Analysis of Shielded Membrane Microstrip Line Using the Finite-Difference Time-Domain Method

Yun Kwon Nam, *Member, IEEE*, and Dong Chul Park, *Member, IEEE*

***Abstract*—A simple and efficient analysis method of the shielded membrane microstrip (SMM) line using the finite-difference time-domain (FDTD) method is presented. New FDTD equations are derived using the contour path FDTD concept for the Yee cell which contains three thin dielectric sheets of membrane. The characteristic impedance and the effective dielectric constant of the SMM line are calculated using our proposed method. Our method is validated by comparison with the results shown in [1].**

***Index Terms*—Finite-difference time-domain (FDTD), shielded membrane microstrip (SMM).**

I. Introduction

So far, the passive components for many millimeter-wave systems are made of waveguides, but waveguides suffer from high production costs and bulky systems. In order to avoid these drawbacks, the membrane-supported transmission lines, which are made by bulk micromachining, have been studied [1], [2]. The SMM line is one of the typical membrane supported transmission lines and its structure is shown in Fig. 1. The thickness of the membrane, which mechanically supports the signal line, is very small compared with other dimensions of the SMM line. Therefore, if the ordinary FDTD method is applied to the analysis of the SMM line, the large storage and long computational time will be required. To overcome these difficulties, in [1], the effects of the dielectric membrane for the SMM line analysis are simulated by introducing ten-times' thick single-layer membrane instead of the original one. In this letter, new FDTD equations are derived using the contour path FDTD concept used in [3] and [4] for Yee cells which contain three original thin dielectric sheets of membrane as shown in Fig. 2. These derived equations are then applied to calculate the SMM line characteristics having the original dimensions of the 3-layer thin membrane. This calculation requires neither large storage nor long computational time, because the spatial increment can be much larger than the thickness of the membrane by adopting our proposed equations in FDTD calculations.

II. Derivation of New FDTD Equations

New equations to advance the electric and magnetic fields in the Yee cell which contains three thin dielectric sheets are derived from the integral form of Maxwell's equations:

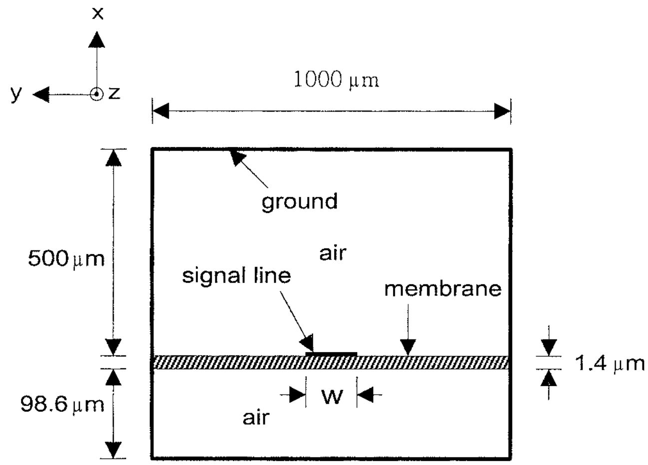
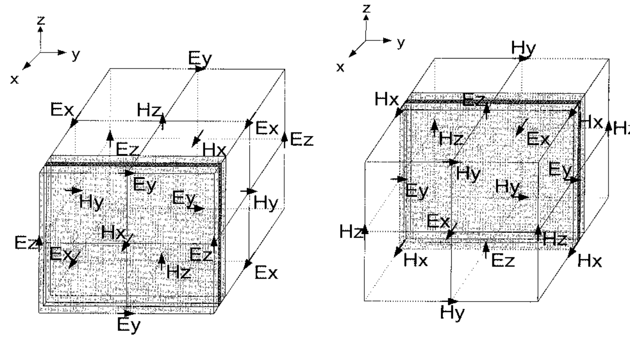


Fig. 1. Structure of the SMM line.



(a) (b)

Fig. 2. Yee cells which contain three thin dielectric sheets: (a) electric cell; (b) magnetic cell.

$$\oint_c \vec{H} \cdot d\vec{l} = \frac{\partial}{\partial t} \iint_s \varepsilon \vec{E} \cdot d\vec{s} \tag{1}$$

$$\oint_c \vec{E} \cdot d\vec{l} = -\frac{\partial}{\partial t} \iint_s \mu \vec{H} \cdot d\vec{s}. \tag{2}$$

Equations (1) and (2) assume that there are no electric or magnetic losses because a SMM line is nearly dielectric-loss free and has no magnetic materials.

Fig. 3 shows two-dimensional cuts of Yee cells containing three thin dielectric sheets of thickness d_n and permittivity $\varepsilon_n(\varepsilon_{r,n}\varepsilon_0)$ where $n = 1, 2, 3$, respectively. In these cells, the electric flux density component normal to sheets, $D_x(=\varepsilon_n E_x)$, the normal component of the magnetic field, H_x, and the tangential components of the field, such as H_y, H_z, E_y, and

Manuscript received July 14, 2002; revised August 29, 2002. This work was supported by KOSEF under the ERC Program through the MINT Research Center at Dongguk University. The review of this letter was arranged by Associate Editor Dr. Shigeo Kawasaki.

Y. K. Nam is with the Department of Electronic Engineering, Chungnam National University, Yuseong-Gu, Daejeon, Korea, (e-mail: s_nyk@cuvic.cnu.ac.kr).

D. C. Park is with the Department of Radio Science and Engineering, Chungnam National University, Daejeon, Korea.

Digital Object Identifier 10.1109/LMWC.2003.808724

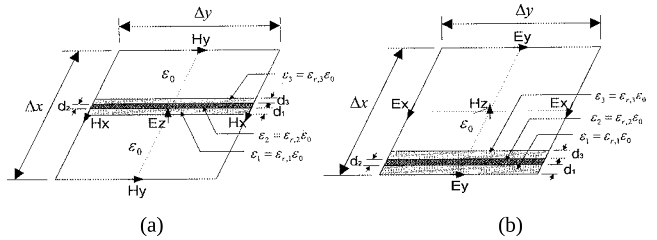


Fig. 3. Two-dimensional cuts of Yee cells containing three thin dielectric sheets: (a) E_z; (b) H_z.

E_z, are continuous across the material boundaries according to the boundary conditions for dielectric materials. The line integrals are performed assuming that the field (including the electric flux density) is constant on the segments of the contour, and the surface integrals are performed assuming that the field is constant over the area of integration. The time derivative is simply approximated by a finite difference. Applying these conditions to (1) and (2), update equations for E_z and H_z are obtained as follows:

$$E_z|_{i,j,k}^{n+1} = E_z|_{i,j,k}^{n} + \frac{\Delta t}{\varepsilon_{r,nf}\varepsilon_0 \Delta x} \cdot \left[H_y|_{i+1/2,j,k}^{n+1/2} - H_y|_{i-1/2,j,k}^{n+1/2}\right] - \frac{\Delta t}{\varepsilon_{r,nf}\varepsilon_0 \Delta y} \cdot \left[H_x|_{i,j+1/2,k}^{n+1/2} - H_x|_{i,j-1/2,k}^{n+1/2}\right] \quad (3)$$

$$H_z|_{i,j,k}^{n+1/2} = H_z|_{i,j,k}^{n-1/2} + \frac{\mu_{r,nf}\Delta t}{\mu_0 \Delta y} \cdot \left[E_x|_{i,j+1/2,k}^{n} - E_x|_{i,j-1/2,k}^{n}\right] - \frac{\Delta t}{\mu_0 \Delta x} \cdot \left[E_y|_{i+1/2,j,k}^{n} - E_y|_{i-1/2,j,k}^{n}\right] \quad (4)$$

where

$$\begin{aligned} \varepsilon_{r,nf} &= (1 - R + \varepsilon_{r,1}R_1 + \varepsilon_{r,2}R_2 + \varepsilon_{r,3}R_3), \\ \mu_{r,nf} &= (1 - R + R_1/\varepsilon_{r,1} + R_2/\varepsilon_{r,2} + R_3/\varepsilon_{r,3}), \\ R &= R_1 + R_2 + R_3, \qquad R_1 = d_1/\Delta x, \\ R_2 &= d_2/\Delta x, \qquad R_3 = d_3/\Delta x, \\ E|_{i,j,k}^{n} &= E(i\Delta x, j\Delta y, k\Delta z, n\Delta t). \end{aligned}$$

Update equations for the E_y and H_y are obtained in a similar manner:

$$E_y|_{i,j,k}^{n+1} = E_y|_{i,j,k}^{n} + \frac{\Delta t}{\varepsilon_{r,nf}\varepsilon_0 \Delta z} \cdot \left[H_x|_{i,j,k+1/2}^{n+1/2} - H_x|_{i,j,k-1/2}^{n+1/2}\right] - \frac{\Delta t}{\varepsilon_{r,nf}\varepsilon_0 \Delta x} \cdot \left[H_z|_{i+1/2,j,k}^{n+1/2} - H_z|_{i-1/2,j,k}^{n+1/2}\right] \quad (5)$$

$$H_y|_{i,j,k}^{n+1/2} = H_y|_{i,j,k}^{n-1/2} + \frac{\Delta t}{\mu_0 \Delta x}\left[E_z|_{i+1/2,j,k}^{n} - E_z|_{i-1/2,j,k}^{n}\right] - \frac{\mu_{r,nf}\Delta t}{\mu_0 \Delta z}\left[E_x|_{i,j,k+1/2}^{n} - E_x|_{i,j,k-1/2}^{n}\right]. \quad (6)$$

Lastly, update equations for the E_x and H_x are the same as that for ordinary Yee cells which do not contain any dielectric sheets.

These new equations can be easily used together with the existing absorbing boundary condition (ABC) because these are similar in form to the normal FDTD equations, as shown earlier.

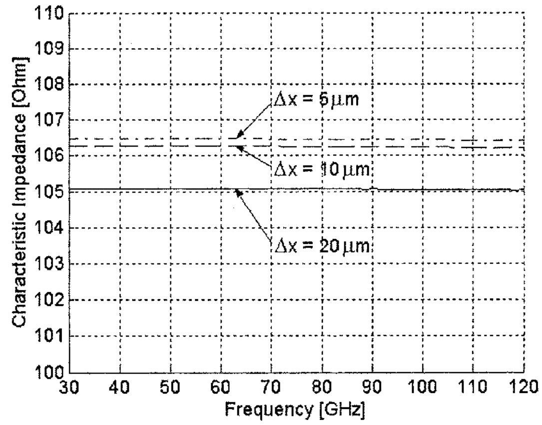


Fig. 4. Characteristic impedances of the SMM line.

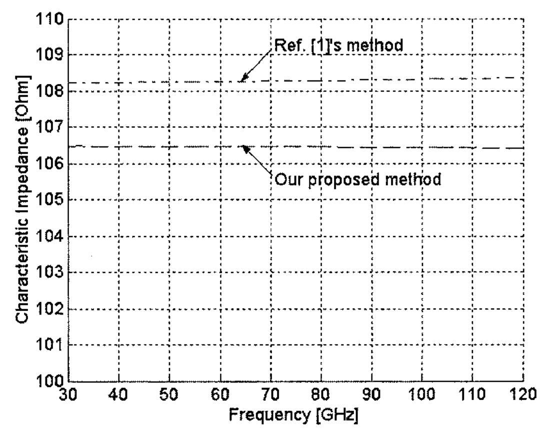


Fig. 5. Characteristic impedances of the SMM line.

III. Results and Comparison

By using the FDTD method with the derived new equations, the characteristic impedance and the effective dielectric constant of the SMM line are calculated. The dimensions of the SMM line are shown in Fig. 1. The width of signal line (w) is 120 μm, and the thickness of each dielectric sheet is 0.4 μm (d_1), 0.3 μm (d_2), and 0.7 μm (d_3), and the dielectric constant is 4.0 ($\varepsilon_{r,1}$), 7.5 ($\varepsilon_{r,2}$), and 4.0 ($\varepsilon_{r,3}$), respectively. For the purpose of checking the stability of new equations and finding out the optimum grid condition, three cases of spatial grid are applied such as $\Delta x = 5$ μm, 10 μm, and 20 μm. On the other hand, $\Delta y = 20$ μm and $\Delta z = 20$ μm are used all the time. As shown in Fig. 4, the calculated results converge to a fixed value as Δx decreases. According to this convergence, it is evident that new equations are stable and $\Delta x = 5$ μm is an optimum grid condition. Therefore, $\Delta x = 5$ μm is used in the calculations below. In Fig. 5, the characteristic impedance calculated by our method is compared with the result computed by the method proposed in [1]. In [1], they considered a single dielectric sheet whose thickness was 15 μm and dielectric constant was 1.1 in order to approximate their original three-layer membrane structure. We applied the same grid sizes as we used above to their simplified structure to check the final results. Two values differ by

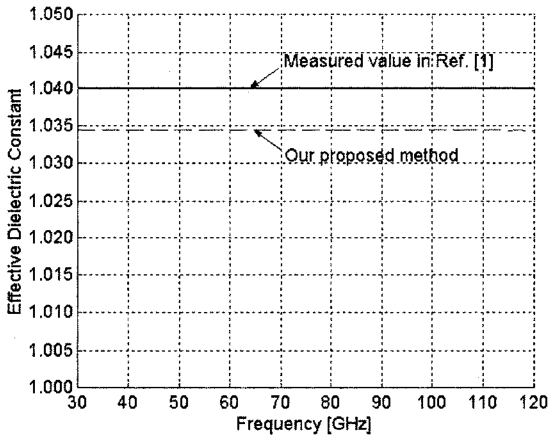


Fig. 6. Effective dielectric constants of the SMM line.

less than 2 Ω. The calculated and measured effective dielectric constants are shown in Fig. 6. Our calculated value is close to the measured value in [1]. These results prove that our proposed method is useful.

IV. Conclusion

For a simple and efficient analysis method of the SMM line, new FDTD equations have been derived using the contour path FDTD concept for the Yee cell which contains three thin dielectric sheets. By using these new FDTD equations, the characteristic impedance and the effective dielectric constant of the SMM line have been calculated. Our proposed method has been validated by comparison with the results shown in [1].

References

[1] S. V. Robertson, L. P. B. Kathehi, and G. M. Rebeiz, "Micromachined W-band filters," *IEEE Trans. Microwave Theory Tech.*, vol. 44, pp. 598–606, Apr. 1996.

[2] G. M. Rebeiz, L. P. B. Kathehi, T. M. Weller, C.-Y. Chi, and S. V. Robertson, "Micromachined membrane filters for microwave and millimeter-wave applications," *Int. J. RF Microwave Comput.-Aided Eng.*, vol. 7, no. 2, pp. 149–166, Mar. 1, 1997.

[3] P. A. Tirkas and K. R. Demarest, "Modeling of thin dielectric structures using the finite-difference time-domain technique," *IEEE Trans. Antennas Propagat.*, vol. 39, pp. 1338–1344, Sept. 1991.

[4] J. G. Maloney and G. S. Smith, "The efficient modeling of thin material sheets in the finite-difference time-domain (FDTD) method," *IEEE Trans. Antennas Propagat.*, vol. 40, pp. 323–330, Mar. 1992.