Improvement of FDTD calculation accuracy for printed bent dipole and loop antennas

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1. Introduction

In recent years Finite Difference Time Domain (FDTD) method [1] is widely used for printed antenna analysis. Because a complicated-shaped model is easily analyzable by using FDTD method. However, it is well known that quite small cell is required when an extremely accurate result is needed for analyzing impedance characteristics of antennas on dielectric substrate. The improving calculation accuracy method has been proposed for straight shape printed antenna [2]. In the method, quasi-static field was used to improve calculation accuracy. In this paper, we expand the quasi-static approximation to bent antennas including loop antenna and we will demonstrate improvement of calculation accuracy.

2. Quasi-static approximation

In general, the electromagnetic field changes rapidly near the antenna conductor and the surface of substrate. In addition, the electric and magnetic fields distribution is to be similar as static field distribution near the antenna. On the other hand, The FDTD method uses discrete electric fields and magnetic fields. Therefore fields are placed discretely. A quite small discrete interval is needed to simulate rapidly changed filed for time and space. This is a disadvantage of FDTD method. Figure 1 is an image of calculation result. However, if the field distribution is known, then high accurate result may be able to obtain even relatively large discrete interval are used. This method is called as sub cell method [3]. The quasi-static approximate solution is shown in a dashed line and is different from the correct electromagnetic field that showed in a solid line, but it is expected that the spatial distribution is similar. In addition, it becomes like a circle in figure 1 when simulation is carried out by the FDTD method, and a correct electromagnetic field near the conductor cannot be calculated by the FDTD method.

In this paper, the quasi-static approximation include into the FDTD method to improve calculation.

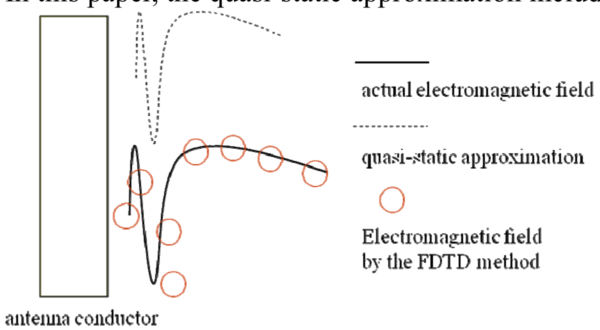

Figure 1: Image of the electromagnetic field distribution

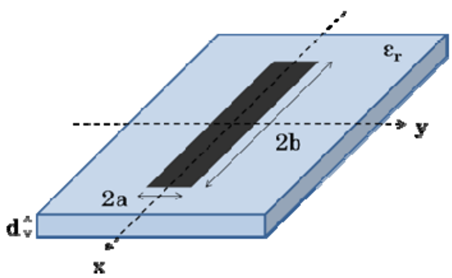

Figure 2: Finite length model

Next, quasi-static approximation is explained briefly. The shape of an antenna conductor on the dielectric substrate is complicated, and it is difficult to assume a general model. However, if a length of conductor is a relatively long, TEM wave is dominant in the electromagnetic field along it. Conventional quasi-static approximation is used the electrostatic potential that calculated from an infinite length model [2]. But, the technique to propose in this paper uses the electrostatic potential that calculated from a finite length model shown in figure 2. As for the model of figure 2, a thin perfect conductor with width 2a is put on the dielectric surface. Green's function G for the electrostatic potential can be found easily by assuming the electric charge distribution on the conductor σ(y') as

$$\sigma(y') = \frac{\sigma_0}{\sqrt{a^2 - y'^2}} \tag{1}$$

The electrostatic potential can be calculated next equation.

$$\phi(r) = \frac{1}{\varepsilon_0} \int_S G(r, r')\sigma(r')dS' \tag{2}$$

Electrostatic potential ϕ of the model of figure 2 can be calculated from (1) and (2), and each domain of electrostatic potential ϕ are expressed by (3).

$$\phi(r) = \begin{cases} \phi_0(r) + \phi_s(r) & ; z \geq 0 \\ \phi_1(r) & ; -d \leq z < 0 \\ \phi_2(r) & ; z < -d \end{cases} \tag{3}$$

ϕ_0 is electrostatic potential in free space, and ϕ_s is electrostatic potential by the scattering field. Here, the calculation method of electrostatic potential is explained as an example in φ_s. Green's function G_s for the scattering field can be obtained by (4).

$$G_s(r,r') = \frac{1}{4\pi}\int_0^\infty R(\lambda)J_0(\lambda s)e^{-\lambda z}d\lambda = \frac{R_0}{4\pi}\left[\frac{1}{\sqrt{(x-x')^2+(y-y')^2+z^2}} - \sum_{n=0}^{\infty}\frac{(1-R_0^2)R_0^{2n}}{\sqrt{(x-x')^2+(y-y')^2+\{z+2(n+1)d\}^2}}\right] \tag{4}$$

J_0 is the 0th Bessel function, λ is the wave number in the z direction, and R(λ) is calculated based on boundary condition and becomes (5).

$$R(\lambda) = R_0 \frac{1 - e^{-2\lambda d}}{1 - R_0^{\ 2} e^{-2\lambda d}} \qquad R_0 = \frac{1 - \varepsilon_r}{1 + \varepsilon_r} \tag{5}$$

(6) is given when (1) and (4) are substituted for (2).

$$\phi_s(r) = \frac{1}{\varepsilon_0}\int_S G_s(r,r')\sigma(r')dS = \frac{R_0}{4\pi\varepsilon_0}\int_{-a}^{a}\sigma(r')\left\{\left[\log\left|2\left\{x'-x+\sqrt{s^2+z^2}\right\}\right|\right]_{-b}^{b} - (1-R_0^2)\sum_{n=0}^{\infty}R_0^{2n}\left[\log\left|2\left\{x'-x+\sqrt{s^2+\{z+2(n+1)d\}^2}\right\}\right|\right]_{-b}^{b}\right\}dy' \tag{6}$$

φ_1 and φ_2 can be calculated in a similar procedure, and electrostatic field E is given from (7).

$$E = -\nabla\phi = -\frac{\partial\phi}{\partial x}\hat{x} - \frac{\partial\phi}{\partial y}\hat{y} - \frac{\partial\phi}{\partial z}\hat{z} \tag{7}$$

Next, a calculation method of the magnetic field is explained. Assuming that the current J_x flows in the x direction, the vector potential **A** becomes only A_x of the x ingredient. Because A_x satisfies an equation similar as electrostatic potential φ, A_x can be calculated in the procedure like the calculation of the electrostatic potential. Magnetic field H is given from (8).

$$H = \frac{1}{\mu}\nabla \times A = \frac{1}{\mu}\left(\frac{\partial A_x}{\partial z}\hat{y} - \frac{\partial A_x}{\partial y}\hat{z}\right) \tag{8}$$

4. Include method into the FDTD method

The method to incorporate the electrostatic field and the static magnetic which were given in a previous chapter into the FDTD method is explained. Figure 3 shows field a part of the Yee cell on the x-y plane. When a Faraday's law is applied to closed curve $C=C_1+C_2+C_3+C_4$,

$$\oint_C E \cdot dl = -\frac{\partial}{\partial t}\int_S \mu\boldsymbol{H} \cdot d\boldsymbol{S} = -\frac{\partial}{\partial t}\int_S \mu H_z dS \tag{9}$$

it is thought that an electrostatic field distribution and a static magnetic field are dominant in near the conductor. At first, the magnetic field of the right-hand side of (9) is approximated by using (8) as

$$H_z(r,t) \cong \frac{1}{A_0} H_z(i+1/2, j+1/2, k, t) \frac{\partial A_x(r)}{\partial y} \qquad A_0 = \partial A_z / \partial y \,|_{y=(j+1/2)\Delta y, z=k\Delta z} \qquad (10)$$

Then the right-hand side of (9) can be derived as

$$\frac{\partial}{\partial t}\int_S \mu H_z dS = \mu \frac{\Delta x}{A_0}\int_a^{(j+1)\Delta y} \frac{\partial H_z}{\partial t}\frac{\partial A_x}{\partial y} dy = \mu \frac{\Delta x}{A_0} \frac{\partial H_z(i+1/2.j+1/2,k,t)}{\partial t}\{A_x(j+1,k) - A_x(a,k)\} \qquad (11)$$

Next, the left-hand side of (9) is explained. It is similar using (7) like (10) on C_2 and C_3.

$$E_y(r,t) \cong E_y(i, j+1/2, k, t) \frac{\partial \phi(r)/\partial y}{B_0} \quad \text{on } C_2 \qquad B_0 = \partial \phi(r)/\partial y \,|_{y=(j+1/2)\Delta y, z=k\Delta z} \qquad (12)$$

$$E_y(r,t) \cong E_y(i,+1 j+1/2, k, t) \frac{\partial \phi(r)/\partial y}{B_0} \quad \text{on } C_3 \qquad B_0 = \partial \phi(r)/\partial y \,|_{y=(j+1/2)\Delta y, z=k\Delta z} \qquad (13)$$

The tangential electric field E_x should be E_x=0 on C_4, and the approximation is not used on C_1 because there are few changes of the x direction. When the left-hand side of (9) is integrated, $H_z^{n+1/2}$ (i+1/2,j+1/2,k) is given. The procedure of the calculation is the same for y-z plane and the x-z plane.

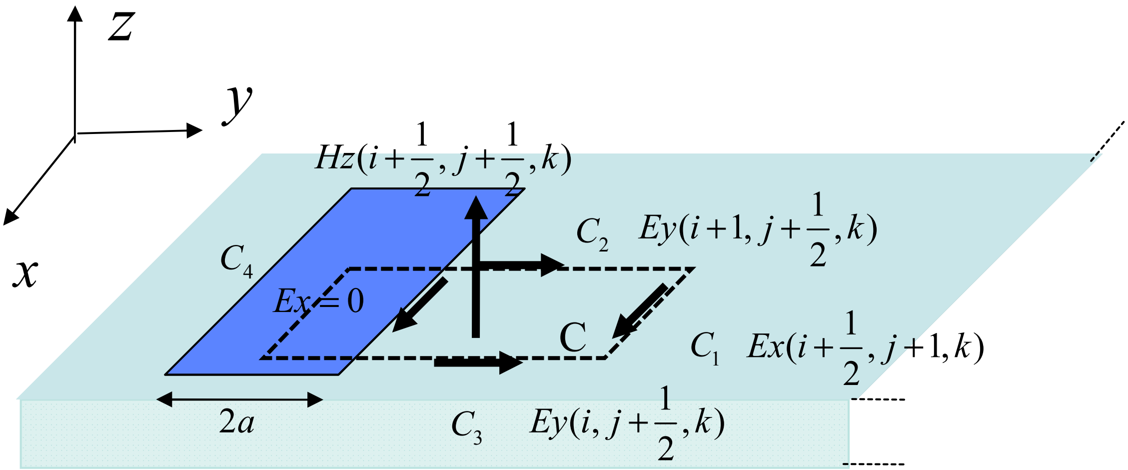

Figure 3: Yee cell

5. Analysis result

The model of the bent antenna is shown in figure 4. In this paper, a corner is regarded as a combination of finite length model like figure 8. The model 1 is ε_r=6.0, d=3.0mm, 2a=2.0mm, 2b=50mm, the model 2 is ε_r=6.0, d=3.0mm, 2a=2.0mm, L=30mm. An analysis result of the impedance is shown in figure 8. A highly accurate result is given by the proposed method comparing with the FDTD method with a small cell. Furthermore, this method is 24 times faster computation time and 7 times less memory consumption than normal FDTD method.

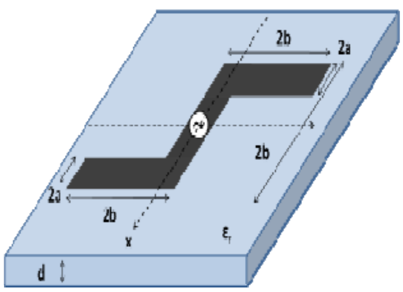

Figure 4: Analysis model 1

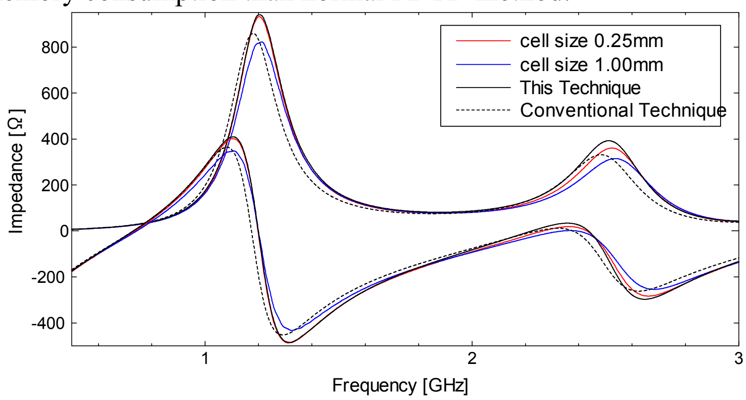

Figure 5: Impedance of Analysis model 1

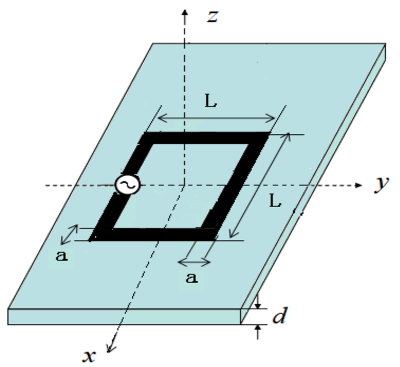

Figure 6: Analysis model 2

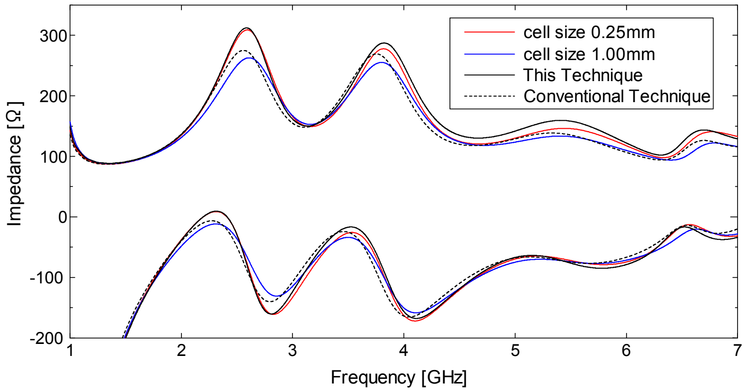

Figure 7: Impedance of Analysis model 2

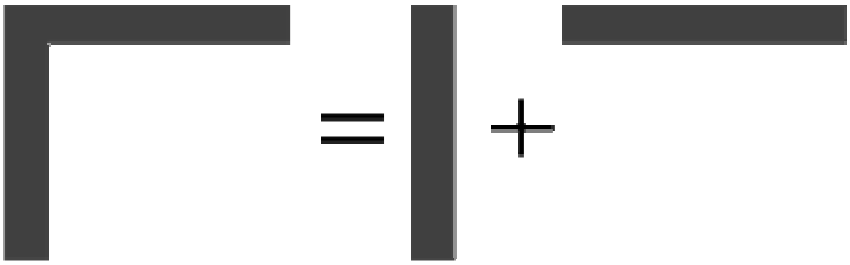

Figure 8: Concept of the flexion

Table 1: Consumption calculation resources of model1

Cell Size	0.25mm	1.00mm
Analysis Method	Normal FDTD	This Technique
Calculation Time[s]	9303	393
Memory[MB]	7488	1024

Table 2: Consumption calculation resources of model 2

Cell Size	0.25mm	1.00mm
Analysis Method	Normal FDTD	This Technique
Calculation Time[s]	991	81
Memory[MB]	3072	512

6. Conclusion

In this paper, the electrostatic potential was calculated from the finite length model, to improve analysis accuracy. Furthermore, the effectiveness of the FDTD method which incorporated the quasi-static approximation to bent antenna on dielectric substrate was shown.

7. References

[1]Toru Uno, Finite Difference Time Domain Method for Electromagnetic Field and Antennas, CORONA PUBLISHING CO., LTD., 1998

[2]Takuji Arima, Toru Uno, "Improvement of FDTD Calculation Accuracy for Analyzing Linear Antenna on Dielectric Substrate by Using Quasi-static Approximation", IEICE Transactions on Communications, Vol. J85-B,No.2 pp.200-206, 2002.2.

[3]A. Taflove, Computational Electrodynamics: The Finite-Difference Time-Domain Method, Atrech House, 1995