PROPAGATION PARAMETERS OF COUPLED MICROSTRIP-LIKE TRANSMISSION LINES FOR MILLIMETER WAVE APPLICATIONS

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ABSTRACT

Variational expression is derived for the propagation parameters of coupled microstrip-like transmission lines for millimeter wave applications using the 'transverse transmission line' method. Numerical results are presented for the coupled inverted and coupled suspended lines.

Introduction

Parallel coupled microstrip lines are commonly used in the design of filters and couplers at microwave frequencies. However, their use at higher frequencies is limited due to the increasing circuit losses and stringent dimensional tolerances required during the fabrication. These problems are circumvented in certain modified versions such as the coupled sandwiched microstrip as shown in Fig. 1 and its two special cases, namely, the coupled inverted and suspended microstrip lines which result when $h_2 = 0$ and $h_3 = 0$ respectively. In these configurations, the introduction of the air gap results in (i) the reduction of the effective dielectric constant of the medium, thereby permitting larger circuit dimensions compared with the conventional coupled microstrip lines and (ii) the reduction of the conductor loss in the ground plane, since most of the energy is concentrated in the dielectric substrate. Smith[1] has analyzed the even and odd mode capacitances of the coupled lines on a suspended substrate based on conformal transformation. The data available however are far from adequate and there is need for a comprehensive analysis of both the coupled inverted and suspended structures from the point of view of their applications at millimeter wave frequencies.

This paper presents variational expressions for the even and odd mode capacitances for the general shielded sandwiched structure shown in Fig. 1. These expressions are derived under the quasi-static approximation using the 'transverse transmission line' method outlined by Crampagne et al[2]. Numerical data are presented for the even and odd mode impedances (Z_{oe} and Z_{oo}) for the coupled inverted and suspended lines in the shielded configuration. The effect of introducing dielectric overlay for equalizing the even and odd mode phase velocities is discussed.

Variational Expression for Capacitances

The general variational expression for the capacitance C of a microstrip-like transmission line shown in Fig. 1 can be written in the form [3]

$$C = \frac{[\int f(x)\,dx]^2}{\int\int f(x) G(x, h_1+h_2/x_o, h_1+h_2) f(x_o)\,dx\,dx_o} \qquad (1)$$

In order to determine the even and odd mode capacitances, we assume the charge distribution f(x) for the two excitations to be of the form,

$$f(x)_{\substack{oe\\oo}} = \frac{1}{w}\{1 + A_{\substack{oe\\oo}} |\tfrac{2}{w}(x - \tfrac{c-s-w}{2})|^3\}, \quad \frac{c-s}{2} - w \le x \le \frac{c-s}{2} \qquad (2)$$

$$= 0 \qquad \text{otherwise}$$

A_{oe} and A_{oo} are the constants for the even and odd mode excitations respectively. The expressions for the Green's function $G(x, h_1+h_2/x_o, h_1+h_2)$ at the charge plane $y = h_1+h_2$ for the even and odd mode excitations can be easily derived using the 'transverse transmission line' method[2].

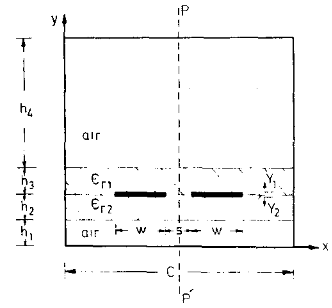

FIGURE 1: COUPLED SANDWICHED MICROSTRIP STRUCTURE, PLANE PP' IS ELECTRIC WALL FOR ODD MODE CASE AND MAGNETIC WALL FOR EVEN MODE CASE

$$G(x, h_1+h_2/x_o, h_1+h_2)|_{\substack{oe\\oo}} = \sum_{\substack{n\ odd\\ even}} \frac{4}{n\pi Y} \sin\frac{n\pi x_o}{c} \sin\frac{n\pi x}{c} \qquad (3)$$

The admittance Y at the charge plane is given by

$$Y = Y_1 + Y_2 \qquad (4)$$

Y_1 and Y_2 are the admittances at the plane $y = h_1+h_2$ looking in the positive and negative y directions respectively. Using the transmission line formula to obtain Y_1 and Y_2, Y is expressed as

$$Y = \epsilon_o[\epsilon_{r1}\{\frac{\coth\frac{n\pi h_4}{c}\coth\frac{n\pi h_3}{c} + \epsilon_{r1}}{\epsilon_{r1}\coth\frac{n\pi h_3}{c} + \coth\frac{n\pi h_4}{c}}\} + \epsilon_{r2}\{\frac{\coth\frac{n\pi h_2}{c}\coth\frac{n\pi h_1}{c} + \epsilon_{r2}}{\epsilon_{r2}\coth\frac{n\pi h_2}{c} + \coth\frac{n\pi h_1}{c}}\}] \qquad (5)$$

Substituting (2) and (3) in (1), and simplifying, we obtain the following expressions for the even and odd mode capacitances.

$$C_{\substack{oe\\oo}} = \frac{(1+A_{\substack{oe\\oo}}/4)^2}{\sum\limits_{\substack{n\ odd\\ even}} g_n (L_n + A_{\substack{oe\\oo}} M_n)^2} \tag{6}$$

where

$$g_n = \frac{4}{n\pi Y} \left(\frac{2c}{n\pi w}\right)^2 \tag{7a}$$

$$M_n = \left(\frac{2c}{n\pi w}\right)^3 \text{Sin}\{\frac{n\pi}{2c}(c-s-w)\}[3\{(\frac{n\pi w}{2c})^2-2\}\cos(\frac{n\pi w}{2c}) + (\frac{n\pi w}{2c})\{(\frac{n\pi w}{2c})^2 - 6\}\,\text{Sin}(\frac{n\pi w}{2c}) + 6] \tag{7b}$$

$$L_n = \text{Sin}\{\frac{n\pi}{2c}(c-s-w)\}\ \text{Sin}(\frac{n\pi w}{2c}) \tag{7c}$$

$$A_{\substack{oe\\oo}} = -\frac{\sum\limits_{\substack{n\ odd\\ even}} (4M_n - L_n) L_n g_n}{\sum\limits_{\substack{n\ odd\\ even}} (4M_n - L_n) M_n g_n} \tag{7d}$$

The constants A_{oe} and A_{oo} are derived by maximizing C_{oe} and C_{oo} respectively. Combining (6) with the standard formulae[3], the even and odd mode characteristic impedances and phase velocities can be computed.

Expressions (6) and (7) are general and can be applied to a class of microstrip-like structures when appropriate expression for Y at the charge plane is substituted.

Numerical Results and Discussion

In all the computations, the shielding side walls and the top wall are chosen sufficiently away from the strips $[c/(2w+s) = 15,\ h_4/(h_1+h_2) = 10]$ so that they have negligible effect on the field configuration.

Numerical results of coupled microstrip lines (Fig. 2) computed by setting $h_1=h_3=0$, $h_2=b$ and $h_4=h$, are found to be in good agreement with the results of Bryant and Weiss[4].

Computations of Z_{oe} and Z_{oo} for the coupled inverted microstrip are carried out by setting $h_1=b$, $h_2=0$, $h_3=a$ and $h_4=h$ and for the coupled suspended microstrip by setting $h_1=b$, $h_2=a$, $h_3=0$ and $h_4=h$. Their variations as a function of w/b with s/b as parameter are shown in Figs. 3 and 4 respectively. It is found that for a given set of values s/b, Z_{oe} and Z_{oo}, the strip conductor in the case of coupled inverted and suspended configurations is nearly 2 to 3 times wider compared with that of the coupled microstrip. These structures therefore have useful applications at millimeter wave frequencies.

Compared with coupled microstrip, it was found that there is considerable difference between v_{phe} and v_{pho} in the case of coupled inverted and suspended configurations. For example, in the coupled inverted microstrip having w/b = 1.0 and s/b = 0.2; v_{phe}/v_{pho} is equal to 1.508 when $\varepsilon_r = 9.6$ and a/b = 0.64. For coupler applications, such large differences in v_{phe} and v_{pho} lead to poor directivity. Since this effect is essentially due to odd mode loading, equalization of the phase velocities can be achieved by perturbing only the even mode fields. This can be implemented by introducing a dielectric overlay on the bottom ground plane. Figs. 5 and 6 show the effect of such overlay on Z_{oe} and Z_{oo} of the coupled inverted and suspended microstrip configurations respectively. As expected, with increase in overlay thickness a_2, Z_{oo} decreases rather slowly and Z_{oe} decreases rapidly in both the cases. The dotted lines in both the figures indicate the contour along which $v_{phe} = v_{pho}$.

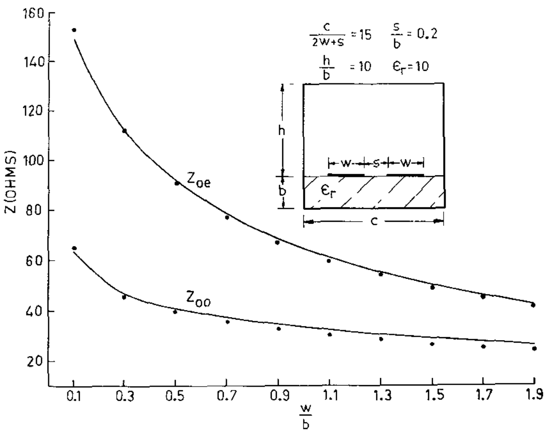

FIGURE 2: COMPARISON OF PRESENT THEORY (——) WITH BRYANT AND WEISS[4] (...) FOR COUPLED MICROSTRIP

Using the formulae presented in this paper, complete set of design curves with and without dielectric overlay can be easily generated to serve as an aid in the design of millimeter wave integrated circuits.

References:

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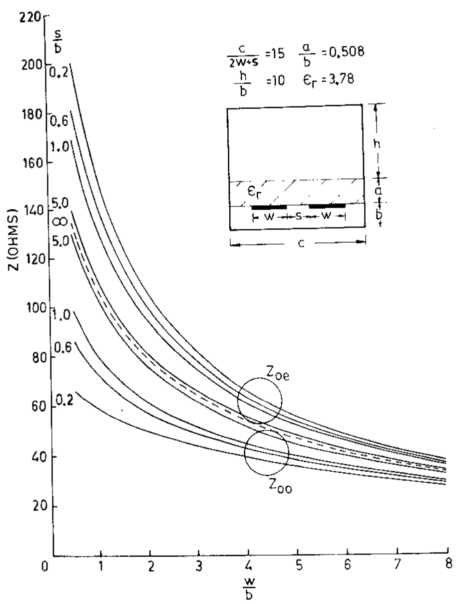

FIGURE 3: CHARACTERISTIC IMPEDANCE OF COUPLED INVERTED MICROSTRIP TRANSMISSION LINES

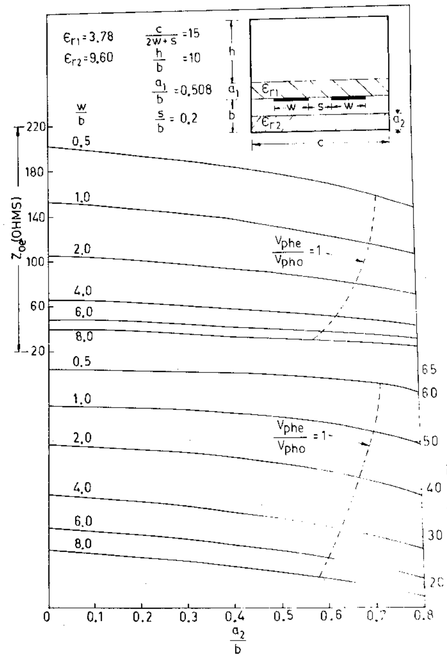

FIGURE 5: EFFECT OF DIELECTRIC OVERLAY ON IMPEDANCE CHARACTERISTICS OF COUPLED INVERTED MICROSTRIP

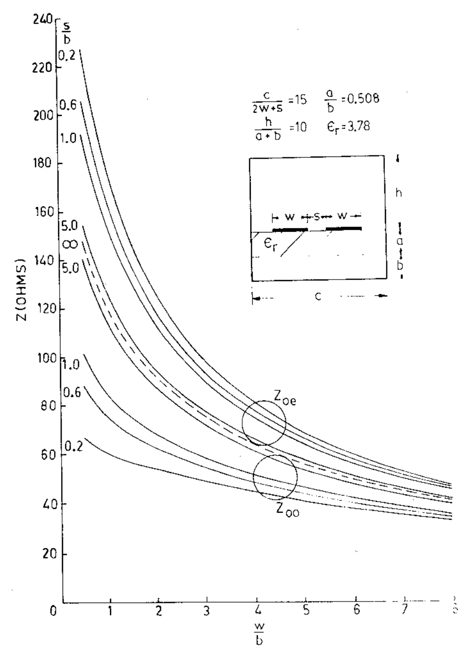

FIGURE 4: CHARACTERISTIC IMPEDANCE OF COUPLED SUSPENDED MICROSTRIP TRANSMISSION LINES

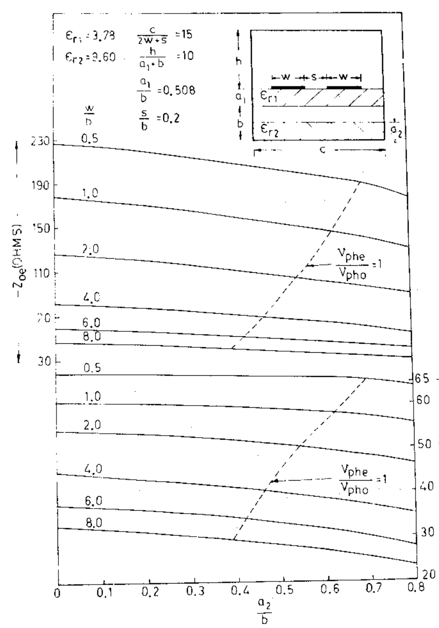

FIGURE 6: EFFECT OF DIELECTRIC OVERLAY ON IMPEDANCE CHARACTERISTICS OF COUPLED SUSPENDED MICROSTRIP