Single and Multiple Coaxial Inputs to Excite a Cylindrical Waveguide for Traveling Wave MRI at 21.1 T

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Target Audience Emerging RF technology research on the design and application of traveling wave MRI at ultra-high fields.

Purpose Traveling wave MRI provides an alternative mechanism to the typical near field RF coil implementations seen at all available field strengths for MR. Increases in magnetic field strengths at both the clinical and preclinical research level further the need for unique RF excitation/reception mechanisms considering the negative effects from high frequency operation through conductive and lumped elements. The feasibility of traveling wave MRI is largely dependent on waveguide designs and their respective cut-off frequencies for different modes of propagation, particularly those modes useful for imaging. Beginning with the first useful mode (TE_{11}), traveling wave MRI was first implemented at 7 T (298 MHz for ^{1}H) and provided a relatively large imaging FOV dependent on the periodicity of traveling wave mode as well as the longitudinal limit imposed on by imaging gradients.[1,2] At 7 T, the free space cut-off frequency (TE_{11} mode in 60 cm waveguide) is just below 300 MHz and traveling wave MRI is only feasible due to the relatively high permittivity dielectric found in tissue. The feasibility of traveling wave MRI at ultra-high fields (21.1 T) has been demonstrated where the free space cut-off frequency for the TE_{11} mode (in a 6.3 cm waveguide) is now 2.9 GHz and reduces to 561 MHz within a 3.5 cm water dielectric waveguide.[3] In an effort to improve the excitation and detection of propagating modes, multiple transmit and receive elements can be utilized. Considering the typical specimen size (large rodent), the stringent space constraints in an ultra-high field widebore imaging system limits this implementation via RF coils. Alternatively, multiple RF sources can be placed along the waveguide in the form of flexible coaxial cables. The feasibility of this coax-fed traveling wave setup is examined through both full-wave EM simulations and experiments at 21.1 T (900 MHz for ^{1}H).

Methods The traveling wave setup consists of a concentric setup with a dielectric waveguide surrounded by a hollow metallic waveguide (see Fig. 1). The imaging volume is located 15-20 cm away from the RF source. For Tx/Rx, coaxial cables (grounded to the outer waveguide) were fed through the outer waveguide and into the dielectric waveguide. Excitation profiles can range from one to four individual coaxial cables for transmit and receive, or any combination of, including quadrature operation in order to improve B_1 homogeneity and reduce power requirements. The dielectric waveguide (3.5 cm diameter, 33 mm length) is composed of deionized water ($\varepsilon_r = 80$) and allows for the dielectric waveguide to be imaged directly or a sample placed within the imaging volume, submerged within the dielectric waveguide. MRI experiments were performed at 21.1 T using a 2D-FLASH sequence with 4x4 mm and 8x4 mm field of views with 312 µm spatial resolution. Also, electromagnetic simulations were performed on CST Microwave Studio.

Results & Discussion Both simulations (Fig. 2) and experiments (Fig. 3) point to a dominant TE_{11} waveguide mode along the length of the waveguide. Simulations indicate that with more coaxial inputs, at least within the first half of the waveguide, the profile of the B_1 field along the length of the waveguide is more symmetric and thus provides a more homogeneous field. However, with initial experiments, this is not easily seen since the imaging volume is past this length. When comparing single coaxial vs. two or more coaxial cables, as expected, the measured *SNR* is increased when more than one coaxial cable is used for Tx/Rx. Interestingly, linear vs. quadrature operation for one and two coaxial cables, respectively, produce slightly different patterns as can be seen in Figs. 3b and 3c. This can be attributed to degenerative modes from both the transmission and reception profiles. It is important to note that variations in the way that the coaxial cable is fed, either horizontally, vertically, or at an angle, will cause changes in the wave propagation and thus producing distinct patterns seen at the imaging volume. Other than altering cut-off modes through diameter/dielectric materials, the alignment of the coaxial cable in the waveguide provides another way of waveguide mode alteration or manipulation. This has been seen before while coupling a simple loop coil into a dielectric waveguide with two different alignments, orthogonal to one another.[3]

Conclusion A simple coaxial-fed concentric waveguide was designed, constructed and tested for traveling wave MRI at 21.1 T. The design does not require a tuning and matching circuit and can be scaled up to include up to eight symmetrically placed RF sources at the ends of a waveguide. Previous transmission and reception configurations have consisted of either patch antennas for Tx/Rx (high field strengths), patch antennas for Tx and array coils for Rx (high field strengths), and simple RF coil loops for Tx/Rx (ultra-high field strengths). The featured coaxial fed waveguide provides the necessary flexibility to implement multiple RF transmit and receive locations within the clearance after gradients on ultra-high field imaging systems. Future considerations include the construction of a four port 0-270° hybrid coupler for Tx/Rx profiles that utilize four or eight coaxial ports. In addition, design optimizations utilizing different dielectric materials can be implemented for *ex vivo* tissue imaging and possibly *in vivo* rodent imaging, albeit with monitoring of the specific absorption rate.

References **1.** Brunner DO, et al. Nature. 2009; 457: 994-999. **2.** Webb AG, et al. Magn. Reson. Med. 2010; 63: 297-302. **3.** Muniz JA, et al. Proceedings 22nd ISMRM. 2012; 25.