Influence of metamaterial insert to cylindrical RF coil array in human knee MR imaging at 1.5T

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Introduction Metamaterials with negative permeability provide unique capability of recovering the evanescent wave and have been proposed in magnetic resonance imaging (MRI) applications to image an object in deep sub-wavelength. The several kinds of microstructures of metamaterial were designed for MRI applications, such as Swiss roll cell [1], split resonance ring [2], the wire medium endoscope [3] and cylindrical rolled-up [4]. These metamaterials were difficult to use and complicated for fabrication. Furthermore, in order to improve the patient comfort, the metamaterial for MR imaging needs to be thin and fit different subjects. In this work, a compact and flexible metamaterial which is readily to be inserted into an existing RF coil, was designed and fabricated for 1.5T MRI. The phantom and *in-vivo* experiment were performed on 1.5T Siemens Avanto MRI to study the influence of proposed metamaterial insert to 8-channel cylindrical knee coil array.

Methods Coil Design: A metamaterial with a square winding microstructure was designed for 1.5T MRI as shown in Fig. 1. In our designing, the square spiral had 3 turns with line width 1mm, line space 0.1 mm, thickness 0.035 mm. Two square spirals were connected by a metallic via, which forms a double-sided square spiral. The metallic via had a diameter 0.7 mm and the substrate was FR4 with thickness 0.164 mm, dielectric constant 4.8 and loss tangent 0.013. The copper strips on the two sides of a printed circuit board (PCB) substrate were electrically connected by the metallic via using a standard PCB fabrication technology. The side length of the unit square cell was 15 mm. The copper strips were protected by an FR4 pre-preg with thickness 0.06 mm on both sides. The final fabricated metamaterial had 19×19 cells in a plane with the total size 28.5×28.5 cm^2 and relative permeability $\mu = -1$ at 63.8 MHz. **Phantom Studies:** The phantom experiments were carried out on a 1.5T Siemens Avanto MRI system to study the variations of noise correlation matrix and signal to noise ratio (SNR) with the proposed metamaterial insert to 8-channel cylindrical knee coil array. A cylindrical bottle with 115 mm diameter and 200 mm length were employed and filled by 3.75g/L $NiSO_4 \cdot 6H_2O$ and 5g/L NaCl. The sagittal directional images of the phantom were acquired by using gradient recalled echo (GRE) sequence with the following parameters: TR/TE = 300/15 ms, flip angle = 20º, FOV = 180×180 mm^2, slice thickness = 8 mm, imaging matrix = 128×128, and bandwidth = 130 Hz/pixel. ***In-Vivo* Studies:** The *in-vivo* experiments were performed in accordance with the institution's IRB regulations including informed consent. The knee of a volunteer was imaged by GRE sequence with following parameters: TR/TE = 600/15 ms, flip angle = 20º, FOV = 180×180 mm^2, slice thickness = 3.5 mm, imaging matrix = 128×128, and bandwidth = 100 Hz/pixel. The variations of SNR and reconstruction image of knee was considered. In all experiments, the noise image of each channel of 8-channel knee coil array was acquired to evaluate noise correlation matrix by using the same sequence with none transmit power. The covariance sum of square (Cov-rSoS) method was employed to reduce the coupling effects on the SNR performance of the 8-channel knee coil array [5]. The proposed metamaterial was bent to better fit the phantom and knee of volunteer.

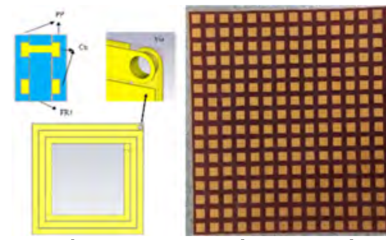

Fig.1 The microstructure and metamaterial.

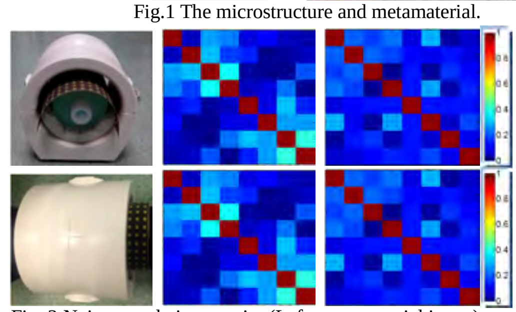

Fig. 2 Noise correlation matrix. (Left: metamaterial insert)

Table 1 Maximal mutual coefficient

	Metamaterial insert	Non-metamaterial
Phantom	0.3849	0.2909
Knee	0.39	0.289

Results The noise correlation matrix of phantom and *in-vivo* experiments were shown in Fig. 2. The maximum values of mutual coupling coefficient were listed in Table 1. It can be seen that the mutual coupling was increased when the metamaterial insert was added to the coil array, which may lead to SNR decrease. The SNR maps of sagittal profile with Cov-SoS for phantom and knee were demonstrated in Fig 3. It can be seen that the SNR increases in the region closed to the metamaterial insert and deeper region as well. The Cov-SoS reconstruction image of knee was shown in Fig. 4.

Conclusion/Discussion In this specific study, the use of the metamaterial insert to the existing coil array can alter the coil array's performance. The mutual coupling of 8-channel knee coil array was enhanced once the proposed metamaterial insert. It was also observed SNR decreased in some regions in the knee image. Further study in metamaterial design and positioning in the RF coil array is needed in order to have much improved SNR gain the entire region of imaging.

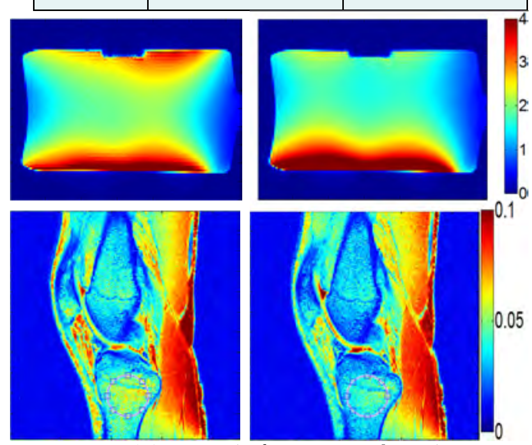

Fig. 3 SNR map (Left: metamaterial insert)

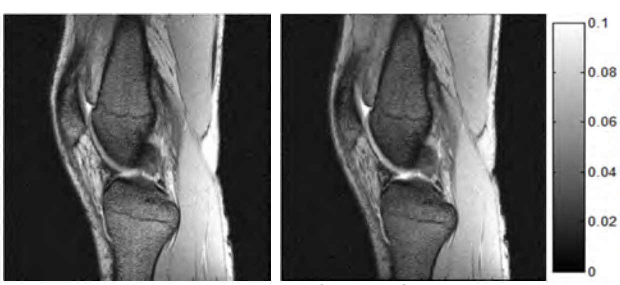

Fig. 4 Cov-SoS reconstruction image of knee (Left: metamaterial insert)

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