B1 shimming using phase shifts for travelling wave MRI with a coaxial waveguide

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Introduction

The use of a coaxial waveguide geometry was proposed [2,3] as a modification of the original travelling wave approach [1]. While this allows focusing the RF energy to an imaging region, the dominant mode of propagation in the coaxial setup is transversal electromagnetic (TEM). This mode does not have a lower cut-off frequency, but the magnetic field vectors are oriented circularly, which leads to an inherent destructive interference at the center, and thus a signal void is seen along the longitudinal axis (Fig. 1).

B_1-shimming can be employed to annihilate this interference. Therefore, the coil is fed at multiple source points with adjustable phase shifts. In this work, a prototype coaxial setup was equipped with four feed points to assess improve B_1 homogeneity at the center.

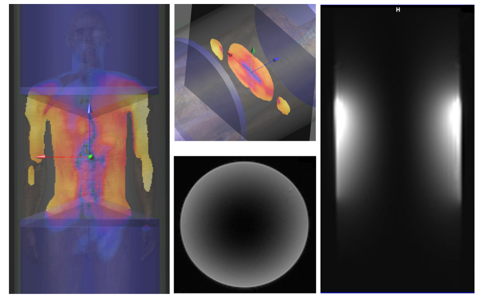

Fig. 1: Signal void along the central axis, apparent in FDTD simulations (B_1 map shown) with a virtual family model and images of an oil phantom acquired without shimming.

Material & Methods

A coaxial setup is shown in Fig. 2. The conductive surfaces of the coaxial setup were composed of two layers of copper segments, isolated by a dielectric PE foil and arranged to form series of plate-type capacitors along the waveguide direction. Thus, high-frequency currents along the waveguide were supported, but radial and low-frequency eddy currents were suppressed, and the phase-shifted currents at the feed points cannot penetrate to other feed lines.

On one of the coaxial connection rings, the contact springs were divided into four quadrants, (90° each). All feed points were separately matched to 50 Ω (low-pass pi type networks). To apply equal RF power to each feed point, a 4-channel Wilkinson power splitter was built and connected to the setup by cables of different lengths, creating a static phase difference $\Delta\varphi$ = 90° between adjacent feed points (Fig. 2b). As this $\Delta\varphi$ causes a voltage difference between the quadrants of the inner conductor, an inner shielding layer was applied to the feed line in order to prevent the formation of electromagnetic fields within the inner conductor.

The setup was loaded with a cylindrical phantom (acrylic glass, diameter 18cm, length 85cm) filled with vegetable oil, and an imaging gap of 10cm was set for measurement. Spoiled gradient echo images were acquired at a whole body 7 T MR system (Siemens Magnetom 7T, Erlangen/Germany) using the coaxial coil for both signal transmission and reception. Imaging parameters were: TE = 1.33/1.79 ms, TR = 90ms, slice thickness = 20mm, base resolution = 128, excitation voltage 170V and 8 averages.

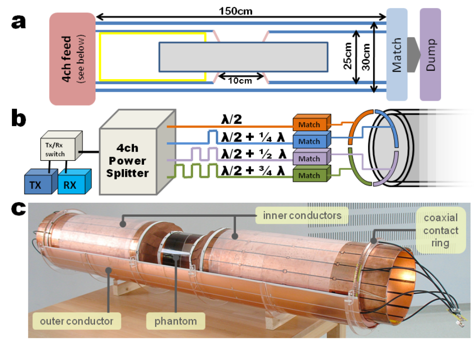

Fig. 2: (a) schematic of the coaxial coil. Wave are coupled in from the left and guided to the imaging area in the center. Excessive energy is dissipated in the dump on the right. An inner shield layer (yellow) was applied to the feed line. (b) schematic of the 4ch-feeding section. Static phase shifts are created by cables of varying lengths. (c) coaxial prototype coil with upper half of the outer conductor removed.

Results and Discussion

Images of the oil phantom are shown in Fig. 3. The signal void in the center is successfully eliminated. Illumination is not restricted to the imaging gap, but rather reaches from to the end of the shield layer on the excitation side to the far end of the imaging gap (Fig. 3b). This shows that the phase differences lead to RF fields within the inner conductor. For comparison, signal intensities with (4ch) and without (1ch) B1 shimming were averaged over 11mm-wide concentric rings in transverse slices, and normalized to their maximum (Fig. 4). While a strong central signal reduction is seen without B1 shimming in transverse slices, the signal remains almost constant for the 4-channel approach (Fig. 4b). However, as seen in Fig. 3a, the signal was not equally distributed in circular orientation, but showed maxima (left and right edge) and minima (upper and lower edge of the phantom).

Conclusion

The results demonstrate that the central signal void problem of the coaxial travelling wave coil can be removed by using multiple feed points with phase shifts. However, static phase shifts created by different cable lengths are insufficient. A more sophisticated setup with individually adjustable phases and amplitudes (as was presented in [4]), and also more than four feed points, is required to create a homogenous signal distribution and support different loading conditions. Furthermore, with individual Tx/Rx switches for all feed points, parallel imaging techniques (e.g. GRAPPA, TransmitSENSE) used in multi-channel Tx/Rx arrays could be implemented into the coaxial waveguide approach without loosing its RF energy focusing and broadband capabilities, or the option to combine the method with local Rx hardware for higher sensitivity.

References

[1] Brunner et al. Nature, **457**(7232):971-972 (2009) [2] Alt S et al. ISMRM 2010:3559 [3] Mueller M et al. ISMRM 2010:2580 [4] Orzada et al. Magn Reson Med. 2010 Aug;64(2):327-33

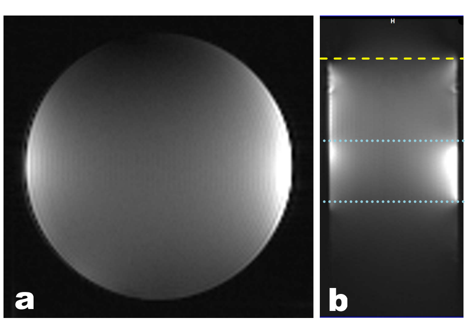

Fig. 3: Transverse and coronal images through the center of the phantom. Imaging gap (blue) and the end of the shield (yellow) are indicated.

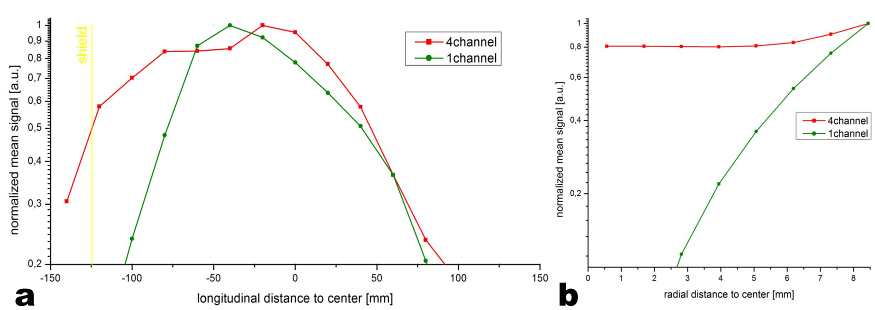

Fig. 4: Signal distributions of shimmed (4ch) and conventional (1ch) images in (a) waveguide and (b) radial direction. Excitation waves are sent from the left in the longitudinal plot and the end of the shield layer is indicated. For the 1-channel measurement, the imaging gap was 15 cm.