Head RF Coil Design with Surface Current Density Optimization for SENSE Imaging

L. T. Muftuler[1], G. Chen[1], O. Nalcioglu[1]

[1]John Tu & Thomas Yuen Center for Functional Onco-Imaging, University of California, Irvine, CA, United States

Purpose

The goal of this study was to find the coil topography on a pre-defined coil former that will yield the maximum SNR and minimum g-factor related artifacts in SENSE imaging of human head. Previously, researchers sought for coils that yielded best SENSE performance by simulating various pre-defined coil topographies [1,2]. However, this approach is restricted by the limited number of coils simulated, and the result may not yield the best SENSE performance. We have previously proposed a method to design SENSE-optimized RF coils based on a *target field approach* [3]. Recently, we investigated two methods in modeling the coil structure: 1) Coil is made up of straight conductor segments and the position of vertices were varied to maximize performance (which is submitted concurrently for 2D encoding in 3D SENSE imaging); 2) A volume of interest (VOI) is specified and the surface current distribution on a coil former is calculated to achieve the maximum SNR in a SENSE encoded image. This second approach is described here.

Methods

The coil system consists of wires placed on a predefined surface in 3D space, which can be approximated by a surface current density J_s. The surface can be any prescribed shape but a cylindrical surface with 28 cm diameter and height was chosen for head imaging. The surface on which J_s flows can be approximated by a FEM consisting of flat triangular elements of a Finite Element Mesh (FEM) (Fig.1). In this element, J_s must satisfy the continuity equation, whose solution gives $J_{su} = \partial\sigma/\partial v$, $J_{sv} = -\partial\sigma/\partial u$, where (u,v,w) is the system of coordinates in the plane of the triangle and σ is called the *stream function*. Solution of these equations gives J_s, (Eq 1). Here, S^e is the area of the triangle and σ_p, σ_q and σ_s are the values of σ at nodes P, Q, S, respectively. Using Eq.1, one can calculate the magnetic vector potential $\boldsymbol{A}$ and magnetic flux density $\boldsymbol{B}$ generated by J_s at any point in space (Eq. 2; Note that only u-component is given here). Details were given in [4] and will be omitted here. Using Eq.2 and the transformation between the (u,v,w) and the (x,y,z) coordinate systems, the field components B_x, B_y and B_z generated by the current density in each element can be calculated. Then, the total $\boldsymbol{B}$ field is determined by summing over all the elements of the mesh.

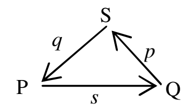

Fig.1. Triangular element of the FEM

$$J_s = \frac{1}{2S^e}(\sigma_p \cdot p + \sigma_q \cdot q + \sigma_s \cdot s) \quad (1)$$

$$B_u^e = \frac{-\mu 0}{4\pi} \cdot J_{sv} \cdot \frac{\partial}{\partial w} \int_{S^e} \frac{dS'}{r} \quad (2)$$

$$SNR_{sense,\rho} = SNR_{full,\rho} / (g_\rho \cdot \sqrt{R}) \quad (3)$$

$$g_\rho = \sqrt{\left(\left(S^H \cdot \Psi^{-1} \cdot S\right)^{-1}\right)_{\rho,\rho} \left(S^H \cdot \Psi^{-1} \cdot S\right)_{\rho,\rho}} \quad (4)$$

$$\Psi_{\gamma,\gamma'} = \sum_{i=1}^{N} B_\gamma(\mathbf{r}_i) \cdot B_{\gamma'}(\mathbf{r}_i) \quad (5)$$

The SNR_{sense} and the *g-factor* in the ρth pixel are given by Eq.3-4, respectively [5]. Here, S is the coil sensitivity matrix, $\boldsymbol{R}$ is the reduction factor, and Ψ is the receiver noise matrix (Eq.5), where $B_\gamma(\mathbf{r}_i)$ is the field generated by the γth coil at point $\mathbf{r}_i$. Once $SNR_{sense,\rho}$ is formulated in terms of coil $\boldsymbol{B}$ fields using Eq (3-5), it is possible to calculate the current density distribution that maximizes the average SNR_{sense}. This is done by finding the J_s that minimized sum of squared ($1/SNR_{sense,\rho}$) in the VOI using a *least squares procedure*. By using the symmetry of the structure, J_s in only one quadrant was calculated and it is confined to one quadrant by boundary conditions to design a four-coil array. The VOI was a 16.7cm long cylinder with 22.4cm diameter. The coils, which were the resulting current paths, were etched on a flexible copper clad board and wrapped around an acrylic cylinder (Fig.2). The array elements were tuned to 64MHz to operate inside a 1.5T Philips Eclipse system. Minimum –20dB Isolation between the coils was achieved by a lumped element network.

Results and Discussion

Images were collected from a cylindrical phantom filled with CuSO4 solution. A standard spin-echo pulse sequence was used with TR=200ms, TE=4.7ms, FOV=24cm and slice thickness of 5mm. The phantom had 19cm diameter and 18cm height. The results were compared with those of a standard rectangular 4-coil array of the same size. The standard array was simulated using the parameters described in [2]. A reduced FOV imaging experiment was also run with a reduction factor of 4 and an acquisition matrix of 256*128. The resulting aliased image and SENSE reconstructed image with 256*512 matrix size were illustrated in Fig.1. As shown in Table 1, the mean SNR was improved by 20% and the mean *g-factor* was reduced by 40%. It is also important to note that the maximum value of *g-factor* was reduced by 60%, which indicates that the *g-factor* is more uniformly distributed for the optimized coil. In SENSE imaging it is critical to maximize the average SNR_{sense}, while reducing the variance of the *g-factor*, which directly affects the uniformity of SNR. Using the basic approach outlined here, one can add variance of *g-factor* to the cost function together with the sum of squared $1/SNR_{sense}$ and assign different weighting factors to these components for a trade-off between maximum average SNR and maximum SNR uniformity. Although this coil was implemented on a cylindrical surface, the method can easily be applied to any arbitrary geometry, such as the dome shape described in [2]. In our future studies, we plan to use this coil in an fMRI study to increase the spatial resolution without sacrificing the temporal resolution.

	Mean SNR_{SENSE}	Mean g	Max g
Standard SENSE array	67.7	5.80	34.6
Optimized SENSE array	81.3	3.48	13.9

Table 1 Comparison of SNR and g-factor of the coil arrays

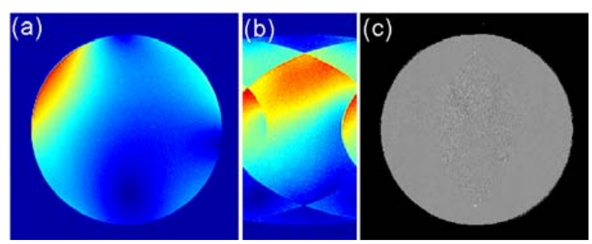

Fig.1. (a) Sensitivity profile of one coil; (b) Aliased MR image with 4-fold reduction; (c) SENSE reconstructed image.

Fig.2. Picture of the 4-coil SENSE optimized array

References:

[1] Weiger M *et al, MRM 45: 495-504, 2001;* [2] De Zwart JA, *et al*, *MRM 47:1218-1227, 2002;* [3] Muftuler *et al*, Proc. ISMRM 2005, p 886; [4] Pissanetzky, *Meas.Sci. Technol. 3:667-673, 1992*; [5] Pruessmann *et al*, *MRM 42:952-62, 1999*