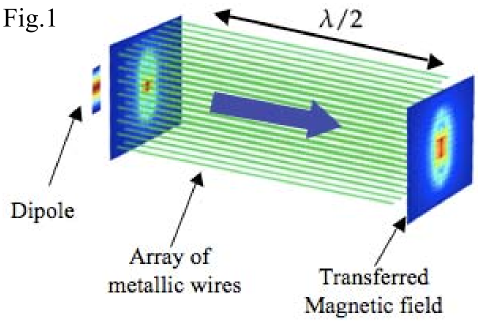
Numerical and experimental analysis and demonstration of a wire medium collimator for MRI

X. Radu[1], A. Raaijmakers[2], A. L. van Lier[2], C. Craeye[1], and C. A. van den Berg[2]
[1]Laboratoire de Télécommunications et Télédétection, Université catholique de Louvain, Louvain, Belgium, [2]Dept. of Radiotherapy, Imaging Division, Utrecht, Netherlands

Introduction

Metamaterials are materials which, in some frequency bands, enable to manipulate the near-field generated by an electromagnetic source. In the present paper, we propose to use this property to create new devices to facilitate the manipulation of RF transmit and receive field in MRI. The metamaterials structure considered here is made of an array of parallel wires forming a Fabry-Perot resonator and capable of transporting evanescent waves via their transformation into propagating waves inside the medium. Regarding the transmitted fields, a wire medium enables to collimate the magnetic fields orthogonal to the wires (TM component), which is anyway the only component of the RF magnetic field component measured in standard MRI systems (Fig.1). The collimated field distribution is then efficiently transferred to a more distant location. Since the length of the structure should be close to a multiple of half a wavelength, transfer over very large distances can be obtained. It is interesting to notice that the weakly resonant nature of the structure does not make fabrication accuracy a critical issue and allows us to imagine variations like convergent, divergent and curved geometries.

Fig.1



The use of a wire medium in MRI opens several prospects : (i) the possibility to design more reliable endoscopic sensors; (ii) the possibility to create a flexible transmit configuration to excite particular regions with good homogeneity. Hereafter, the properties of wire media are investigated both numerically and experimentally.

Methods

Wire media are investigated numerically from the point of view of their coefficient of transmission and eigenmodes. Special attention is given to the recuperation of the imaged fields, through the insertion of the receiving coils inside the metamaterial. The simulated absolute value of the magnetic field generated in a phantom bottle either by directly placing a surface coil against the bottle (Fig.2) or inside a straight wire medium (Fig.3) is compared. Transmission losses stay low and could be further reduced by optimising the length of the wire medium. In Fig.3 the very effective collimation is clearly seen. Also, very little perturbation of the fields lines is seen at the interface between the wire medium and the bottle, which indicates a good matching. Extreme configurations, in terms of curvature and in terms of reduction of the cross-section are also investigated numerically; the obtained results indicate that flexible endoscopic devices based on wire medium metamaterials may be envisaged.

Fig.2

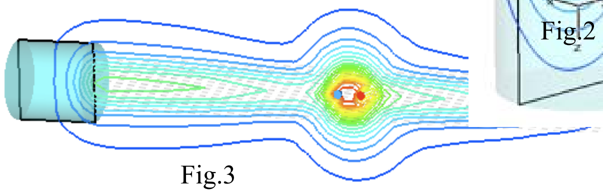
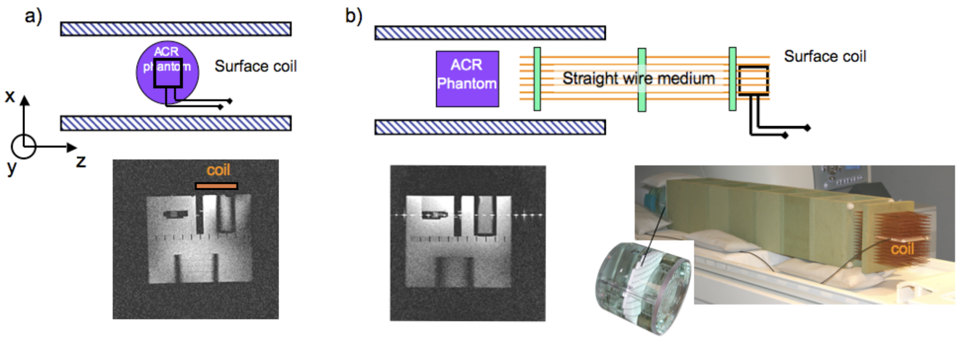


Fig.3

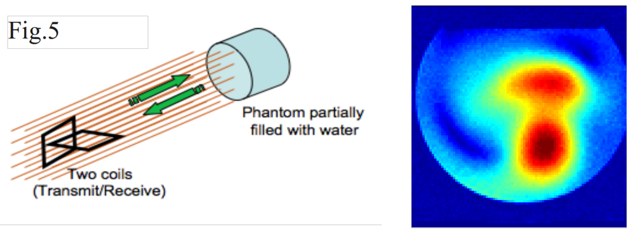
Results & Discussion

Wire media have been experimental tested on two different MRI scanners namely: a 3T and 7T. In 3T various geometries of wire medium have been tested in received only (straight, convergent, divergent and 63° curved). The source employed is an ACR phantom. A receiving surface coil is inserted between the wires at the end of the wire medium (see photo in Fig.4). The MR image transferred through a straight wire medium is presented in Fig.4.b. A conventional MRI capture of the ACR phantom is presented in Fig.4.a. Both images have approximatively the same signal-to-noise ratio. These results confirm the ability of wire media to transfer MR images with low losses and open the possibility to build new MRI devices devoted to internal imaging.



In 7 Tesla a wire medium has been tested in transmit an received modes with two coils inserted between the wires. One of the loops has been placed horizontally inside the metamaterial (see Fig. 5), the other one has been inserted vertically. The loops are decoupled from each other. Both loops are able to transmit and receive and results are optimally combined to form the image shown in Fig. 5. The two spots approximately correspond to the positions of the loops, which means that the metamaterials allowed us to specifically address different regions of the target. Further experiments will involve more elements and a more advanced combination of the signals.

Fig.5



Conclusions

A wire medium offers the possibility to collimate and transfer transmit and receive field from source to more distant locations. We have shown that this can be very efficient. Applications include endoscopic TxRx devices based on the wire medium principle and the opportunity to create a flexible transmit configuration to excite particular regions with good homogeneity.