3-D MODELING OF INTERCONNECTS IN MMICS BY THE METHOD OF LINES

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Abstract

A new eigenmode algorithm, based on the method of lines, is presented for full-wave analysis of real 3-D structures. Finite conductor thickness, finite substrate and very short or long interconnection are rigorously modelled. S-parameters of air bridges, via holes and bead transitions investigated agree very well with literature.

1 Introduction

In the design of planar integrated circuits various types of interconnections between different parts of the devices are indispensable. In packed structures the transmission lines in different layers can be connected by via holes, a connection to a chip can be done by air bridges or bondwires and, if single parts of the structure are encapsulated, special forms of transitions through a wall are needed. All these transitions are three-dimensional, even though the connected circuits are planar. As these discontinuities cause reflections and disturb the propagation, the intended electrical performance of the microwave device may be severely deteriorated. Hence an accurate analysis of a wide class of complex three-dimensional structures encountered in practice is necessary.

Some of these interconnecting structures have been investigated by various methods: FD [1], FEM [2], FDTD [3], TLM [4] or SDA [5]. In these methods problems may occur in the modeling of a finite substrate, a finite conductor thickness or in the analysis of very short or long interconnections. Additionally, in some methods artificial boundaries have to be provided at the input and output. This paper aims at presenting a new algorithm, based on the method of lines (MoL) for full-wave analysis of real 3-D structures eliminating the difficulties relevant to above methods.

It has been shown in numerous papers, that the MoL is highly suitable for analysis of planar waveguides [6]. In the design of microwave circuits, however, the MoL has been applied mostly to planar structures with few discontinuities, using a 2-D discretization perpendicular to the propagation direction. Recently, single planar discontinuities have been studied by the MoL, using discretization lines in propagation direction [7]. In this paper this new approach is substantially extended for the analysis of cascaded discontinuities with 3-D metallizations and finite substrate.

2 Theory

The first step in the analysis is a suitable division of the structure into a series of sections with a longitudinally homogeneous distribution of dielectric media and metallization (see. Fig. 1).

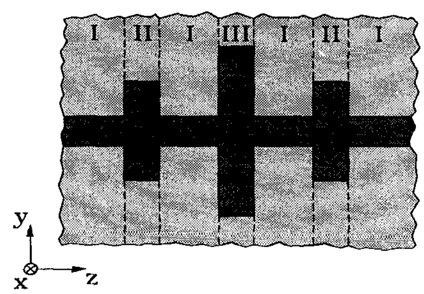

Figure 1: Top view of an example

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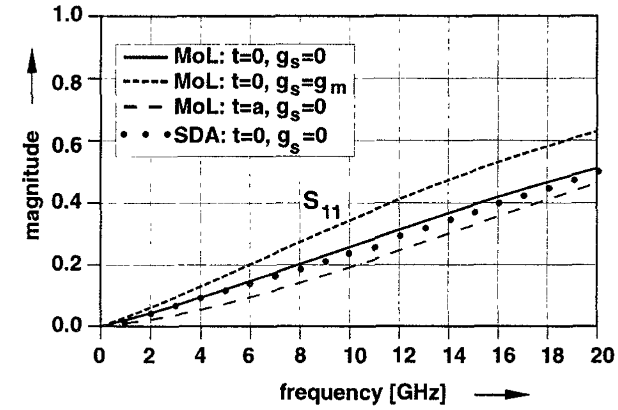

Figure 9: Reflection coefficient in comparison to [5]

For all three examples our results are in good agreement with the results obtained by other methods.

4 Conclusion

The main features of the proposed method can be summarized as follows: An advantage of this procedure is the analytical calculation in z direction. There is no need for special boundaries at the input and output. The size of the discretization window depends only on the cross-section, which is extremely favorable for long structures or structures with significant differences in the length of the sections. In the analysis of the structure all eigenmodes are considered. High accuracy of the calculation is achieved by matching the field components instead of the modes. The use of different boundary conditions for the cross-section makes the investigation of open and shielded structures possible. The scattering parameters are calculated directly, with an analytical distinction between the different modes. The easy mathematical description and the general formulation allow the analysis of a great variety of structures with the same program.

Three different 3-D structures have been analyzed and a good consistency with results published in literature can be stated.

References

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The finite conductor thickness and the finite substrate are modelled by a two-dimensional variation of the permittivity and metallization within the cross-section (see. Fig. 2).

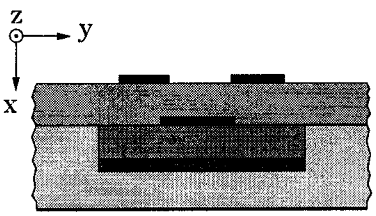

Figure 2: Cross-section of an example

In every section the electromagnetic field is derived from a vector potential $\mathbf{\Pi}$. It is important that the potential has the same vector components as the gradient of the permittivity of the material ε_r.

$$\mathbf{\Pi} = \phi_x \cdot \mathbf{e}_x + \phi_y \cdot \mathbf{e}_y \tag{1}$$

Only this general solution leads to a consistent system of coupled differential equations for the potential components ϕ_x and ϕ_y.

The cross-section of each section is now subjected to a two-dimensional discretization, the solution in propagation direction being analytical. Considering the boundary conditions at the metallization leads to a reduction of the difference operators for both directions of the cross-section. Transforming the discretized wave equation to principal axes gives a system of uncoupled differential equations

$$\frac{\partial^2}{\partial z^2}\hat{\hat{\mathbf{\Pi}}} - \hat{\mathbf{\Gamma}}^2\hat{\hat{\mathbf{\Pi}}} = \mathbf{0} \tag{2}$$

with

$$\hat{\mathbf{\Pi}} = \hat{\mathbf{T}}\,\hat{\hat{\mathbf{\Pi}}} \qquad \hat{\mathbf{T}}^{-1}\hat{\mathbf{Q}}\hat{\mathbf{T}} = \hat{\mathbf{\Gamma}}^2 \tag{3}$$

where the vector $\hat{\mathbf{\Pi}}$ contains the discretized and reduced potential components of ϕ_x and ϕ_y. The solution for the transformed potential is given by

$$\hat{\hat{\mathbf{\Pi}}}(z) = e^{-\hat{\mathbf{\Gamma}}z}\mathbf{A} + e^{\hat{\mathbf{\Gamma}}z}\mathbf{B} \tag{4}$$

or

$$\hat{\hat{\mathbf{\Pi}}}(z) = \cosh\left(\hat{\mathbf{\Gamma}}z'\right)\mathbf{A}' + \sinh\left(\hat{\mathbf{\Gamma}}z'\right)\mathbf{B}' \tag{5}$$

with the position of the different coordinate systems in z given in Fig. 3.

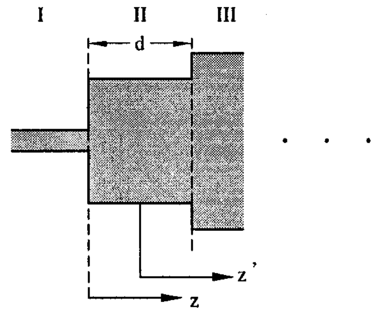

Figure 3: Position of the coordinate systems

In the outer sections the first formulation is chosen. $\mathbf{A}$ and $\mathbf{B}$ denote the amplitudes of the forward and backward going waves and $\hat{\mathbf{\Gamma}}$ is a diagonal matrix, containing the normalized propagation constants in z direction, including evanescent and complex modes. For the inner sections the second formulation is numerically favorable.

Matching the tangential field components at all interfaces leads to the generalized scattering matrix of the whole structure under study. For a given input – one or several of the propagating modes – scattering parameters and field distributions are calculated directly.

3 Results

To demonstrate the versatility and accuracy of the new approach, which allows investigation of a great variety of 3-D structures using the same program, three different examples of transitions are investigated and compared with results published in literature.

The first example is a hermetic bead transition (Fig. 4), frequently encountered in encapsulated circuits to provide physical protection and electromagnetic shielding. The interconnecting coaxial line is approximated by a rectangular 50 Ω stripline as in [3]. The scattering parameters are plotted vs. frequency in Fig. 5.

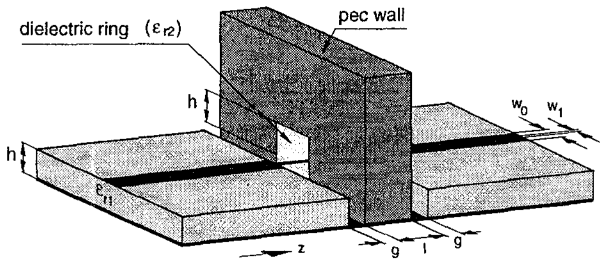

Figure 4: Geometry of the hermetic bead transition
$w_0 = 0.55$ mm, $w_1 = 0.21$ mm, $\varepsilon_{r1} = \varepsilon_{r2} = 10.8$
$h = 0.635$ mm, $g = 0.4$ mm, $l = 1.5$ mm

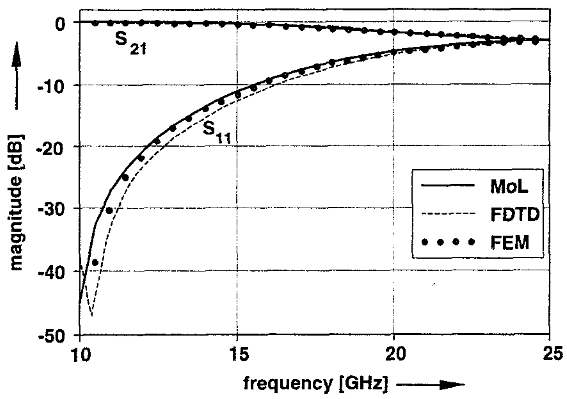

Figure 5: Scattering parameters of the bead transition

The second example (Fig. 6) is a via hole, used for the connection of two 50 Ω striplines arranged in a three layer package [2]. The structure is divided into five regions, containing several metallizations of finite thickness. Fig. 7 is a plot of the S-parameters of the transition vs. frequency.

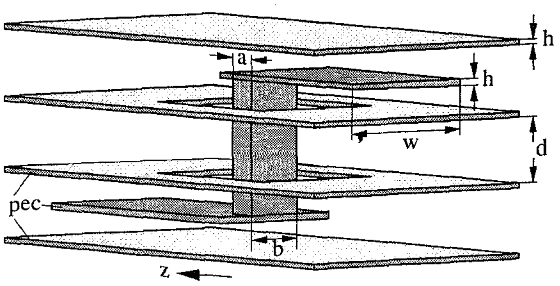

Figure 6: Rectangular via connection of two striplines
$w = 1.25$ mm, $h = 0.25$ mm, $d = 1.25$ mm,
$a = 0.5$ mm, $b = 0.75$ mm

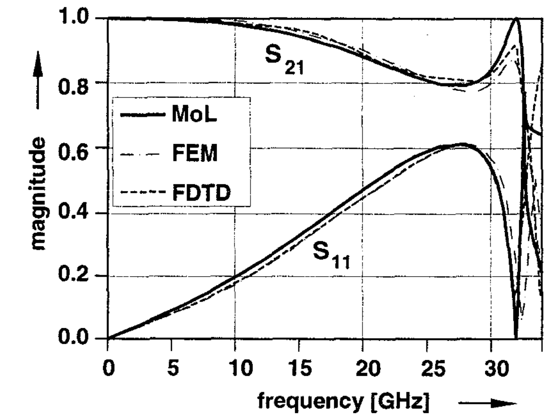

Figure 7: S-parameters of the via connection

The third structure analyzed with the new algorithm is the connection of two microstrip lines by a bondwire (Fig. 8), where the horizontal part of the wire is modelled as infinitely thin metallization [5]. Additionally, the influence of an air gap and the bondwire thickness on the circuit performance has been investigated. In Fig. 9 the computed reflection coefficient for different geometries is compared with the results of [5], showing the influence of finite gap width and finite bondwire thickness.

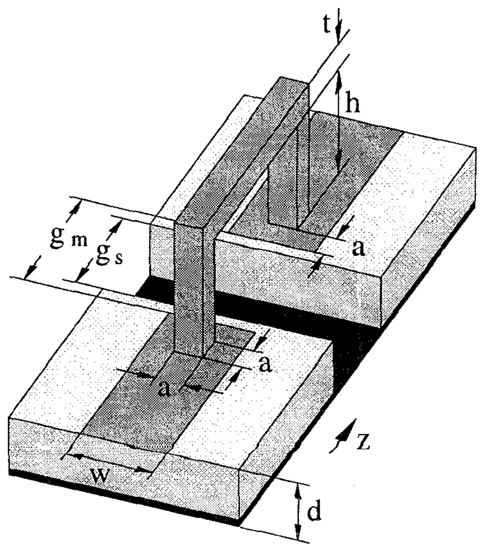

Figure 8: Schematic view on the interconnection by a bondwire
$w = 0.635$ mm, $a = 0.211$ mm, $\varepsilon_r = 9.8$,
$d = 0.635$ mm, $h = 0.211$ mm, $g_m = 0.635$ mm