The SENSE-Cage: A Half-Birdcage Volume Coil

T. P. Eagan[1], J. D. Willig-Onwuachi[2], S. M. Shvartsman[3], Y-C. N. Cheng[1], R. W. Brown[4]

[1]Department of Phyiscs, Case Western Reserve University, Cleveland, OH, United States, [2]Department of Radiology, University of California at Davis, Davis, CA, United States, [3]Philips Medical Systems, Cleveland, OH, United States, [4]Department of Physics, Case Western Reserve University, Cleveland, OH, United States

Introduction

In recent years, many coils have been proposed for parallel imaging applications. [1-5] Most of these designs are loop arrays that have been optimized for a particular parallel imaging application. For instance, it is now accepted that the use of non-overlapped loop coils improves SENSE performance even though on the face of it the coils have a stronger inductive coupling. Here, we present a method of designing a coil based on optimizing for a particular B_1 field profile that may offer advantages for SENSE imaging. The method is essentially a target field method common in gradient coil design applied to rf coils. [6]

Methods

The current on a half-birdcage coil is expanded in terms of Fourier series in ϕ .

$$\vec{J}(\vec{x}) = \sum_{m=0}^{N} a_m \cos(m\phi)\hat{z} + b_m \sin(m\phi)\hat{z} \tag{1.1}$$

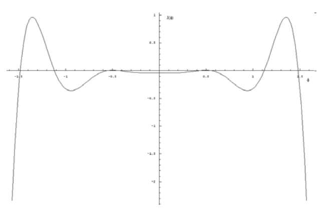
The corresponding magnetic contribution field is then computed from each of the Fourier terms in the current expansion. For SENSE imaging, the desired field on a half-birdcage might be a step function (albeit unphysical) on one half of the cylinder. One could then produce a four-channel SENSE coil by rotating the coil by an integer times $\pi/2$ radians. Knowing the B-fields due to each Fourier term in the current and the desired field behavior, we can now write a matrix equation for the Fourier weightings, a_m and b_m

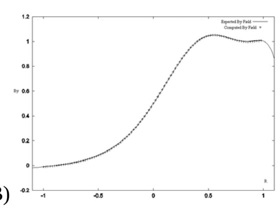
$$\tilde{B}c = \mathrm{B} \tag{1.2}$$

where c is a vector with elements c_i , containing a_m and b_m, strung out into a single column; the unknown Fourier coefficients, B is a vector with elements B_i , the desired B-field at the point x_i, and $\tilde{B}$ is a matrix with matrix elements $\tilde{B}_{ij}$, the B-field due to the jth term in the current expansion with unit magnitude at the point x_i. A simple matrix inversion yields the unknown coefficients. Note that the desired field must be physically reasonable for an inverse to exist. The initial work presented here assumes a long cylinder and continuous current density.

Results

We have successfully applied this technique to find the current distribution on a half-birdcage. The current density depicted in Fig. 1A in arbitrary units was found using a six-term expansion in Eq. 1.1. Although it is not clear from Fig. 1A, there are eight zero crossings. With the desired field and geometry chosen here, it was found that only the cosine terms were needed in the expansion. The desired field is a step function in both ρ and ϕ; however, it was found that asking the field to be step-like in ρ was sufficient to achieve the desired behavior in both directions. Fig. 1C depicts the magnitude of the B_1 field inside the birdcage. One should note that we have been quite successful in producing a B_1 that is localized to one half of a birdcage. This may be an interesting coil to explore for volume SENSE imaging. The coefficients of the higher-order terms in the expansion were found to a significant fraction of the lower-order coefficients. If these terms turn out to be important, it would greatly affect the manufacturability of this coil. However, the total current density is relatively smooth as is the resulting field, thus tempering this concern. Fig. 2B depicts the y-component of the field inside the birdcage as a function of ρ for ϕ=0. The field may not fall off as fast as one may like, and thus field from one half of the birdcage "leaks" into the other half. One is able to control this by keeping a sufficient number of terms in the expansion and choosing the points x_i very carefully. Calculating matrix elements of $\tilde{B}$ can be very time consuming especially when many terms in the Fourier expansion are used and many points x_i are employed. It should be noted, however, for each order, m, and spatial location, x_i, the matrix element need be only calculated once. One can keep a record of matrix elements calculated previously to make most efficient use of computing power.

A) 

B) 

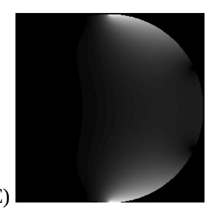
C) 

Fig. 2 A) Current density vs. ϕ B) By vs r for ϕ=0 Fig. 1 C) Magnitude of the B-field within the birdcage

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