A parallel technique for the inverse design of RF coils

Ben Gerard LAWRENCE1, Desmond Yau2, Stuart CROZIER2, Kurt LUESCHER2, Wolfgang ROFFMANN2, David DODDRELL2
1University of Queensland, St Lucia, Brisbane, Queensland Australia; 2;

Introduction
The quasi-static inverse method [1] has been used in the design of RF coils. This paper presents a novel technique using this method for the design of RF coils that do not operate in a resonant condition. The inverse method produces current density distributions that are calculated to generate a homogeneous magnetic field within a specified volume. The stream function approach is then used to calculate appropriate contours from these current density distributions and these contours dictate wire positions in the RF coil design. However, to generate a current distribution in these wires corresponding to the theoretical current distribution remains difficult. This paper outlines a procedure of adjusting the coil design to produce an adequate approximation of this theoretical current distribution.

Method
The inverse approach calculates a current density distribution on a cylinder with an axis coinciding with the z-axis, such that the magnetic flux density $\mathbf{B}$ has a uniform xy component, in this case, specified by $B_z = K$. The procedure to calculate the current density is that as described in [1]. Once the current density is found, the coil is designed using the contours of a radial stream function $S$ where $\mathbf{J} = \nabla \times (S \mathbf{u}) = \nabla S \times \mathbf{u}$ on the surface. The position of the contours determine the position of the wires assuming that the current in each of the wires is the same for all. However, because of electromagnetic coupling and the fact that the length of the wires is comparable to a wavelength, this requirement is difficult to fulfill. An approach taken in this research is to implement the contours in the form of parallel conducting strips and to vary the width of the strips to adjust the current levels in each strip. The inductance of a strip of width $w$ (m) and length $l$ (m) is [2]:

$$L = 2e^{-7/0.5+\ln(2l/w)} \mu H$$

(1)

and hence the impedance of a strip can be increased by decreasing the width of the strip. For strips in parallel, if a strip’s impedance increases for instance, the current through that strip will decrease.

In some cases however, the range of width variation is limited and the width cannot be adjusted to produce the required impedance. In this case, the position of the contours themselves must be adjusted. After integrating $\mathbf{J}$, the contours are generated at values of $S_p$ such that:

$$S_p(z,\phi) = f(n) \delta S_p$$

(2)

where $f(n)$ is determined iteratively for each contour $n$ from a method of moments implementation of the coil. For instance, in (2), $f(n) = n$ firstly. The coil is then simulated using a method of moments package and the currents determined. If the current in wire $n_k$ is not the same amplitude as the others and its current cannot be adjusted to the required level by varying the strip width, the strip’s position is altered by adjusting $f(n_k)$ such that the proportion of current in each contour matches the proportion of difference $\delta S_p$.

Results
An RF coil of diameter 60mm and length 70mm was designed using the above principles and is shown in figure 1. At 190MHz, the magnetic field is homogeneous to within a 5% variation in a ellipsoid of axial length $(xy)(z)$ of $56\times30\times36$mm as is shown in figure 2. The device has essentially four feed-points at the top and bottom of each side, and these are all connected to one input that has tuning and matching capacitors. Care is required to prevent coupling through the four feed-point connections. Figure 3 shows an image acquired from a silicon oil phantom in a MRI test at 190MHz. The imaging sequence was RARE (rare factor =8), the acquisition matrix $256 \times 256$, TR/TE were $3100/58$ ms and the image was acquired in 1.2 minutes.

The device has no resonant frequency in the range of operation except for that which is imposed by the tuning and matching capacitors at the feed-point. Its mode of operation is distinctly unlike that of the RF birdcage coil, resembling more the Helmholz-pair in operation.

Conclusion
A new type of RF coil was designed using the hybrid quasi-static inverse approach and a novel arrangement of the consequent conductor positioning and feeding. Results show that the technique is a valid one for the design of RF coils.

References