CHARACTERIZATION METHOD FOR MICROSTRIP LINES NEAR AN EDGE OF A SUBSTRATE WITH ANISOTROPIC PERMITTIVITY

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INTRODUCTION Microstrip lines have been employed as interconnections between passive and active elements in microwave integrated circuits (MIC). Proximity effects between these elements should be considered when designing circuit patterns of high-packing-density MIC's. The proximity effects of one type is observed when a strip conductor is located close to a conductor having ground potential on the top surface of a substrate. The proximity effects of the other type is observed when a strip conductor is located close to a substrate edge. The proximity effects of these two types have already been analyzed by the authors in recent papers[1],[2]. However, the case of a substrate with anisotropic permittivity has not been discussed yet.

In this paper, the proximity effects of a microstrip line near an edge of a substrate with anisotropic permittivity are analyzed by using the rectangular boundary division method given in the previous papers[2][3]. It is assumed that the quasi-TEM wave approximation is validated by taking the cross-sectional dimensions of microstrip lines much smaller than propagation wavelengths. The thickness of the strip conductor is assumed to be negligibly thin.

RECTANGULAR BOUNDARY DIVISION METHOD Fig.1 shows a microstrip line near an edge of a substrate with anisotropic permittivity. The rectangular boundary division method is employed here because each dielectric region of this structure is of the rectangular shape suited to this method as shown in Fig.2. The upper and side enclosure conductors do not affect the quasi-TEM characteristics of this transmission line when the enclosure conductors are sufficiently separated from the center strip conductor.

At first, scalar potentials in each rectangular region, as the solutions of Laplace's equation, are expressed in Fourier series as follows:

$$\phi_1(x,y) = \frac{xy}{ph}\phi_0 + \sum_{n=1}^{\infty}\left[A_n \sin\frac{n\pi x}{p}\sinh\sqrt{\frac{\varepsilon_x}{\varepsilon_y}}\cdot\frac{n\pi y}{p} + D_n \sinh\sqrt{\frac{\varepsilon_y}{\varepsilon_x}}\cdot\frac{n\pi x}{h}\sin\frac{n\pi y}{h}\right]$$
$$(0 \leqq x \leqq p,\ 0 \leqq y \leqq h)$$

$$\phi_2(x,y) = \frac{(a-x)y}{qh}\phi_0 + \sum_{n=1}^{\infty}\left[B_n \sin\frac{n\pi(a-x)}{q}\sinh\frac{n\pi y}{q} + E_n \sinh\frac{n\pi(a-x)}{h}\sin\frac{n\pi y}{h}\right]$$
$$(p \leqq x \leqq a,\ 0 \leqq y \leqq h)$$

$$\phi_3(x,y) = \sum_{n=1}^{\infty} C_n \sin\frac{n\pi x}{a}\sinh\frac{n\pi(b-y)}{a} \qquad (0 \leqq x \leqq a,\ h \leqq y \leqq b)$$

where A_n, B_n, C_n, D_n and E_n are unknown coefficients, and ϕ_0 is an unknown value of the potential at the upper edge point of the substrate. ε_x and ε_y denote the x and y component of the uniaxial permittivity of the substrate, respectively. A variational technique is used to determine these Fourier coefficients.

The total electric field energy U per unit length of this structure is given by

$$U = \frac{1}{2}\iint_{S_1}[\varepsilon_x(\frac{\partial\phi_1}{\partial x})^2+\varepsilon_y(\frac{\partial\phi_1}{\partial y})^2)]dxdy + \frac{1}{2}\varepsilon_0\iint_{S_2+S_3}[(\frac{\partial\phi_i}{\partial x})^2+(\frac{\partial\phi_i}{\partial y})^2]dxdy$$

where S_i $(i=1,2,3)$ denotes the cross-sectional area of the i-th region. U is minimized by giving exact potential functions Φ_i $(i=1,2,3)$. Instead of minimizing U by selecting an infinite number of unknown coefficients, A_n, B_n, C_n, D_n and E_n, we use a finite number of spline-knot potentials which represent potentials on the boundary lines of each region. In this paper, the potential function on the boundary line between the region 1 and region 2 is expressed by a spline function with the two knots at both ends, and the Fourier coefficients, D_n and E_n, are taken to be zero. This procedure makes the analysis much easier because U is expressed in a simple form.

Imposing the conditions for minimizing U, we obtain a set of linear, simultaneous, inhomogeneous equations concerning the spline-knot functions as new variables. After the process of solving these equations on a computer, the explicit form of the Fourier coefficients are found for all the regions and, therefore, the characteristics of the microstrip line near the edge are estimated with the usual quasi-TEM wave analysis.

NUMERICAL RESULTS The good numerical convergence of the calculated values of the characteristic impedance Z_0 and wavelength reduction factor λ/λ_0 has been obtained for the number of spline-knots, $m \geqq 50$ and the number of the Fourier series terms, $N \geqq 2000$. Fig.3 and Fig.4 show the calculated data on Z_0 and λ/λ_0, respectively, for the case of a sapphire substrate ($\varepsilon_x=9.4$, $\varepsilon_y=11.7$). The calculated results for an isotropic substrate are also indicated by dotted lines in these figures for comparison.

It is seen in Fig.3 and Fig.4 that how the y-component of anisotropic permittivity affects the transmission characteristics of microstrip lines. It can be also found by this analysis that how far the strip conductor should be placed from the substrate edge to keep the same characteristic impedance. The increase of the characteristic impedance due to the existence of the edge can be compensated by taking a larger value of the strip width. The compensated microstrip line of this type has been named as the edge compensated microstrip line[2]. Fig.5 shows the relationship between the strip width W and the separation S between the strip conductor and the substrate edge in the case of the 50-ohm edge compensated microstrip lines of the sapphire substrate. The dotted line in Fig.5 shows the wavelength reduction factor of the 50-ohm edge compensated microstrip lines. These results can be used quantitatively in the design of the high-packing-density MIC's.

CONCLUSION In this paper, we estimated the proximity effects of a substrate edge on the transmission characteristics of the high-packing-density MIC's using a substrate with anisotropic permittivity. The rectangular boundary division method was found to be useful to calculate the characteristic impedance and the wavelength reduction factor including the proximity effects. The structural data of the edge compensated microstrip lines were obtained to keep the characteristic impedance constant.

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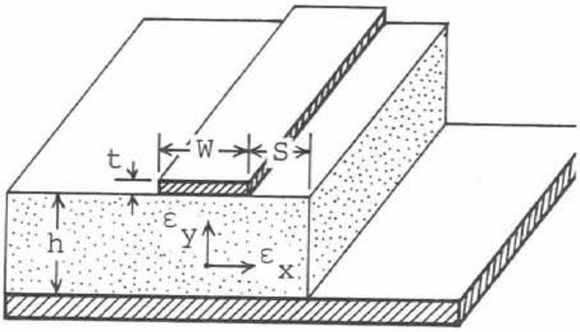

Fig.1
A Microstrip line near an edge of a substrate with anisotropic permittivity.

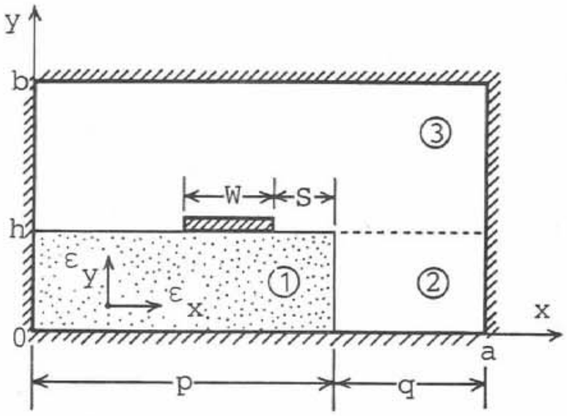

Fig.2
The line structure divided into three regions with rectangular boundaries.

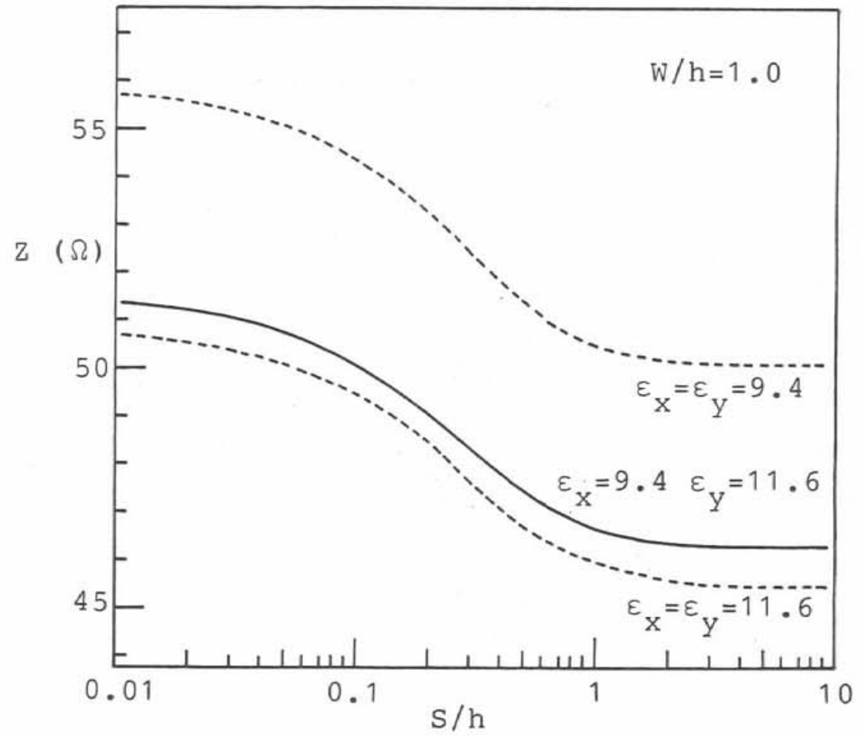

Fig.3 The estimated proximity effects on the characteristic impedance.

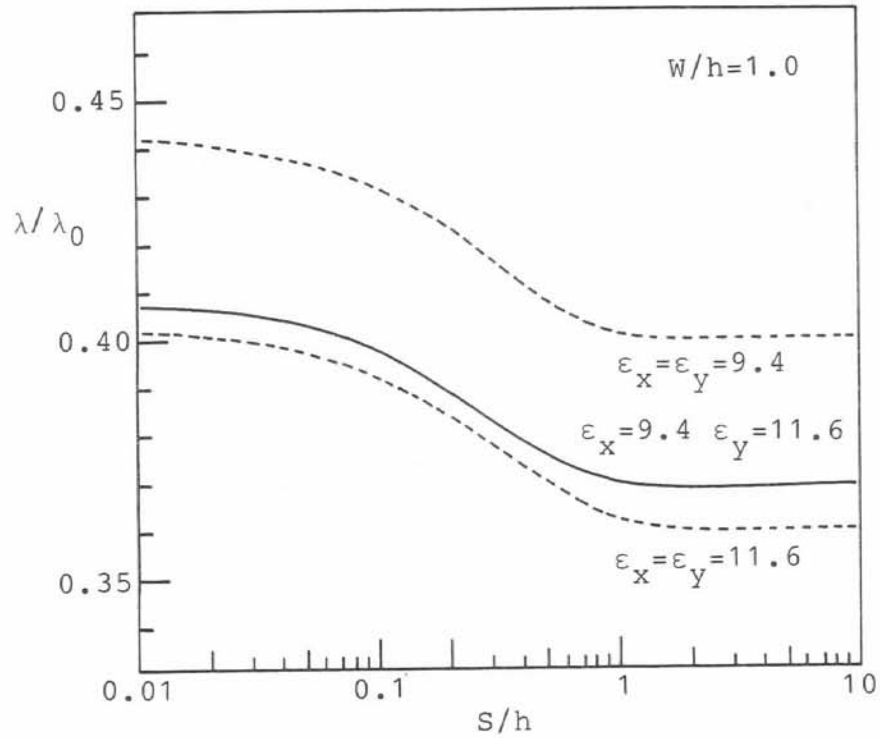

Fig.4 The estimated proximity effects on the wavelength reduction factor.

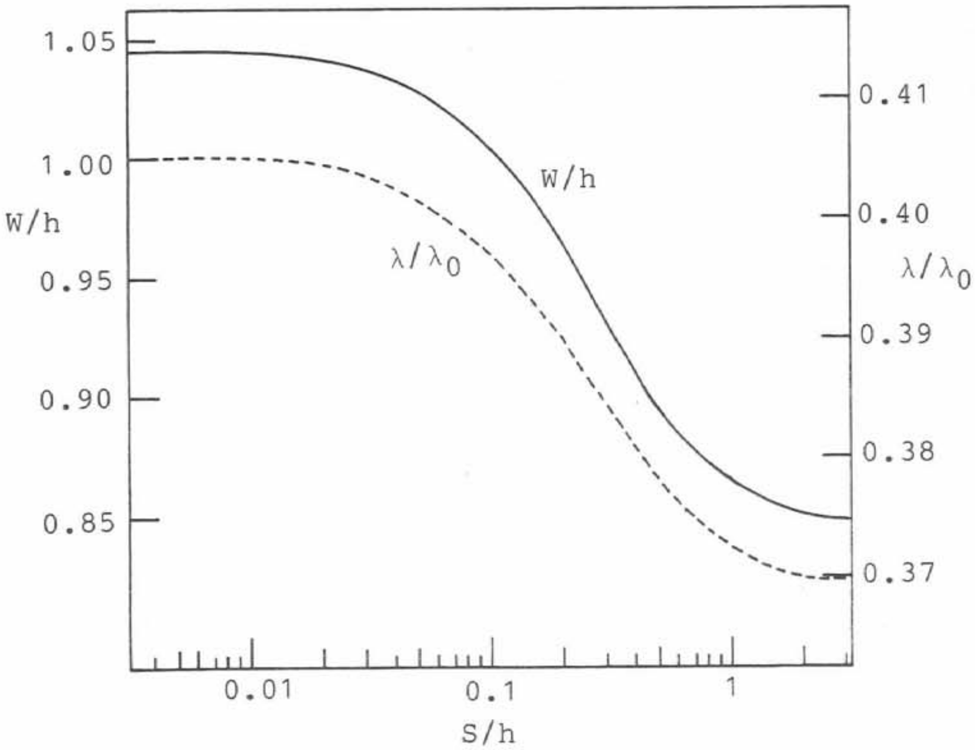

Fig.5 The designed strip width of the 50-ohm edge compensated microstrip line and its wavelength reduction factor.