MATCOIL: A Matlab Based Program for the Calculation of B1 Fields and Sensitivity Profiles for Surface Coils (Single, Multiple, or Quadrature Driven) of Arbitrary Shape and Curvature

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Introduction: The large number of surface coil and coil configuration discussions appearing in the literature are mostly confined to axial configurations of planar surface coils arranged for improved B_1 field homogeneity, albeit at the expense of coil sensitivity. The primary exception to this consists of articles [1-4] whose primary focus is the alteration of the field of the coil by sample conductivity and dielectric resonance effects, and, as far as we can tell, there is no discussion in the literature of how the B_1 field and sensitivity maps of coils driven in quadrature [5-6] are affected by alterations in coil geometry (shape and curvature), angulation and overlap, and thus no guidance on how to arrange coils to be driven in quadrature for optimal performance for a particular application. To remedy this situation, we have taken advantage of both the GUI features in MATLAB, as well as the many display options, to develop MATCOIL, which provides a user-friendly environment for, first, the definition of an arbitrary coil shape and curvature, including such coils driven in quadrature, and second, calculation and display of a variety of outputs for the coil configuration, including fields and sensitivity maps. The current version of the program includes allows for coil shapes that are circular, elliptical, square/rectangular, and can be planar or wrapped (molded) to either a circular or an elliptical cylindrical surface. The addition of a Bloch simulator enables evaluation of the performance of a particular pulse sequence/surface coil combination.

Methods and Results: Planar coil shapes (x-z plane) are defined by $\left|\frac{x}{a}\right|^n + \left|\frac{z}{b}\right|^n = 1$ (Circle: a = b, n =2; Ellipse: a > b, n = 2; Square: a = b, n = 4 or higher; Rectangle: a > b; n = 4 or higher). With increasing n the square and rectangle approximations are improved. The radial distance is expressed in terms of polar coordinates as: $\rho_n(\phi) = \frac{ab}{\sqrt{a^n\,|\cos\phi|^n + b^n\,|\sin\phi|^n}}$. Coils of defined curvature are created by wrapping a given planar coil about either a circular or elliptical cylinder. B_1 field calculations are facilitated by use of a novel approach which involves dividing the desired coil filament geometry into a large number of short, straight segments [8]. For an individual line segment the B_1 field at a point relative to the coil may be readily calculated by use of the Biot-Savart Law, assuming the B_1 field is not distorted by the presence of the sample (the quasi-static approximation). Summation of the B_1 fields produced by all of the individual coil segments yields the total field at a fixed point. A grid of such points defines the B field profile in a given plane or in 3D space. For coils driven in quadrature, the linear fields of the individual coils must be rotated by plus 45° and minus 45°, respectively, to generate the instantaneous B_1 fields of the individual coils. The phase and sensitivity of the received signal at each of the coils is calculated according to the strength and phase of the linearly polarized field of the individual receiving coil, at a particular spatial position [7]. Finally, vector summation of the received signals, along with division by $\sqrt{2}$ to account for the addition of noise, results in the sensitivity map. Figure 1 shows the figure menu for generation of a coil wrapped onto a cylinder, while Fig. 2 displays examples of several wrapped coils. Figures 3 and 4 show B_1 field plots for a wrapped coil and for a pair of circular coils driven in quadrature, respectively.

Summary: A user friendly MATLAB based program, designated MATCOIL (under the assumption of the quasi-static approximation), has been developed for the design and evaluation of different surface coil probe designs, including coils driven in quadrature. Future plans include incorporation of a finite element methodology based 3D PDE package to enable evaluation of B_1 field alterations by sample conductivity and dielectric resonance effects through the solution of the Maxwell equations.

Fig. 1. Menu for a coil wrapped onto a cylinder.

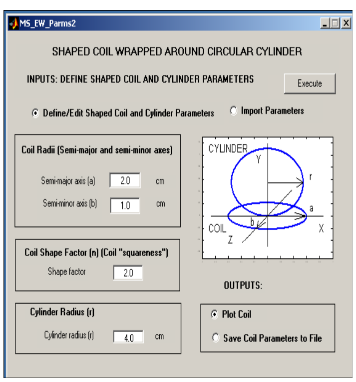


Fig. 2. Examples of wrapped coils: (A) Elliptical Coil, a = 2, b = 1, n = 2, cyl. radius = 2; (B) Elliptical Coil, a = 2, b = 1, n = 1, cyl. radius = 1; (C) Rectangular Coil, a = 2, b = 1, n = 8, cyl. radius = 2; (D) Rectangular Coil, a = 2, b = 1, n = 8, cyl. radius = 1.

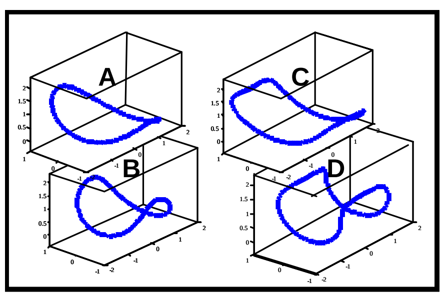


Fig. 3. $B1_{xy}$ contour plot (X – Y plane) for coil geometry D shown in Fig. 2.

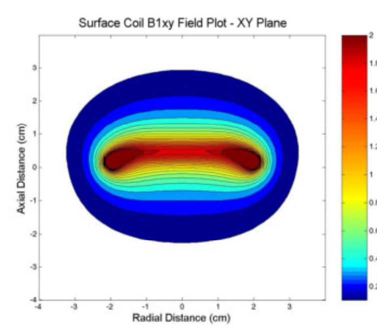
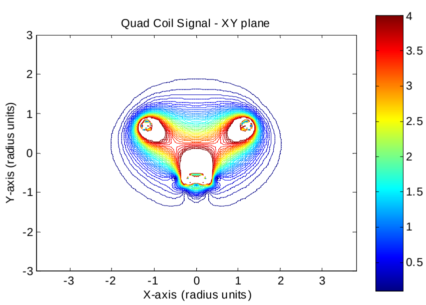


Fig. 4. Quadrature coil (planar circular) sensitivity map.



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