

Simplified RF Modeling of Coil Arrays Composed of Cylindrically Arranged Modules

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Introduction

The development of phased-array radiofrequency (RF) coils (1), as commonly used for improving the signal-to-noise ratio (SNR) as well as for parallel imaging, requires careful full-wave electromagnetic simulations. The subsequent characterization of novel array designs with respect to performance capabilities requires data evaluation and post-processing for calculating the SNR, the g -factor, SAR, just to mention a few. It is convenient to separate these two steps and to perform the full-wave calculation in a dedicated software framework and to use easily adaptable algorithms for evaluation afterwards. Both steps require extensive computing that is accomplished by tackling large amounts of data. As an example, we will here focus on the development of a head coil, which is created by a cylindrical arrangement of a stacked combination of loop coils and intrinsically decoupled microstrip transmission-line elements (MTL) (2). Both, the design of the complete cylindrical arrangement (number of sub coils, distances, ...) as well as the design of stacked elements (number and size of loops, ...) is subjected to optimization processes. Besides, the combination of the data into a final image can be done in many ways that are to be evaluated as well for each design, respectively. In order to simplify the process of finding the optimum design of such a head coil, we simplified the coil simulation: (A) the coil is composed of identical stacked coil-elements that are decoupled; (B) the coils are shifted on of the surface of a cylinder to fully cover it ('wrap-around' arrangement) (3); (C) instead of performing a full-wave electromagnetic simulation of the entire head coil, only one stacked element is simulated in transmit mode; (D) missing electromagnetic fields are calculated by using matrix rotation algorithms making use the cylindrical symmetry of the problem.

Here we investigated the performance of the proposed method by comparing two data sets of the same coil arrangement, but calculating the whole coil by full-wave simulation and by using matrix rotations of one coil element for creating the complete coil, respectively.

Simulation Details

A 3D full-wave Finite Element Method (FEM) electromagnetic field simulation was performed using HFSSTM (Ansoft, Pittsburgh, PA). A steady-state finite element field solution as a phasor representation of the \mathbf{E}/\mathbf{H} -field quantity is obtained from solving Maxwell's equations in the frequency domain. The parametric design of the array coil including all material properties, capacitors, and excitation ports was modeled with the CAD interface of HFSS. This array coil is based on 16 stacks arranged on the extent of a cylinder (\varnothing 25cm). Each stack contains one MTL and one loop (1). Each MTL element consists of a 12 μ m-thick Cu strip (length 30 cm; width 2 cm) on a polypropylene plate (30x5x2cm³; $\epsilon_r \approx 2.2$) and is terminated with capacitors. Each MTL element is supplemented by one loop (5x20cm²) made of 12- μ m thick, 5-mm wide Cu foil and arranged perpendicularly to the MTL. Each channel is tuned and matched to 50 Ω separately. Preamplifier decoupling was employed to minimize mutual coupling between stacked segments. A cylinder phantom with electromagnetic properties values for brain tissue ($\epsilon_r=63.4$, $\sigma=0.46$ S/m) was used as a load. The \mathbf{E}/\mathbf{H} data in a cube around the phantom were resampled on a cartesian raster and imported into MATLAB[®] (The MathWorks, Natick, MA). In all subsequent calculations, data outside the load were zeroed. For comparing the simulation methods, one coil segment was chosen from which fields were calculated as follows: (A) field vector components were rotated using an image rotation algorithm of the Image Processing ToolboxTM (imrotate) that performs data interpolation to enable non-rectangular rotation; (B) the resulting new field vector was rotated by simple vector rotation.

Results

In Fig. 1, the values for $B_{rot}^- = 0.5\mu_0(H_x - iH_y)$ of the loop coil of the stacked element obtained by rotation of about 337.5° (stack 16) of a single slice are shown. For a detailed analysis, data were selected from the diagonal and shown in Fig. 2. As an important characteristic, the absolute value of the electric coupling coefficient matrix, which can be thought of as a noise correlation coefficient matrix Ψ (4), is shown in Fig.3. The differences in Ψ as obtained with both methods, respectively, are minor which is shown by comparing the column characterizing the loop coil of stack 16.

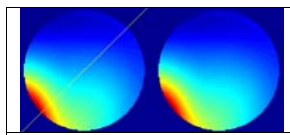


Fig. 1. $|B_{rot}^-|$ of coil element 16 of an arbitrarily chosen single slice; full-wave simulation (left), and simulation obtained by rotation (right).

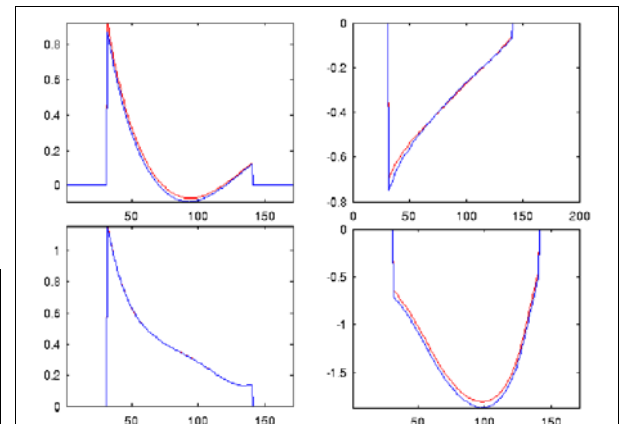


Fig. 2. B_{rot}^- data selected from the diagonal (see Fig. 1.): full-wave simulation (red), data obtained by rotation (blue). Real part (top left, imaginary part (top right), absolute value (bottom left) and phase angle (bottom right).

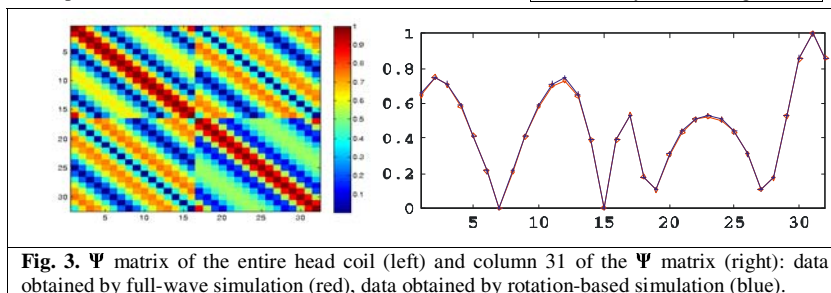


Fig. 3. Ψ matrix of the entire head coil (left) and column 31 of the Ψ matrix (right): data obtained by full-wave simulation (red), data obtained by rotation-based simulation (blue).

Conclusions and Outlook

It was found by comparison that the differences between the results obtained with both simulation methods can be neglected. Thus the proposed method is well suited for simulating a phased-array in the 'wrap-around' arrangement or any other arrangement with intrinsic cylindrical symmetry. The 'rotation-based-simulation' is considerably saving computation time and data storage space and is therefore well situated during the optimization phase when designing new coils.

References

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