# MULTIPLE ARBITRARY SHAPE VIA-HOLE AND AIR-BRIDGE TRANSITIONS IN MULTILAYERED STRUCTURES

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## ABSTRACT

This paper presents a methodology for the design of multiple via-hole and air-bridge transitions of arbitrary shape in multilayered multi-port microstrip circuits. Application of multiple via holes to the design of microstrip filters and other devices will be presented. To describe properly the current along the vertical post, the simple pulse function with a triangular cross section is used. Circular, rectangular and triangular vertical transitions are analyzed and optimized for practical applications. The developed algorithms are much faster than existing softwares. The Green's function applies for any distance between and any location of field and source points.

## 1 INTRODUCTION

Compact size and larger scale integration of electronic devices have been driving the trend toward a multilayered interconnection system. Via holes and other vertical shunt posts, such as bond wires and air bridges, are increasingly important in MIC/MMIC design. Via holes are used to connect parallel microstrip lines for signal transmission between different levels. Vias can be modeled by lumped circuit elements at lower frequencies. The equivalent circuits of vias based on the quasi-static analysis have been investigated by Wang *et al.* [1]. At higher frequencies the propagation characteristics of via holes have a stronger effect on the performance of devices, therefore, rigorous analysis is necessary to predict frequency response correctly. Full-wave analysis and modeling has been carried out by the finite-difference time-domain (FD-TD) approach [2], the transmission line matrix method [3], the mode-matching technique [4], the spectral-domain analysis (SDA) [5, 6], and the matrix-penciled moment method [7]. Most of these analyses are limited to rectangular discretization or the thin wire approximation. In this paper, a combined mixed-potential integral equation (MPIE) and electric-field integral equation (EFIE) technique is presented to model vias of arbitrary shape. The MPIE method [8] combined with the triangular patch expansion function [9] has been proven efficient to model arbitrarily-shaped planar geometries [10]. To model the vertical current along the vias, the simple pulse function with a triangular cross section is used to approximate the current density.

The combined MPIE-EFIE method presented here starts from meshing the whole microstrip geometry with small triangular facets. Basically the MPIE formulation is used to evaluate the self-coupling terms of planar subdomains as well as the mutual-coupling terms between planar and vertical cells. The self-coupling submatrix due to vertical posts is calculated from the EFIE formulation. These will be detailed in the next section.



## 2 COMBINED MPIE-EFIE METHOD

A generalized multi-layered microstrip circuit is shown in Fig.1. Both the upper and lower ground planes are removable to represent either a shielded, semi-open, or open structure.

Galerkin's procedure is applied to solve for the current distribution on the microstrips, vias and air bridges. The triangular patch function [9] is chosen to expand the planar current of



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arbitrarily-shaped geometries. To model the vertical current along the vias, a vertical volume current function with a triangular cross section, shown in Fig. 2, is used in this analysis. This basis function is modified from the similar function with a rectangular cross section [5]. The planar current ($\vec{I}_H$) and vertical current ($\vec{I}_V$) can be expanded as

$$\vec{I}_H = \sum_{n=1}^{N_H} A_n \vec{tri}_n \quad , \quad \vec{I}_V = \sum_{n=1}^{N_V} B_n \vec{ver}_n \qquad (1)$$

where $\vec{tri}$ and $\vec{ver}$ are two different basis functions in Fig. 2, respectively. $\vec{ver}$ is defined along the $\hat{z}$ direction with amplitude $1/d_z$. After testing with the same function, a system of linear equations can be obtained as

$$\begin{bmatrix} [Z_{HH}] & [Z_{HV}] \\ [Z_{VH}] & [Z_{VV}] \end{bmatrix} \begin{bmatrix} [A] \\ [B] \end{bmatrix} = \begin{bmatrix} [V] \\ [0] \end{bmatrix} \qquad (2)$$

$[Z_{HH}]$, $[Z_{HV}]$, $[Z_{VH}]$ and $[Z_{VV}]$ are self and mutual coupling submatrices between two different basis functions. $[Z_{HH}]$ is presented in [10] based on MPIE formulation. The self coupling term $[Z_{VV}]$ can be expressed from EFIE as the following form:

$$Z_{VV} = \frac{1}{d_z d_{zs}} \int \int [\ G_E^{zz\prime}\ ]\ dS\ dS_s \qquad (3)$$

where $G_E^{zz\prime}$ is the Green's function analytic $\hat{z}\hat{z}$ component for the electric-field after performing the integration over $z$ and $z_s$. The Sommerfeld integral of $G_E^{zz\prime}$ is applicable since the integration over vertical axis changes the near-field behavior as $O(1/\rho)$.

The mutual coupling terms $[Z_{HV}]$ and $[Z_{VH}]$ are symmetric to each other. $[Z_{VH}]$ can be written as

$$Z_{VH} = \frac{1}{d_z} \int \int \{\ [j\omega G_A^{vh\prime} + \frac{G_q(z^+) - G_q(z^-)}{j\omega}\ ] \ (\nabla_s \cdot \vec{tri}_n)\ \}\ dS\ dS_s \qquad (4)$$

where the Green's function $G_A$ and $G_q$ of vector and scalar potentials from MPIE are used. Instead of using $G_A^{zx}$, we introduce $G_A^{vh}$ with the relationships $G_A^{zx} = \partial G_A^{vh}/\partial x$ and $G_A^{zy} = \partial G_A^{vh}/\partial y$. Similarly $G_A^{vh\prime}$ denotes the analytic expression of $G_A^{vh}$ after the integration over the vertical length of testing basis $\vec{ver}_m$. The interaction between current basis functions can be eliminated by using the vector identity, so only charge distribution $(\nabla_s \cdot \vec{tri}_n)$ is involved in Eq. (4). Once the matrix elements are evaluated, the current distribution can be solved, and all the circuit parameters can be obtained.

## 3 APPLICATIONS

**Example I.** The first example is an infinite microstrip line grounded by a via, which was presented in [11] from the planar waveguide model. The structure and analyzed results are shown in Fig. 3. Three different simulations are investigated: rectangular via expanded by vertical current basis with a rectangular cross section, rectangular via expanded by vertical current basis with a triangular cross section, and circular via expanded by vertical current basis with a triangular cross section. All cases show that the current flows down to the ground plane and a good short can be achieved over a broad frequency range.

**Example II.** For verification of our method, the spiral inductor is analyzed and compared to the spectral-domain analysis and measurement [5]. The rectangular air bridge is composed of two triangular cells. Fig. 4 demonstrates the excellent agreement of $|S_{21}|$ between this analysis and the measurement. We also obtain good agreement of other scattering parameters, which will be shown during the presentation.

**Example III.** Several multiple via hole filter designs will be discussed. As an example the bandpass filter configuration, shown in Fig. 5 [12] is considered. Two mitered-bend lines with rectangular pads are connected to the main transmission line. Each pad is grounded by a circular via hole with 100 $\mu$m diameter. A triangular mesh is also plotted in Fig. 5. 18 triangular cells are used to expand vertical current of each via hole. The simulated results are shown for lossless layers, perfectly conducting microstrip lines in Fig 5. The resonant frequency is predicted very well at 13.5 GHz.

## 4 CONCLUSIONS

In this analysis, the combined MPIE-EFIE technique is developed to model via-hole as well as air-bridge transitions in multilayered structures. With the help of triangular patch function and vertical volume current basis with a triangular cross section, arbitrarily-shaped microstrips and via holes can be analyzed accurately and efficiently.

## 5 ACKNOWLEDGEMENTS

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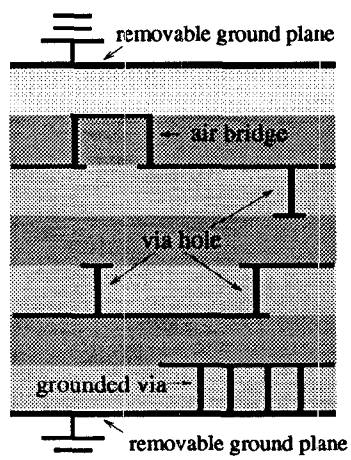


Figure 1: Generic via-hole and air-bridge transitions in a multilayered medium.

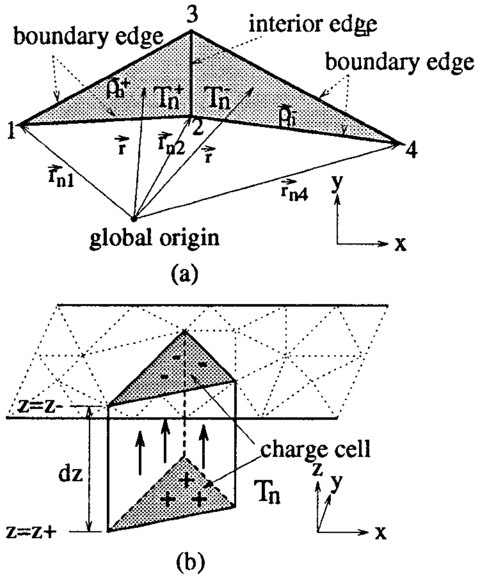


Figure 2: Current expansion functions. (a):triangular patch function ($\vec{tri}$) for planar current; (b):vertical volume current function ($\vec{ver}$) for current along vias.

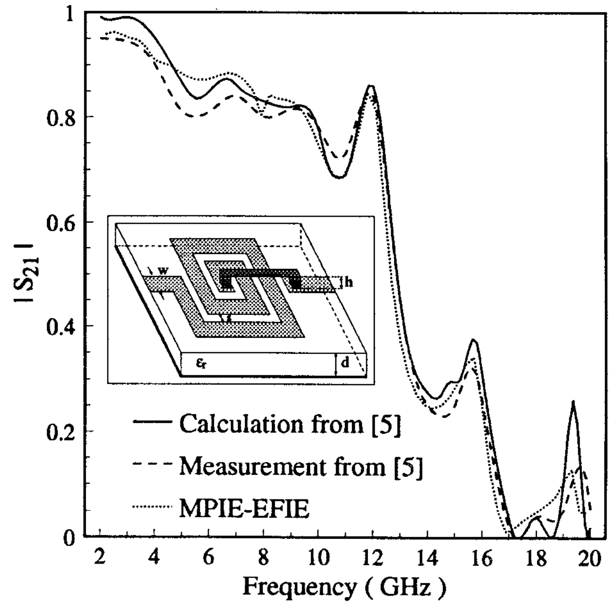


Figure 4: Transmission coefficient of spiral inductor with an air bridge. $\epsilon_r$ = 9.8, d = 0.635 mm, w = 0.625 mm, h = d/2, s = w/2.

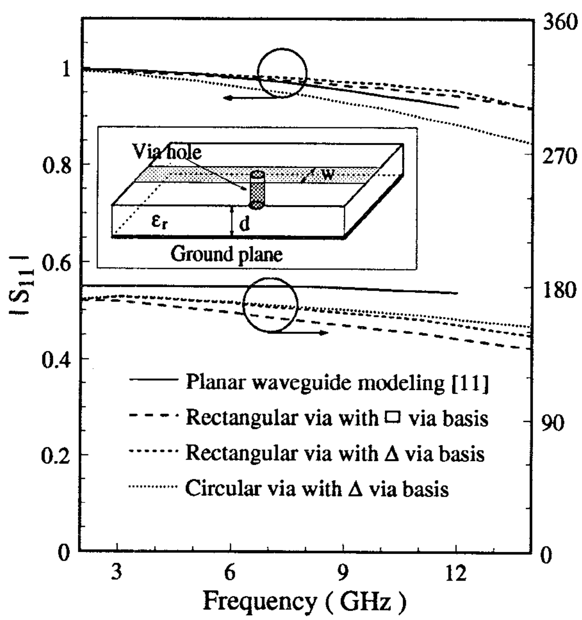


Figure 3: Magnitude and phase of $S_{11}$ for an infinite microstrip line with a grounded via. $\epsilon_r$ = 10.0, d = 0.635 mm, via diameter = 1.22 mm, w = 3 mm.

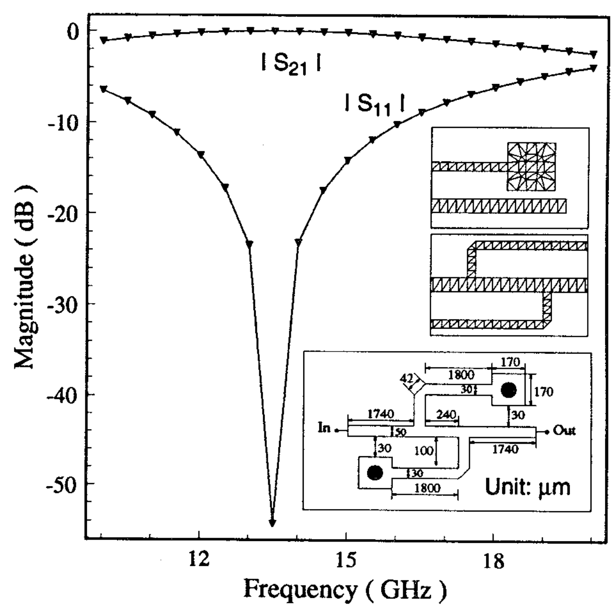


Figure 5: Reflection and transmission coefficients of bandpass filter with two via-hole grounds. $\epsilon_r$ = 12.9, d = 125 $\mu$m, via diameter = 100 $\mu$m.