Electromagnetic field analysis of RF antenna for MRI

H. Tsuboi* H. Tanaka†
T. Misaki‡ M. Fujita**

*Okayama University
†Okayama University
‡Okayama University
**Fuji Electric Corporate Research and Development, Limited

ELECTROMAGNETIC FIELD ANALYSIS OF RF ANTENNA FOR MRI

H. Tsuboi, H. Tanaka and T. Misaki
Department of Electrical and Electronic Engineering,
Okayama University, Okayama 700, Japan

M. Fujita
Fuji Electric Corporate Research and Development, Ltd.,
Ichihara, Chiba 290, Japan

Abstract - In the design of the RF antenna for MRI, its size and structure are determined so that they provide desired distribution of electromagnetic field. The moment method using point matching formulation was used for the computation of electromagnetic field due to the antenna and current distribution on the antenna. In order to verify the computation accuracy of the moment method, comparison between computation results and experimental results are performed. In addition, the effect of loading the RF antenna with capacitors to improve the uniformity of the current distribution has been studied.

INTRODUCTION

Recently, magnetic resonance imaging (MRI) has been noticed as a new technique for medical diagnosis. The radiofrequency (RF) antenna for MRI is used as both transmitter and receiver, and requires that it should have large quality factor (Q), large gain and highly uniform electromagnetic field for high resolution imaging. In the design of the RF antenna, its size and structure are determined so that they provide desired distribution of electromagnetic field. The optimization methods of the geometry of RF antenna have been done by using analytical method[1],[2]. Furthermore, the improvement of the current distribution on the antenna by loading the antenna with capacitors has been reported[3].

The moment method[4],[5] using point matching formulation was used for computation of current distribution on the antenna and electromagnetic field due to the antenna. When applying the moment method, the antenna is approximated by thin wire and is divided into a number of segments on which unknown currents are defined.

For the verification of the accuracy of computation results, a dipole antenna is chosen as a computation model and input admittances are compared with measured data. Next, input admittances of a RF antenna are computed by the moment method. Moreover, it is demonstrated by the application of the moment method, that the uniformity of the current distribution on the RF antenna can be improved by loading the antenna with capacitors.

FORMULATION

The moment method[4] using point matching formulation is used for electromagnetic field analysis of thin wire antenna. When applying the moment method, the antenna approximated by thin wire is divided into a number of short segments and the distribution of electric current I on the wire axis are approximated by a series of rectangular pulse functions[4]. Therefore, I is defined to be constant over each segment. Figure 1 shows the wire axis divided into N segments.

After introducing the equations for the moment method, following matrix form is obtained.

$$[Z]\{I\}=\{V\} \tag{1}$$

where $[Z]$ is the impedance matrix, $\{I\}$ is the cureent matrix consisted by the currents on the segments, and $\{V\}$ is the impressed voltage matrix using gap model for the approximation of impressed field. $\{I\}$ and $\{V\}$ are given as follows:

$$\{I\}=\begin{Bmatrix} I_1 \\ \vdots \\ \vdots \\ I_N \end{Bmatrix}, \quad \{V\}=\begin{Bmatrix} \vec{E}^i_1\cdot\Delta\vec{\ell}_1 \\ \vdots \\ \vdots \\ \vec{E}^i_N\cdot\Delta\vec{\ell}_N \end{Bmatrix} \tag{2}$$

For the antenna impressed at segment m, $\{V\}$ is given as

$$\{V\}=\begin{Bmatrix} 0 \\ \vdots \\ 0 \\ V_m \\ 0 \\ \vdots \\ 0 \end{Bmatrix} \tag{3}$$

$\{I\}$ can be obtained using the inversion of $[Z]$ as follows:

$$\{I\}=[Y]\{V\} \tag{4}$$

where $[Y]$ is the admittance matrix. $[Y]$ is obtained by the inversion of $[Z]$ as follows:

$$[Y]=[Z]^{-1} \tag{5}$$

Iput admittance for segment m is given by element Y_{mm} in $[Y]$.

When an impedance Z_ℓ is loaded at segment n, the self impedance Z_{nn} is modified as

$$Z_{nn}' = Z_{nn}+ Z_\ell \tag{6}$$

where Z_{nn}' is the modified self impedance.

RESULTS

Dipole Antenna

Comparison between computation results of the moment method and experimental results was done by using a dipole antenna model shown in Fig. 2. The conductance and the susceptance of input admittance are shown in Fig. 3. The computation results using 63 segments almost agree with the experimental results. In Fig. 3, the resonance at 22 (MHz) in experimental results probably arised from the influence of external devices because theoretical resonant frequency is 50 (MHz). Applicability of the moment method was verified by the results in Fig. 3.

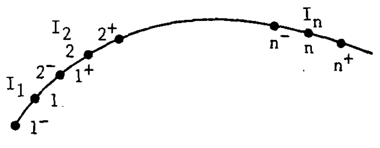

Fig. 1 Wire axis divided into short segments.

0018-9464/88/1100-2591$01.00©1988 IEEE

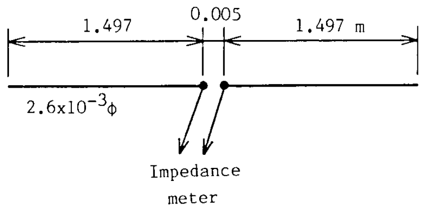

Fig. 2 Dipole antenna.

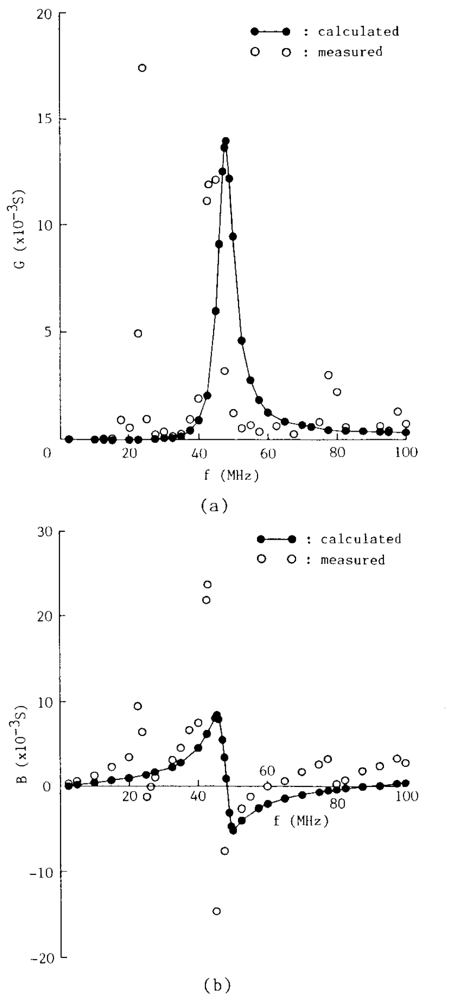

Fig. 3 Input admittance of the dipole antenna, (a) conductance G, (b) susceptance B.

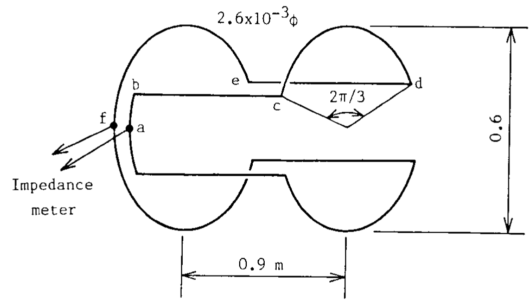

Fig. 4 RF antenna.

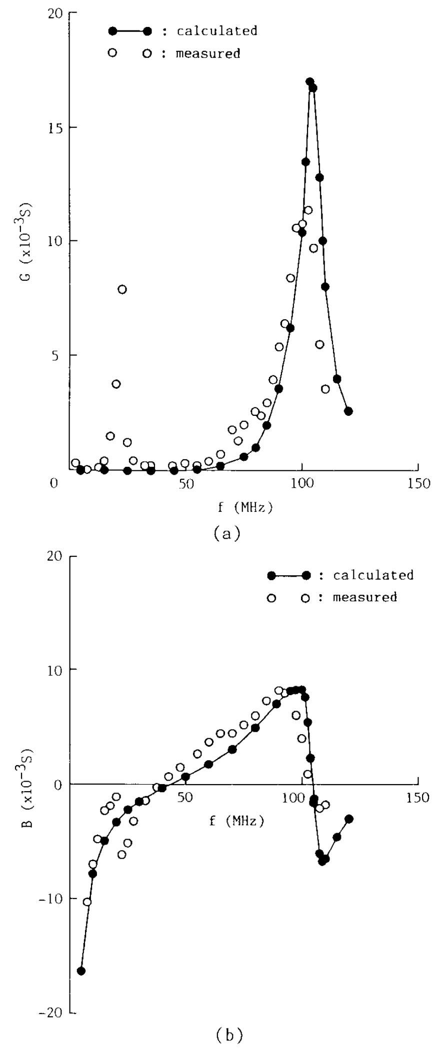

Fig. 5 Input admittance of the RF antenna, (a) conductance G, (b) susceptance B.

RF Antenna

An RF antenna for MRI is shown in Fig. 4. The antenna is divided into 185 segments. The Computation results of input admittance shown in Fig. 5 agree with the experimental results.

The RF antenna for MRI requires that it should generate uniform electromagnetic field for high resolution imaging. In order to simplify the procedure of the structure design of RF antenna, we can assume the current distribution on the antenna to be uniform. Here, the RF antenna is loaded with some capacitors to uniformize the current distribution. Figure 6 shows two cases of RF antenna loaded with capacitors. At 20 (MHz), the optimal capacitance of case A is 33 (pF), and that of case B is 66 (pF) as shown in Fig. 7. In those cases, the values of the uniformity which defined by $|I_{min}|/|I_{max}|$ are shown in Table 1. Case B provides better uniformity than case A, in which optimal capacitance is 66 (pF). Figure 8 shows the current distributions of case B.

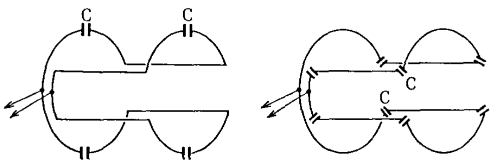

Fig. 6 RF antennas loaded with capacitors, (a) case A, (b) case B.

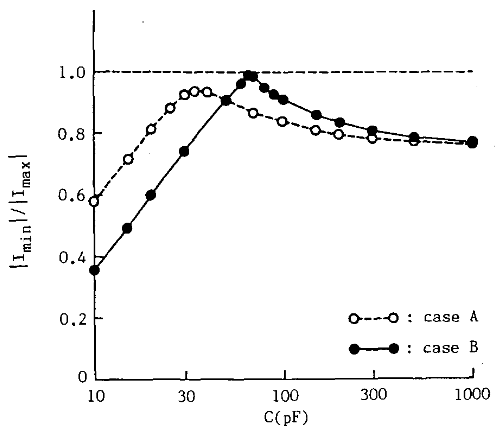

Fig. 7 Variations in the uniformity of the current distribution along the axis of the antenna loaded with capacitors at 20 (MHz).

Table 1 Uniformity of the current distribution along the antenna axis at 20 (MHz).

	loaded with capacitors		not loaded
	Optimal Capacitance (pF)	$\lvert I_{min}\rvert / \lvert I_{max}\rvert$	$\lvert I_{min}\rvert / \lvert I_{max}\rvert$
Case A	33	0.937	0.754
Case B	66	0.972	

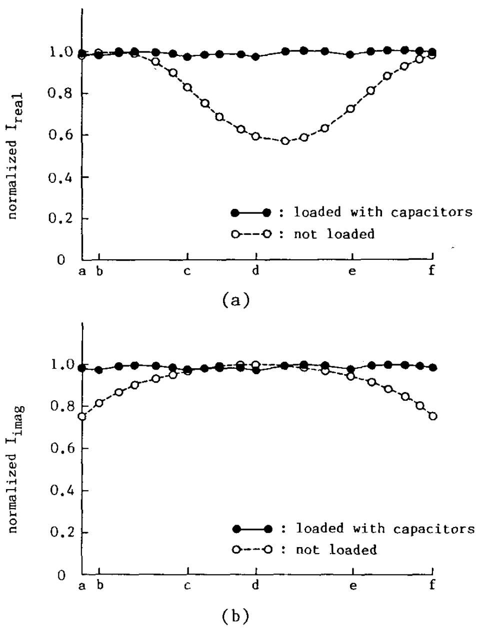

Fig. 8 Distributions of the current along the antenna axis in case B; C=66 (pF), (a) real part, (b) imaginary part.

CONCLUSION

The moment method approximating antenna by thin wire was applied to electromagnetic field analysis of RF antenna for MRI, and expected results were obtained. In addition, the method, which optimizes the capacitors of the loaded antenna in order to uniformize the current distributions, was described as the application of the moment method.

As mentioned above, it was verified that the moment method is practicable for the designing of RF antenna in MRI.

REFERENCES

[1] D.M. Ginsberg and M.J. Melchner, "Optimum Geometry of Saddle Shaped Coil for Generating a Uniform Magnetic Field," The Review of Scientific Instruments, Vol.41, No.1, pp.122-123, January 1970.
[2] H. Hanssum, "The Magnetic Field of Saddle-Shaped Coil: III. Improving the Uniformity of |B| in a Large Volume," J. Phys. D: Appl. Phys., Vol.19, pp.493-501, 1986.
[3] J.F. Shen and I.J. Lowe, "R.F. Coil Design for NMR Imaging," Book of Abstracts of the 4th Annual Meeting of the Society of Magnetic Resonance in Medicine, pp.1117-1118, August 19-23, 1985.
[4] R. F. Harrington, "Matrix Methods for Field Problems," Proceedings of the IEEE, Vol. 55, pp.136-149, February 1967.
[5] J. Moore and R. Pizer, Moment Methods in Electromagnetics, England: Research Studies Press, 1984, Part I, ch. 4, pp.67-74.