Time Domain Analysis of Via Holes and Shorting Pins in Microstrip using 3-D SCN TLM

Channabasappa Eswarappa and Wolfgang J. R. Hoefer

NSERC/MPR Teltech Research Chair in RF Engineering, Department of Electrical and Computer Engineering, University of Victoria, Victoria, B.C., CANADA V8W 3P6

Abstract

The scattering parameters of microstrip via holes and shorting pins have been computed using 3-D SCN TLM method. The results agree well with the available data, thus demonstrating that the TLM method is a powerful tool applicable in the analysis of monolithic microwave integrated circuits of high density and high speed digital microwave circuits.

1.0 Introduction

The design of integrated circuits requires an exact knowledge of the electrical behaviour of discontinuities and interconnections. This is more so in densely packed and high speed (giga bit rate) digital circuits. Via holes are used to interconnect microstrips on different layers in multilayer printed circuit boards. They are also used in single layer circuits such as interdigital filters, etc., to obtain wide band short circuits. In the past, the via hole has been characterized as an inductor [1], [2]. Numerical methods such as TLM, FD-TD, Finite Element method and Mode Matching Technique are more appropriate for such problems [3], [4], [5]. In this paper, we report a detailed TLM analysis of microstrip via holes and of a microstrip shorting pin.

The symmetrical condensed node (SCN) TLM is more powerful than other TLM nodes because the boundary description is easier, all six field components can be defined at single points in space and there is less dispersion in axial directions. The main problem in applying this method to scattering parameter computation of 3-D discontinuities was the lack of good wideband absorbing boundaries. For accurate extraction of scattering parameters with a single time domain simulation, the absorbing boundaries with less than 1 % reflections over the desired frequency band are required. Recently, we have implemented such absorbing boundaries for 3D- TLM analysis of dispersive guiding structures.

2.0 Method of Analysis

To compute the scattering parameters of discontinuities, we need the incident, and reflected fields at the input port, and the transmitted field at the output port. To compute the incident field, we discretize a length of uniform microstrip line with absorbing boundaries on all sides of the computational domain. Then, we include the discontinuity under study in the computational domain, and compute the transmitted field at the output port and the total field in the input plane. The reflected field is obtained by subtracting the incident field from the total field. The scattering parameters are then determined by Fourier transforming these time domain waveforms. We use Gaussian pulse excitation functions which cover the frequency band of interest. The initial spatial distribution (in the transverse direction) of the Gaussian pulse is quasi-static field transverse distribution. It is obtained by 2-D TLM analysis of a similar structure. This proper initial field distribution is very important when applying absorbing boundaries close to the excitation plane. Otherwise, instability occurs very soon.

3.0 Numerical Results

The square via hole geometry in a three layer printed circuit board is shown in Figure 1. The via hole connects the input and output microstrip lines through pads (lands). The clearance hole in the ground plane is large enough to keep the via hole out of contact with the ground plane. The via hole is filled with air. The mesh parameter (Δl) was chosen as 0.33 mm. The time step (Δt) is 0.55 psecs. The Gaussian pulse width is 150 Δt. To ensure the quality of our absorbing boundaries (before trying to extract scattering parameters), a section of microstrip line was dis-

CH3277-1/93/0000-0917$01.00 © 1993 IEEE

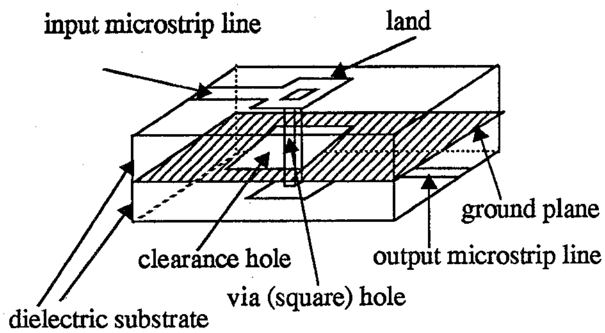

Figure 1. Microstrip via hole geometry: width of the microstrip line = 3. 3 mm, thickness of the substrate = 1. 65 mm, width of the pad(land) = 3. 96 mm, width of the clearance hole = 3. 96 mm, dielectric constant of the substrate = 3. 4.

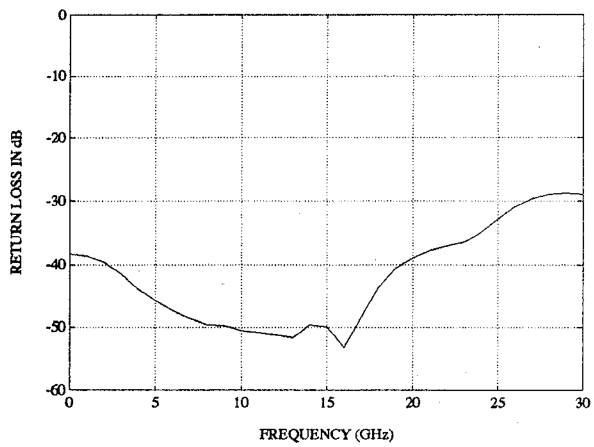

Figure 2. Reflection characteristics of microstrip absorbing boundaries.

cretized with SCN TLM nodes, placing absorbing boundaries on all sides of the computational domain. The field was sampled along the propagation direction and Fourier transformed to get the minimum and maximum values at each frequency. The magnitude of reflections obtained as are plotted in Figure 2. We can see that reflections as low as 1% (- 40 dB) are obtained in the 0 to 20 GHz frequency spectrum. The scattering parameters S11 and S21 for the via hole are plotted in Figures 3 and 4 for via hole widths of 0.66 and 1.32 mm, respectively. The results are compared with those [3] obtained for a circular (staircasing approximation) via hole using the FD-TD method. In Figure 3, TLM and FD-TD results agree well at low frequencies. While sharp breaks are observed in the FD-TD results, the TLM curves are smooth. Since, we have not used any shield to house the microstrip, and since the pad dimension is not very large, we expect the results

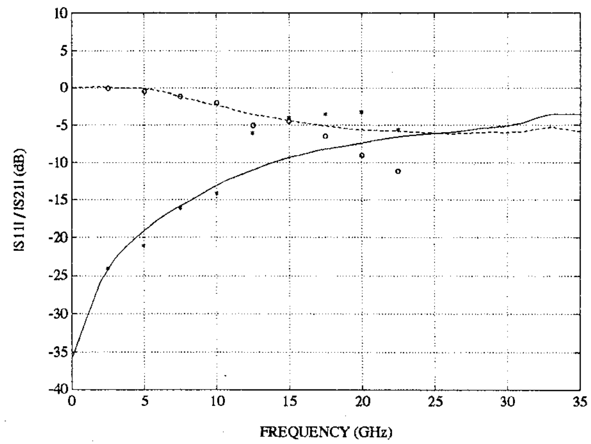

Figure 3. The scattering parameters S11 and S21 for the via hole(width = 0. 66 mm):
– S11 (TLM), * S11 (FD-TD),
-- S21(TLM), o S21 (FD-TD)
(diameter of the circular via hole = 0. 7 mm [3])

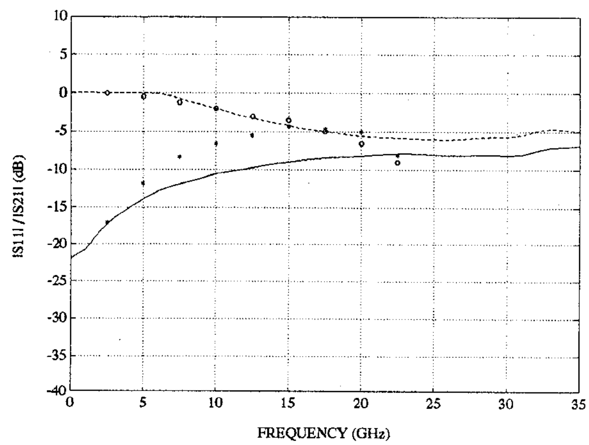

Figure 4. The scattering parameters S11 and S21 for the via hole(width = 1. 32 mm):
– S11 (TLM), * S11 (FD-TD),
-- S21(TLM), o S21 (FD-TD)
(diameter of the circular via hole = 1. 5 mm [3])

to be smoother. In Figure 4, the discrepancy is more pronounced because of the greater difference in via hole dimensions.

A cylindrical via hole on a single layer substrate is shown in Figure 5. The circular geometry is approximated by staircasing approximation. The insertion loss computed using TLM analysis is plotted in Fig. 6 along with mode matching results(in mode matching analysis, the via cross-section is assumed to be rectangular [5]). There is a good agreement between the results. As expected, the via acts as good short circuit only at low frequencies.

Figure 7 shows a microstrip line with a shorting pin connected to the ground plane in the vicinity of the open end.

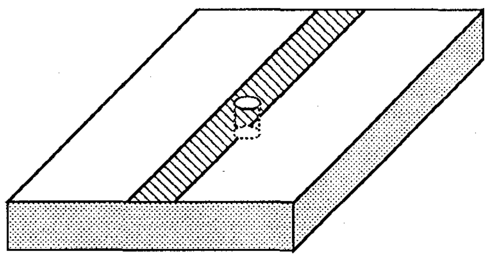

Figure 5. Microstrip via hole in a single layer circuit: width of the microstrip line = 2. 33 mm, thickness of the substrate = 0. 794 mm, diameter of the via hole = 0. 6 mm

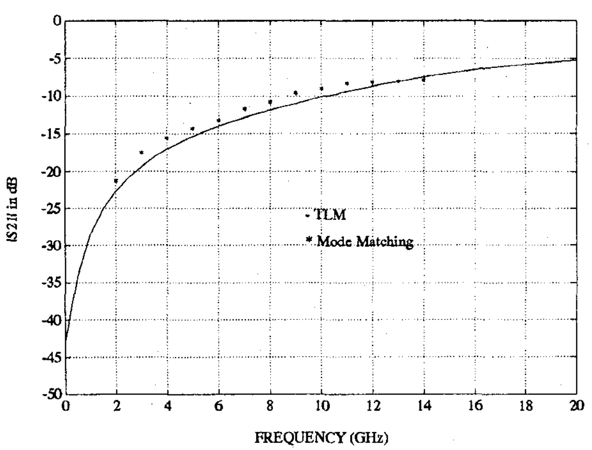

Figure 6. Insertion loss for the via hole of Figure 5.

A staircase approximation of the shorting pin has been used in the TLM analysis. The reflection coefficients S11 computed for an open-end and open-end with the shorting pin are plotted in Figure 8. Resonance occurs between the open end and the shorting pin and hence there is a dip in the S11 plot. Because of this resonance, there will be multiple reflections and hence the TLM simulation had to be done for a large number of iterations when compared to that of a normal discontinuity(As the absorbing boundary conditions tend to become unstable with increasing time, there may be some errors in the TLM results of resonant structures). For a similar structure, a study has been reported by W. Tsay and J. Aberle using the moment method and measurements [6]. Their results are also plotted in this figure. Since the diameter of the shorting pin is not given in their paper, we cannot actually compare the results. However, the behaviour of the shorting pin seems to be the same in both cases.

4.0 Conclusion

The scattering parameters of microstrip via holes and shorting pins have been computed using the 3-D SCN TLM method. The results agree well with published data at low frequencies. This report demonstrates that TLM is a

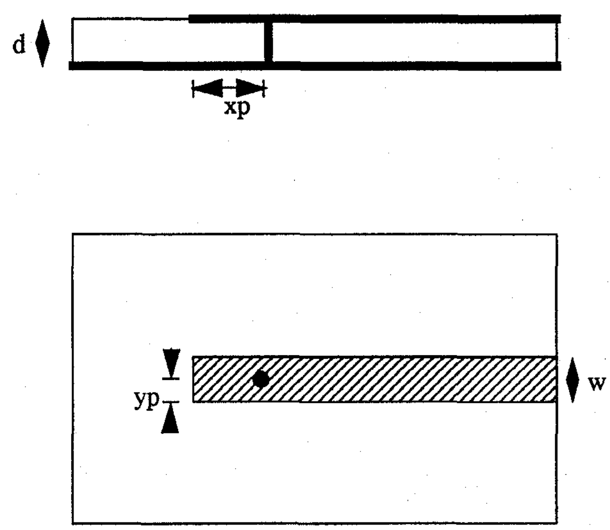

Figure 7. Open-end microstrip line terminated with a shorting pin: w = 4. 667 mm, d = 1 .5875 mm, dielectric constant of the substrate = 2.3 3, xp = 5.5 mm, yp = 3. 0 mm, diameter of the shorting pin = 0. 9 mm.

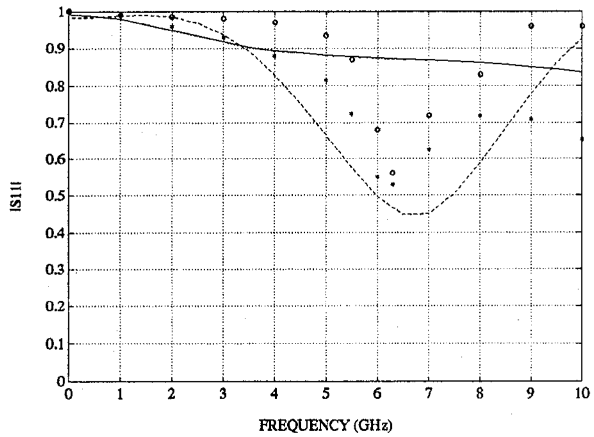

Figure 8. Reflection coefficient S11 for open-end and open-end with shorting pin microstrip lines.
– open end (computed with TLM)
- - open end with shorting pin (computed with TLM)
* * open end with shorting pin (measured)
o o open end with shorting pin (Moment Method [6])

powerful and accurate tool useful in the analysis of monolithic microwave integrated circuits of high density and high speed digital microwave circuits.

References

[1] Marc E. Goldfarb and Robert A. Pucel, "Modeling Via Hole Grounds in Microstrip", IEEE Microwave and Guided Wave Letters, vol. 1, no. 6, June 1991, pp. 135-137.

[2] Wolfgang J. R. Hoefer and A. Chattopadhyay, "Evaluation of the equivalent circuit parameters of microstrip discontinuities through perturbation of a resonant ring", IEEE Trans. Microwave Theory Tech., MTT-23, no. 12, pp. 1067-1071, Dec. 1975.

[3] Shuji Maeda, Tatsuya Kashiwa and Ichiro Fukai, " Full Wave Analysis of Propagation Characteristics of a Through Hole Using the Finite-Difference Time-Domain Method", IEEE Trans. Dec. 1991, vol. MTT- 39, no. 12, pp. 2154-2159.

[4] W. D. Becker, P. Harms and R. Mittra, "Time Domain Electromagnetic Analysis of a Via in a Multilayer Computer Chip Package", 1992 IEEE MTT-S Digest, pp. 1129-1232.

[5] F. Alessandri, M. Mongiardo and R. Sorrentino, " Full-Wave Modeling of Via Hole Grounds in Microstrip by Three-Dimensional Mode Matching Technique", 1992 IEEE MTT-S Digest, pp. 1237-1240.

[6] Wen J Tsay and James T. Aberle, "Analysis of a Microstrip Line Terminated with a Shorting Pin", IEEE Trans. April 1992, vol. MTT-40, no. 4, pp. 645-651.