

Procedure for RF Coil Array Analysis Using the Method of Moments

R. LEMDIASOV¹, R. LUDWIG², AND G. BOGDANOV²

¹INSIGHTMRI, WORCESTER, MA, UNITED STATES, ²ECE, WPI, WORCESTER, MA, UNITED STATES

INTRODUCTION

The Method of Moments (MoM) as a full-wave solver has successfully been applied to simulate multi-channel coil arrays and predict their B_1 -field distributions [1]. However, when comparing coils, or coil arrays, it is often more important to predict the anticipated signal-to-noise ratio (SNR) of a particular configuration [2, 3]. In this present study, we propose an approach that combines the MoM with a numerically computed coil resistance matrix that enables SNR field plots.

METHOD

To demonstrate the procedure, we consider as an example a 4-channel breast coil array as shown in Figure 1(a). A model was generated with four independent loops; the upper loop diameters are 170 mm, the lower loop diameters are 190 mm and the height separation is 130 mm. Each loops depict breaks that are bridged by tuning capacitors, a matching capacitor, and decoupling capacitors (between loops 3 and 4) such that the coil array can be tuned and match to 4-channel receive system.

1. The method of analyzing the coils/arrays starts with creating a triangulated mesh of the conductors (2840 triangular patches) as seen in Figure 1(b). We use the MoM to compute the scattering, or S-parameter, matrix of the configuration. The simulations can be performed under unloaded or loaded conditions. Furthermore, in place of MoM, other methods such as FEM or FDTD could be used to compute the S-parameters.
2. We interpolate the S-matrix coefficients to neighboring frequencies by first converting the S-matrix to the admittance or Y-matrix; it is assumed that each term in the Y-matrix depends on frequency inductively according to $1/(a_{mn} + j\omega b_{mn})$. After obtaining the frequency independent coefficients a_{mn} , b_{mn} around the resonance frequency, the Y-matrix is then converted back into S-matrix form.
3. We terminate the coil with capacitors and reduce the S-matrix into a 4×4 matrix which is consistent with the number of loops (channels). The S-parameters are plotted against frequency and the plots are used as a basis to tune, match, and decouple each channel, as shown in Figure 1(c). The individual MoM solutions are combined to calculate the solution vectors of the Rao-Wilton-Glisson current elements [1] for each of the 4 channels. We next plot the currents in each channel, see Figure 1(d), and the magnetic B_1 -field, see Figure 2(a), as well as the combined magnetic field, shown in Figure 2(b).
4. We then remove the matching capacitors and calculate the 4×4 S-matrix in the presence of the tuned capacitors. The S-matrix is converted into Z-matrix form, the real part of which represents the resistance matrix \mathbf{R} . Here, the off-diagonal terms of the \mathbf{R} matrix are the correlation resistances that give rise to the correlated noise.
5. The matching capacitors are then removed and a 1 A current is consecutively applied into each loop, with zero currents into the remaining loops. Based on this 1A input current, the magnetic field B_1 is calculated for each channel.
6. The SNR is computed from the expression:

$$SNR^2 \sim \frac{\sum_i I_i^* B_{1i} \sum_j I_j B_{1j}}{\frac{1}{2} \sum_i \sum_j I_i^* R_{ij} I_j} \quad (1)$$

where a vector of weights \mathbf{I} is determined according to $\mathbf{I} = \lambda \mathbf{R}^{-1} \mathbf{B}_1^*$ (λ being a constant scalar) that yields the highest SNR for a particular point in space. We can now plot the SNR of individual channels, such as channel 1 in Figure 2(c), or the combined SNR, see Figure 2(d). This SNR plot enables the assessment and optimization of various coil parameters as well as a comparison of competing coil designs.

DISCUSSION

There are several steps that warrant further elaboration. When extrapolating the S-matrix to neighboring frequencies, we assume that each term of the corresponding Y-matrix exhibits an inductive frequency behavior. Strictly speaking, this is true only for structures that consist of several loops (inductive behavior) rather than those containing surfaces separated by a short distance (capacitive behavior). In most cases when we work with MRI coils, we can make such an assumption. This enables us to perform a frequency sweep without resorting to expensive MoM simulations for each discrete frequency point.

Instead of using the integral expression reported in [2, 3] to calculate resistance matrix, we calculate the \mathbf{R} matrix as part of the real part of the impedance matrix \mathbf{Z} , which can be easily determined by calculating the S-matrix after removing the matching networks.

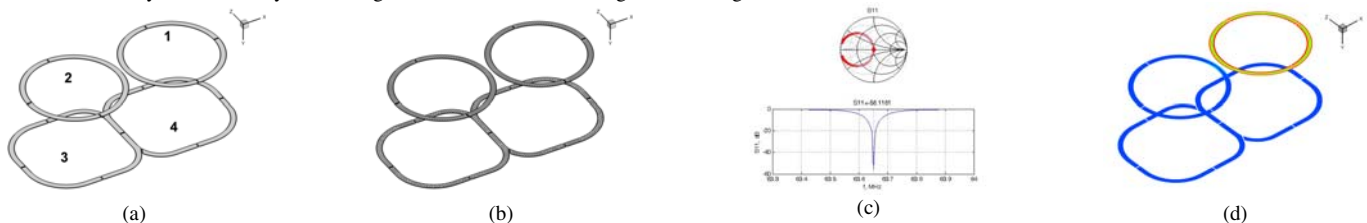


Figure 1: 4-channel breast array. (a) Structure, (b) Mesh, (c) Dependence of S_{11} parameter on frequency, (d) Current in the 1st channel.

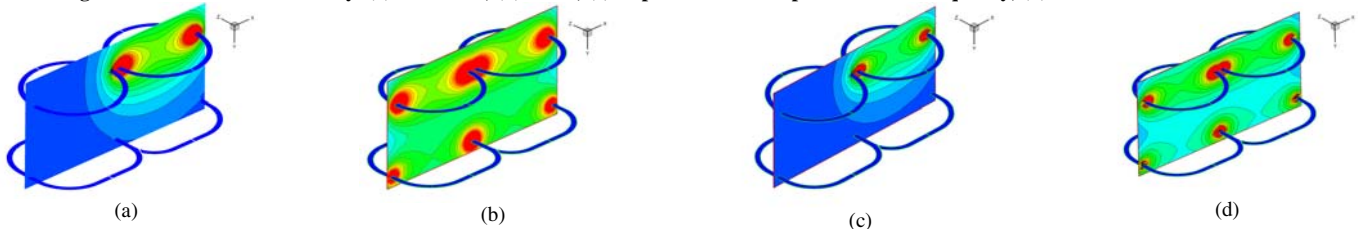


Figure 2: (a) B_1 field plot for 1st channel. (b) Total B_1 field plot for all channels, (c) SNR plot for 1st channel, (d) SNR plot for all channels.

CONCLUSION

The presented method outlines a structured, practical numerical approach to simulate MRI coils/arrays in an effort to establish a basis of comparing different configurations. The comparison is performed based on a figure of merit that is proportional to the SNR. The method can be applied on a routine basis to analyze the efficiency of RF coils/arrays.

REFERENCES

- [1] S.M. Rao, D.R. Wilton and A.W. Glisson, "Electromagnetic Scattering by Surfaces of Arbitrary Shape," *IEEE Trans. Antennas Propagat.*, vol. 30, no. 3, pp. 409-418, May 1982.
- [2] P.B. Roemer, W.A. Edelstein, C.E. Hayes, S.P. Souza and O.M. Mueller, "The NMR Phased Array," *Magn. Reson. In Med.*, 16, pp. 192-225, 1990.
- [3] S.M. Wright, L.L. Wald, "Theory and Application of Array Coils in MR Spectroscopy," *NMR in Biomedicine*, 10, pp. 394-410, 1997.