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FDTD ANALYSIS OF PRINTED ANTENNA ON THIN DIELECTRIC SHEET INCORPORATING WITH QUASI-STATIC FIELD SPATIAL DISTRIBUTION

Takuji ARIMA, Toru UNO and Masaharu TAKAHASHI
Dept. of Electrical & Electronics Eng., Tokyo Univ. of Agri.& Tech.
Telephone: +81 (42) 388-7441
Email: t-arima@cc.tuat.ac.jp

1 Introduction

The FDTD method is widely used for electromagnetic problems including the EM scattering, antennas and so on. Its reason is considered that the FDTD method has a simple algorithm, is capable of modeling the complicated structures, and can obtain the practical level of the accuracy easily. However, if very small structures such as a thin dielectric film are included in calculation area, many computer resources are required because much more finer cells are needed for modeling small structure. In this case, a cell size should be less than thickness of the film. Therefore the great amount of FDTD cells are needed when other large structures are included in the same computation region. This is on of the disadvantages of FDTD method. In order to overcome this difficulty, some techniques have been proposed. One of which is a subgridding method[2] in which the fine cell is locally used for the film region. However, in this method, the computation time increases over original FDTD method, because fine cell is used. Moreover it is known that sometime unnecessary reflection occurs from the boundary between fine cell and coarse cell. Other technique is auxiliary electric field technique[3] in which the auxiliary electric field is used for modeling thin film. However, this method does not give the highly accurate result when the antenna conductor attached just on the dielectric surface, because the electromagnetic field changes very rapidly near the edge of antenna conductor on the interface. The purpose of this paper is to analyze the planer antenna on thin dielectric film accurately with keeping the cell large. To do this, how physically accurate field distribution can be introduced to the FDTD cell is essential. In this paper, a quasi-static field spatial distribution is utilized because this field is considered dominant in the region near the conductor edge. The validity and effectiveness of the method are confirmed numerically and experimentally.

2 Modeling method for thin dielectric sheet

The geometry of the printed antenna on thin dielectric sheet is shown in Fig. 1. In the region far from the antenna conductor, the electric and magnetic fields are expected to change very slowly. Therefore, the original auxiliary field technique is fairly available in this region. The effective permittivity and conductivity are obtained by applying the Ampere's law to the contour C_1 in Fig. 2, and there values are given by

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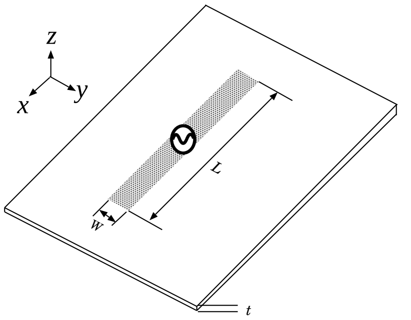

Fig. 1: The printed antenna

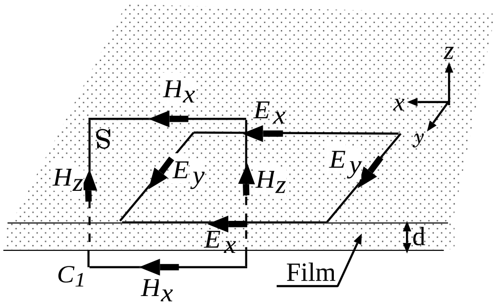

Fig. 2: Contour paths for E and H

$$\varepsilon_{\text{ave}} = \frac{\varepsilon_0 \left(\Delta z - d\right) + d\varepsilon_r}{\Delta z}, \quad \sigma_{\text{ave}} = \frac{0 \left(\Delta z - d\right) + d\sigma}{\Delta z} = \frac{d}{\Delta z}\sigma \tag{1}$$

where d is a thickness of the substrate, Δz is the cell size along z direction. Using average value of σ and ε, E_y just on surface can be derived as

$$\begin{aligned} E_y^n \quad \left(i, j+\frac{1}{2}, k+1\right) &= \frac{1 - \frac{\sigma_{\text{ave}}\Delta t}{2\varepsilon_{\text{ave}}}}{1 + \frac{\sigma_{\text{ave}}\Delta t}{2\varepsilon_{\text{ave}}}} E_y^n \left(i, j+\frac{1}{2}, k+1\right) \\ &+ \frac{\Delta t/\varepsilon_{\text{ave}}}{1 + \frac{\sigma_{\text{ave}}\Delta t}{2\varepsilon_{\text{ave}}}} \frac{1}{\Delta z} \left\{ H_x^{n-\frac{1}{2}} \left(i, j+\frac{1}{2}, k+\frac{3}{2}\right) - H_x^{n-\frac{1}{2}} \left(i, j+\frac{1}{2}, k+\frac{1}{2}\right) \right\} \\ &- \frac{\Delta t/\varepsilon_{\text{ave}}}{1 + \frac{\sigma_{\text{ave}}\Delta t}{2\varepsilon_{\text{ave}}}} \frac{1}{\Delta x} \left\{ H_z^{n-\frac{1}{2}} \left(i+\frac{1}{2}, j+\frac{1}{2}, k+1\right) - H_z^{n-\frac{1}{2}} \left(i-\frac{1}{2}, j+\frac{1}{2}, k+1\right) \right\} \end{aligned} \tag{2}$$

The E_x component is similarly obtained. However, E_z just under/or above the film is not obtained as a form that includes the properties of the film, because contour path for E_z in $x-y$ plane does not cut the dielectric film. On the other hand, the electric field E_z normal to the dielectric interface is discontinuous when crossing over the film. This property may becoming more and more serious near the antenna conductor, because the electric and magnetic fields changes very rapidly in this region. Therefore , the E_z component should be introduced into FDTD update equation by another method. In this paper, the spatial distribution of the E_z component will be obtained using quasi-static approximation, because the quasi-static field is considered as dominant. Fig. 4 shows an infinitely long strip conductor attached on the dielectric substrate. When the electric charge on strip conductor[6] is assumed as

$$\sigma\left(y\right) = \frac{\sigma_0}{\sqrt{a^2 - y^2}} \tag{3}$$

then the static electric field in the dielectric film is given as

$$\begin{aligned} E_z^{static}(y,z) \quad &= \quad \frac{\sigma_0}{2\varepsilon_0} \left[(1+R_0) \sum_{n=0}^{\infty} R_0^{2n} \left\{ \frac{1}{2u_p^n w_p^n} \sqrt{(u_p^n + w_p^n)^2 - 4y^2} \right\} \right. \\ &+ \quad \left. R_0 \left(1+R_0\right) \sum_{n=0}^{\infty} R_0^{2n} \left\{ \frac{1}{2u_m^{n+1} w_m^{n+1}} \sqrt{(u_m^{n+1} + w_m^{n+1})^2 - 4y^2} \right\} \right] \end{aligned} \tag{4}$$

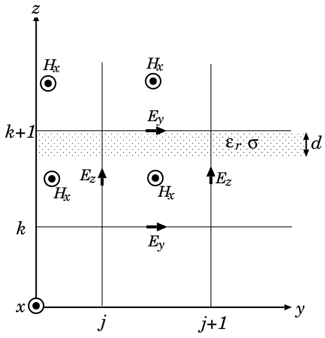

Fig. 3: The FDTD cell including film

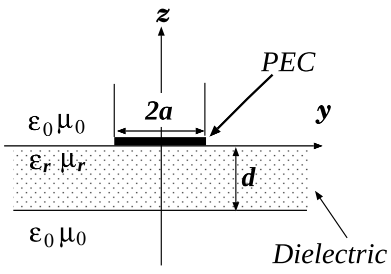

Fig. 4: The 2-D model

where σ_0 is constant, and

$$\begin{aligned} R_0 &= \frac{1-\varepsilon_r}{1+\varepsilon_r} \\ u_p^n &= \sqrt{(z+2nd)^2+(y-a)^2} \\ u_m^n &= \sqrt{(-z+2nd)^2+(y-a)^2} \end{aligned}$$

The static field in other regions are obtained similarly. Using the spatial distribution of this static field solution we approximate the temporal electric field a

$$E_z(y,z,t) \simeq E_z(y,k+\frac{1}{2},t)\frac{1}{B_P}E_z^{stat}(y,z) \tag{5}$$

where $B_P = E_z^{stat}(y,k+\frac{1}{2})$, and $E_z(y,k+\frac{1}{2},t)$ is the electric field on FDTD cell edge. The update equation for the magnetic field is obtained by applying the Faradays law

$$\oint_C \boldsymbol{E}\cdot d\boldsymbol{l} = -\frac{\partial}{\partial t}\int_S \mu\boldsymbol{H}\cdot d\boldsymbol{S} \tag{6}$$

to the appropriate contour. Thus the quasi-static approximation of magnetic field can be introduced into FDTD cell.

3 Numerical result

In order to confirm the validity of our proposed method, we analyzed input impedance frequency characteristics of the printed dipole antenna shown in Fig. 1. In this calculation the proposed method is applied to only the nearest cell of the conductor's edge. The thickness of the substrate is $2.4mm$ and its relative permittivity $\varepsilon_r = 10.2$. The cell size is set as $\Delta x = 4.762mm, \Delta y = \Delta z = 4.8mm$. Then, the substrate is modeled by 1/2 cell. The calculated input impedances are shown in Fig. 5. The result using only the auxiliary field method is also shown. It is found that our method agrees very well with the measured date for a wide frequency range. Next, results for enlarging the cell size are also calculated. Fig. 6 is the case that $\Delta z = 9.6mm$. The accuracy is not so good as that for Fig. 5, but the discrepancy between the measured date and the calculated result is not so large.

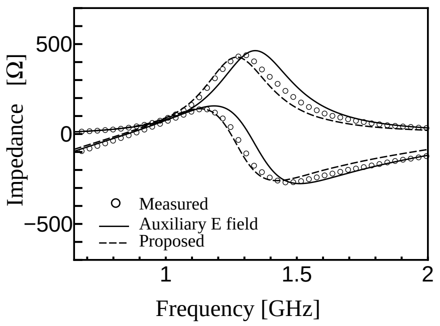

Fig. 5: Input impedance

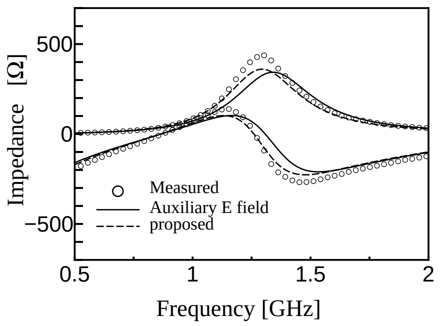

Fig. 6: Input impedance

4 Conclusion

In this paper, new modeling method for analyzing the printed antenna on the thin dielectric film has been proposed. In this method, the quasi-static approximation of electromagnetic field was incorporated into the FDTD update equation. It has been shown by comparing with the measured date that our method is accurate for wide frequency range.

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