<u>**A Traveling-Wave Setup for Parallel RF Transmission**</u>

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Introduction

The traveling-wave concept for ultra high field MRI offers high FOV and patient space. In [1] a patch antenna with two ports was used to excite the two degenerate TE_{11} modes of a circular waveguide, which are the only modes below cut-off in an empty bore at 7T. To extend the traveling-wave concept for parallel transmit with more than two channels more degrees of freedom are needed.

In this work this is achieved by lowering the cut-off frequencies of the higher order modes with dielectric inserts. The orthogonality of the waveguide modes is beneficial for parallel transmission. Therefore, selective mode coupling is desirable. The simultaneous excitation of multiple modes in a waveguide is a demanding task. The location and the type of the exciting elements have to be chosen carefully.

Methods & Results

The cylindrical RF shield of a 7T Philips Achieva system (Philips Healthcare, Cleveland, OH) bore (ø=580 mm, L=1.3m) was extended with a 2m long, 560/542mm (inner/outer diameter) PE tube. The extension was inserted coaxially into the scanner's bore. A circular waveguide structure was formed by fixing brass mesh on the tube. The extension was terminated with a short plane on one end (see Fig1a. This forces the wave into the scanner, reduces noise from radiation, and simplifies coupling to the waveguide modes.

A dielectric insert was designed to lower the cut-off frequencies of the higher order modes. Filling the extension completely with a dielectric material would be too heavy. Therefore, we used 2m long PMMA tubes, filled with distilled water, arranged in a Cartesian grid along the z-direction (see Fig1b). The effective material of this insert can be approximated as a homogeneous material with an anisotropic permittivity tensor, shown in Eq1. Where $\varepsilon_{r,MG}$ is computed with the Maxwell-Garnett formula [2], and ε_{ave} is the average permittivity of this material.

For our setup this yielded $\varepsilon_{r,MG}$ =1.7 and ε_{ave} =23. The modal distributions and the cutoff frequencies of the actual 2D geometry were simulated using the 2D-modal solver of COMSOL (FEM). The simulation showed that 17 modes are supported by this waveguide at 300MHz. Table 1 shows these modes together with the simulated cut-off frequencies $f^c_{n,m}$', the cut-off frequencies of these modes in the empty waveguide $f^c_{n,m}$, the equivalent permittivity $\varepsilon'_{hom,eq}$ for each mode (for a homogeneous, isotropic filling), and the wavelength of the mode with insert at 300MHz.

Excitation elements targeting 8 modes (indicated by arrows in Table 1) were included. The positions of the excitation elements were determined based on the modal field distribution, computed by simulations. The TE_{11} modes were excited with stubs on the cylindrical shell of the extension, the TM-modes with stubs and a loop on the backplane for the TM_{01} mode [3], see Fig1a. As an example, the modal field distributions for four modes are shown in Fig3, the crosses and lines indicate the positions of the stubs and loop (Fig3a) on the backplane and on the outer shell of the extension, see also Fig1b. The lengths of the stubs and the loop were adjusted to match the individual ports.

The scattering matrix measured with a VNA for the unloaded bore extension is shown in Fig2. The ports are well decoupled. This implies that the ports do not couple into the same mode. For imaging experiments a Philips Achieva 7T scanner with MultiX system was used with 8 independent transmit/receive channels. The ports of the waveguide extension were used in transceive mode.

The excitation pattern of each port was measured, by placing the insert waveguide into the isocenter. The remaining part of the bore was left empty. Low flip angle gradient echo images were acquired to measure the relative intensities of the receive sensitivities, see Fig4a. Selective mode excitation was degraded due to coupling into the higher order modes (modes 9-17) and due to coupling in the feeding structure. However, this diverse field distribution in the bore extension translates into a diverse field distribution in the sample (cylindrical phantom, ø20cm L=30cm, ε_r=58, σ=0.78S/m), shown in Fig4b. In Fig4c localized RF-shimming was applied to the phantom, trying to focus the excitation within the dashed circle.

Conclusion

Dielectric filling of a waveguide allows excitation of spatially distinct field patterns in the sample using traveling wave modes. This can be used for parallel transmission enabling RF-shimming as well as for parallel receive. The dielectric insert allows for selective modulation of the cut-off frequencies of the modes. This concept can be further optimized by changing the dielectric material, or the distribution of the tubes.

References [1] Brunner et al., Nature, 457: 994-999,2009; [2] Wu et al., Electromagnetics, 21: 97-114, 2001; [3] Pozar, Microwave Engineering, 1998;

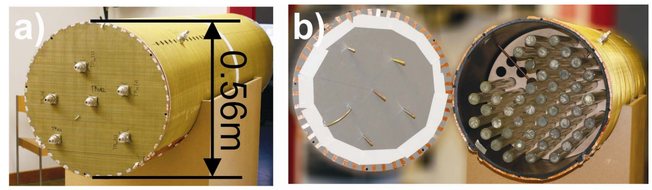


Fig1: Bore extension with inserts and stubs and loop for excitation.

$$[\varepsilon] = \begin{bmatrix} \varepsilon_{r,MG} & 0 & 0 \\ 0 & \varepsilon_{r,MG} & 0 \\ 0 & 0 & \varepsilon_{ave} \end{bmatrix} \quad (1)$$

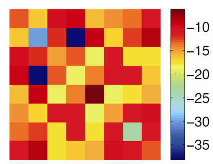


Fig2: Measured S-parameter [dB]

Port	Mode	$f^c_{n,m}$ [MHz]	$f^c_{n,m}$' [MHz]	$\varepsilon'_{hom,eq}$	λ [m]
port 1 →	TM_{01}	411	85	23.4	1.04
port 2,3 →	TM_{11}	654	136	23.1	1.13
port 4,5 →	TM_{21}	876	187	21.9	1.29
port 6 →	TM_{02}	942	193	23.8	1.32
	TM_{31}	1089	225	23.4	1.53
port 7,8 →	TE_{11}	314	246	1.6	1.78
	TM_{12}	1196	248	23.3	1.81
	TM_{41}	1293	266	23.6	2.23
	$TM_{22}(1)$	1435	284	25.5	3.32
	TM_{03}	1476	291	25.7	4.67
	$TM_{22}(2)$	1435	297	23.3	12.29

Table1: Cut-off frequencies, eq. permittivities, and wavelengths of the bore extension with inserts. Excited modes are marked.

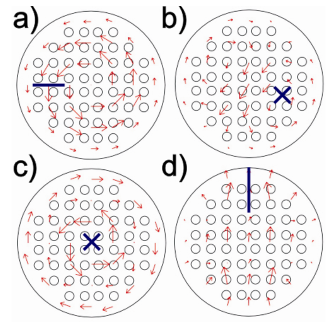
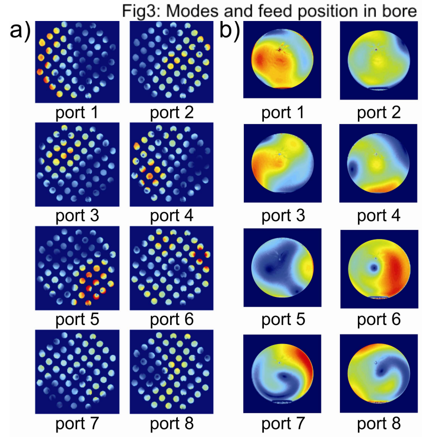


Fig3: Modes and feed position in bore



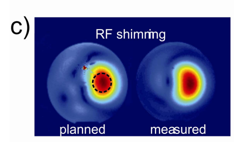


Fig4: Measured relative intensities of the receive sensitivities, (a) in the dielectric stubs, and (b) in a cylindrical phantom, (c) planned and measured RF shim .