Design of a Patch Antenna for Creating Traveling Waves at 7 Tesla

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Introduction Recently the use of traveling waves for high field MRI has been suggested as a promising method for large FOV imaging and comparatively uniform excitation [1]. In the traveling wave system, conventional volume coils and surface coils used as the transmitter/receiver are replaced by a patch antenna, a kind of directional electromagnetic antenna, placed a considerable distance from the sample. Here, we study the practical design of a patch antenna and its properties in the traveling wave system.

Methods A patch antenna with two orthogonal coax feeds matched to 50Ohm was designed for excitation and reception at 297.2MHz. The patch antenna consists of three parts: a conductive patch, a substrate and the ground plane, with coaxial-line feeds, where the inner conductor of the coax is attached to the radiation patch while the outer conductor is connected to the ground plane. Since the scanner bore is circular, a circular patch was used for reasons of symmetry. The resonant frequency of the circular patch antenna for the dominant patch mode TM_{110} is [2]

$$(f_r)_{110} \approx \frac{1.8412}{2\pi a_e\sqrt{\mu\varepsilon}} \approx \frac{1.8412c}{2\pi a_e\sqrt{\varepsilon_r}} \qquad \text{(eq. 1)}$$

where a_e is the effective radius of the conductive patch, ε_r is the relative permittivity of the substrate and c is the speed of light in free space. The effective radius a_e takes fringing into account, and it has the following relationship with the actual radius a [2]:

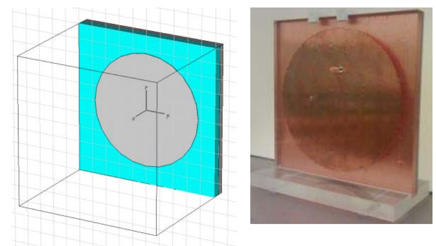

Fig.1 Schematic for simulation (left) and photograph (right) of the patch antenna

$$a_e = a\left\{1+\frac{2h}{\pi a\varepsilon_r}\left[\ln\left(\frac{\pi a}{2h}\right)+1.7726\right]\right\}^{1/2} \qquad \text{(eq. 2)}$$

Here, h is the height of the substrate. Once the material of the substrate and the height of the substrate are decided, the resonant frequency is determined by the effective radius of the conductive patch.

The input impedance of the patch antenna at any radial distance $\rho' = \rho_0$ from the center of the patch is determined from the following Equation [2]:

$$R_{in}(\rho'=\rho_0) = R_{in}(\rho'=a_e)\frac{J_m^2(k\rho_0)}{J_m^2(ka_e)} \qquad \text{(eq. 3)}$$

$$R_{in}(\rho'=a_e) = \frac{1}{G_t}$$

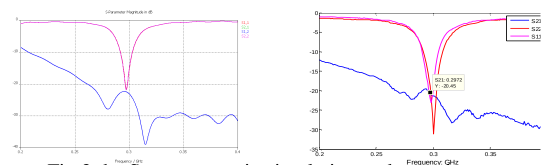

Fig.2 the S parameters in simulation and experiment

G_t is the total conductance due to radiation, conduction and dielectric losses, while $J_m(x)$ is the Bessel function of order *m*.

A commercially available Acrylic slab (www.mcmaster.com) with the size of 400mm*400mm*31.75mm was chosen for our patch antenna system. the radius of the patch is 174mm and the position of the coax feeds are 75cm from the center of the patch, while the size of the s In order to generate quadrature excitation, two coaxial feeds were placed at the same distance from the center of the patch but with a 90º angular offset (using the length difference of the coax line), so as to generate fields orthogonal to each other both under the patch and outside the patch. Theoretically, when the two coaxial feeds are separated by 90º, the two feeds are isolated very well from each other. However, we left a very small slot at one feed position in our antenna to make it adjustable for best isolation. RF power is split equally with a Wilkinson power splitter, and one T/R switch and preamp assembly is used for each channel (Stark Contrast, Erlangen Germany).

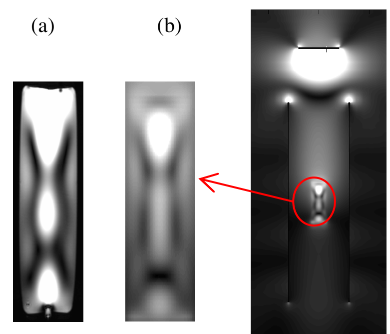

Fig. 3 field pattern of the phantom (a) Image of the phantom, (b)The simulated H field distribution in the phantom and system

S parameters of the patch antenna were measured and were determined to be in close correspondence with simulations. For MR transmission and reception, the patch antenna was placed at the service end of the bore of a 7T MR scanner (Siemens Medical Solutions). The system was loaded with a cylindrical phantom (17cm in diameter and 40cm in length) filled with 2.63 g/l NaCl and 1.24g/l NiSO4.6H2O. Simulations were performed to analyze wave propagation for a loaded bore, variation of S11 when changing the position of the phantom in the bore, and signal distribution within the sample. Simulation results were compared with corresponding experimental results.

Results The S parameters of the patch antenna tested in free area matches the simulation results very well (Fig. 2), and after the patch antenna is placed in the MR system, S parameters change substantially when the sample is placed at different positions in the bore, as verified in Figure 4. Since the traveling wave is quite uniform in the bore without the sample, the field pattern of the sample (Fig. 3) does not change wherever the sample is placed.

Conclusions A patch antenna was successfully designed, with the size of the patch and the positions of the coaxial feeds determined by simulation. The simulation plays a very important role in patch antenna's design, since after the antenna is built, modification is more difficult than for conventional coil design, which uses lumped elements for matching and detuning. The image of the phantom is brightest on the side closer to the patch antenna and the signal attenuates in the dielectric material.

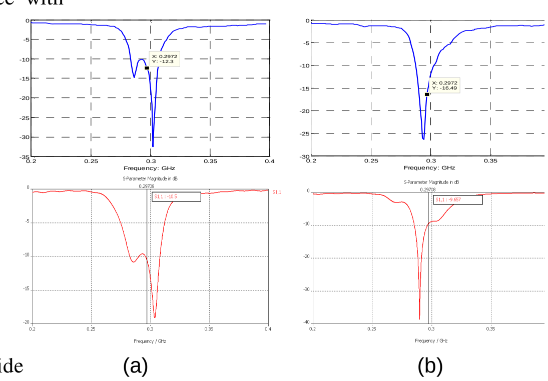

Fig.4 Experimental (top) and simulated (bottom) S parameters (a) in the middle of the bore, and, (b) 281mm closer to the patch antenna.

References [1] D.O. Brunner et al. 16th ISMRM, Toronto 2008. [2] C.A. Balanis. Antenna Theory: analysis and design, 2nd ed. John Wiley & Sons, Inc. 1997