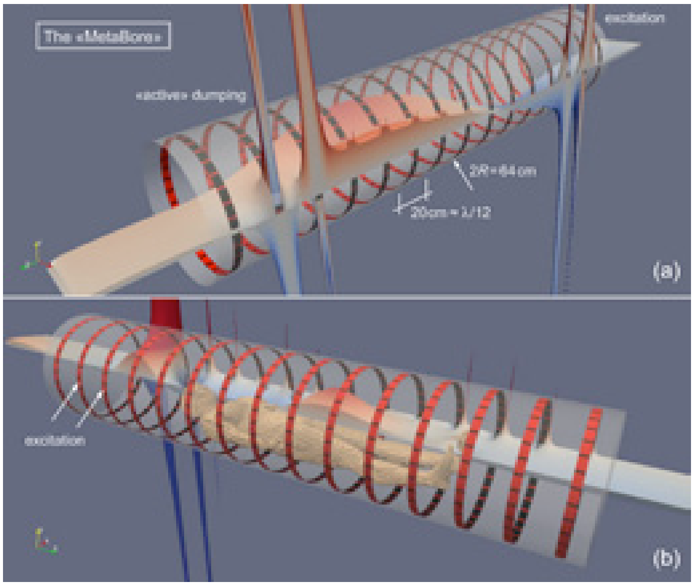

Figure_3

References:

[1] Brunner, D. O., Nature, 457, 994-998, (2009)
[2] Erni, D., German patent pending, ref. Nr. 10 2010 010 189.3-54, (2010)
[3] Rennings, A., EuCAP 2009, March 23-27, Berlin, Germany, 3231-3234, (2009)

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Concurrent RF excitation and detection by frequency separation

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Introduction: Most NMR and MRI acquisition are performed by time interleaving RF transmission and reception. Concurrent excitation and reception would be favorable in many cases such as stochastic resonance, ultra short T_2 samples and nuclei, measurements of relaxation parameters under RF irradiation, re-excitation of NMR magnetic field sensors etc. However, the achievable isolation cannot cope with the high RF power in transmission to render uncontaminated NMR signals on the receive side. To circumvent this problem we propose a method based on fast modulation that provides robust separation of transmit and receive signals by frequency separation.

Theory: Fast modulation by a time-harmonic magnetic field B_m along the main field direction produces sideband copies of the NMR lines at $\omega_0 \pm n\omega_m$ (see Fig.1a) whose amplitudes depend on the modulation depth factor $\beta=\gamma B_m/\omega_m$. Interestingly, an RF magnetic field transmitted at any of these frequencies fulfils resonance condition for the sideband and induces spin nutation[1,2] with an effective field of $\beta \cdot B_1$. If ω_m is chosen larger than the TX and RX bandwidths, the two bands are effectively separated permitting isolation of the high-power transmit signal from the receive chain by analogue and digital filtering.

Materials: Fig 1.b shows the setup for 7T with ω_m=2.25MHz. 10W of modulation power were used on a Helmholtz coil and crossed loop coils were used for transmission (250mW) and detection. For simplicity only the first lower sideband was irradiated but efficiency could be gained by using both. The