G-12

SIMPLIFIED ANALYSIS OF STRIPLINE, MICROSTRIPLINE AND COPLANAR STRIPS, WITH ANISOTROPIC SUBSTRATES FOR MIC AND SAW APPLICATIONS

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ABSTRACT

A unified variational expression is derived for the line capacitance of a general, multilayer anisotropic structure. The propagation parameters of a variety of striplines, microstriplines and coplanar strips with anisotropic substrates, in isolated and coupled configurations, can be obtained by simply determining the admittance parameter.

Introduction

The conventional stripline, microstripline and coplanar structures are extensively used to fabricate various MIC components[1]. Detailed analysis and design data for these transmission lines on isotropic substrates are available in the literature. The isotropic substrates commonly used are: RT duroid, alumina and fused quartz. Some anisotropic substrates, e.g. sapphire and pyrolytic boron nitride have certain advantages over ceramics, which include: lower losses, higher homogeneity and lower variations of electrical properties from specimen to specimen. The analysis of conventional stripline and microstripline, in isolated and coupled configurations, with anisotropic substrates are reported in several papers[2-3].

Recently, an exhaustive analysis and design data on various microstrip-like transmission lines on isotropic substrates, for microwave and millimeter wave applications, have been reported by the authors[4-5]. Except for the isolated inverted microstrip and suspended microstrip[6], the analysis of other microstrip-like structures with anisotropic substrates has not been attempted so far.

A typical surface acoustic wave device uses an interdigital transducer deposited on a nonpiezoelectric substrate. A thin film of piezoelectric material is placed on top of the transducer in good acoustic contact with it, and a metal film may be deposited on top of the piezoelectric film. Typical examples of the materials which are used are Zno, Cds or $LiNbo_3$ for the piezoelectric layer and Si, sapphire and fused silica for the nonpiezoelectric substrate. Most of these materials exhibit anisotropic behaviour. Following certain assumptions, the determination of static capacitance of a surface wave acoustic interdigital transducer reduces to the determination of capacitance of a pair of coplanar strips embedded in multilayer iso/anisotropic dielectrics. The analysis of SAW interdigital transducer has been reported in the literature[7-8]. This analysis uses the conventional method of determining the potential function by matching the boundary conditions at various interfaces, which becomes increasingly complicated as the number of dielectric layers increase.

This paper presents a simple, unified variational expression for the line capacitance of a general, multilayer anisotropic structure. To use this unified variational expression for determining the line capacitance of various striplines, microstriplines and coplanar lines, in isolated and coupled configurations, it is only necessary to substitute the admittance parameter for the particular structure. This admittance parameter can be easily determined from the transmission line equivalent circuit.

Analysis

For generality of analysis, using electric and magnetic walls at the planes of symmetry, the stripline, microstripline and coplanar strips, in isolated and coupled configurations can be represented by a single structure with multilayer anisotropic dielectrics as shown in Fig. 1. There are four different cases to be considered:

1. Electric wall at x=c and electric wall at y = d.
2. Magnetic wall at x=c and electric wall at y = d.
3. Electric wall at x=c and magnetic wall at y = d.
4. Magnetic wall at x=c magnetic wall at y = d.

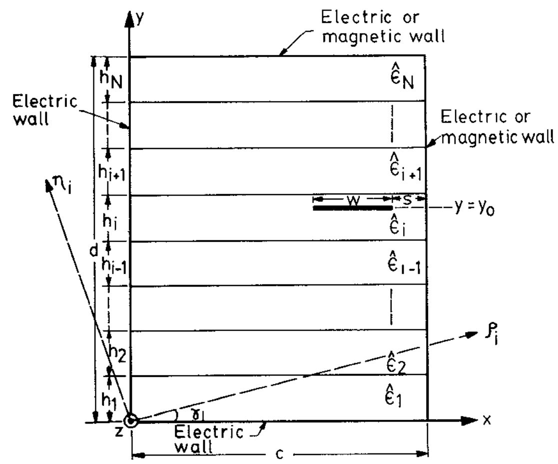

FIGURE 1: MULTILAYER STRUCTURE WITH ANISOTROPIC DIELECTRIC SUBSTRATE

The Green's function for these four cases can be easily obtained using the transverse transmission line method[4]. In order to determine the line capacitances, we assume a suitable charge distribution on the strip conductor and use variational expression in the space domain[4]. The resulting capacitance expressions are:

$$C_{(1,2,3,4)} = \frac{[1+0.25\,A_{(1,2,3,4)}]^2}{\sum\limits_{n(e,o,e,o)} [L_n + A_{(1,2,3,4)} M_n]^2 P_n / Y_{(1,2,3,4)}} \quad (1)$$

$$L_n = \sin(\beta_n w/2)\ \sin(\beta_n (2c-2s-w)/2),\ \beta_n = n\pi/2c \quad (2)$$

$$M_n \quad (2/\beta_n w)^3 \sin(\beta_n (2c-2s-w)/2)\,[3\{(\beta_n w/2)^2-2\}\cdot \cos(\beta_n w/2) + (\beta_n w/2)\{(\beta_n w/2)^2-6\}\sin(\beta_n w/2)+6] \quad (3)$$

$$A_{(1,2,3,4)} = -\frac{\sum_{n(e,o,e,o)} (L_n-4M_n)L_n P_n/Y_{(1,2,3,4)}}{\sum_{n(e,o,e,o)} (L_n-4M_n)M_n P_n/Y_{(1,2,3,4)}} \quad (4)$$

$$P_n = (4/n\pi)\ (2/\beta_n w)^2 \quad (5)$$

Here 1,2,3,4 refer to four different cases discussed earlier and n(e) and n(o) refer to even values of n and odd values of n, respectively. The only unknown parameter in the capacitance expression is the admittance Y at the charge plane $y=y_0$. This can be simply determined from the transmission line equivalent circuit of multilayer anisotropic structure (Fig.2) with β_n as the propagation constant. It should be noted that Y_1, Y_2 correspond to electric wall at y=d and Y_3, Y_4 correspond to magnetic wall at y=d. The characteristic admittances $Y_{ci} = \varepsilon_i^*$ and lengths h_i^*, i-1,...N, of various transmission line sections depend on the type of anisotropy of the dielectric substrate. Various cases are discussed below.

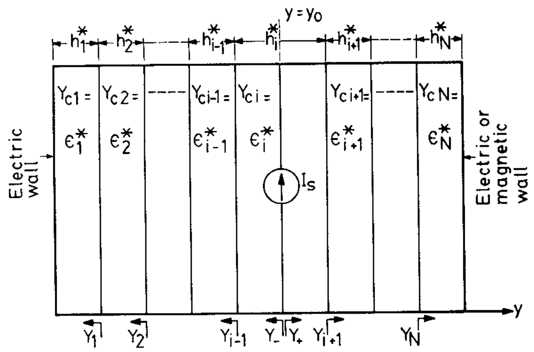

FIGURE 2 : TRANSMISSION LINE EQUIVALENT CIRCUIT. ADMITTANCE AT THE CHARGE PLANE $Y=Y_+ + Y_-$.

Case 1

$$\hat{\varepsilon}_i = \varepsilon_0 \begin{bmatrix} \varepsilon_{xi} & 0 & 0 \\ 0 & \varepsilon_{yi} & 0 \\ 0 & 0 & \varepsilon_{xi} \end{bmatrix} \quad (6a)$$

$$h_i^* = h_i \sqrt{\varepsilon_{xi}/\varepsilon_{yi}} \quad ; \quad \varepsilon_i^* = \varepsilon_0 \sqrt{\varepsilon_{xi}\ \varepsilon_{yi}} \quad (6b)$$

Case 2

$$\hat{\varepsilon}_i = \varepsilon_0 \begin{bmatrix} \varepsilon_{\zeta i} & 0 & 0 \\ 0 & \varepsilon_{\eta i} & 0 \\ 0 & 0 & \varepsilon_{zi} \end{bmatrix} \quad (7a)$$

$$h_i^* = \frac{h_i \sqrt{\varepsilon_{\eta i}/\varepsilon_{\zeta i}}}{[((\varepsilon_{\eta i}/\varepsilon_{\zeta i})-1)\cos^2 \gamma_i + 1]} \quad ; \quad \varepsilon_i^* = \varepsilon_0 \sqrt{\varepsilon_{\eta i}\ \varepsilon_{\zeta i}} \quad (7b)$$

Case 3

$$\hat{\varepsilon}_i = \varepsilon_0 \begin{bmatrix} \varepsilon_{xxi} & \varepsilon_{xyi} & 0 \\ \varepsilon_{xyi} & \varepsilon_{yyi} & 0 \\ 0 & 0 & \varepsilon_{zzi} \end{bmatrix} \quad (8a)$$

$$h_i^* = h_i \sqrt{\frac{\varepsilon_{xxi}}{\varepsilon_{yyi}} - \left(\frac{\varepsilon_{xyi}}{\varepsilon_{yyi}}\right)^2} \quad ; \quad \varepsilon_i^* = \varepsilon_0 \sqrt{\varepsilon_{xxi}\varepsilon_{yyi} - \varepsilon_{xyi}^2} \quad (8b)$$

Numerical Results

In all the computations the dielectric substrates are considered to have the permitivity tensor given by (6a). Fig. 3 shows the variations of the characteristic impedance Z_1 and normalised guidewave length λ_1/λ_0 as a function of w/b for stripline-like microstrip. The substrates considered are pyrolytic boron nitride ($\varepsilon_x = 5.12$, $\varepsilon_y = 3.4$), sapphire ($\varepsilon_x = 9.4$, $\varepsilon_y = 11.6$) and fused quartz ($\varepsilon_x = \varepsilon_y = 3.78$). It is observed that Z_1 decreases for all the three cases, whereas, λ_1/λ_0 is constant for fused quartz, decreases for sapphire and increases for pyrolytic boron nitride substrates. Fig. 4 illustrates the variations of odd mode impedance Z_{1o} and even mode impedance Z_{2e} as a function of w/b with 2s/b as parameter, for edge-coupled inverted microstrip. The variations of the odd-and even-mode impedances (Z_{1o}, Z_{3e}) and the ratio of odd- and even-mode phase velocities (v_{1o}/v_{3e}) for broadside-coupled suspended microstrip are plotted in Fig. 5 as a function of w/b with d/b as a parameter. In both these cases, sapphire substrate is considered.

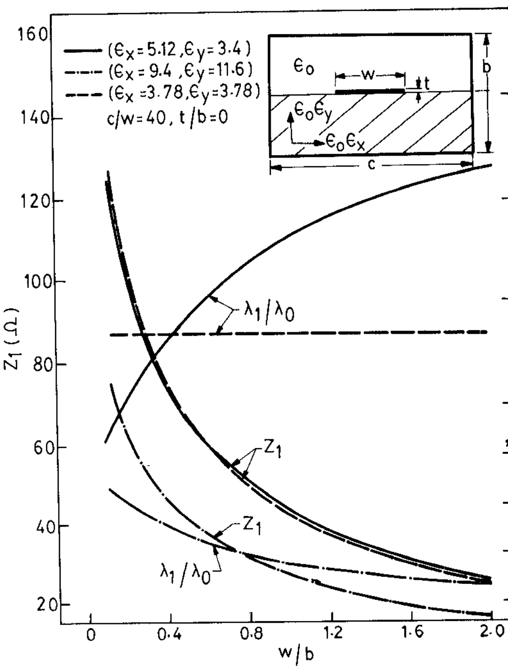

FIGURE 3 : CHARACTERISTIC IMPEDANCE AND NORMALISED GUIDE WAVE LENGTH OF STRIPLINE-LIKE MICROSTRIP

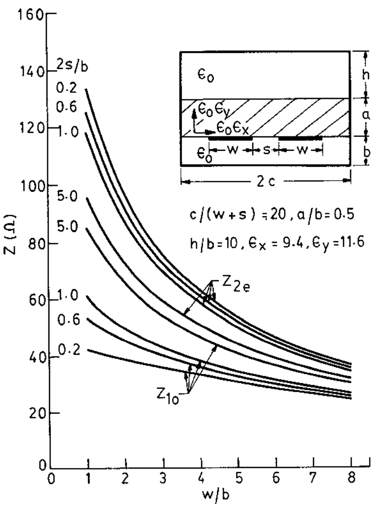

FIGURE 4: CHARACTERISTIC EVEN-AND ODD-MODE IMPEDANCES OF EDGE-COUPLED INVERTED MICROSTRIP

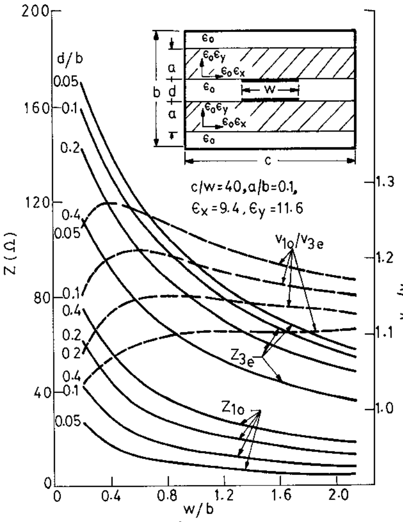

FIGURE 5: CHARACTERISTIC EVEN-AND ODD-MODE IMPEDANCES AND PHASE VELOCITY RATIO OF BROADSIDE COUPLED SUSPENDED MICROSTRIP

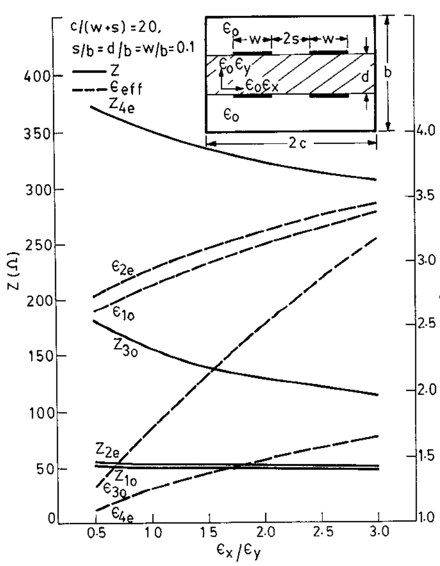

FIGURE6: EFFECT OF DIELECTRIC ANISOTROPY ON THE CHARACTERISTICS OF BROADSIDE, EDGE-COUPLED MICROSTRIP WITH INVERTED DIELECTRIC

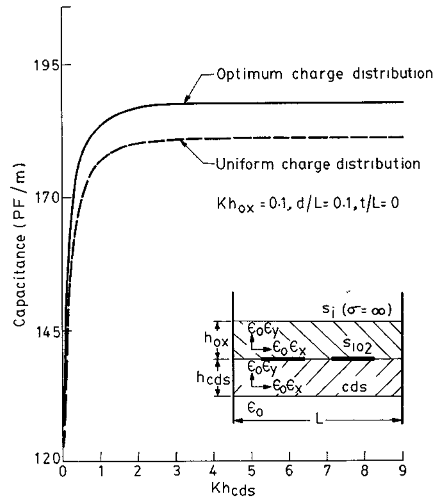

FIGURE 7: CAPACITANCE OF A Cds-Sio_2-Si SAW IDT AS A FUNCTION OF NORMALISED THICKNESS OF Cds LAYER

Fig. 6 illustrates the variations of the odd-odd, even-odd, odd-even and even-even mode impedances (Z_{1o}, Z_{2e}, Z_{3o}, Z_{4e}) and effective dielectric constants (ε_{1o}, ε_{2e}, ε_{3o}, ε_{4e}) of broadside, edge-coupled microstrip with inverted dielectric, as a function of ε_x with ε_y=3.78. The computed results of a typical SAW structure using uniform charge distribution on the electrodes (A=0 in our theory) have been compared with the results reported by Venema et.al.[8] and are found to be in good agreement. Fig. 7 shows the variations of the capacitance as a function of normalised height of Cds layer for a Cds-Sio_2-Si SAW structure using optimum and uniform charge distributions.

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