Development of Metamaterial Components for Use in MRI and NMR Systems

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Introduction: Metamaterials [1,2,3] offer the possibility of manipulating RF fields and fluxes in a variety of ways, including making yokes which have an effectively increased permeability at RF frequencies, and so provide "conduction paths" for magnetic flux. However, the space available inside an MRI system bore is strictly limited and, particularly at lower operating frequencies, the elements used in metamaterials (which are essentially resonant circuits) can be quite sizable [4]. In order to use the materials successfully, it is necessary to develop various components which can be incorporated into metamaterial assemblies. This abstract describes two embodiments of one such component, a flux compressor, designed to work at a relatively low MRI frequency, and intended to collect signal from a significant area and output it to a much smaller one.

Methods and Materials: In the flux compressor, flux entering at one, relatively large diameter, end is compressed to leave from a very much smaller exit diameter with a much higher flux density. Reciprocity, of course, teaches that the reverse function also applies. Two primary forms of compressor have been theoretically modelled and developed. One of these is essentially a tight wound tuned resonant solenoid (Figure 1(a)). The output of this device was characterized using two loops, one of the same size as the input and one matched to the output diameter. The other device comprised a set of tuned coils wound on different diameter formers. The coils were then assembled on a common insulating mandrel (Figure 1(b)). The number of turns in each coil was allowed to vary to make it easy to tune each coil of the set to 21.3 MHz (for experiments in a 0.5T system) using easily available capacitors. Coil interactions are not intuitively simple. They result in the emergence of magneto-inductive (MI) waves which propagate along the coupled coils. They were predicted theoretically [3] and proven experimentally [5] during the last two years. In the present work, MI waves have been shown to exist on structures in which the coil diameters vary. Two configurations have been studied. In the first one, the coils are pushed tightly against one another resulting in an effective coil separation of 2.2 mm; in the second one they are separated by 5.2 mm. Experiments and theoretical analysis, relating the input flux to the output flux have been conducted on both configurations.

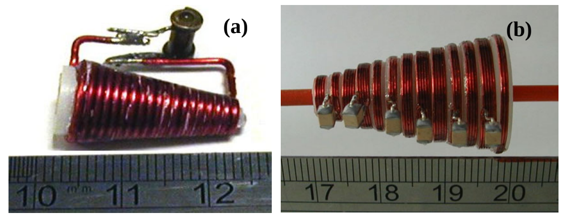

Figure 1. (a) The solenoid compressor, and (b) the multiple coil compressor

Results: When the design shown in Figure 1(a) was tested, both test loops recorded the same signal, demonstrating that the device does indeed function as a flux compressor. The measured results from the two arrangements of the multiple coils are shown in Figure 2 (a) and (b). The corresponding theoretical results, displayed in Figure 2(c) and (d), show a remarkably good match. Although the bandwidths of the devices and the details of the resonant peaks change, their overall transmission levels are little affected, so that the design of these devices can be seen to be quite robust.

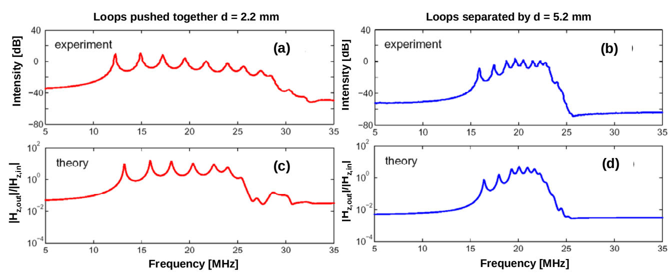

Figure 2. Performance of the multiple coil compressor. (a), (b) measured, (c), (d) theoretical results for different coil spacings

Discussion and Conclusion: Both forms of compressor work satisfactorily, though, in practice, to maximize Q and minimize loss, it may be necessary to refrigerate them. The application of this sort of component is in the collection (or transmission) of flux to the quite large areas associated with MRI coils and its compression so that a yoke passing round the patient's body from one side of the machine to the other can be of minimal size. By this means it should be possible to minimize gradient coil apertures, while achieving excellent RF performance.

References:

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