COMPACT TWO-DIMENSIONAL FD-TD ANALYSIS OF ATTENUATION PROPERTIES OF LOSSY MICROSTRIP LINES

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ABSTRACT

A compact two-dimensional FDTD (2-D FDTD) algorithm has been applied to the analysis of propagation properties of lossy microstrip lines. The electromagnetic field in the conductors are analyzed by forming grids inside the conductors to consider the conductor loss of microstrip lines. Furthermore, the autoregressive (AR) signal analysis method is combined to obtain accurate propagation constants, and good agreement between computational and experimental results is obtained.

INTRODUCTION

In MMIC and MCM (multichip module), the width of microstrip lines becomes finer, and the conductor loss of the lines becomes larger. The conductor loss of microstrip lines has generally been analyzed with the incremental inductance method [1] which assumes TEM mode transmission in the line. However, it is known that the incremental inductance method fails to predict accurately the conductor loss in lossy microstrip lines such as in MMIC and MCM [2]-[6].

The finite-difference time-domain (FD-TD) method[7] has been applied to the analysis of dispersion characteristics of variety of microwave guiding structures[8][9]. And two-dimensional FD-TD method has been reported to be quite effective for the analysis of propagation characteristics of infinite length waveguide structures having arbitrary cross section[10]-[12].

We have applied a compact 2-D FDTD method to the analysis of lossy microstrip lines. Unlike the above reports, our analysis has the following features. (i) The electromagnetic fields in conductors are directly analyzed by forming sufficiently small grids in the conductors compared to the skin depth, also the number of grids are suppressed by using graded grid division. and (ii) the characteristic parameters of damped oscillation such as damping factor and frequency obtained with the FDTD method are identified by signal analysis method based on the autoregressive (AR) model.

This paper describes the algorithm of the FDTD method, and the calculated results together with the measured performance of a microstrip line.

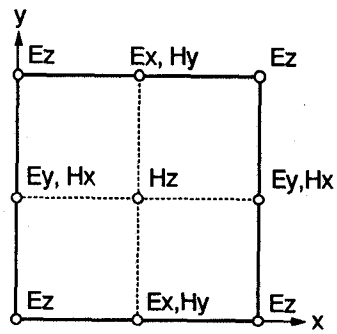

Figure 1. The compact two-dimensional FDTD grid.

ALGORITHM

The compact 2-D FDTD grids adopted are shown in Fig. 1. The z-axis is chosen as the propagation direction. The electromagnetic fields are assumed to have the z dependency as:

$$X(x,y,z) = X(x,y)\sin(\beta z), \quad X = Ex, Ey, Hz, \qquad (1)$$

and

$$Y(x,y,z) = Y(x,y)\cos(\beta z), \quad Y = Ez, Hx, Hy, \qquad (2)$$

where β is the propagation constant in z-direction. Thus all the components in electromagnetic fields are expressed in real numbers. The Maxwell curl equations are adopted in the FDTD analysis.

By the FDTD analysis, damped oscillation signals for voltage and current are obtained after the system is excited by a raised cosine pulse. The damped oscillation can be written for a single mode transmission as

$$f_n = \exp(-\xi\, n\,\Delta t_s)\{A_f\cos(\Omega\, n\,\Delta t_s) + B_f\sin(\Omega\, n\,\Delta t_s)\}, \quad n=1,2,... \qquad (3)$$

where f_n denotes V_n or I_n, ξ the damping factor, Δt_s the sampling time period, Ω the angular frequency of the oscillation. V_n and I_n have the strong autoregressive characteristics expressed by

$$f_n = a_1 f_{n-1} + a_2 f_{n-2}, \quad n=1,2, ... \qquad (4)$$

where the coefficient a_1, a_2 are the AR coefficients given by

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$$a_1 = -2\exp(-\xi\,\Delta t_s)\cos(\Omega\,\Delta t_s)\ ,$$

$$a_2 = \exp(-2\xi\,\Delta t_s)\ . \quad (5)$$

These coefficients are calculated by least mean square method from the time series data of V_n, I_n. The attenuation constant of transmission line is given by

$$\alpha = \beta\,\xi\ /\ (\Omega^2+\xi^2)^{1/2}\ . \quad (6)$$

The sampling period Δt_s is not necessary to coincide with the time step Δt adopted in the FDTD analysis. Preliminary numerical experiments showed that (i) the accuracy of estimated Ω is scarcely affected by Δt_s, but (ii) the accuracy of estimated ξ is best when $\Omega\,\Delta t_s = \pi/2$. Thus, in the parameter estimation, Ω is roughly estimated for $\Delta t_s = \Delta t$, and then accurate parameters Ω and ξ are estimated by using the optimum Δt_s chosen from the roughly estimated Ω.

EXPERIMENT

The microstrip line under investigation is shown in Fig. 2 (a). The materials are polyimide (εr=3.2, tanδ=0.002) for the dielectric, and copper (ρ=3.5x10^{-8} Ωm) for the conductor, and the line length is 50 mm. The S-parameters of the sample were directory measured with high frequency wafer probe (Cascade Microteck Inc.) and network analyzer (HP8510). The characteristic impedance measured by Time Domain Refrection (TDR) is approximately 42Ω.

In Fig.4 (b), the ripple of the measured attenuation constant due to impedance mismatch is suppressed by the relatively high insertion loss of the sample.

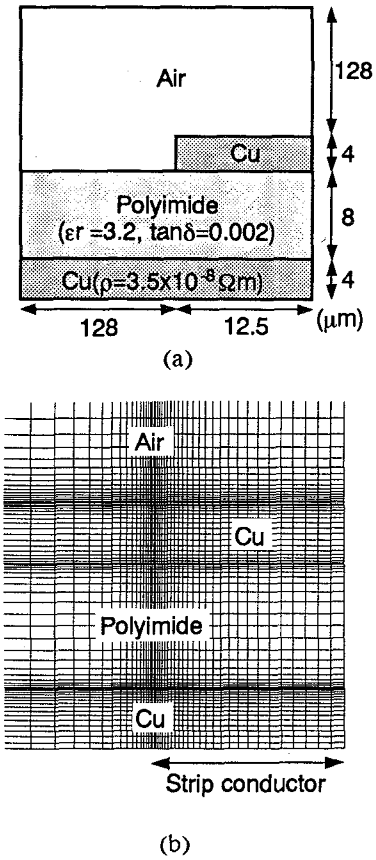


Figure 2. (a) The cross section of the microstrip line under investigation. Magnetic wall condition is set on the center of the strip conductor. (b) The graded grid division in the vicinity of the strip conductor of the microstrip line. The minimum grid spacing is 1/10 of the skin depth.

RESULTS

In the numerical analysis, the cross section of the transmission line was divided into graded square grids as shown in Fig. 2 (b). The minimum grid spacing is chosen to be 1/10 of the skin depth, and the entire grid count, depending on the expected frequency, is around 140x160. The electrical wall conditions are set on the upper and the lower boundaries, and the magnetic wall conditions are set on the center of the strip conductor and the side boundaries.

A series of preliminary calculation showed that the effects of analytical region is negligible for parameter estimation when the width (x-direction) and the height (y-direction) of the region are larger than 10 times of the dielectric thickness H. Thus the width and height of the analytical region were chosen to be 16 times of the dielectric thickness.

Figure 3 shows the time series voltage and current

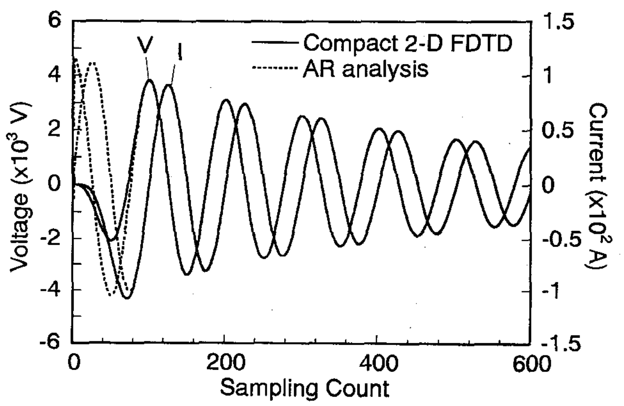


Figure 3. Time series data of voltage and current of the microstrip line obtained with 2-D FDTD and AR signal analysis method.

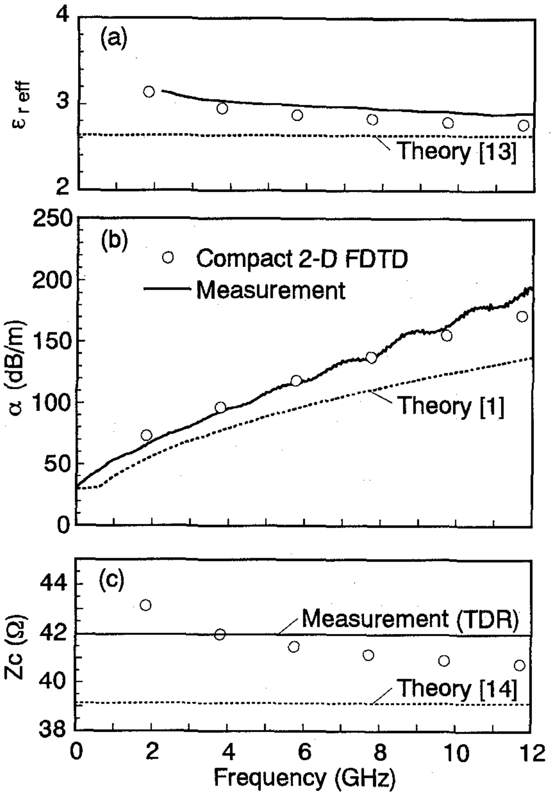
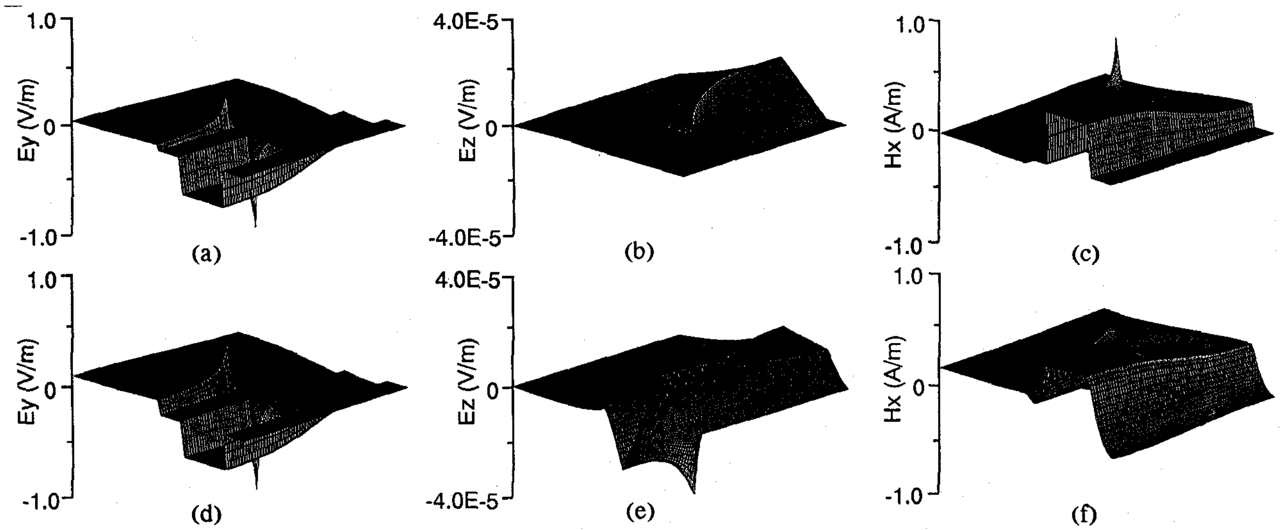


Figure 4. The results of the effective dielectric constant (a), the attenuation constant (b), and the characteristic impedance (c).

of the microstrip line obtained with the 2-D FDTD method, together with the fitting results by the AR signal analysis. After the end of the launched raised cosign pulse, the time series data demonstrate single mode damping oscillation, and are accurately fitted by AR signal analysis.

The computational results of the effective dielectric constant, the attenuation coefficient, and the characteristic impedance are shown in Fig. 4 (a)(b) and (c) respectively, together with the experimental results and the theoretical results. The FDTD results agree well with the experimental data, while the theoretical results show appreciable deviation from the experimental data. These deviations will be owing to the electromagnetic field penetrating into conductors with finite conductivity, while the conventional theories assume the fields as those of perfect conductors.

Figure 5 compares the calculated distribution examples of *Ey*, *Ez*, and *Hy* components for complete conductor with those for conductor with a finite conductivity at 2GHz. Although the electric field distributions in *Ex* and *Ey* were almost equal respectively, the *Hx*, *Hy*, *Hz* showed magnetic field penetrating into conductors as the example of *Hx* in Fig.5(f). Furthermore, appreciable *Ez* component exists around and inside the conductor with a finite conductivity (Fig.5 (e)). Therefore, TEM mode approximation theory fails to predict the attenuation constants of relatively high lossy microstrip line incorporating conductors with finite conductivity.



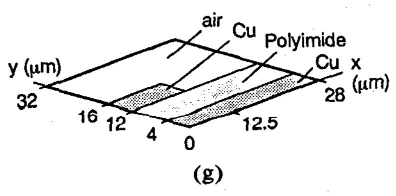


Figure 5. The electromagnetic field distributions at 2GHz for complete conductor (a)-(c), and for conductor with finite conductivity (d)-(f). The analyzed region is 28x32μm as in (g), and the z axis is upward. The ratio of electric field to magnetic field is arbitrary.

CONCLUSION

The compact 2-D FDTD method combined with the AR signal analysis is applied to the analysis of propagation properties of a lossy microstrip line. The electromagnetic field in the conductors is directly analyzed and an accurate attenuation factor can be predicted for a lossy microstrip line. Moreover, the reason of the deviation between the TEM mode approximation theory and experimental data of propagation constants is estimated from the electromagnetic field in a microstrip line obtained with 2-D FDTD method.

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