Metamaterial Yoke for signal reception- an initial investigation

M. C. Wiltshire[1], R. M. Henkelman[2], I. R. Young[3], J. V. Hajnal[1]

[1]Robert Steiner MRI Unit, Imaging Sciences Department, Clinical Sciences Centre, Hammersmith Hospital, Imperial College London, London, United Kingdom, [2]Mouse Imaging Centre (MICe), Hospital for Sick Children, Toronto, Ontario, Canada, [3]Dept. of Electrical and Electronic Engineering, Imperial College London, London, United Kingdom

Introduction:

Metamaterials are synthetic materials that can be used to manipulate electromagnetic fields by virtue of their designed permeability and permittivity. Although initial development of these materials has mostly focused on their physical properties, there have also been demonstrations of the use of a Swiss Roll structure to duct B$_1$ fields in MRI [1,2]. Following these principles, we have investigated the concept of a Yoke made of Swiss Roll metamaterial to provide a low reluctance pathway that could potentially assist in signal reception in imaging and spectroscopy applications.

Concept:

We consider a small element of a sample that produces a dipolar flux pattern that is to be detected by a receiver coil, which is outside the object and so may not be very close to the volume of interest. By analogy with magnetostatics we might expect that increased coupling could be achieved between source and receiver though the provision of a yoke of high magnetic permeability that provides a low reluctance return path. Metamaterials can provide such a high permeability yoke for the RF field, without introducing perturbations of the static polarising field, B$_0$.

Method:

Individual Swiss rolls were constructed by wrapping flexible circuit board (18 μm copper bonded to 30 μm kapton) tightly around glass reinforced plastic mandrels 8 mm in diameter. These rolls were designed to resonate at 21.5 MHz and they had a Q of ~ 30. A rectangular frame was constructed as shown in Figure 1, with bundles of 7 rolls arranged in a close packed hexagon on each side. The lengths of the individual rods were chosen so that each bundle had a 45^0 mitred end. The bundles could be assembled into two distinct configurations: a rectangular yoke with a 15mm gap between pole pieces that comprise one side (Fig1a), or a linear array with identical 15mm gap (Fig 1b). To test the concept a small (3mm diameter) un-tuned loop was used as a source and a co-planar 35mm un-tuned loop was used for reception. The source loop was placed in the gap. Un-tuned loops were used so that the only tuned elements in the experiment were the Swiss Rolls that comprise the metamaterial. A second un-tuned loop was placed around the bundle S3 (see fig 1) to measure the flux in the metamaterial in the different configurations. Measurements were made using an HP4195A network analyser as follows. A reference level (0dB) was taken from the source and receiver loops alone. These were then inserted between the pole pieces, and increasing amount of metamaterial components were added as the linear array or yoke were built up. Independent measurements of the Swiss rolls determined the maximum permeability of the material. The junction loss between pairs of Swiss rolls, both in the linear configuration and when placed at right angles, was measured by exciting one roll with a small loop butted up to its end and receiving with a similar loop at the further end of the second roll.

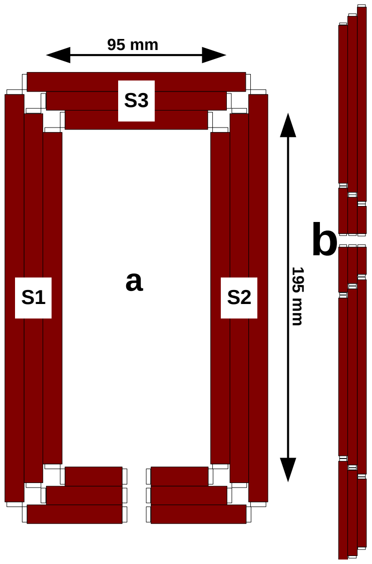

Figure 1. Schematic layout of the metamaterial bundles assembled (a) as a yoke, and (b) as a linear array

Results:

The maximum permeability of the rolls was found to be ~17 and this occurred at typically 21.7 MHz. There was a spread in resonant frequency with 90% of the rolls resonating between 21.0 and 22.5 MHz. The straight junction loss for single rolls was ~2 dB and this increased slightly (<1 dB) for the 90° bends. Addition of the pole pieces introduced a parasitic tuned element and increased the output to +7.0dB. As more components were added the signal level fell, presumably because of increasing losses. In the full collinear arrangement the received signal was 5.6dB and this rose to 6.1dB in the yoke configuration. The second receiver coil produced a signal of -4.6dB in the linear configuration, rising to +0.3dB in the yoke configuration. This confirms that the flux channelled through the material was substantially increased when in the yoke configuration and explains the increase in signal from the main receiver coil.

Discussion:

This pilot experiment confirms that metamaterials formed into a yoke can provide a preferred flux path that may increase signal coupling between source and receiver. The present material used is lossy and does not have a very high permeability. Moreover, there is significant loss at the junctions between the bundles. This combined with the long path lengths involved makes the effect small. However, it is reproducible and appears to provide a proof of principle that metamaterial yokes could enhance signal reception by introducing a low reluctance flux return path. We have improved materials [3] that will increase the permeability and Q by at least a factor of 2, and materials under development can provide an increase of an order of magnitude. These may enhance the effect substantially. As in all applications of RF technology to MRI and MRS, noise is a critical factor and it remains to be seen if a practically realisable yoke that produces a net signal to noise ratio benefit can be achieved.

References:

1. Wiltshire MCK, Pendry JB, Young IR, Larkman DJ, Gilderdale DJ, Hajnal JV, Science, **291**, 849 - 851 (2001)
2. Wiltshire M C K, Pendry J B, Larkman D J, Gilderdale D J, Herlilhy D, Young I R and Hajnal J V 2003, Proc. Intl. Soc. Mag. Reson. Med. **11**, 713
3. Wiltshire M C K, Pendry J B, Hajnal J V, Edwards D J and Stevens C J, 2003, Optics Express, 11, 709-715

Acknowledgments: MCKW is supported by the EC Information Societies Technology (IST) programme Development and Analysis of Left-Handed Materials (DALHM), Project number: IST-2001-35511. Philips Medical Systems provided a grant to JVH.