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MODELING OF CROSSTALK BETWEEN SIGNAL LINES ON ANISOTROPIC PRINTED CIRCUIT BOARD

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ABSTRACT

This paper investigates the effect of anisotropic substrate of printed circuit board (PCB) on the characteristics of adjacent signal lines (microstrip transmission lines). Specifically, simple and accurate design expressions for the characteristic impedance, phase velocity, and effective dielectric constant are obtained by conformal mapping. The results are compared with full wave solutions, where excellent agreement is observed.

Keywords: PCB, conformal mapping, microstrip, coupling, anisotropic.

1. INTRODUCTION

Crosstalk between adjacent tracks on PCB becomes important design issue because of the small room in modern high-speed digital systems. Subsequently, capacitive and inductive coupling occurs, between signal lines of the PCB, which leads to near-end and far-end crosstalk [1,2]. These lines have generally two unequal phase velocities for odd and even modes. The characteristics of this structure become worse as the velocity separation increases [3]. These limitations can be reduced by using dielectric overlay [4], or via fences [5, 6].

To calculate the parameters of the coupled microstrip lines with anisotropic substrate, variational technique combined with Fourier transform in conjunction with Green's function was used [3]. A unified variational expression for the capacitance of a general multilayer anisotropic structure is presented in [7]. In addition, an approximate filling fraction for microstrip line with isotropic substrate was obtained, and then used to find the parameters for the case with anisotropic substrate [8].

In this paper, simple and accurate design expressions for the parameters of shielded coplanar microstrip lines are obtained by using conformal mapping to find the mode capacitances of the structure and hence the phase velocities and impedances. This approach, unlike the numerical methods which need relatively large computational effort, provides an easy way to evaluate closed-form expressions. The results obtained compare very well with the data obtained by the variational approach [3] where the relative difference is less than 1%.

2. METHOD

Consider edge-coupled shielded microstrip lines, shown in Figure-1(a), with anisotropic substrate described by permittivity tensor:

$$[\varepsilon]=\begin{bmatrix}\varepsilon_1 & 0\\ 0 & \varepsilon_2\end{bmatrix} \tag{1}$$

Using substrate coordinates [9]; this tensor can be written as

$$[\varepsilon_Z]=\begin{bmatrix}\varepsilon_1\cos^2\beta+\varepsilon_2\sin^2\beta & (\varepsilon_2-\varepsilon_1)\sin\beta\cos\beta\\ (\varepsilon_2-\varepsilon_1)\sin\beta\cos\beta & \varepsilon_1\sin^2\beta+\varepsilon_2\cos^2\beta\end{bmatrix} \tag{2}$$

Where β is the tilt angle, i.e., angle between axis of the substrate and axis of the anisotropic material as illustrated in Figure-1(a).

This full matrix may be diagonalized through the following transformation into the w-plane; Figure-1.

$$[\varepsilon_\omega]=[m]^{-1}\,[\varepsilon_z]\,[m],\ [\varepsilon_\omega]=\begin{bmatrix}\sqrt{\varepsilon_1\varepsilon_2} & 0\\ 0 & \sqrt{\varepsilon_1\varepsilon_2}\end{bmatrix} \tag{3}$$

Where [m] is the transformation matrix, subscript z refers to z=x+jy complex plane, w refers to ω=u+jv complex plane, and j is square root of minus one. The conformal transformation used is $\omega=(a_1x+a_2y)+j(b_1x+b_2y)$. To preserve the geometry of the structure, $a_1=1$ and $b_1=0$ are chosen, then

$$\omega=(x+a2y)+j(b2y) \tag{4}$$

Combining (2)-(4) yields:

$$[m]=\begin{bmatrix}1 & -(\varepsilon_2-\varepsilon_1)\sin\beta\cos\beta/F\\ 0 & \sqrt{\varepsilon_1\varepsilon_2}/F\end{bmatrix},\ F=(\varepsilon_1\sin^2\beta+\varepsilon_2\cos^2\beta) \tag{5}$$

This transformation is used to convert the structure of Figure-1(a) into the new structure in Figure-1(b) that has the following parameters:

$$\mathbf{b}'=\frac{\sqrt{\varepsilon_1\varepsilon_2}}{\varepsilon_1\sin^2\beta+\varepsilon_2\cos^2\beta}\mathbf{b},\ \varepsilon=\sqrt{\varepsilon_1\varepsilon_2} \tag{6}$$

If b and h are much smaller than the outer conductors width a, the E field is essentially zero at the edges of the outer conductors and the problem is simplified, without loss of generality, by assuming that the outer conductors are infinitely wide.

For the even mode, the vertical centerline may be considered as magnetic wall. Thus, capacitance per unit length for the even mode is

$$C_e=C_{re}+C_{0e} \tag{7}$$

Where, C_{re}, C_{0e}, are capacitances of lower dielectric part and upper air part, respectively. Using Christoffel transformation [10], mapping from ω-plane, Figure-1(b), into z'-plane, Figure-2(a), is written as:

$$\omega = -(2b'/\pi)\ln\left|\sqrt{z'} + \sqrt{z'+1}\right| + jb' \quad (8)$$

We further map the upper half in z'-plane, Figure-2(a), into parallel plate capacitor in ω'-plane, Figure-2(b), which gives:

$$\mathbf{d} = \frac{\mathbf{K(k_e)}}{\mathbf{K(k'_e)}}, \mathbf{k_e} = \cosh\left(\frac{\pi s}{2b'}\right)\mathrm{sech}\left(\frac{\pi(s+w)}{2b'}\right) \mathbf{k'_e} = \sqrt{1-\mathbf{k_e^2}} \quad (9)$$

So,

$$\mathbf{C_{re}} = \sqrt{\varepsilon_1\varepsilon_2}\, \mathbf{K(k'_e)/K(k_e)} \quad (10)$$

Following the same procedure, C_{0e} is found to be:

$$\mathbf{C_{0e}} = \frac{\varepsilon_0 \mathbf{K(k'_{0e})}}{\mathbf{K(k_{0e})}}, \mathbf{k_{0e}} = \cosh\left(\frac{\pi s}{2h}\right)\mathrm{sech}\left(\frac{\pi(s+w)}{2h}\right) \mathbf{k'_{0e}} = \sqrt{1-\mathbf{k_{0e}^2}} \quad (11)$$

The ratio K (k)/K (k') can be easily evaluated using the accurate approximation given in [10]:

$$\frac{\mathbf{K(k)}}{\mathbf{K(k')}} = \begin{cases} \dfrac{1}{\pi}\ln\left(2\dfrac{1+\sqrt{k}}{1-\sqrt{k}}\right), & 0.5 \le k^2 \le 1 \\ \dfrac{\pi}{\ln\left(2\dfrac{1+\sqrt{k'}}{1-\sqrt{k'}}\right)}, & 0 \le k^2 \le 0.5 \end{cases} \quad (12)$$

Using equations (7) and (9)-(12), the even mode characteristic impedance, phase velocity and effective dielectric constant are given by:

$$Z_{ce} = \frac{1}{3*10^8\sqrt{C_e C_a}}, V_{pe} = \frac{1}{(Z_{0e}C_e)}, \varepsilon_{\mathbf{eff}} = \frac{\mathbf{C_e}}{\mathbf{C_a}} \quad (13)$$

Where C_a is the capacitance per unit length without dielectric substrate.

$$\mathbf{C_a} = \varepsilon_0 \frac{\mathbf{K(k'_e)}}{\mathbf{K(k_e)}} + \varepsilon_0 \frac{\mathbf{K(k'_{0e})}}{\mathbf{K(k_{0e})}} \quad (14)$$

Similarly, the following parameters of the odd mode are obtained by considering the vertical centerline as an electric wall.

$$\mathbf{d'} = \frac{\mathbf{K(k_o)}}{\mathbf{K(k'_o)}}, \mathbf{k_o} = \sinh\left(\frac{\pi s}{2b'}\right)\mathrm{csch}\left(\frac{\pi(s+w)}{2b'}\right) \mathbf{k'_o} = \sqrt{1-\mathbf{k_o^2}} \quad (15)$$

From these relations, it is easy to find per unit length capacitance, characteristic impedance and phase velocity.

3. RESULTS

Among the most common anisotropic materials used in microstrip line fabrication are sapphire and boron nitride. The variations of phase velocity ratio v_{pe} / v_{po} versus anisotropy ratio ε_1 / ε_2 with the angle of tilt β as parameter are plotted in Figure-3. It is observed that the two-phase velocities can be equalized by a suitable choice of β and anisotropy ratio.

Also, it is possible to equalize phase velocities by changing the top cover height, Figure-4, where the results are compared with other published data, and relative difference is less than 1%. In Figures 5 and 6, the mode impedances and phase velocities, respectively, are plotted versus the angle of tilt β. It is clear that the even mode impedance and phase velocity are more sensitive to changes in β, as compared with the odd mode.

4. CONCLUSIONS

Closed-form equations are presented for the design of adjacent traces (coupled microstrip lines) on shielded PCB with anisotropic substrate. Furthermore, various design curves are given where it is possible to optimize the performance of the PCB traces by the proper choice of the geometry and substrate material. The results compare well with full wave solutions.

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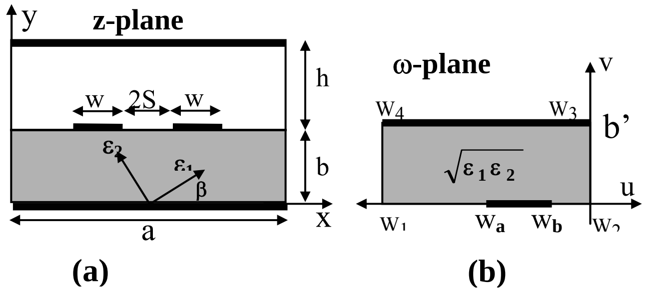

Figure-1. (a) Shielded coupled microstrip lines; (b) lower left part (flipped vertically).

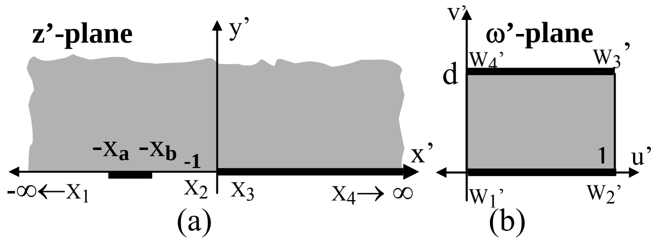

Figure-2. Mapping (a) from lower left part (see Figure-1(b)); (b) from upper half in z'-plane to ω'-plane.

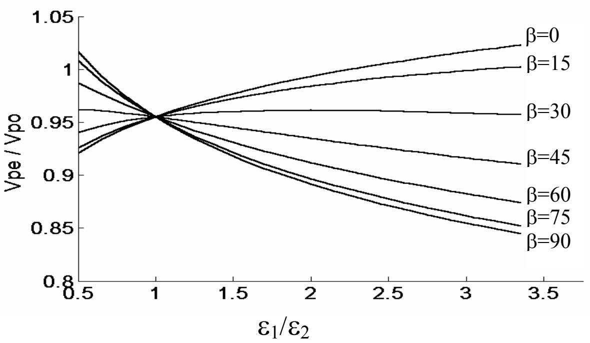

Figure-3. Phase velocity ratio versus anisotropy ratio with angle of tilt β as a parameter ($\varepsilon_2 = 3.78$, $2s/b = 0.25$, $h/b = 10$, $w/b = 0.1$).

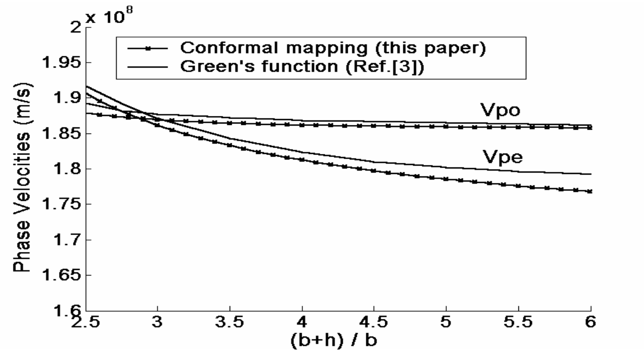

Figure-4. Phase velocities for boron nitride coupler versus (b+h) / b, ($w/b = 1.6$, $2s/b = 0.095$, $\varepsilon_1 = 5.12$, $\varepsilon_2 = 3.4$ at $\beta = 0$)

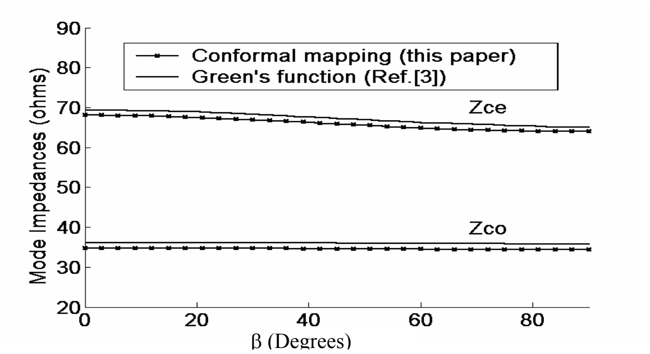

Figure-5. Mode impedances of sapphire substrate versus angle of tilt β, ($\varepsilon_1 = 11.6$, $\varepsilon_2 = 9.4$, $h/b = 1.2$, $2s/b = 0.225$, $w/b = 0.69$).

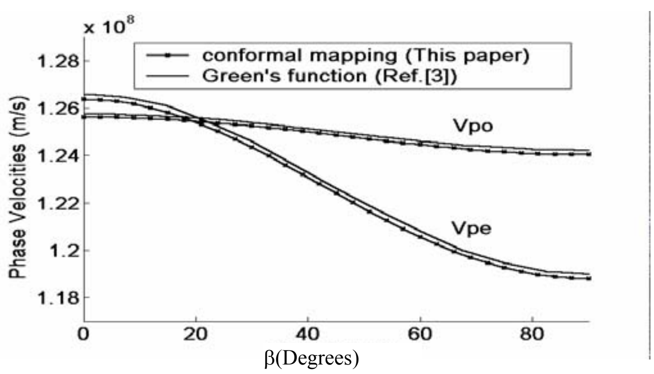

Figure-6. Phase velocities of sapphire substrate versus angle of tilt β, ($\varepsilon_1 = 11.6$, $\varepsilon_2 = 9.4$, $h/b = 1.2$, $2s/b = 0.225$, $w/b = 0.69$).