Full-Wave Modeling of Via Hole Grounds in Microstrip by Three-Dimensional Mode Matching Technique

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ABSTRACT

A rigorous full-wave analysis of microstrip via hole grounds is performed using a three-dimensional mode-matching method by means of a suitable segmentation technique. Theoretical results are compared with measured data showing an excellent agreement. Comparisons with available approximate methods have also been made to exploit their limits of validity.

1. Introduction

The use of shunt posts in microstrip transmission lines is now a common practice in microwave and mm-wave hybrid and monolithic circuits. Via holes are used in multilayer printed circuit boards to connect by vertical pathways (vias) microstrips of different layers. They are also used in single layer circuits to obtain wide-band short circuits (via hole grounds).

The accurate characterization of the microstrip via hole discontinuity is an important issue in the successful design of the circuit. Previous attempts to model this discontinuity have been limited to the quasi-static regime [1], or have modeled the microstrip as a planar waveguide, i.e. a rectangular waveguide structure with sidewalls composed by a fictitious perfect magnetic conductor [2]. Both approaches are approximate and fail as the frequency increases. Moreover, they cannot take into proper account the possible coupling due to vias on different lines but on the same printed circuit board.

In this paper we present a rigorous and efficient method for the full-wave analysis of the microstrip-via hole ground discontinuity, based on the 3-D version of the mode-matching technique introduced in [3],[4]. Theoretical results are compared with measured data and with approximate data available in the literature [1, 2] or in commercial packages.

2. Method of Analysis

A 3-D view of a via hole ground is sketched in Fig. 1. The microstrip is enclosed in a metallic box of suitable size, i.e. such as not to perturb the reactive fields in the proximity of the microstrip via hole discontinuity. It could be noted that, because of the fabrication procedure [5], the via hole is generally cone-shaped. In the EM modeling of such a discontinuity, however, a considerable reduction of the complexity of the problem is achieved considering the via as a cylinder of rectangular cross-section. This is assumed to introduce only minor alterations.

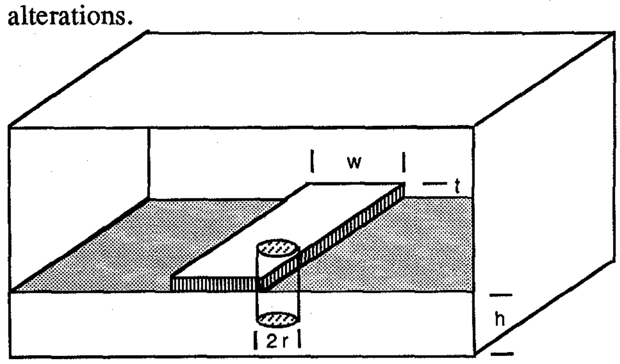

Fig. 1 Geometry of the via hole ground.

Taking advantage of the symmetry along x and z and by properly placing electric and magnetic walls, we may consider just one quarter of the structure, as depicted in Fig. 2a. This structure has been further segmented into four parallelepipedal regions (Note that the finite thickness of the metal

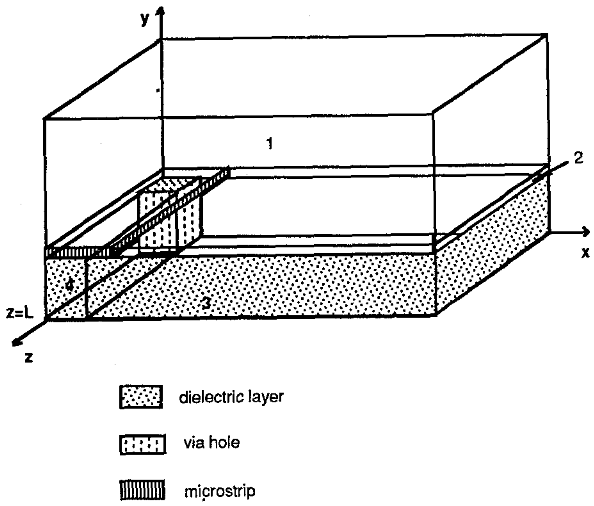

Fig. 2a Structure used for the analysis

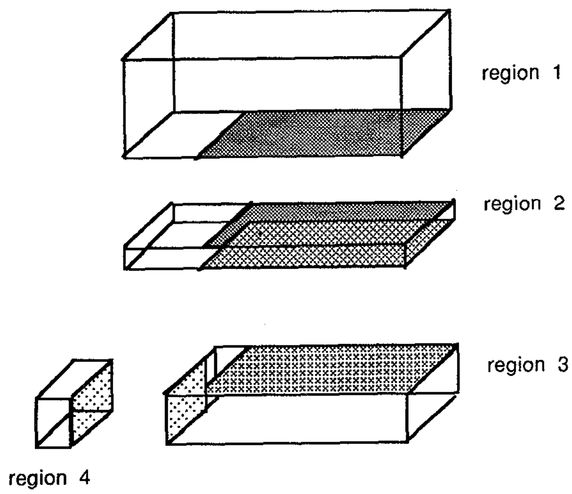

Fig. 2b Segmentation of the structure shown in fig. 2a.

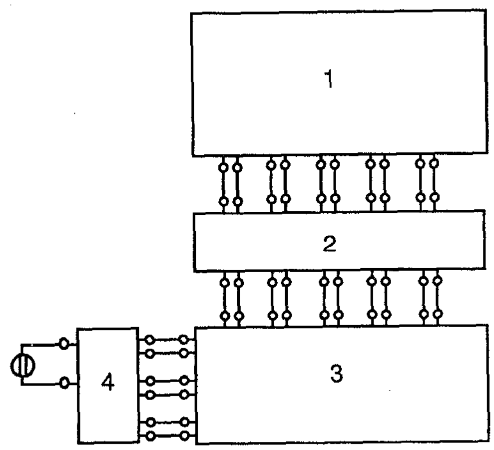

Fig. 2c Network description of the via hole

strip has been taken into account). In particular region 1 corresponds to the region above the strip, region 2 is the volume aside the strip, and regions 3, 4 are in the dielectric layer. The various regions interface each other, and are shown separately in fig. 2b.

Making use of the Love's field equivalence theorem [6], an electric wall with unknown magnetic currents can be placed at each interface between adjacent regions. In this manner, each region is bounded by either electric or magnetic walls. Fast convergent modal series expansions for the Green's function in each region have been adopted [4]. Finally, by equating the tangential components of the magnetic field at the various interfaces we recover a set of integral equations in the electric fields at the interfaces. Final solution is obtained by application of Galerkin's method.

From a network point of view each region is described by means of a generalized admittance matrix. The four admittance matrices are then interconnected (Fig. 2c) to enforce the continuity of the currents, i.e. of the tangential components of the magnetic fields at the interfaces.

For the computation of the parameters of the discontinuity, the repeated analyses of a resonator with differenty dimensions implied by the transverse resonance technique [7], can be avoided by solving a deterministic rather than an eigenvalue problem. This is done considering an impressed source which generates the EM field in the structure.

In our case, an E-field distribution has been impressed at the front side (z=L) of region 4. In the proximity of the source as well as near the via-hole discontinuity higher order modes are excited, but, provided that the structure is long enough (along z), only the fundamental mode exists in the central region while higher order modes are died out. This makes it possible to readily compute the scattering parameters of the microstrip via hole discontinuity by evaluating the E-field distribution along z in the central region.

Observe that a conventional mode matching analysis of the structure of Fig. 2, although feasible, would require the previous evaluation of modal spectra containing also complex modes. This would have involved a much higher computer expenditure.

3. Results

An excellent agreement between the theoretical (continuous line) and measured (dotted line) scattering parameter |S12| of a microstripline grounded by a via hole is demonstrated in Fig. 3.

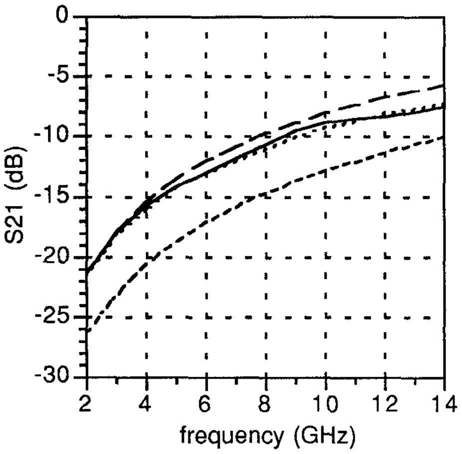

Fig. 3 Theoretical and measured insertion loss of a via hole ground in microstrip with w=2.3 mm, h=0.794 mm, 2r=0.6 mm and ε_r=2.32. The upper curve refers to eq.(2) of [1], while the lower curve refers to a commercially available program. Continuous line refers to the full-wave analysis, while dots refers to the measure.

Experimental results have been provided by W. Menzel [8]. For comparison, the results computed by the static formula (2) of [1] (dashed line), and by a commercial microwave simulation package (dashes-dots) are also shown in the figure. Results obtained by the static inductance formula are seen to provide a good approximation at low frequency. Observe that in the rigorous analysis the thickness of the microstrip has been taken into account. In the numerical simulation a strip thickness of 10 μm has been used.

Fig. 4 shows the effect of an increase of the via's diameter to 0.8 mm. The curves are calculated by the rigorous model (continuous line), the approximate static formula of [1] (dashes), and the same commercial program.(dashes-dots). It is noted that the short circuit effect of the via improves as the diameter increases.

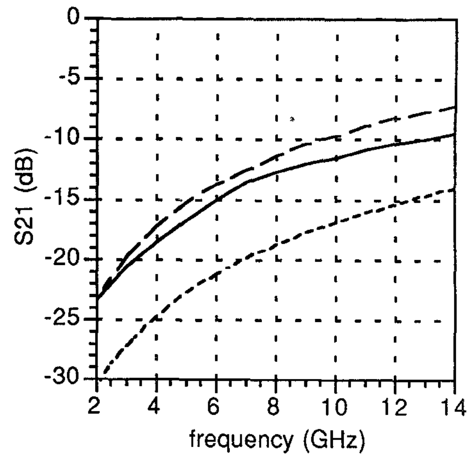

Fig. 4 Theoretical insertion loss of a via hole ground in microstrip with w=2.3 mm, h=0.794 mm, 2r=0.8 mm and ε_r=2.32. The upper curve refers to eq.(2) of [1], while the lower curve refers to a commercially available program. Continuous line refers to the full-wave analysis..

Finally, the planar waveguide model for the microstrip-via hole transition has been checked in Fig. 5. The continuous line represents our full-wave analysis while the dashed line refers to the results of [2, Fig. 8]. The agreement can be considered satisfactory only at low frequencies, while the discrepancy between the two analyses becomes quite large above 6 GHz.

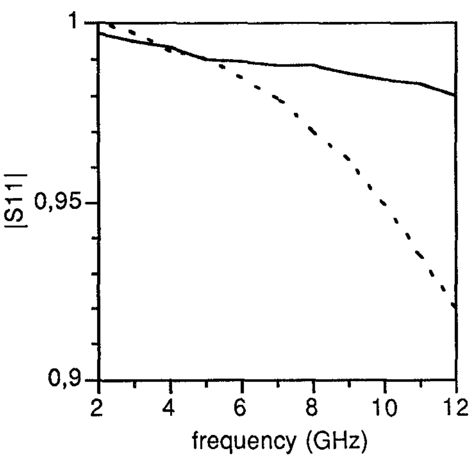

Fig. 5 Comparison with the data calculated in [2] (dashes) and full-wave analysis (continuous line). With reference to fig. 1 w=3 mm, h=0.635 mm, 2r=1.22 mm and ε_r=10.

4. Conclusions

A rigorous fullwave analysis of microstrip via holes has been presented. The method is based on a 3D mode-matching method using a suitable segmentation technique. Theoretical results have been shown to be in excellent agreement with experimental data.

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