Accurate FDTD Analysis of Bow-tie Antenna

Young-Il Cho · Dong-Hyuk Choi · Soeng-Ook Park

Abstract

In this paper, FDTD analysis of the bow-tie antenna is investigated by incorporating static field solution that is suitable to the bow-tie antenna without increasing computational time. Transforming static field solution to the rotated grid system, we can obtain the transformed static field solution which is able to represent field behavior near the oblique edge line of the bow-tie antenna. The result shows a good agreement with a MoM analysis and is compared conformal modeling technique and regular FDTD method.

Key words : FDTD, Locally Conformal Modeling Technique, Static Field Incorporation.

Ⅰ. Introduction

The Finite-Difference Time-Domain(FDTD) technique has been used in various electromagnetic problems. This algorithm is not only simple to implement but also powerful to simulate arbitrary type of objects. It is, however, not accurate if the surface of material is inclined or curved because of its staircase mesh representation.

Many trials have been attempt to overcome this limitation of FDTD method. Nonorthogonal grid modeling can be applied to treat this staircase scheme into boundary fitted grids[1]~[3]. However, it takes more computation time than regular FDTD algorithm, and this scheme are difficult to implement. The Contour-Path FDTD(CPFDTD) is the one of the successful schemes for solving the curved surface objects. This technique uses a Faraday's law to incorporate the fine curved geometry, that is, thin wires, narrow slots, and curved surfaces, into FDTD algorithm[4]~[6]. However, this method was subjected to late-time numerical instability. Dey and Mittra proposed a locally conformal modeling technique(CFDTD), which is more accurate and easy to implement[7].

Attempt to incorporating the near field solution into the FDTD algorithm is also performed by Umashankar[4]. Shorthouse and Railton studied the method that integrates near-zone static field solutions of MMIC structures into FDTD algorithm[8],[9]. They solved a Laplace equation near the metal edge of arbitrary open angle by using finite element method and calculated the correction factors that are needed in constructing the new H-field update equation.

However, it is not simple to obtain proper static field solution if the surface of object is not parallel to the Yee grid. It means that the static field solution should be modified or transformed as simple as possible. In this paper, the static field solution will be transformed according to the oblique edge line of the bow-tie antenna and used in FDTD analysis.

Ⅱ. The Basic Algorithm

2-1 Correction Factors

The Maxwell's equation in differential forms can be equivalently represented in integral forms, that is, Ampere's law and Faraday's law[8].

$$\frac{\partial}{\partial t}\int_S \varepsilon \mathbf{E}\cdot dS=\oint_C \mathbf{H}\cdot dl-\int_S \mathbf{J}\cdot dl \qquad (1)$$

$$\frac{\partial}{\partial t}\int_S \mu \mathbf{H}\cdot dS=-\oint_C \mathbf{E}\cdot dl \qquad (2)$$

For introducing vector function $\mathbf{F}$ which may be $\mathbf{E}$ or $\mathbf{H}$, we can reduce (1) and (2) into discrete types as

$$\int_S \mathbf{F}\cdot dS\approx \overline{F}\Delta a\Delta b \qquad (3)$$

$$\int_C \mathbf{F}\cdot dl\approx \overline{F}\Delta l \qquad (4)$$

where the $\overline{F}$ denotes the center value of $\mathbf{F}$ in discrete problem space and the $\Delta a, \Delta b,$ and Δl are the length of Yee cell in $x, y,$ and z directions respectively.

If we incorporate the static field solution, (3) and (4)

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should be corrected as (5) and (6)

$$\int_S \mathbf{F}\cdot dS \approx \overline{F}\Delta a\Delta b\cdot CF_s \tag{5}$$

$$\int_C \mathbf{F}\cdot dl \approx \overline{F}\Delta l\cdot CF_l \tag{6}$$

where CF_s and CF_l are unknown coefficient to be determined and we define them as correction factors.

From (5) and (6), we can define the correction factors as follows.

$$CF_s = \frac{\int_S \mathbf{H}\cdot dS}{\overline{H}\Delta a\Delta b} \tag{7}$$

$$CF_l = \frac{\int_C \mathbf{E}\cdot dl}{\overline{E}\Delta a\Delta b} \tag{8}$$

The correction factors are determined from the near-field characteristics of EM fields and should be calculated prior to the H-field update equation. The corrected H-field update equation is as follows.

$$H_x|^{n+1/2}_{i,j+1/2,k+1/2} = H_x|^{n-1/2}_{i,j+1/2,k+1/2} + \frac{\Delta t}{\mu_0 CF_s\Delta y\Delta z}\left[(CF_l^+ E_y|^n_{i,j,k+1} - CF_l^0 E_y|^n_{i,j,k})\Delta y + (E_z|^n_{i,j+1,k})\Delta z\right] \tag{9}$$

2-2 Static Field Solutions

According to [10], the quasi-static fields near the sharp and infinitely long metal edge are behaved as $1/\sqrt{r}$, where r is the distance from the edge.

This equation can be incorporated easily into FDTD method if the metal plane is aligned to Yee grid in parallel. For the analysis of bow-tie antenna, however, the form of equation may be changed because of the edge line is oblique to the Yee grid.

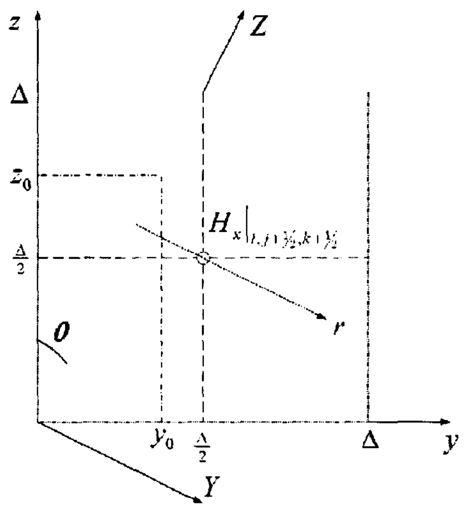


Fig. 1. Two coordinate system under rotation.

We now define two coordinate systems which are depicted in Fig. 1. Let (x, y, z) denotes a point in an original coordinate system which is parallel to Yee grid and (X, Y, Z) does a point in rotated coordinate system under angle θ. Equation (10) denotes the static field solution with unknown coefficient A in an original coordinate system.

$$H_x(Y, Z) = \frac{A}{\sqrt{Y}} \tag{10}$$

The relationship between two coordinate system is represented as follows.

$$\begin{pmatrix} Y \\ Z \end{pmatrix} = \begin{pmatrix} \cos\theta & -\sin\theta \\ \sin\theta & \cos\theta \end{pmatrix}\begin{pmatrix} y \\ z \end{pmatrix} \tag{11}$$

From (11), we can obtain the transformed static field solution.

$$H_x(y,z) = \frac{A}{\sqrt{y\cos\theta - z\sin\theta}},\quad 0\le y\le\Delta,\ 0\le z\le y\tan\theta \tag{12}$$

This function should be satisfied the following condition (13) and (14).

$$\lim_{(y,z)\to(y_0,z_0)} H_x(y,z)\to\infty \tag{13}$$

$$H_x(\Delta/2, \Delta/2) = H_x|_{i,j+1/2,k+1/2} \tag{14}$$

From these restrictions, we can calculate the unknown coefficient A.

$$A = \sqrt{\frac{\Delta}{2}}(\cos\theta - \sin\theta)H_x|_{i,j+1/2,k+1/2} \tag{15}$$

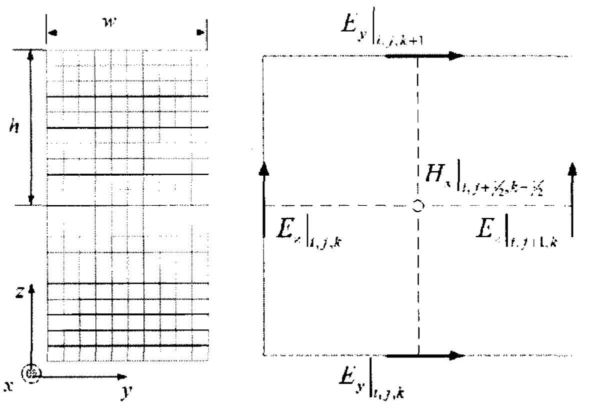
E-field solution is also represented as (16) in the original coordinate system but it may use another procedure to obtain the field solution.

$$E_Y(Y) = \frac{B}{\sqrt{Y}} \tag{16}$$

If the metal plane exceeds the $y=\Delta/2$, we cannot apply these methods because of its singularity. Therefore, we first assume that the formula of rotated coordinate system is approximately equal to that of original coordinate system and revise the formula by multiplying factor $\cos\theta$ or $1/\cos\theta$. Let $E_y^+(y)$ refers the solution at $(i, j, k+1)$ and $E_y^0(y)$ does the solution at (i, j, k). Then we can obtain the formulas as like (17) and (18).

$$E_y^+(y) \approx E_Y(Y)\cos\theta \tag{17}$$

$$E_y^0(y) \approx E_Y(Y)\sec\theta \tag{18}$$



(a) (b)

Fig. 2. Geometry of bow-tie antenna. (a) Mesh view, (b) Detailed cell configuration.

2-3 Calculation of Correction Factors

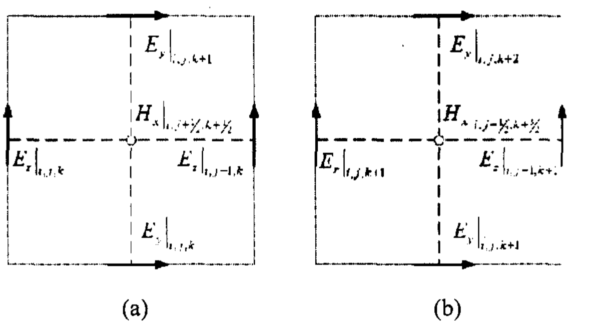
In order to validate the proposed method, we construct the geometry model of the bow-tie antenna which is shown in Fig. 2. The antenna is placed on y-z plane and the width and half height are 20 mm. The thickness of the condcutive plane is neglected in FDTD analysis. For this model, correction factors were calculated analytically. The value is

$$CF_s \approx 0.894,\ CF_l^{+} \approx 0.632,\ \text{and}\ CF_l^{0} \approx 0.791,$$

respectively. With substituting these values into (9), we can construct the corrected H-field update equation.

Ⅲ. Simulation and Results

Fig. 3 represents the two possible cases of mesh configuration in this simulation. If we generate mesh of the bow-tie antenna, we can find out that H-fields are



(a) (b)

Fig. 3. Two possible configurations. The H-fields located inside the metal plane are calculated by conformal technique. (a) $H_y|_{i,j+1/2,k+1/2}$ component, (b) $H_y|_{i,j+1/2,k+1/2}$ component.

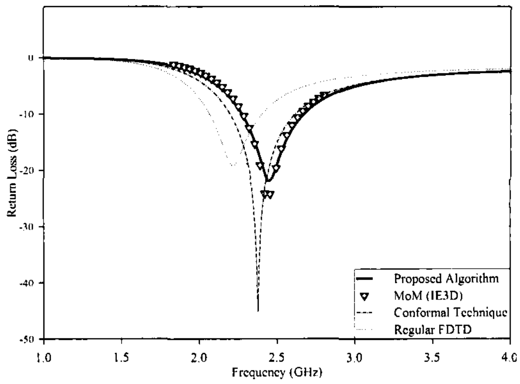


Fig. 4. Return loss of the bow-tie antenna.

located at the inside or outside of edge metal as seen in Fig. 3(a) and (b). H-fields that are located at the outside of metal plane could be calculated by using the proposed algorithm. However, if H-fields are located at inside of metal plane, the conventional conformal technique will be used. Using the newly developed technique, we perform the return loss of the bow-tie antenna with width 20 mm and half height 20 mm. The cell size is 2 mm in each direction and derivative Gaussian pulse is forced as input source to inspect the return loss of antenna. PML boundary condition is used as an absorbing boundary condition.

The result of proposed method is compared with those of three different methods by using the MoM, conventional conformal technique, and regular FDTD. Each associated results are shown in Fig. 4. The proposed algorithm shows a more good agreement with the MoM result than other methods. The MoM analysis was obtained by using IE3D, a commercial MoM program which is well suited to solve the bow-tie structure.

Ⅳ. Conclusions

The accurate analysis of the bow-tie antenna was performed by incorporating the approximated static field solution. This paper is focused on solving the static field solutions under the oblique edge line of the bow-tie antenna and calculating efficiently correction factors without making a sacrifice of computational cost. By considering these restrictions, we can derive the approximated static field solutions that are suitable for the bow-tie antenna. The result of the proposed algorithm shows that the remarkable accuracy of simulation can be achieved in spite of rather coarse mesh. Furthermore, due to the analytical calculation of correction factors, additional computation time is not required in the proposed algorithm.

References

[1] N. K. Madsen, "Divergence preserving discrete surface integral methods for Maxwell's curl equations using nonorthogonal unstructured grids", *J. Comput. Phys.*, vol. 119, pp. 3445, 1995.

[2] S. D. Gedney, J. A. Roden, "Numerical stability of nonorthogonal FDTD methods", *IEEE Trans. Antennas Propagat.*, vol. 48, pp. 231-239, Feb. 2000.

[3] R. Schuhmann, T. Weiland, "Stability of the FDTD algorithm on nonorthogonal grids related to the spatial interpolation scheme", *IEEE Trans. Magn.*, vol. 34, pp. 2751-2754, Sep. 1998.

[4] K. R. Umashankar, A. Taflove and B. Becker, "Calculation and experimental validation of induced currents on coupled wires in an arbitrary shaped cavity", *IEEE Trans. Antennas Propagat.*, vol. 35, pp. 1248-1257, 1987.

[5] T. G. Jurgens, A. Taflove, K. R. Umashankar and T. G. Moore, "Finite-difference time-domain modeling of curved surfaces", *IEEE Trans. Antennas Propagat.*, vol. 40, pp. 357-365, Apr. 1992.

[6] T. G. Jurgens, Taflove, "Three-dimensional contour FDTD modeling of scattering from single and multiple bodies", *IEEE Trans. Antennas Propagat.*, vol. 41, pp. 1703-1708, Dec. 1993.

[7] S. Dey, R. Mittra, "A locally conformal finite-difference time-domain(FDTD) algorithm for modeling three-dimensional perfectly conducting objects", *IEEE Microwave Guided Wave Lett.*, vol. 7, pp. 273-275, Sep. 1997.

[8] D. B. Shorthouse, C. J. Railton, "The incorporation of static field solutions into the finite difference time domain algorithm", *IEEE Trans. Microwave Theory Tech.*, vol. 40, pp. 986-994, May 1992.

[9] C. J. Railton, "Use of static field solutions in the FDTD method for the efficient treatment of curved metal surfaces", *IEE Electronic Lett.*, vol. 29, pp. 1466-1467, Aug. 1993.

[10] J. Van Bladel, *Singular Electromagnetic Fields and sources*. Oxford, U. K., Clarendon, pp. 121, 1991.

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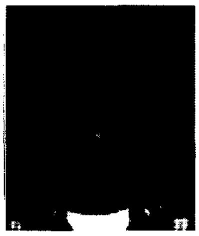

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