One coil to light them all: Broadband body coil for multi-frequency imaging using a coaxial waveguide

S. Alt[1], M. Müller[1], A. M. Nagel[1], F. Meise[1], R. Umathum[1], and M. Bock[1]
[1]Medical Physics in Radiology, German Cancer Research Center (DKFZ), Heidelberg, Germany

INTRODUCTION

A major limitation of multi-nuclear MRI is the need for dedicated transmit-receive (Tx/Rx) hardware for each nucleus. Even if only two nuclei are imaged, double-resonant Tx/Rx coils are difficult to build as they often require separate resonance structures.

Recently, a travelling wave system using a coaxial waveguide with interrupted inner conductor was proposed [1,2]. While the original travelling wave MRI approach [3], that uses the MRI tunnel as a hollow waveguide (TE11 mode), has a lower cutoff frequency at about 300 MHz, the coaxial system does not have this limitation (TEM mode). In this work, we demonstrate that an interrupted coaxial waveguide can be used for signal transmission and reception at multiple frequencies. In a prototype setup both ^{1}H and ^{23}Na MRI was performed, and the same coil was operated at different field strengths.

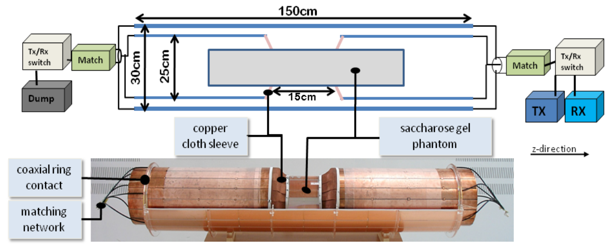

Fig. 1: Schematic of the coaxial prototype and its connection to the MRI system. Travelling waves are coupled in from the right. Excessive energy is dissipated in the dump to avoid reflections. Below, an image of the setup is shown (upper half of the outer conductor removed).

MATERIAL & METHODS

The coaxial coil setup is shown in Fig. 1. The dimensions of the prototype were chosen to be half the size of a conventional high-field MRI magnet bore. All conductive surfaces consisted of a two-layer copper stripe pattern to form plate-type capacitors in waveguide direction. Thus, RF currents along the waveguide were supported, but all radial and low-frequency eddy currents were suppressed. For imaging, a cylindrical acrylic glass phantom (diameter: 18 cm, length: 80 cm) filled with saccharose/cellulose gel (tissue equivalent for SAR measurements at 300 MHz [4]) and a plastic bottle (10 liters, diameter: 21cm) filled with 0.9% saline water solution were used.

Frequency-dependent matching networks (capacitive pi type) and Tx/Rx switches were built to connect the coil to the different MRI systems. Both components were exchanged with equivalent devices for each frequency. Using the prototype TxRx coil, spoiled gradient echo ^{1}H images of the gel phantom were acquired at three field strengths: B_0 = 7 T, f_L = 297.15 MHz (Siemens Magnetom 7T), B_0 = 3 T, f_L = 123.35 MHz (Siemens Magnetom Trio) and B_0 = 1.5 T, f_L = 63.68 MHz (Siemens Magnetom Symphony). Imaging parameters at 7T/3T/1.5T were: TE = 1.9/3.3/3.6 ms, TR = 90/78/84 ms, slice thickness 20 mm, bandwidth 610/260/260 Hz/px, excitation amplitude 238/107/50 V and 8 averages, respectively. In addition, spoiled gradient echo images of the saline phantom were acquired in the 7T system both at the ^{1}H and the ^{23}Na (f_L = 78.6 MHz) frequency. Imaging parameters for the sodium images were: TE = 8.83 ms, TR = 316 ms, slice thickness 20 mm, bandwidth 50 Hz/px, excitation amplitude 111 V, and 16 averages.

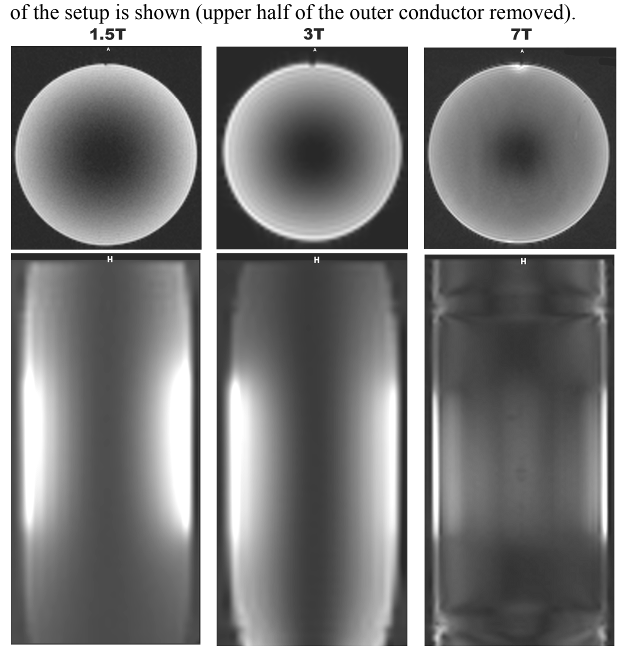

Fig. 2: Transverse and coronal ^{1}H images through the center of the same phantom taken at 3 different B_0 and f_L. RF waves travel from above ("head"-side) in coronal slices.

RESULTS AND DISCUSSION

Transverse and coronal images through the center of the phantoms are shown in Fig. 2 (gel) and Fig. 3 (saline). Similar signal distributions are seen at all frequencies. The signal void along the central axis is inherent to the native TEM mode of the coaxial waveguide. As seen in Fig. 2, the focusing effect to the gap between the inner conductors (imaging area) is strongest at 7T, while the prolonged wavelength and reduced absorption at lower frequencies cause a deeper lateral penetration. The size of the central signal void also increases with higher wavelength. At isocenter and within a 1.1 cm wide ring beneath the edge of the phantom mean SNR values (^{1}H) of 51 (7T), 73 (3T) and 68 (1.5T) were measured. Sodium images show a similar signal distribution as the proton images, although the overall signal strength is reduced due to the lower sensitivity of the ^{23}Na nucleus. Mean SNR within a 1.3 cm ring wide beneath the edge of the bottle was 23 (^{23}Na) and 75 (^{1}H). At both frequencies, imaging is well restricted to the predefined gap near iso-center.

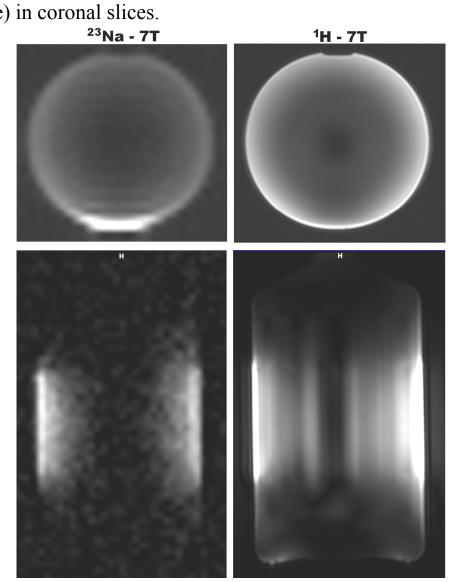

Fig. 3: Sodium and proton images through the center of the same phantom (filled with saline solution). The bottle was not centered on the longitudinal axis, causing a signal enhancement at the bottom in transverse view.

CONCLUSION

With the presented travelling wave coil approach images could be acquired over a wide range of frequencies and far below the cut-off frequency of the bare magnet bore. The waveguide coil itself did not have to be adapted, and only the narrow-bandwidth matching networks and Tx/Rx-switches, which are simple to build and adapt, had to be exchanged. This broadband capability of the coil naturally lends itself to multi-nuclear studies, as was demonstrated in a saline phantom.

By arranging the frequency dependent components in parallel (multiplexer), simultaneous multi-nuclei studies could be performed. To avoid the signal cancelation at the center, excitation at multiple feed points with different phases (B1 shimming) could be used to realize a cost effective and truly broadband body coil for high-field systems.

REFERENCES

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