Improved RF control of the travelling wave MR using a multi-mode coaxial waveguide.

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Introduction

RF multi-transmit relies upon a tailored complex combination of B1+ fields to manipulate the total RF excitation field. The individual B1+ fields of the transmit elements can be seen as basis functions to construct a desired excitation pattern. An alternative concept is to use a superposition of modal fields of the closed waveguide formed by the cylindrical RF screen [1]. Such a concept connects naturally well with a multi-transmit travelling wave system. A sum of modal fields can span any B1+ field distribution based on the completeness of the infinite set of modes inside a closed waveguide. Thus, in terms of B1+ steering it is advantageous to excite as many modes as possible providing a larger set of orthogonal basis functions. Here we demonstrate a multi-transmit travelling wave setup with a coaxial feeding section [2] capable of supporting several modes for optimal RF shimming performance. Selective mode excitation is performed in the coaxial feeding section at a distant location from the sample. The cut-off frequencies of the higher order modes were tuned under 300 MHz by placing a circular array of densely packed water tubes along the RF screen. Such a dielectrically lined waveguide can support surface modes with similar field patterns and B1+ efficiency as normal volume waveguide modes but are less susceptible to RF attenuation [3, 4].

Methods and materials

With the coaxial feeding in place the scanner’s bore is divided into two sections: a cylindrical waveguide section where the load is located and a coaxial feeding section with 8 antennas (stubs). See Fig. 1. Each stub was matched to 50 Ohm and coupling did not exceed 10 dB. EM field distributions in the phantom were simulated with using the FDTD method (SEMCAD, SPEAG, Zurich, Switzerland). For MR experiments the 8 channel coaxial feeding section and the phantom were placed in the bore of a 7T MR scanner. To demonstrate the effect of the increased number of modes present with water tubes in place, simulations as well as measurements were performed for 9 and all 32 tubes present. In the experiments the B1+ field patterns were measured with the AFI method (TR1 = 50 ms, TR2 = 250 ms). The B1+ phases were acquired with interleaved GRE measurements with two echo times (TE1 = 3.89 ms, TE2 = 4.89 ms) [5]. Cut-off frequencies of the several modes were estimated for the coaxial and cylindrical sections with and without the water tubes by solving analytically the 2D Helmholtz equation. From waveguide theory the first mode number n is the order of the complex exponential $\exp(-jn\phi)$ which defines azimuthal dependence of the mode’s EM field. The relative mode intensity in the given transverse field pattern can be calculated by Fourier transformation as the $\exp(-jn\phi)$ functions form Fourier basis. We refer to this as the angular mode spectrum.

Results and discussion

Cut-off frequencies evaluation showed that without water tubes only a single propagating TE11 mode is present in both the coaxial and cylindrical sections; higher order modes are evanescent. Inserting water tubes significantly increases the number of propagating modes in the coaxial and cylindrical sections (Table 1). The dielectric layer (water tubes) supports propagation of surface modes in both coaxial and cylindrical waveguides (Fig. 3). Although most power is located in the tubes, a strong B1+ field can be generated in the load. Modes B1+ field patterns experience minimal attenuation and reflection while propagating from the coaxial into cylindrical waveguide. Measured B1+ fields of individual stubs correspond well to the simulations results (Fig. 4). Presence of more water tubes increases B1+ efficiency as well as the spatial diversity. This implies that a larger number of modes are being excited by a single channel. To demonstrate this we supplied the stubs with a phase modulation corresponding to a TE11 and TE31 mode respectively. As can be seen from Fig. 5 (bottom row) our antenna geometry is able to selectively excite the desired mode patterns. The obtained B1+ fields for both mode excitations differ significantly for the 32 water tubes. In case of 9 water tubes almost no difference is observed suggesting that no 3rd order mode is present. In addition, the angular mode spectra from the simulations confirm that fewer modes are present in case of 9 water tubes compared to 32 tubes (Fig. 6, left and middle spectra). The presence of at least 5 different modes was also confirmed by the angular mode spectrum of the B1+ measurements for the 32 tubes (Fig 6, right spectrum). Thus, the higher angular spatial diversity supplies us an optimal control of the excitation field in the cylindrical section. Comparison of the relative intensities change for the 1 and 0 order modes, for the three stubs, located at 0°, 45° and 90°.

Conclusions

We have demonstrated that with our waveguide design, a large number of distinct modal B1+ patterns can be selectively excited by an 8 channel coaxial feeding. The presence of more water tubes in both the feeding and imaging sections preserves B1+ control even at the distant locations from the feeding section. This confirms the advantage of using a multi-transmit travelling wave system based on surface modes rather than conventional volume modes, for optimal B1+ steering.

References