A METHOD FOR OBTAINING DISPERSION CHARACTERISTICS OF SHIELDED MICROSTRIP LINES

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Abstract

The properties of shielded microstrip lines are analyzed by the method of equivalent network, which properly takes into account the hybrid nature of the guided waves. The effective dielectric constants and characteristic impedances of microstrip lines are obtained to illustrate the effects of the size of the waveguide crosssection. Numerical results obtained are shown to be in good agreement with available data in the literature.

Introduction

In this paper, the method of equivalent network is presented for the analysis of dispersion characteristics of shielded microstrip lines, with a particular attention directed toward the effects of waveguide crosssectional geometry. In particular, the formula for the characteristic impedance is derived and the numerical results are obtained. The method is based on the building block approach of the microwave network theory, employing the rigorous mode matching technique to solve the boundary value problem. The approach offers many advantages: The problem is formulated in a rigorous fashion, with both TE and TM modes of each constituent region included to account for the hybrid nature of the guided modes. The treatment of a complicated boundary value problem reduced to one of a simple junction discontinuity. Finally, The analytic results so obtained are simple in form and clear for establishing physical concepts associated with the microstrip lines.

Analysis of Guided Wave oblique Incident Problem

The crosssectional geometry of the shielded microstrip is shown in Fig. 1. The structure is assumed to be lossless and the strip has a zero thickness. Here, the crosssection is viewed as consisting of the strip region, to be referred to as the inside region, sandwiched between two identical outside regions. The inside region includes two subregions, labelled as Region I and II with the metal strip as the dividing boundary. For convenience, the outside region will be referred to as Region III in the sequel. From such a viewpoint, Region I and II can be considered as parallel-plate waveguides filled with uniform dielectrics, whereas Region III is a structure filled with multilayer dielectrics. The electromagnetic fields in each constituent region can be expressed in terms of the mode functions of the parallel-plate waveguides, which are well known. The analysis of the shielded microstrip line is then reduced to the treatment of the boundary conditions at the junction discontinuity between the inside and outside regions, as we shall do here.

The guiding of waves by the strip line can be viewed as waves being bounced back and forth by the discontinuities at the two edges of the strip. Thus, the basic problem to be analyzed is the scattering of a guided wave by the discontinuity at an oblique incidence angle, as shown in Fig. 2. For such a boundary value problem, the general field solution in each constituent region can be represented a superposition of a complete set of waveguide modes, including both TE and TM modes of the parallel-plate waveguide. With respect to the x direction, the transmission-line parameters for every mode can be determined easily, and the general modal solutions for all the field components in the structure coordinate system are considered completely determined.

Referring to Fig. 2, we observe that the tangential components of the fields at the junction discontiunity consist of the y and z components, and we shall therefore consider only these components explicitly. With the dependence, $\exp(-jk_z z)$, suppressed for clarity, we have

$$E_y = -\Sigma V_n''(x)F_n''(y)\,\frac{1}{\epsilon(y)} \quad (1a)$$

$$E_z = j\,\Sigma\,[V_n'(x)F_n'(y)+V_n''(x)F_n''(y)\,\frac{1}{\epsilon(y)}] \quad (1b)$$

$$H_y = -j\Sigma\, I_n'(x)F_n'(y) \quad (1c)$$

$$H_z = -\Sigma\,[I_n'(x)F_n'(y)-I_n''(x)_n''(y)] \quad (1d)$$

The tangential field components must be continuous across the junction discontinuity at x=0. From the continuities of these four tangential field components and the orthogenality of the mode functions, we obtain the following systems of linear equations:

$$\underline{\overline{V}}'' = \overline{P}''\underline{V}'' \quad (2a)$$

$$\underline{\overline{\overline{V}}}'' = \overline{\overline{P}}''\underline{V}'' \quad (2b)$$

$$\overline{P}''^{T}\underline{\overline{V}}''+\overline{\overline{P}}''^{T}\underline{\overline{\overline{V}}}'' = \underline{V}'' \quad (2c)$$

$$\bar{\underline{V}}'+\bar{R}''\bar{\underline{V}}'' = \bar{P}'\underline{V}'+\bar{S}''\underline{V}'' \quad (2d)$$

$$\bar{\bar{\underline{V}}}'+\bar{\bar{R}}''\bar{\bar{\underline{V}}}'' = \bar{\bar{P}}'\underline{V}'+\bar{\bar{S}}''\underline{V}'' \quad (2e)$$

$$\bar{P}'^T\bar{\underline{V}}'+\bar{\bar{P}}'^T\bar{\bar{\underline{V}}}'+\bar{Q}''\bar{\underline{V}}''+\bar{\bar{Q}}''\bar{\bar{\underline{V}}}'' = \underline{V}'+Q''\underline{V}'' \quad (2f)$$

$$\bar{\underline{I}}' = \bar{P}'\underline{I}' \quad (2g)$$

$$\bar{\bar{\underline{I}}}' = \bar{\bar{P}}'\underline{I}' \quad (2h)$$

$$\bar{P}'^T\bar{\underline{I}}'+\bar{\bar{P}}'^T\bar{\bar{\underline{I}}}' = \underline{I}' \quad (2i)$$

$$\bar{R}'\bar{\underline{I}}'+\bar{\underline{I}}'' = \bar{S}'\underline{I}'+\bar{P}''\underline{I}'' \quad (2j)$$

$$\bar{\bar{R}}'\bar{\bar{\underline{I}}}'+\bar{\bar{\underline{I}}}'' = \bar{\bar{S}}'\underline{I}'+ \bar{\bar{P}}''\underline{I}'' \quad (2k)$$

$$\bar{P}''^T\bar{\underline{I}}''+\bar{\bar{P}}''^T\bar{\bar{\underline{I}}}''+\bar{Q}'\bar{\underline{I}}'+\bar{\bar{Q}}'\bar{\bar{\underline{I}}}' = Q'\underline{I}'+\underline{I}'' \quad (2l)$$

where $\underline{V}'$ and $\underline{I}'$ are column vectors with the transmission-line voltage and current of the n-th TE mode, $V'_n(0)$ and $I'_n(0)$, at the n-th positions, and similarly for all other vectors above.

The P's, Q's, R's and S's are matrices characterizing the coupling of modes at the junction discontinuity; their general elements are defined by the scalar products or overlap integrals of mode functions on the two sides of the discontinuity. It is evident from (2) that the matrices P's are responsible for the coupling among modes of the same polarization, whereas Q's, R's and S's are responsible for the cross-coupling among modes of opposite polarizations.

Guidance of Waves by Shielded Microstrip Lines

We employed the mode-matching technique to obtain an equivalent network for the junction discontinuity. With the equivalent network for the junction discontinuities shown in Fig. 3, we now employ the concept of input admittance and the technique of transverse resonance in the lateral direction of the waveguide. All the parameters of the equivalent network are implicit functions of k_z, and the resonance condition of the network determines the allowable values of k_z for a given waveguide structure.

In practice, most microstrip lines are symmetric in geometry such as the one shown in Fig. 1. Therefore, the network may be analyzed in terms of the two simpler networks obtained from open-circuit and short-circuit bisection, as shown in Fig. 3. For simplicity, we shall deal only with symmetric structure in this paper; the generalization for asymmetric structures is almost trivial and is omitted.

Referring to Fig. 3(b), the relationships between the voltages and currents at the point immediately to the left of the junction can be expressed as

$$\underline{I} = -\overleftarrow{Y}\underline{V} \quad (3)$$

where $\underline{I}$ and $\underline{V}$ are current and voltage vectors, with the modal current and voltage amplitudes as their elements, and $\overleftarrow{Y}$ is a diagonal matrix, with the input admittances of the transmission line sections as its elements.

On the other hand, the relationship between the voltages and currents may also be expressed in terms of the network for junction discontinuity, including the effect of the outside region.

$$\underline{I} = \overrightarrow{Y}\,\underline{V} \quad (4)$$

where $\overrightarrow{Y}$ is admittance matrix looking to the right, as derived from (2), which depend on the coupling coefficients and the characteristic admittances of the LSE and LSM modes in the outside region.

Evidently, (3) and (4) are two different sets of equations relating the same sets of voltages and currents to each other. Combining these two equations together, we obtain a homogeneous system of matrix equations

$$(\overleftarrow{Y} + \overrightarrow{Y})\underline{V} = \underline{0} \quad (5)$$

The condition for the existence of a non-trivial solution of such a homogeneous system is:

$$\det(\overleftarrow{Y} + \overrightarrow{Y}) = 0 \quad (6)$$

This determinantal equation is often referred to as the transverse-resonance relation and it defines the dispersion relation for the microstrip line under consideration. The characteristic amditTances are related to the propagation constant along the waveguide axis, k_z, which can now be determined as a root of the dispersion relation (6). Then, for each dispersion root, the voltages are determined by solving (5). Thus, the fields everywhere within the system can be determined from the voltage-current relations in (3) or (4), and the boundary value problem is now completely solved.

Characteristic Impedance of Shielded Microstrip

For a hybrid mode, there exists no exact definition for characteristic impedance. The impedance is usually defined by

$$Z_c = 2P/|I_z|^2 \quad (7)$$

where P is the power and I_z is the total current flowing in the z-direction. They are defined by

$$P = \mathrm{Re}\iint_S [(E'_x H'^*_y+E''_x H'^*_y)-(E''_y H'^*_x+E''_y H''^*_x)]\,dxdy \quad (8)$$

$$I_z = 2\int_0^{w/2} [(\bar{H}'_x+\bar{H}''_x)-(\bar{\bar{H}}'_x+\bar{\bar{H}}''_x)]\,dx \quad (9)$$

where S represents the crosssection of the enclosure waveguide.

Numerical Results

The transverse resonance relation (6) involves matrices of infinite order. In practice, these infinite systems of equations must be truncated to a finite order for an approximate numerical analysis. The accuracy obtainable from an approximate analysis depends on the order of the truncation, i.e., the number of modes considered in the analysis. In this paper, we investigate the effect of the crosssectional geometry of the waveguide, with the inclusion of both TE and TM modes. The results obtained check with available data in the literature with very good agreement.

Fig. 4 shows the comparisons of the present method with two other methods published in the literature. With 18 LSE modes and equal number of LSM modes included in the analysis, our results for the effective dielectric constant check very well with those of Itoh and Mittra(3), but not so with those of Krage and Haddad(4). On the other hand, if only 10 modes of each polarization are included in the analysis, our results check very well with those of Krage and Haddad, as shown for the impedance in Fig. 5. This shows that the number of modes taken in the analysis may affect the propagation characteristics considerably. The accuracy of the theorectical results remains to be verified experiments.

Fig. 6 shows the variation of the effective dielectric constant with the ratio of the vertical height of the waveguide to the thickness of the dielectric film. It is seen that the outer enclosure has an important effect on the propagation characteristics of the microstrip line, when the ratio is relatively small. On the other hand, when the ratio is large, the outer enclosure would have very little effect on the propagation characteristics of the line, as expect.

Figs. 7 and 8 show the effect of the horizontal dimensions of the structure on the propagation characteristics. When the side walls are at a sufficiently large distance from the strip, their presence does not affect the guiding characteristics, as is evident in Fig. 7. Fig. 8 shows that the effective dielectric constant increases with the increasing strip width, which is consistent with physical expection. These results check favorably with those for open microstrip lines.

Conclusions

An efficient numerical method has been presented for obtaining the dispersion properties of shielded microstrip lines. The guidance of waves are analyzed in terms of the scattering of guided waves by a junction discontinuity at an oblique incidence angle. Numerical results are shown to be in very good agreement with available data in the literature.

Acknowledgement

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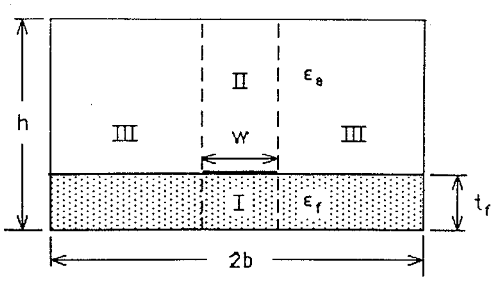

Fig.1 Shielded microstrip geometry

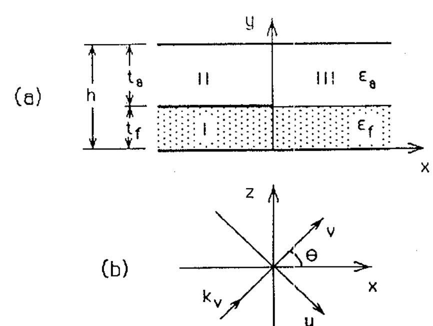

Fig.2 Oblique incidence of quided wave on a junction discontinuity

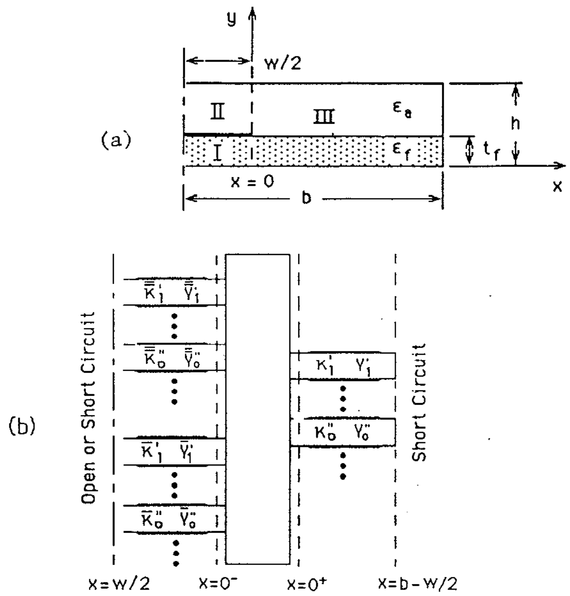

Fig3. Transverse equivalent network for shielded microstrip

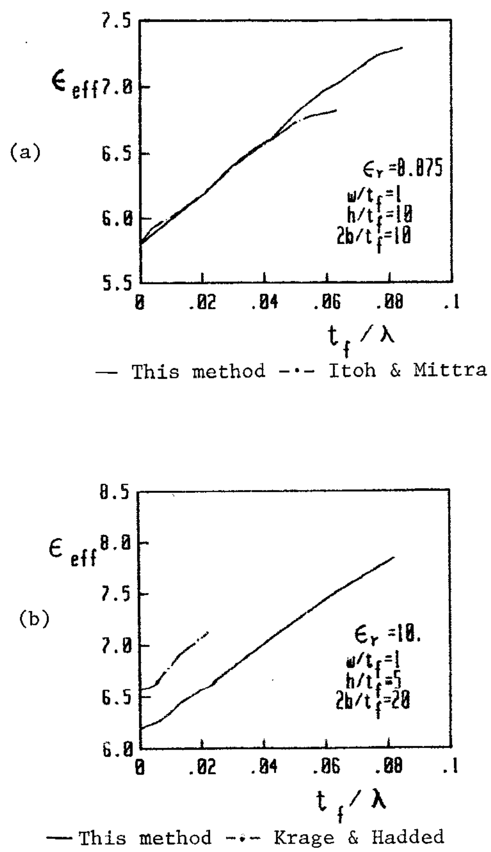

Fig.4 Effective dielectric constant ϵ_{eff} versus t_f

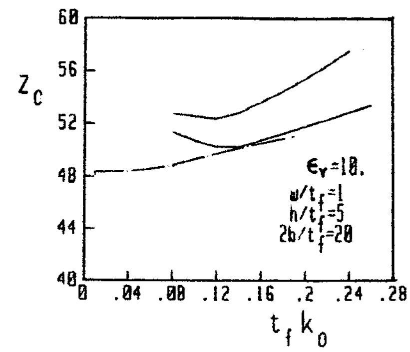

Fig.5 Characteristic impedance Z_c versus $t_f k_o$

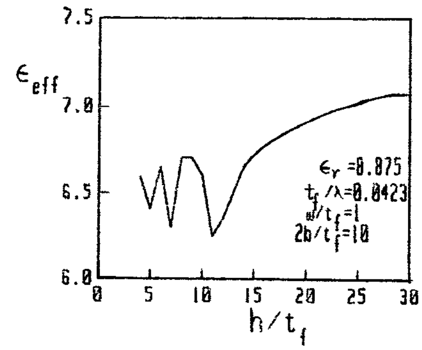

Fig.6 ϵ_{eff} versus h/t_f

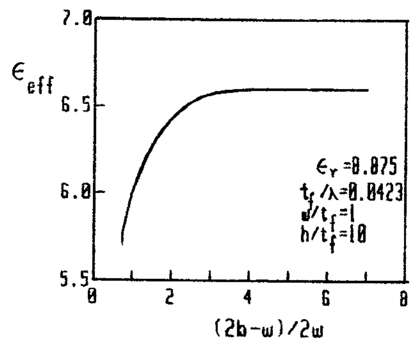

Fig.7 ϵ_{eff} versus $(2b-w)/2w$

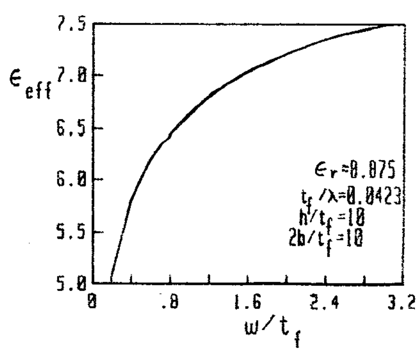

Fig.8 ϵ_{eff} versus w/t_f