Highly Accurate FDTD Analysis of Bend Microstrip Lines Using Quasi-static Approximation

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Abstract

The Finite Difference Time Domain (FDTD) method is widely used for analyzing electromagnetic field scattering, antennas, microwave devices and so on. However a quite smaller cell is required when an extremely accurate result is needed for analyzing conductor on dielectric substrate such as microstrip line structure. In this paper, an improvement method of FDTD calculation accuracy for such structure is proposed by incorporating with quashi-static approximation of the spatial field distrubution on a cross-section.

1. Introduction

The FDTD method[1][2] is widely used for electromagnetic problems including microstrip lines and so on. Its reason is considered that the FDTD method has a simple algorithm and a high capability of modeling the complicated structures, and can easily obtain the practical level of the accuracy. However, the original FDTD method needs smaller cell and requires great amount of computer resources when requiring the extremely accuracy result. Therefore a great amount of computer recourses is required to analyze microstrip structures when other large structures include in the same region. This is one of the disadvantages of the FDTD method. In order to improve calculation accuracy three type techniques have been proposed. First type of approach to improve calculation accuracy is to use a grobally nonuniform mesh[3]. Another is to use a uniform mesh in a locally subgridded region which is placed within an otherwise coarse grid[4]. In these methods, fine cells are locally used in the region that the electromagnetic field distribution is expected to change rapidly, or used to fit these fine geometries. These techniques are efficient, but some instabilities or mismatch reflection errors may still present in a problem. Second type is a local subcellular technique in which the particular cell edges are locally deformed to adjust these cells to the geometry. In this method, field distribution which has to be theoretically expected in advance is incorporated into the FDTD update equations by using the integral form of the Faraday's law[5]. Third type of approach to improve calculation accuracy is using a higher-order difference to approximate differential of maxwell equation[6].

On the other hand, we have proposed the highly accurate FDTD[7] technique. In this method, the FDTD update equations were modified by introducing a spatial distribution of quasi-static field near the antenna conductor into the FDTD update equations using the integral form of Faraday's law.

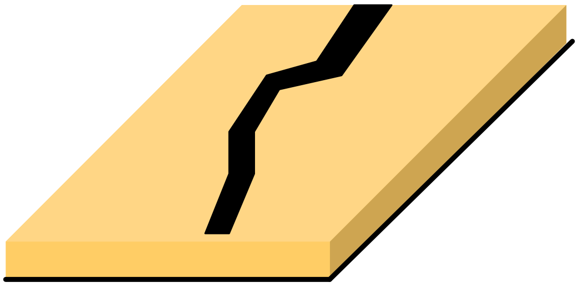


Fig. 1: An microstrip line

Therefore, the method is besed on second type. We have indicated that the accuracy is significantly improved and agree very well with measured data without reducing cell size. In this paper, the method is applied to bend microstrip lines which including chamfered microstrip line. In the first half of this paper, we briefly review our proposed method and indicate the modified FDTD update equation. In the second half, reflection coefficient of a right-angle microstrip line will be calculated and be compared with the original FDTD method. The validity of our proposed method is confiremed by numerucally.

2. Quasi-static Approximation

Fig.1 shows microstrip line which includes slightly discontinuity. The electric and magnetic fields in the cross section of the microstrip line shown in Fig.2 are well approximated by the TEM fields even if the slight discontinuities are involved within the line. The fields are expressed by scalar potential Ψ which correspond to an x component magnetostatic vector potential wen the current on the conductor is in x direction. from which Then the electric and magnetic fields are calculated by

$$\begin{cases} \boldsymbol{H}(y,z) = \frac{1}{\mu}\nabla_t \times (\Psi(y,z)\,\hat{x}) \\ \qquad\quad = \frac{1}{\mu}\left(\frac{\partial\Psi}{\partial z}\,\hat{y} - \frac{\partial\Psi}{\partial y}\,\hat{z}\right) \\ \boldsymbol{E}(y,z) = \sqrt{\frac{\mu}{\varepsilon}}\,\boldsymbol{H}(y,z)\times\hat{x} \end{cases} \tag{1}$$

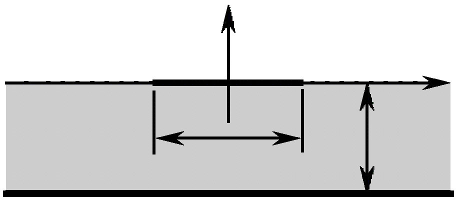


Fig. 2: Cross section of microstrip line

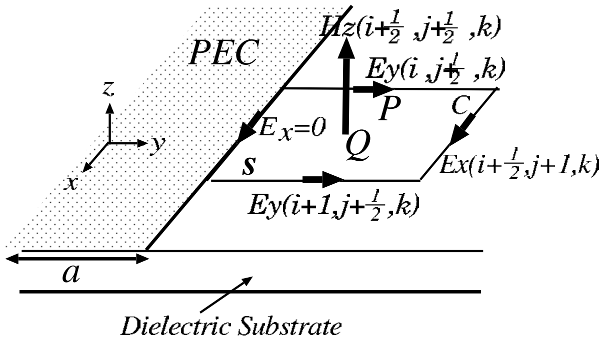


Fig. 3: FDTD cell

The integral expression Ψ can be obtained by introducing a two dimensional Green's function $G(\boldsymbol{r}, \boldsymbol{r}')$ that represents the potential from a line source at $\boldsymbol{r}'$ as follows.

$$\Psi(\boldsymbol{r}) = \mu_0 \int_S G(\boldsymbol{r}, \boldsymbol{r}') J_x(\boldsymbol{r}')\, dS' \tag{2}$$

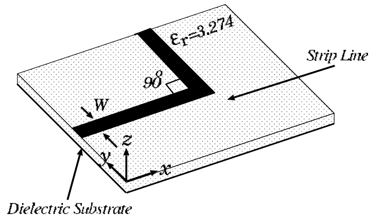
where S is the surface of the microstrip conductor shown in Fig.2. The Green's function $G(\boldsymbol{r}, \boldsymbol{r}')$ of eq.(2) is easily found using the boundary conditions at the air-dielectric interface and at the ground surface.

The current distribution $J_x(y)$ is well approximated by

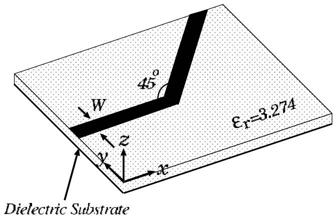
$$J_x(y) = \frac{I_0}{\sqrt{a^2 - y^2}} \tag{3}$$

Substituting (3) to (2) we obtain Ψ analytically.

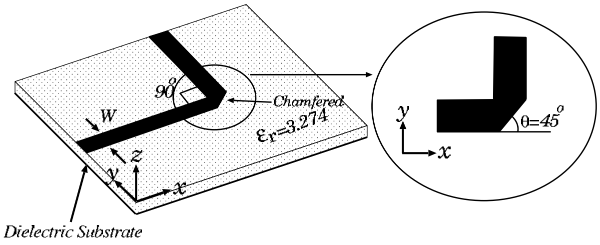
$$\begin{aligned} \Psi(y, z) \quad = \quad & \frac{\mu_0 I_0}{2} \left[\log \left| \frac{u_0 + w_0}{2a} \frac{Q_0 - z}{Q_0} \right| \right. \\ & \left. - \log \left| \frac{u + w}{2b} \frac{Q - (z + 2d)}{Q} \right| \right] \end{aligned} \tag{4}$$



(a) An infinite model



(b) A 45-degree bend model



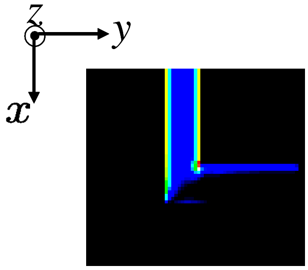
(c) A chamfered model

Fig. 4: Right-angled bend microstrip lines

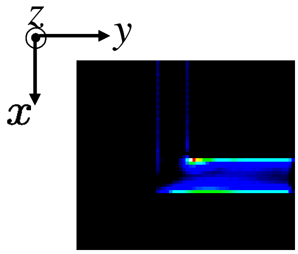
where

$$\begin{cases} u_0 = \sqrt{(y - a)^2 + z^2} \\ w_0 = \sqrt{(y + a)^2 + z^2} \\ Q_0 = \sqrt{\left(\frac{u_0 + w_0}{2}\right)^2 - y^2} \end{cases} \tag{5}$$

$$\begin{cases} u = \sqrt{(y - a)^2 + (z + 2d)^2} \\ w = \sqrt{(y + a)^2 + (z + 2d)^2} \\ Q = \sqrt{\left(\frac{u + w}{2}\right)^2 - y^2} \\ b = \sqrt{a^2 + (2d)^2} - 2d \end{cases} \tag{6}$$



(a) J_x



(b) J_y

Fig. 5: Current distribution on the microstrip line

Next, we modify the original FDTD update equations using the spatial distribution of the static electromagnetic field. Fig. 3 shows an electric cell edge on the interface. In this region, quasi-static fields are considered dominant, and well approximated by $\boldsymbol{E}^{stat}$ and $\boldsymbol{H}^{stat}$. Using these fields, temporal electric and magnetic fields on FDTD cells can be approximated as

$$E_y(y,z,t) \simeq E_y^{FDTD}(P,z,t)\frac{1}{B_P}E_y^{stat}(y,z) \quad (7)$$

$$H_z(y,z,t) \simeq H_z^{FDTD}(Q,z,t)\frac{1}{B_Q}H_z^{stat}(y,z) \quad (8)$$

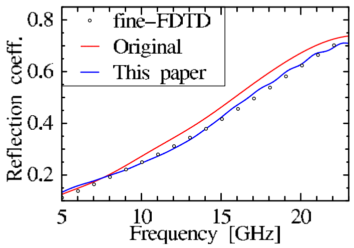
where $B_P(\boldsymbol{r}) = E_y^{stat}(P,z), B_Q(\boldsymbol{r}) = H_z^{stat}(Q,z)$
After, this approximation, applying the Faraday's law

$$\oint_C \boldsymbol{E}\cdot d\boldsymbol{l} = -\frac{\partial}{\partial t}\int_S \mu\boldsymbol{H}\cdot d\boldsymbol{S} \quad (9)$$

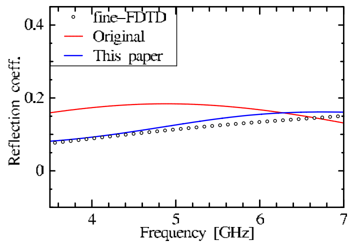
to contour path C in Fig.2, the modified FDTD update equation can be derived.

3. Results

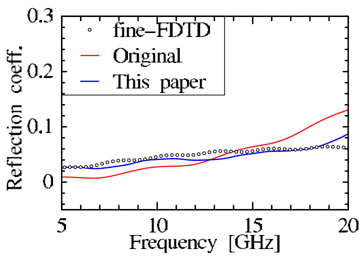
In order to confirm validity of our proposed method, the reflection coefficients of three types of strip lines as Fig. 4(a)~(c) are calculated. Fig. 4(a) is right-angled bend microstrip line which has infinite length, Fig. 4(b) is 45-degree bend microstrip line which has infinite length and Fig. 4(c) is right-angled bend microstrip line which is chamfered with



(a) An infinite model



(b) A 45-degree bend model



(c) A chamfered model

Fig. 6: Reflection coefficient of the microstrip lines

a 45-degree the corner. The width of line is $w = 1.8mm$ and thickness of substrate is $t = 0.827mm$. At first, we calculate the current distribution on the microstrip line which is calculated by original FDTD as shown in Fig.5(a)(b). These figures show that the J_x and J_y, respectively. Therefore the same approximation as straight structure will be effective for this example. Fig.6(a)~(c) show the reflection coefficients of Fig.4(a)~(c). In this calculation cell size are set as $\Delta x = \Delta y = 0.45mm$ and $\Delta z = 0.27566mm$. In the calculation of Fig. 4(b),(c) models, the inclinedlines are modeled by CP method[8]. It is found that our method agrees very well with the original FDTD with very fine cell($\Delta x = \Delta y = 0.1125mm$, $\Delta z = 0.068915mm$) for a wide frequency range.

4. CONCLUSION

In this paper, high accuracy FDTD method which utilize the quasi-static approximation was applied to microstrip structures including 45-degree bend microstrip line. It has been shown that the higher accurate result can be obtained without reducing cell size.

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