The use of metamaterials: a solution to improve the performance of Radiofrequency Coil for Magnetic Resonance Imaging (MRI)?

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Abstract

In this paper we coupled a coil for Magnetic Resonance Imaging with metamaterials in order to increase its sensitivity and improve the RF magnetic field pattern. To radiation patterns of the coil and the coil associated with metamaterials are so compared. We present in this paper one configuration of the coil coupled with metamaterials and their first encouraging numerical results

1. Introduction

In magnetic resonance imaging (MRI), the use of small sized radio frequency (RF) surface coil allows to perform high resolution images with sufficient signal to noise ratio (SNR) [1]. However, such coils present a rapid decrease in depth of their sensitivity that limits the achievable field of view. Moreover, the presence of samples having high permittivity and conductivity detunes the RF coil and decreases its quality factor. But a new material called metamaterial on which the scientific community has a growing interest in recent years could be the solution to the problems mentioned for the medical coils. Indeed, metamaterials have effective parameters (permeability and permittivity) that can be adjustable, both positively and negatively [2]. A team has already used this concept by placing swiss-roll on a RF coil to act as a magnetic flux guide [3], thus allowing to remote the RF coil from the sample. Here, the metamaterials will be used to match the electrical impedance of the coil with that of the tissues, thus limiting the coil detuning. Our work consists by finding the better configuration on coil and metamaterials to increase the sensitivity of small surface coil by both improving the RF magnetic field pattern and reducing losses and frequency shift resulting from dielectric coupling with the sample.

2. Design of the RF coil and metamaterials coupled with this coil

The RF coil consists of two transmission lines (4 laps each) which are separated by a dielectric of relative permittivity 23.6 and 0.5mm thick. The each two lines have a slot diametrically opposite to each other. These two lines are equivalent to an inductance and the substrate placed between the copper stripes acts as a distributed capacitance (Fig. 1). This coil operating in the VHF (Very High Frequency) band for high resolution MRI at 1.5 Tesla has been calculated by using finite elements software (HFSS by Ansoft).

To obtain small metamaterial structures with size of the order of $\lambda/100$, we used spiral rings resonator instead of usual one-turn split ring resonators. The dimensions of the metamaterials have been calculated so that the array has a resonance similar to that of the coil alone. For the calculations, the layers of metamaterials consists on only four spiral rings resonators to avoid very long computational time. The coil is placed under this layer in the middle. A top view on one layer is given on Fig. 2.

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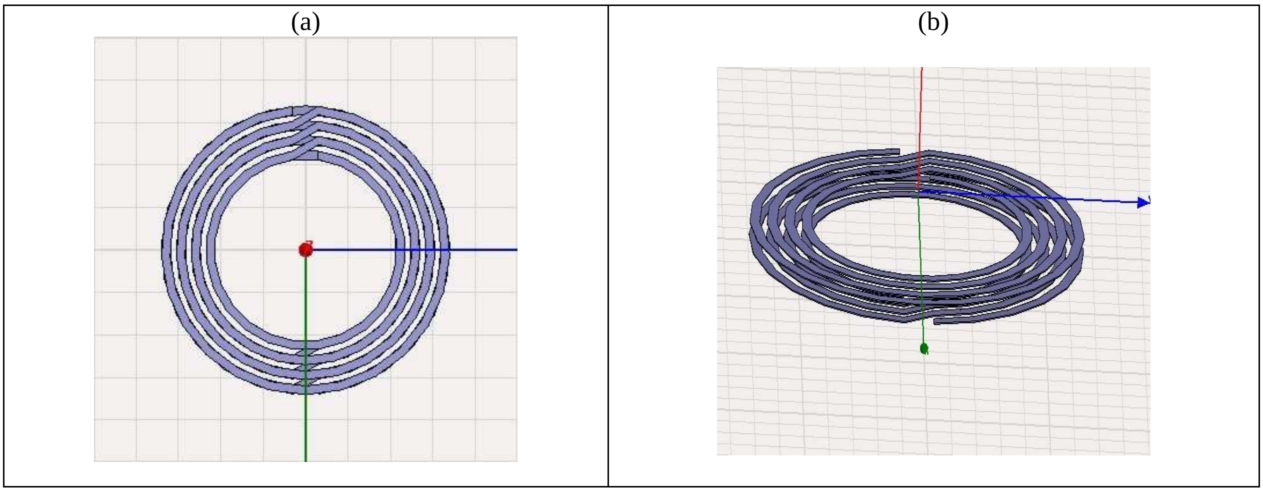

Fig. 1: (a) Top view and (b) side view of the numerical design of the coil

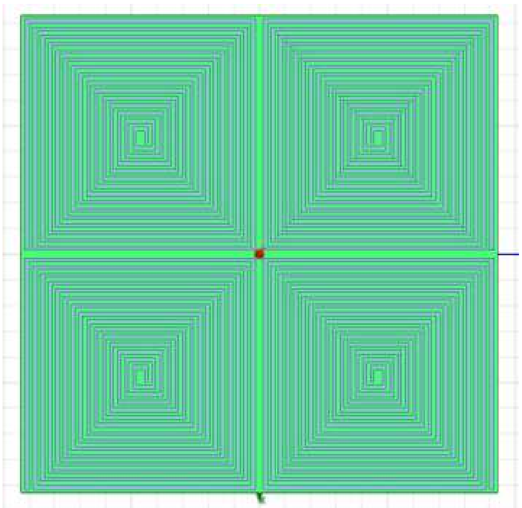
Fig. 2: The layer of four spiral rings resonators which constituted the metamaterial.

3. Numerical results

The magnitude of the magnetic field has been calculated in the same condition in the case of the RF coil alone and the coil coupled with only one layer of metamaterials. As we can see on Fig. 3, the magnetic field really increased with the presence of metamaterial. And the maximum RF field amplitude in a plane parallel to the coil surface at a 10 mm distance (Fig. 3 d), obtained in presence of the metamaterial is increased by a factor of 2.5

Moreover, the use of metamaterial provides also homogeneity for the RF field pattern with a higher intensity, effect that is expected for the medical measurements.

4. Conclusion

In this paper, we present the improvement of RF coil for RMI by using metamaterials. By using only one layer of 4 spiral resonators, the magnetic field has been increased and became homogenous. The magnitude of the magnetic field can be further improved by using several layers of metamaterials, which is currently being studied. A prototype will then be realized and tested on the bench.

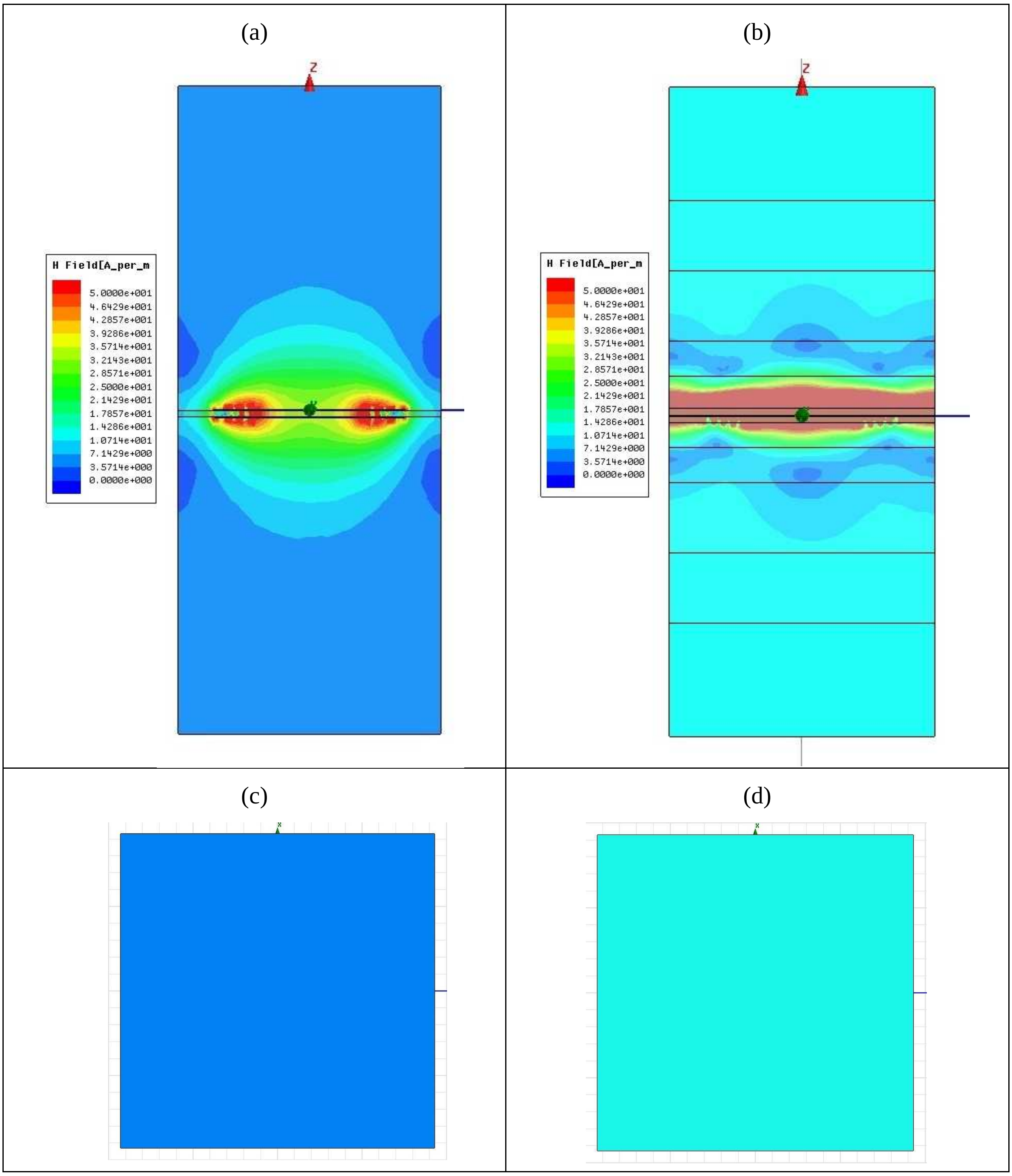

Fig. 3: Vertical cut plane for the magnetic field in the case of the RF coil alone (a) and associated with metamaterials (b).RF amplitude at 10mm distance for: (d) the coil and metamaterial, (c) the coil alone

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