Field and S-Parameter Simulation of Arbitrary Antenna Structure with Variable Lumped Elements

R. Zhang[1], Y. Xing[1], J. Nistler[2], and J. Wang[1]

[1]Siemens Mindit Magnetic Resonance Ltd., Shenzhen, Guangdong, China, People's Republic of, [2]Siemens Medical Solutions Magnetic Resonance, Erlangen, Germany

Introduction

With the availability of the high speed workstation computers and graphic computation accelerators, the use of electro-magnetic (EM) simulation software is becoming increasingly important for RF coil design for MRI system. But even with the most powerful hardware, the EM simulation usually requires a few hours. This is very inconvenient if we need to iteratively change some component values (like matching capacitors) to achieve better field distribution and matching at the desired operation frequency. In this paper we demonstrate a new method to simulate first the matching coefficient and E- & B-field pattern of the antenna structure without the information (or value) of the lumped circuit elements (like capacitors and inductors) connected to the antenna. These lumped circuit elements are not only limited to the matching circuit at the excitation ports, they can be any lumped circuit elements connected to arbitrary place of the antenna structure. The missing lumped elements are presented as an RF port in the simulation software. EM simulation usually takes a very long time because the FEM and FDTD methods have to be used with very large matrix size. With the help of a Matlab program, the matching coefficient and the field pattern with arbitrary lumped element connected to the antenna can be then easily synthesized within a few seconds. The lumped circuit element values can be changed arbitrarily to test the matching of the circuit and in the same time observing the changes of the field pattern.

Method

We use the high-pass birdcage body coil antenna to illustrate our simulation method in this abstract. As shown in Fig.1, the coil has 8 legs (copper strips conductors) whose ends are connected by 16 capacitors. In order to simulate the EM properties of the antenna structure without the capacitor values, each capacitor is modeled as an RF-port, with port 1 and 2 signed to the excitation port and the other 14 ports are only used to connect arbitrary capacitors. After running the EM software, we get:

1) S-parameter of the 16 port antenna structure $S_{16\times16}$ for all required frequency values.
2) E-field pattern E_k and B-field pattern B_k of the antenna when only one port k (k=1, 2…16) is excited and the other ports are terminated with matching impedance (50 Ohm).

In order to calculate the matching and field pattern of the antenna structure with arbitrary capacitors terminated at port 3 to 16, we can rewrite the simulation results as follow:

a) Calculation base on the definition of S-parameter $\begin{bmatrix} b_{1-2} \\ b_{3-16} \end{bmatrix} = \begin{bmatrix} S_{2\times2} & S_{2\times14} \\ S_{14\times2} & S_{14\times14} \end{bmatrix} \cdot \begin{bmatrix} a_{1-2} \\ a_{3-16} \end{bmatrix}$, with vector a_{1-2}, b_{1-2}, a_{3-16} and b_{3-16} representing the incident and reflected wave at port 1 and 2 (vector length = 2) and at port 3 to 16 (vector length 14) and $S_{2\times2}$, $S_{2\times14}$, $S_{14\times2}$ and $S_{14\times14}$ (matrix size 2x2, 2x14, 14x2 and 14x14) representing the sub-matrix of the simulated 16x16 s-parameter matrix $S_{16\times16}$.

b) The relation between a_{3-16} and b_{3-16} can be given by the diagonal matrix S_{cap} (matrix size 14x14) defined by the lumped element impedance values at the port 3 to 16: $a_{3-16} = [S_{cap}] \cdot b_{3-16}$

c) Combining b) and a), we get $b_{3-16} = [I_{14\times14} - S_{14\times14} \cdot S_{cap}]^{-1} \cdot S_{14\times2} \cdot a_{1-2}$ with $I_{14\times14}$ representing a 14x14 diagonal unit matrix.

d) Combining b), c) and a), we get $b_{1-2} = (S_{2\times2} + [S_{2\times14}] \cdot [S_{cap}] \cdot [I_{14\times14} - S_{14\times14} \cdot S_{cap}]^{-1} \cdot S_{14\times2}) \cdot a_{1-2}$

e) The 2-port S-parameter (size 2x2 for port 1 and 2): $S = S_{2\times2} + [S_{2\times14}] \cdot [S_{cap}] \cdot [I_{14\times14} - S_{14\times14} \cdot S_{cap}]^{-1} \cdot S_{14\times2}$

f) In case only port 1 and port 2 are applied with incident wave a_{1-2}, the incident wave to the port 3 to 16 can be also calculated according to b) and c): $a_{3-16} = S_{cap} \cdot [I_{14\times14} - S_{14\times14} \cdot S_{cap}]^{-1} \cdot S_{14\times2} \cdot a_{1-2}$

g) The synthesized B and E field pattern can be derived by the matrix operation:
$B\_result = \sum_{1}^{16} B_k \cdot a_k$ and $E\_result = \sum_{1}^{16} E_k \cdot a_k$

We used the procedure defined above to calculate the matching circuit and combine the B-field in Matlab. The first simulation run with AMDS takes very long time. But for the simulation within AMDS the capacitor values need not to be defined. Then we define the capacitor values in Matlab and get the final S-parameter and field distribution from Matlab. The calculation time within Matlab takes less then a minute. But if we tune the capacitor in EM software, we would have to spend several hours to wait for the EM simulation every time.

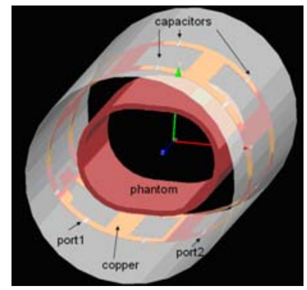

Fig.1 structure of the body coil

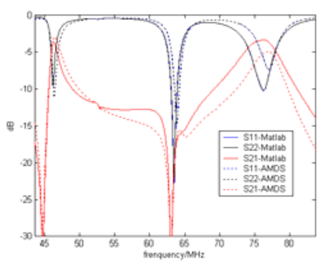

Fig.2 S-parameters with phantom

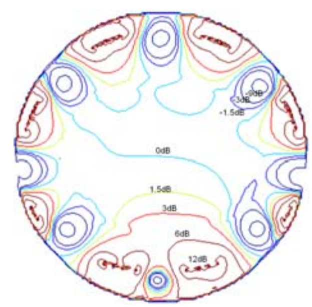

Fig.3 Contour plot of B-field in cross section plane when two ports are

Calculation Result

We tested this simulation procedure with the 3D EM simulation software AMDS. After the simulation of the antenna structure with 16 RF ports, the s-parameter for different frequency are exported to Matlab. Using equation e) and together with capacitor values defined in b), the 2-port S-parameter at different frequencies can be calculated. As Fig.2 shows, we get the S-parameters of the coil tuned by our method in solid line. As a compare, we use AMDS to simulate the antenna with the same value of capacitors to get the S-parameters in dashed line. We see the Matlab calculation matches very well to the direct simulation. Fig.3 shows the B-field pattern of the cross section (XY plane) in the middle of the coil according to the equation g).

Conclusions

We demonstrated a method to run B and E field pattern and S-parameter simulation of any arbitrary antenna structure without exact values of the lumped elements connected to the antenna structure. With these simulation results, the S-parameters and field pattern can be easily calculated with any arbitrary lumped element values connected to the antenna structure by using simple matrix operation as defined above. Because the Matlab calculation requires very small computation time, this method can be used to optimize the capacitor values to achieve matching at specific frequency, to improve field distribution and to reduce coil coupling.

Acknowledgement

Thanks to Agilent EEsof EDA China for the great support and providing AMDS simulation tools for evaluation.