A novel matching strategy to increase power efficiency of the travelling wave MR imaging

A. Andreychenko[1], H. Kroeze[2], D. W. Klomp[2], J. J. Lagendijk[1], P. Luijten[2], and C. A. van den Berg[1]
[1]Radiotherapy, University Medical Center Utrecht, Utrecht, Utrecht, Netherlands, [2]Radiology, University Medical Center Utrecht, Utrecht, Utrecht, Netherlands

Introduction: Travelling wave MR imaging exploits the waveguide action of the RF shield. The transmitting and receiving patch antenna is placed at the beginning of the bore of the scanner. Different sections of the bore will have different wave impedances due to different loading conditions. This can lead to abrupt changes in impedance causing large reflections and inefficient power transfer to the target region [1,2]. Here we present a matching methodology for travelling wave MR imaging based on transmission line theory. We propose to introduce a coaxial waveguide section [3] between the antenna and load to achieve a gradual transformation of the impedance of the antenna to the impedance of the load (Figure 1).

Theory: The patient region will generally have much lower impedance than the hollow waveguide due to a lower cut-off frequency caused by dielectric loading effect of the patient. As a result, a large part of the wave will be reflected when it impinges upon the patient, especially at the shoulder region. [2, 4]The coaxial waveguide inset transforms impedance at the antenna similar to the coaxial cable: $Z_A = Z_C \cdot \frac{Z_L + j \cdot Z_C \cdot \tan(2\pi l / l_z)}{Z_C + j \cdot Z_L \cdot \tan(2\pi l / l_z)}$, where l is the resonator length, l_z - longitudinal wavelength. As it follows from the equation, the impedance seen by antenna changes from Z_L when $l = l_z \cdot n/2$ (half wavelength waveguide) to Z_C^2 / Z_L when $l = l_z \cdot (2n+1)/4$ (quarter wavelength waveguide). Thus, by varying the length of the coaxial waveguide we can obtain optimal matching conditions and efficient power transfer to the load.

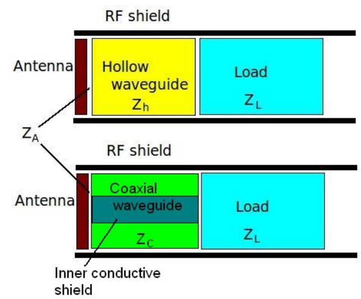
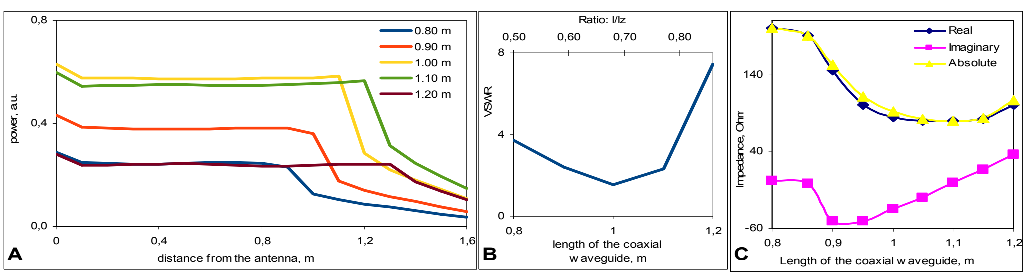


Figure 1. Impedance distribution in the RF shield with and without the coaxial waveguide.

Materials and Methods: A coaxial waveguide was created by the RF shield and the inner conductive inset. The inset was made with a 32 cm diameter plastic tube covered with thin aluminum foil. Safety and efficiency of this construction was demonstrated earlier[3]. An easily sliding thin plastic framework covered with thin aluminum foil was made to vary the length of the coaxial waveguide. The vertical port of the circular patch antenna was used to transmit and receive. Electro-magnetic field distributions in the bore for different lengths of the coaxial waveguide were simulated with FDTD method and normalized to 1W delivered power to the port of the antenna. In the simulations the bore was loaded with a cylindrical phantom. Power flow along the longitudinal axis of the bore was calculated by integrating z-component of Poynting vector over the bore cross-section at the different distances from the antenna. Voltage standing wave ratios and longitudinal wavelengths were estimated from maxima and minima electric fields components in the coaxial waveguide section of the bore. To demonstrate experimentally the impedance transformation with the coaxial waveguide a human torso phantom was placed in the bore of a 7T MRI scanner (Achieva, Philips Medical Systems) and the antenna's port impedance for different lengths of the coaxial waveguide was measured with a network analyzer. For the in-vivo measurements a human healthy volunteer was placed in the bore with her head to the patch antenna. The coaxial waveguide was located between the antenna and head. The port of the antenna supplied with 2 kW peak power was used for transmit and receive. Fast field gradient echo images in the sagittal plane (FFE, TR/TE = 200/2.2ms, ACQ voxel 0.5/0.5/4 mm^3) were obtained for three lengths of the coaxial waveguide (0.86, 0.95 & 1.0 m) and without the coaxial waveguide. Signal-to-noise ratios were mapped in the brain region to compare power being delivered to the head for every set-up.

Results and discussion: Calculated power flows in the bore and voltage standing wave ratios are plotted in Graph 1 (A, B). When the length of the coaxial waveguide is close to the ¾ of longitudinal wavelength (1 & 1.1 m) around 2 times more power is delivered from the antenna to the load. The reduced reflections by the better impedance match between the antenna and load are indicated by significantly lower standing wave ratios when the quarter wave length coaxial waveguide is present. We also found that a matched condition also leads to higher initial power flow. This could be explained from the simulations by lower radiated power out of antenna side of the bore and by lower electric fields in the substrate of the patch antenna leading to higher power being transferred to the load. Graph 1C illustrates measured impedance at the port of the antenna for various lengths of the coaxial waveguide. Based on the simulations the estimated length of quarter wavelength coaxial waveguide is 1-1.1 m. This range is in good correspondence with impedance measurements: the total impedance at the port reaches its minima when the coaxial waveguide is approximately 1.1 m long. Unfortunately, maximum possible length of the coaxial waveguide for in-vivo MR measurements was restricted to 1 m due to the position of the iso-center in the bore. Note that a lower real impedance also means that the noise picked up by the antenna will also have a minima here. Figure 2 shows SNR distributions in brain calculated from the in-vivo GRE sagittal images. High SNRs in the top of the head for the 1 m long coaxial waveguide indicate that more power is delivered to the head comparing with 0.86 m and 0.95 m coaxial waveguide. Moreover, the relatively high homogeneity of SNR distributions in the brain for 1 m long coaxial waveguide demonstrates that fewer reflections (lower VSWR) appear comparing with shorter coaxial waveguides and when the coaxial waveguide (conventional travelling wave) is absent.



Graph 1. A: Power flow in the bore for different lengths of the coaxial waveguide; B: Voltage standing wave ratio in the coaxial waveguide sections of the bore and corresponding ratio between the coaxial waveguide length and the longitudinal wavelength; C: Measured real, imaginary and absolute impedance at the port of the patch antenna depending on the length of the coaxial waveguide.

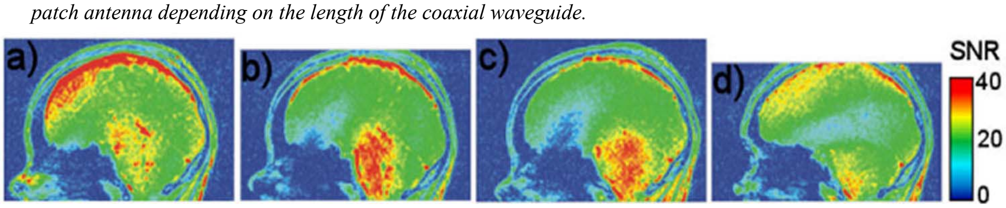


Figure 2. Calculated sagittal SNR maps in the brain for: a) 1.0 m, b) 0.95 m, c) 0.86 m and d) without the coaxial waveguide between the patch antenna and load.

Conclusions: The impedance mismatch inside the bore of the scanner can be effectively compensated by the quarter wavelength coaxial waveguide placed between antenna and the load. Simple impedance measurements can be used to find the appropriate length of the quarter wavelength coaxial waveguide. In this way the power transfer to the patient can be increased while noise picked up by the antenna will also be minimized.

References: [1] C.A. van den Berg et al., "Optimizing traveling wave RF excitation for in vivo use", 17th ISMRM, Honolulu 2009; [2] D.O. Brunner et al., "Travelling-wave MRI: Initial results of in-vivo head imaging at 7T", 17th ISMRM, Honolulu 2009; [3] A. Andreychenko et al., "Effective delivery of the traveling wave to distant locations in the body at 7T", 17th ISMRM, Honolulu 2009; [4] D.O. Brunner et al., "Traveling-wave nuclear magnetic resonance", Nature 457, 994-998