A Horn Antenna Improves the Transmit Field Homogeneity in the Human Brain using the Travelling Wave Technique

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Introduction Human imaging at 7T is a great challenge for conventional RF hardware and techniques due to its more inhomogeneous B_1 field and likelihood of tissue heating [1]. Recently the travelling wave technique utilising the waveguide mode guided by the magnet bore has been suggested as a promising technique to address the above mentioned problems [2]. However the waveguide mode mismatch between that from the travelling wave transmitter, usually a patch antenna, and the loaded magnet bore will cause reflection of the EM wave and a 'hotspot' on top of the head will be present. The hotspot effect may be alleviated by using a cylinder of dielectric positioned at the top of the head, but the field inhomogeneity is still substantial [2]. This work proposes a horn antenna type of structure to improve the coupling of the travelling wave to the head and also improve the field homogeneity, especially at the upper cerebrum area. A comparison of its performances against a patch antenna, and a patch antenna with a matched load, were studied by using the numerical simulation (xFDTD, Remcom. Inc, PA).

Method and Results A patch antenna placed 90 cm away from the human head has been demonstrated by several groups to generate circular polarised plane waves. The magnet bore shielded with an RF screen behaves like a metallic waveguide loaded with dielectric material and the TE_{11} mode, with homogeneous magnetic field, propagates down the bore. On reaching the human head reflection of EM waves occurs at the top of the head which result in a hot spot with a size about 30 cm^2 and a B_1 level twice as high as the rest of the human head (Fig. 1 (a.1) & (a.2)). This is because of the mode pattern mismatch between the plane wave and TE_{11} mode at 298MHz. Therefore most of plane waves are reflected at the air/head interface. The power flow direction inside the head generated by the patch antenna setup is studied by plotting the Poynting vector distribution in the sagittal plane, where there is substantial energy reflected back from the lower cerebrum and the nose (Fig. 2(a)). To alleviate the reflection, a cylinder with 20 cm in diameter and 41 cm in length filled with a dielectric ($\varepsilon = 55$, σ=0.2 Sm^{-1}), similar to human tissue, is modelled on top of the head. This provides an extra length of loaded waveguide and helps the plane wave to convert to guided mode before it reaches the head [2]. The size of the hotspot on top has been reduced to 5 cm^2 by adopting such matching load. However the B_1 field drops quickly at the upper and front area of the head, including the upper cerebrum, forehead, nose and mouth (Fig. 1(b.1) &(b.2)). The B_1 increase between the central brightening spot and the dark area at the upper cerebrum is about a factor of 3.8. This work proposes a new setup to connect the travelling wave transmitter and matching load with a tapered cylinder made from the same dielectric material (Fig. 3). For the new setup, the transmitter utilises an 8 cm diameter by 8 cm long cylindrical metallic waveguide filled with dielectric material with $\varepsilon \approx 55$ as a travelling wave transmitter. The end of the waveguide is blocked by using a circular metal cap to stop its backward wave transmission. Two orthogonal 50 Ω wave ports are placed at the plane parallel to the end cap of the waveguide to excite the TE_{11} mode of the waveguide transmitter at 298 MHz. The same 20 cm in diameter cylinder with salt water solution ($\varepsilon \approx 55$) as used in the previous setup is used as match load. In order to reduce the reflection between the transmitter and matching load, a tapered cylinder 50 cm in length is used to connect the transmitter and match load together. The whole setup is similar to horn antenna shape, and this helps the wave impedance to gradually transform inside the horn to match the different impedance between the small transmitter and matching load. [3] The distance between the human head and the end of the transmitter is 90 cm, the same as the patch antenna setup. This relative long length of flared horn section provides a smoother impedance transition. The Figure 1(c.1) shows the B_1^+ field and B_1^- fields generated by this new setup. The hot spot has been greatly reduced. The sudden drop out of the signal at the top of the head was reduced further. For the B_1^- field (Fig. 1(c.2)), the new antenna also minimises the large proportion of negative rotating region in the front part of the head during the reception compared with the other two arrangements. From the Poynting vector plot, it can be seen that the direction of power flow points to the inside of the head compared with that without any matching technique (Fig. 2(b)).

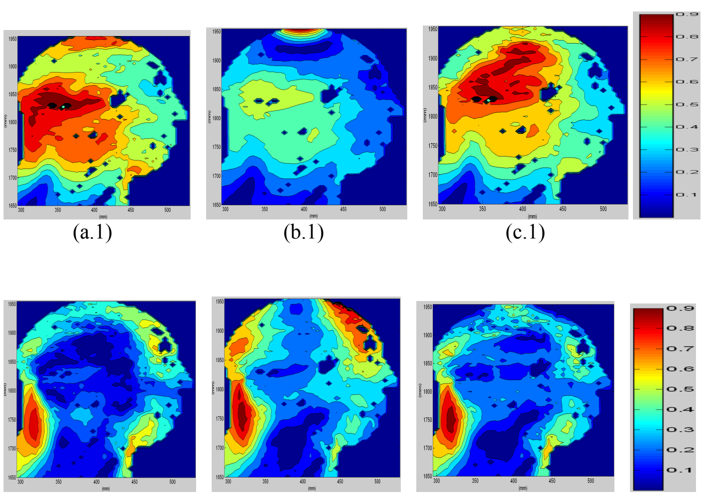

Fig. 1: (a.1) B_1^+ field (a.2) B_1^- field distributions at sagittal plane by using the patch antenna as transmitter, .(b.1) & (b.2) field distribution for the patch antenna with cylinder match load, (c.1) & (c.2) fields for the new setup.

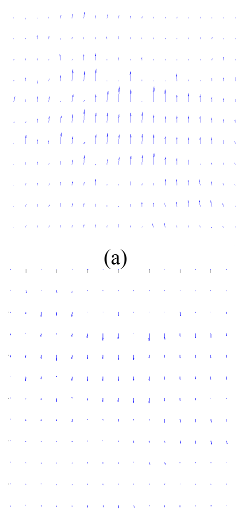

Fig. 2: Poynting vector distribution for (a):patch antenna, (c) new setup

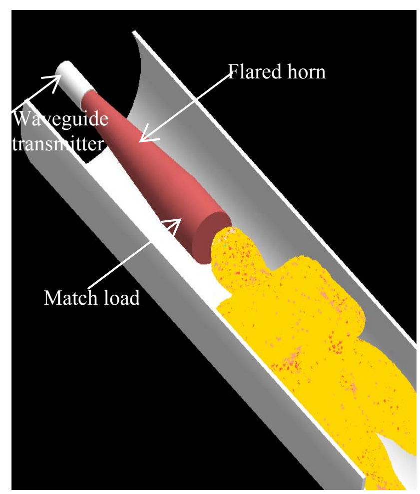

Fig. 3: Geometry of the horn antenna type of setup

Conclusion and Discussion In this work, a horn antenna type of setup is proposed to connect the travelling wave transmitter and the matching load together, and this allows the wave to transform gradually inside the horn mouth to match the different wave impedances between the transmitter and matching load. Both the B_1 field map and Poynting vector plot shows the field imhomogeneity is been improved and more of the transmitted power flows into the head. The B_1 hotspots at top of the cerebrum and forehead area are greatly reduced. In further work, such a setup will be fabricated and tested.

References [1] Z. Zhai et al. ISMRM, 2007, Birlin. [2] D. O. Brunner et.al. ISMRM 2009, Hawaii. [3] H. Jasik, Antenna engineering handbook, 2007.