Full Wave Analysis of Tapered Microstrip Lines Using the Conformal Grids FD-TD Method

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ABSTRACT

In this paper, three-dimensional full wave analysis of tapered microstrip lines is carried out in the time domain. The method used is the conformal grids FD-TD method. Computed results are compared with experimental ones and those obtained by the finite element method. The results agree well. As a result, it is shown that the propagation characteristics are very different from those obtained through two-dimensional modeling.

INTRODUCTION

The miniaturization and ever higher density packing of electronic devices is driving a trend toward three-dimensional configurations. At the same time, the clock rates in digital devices and the operating frequencies are steadily increasing. The tapered microstrip line is often used in such MMICs. Its complex three dimensional structure exerts a strong influence on the MMIC circuit performance. Due to the increase in operating frequencies, it has become necessary to predict the time domain responses as well as the broad band frequency characteristics to directly estimate its performance. Furthermore, time domain analysis has the advantage of being able to obtain the broad band characteristics in a single computer run using Fourier transforms as well as being able to obtain the transient responses themselves. The traditional numerical approaches have lacked the versatility to enable such analysis.

The finite-difference time-domain (FD-TD) method [1],[2] is effective for such a three-dimensional time domain problem. However, the traditional rectangular mesh is not suitable for problems where the boundary has an arbitrary configuration, because numerical errors occur at the boundary using stair casing approximation. Consequently, instead of the traditional rectangular mesh, a conformal grids mesh is more appropriate because the boundary condition for an arbitrary angled taper can be calculated precisely[3]-[6]. Furthermore, this approach is suitable for CAD in conjunction with a mesh generator. Such an analysis of a tapered microstrip line in a three-dimensional space and time domain using the conformal grids finite difference approach has not been carried out as far as we know.

In this paper, the full wave analysis of tapered microstrip lines is carried out in the time domain [7],[8]. The method used is the conformal grids FD-TD method. Computed results are compared with those obtained by the experiment and the finite element method. The results are seen to agree well.

NUMERICAL RESULTS AND DISCUSSION

Fig.1 shows the tapered microstrip line. The relative permittivity ε_r of the substrate is 2.53. The thickness of the substrate is 0.79 mm. The widths of the wide line and the narrow one are 5.32 and 2.66 mm, respectively.

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Fig. 2 shows the conformal grids arrangement used in this analysis. The microstrip line is divided by 8 cells in the transverse direction. The discretization in the y direction is uniform.

Firstly, to validate the modeling of a tapered structure by the conformal grids FD-TD method, a two-dimensional case using magnetic walls is simulated. Such a case can be precisely predicted by other two-dimensional numerical methods. Figs. 3 and 4 show the S-parameters ($|S_{11}|$ and $|S_{21}|$), respectively, of a two-dimensional strip line. $|S_{11}|$ and $|S_{21}|$ are respectively obtained by the Fourier transforms of the pulse responses in a single computer run, using the following equations.

$$S_{11} = V_{ref}(f)/V_{inc}(f) \qquad (1)$$

$$S_{21} = \frac{V_{trans}(f)/\sqrt{Z_2(f)}}{V_{inc}(f)\ /\ \sqrt{Z_1(f)}} \qquad (2)$$

where Z_1 and Z_2 are the characteristic impedances of the lines connected to ports ① and ② of the discontinuity. In this paper, these impedances are obtained by using an analytical formula. The pulse wave form used is a Gaussian pulse. In Fig. 3, simulated results agree well with those obtained by the segmentation method [9] for a wide band range. In Fig.4, the energy conservation in this analysis is seen to be confirmed between $|S_{11}|$ and $|S_{21}|$. Furthermore, the convergence in this analysis is confirmed by calculations using a finer mesh. The validity of the conformal grids arrangement for a tapered structure can thus be validated.

Next, a shielded tapered microstrip line is similarly simulated in a three-dimensional space. Fig. 5 shows the reflection coefficient $|S_{11}|$ of the microstrip line obtained by this method. In Fig. 5, results obtained by 3-D FEM software HFSS (Ansoft Corp.) are also shown. The values obtained by each approach can thus be seen to agree well with each other.

Next, an unshielded tapered microstrip line is simulated in a three-dimensional space. The truncated surfaces are formulated by using Mur's first order boundary condition. Fig. 6 shows the reflection coefficient $|S_{11}|$ of the microstrip line obtained by this method. In Fig. 6, results obtained by experiment can also been seen. In the case of the microstrip line used, the amount of radiation is small, so no significant differences in the S parameters of the open or shielded model are shown. Calculated and measured values at 20 Ghz are seen to be slightly different. This is considered to be due to the loss at the connector. Figs. 3, 5 and 6 show that the propagation characteristics of the strip line and the microstrip line are different. Consequently, the microstrip line needs to be be calculated by considering the three-dimensional structure.

Fig. 7 shows the transient field pattern of the pulse propagation. Reflected and transmitted pulse waves affected by the electrical properties of the tapered microstrip line are shown.

All computations were carried out on a HP9000-720 workstation. The memory and CPU time for simulations were about 10MB and 10hrs, respectively.

CONCLUSION

In this paper, three-dimensional full wave analysis of tapered microstrip lines is carried out in the time domain using the conformal grids FD-TD method. Both open and shielded models were considered. The respective results obtained through the FD-TD method agree well with those obtained through FEM and experimentation. As a result, it is shown that the propagation characteristics are very different from those obtained through two-dimensional modeling. This approach is suitable for CAD in conjunction with a mesh generator. A way to achieve more efficient computation through reduction of required memory and CPU time is currently being investigated. Analysis of other types of taper configurations, shown in Fig.8(a) and Fig.8(b), is considered essential. The same approach can be used and these analyses are currently in progress.

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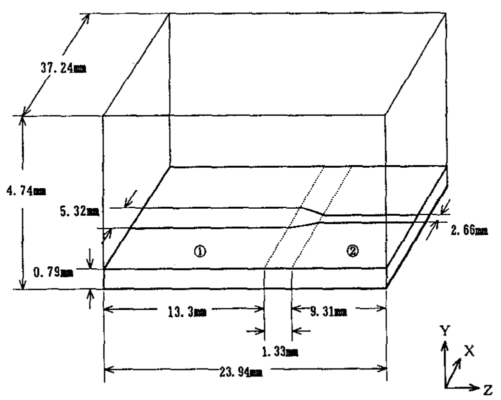

Fig.1 Tapered microstrip line.

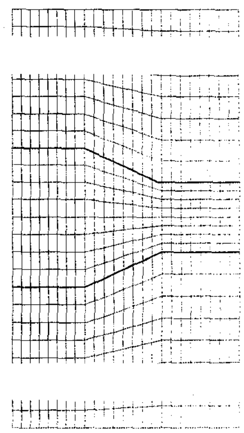

Fig.2 Conformal grids arrangement.

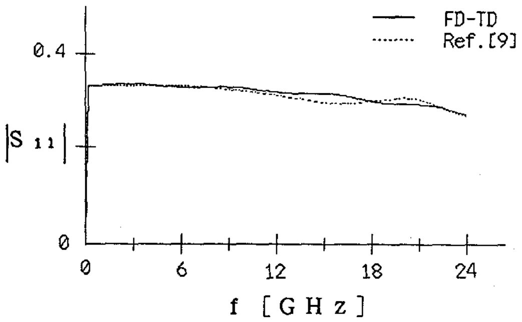

Fig.3 $|S_{11}|$ vs. frequency by 2D-analysis.

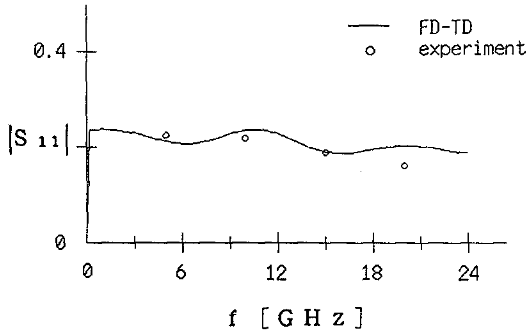

Fig.6 $|S_{11}|$ vs. frequency by 3D-analysis. (unshielded)

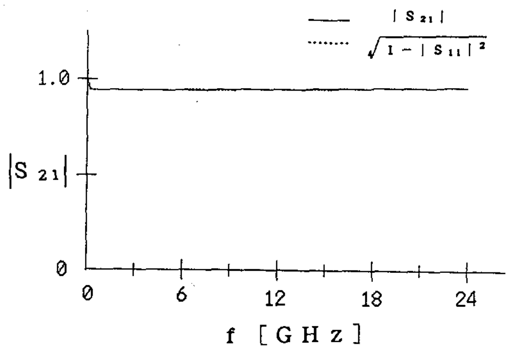

Fig.4 $|S_{21}|$ vs. frequency by 2D-analysis.

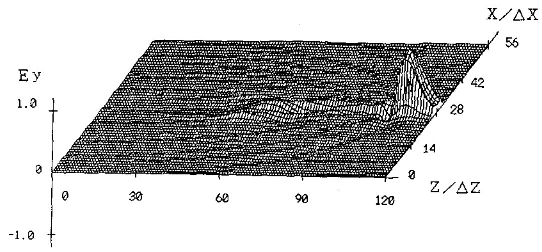

Fig.7 Propagation wave form.

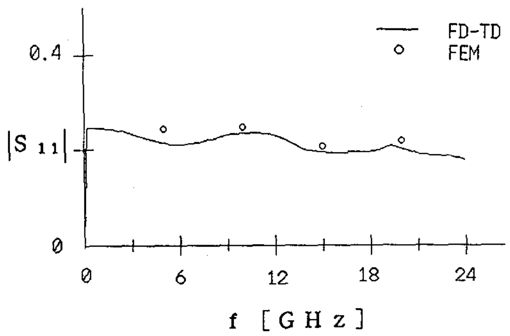

Fig.5 $|S_{11}|$ vs. frequency by 3D-analysis. (shielded)

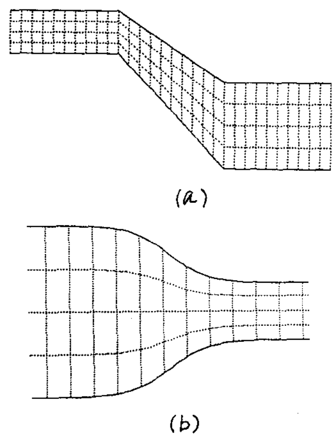

Fig.8 Tapered microstrip line for other types.