

Optimizing Artwork Cross-Section for Surface RF coils

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Introduction

One of the most important sub-systems of the MRI system is the multi-channel-phased array coil used in most cases for detection of the MR radiation from the subject under study. The problem of optimization such coils is far from straightforward due to many remaining problems like optimum element shapes and positions, electronic component minimization and connection cabling decoupling. To be able to solve the problem of the optimum position and shape of the artwork so that it must have a minimum impact on the B1 transmit field distortion, we need to solve the problem of optimum copper strip dimensions being used in the artwork. It is clear that the larger the copper strip cross-section, the lower will be its ohmic resistance. However, knowing that at very high frequency the current flows only on the surface of the conductor due to the well known skin effect, the excess of copper will not lower the noise coming from the coil itself. Moreover, very large copper strips will shield the subject (object) under study from transmit RF field introducing significant B1 field distortion. This problem can be easily solved for one dimension and even in two dimensions for a rectangular cross-section using various methods [3]. They however are mathematically complicated and not easily applicable when excitation is a complicated function of position. According to current method the Maxwell equation can be brought in a quasi-static limit to the model used by Edelstein [1] for calculating eddy currents on the warm bore of the high field MRI system. This method can easily be applied to any cross section of the copper strip.

Theory

The approximation in which the problem of the cross-section current density can be solved is used by Edelstein [1], according to which we consider the coil element to be a circular with and rectangular cross section. The integral equation describing this case is given by

$$\frac{\mu_0}{4\pi} \int \frac{j(\mathbf{r}', t) \cos(\varphi - \varphi')}{|\mathbf{r} - \mathbf{r}'|} d^3 r' + A(r, z, t) = A_s(r, z, t) \quad (1)$$

where $A_s(r, z, t)$ is the vector potential generated by the sources of magnetic field everywhere in space, $j(\mathbf{r}', t)$ is the resultant current density inside the conductor and $A(r, z, t)$ is the resultant vector potential due to original source and the conducting coil in the magnetic field. Applying the equation (1) for a cylindrical coil of the radius R and cross-section given by area $S = (\Delta R, \Delta z)$ and discretizing the width and the thickness of the copper strip in small cross-section coil of the area $(\varepsilon_r = \Delta R/N, \varepsilon_z = \Delta z/M)$ with N and M some integer numbers, we can obtain

$$\sum_{n'=0}^N \sum_{m'=0}^M L_{nmn'm'} \partial_t I_{n'm'}(t) + \bar{R}_{nm} I_{nm}(t) = V_{nm}(t) \quad (2)$$

where $L_{nmn'm'}$ is the inductance between the loop (n, m) and loop $(n'm')$, $I_{nm}(t)$ is the current through the loop (nm) and \bar{R}_{nm} and $V_{nm}(t)$ are correspondingly resistance and external voltage applied to it. Calculating initially the matrices for self and mutual inductances, resistances and applied voltages, by diagonalizing the equation (2) and assuming periodic current dependence $\exp(i\omega t)$, we can easily solve the current density problem.

Results

The equation (2) was solved for a rectangular cross section circular copper strip of radius 10 cm, width 10 mm and thickness 0.05 mm. The width was discretized into $N = 100$ and the thickness into $M = 50$ intervals (Figure 1). All inductances and resistances coefficients are calculated according to formulae given in [1,2] and equation (2) is diagonalized. Total current through the cross-section, representing the sum of all currents through the discrete small loops, is a function of the width and thickness.

Conclusion

The approach described above allows accurate calculation of the current density through the cross-section of the artwork to the unmatched resolution. The shape of the cross-section can be arbitrary and the discretization itself doesn't need to be homogeneous.

References

- [1] W. A. Edelstein et al., *Calculation of Time-Dependent, Gradient-Induced Axisymmetric Eddy Currents and Fields*, Proc. ISMRM, (1997);
- [2] F. W. Grover, *Inductance Calculations: Working Formulas and Tables*, D. Van Nostrand Co. New York. 1946;
- [3] Y.T. Lo, *A note on the cylindrical antenna of noncircular cross section*, J. App. Phys. 24, 1338 (1953)

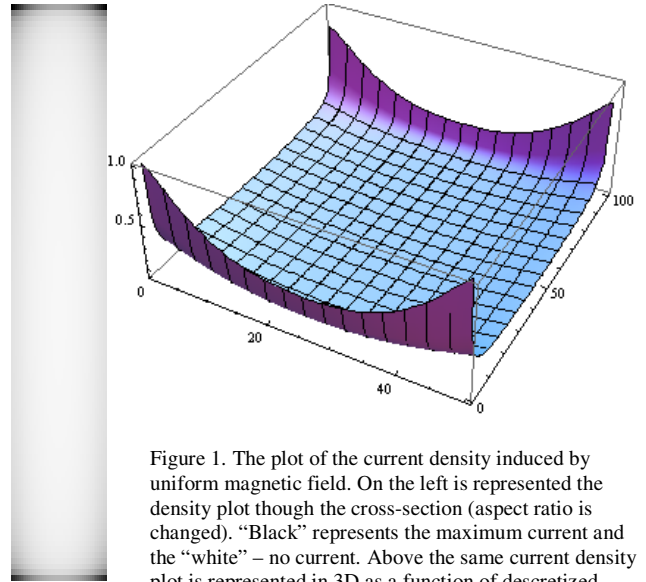


Figure 1. The plot of the current density induced by uniform magnetic field. On the left is represented the density plot through the cross-section (aspect ratio is changed). "Black" represents the maximum current and the "white" – no current. Above the same current density plot is represented in 3D as a function of discretized segments.