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# MODELING OF HIGH FREQUENCY MMIC PASSIVE COMPONENTS

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**Abstract**

The fullwave Green's function and Method of Moments approach is recognized as the most general and accurate solution method to the problem of high frequency modeling of MMIC passive circuit components. However, the computer codes derived on the basis of that method are usually computationally intensive. Several numerical techniques that significantly improve both the accuracy and efficiency of the method are presented. The numerical procedures do not reduce the generality of the method. The numerical technique is described as it has been applied to the problem of the enclosed or boxed microstrip structure. Results for the closed structure open-end and step discontinuities are presented.

## 1 INTRODUCTION

The successful design of high frequency MMIC circuits requires highly accurate models of the individual passive components. Moreover, to be practical, the solutions must be numerically effcient. The Green's function and Method of Moments approach is very general. Because the fullwave Green's function is used, the solution includes all the significant high frequency phenomena, such as dispersion and the waveguide mode effects. (The space waves and surface waves of the open structure are related to the waveguide modes of the closed structure.) As indicated, the Green's function Moment Method is very general; however, the application of the method is restricted by practical considerations related to the numerically intensive nature of the solutions. To address this problem, several simple but powerful numerical techniques have been developed that can be incorporated in the general Green's function. These techniques result in greatly improved numerical efficiency and accuracy. They have been applied to the closed structure, which consists of the circuit element in rectangular waveguide.

Although the method, in theory, can address a complete circuit, this is not practical or efficient. One would quickly exhaust available computer resources. Rather the general circuit problem can be addressed as an interconnection of interacting discontinuity elements. The individual element models, in the form of Z, Y, or S matrices, can be made general enough to include all the significant high frequency phenomena. It is assumed that the terminal planes of the individual circuit component (discontinuity) are at a sufficient distance from any significant junction features so that all the higher order fields caused by the discontinuity have decayed. In all that follows the assumption is that the terminal planes are sufficiently removed from the junction(s), such that the connection to the balance of the circuit can be properly described in terms of a dominant guided mode. For high frequency applications, each component module can be characterized as a frequency dependent module.

The junction scattering parameters can be extracted by various ways. One approach uses a subdomain basis and a delta-gap excitation [1], which required the interpretation of a standing wave pattern in order to extract the dominant behavior. This process generally introduces non-negligible errors. The adopted method uses a combination of entire domain and subdomain bases [2]. Away from the junction region the current is the sum of two modified traveling waves, the incident and scattered traveling waves. The advantage of this method is that the scattering parameters are found directly from the moment method solution.

## 2 GREEN'S FUNCTION

The geometry of interest is shown in Figure 1. It consists of a three layer structure with uniaxial permittivities. Each layer is characterized by $\hat{\epsilon}_i$ with layer thickness of $s_i$ where $i = 1,2,3$. Side walls are set at $x = \pm a$ where the wall conditions can be mathematically chosen as electric or magnetic walls. When the material is uniaxial, the complete field configuration can be reproduced by a combination of $TE_y$ and $TM_y$ Fourier modes since the Helmholtz equation is analytically separable. The formulation of the problem can be carried out separately for the $TE_y$ and $TM_y$ Fourier modes. The superposition of these Fourier modes can then be used to reproduce the actual fields or currents of the system. The axial direction, also the current direction for the microstrip case, is labeled as the $y$ direction and the geometry is considered to be open for this direction. Mathematically the Fourier modes can be described as discrete in the $x$ direction and continuous in the $z$ direction. The general summation and integral form [3] for a field term is:

$$\vec{\Psi}(x,y,z) = \sum_{n=0}^{\infty} \int_{-\infty}^{+\infty} \mathbf{\Omega}(k_{zn}, y, k_z) \cdot \tilde{\vec{\Phi}}(k_{zn}, k_z) e^{jk_z z} sc(k_{zn}x) dk_z, \quad (1)$$

where $sc(k_{zn}x)$ is defined as the *sine* or *cosine* Fourier transform. $\vec{\Phi}$ and $\vec{\Psi}$ are defined as either current or electric field vectors. The dyadic Green's function is represented by $\mathbf{\Omega}(k_{zn}, y, k_z)$ in the Fourier transform domain.

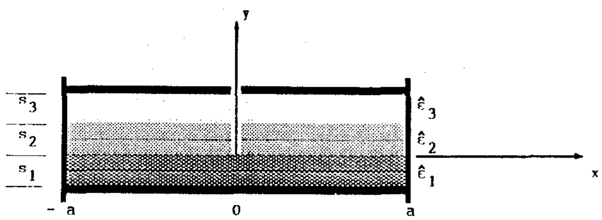



Figure 1: Geometry of Enclosed Guiding Structure

## 3 FOURIER SUMMATION

The problem is first formulated for the 2-Dimensional cases, where the current/field depends only on the cross section of the geometry.

$$\tilde{z}_{m'm}(y, k_z) = \sum_{n=0}^{\infty} \tilde{\vec{\Phi}}^*_{m'}(k_{zn}, k_z) \cdot \mathbf{\Omega}(k_{zn}, y, k_z) \cdot \tilde{\vec{\Phi}}_m(k_{zn}, k_z) \quad (2)$$

The closed form expression is found by obtaining the asymptotic expression of the dyadic Green's function. The type of closed form is determined by the current/field expression and dyadic Green's function form. The efficiency and the accuracy of the computation is improved drastically by employing closed form expressions. The above expression is also used to find the eigenfunctions and eigenvalues of the system.

When the expression above is evaluated for a given integration variable $k_z$, the infinite sum exhibits pole-like behavior on the real and imaginary axes (shown in Figure 2). These pole-like behaviors are due to the waveguide modes. If the integration path is deformed and chosen in the complex plane, the overall function behavior becomes smooth. This smooth behavior allows us to employ an interpolation technique without degrading the accuracy of the evaluation of the infinite sum.

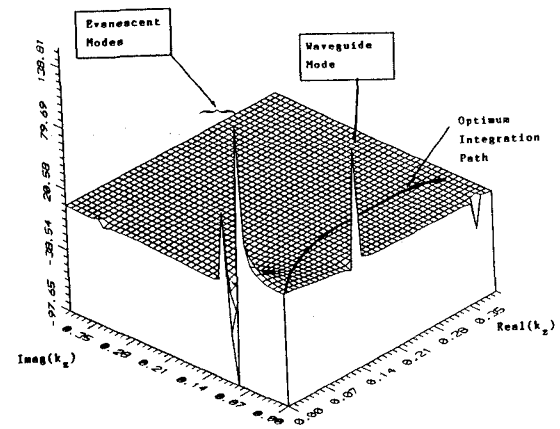



Figure 2: Behavior of Infinite Summation versus Complex Integration Variable $k_z$

## 4 NUMERICAL RESULTS

When the microstrip devices are constructed, it is almost always necessary to have covers in order to protect the devices from the environment and from electromagnetic interference. The protection can include side walls and a top cover. It is necessary to understand the resonance nature of the enclosure since the characterization of the discontinuities may also strongly depend on the enclosure. A cross section of the enclosure and substrate then appears as a rectangular waveguide cross section with material layers. This structure will support waveguide modes, both propagating and evanescent. Strong coupling is possible between these modes and the circuit element. When this strong coupling occurs, the behavior of the current distribution on the strip conductors may not be as predicted by the open structure analysis.

### 4.1 Open-end Microstrip Line

The open-end is the simplest microstrip discontinuity. It is also fundamental in that with the adopted solution method it involves all the significant phenomena associated with the more complex components, in particular, the phenomena of coupling with the waveguide modes of the boxed structure at high frequencies. The excess length computation for the open-end microstrip in an enclosure is shown in Figure 3.

### 4.2 Step Discontinuity of the Microstrip Line

The foregoing analysis and the numerical results indicate that the transverse current is negligible. This is because of the fact that there is no mechanism to excite strong transverse currents for the open-end and symmetric gap discontinuities (when the side walls are placed sufficiently far away from the strip element.) However, the step discontinuity problem, because of its current flow in the vicinity of junction, requires the transverse current distribution. The current distribution in the vicinity of the step discontinuity is plotted in Figure 4. The frequency dependent scattering parameters are also plotted in Figure 5 where $w_p/w_s$ ratio is 1 : 5.

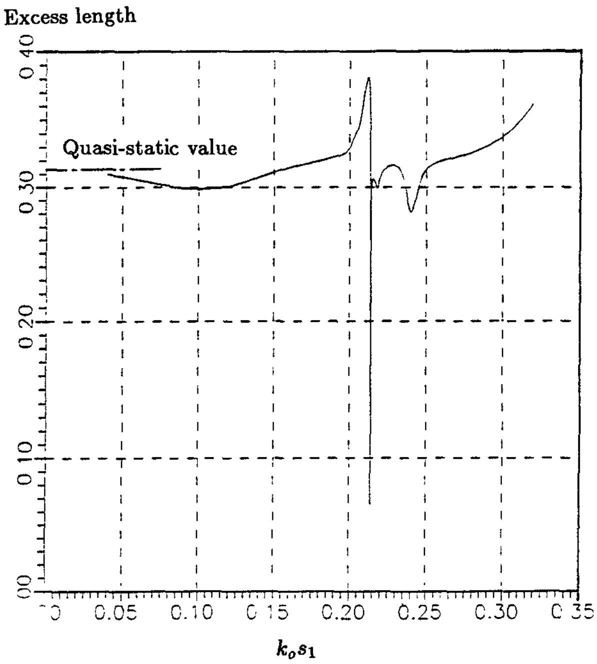



Figure 3: Frequency Dependent Excess Length. $\epsilon_{r1} = 10.0$, $\epsilon_{r2} = \epsilon_{r3} = 1.0$, $w = 1.0$, $s_1 = 1.0$, $s_2 = s_3 = 10.0$, and $b = 21.0$.

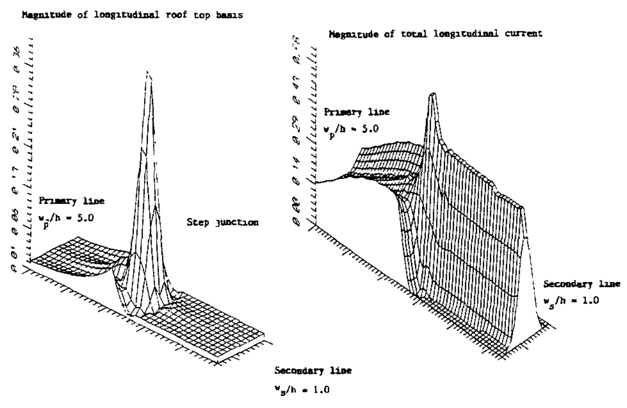
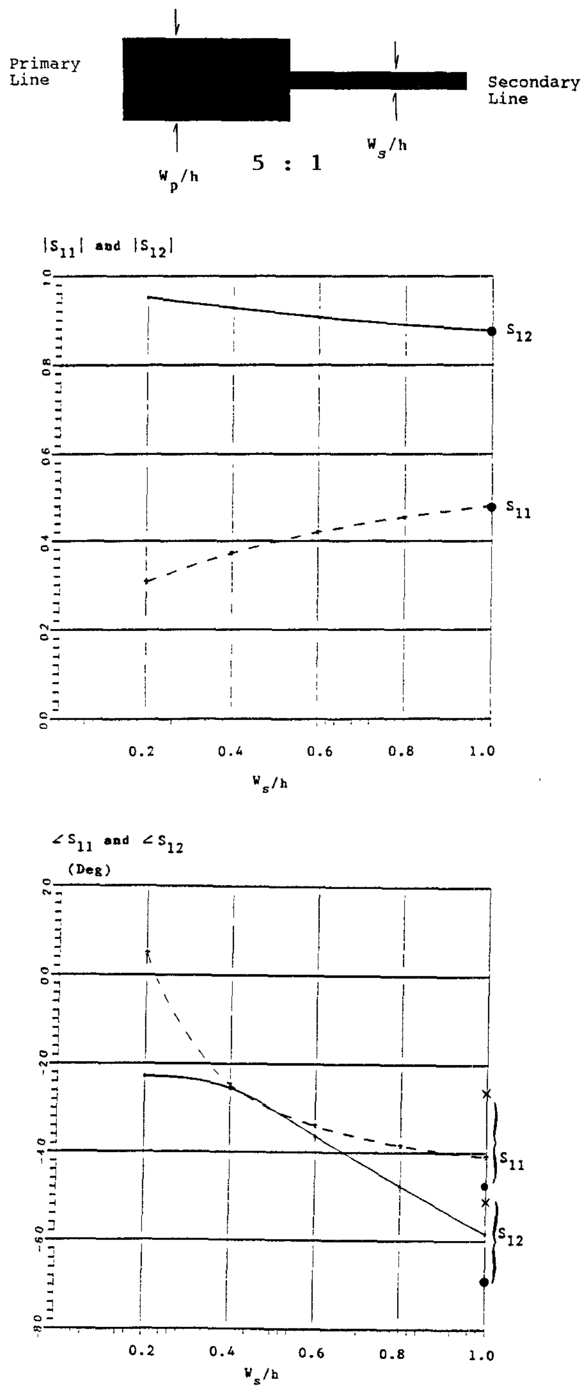



Figure 4: Current Distribution in the vicinity of step discontinuities. $\epsilon_{r1} = 10.0$, $\epsilon_{r2} = \epsilon_{r3} = 1.0$, $w_p = 5.0$, $w_s = 1.0$ $s_1 = 1.0$, $s_2 = s_3 = 10.0$, and $b = 21.0$. Strips are centered in the enclosure configuration.




• : Koster and Jamsen

× : R. Mehran

Solid and dashed lines : Current method

Figure 5: Frequency Dependent Characteristics of the Step Discontinuity. $\epsilon_{r1} = 10.0$, $\epsilon_{r2} = \epsilon_{r3} = 1.0$, $w_p : w_s = 5 : 1$, $s_1 = 1.0$, $s_2 = s_3 = 10.0$, and $b = 21.0$.

## 5 CONCLUSION

An very efficient technique for the evaluation of the sums and integrals that arise in the Green's-Function-Moment-Method solution to the problems of MMIC passive components has been described. The methods make it practical to apply the Green's function method to more complex components.

## 6 REFERENCE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