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Modeling of Microstrip line Gap Discontinuity on Multilayer Substrate

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Abstract: In this paper, the modeling of microstrip line gap discontinuity on multilayer semiconductor substrate is presented. The reflection coefficient and transmission coefficient are computed from the equivalent lumped circuit model of microstrip line gap discontinuity. The lumped circuit elements- capacitance, inductance and resistance are calculated using closed-form expressions in term of the gap discontinuity, width of microstrip line and dielectric substrate thickness. Static Spectral Domain Analysis (SDA) method is used to compute characteristic impedance of microstrip line.
Keywords: Static Spectral Domain Analysis, Gap Discontinuity, Multilayer Microstrip line.

I. INTRODUCTION

Microstrip line are used in the design of microwave integrated circuits (MICs) and monolithic MICs. The microwave components such as couplers, filters, interconnecting lines and matching components are essential part of a complex microwave circuits in hybrid and monolithic MICs. Discontinuities such as open-end, step and gap discontinuity are widely used in the microwave components design. For frequency dependent analysis, Full wave methods have been used, but these methods are complex and difficult to implement. Circuit model provides fast and accurate results at low frequencies; hence circuit models are used at low frequency for circuit design. [1-9]. The circuit model for gap discontinuity has been modified by incorporating lumped circuit elements. The results are compared with full-wave spectral domain analysis [5].

For the hybrid and semiconductor based integrated circuits, it is important to analyze and characterize the microstrip line discontinuities on multilayer substrate. This paper presents analysis of microstrip line gap discontinuity on multilayer substrate. For this, the static spectral domain analysis method and single layer reduction (SLR) technique are used to obtain the effective relative permittivity and characteristic impedance of microstrip line. The equivalent circuit model has been used to compute the frequency dependent reflection coefficient and transmission coefficient of microstrip line gap discontinuity. In section-II, SDA method for multilayer microstrip line is discussed. The circuit model for gap discontinuity and calculated numerical results are discussed in section-III and Section-IV respectively.

II. ANALYSIS OF MULTILAYER MICROSTRIP LINE

In this paper, Galerkin's technique based static SDA method have been used for computing the capacitance of multilayer microstrip line. The characteristic impedance is computed from the line capacitance. The Green's function in Fourier domain for multilayer microstrip line structure is obtained using transverse transmission line (TTL) technique [10-12].

The cross section of a shielded multilayer microstrip line is shown in Fig.1. The width of strip is S. The thickness of lower and upper dielectric substrate is H_1 and H_2 respectively. The permittivity of dielectric substrate is ε_1 and ε_2. The capacitance is computed from following relation [10-12].

$$\frac{1}{C} = \frac{L}{2\varepsilon_o Q^2}\sum_{n=1}^{\infty} \tilde{\rho}_s^2\,(\beta_n, y)\tilde{G}(\beta_n, y) \qquad (1)$$

where $\tilde{G}(\beta_n, y)$ is Fourier transform of Green's function, $\tilde{\rho_s}$ is Fourier transform of charge distribution and Q is total charge present on strip. The characteristic impedance is computed from Equation (2).

$$Z_o = \frac{1}{c\sqrt{C_d C_{air}}} \qquad (2)$$

where c is velocity of light in free space, C_d is capacitance with dielectric substrate, and C_{air} is capacitance when dielectric is replaced with air.

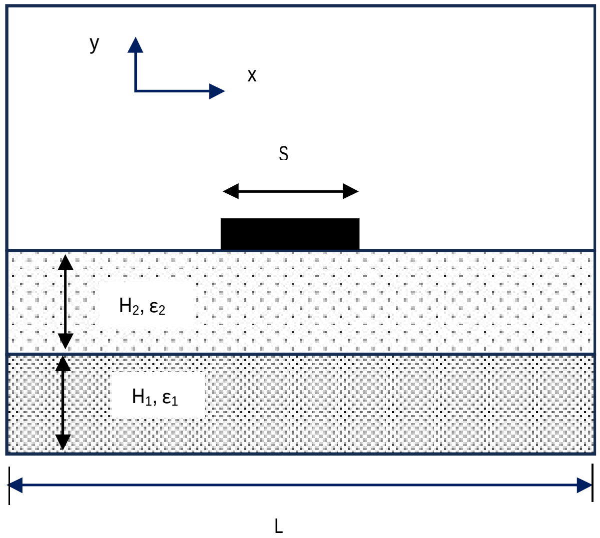


Fig.1 Multilayer Microstrip Line

III. MICROSTRIP LINE GAP DISCONTINUITY

The microstrip line gap discontinuity and its equivalent circuit model are shown in Fig.2(a) and Fig.2(b) respectively. This circuit model pi-network of admittance parameters. The closed form expression for capacitance, inductance and resistance are calculated in terms of physical parameters of microstrip line, i.e., width of strip conductor (S), gap (G) and thickness of dielectric substrate [5].

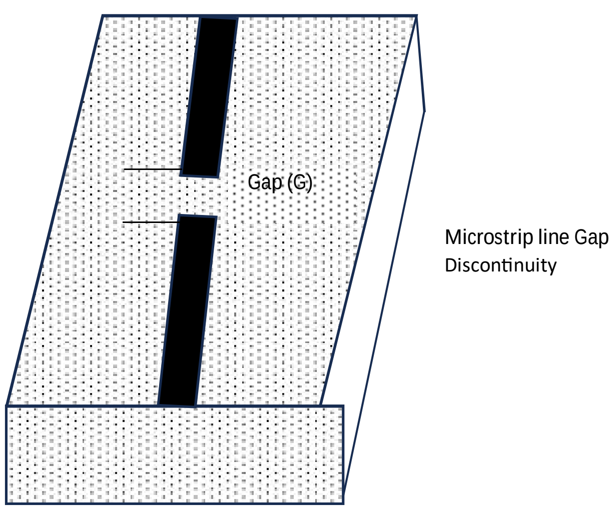
$$C_{11} = \left(\frac{1}{Z_o}\right)(A1).\tanh(A2)\ pF \qquad 3(a)$$

$$A1 = 1.125 tanh\left(\frac{1.358S}{H_t}\right) - 0.315$$

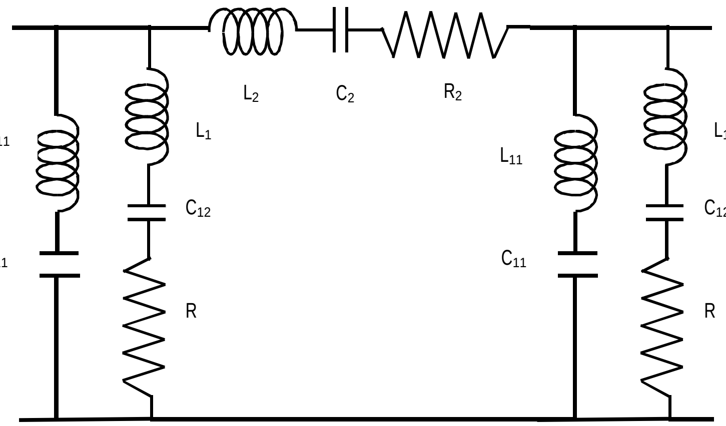
$$A2 = \left(0.0262 + 0.184\frac{H_t}{S}\right) + \left(0.217 + 0.0619 ln\left(\frac{S}{H_t}\right)\right)\frac{G}{H_t}$$

$$C_{12} = \left(\frac{1}{Z_o}\right)(B1).\tanh(B2)\ pF \qquad 3(b)$$

$$B1 = 6.832 tanh\left(\frac{0.0109S}{H_t}\right) + 0.91, \quad B2 = \left(1.411 + 0.314\frac{H_t}{S}\right) + \left(\frac{G}{H_t}\right)^{1.248 + 0.36 tan^{-1}\frac{S}{H_t}}$$



(a)



(b)

Fig.2 Microstrip line (a) Gap Discontinuity and (b) Equivalent Circuit Model

$$L_{11} = (Z_o)D1 * exp(D2) \ \ nH \qquad 3(c)$$

$$D1 = 0.134 + 0.0436ln\left(\frac{H_t}{S}\right), \quad D2 = -\left(3.656 + 0.246\frac{H_t}{S}\right).\left(\frac{G}{H_t}\right)^{1.739+0.39ln\frac{S}{H_t}}$$

$$L_{12} = (Z_o)\left(E1 + \left(0.1827 + 0.00715ln\frac{S}{H_t}\right) * exp(E2)\right) \ nH \qquad 3(d)$$

$$E1 = 0.008285tanh\left(\frac{0.5665S}{H_t}\right) + 0.0103$$

$$E2 = -\left(5.207 + 1.283tanh\left(\frac{1.656H_t}{S}\right)\right).\left(\frac{G}{H_t}\right)^{0.542+0.873tan^{-1}\frac{S}{H_t}}$$

$$R_1 = (Z_o).F1 * \tanh(F2) \ ohm \qquad 3(e)$$

$$F1 = 1.024tanh\left(\frac{2.025S}{H_t}\right), \quad F2 = \left(0.01584 + 0.0187\frac{H_t}{S}\right)\frac{G}{H_t} + 0.1246 + 0.0394sinh\left(\frac{S}{H_t}\right)$$

$$C_2 = J1 + (J2).\text{sech}\left(\frac{2.3345G}{H_t}\right) \ pF \qquad 3(f)$$

$$J1 = \left(0.1776 + 0.05104ln\frac{S}{H_t}\right)\frac{H_t}{G}, \quad J2 = \left(0.574 + 0.3615\frac{H_t}{S} + 1.156ln\left(\frac{S}{H_t}\right)\right)$$

$$L_2 = (Z_o)(K1).\sinh\left(\frac{2.3345G}{H_t}\right) \ nH \qquad 3(g)$$

$$K1 = \left(0.00228 + \frac{0.873}{7.52\left(\frac{S}{H_t}\right) + cosh\left(\frac{S}{H_t}\right)}\right)$$

$$R_2 = (Z_o)\left(M1 + (M2).sinh\frac{2.3345G}{H_t}\right) \ ohm \qquad 3(h)$$

$$M1 = \left(-1.78 + \frac{0.749S}{H_t}\right)\frac{G}{H_t}, \quad M2 = \left(1.196 - 0.971ln\left(\frac{S}{H_t}\right)\right)$$

$$H_t = H_1 + H_2$$

The admittance parameters of circuit is evaluated from the lumped parameters of equivalent circuit using Equation 3(a)-3(h). From the admittance parameters equivalent circuit, the frequency dependent reflection coefficient and transmission coefficient are computed [5].

IV. NUMERICAL RESULT AND DISCUSSION

Microstrip line gap discontinuity is present on two-layer dielectric substrates. First layer is silicon (Si) dielectric substrate ε_{r1} = 11.9 and thickness H_1 = 0.4mm. Above the silicon dielectric substrate, a thin silicon dioxide layer is present. The relative permittivity of silicon dioxide is ε_{r2} = 3.9 and thickness H_2 = 3µm. The width of microstrip line strip is S=0.3mm. The characteristic impedance for S=0.3mm is 52.6 ohm. For different gap (G) ranging from 10µm to 20µm, 30µm and 40µm, the lumped circuit parameters are calculated.

Fig. 3(a) and Fig. 3(b) shows the variation of reflection coefficient (mag.) and reflection coefficient (phase, deg.) with frequency for different gap (G) discontinuity. More field is radiated from the edges of gap discontinuity with increase of frequency. Due to increase of frequency, radiation loss and surface wave loss increases. For G=10µm and G=40µm, reflection coefficients are 0.34 and 0.62 respectively at 30GHz. Furthermore, the magnitude and phase angle of transmission coefficient are also plotted in Fig. 4(a) and Fig. 4(b) respectively for four gap, G=10µm, 20µm, 30µm and 40µm. As frequency increases, the radiation loss and surface wave loss increases. The higher order modes are also generated at high frequencies. Therefore, as the operating frequency increases, the transmission coefficient also increases.

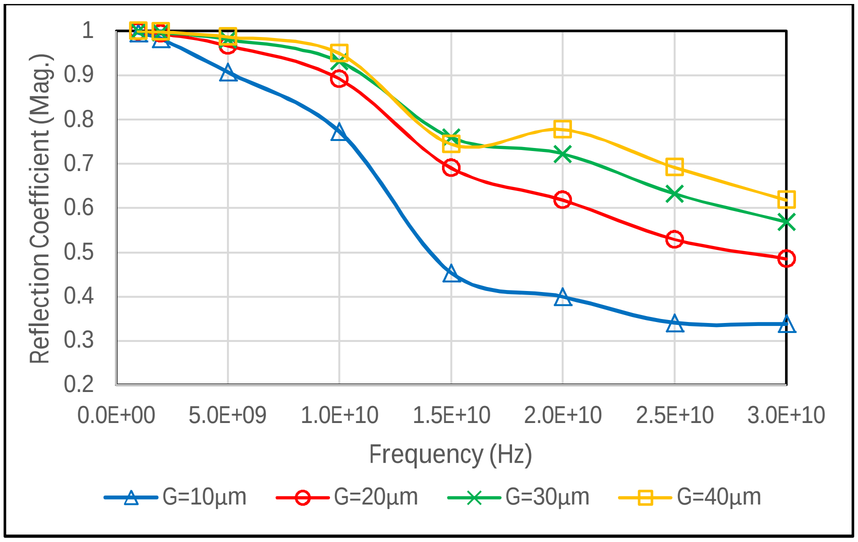


Fig. 3(a) Reflection Coefficient (Mag.)

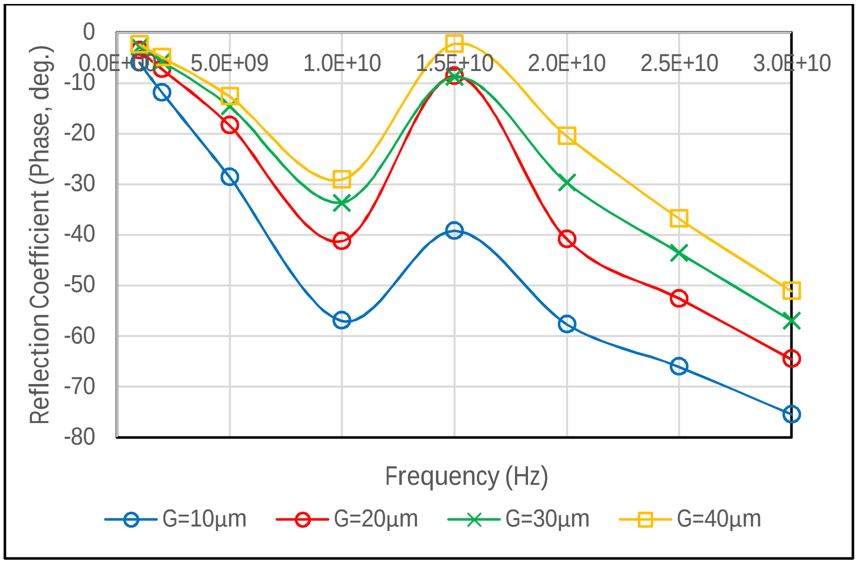


Fig. 3(b) Reflection Coefficient (Phase, deg.)

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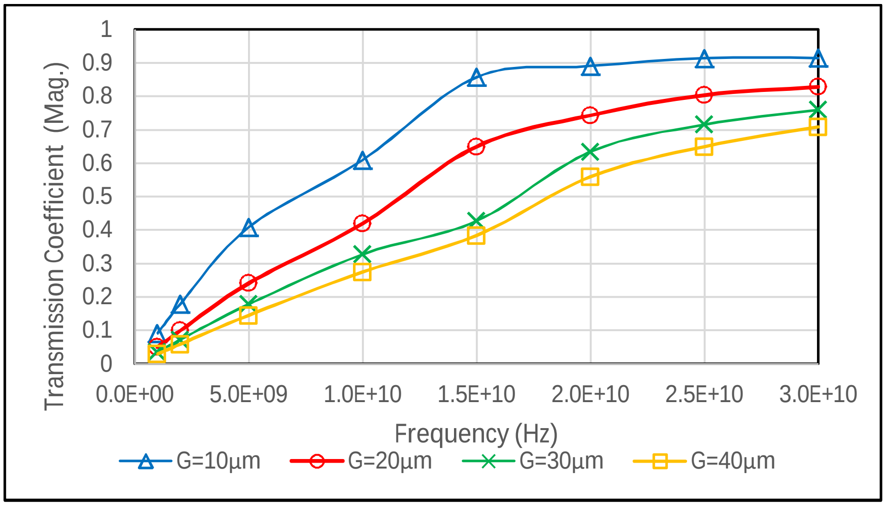

Fig. 4(a) Transmission Coefficient (Mag.)

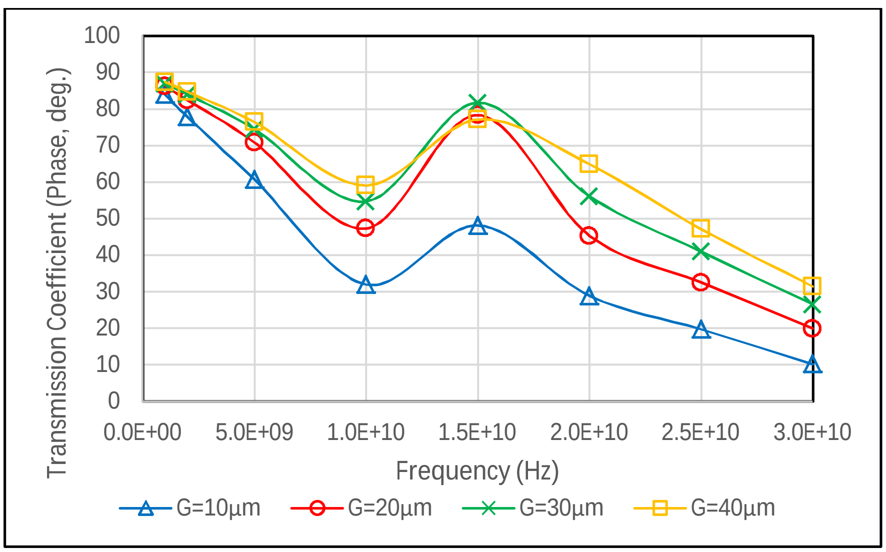

Fig. 4(b) Transmission Coefficient (Phase, deg.)

V. CONCLUSION

In this paper, equivalent lumped circuit model of microstrip line gap discontinuity on multilayer semiconductor substrate has been analyzed. The circuit model can be used to study and compute the reflection and transmission coefficient of gap discontinuity on multilayer substrate.

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