

Metamaterial Media for MRI Applications

M. A. Lopez Terrones¹, J. M. Algarin¹, M. J. Freire¹, P. M. Jakob^{2,3}, V. C. Behr², and R. Marques¹

¹Electronics and Electromagnetism, University of Seville, Seville, Andalusia, Spain, ²Experimental Physics 5, University of Würzburg, Würzburg, Bavaria, Germany, ³Research Center Magnetice Resonance Bavaria, Würzburg, Bavaria, Germany

Introduction

Metamaterials are artificial composites whose electromagnetic properties can be engineered to achieve phenomena not observed in natural materials [1]. They are usually manufactured by means of the repetition of resonant elements to constitute a periodic structure and an essential characteristic is that an effective permittivity and permeability (μ) can be defined through the appropriate homogenization procedure [2]. Application of the metamaterials in MRI has been previously explored in several works [3-7]. Basically, two types of metamaterials which correspond to two different resonant elements have been used: swiss rolls [3-5] and capacitively-loaded split rings [6-7]. Split rings have the major advantage over swiss rolls of providing three-dimensional isotropy when they form a cubic lattice. In previous works [6-7], a slab of split-ring metamaterial with $\mu=-1$ was shown, which behaves as a superlens with subwavelength resolution [1] for the radiofrequency (RF) magnetic field of a 1.5T system. In the present work, we explore the application of split-ring metamaterials with different permeability values, in particular, slabs with zero permeability ($\mu=0$) and high permeability ($\mu=\infty$), which will reject and confine, respectively, the RF magnetic field. These slabs have been designed to work at 63.6 MHz, and their applications on MRI experiments evaluated at 1.5 T.

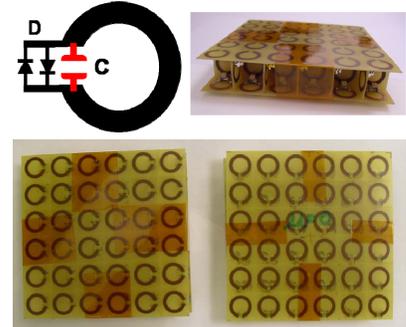


Figure 1. Top-left: Schematics of a ring. Top-right and bottom: Different views of both active metamaterials media.

Methods

Two active split-ring slabs of 6X6 unit cells and one unit cell in depth were designed to show $\mu=0$ and $\mu=\infty$ at 63.6 MHz, respectively (see Fig. 1 bottom). Each ring in the array contains a 470pF capacitor and crossed diodes in order to switch off the slab in transmission (see Fig.1). A 90mm in diameter receive-only single loop coil was used and a cylindrical bottle 16 cm in diameter, filled with a H₂O solution doped with 5 g/l NaCl and 1.25 g/l NiSO₄, was used as a load for both experiments. The loop was tuned to 63.63 MHz and matched to 50 Ω in the presence of the slabs and the phantom. It was actively decoupled by a tuned trap circuit including a PIN diode in transmission. The active decoupling for the loop was -25dB with and without metamaterial slabs. All the experiments were performed in a 1.5 T whole body scanner. In the $\mu=0$ experiment, the metamaterial slab is perpendicular to the loop (see Fig. 2), so that the magnetic flux is rejected by the slab and then confined inside the phantom. In the $\mu=\infty$ experiment, the metamaterial slab is placed parallel to the loop in the opposite side of the phantom (see Fig. 3) in order to "guide" the flux lines through the phantom.

Results

SNR maps were calculated from a series of identical phantom measurements [8] for both the $\mu=0$ and the $\mu=\infty$ slabs and compared with the situation where the slabs were removed. In Fig. 2 top, the calculated SNR maps are shown for both the presence and the absence of the $\mu=0$ slab and profiles are compared (see Fig. 2 bottom). In the side of the phantom where the $\mu=0$ slab is placed, the signal increases (approx. 15%). The calculated SNR maps for the $\mu=\infty$ slab are shown in Fig. 3 top, and the corresponding profiles in Fig. 3 bottom. Again, the signal presents an increment of approximately 15% with the presence of the slab.

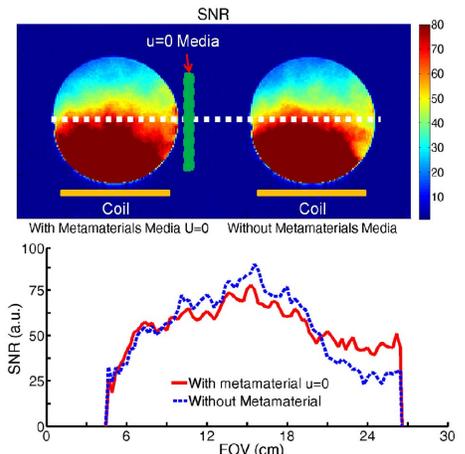


Figure 2. Top: Calculated SNR-Maps, left: with $\mu=0$ metamaterial slab, right: without metamaterial. Bottom: Corresponding SNR Profiles.

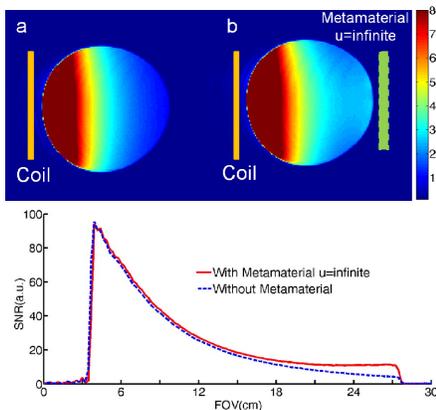


Figure 3. Top: Calculated SNR maps. a) Without Metamaterial slab, b) with $\mu=\infty$ metamaterial. Bottom: Corresponding transversal SNR profiles.

Discussion/Conclusion

This work demonstrates how split-ring metamaterial slabs designed with specific permeability values can increase the SNR in different configurations. The SNR gain in the demonstration was moderate, but it could be improved with a smart design of the configuration with the coil and the phantom. Moreover, although the SNR gain could not be comparable to that provided by another loop coil positioned in the same as the slab, the metamaterial slabs could be useful in limited channel systems or as complement of an array. Some artifacts appear in the phantom's surface due to the discrete nature of the split-rings, but our current work addresses this problem by removing the rings on the surface in the slab which is in contact with the phantom.

References

1. R. Marques et al. Wiley, Hoboken, New Jersey, 2008.
2. J.D. Baena et al. Phys. Rev. A 2008, 78 013842 1-5.
3. V.C. Behr et al. Concepts Magn. Reson. Part B.2004, 23B, 44-49.
4. M.C.K. Wiltshire et al. Phys. Status Solidi B.2007, 244, 1227-1236.
5. A. Mathieu et al. J. Magn. Reson. 2006, 182, 200-207.
6. M.J. Freire et al. Appl. Phys. Lett. 2008, 93, 231108 1-231108 3.
7. M.J. Freire et al. J. Magn. Res. 2010, 203, 81-90.
8. M.A. Ohliger et al. Magn Reson Med. 2004, 52:628:639.

Acknowledgements: This work was supported by the Spanish Ministerio de Educacion y Ciencia and European Union FEDER funds under project Consolider CSD2008-00066. The authors want to thank the company NORAS MRI Products for the advice.