Flux Ducting

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RF technology is a key element of MR scanners. Although the advent of parallel imaging has led to renewed vigour in research in this area, traditional concepts of coil design have remained central. We have been exploring a radically different approach, using metamaterials concepts to design and experiment with compound RF structures. Metamaterials consist of arrays of electrically active, structured elemental units, which are small in comparison to the wavelength of electromagnetic fields at the frequency of operation. Accordingly, the material can be viewed as a continuum with effective magnetic permeability and electric permittivity. The engineered response of such artificially constructed metamaterials has had a dramatic impact on the physics, optics, and engineering communities, because metamaterials can offer electromagnetic properties that are difficult or impossible to achieve with conventional, naturally occurring materials[1].

For example, artificial magnetic materials based on non-magnetic conducting elements[2] can provide a designed magnetic response at microwave and lower frequencies. Achieving magnetism without using inherently magnetic materials is a natural match for magnetic resonance imaging (MRI). This has led to the design of magnetic metamaterials that have permeability ranging from large positive to negative at the Larmor frequency, but have little or no magnetic activity in static fields. Such materials offer the potential to be compatible with the need to preserve the homogeneity of the static B_0 field in MR systems, while still interacting strongly with the RF fields.

The concept of artificial electromagnetic materials was inspired by the work of Veselago[3] who investigated the nature of electromagnetic waves in regimes where the permeability and permittivity are negative. This simple change leads to surprising behaviour in which the refractive index becomes negative. However, materials with such negative properties do not occur in nature. In 1999, Pendry introduced a class of metamaterials made up of split ring resonators and these have now been shown to exhibit the required negative properties in microwave frequency bands. For example, a microwave beam passing though a negative material is refracted in the opposite direction to a beam passing though a material with a conventional positive refractive index[4]. The advent of metamaterials has yielded new opportunities to realize physical phenomena that were previously only theoretical exercises.

To operate at the frequencies used in MRI, a modified structure was required with a lower resonant frequency and this was achieved with the Swiss Roll structure. The Swiss Roll metamaterial design is ideal for RF applications, and is manufactured by rolling an insulated metallic sheet around a cylinder, and stacking many of these cylinders together. We have demonstrated that Swiss Roll metamaterials could be used in the MRI context in the large positive permeability regime. This results in flux ducting, in which RF fields produced by the NMR process are preferentially guided through the material to a remote receiver coil[5]. We have also shown the benefit of higher performance material, assembled into a prism that behaved as a faceplate, transferring a magnetic field distribution faithfully from the input to the output face[6,7]. In more recent experiments, we have shown the potential of this material for constructing an RF yoke for directing and concentrating magnetic flux[8], and we wish to explore the possibility of enhancing parallel imaging procedures in MRI.

Metamaterials provide a challenging new paradigm for considering RF systems. This approach complements the conventional view, which remains valid. The use of such materials in MR systems is in its earliest phase of exploration, with much work to be done in optimising material properties and in exploring how best to make use of them.

References:

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