ELECTROMAGNETIC ANALYSIS OF PLANAR CIRCUITRY AND THE DIMENSIONALITY ARGUMENT

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ABSTRACT

In this paper evaluations are carried out on the EM simulation accuracy of microstrip circuits using 2D and 3D Electromagnetic solvers, employing the TLM method. Different aspects of microstrip modelling are addressed including a new simplified excitation methodology. Illustrated simulations, supported by measured data, identify the advantages and disadvantages of modelling planar circuitry in both domains. The 3D domain provides greater accuracy due to its ability in representing more realistically the physical layout of these circuits.

INTRODUCTION

The TLM method is well-known for its generality, versatility and the method's physical approach for analysing field propagation in passive circuits. However, and as with all EM simulations, computational efficiency and memory requirements are fundamental sources of concern. Methods of enhancing the efficiency by reducing computations time are, therefore, desirable. The domain of analysis is not to be compromised for efficiency. The choice between two dimensional and three dimensional domain is dependent on the structure analysed. Microstrip circuits have been controversial in electromagnetic simulations. They have been analysed under 2D and 3D domains with varying results. The structure topology has contributed towards this dilemma. This paper fully explores microstrips simulation under both domains and reports on which is more accurate and why. The paper also discusses the different aspects of TLM microstrip geometry modelling. It is concluded that computational savings can be accomplished by placing emphasis on accurately modelling the critical parameters of the circuit such as substrate height and thickness of the top conducting strip [1].

TWO-DIMENSIONAL TLM MODELLING OF PLANAR CIRCUITRY

A commercial 2D TLM software was used for this part of the work [2]. The important point to consider is whether the structures under test and associated field lines can be represented in two dimensions. In 2D TLM modelling, this is only possible by modelling the microstrip using an equivalent parallel plate waveguide model with non-dispersive effective permittivity [2]. This model is quite limited and supports only uniform sections of a full TEM mode. The non-dispersive permittivity and the model support of TEM modes contradicts with basic microstrip characteristics of dispersion and quasi-TEM mode of propagation. Therefore, the air-dielectric field variations and interface in microstrips are not fully modelled in 2D TLM simulation. One structure is presented in this paper, a Microstrip CROSS, Alumina substrate, $\epsilon_r = 10$, dimensions as shown in Figure 1. The frequency range was between 30 to 40GHz.

The results of the simulations are given in terms of the S-parameters. The simulation results are poor with clear differences in the results shown in Figure 2 when compared with predictions by Supercompact. The latter was used as a reference in this simulation. This is justifiable as the analysed structure is well characterised and an accurate circuit model is available for it in Supercompact. These results emphasize the need to properly simulate microstrip by direct modelling and that the use of an equivalent parallel-plate model used in 2D-TLM simulations is inadequate.

MODELLING OF PLANAR MICROSTRIP CIRCUITS USING THE 3D TLM METHOD

The use of the three-dimensional TLM symmetrical condensed node with graded mesh scheme requires considerable computation time and memory capacity. The microstrip critical dimensional parameters are the microstrip width *w* and the substrate height *h.* The thickness *t* of the metallic, top conducting strip is generally of much less importance , however, it must be physically thin enough such that it can be computationally neglected in the model. It is therefore envisaged in this paper that special consideration of the critical parameters must be made by emphasising their accurate electromagnetic modelling and

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the effects they have on the field distribution and propagation within the circuit. In such case, more accurate results can be achieved with less computational times.

An abrupt dielectric interface between the substrate and the air above it is clearly seen in microstrips. The non-uniform dielectric filling makes the microstrip unable to support a single, well-defined mode of propagation but rather a field distribution which quite resembles TEM. The complete field distribution of such a mode is relatively complicated, roughly comprising of a hybrid TEM mode with longitudinal components. The field components are more concentrated in the area just above and inside the substrate. This puts more emphasis on the need to use a fine mesh around the conductor surroundings and a coarse mesh elsewhere. Indeed the use of three nodes to model the height of the substrate was shown in [3]. The number of nodes simulating the width of strip is dependent on its actual physical value and the characteristic impedance of the line. It was found in this research that three nodes are needed to model the strip width with acceptable accuracy

EXCITATION OF MICROSTRIPS BY THE TLM NETWORK

An excitation resembling the fundamental mode of a structure results in a much reduced analysis time and convergence of the solution is faster. Convergence was much faster if the approximate field distribution was specified at the onset and the network excited to enhance this mode [3]. To enhance the fundamental-mode field configuration E_y was excited at all the nodes lying directly below the strip and E_x was excited at the edge of the strip to provide the correct biasing for the field configuration of the mode. The code was written so that excitation nodes lay on a single plane orthogonal to the direction of propagation (usually the *z*-plane). Hence it is possible to excite all the nodes in the *x-y* plane but only at a single *z*-plane location. This is consistent with experimental methods of launching signals into circuits close to the input boundary plane. Figure 3 shows a cross section of a microstrip line where the conductor strip is modelled by three nodes wide and *h*, the substrate height, is modelled by three nodes high.

TLM SCN ASSOCIATED ERRORS IN MODELLING MICROSTRIP LINES

It was observed that some of the solutions obtained suffered from minor deviations, particularly when embedding devices into the TLM mesh [4], that can only be attributed to the modelling criteria of microstrips. The most relevant of these was an occasional frequency shift from the intended design value and/or experimental results. It was found that, despite suppressing inherited errors in the domain transfer mechanism [5], the frequency shift remained in the final solution. Such a situation is unacceptable in the design of narrowband microwave filters where the error may exceed the design bandwidth. It was observed that there is an error in the representation of edges and corners. The probable explanation of the error is that the transmission of the signal around the corners in the TLM mesh as shown in Figure 6 is subject to additional delays. The lack of direct link between the nodes diagonally adjacent to the conducting surfaces, such as nodes 1, 3 in Figure 4, causes the circumferential signal transmission to be longer than it should be. In other words, the diagonal corner node acts like a capacitive storage element that gives rise to dispersion in the time domain signal slowing down the propagating waves and hence influencing the resonant frequency of the design. The 3D corner coarseness error has been reported [6], while modelling wires using the TLM method. The solution in [6] requires an isotropic uniform medium of free space. Microstrips, on the other hand, contain an interface between air-filled space and substrate; altering ϵ_r surrounding the conductor strip requires that the substrate and air specifications of the design must be changed, grossly altering the circuit behaviour and intended simulation. A more appropriate solution is to reduce the physical separation between the diagonal condensed nodes and the strip edges by using graded mesh around the strip. The close proximity between the nodes and the strip would offset the remaining indirect coupling between them.

SIMULATION EXAMPLES: (I)MODELLING OF "WIGGLED-LINE" COUPLER

The electromagnetic model of the fields of a new type of planar coupler had been investigated. The structure comprises of a very short planar wiggled-line that couples to a straight strip line, the structure sketch together with related dimensions in millimetres are shown in Figure 5. The design specifications were a dielectric constant ϵ_r = 9.8 and substrate height = 0.25mm. Interest was focused on the effects of odd mode excitation. The matched 50Ω load impedances required to avoid reflections were modelled by extending the length of the output lines after the wiggles by an amount equal to the total length of the wiggles, and setting the number of time-steps so that the simulations would terminate before the pulses reach the output boundary, which was allocated a random absorptive reflection coefficient value.

The importance of this simulation is that it would almost be impossible to model the circuit using a two-dimensional model. The field variations with the topology of the structure are very complicated and can only be visualised using a 3D model. The way to model wiggles using the Cartesian TLM mesh is to use step-wise linear approximations by modelling a series of cascaded transmission lines of varying widths. The mesh was designed such that the coupling area containing the wiggles and the coupling line was modelled using a very fine mesh.

Figures 6 and 7 are for the Electric (E_y) field distributions. The observation output nodes were confined to the coupler's finely meshed area and were taken at the nodes directly above the conductor strips. Localised areas of field concentrations are apparent which appear to be positioned round and above the tips of the wiggles as theoretically expected. This is also related to the discontinuities encountered by the fields as they propagate through the coupled area, and to the design of the structure.

(II) RESONATING LINE BANDPASS FILTER

The bandpass filter shown in Figure 8 utilizes a two-port series connected capacitively coupled stripline resonator. The characteristic impedance of the resonator section equals that of the connecting lines (Z_o = 50Ω). The capacitance value C is chosen to produce a large value of reactance X_c in the designed frequency range. The circuit was designed to resonate with a length of 4.53mm and the value of the capacitances used were designed at C = 0.16pF each. However, only capacitors as low as 0.2pF were available and this caused a slight shift and loss in the response of the circuit.

It was important to properly model the resonance length in the z-direction and an $11\times10\times220$ TLM mesh was used for this circuit with x and y transverse dimensions having a graded mesh internodal spacing and longitudinal z-direction Δl fixed at 0.3mm. The result of the simulation is shown in Figure 9 for the insertion loss compared to measured results. Good agreement is reached between the two results.

CONCLUSIONS

In this paper, a detailed study on the modelling of microstrip lines using 2D and 3D electromagnetic simulations were presented. Despite the planar topology of microstrips, 3D TLM modelling has successfully shown accurate simulations. This makes the method appealing for both planar circuitry and full 3D structures, a clear advantage over other numerical techniques. Various circuits were analysed and good agreements achieved between measured and simulated results. This included a wiggled line coupler and a band-pass filter.

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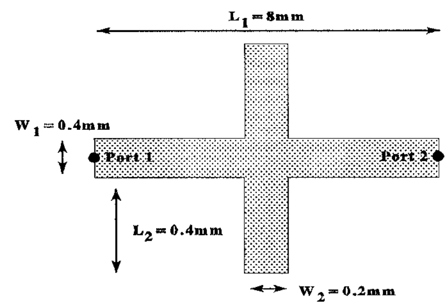

Figure 1 Microstrip CROSS

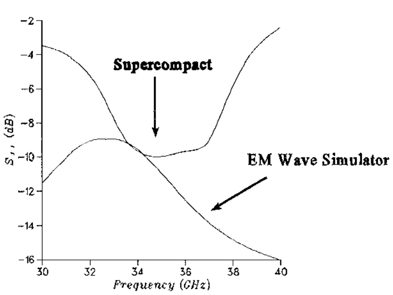

Figure 2 Microstrip CROSS S_{11} magnitude

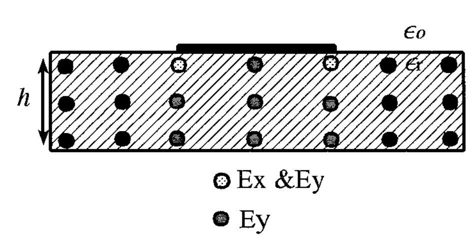

Figure 3 TLM microstrip excitation

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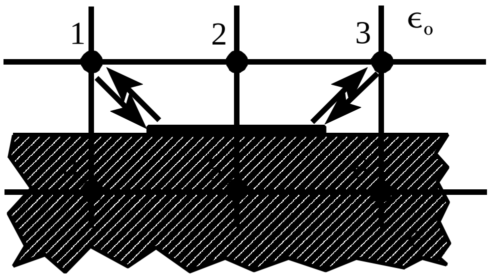

Figure 4 Embedded conductor strip

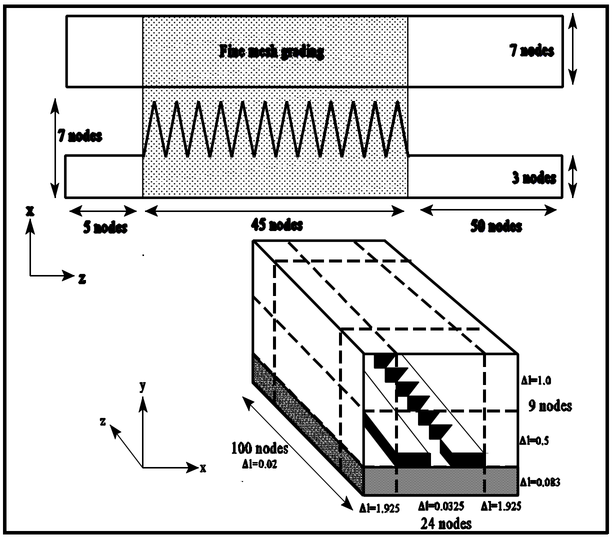

Figure 5 TLM diagram of wiggled line coupler

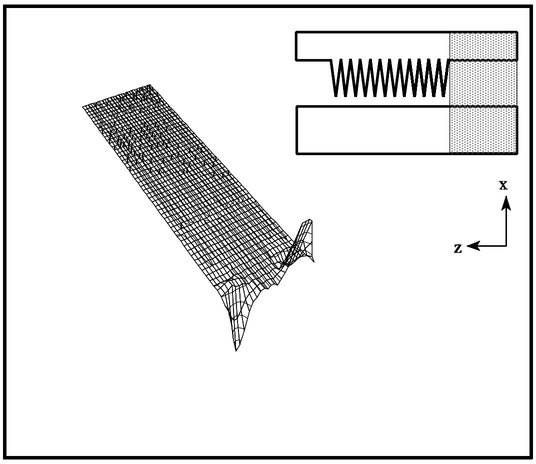

Figure 6 Launch of E_y odd mode

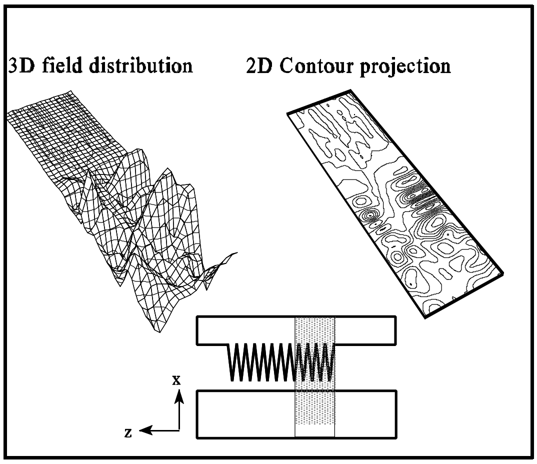

Figure 7 E_y after 1000 timesteps

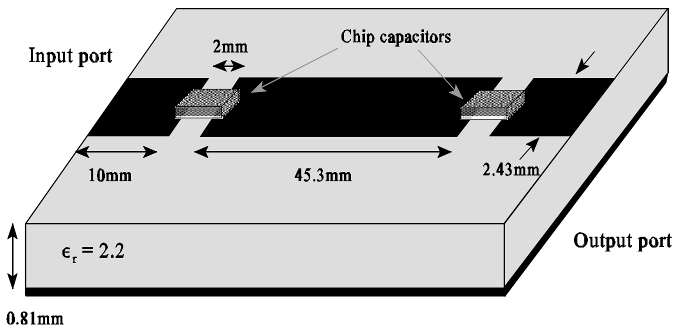

Figure 8 Capacitively coupled bandpass filter

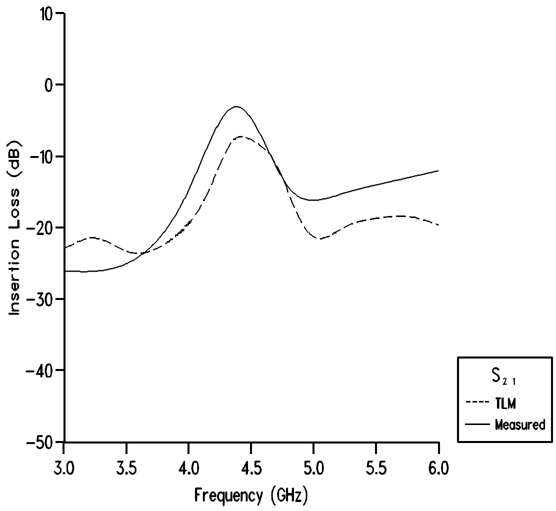

Figure 9 Measured and simulated response of Microstrip bandpass filter