Traveling wave MR on a whole-body system

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Introduction: RF probe design faces novel problems in ultra-high field MRI due to decreased wavelengths. The RF fields produced by classical RF probes such as volume resonators or surface coil arrays suffer from interference effects appearing as dark holes and bright spots. Furthermore, the efficiency of RF probes is lowered as the reactive region of their electro-magnetic fields becomes significantly smaller than the object size. The robustness of such probes with respect to changes of loading and cable routing is also crucial to provide optimal performance and safety. For these reasons we propose to deliberately leave the near-field RF regime and explore MR probe design based on propagating waves. In this work, experiments and simulations are performed demonstrating the feasibility, effectiveness and advantages of a novel family of RF probe devices based on traveling RF waves guided by the cylindrical RF shield that usually lines the bore of MRI systems.

Theory: A propagating plane wave in free space would have maximum homogeneity and transverse polarization up to arbitrarily small wavelengths. Indeed, a freely propagating wave cannot be established inside the bore of an MR magnet. However, a traveling wave can still be guided by the bore and its RF shield. The modes of the empty bore of typical whole-body 7T systems (see Fig. 1 a) have cutoff frequencies slightly above the proton Larmor frequency. Therefore filling the bore with lossless dielectric material (in addition to the subject or sample, Fig. 1 c) reduces the cutoff frequencies of the first modes sufficiently ([2]) to support wave propagation at the proton frequency.

In order to prevent axial standing waves stemming from reflections due to guided mode mismatches at the dielectric interfaces of the subject, a dielectric load tapering towards the subject should be placed at the center of the bore (Fig. 1 d). Additionally, the dielectric loading can be used to shape the transverse field pattern of the mode. Such a setup could provide highly homogenous RF fields in the axial direction if the standing wave ratio can be kept low enough. Furthermore the field patterns (dominated by the mode structure of the loaded bore) are expected to be largely independent of the probing device, which could ease the safety assessment of novel probe designs.

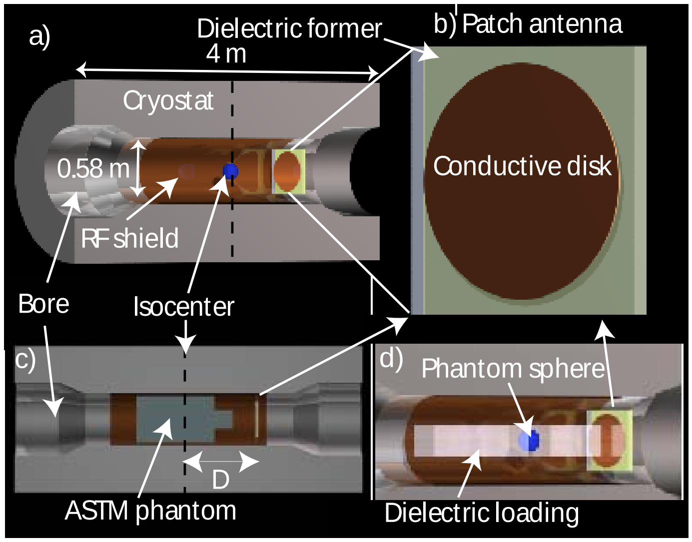

Figure 1: Drawings of the experimental setup

Methods: Two RF probes were constructed, a 350 mm diameter circular patch antenna [1] with quadrature driving ports on a PMMA former (400 mm side length, 30 mm thick) with copper backplane (see Fig. 1 b) and a pair of crossed folded dipole antennas of 250 mm length driven in quadrature. The ports of the patch antenna were matched by attaching the feeding posts directly to 50 Ω impedance points on the disk [1]. Imaging experiments were carried out on a 7T Philips Achieva whole-body system using standard quadrature RF coil interfaces. The RF probes acted as transmit-receive devices in all experiments, and in reception the two quadrature channels were acquired independently. For imaging, a standard small flip-angle gradient-echo sequence (FLASH) was used without averaging.

Experiments and Results: For all experiments the antennas were placed at one end of the bore's RF shield at 65 cm distance from the isocenter (Fig. 1). Using the patch antenna, a central coronal image was taken from a 15 cm saline water sphere placed at isocenter without dielectric load (Fig. 2 d). The same image was taken using 10 3-litre demineralized water containers for dielectric loading (see Fig. 1 d) and replacing the patch by the folded dipole (Fig. 2 e,f). It is seen that the dielectric matching affects the excitation pattern greatly. However, exchanging the RF probe did not change the received image significantly. Using the dielectric loading, coronal images of 9 kiwi fruit (Actinidia Chinensis) arranged in a 3 × 3 array were acquired. The resulting high resolution (0.375 x 0.375 x 2 mm^3) image in Fig. 2 a) shows excellent SNR with a probe that is actually 60 cm away from the sample. Figure 2 b) shows a transverse slice placed as marked by the dashed line in Fig. 2 a), illustrating homogeneous coverage also in the third dimension. Whole-body imaging was mimicked using a standardized ASTM [3] phantom. Figure 2 c) shows the resulting coronal image acquired using the maximum possible FOV of 500 mm with an in-plane resolution of 1 mm. The coverage thus achieved is visibly inhomogeneous but nevertheless remarkable for "whole-body" imaging at 7T.

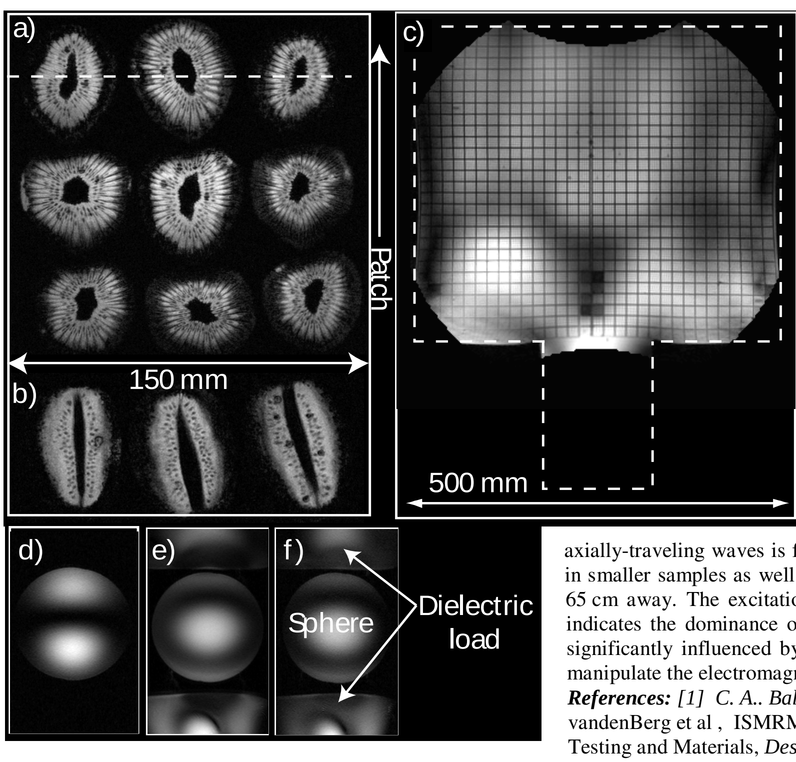

Figure 2: Imaging results

Simulations: Electromagnetic model calculations were carried out using CST Microwave studio®. The results confirmed that although the empty bore has a cutoff frequency of about 303 MHz, very little dielectric loading allows a traveling wave to be established. Furthermore it was found that the transverse field distribution can be altered and unwanted reflections can be lowered by tapering the dielectric interfaces of the subject.

Conclusion: It has been shown that MR excitation and detection by axially-traveling waves is feasible and quite efficient at 7T. High SNR and good coverage was achieved in smaller samples as well as in a whole-body phantom, using an antenna that was placed a remarkable 65 cm away. The excitation pattern produced does not significantly depend on the probe used which indicates the dominance of the mode structure of the loaded bore system. The mode structure can be significantly influenced by dielectric loading of the bore thus allowing various degrees of freedom to manipulate the electromagnetic fields for optimal imaging performance.

References: *[1] C. A.. Balanis, Antenna Theory: Analysis and Design*, Wiley (1997), [2] C.A.T vandenBerg et al , ISMRM workshop Advances in high field MRI Asilomar [3] American Society for Testing and Materials, *Designation: F 2182 – 02a - Standard Test Method for Measurement of Radio Frequency Induced Heating Near Passive Implants During Magnetic Resonance Imaging*