A Travelling Wave Antenna with Matched Waveguide for Head Imaging at 7 T: Simulation Results

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Introduction The travelling wave (TW) approach [1] to MRI involves using an antenna to propagate a TW through the bore of a 7T (or stronger) scanner. It is this wave that excites the spins which are then used to acquire the MRI image. This approach leads to an improvement in B_1^+ homogeneity as the incident wave has a uniform magnitude. However, the TW approach is relatively inefficient at delivering power to the volume of interest (VOI) due to impedance mismatches between the antenna and VOI. By using a waveguide to match the incident wave into the head, these mismatches can be reduced and a stronger B_1^+ can be generated in the VOI. Such a setup has been simulated and assessed using SEMCAD X [2]. This design is also compatible with the use of local receive coils and local shim coils, for improved SNR and B_0 homogeneity respectively. Multiple modes of propagation are also supported, allowing this design to function with transmit SENSE and therefore achieve even better $B1^+$ homogeneity [3].

Methods Simulations were performed using SEMCAD X and the virtual family [4]. The geometry is shown in Figure 1. The waveguide has a radius of 15 cm and is 75 cm long. The entire waveguide is filled with water. Not shown is a thin perfect electrical conductor which surrounds the blue region of the waveguide. The green region of the waveguide is not shielded so it does not interfere with gradient function and also allows for the positioning of local receive and/or local shim coils. TW modes were generated using either dipoles or stubs, driven by a 50 Ω current sources. The distance between the dipoles and back of the waveguide p was varied until standing waves were established between the dipoles and the back of the waveguide, ensuring that power was flowing towards the head. The distance between the dipoles and the front-end of the waveguide h was then varied (by extending the length of the waveguide in the z direction and moving the dipole to maintain p) until an optimum amount of B_1^+ was generated in the head. The relative permittivity of the water was then varied until a maximum B_1^+ was generated in the head ($\varepsilon_r = 40$). The final p value was 20 cm and the final h value was 35 cm. The stubs were positioned at radii r to correspond to the maxima in each mode's amplitude for maximum coupling into the given mode. Each mode was driven in two orthogonal directions, for a total of eight possible channels. B_1^+ and SAR maps were extracted from the simulations. Simulations were also performed with just the blue region of the waveguide, with the blue region plus the 10 cm of the green region to bring the waveguide into contact with the head, and of the entire waveguide and dielectric cavity to demonstrate the improved power delivery achieved by this design.

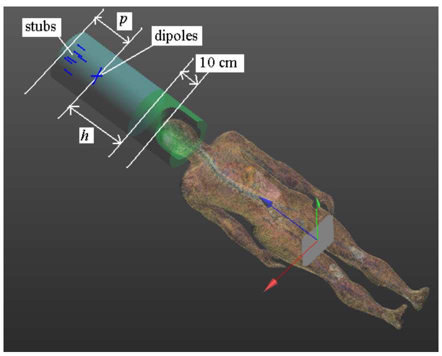

Figure 1 – simulation geometry.

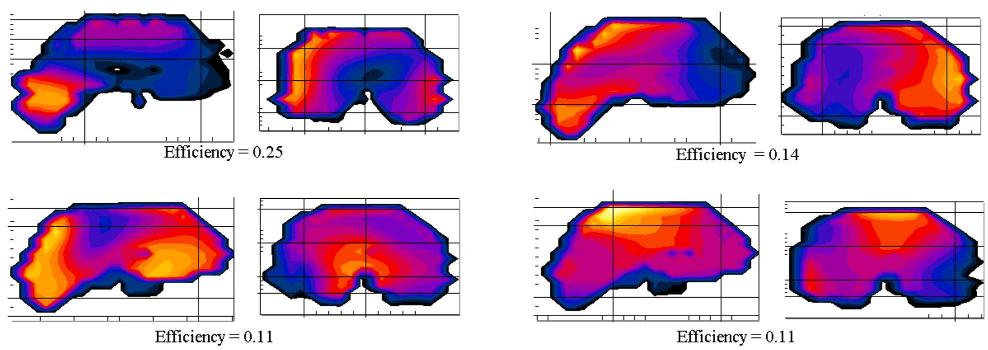

Figure 2 – Sagittal and coronal B_1^+ maps for a selection of modes across the brain and their peak efficiencies in μTW^{-1}. Top left: TE_{01} mode. Top right and bottom left: orthogonal TM_{11} modes. Bottom right: TM_{12} mode.

Mode	Cut-off Frequency (MHz)	Driven by…
TE_{01}	123	Centre dipole
TE_{11}	193	r = 7.5 cm stub
TM_{11}	93	r = 8 cm stub
TM_{12}	268	r = 3.5 cm stub

Table 1 – simulated modes' cut-off frequency and their driving points.

Simulation contained…	Power efficiency (μTW^{-1})
Waveguide only	0.3
Waveguide extends all the way to the head	4.2
Waveguide extends all the way to the head, plus a dielectric cavity around the head.	4.8

Table 2 – simulated B_1^+/power efficiencies.

Results The example B_1^+ maps shown in Figure 2 demonstrate that it is possible to achieve complete brain coverage using as few as four modes. Figure 3 is a typical SAR map from the TE_{01} mode. It shows that the SAR is predominantly constrained to the head, with SAR also arising in the arms and shoulders. Negligible SAR is generated in the torso or legs. Very similar SAR maps were obtained for all modes. Table 2 contains efficiency data that demonstrates a significant increase in efficiency by extending the waveguide to touch the head (as this reduces reflections from air-tissue interfaces), and a modest increase in efficiency from surrounding the head in dielectric (as this accommodates the wave propagating through the entire head better).

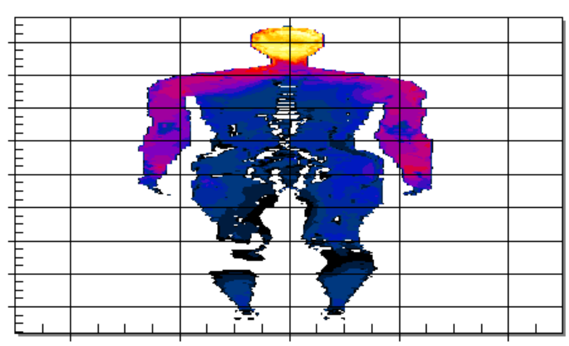

Figure 3 – a typical simulated SAR map (logarithmic scale).

Conclusion This work indicates that this TW antenna with waveguide setup is capable of generating B_1^+ in the head with increased efficiency compared to normal TW methods. Multiple modes can be generated allowing for a multi-transmit approach to improve B_1^+ homogeneity across the brain. This design is also compatible with the use of local receive and/or shim coils for improved SNR and B_0 homogeneity. A prototype will now be built for phantom and *in vivo* imaging. The green region of the waveguide shown in Figure 1 will be filled with D_2O to stop it generating an MRI signal.

References [1] Brunner et al., Nature 457:19, (2009). [2] SEMCAD X by SPEAG, www.speag.com. [3] Brunner et al., MRM 66:1 (2011). [4] A. Christ et al., Physics in Medicine and biology, 55 N23-N38, (2010).