MICROSTRIP DISCONTINUITY MODELLING FOR MILLIMETRIC INTEGRATED CIRCUITS

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ABSTRACT

A theoretical approach for the representation of microstrip discontinuities by equivalent circuits with frequency dependent parameters is presented. The method accounts accurately for the substrate presence and associated surface wave model, strip finite thickness and radiation losses. The method can also be applied for the solution of microstrip components in the millimetric frequency range.

Introduction. A representation of microstrip discontinuities by equivalent circuits with frequency dependent parameters is presented. The method of solution is based on solving Pocklington's Integral Equation by employing the method of moments and accounts for conductor thickness as well as substrate and radiation effects. The method gives very good accuracy for microwave and millimetric wave frequencies.

Summary. Several methods have been previously adopted to model microstrip discontinuities in terms of equivalent circuits and/or scattering matrices (1)-(5). However, these methods give results which differ significantly and in addition they fail for high frequencies (f > 12 GHz). Although some discontinuities give rise to very small capacitances and inductances, the reactance of such discontinuities becomes particularly significant at the millimeter wave frequencies. For this frequency range, accuracies of a tenth of pF/m or nH/m are critical for the design of integrated circuits. To overcome the limitation to electrically thin substrates, a Green's function approach has been suggested and has provided excellent results for microstrip antennas including the excitation mechanism (6)-(8).

This paper applies the Green's function method to the solution of microstrip discontinuities. The approach presented is based on solving Pocklington's integral equation for the unknown current density $\vec{J}$ on the microstrip by employing the method of moments. The integral equation for the electric field is shown below,

$$\vec{E}(\vec{r}) = \int_S (k_o^2 \bar{\bar{I}} + \bar{\nabla}\bar{\nabla}) \cdot \bar{\bar{G}} \cdot \vec{J}\, ds$$

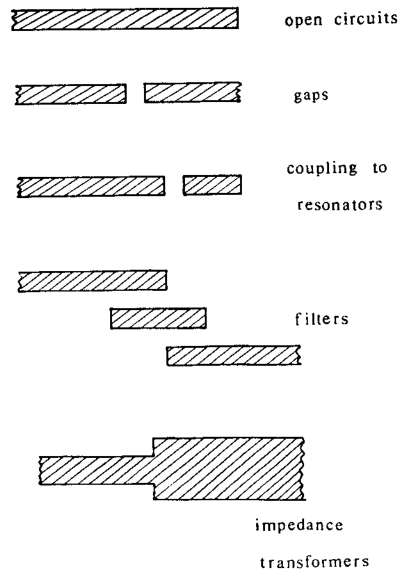

Figure 1: Microstrip Discontinuities

where $\bar{\bar{I}}$ ≡ the unit dyadic,
$\bar{\bar{G}}$ ≡ the dyadic Green's function for an infinitesimally small printed dipole,
$\vec{J}$ ≡ the unknown current distribution and
S ≡ the surface of the strip conductors.

In the class of problems treated here, the excitation of the microstrip transmission line takes place two to three guided wavelengths away from the discontinuity and the currents are assumed to be undirectional, an assumption which is very accurate for $w \leq 0.3\ \lambda_o$ (Fig. 1). In the use of the method of moments, the current density is expanded in piecewise sinusoidal functions along the longitudinal direction of the microstrip lines. In the transverse direction $\vec{J}(x,y)$ is chosen so as to satisfy the edge condition at $\pm w_e/2$, where w_e is the effective width of the conductor ($w_e = w + 2\delta$, $\delta \sim f(t)$ with f(t) being a correction factor for the conductor thickness). Integrations in the

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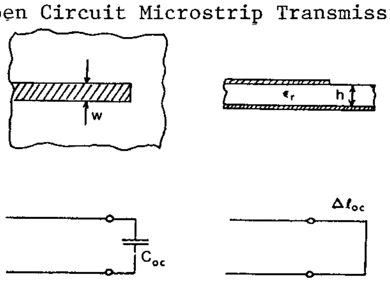
(a) Open Circuit Microstrip Transmission Line.



(b) Microstrip Gap.

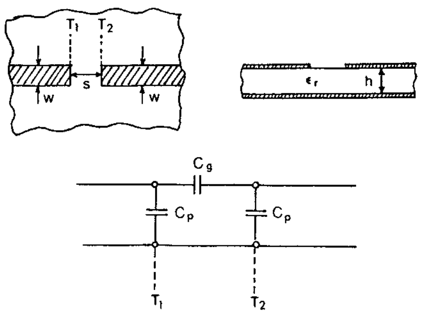


Figure 2: Equivalent Circuits for Microstrip Discontinuities.

transverse direction are carried out over the interval [-w/2,w/2].

Results obtained by this approach will be presented for the structures shown in Fig. 1. As an example, results for two of these structutes will be presented here. The equivalent circuit for the open circuit microstrip transmission line is shown in Fig. 2(a). The shunt capacitance varies with frequency and is equivalent to an excess length $\Delta\ell_{oc}$ given by

$$\frac{\Delta\ell_{oc}}{h} = \frac{C_{oc}}{w} \frac{\omega_o}{\beta} Z_o \frac{w}{h} \qquad (2)$$

where ω_o = operating frequency, $\beta = 2\pi/\lambda_g$ = propagation constant and Z_o is the characteristic impedance in the microstrip transmission line. The propagation constant and the excess length are evaluated as functions of frequency from the standing waves of the amplitude of the current on the microstrip. Similarly, the characteristic impedance Z_o is calculated with very good accuracy using the values of the computed current in a simplified model of the microstrip transmission line (9). The values for the characteristic impedance, the guided wavelength, the excess length and the shunt capacitance as functions of the frequency are shown in Figs. 3 and 4. Similarly, the equivalent circuit for the gap discontinuity (Fig. 2b) is evaluated by considering even (magnetic wall) and odd (electric wall) mode excitation. The even and odd mode gap capacitances are evaluated from the even and odd mode excess lengths $\Delta\ell_{e,o}$ as shown below.

$$\frac{C_{e,o}}{w} = \frac{\Delta\ell_{e,o}}{h} \frac{\beta}{\omega_o} \frac{1}{Z_o} \frac{h}{w} \qquad (3)$$

The capacitances C_p and C_g of the equivalent circuits are given by

$$C_p = \frac{C_e}{2} \qquad (4)$$

$$C_g = \frac{1}{2}(C_o - C_p) \qquad (5)$$

and they are shown graphically in Figs. 5 and 6 for different operating frequencies. The results presented in this summary are for microstrip transmission lines with w/h = 1 on a 0.6 mm Alumina substrate ($\varepsilon_r = 9.6$). They are in a very good agreement with previously published results for low frequencies.

A wealth of results will be presented for the structures of Fig. 1. Emphasis also will be placed on the radiation losses of these discontinuities.

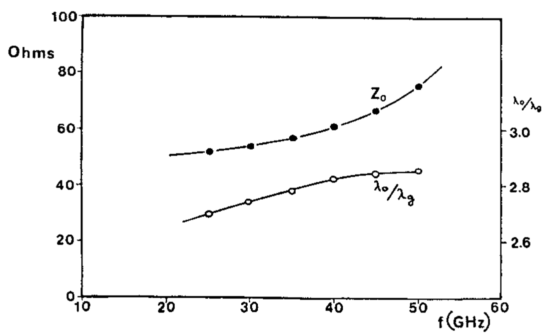


Figure 3: Characteristic Impedance and Guided Wavelength as Functions of Frequency (h = 0.6 mm, ε_r = 9.6, w/h = 1).

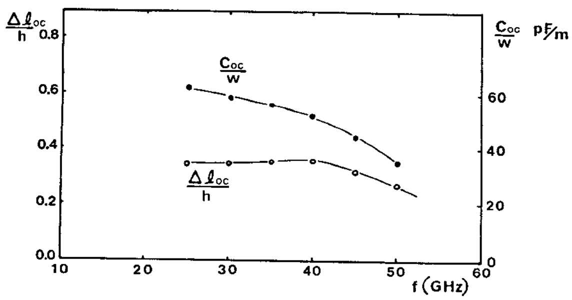


Figure 4: Open Circuit Capacitance and Excess Length as Functions of Frequency (h = 0.6 mm, ε_r = 9.6, w/h = 1).

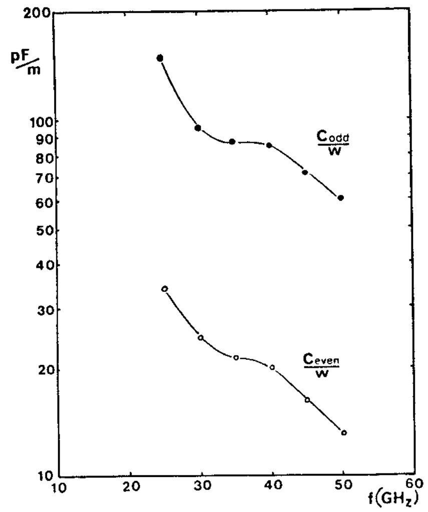


Figure 5: Even and Odd Mode Gap Capacitances as Functions of Frequency (h = 0.6 mm, ε_r = 9.6, w/h = 1, s/h = 0.3762).

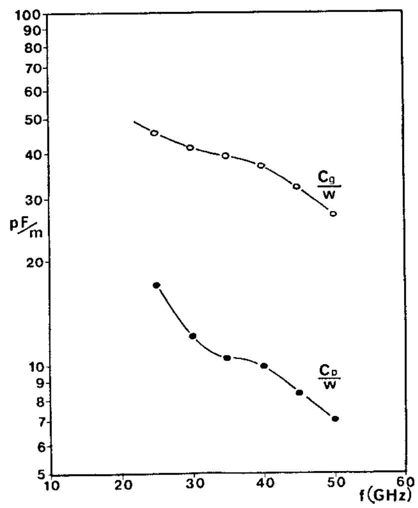


Figure 6: Equivalent Circuit Gap Capacitances as Functions of Frequency (h = 0.6 mm, ε_r = 9.6, s/h = 0.3762).

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