THE MODELING OF COPLANAR CIRCUITS IN A PARALLEL COMPUTING ENVIRONMENT

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ABSTRACT

The time-domain simulation of coplanar waveguide (CPW) elements for picosecond pulse applications is described. CPW discontinuities were simulated using the 3D transmission-line-matrix (TLM) method. We present a cost–effective approach for the time–domain simulation of coplanar circuit structures utilizing distributed computing within a parallel software environment. The use of matched layers and skin effect models is discussed. The application of TLM method and distributed computing to the efficient analysis of coplanar structures is presented.

INTRODUCTION

The present work arose from the requirement of an accurate analysis of planar circuits. The high-density packaging of monolithic microwave integrated circuits (MMIC) demands full-wave analysis. In recent years, the transmission line matrix method has emerged as a powerful tool to solve electromagnetic field problems in the time domain [1]. The TLM method is inherently suitable for the simulation of structures consisting of dielectric, anisotropic and lossy media and is not restricted to planar geometries. Recently, efforts have been made to improve the accuracy and efficiency of the TLM schemes based on symmetrically condensed nodes [2]. Generally the simulation of complex microwave circuits is limited by the accessible computer memory and computer performance. In particular, the modeling of planar circuits with several interfering discontinuities requires TLM meshes consisting of a large number of nodes. Since the TLM algorithm is based on local operations at neighboring mesh nodes only, the TLM method is predestinated for parallel computing, which provides scalable computational power.

SIMULATION IN A PARALLEL COMPUTING ENVIRONMENT

Distributed computing makes best use of the available resources and features the re-use of existing software modules. As a parallel computing environment for distributed computing we use the Parallel Virtual Machine (PVM), which became a standard environment for parallel computation [3, 4]. PVM supports the message-passing paradigm and preserves compatibility to the now up-coming MPI-(Message-Passing-Standard). PVM supplies a platform for portable parallel programming and provides a reliable communication interface even in heterogenous computing environments. Load balancing is achieved by an optimum segmentation of the mesh with respect to the available computer power of the particular machines and with respect to minimum communication traffic between the computing nodes. The space partitioning is performed automatically by a sepa-

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rate preprocessing to minimize the number of variables that have to be exchanged and due to the available computational power of the specific computing nodes and network links.

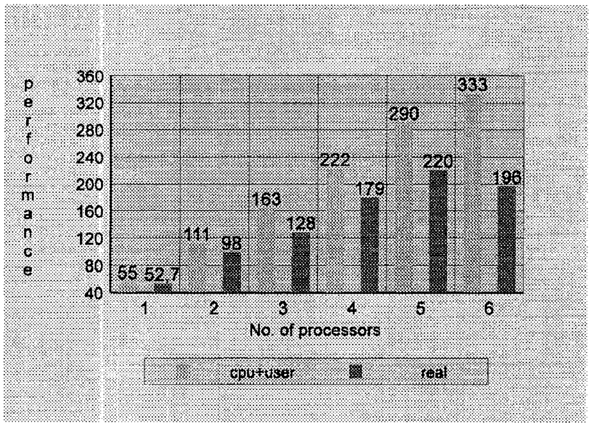

Fig. 1: Performance of distributed TLM simulation measured with respect to accumulated cpu-plus user-time and by the occupation time

We are employing interconnected workstations as well as an IBM-SP2 supercomputer with up to 56 computing nodes. As a result of the synchronization required throughout the mesh after each TLM time step, each working client has to await the completion of the scattering and propagation processes at the adjacent sub meshes. The access mode in commonly used Ethernet-LANs limits the throughput within the PVM, and thus, the suitable number of computing nodes within a loosely coupled network. The time required for the communication between all adjacent clients is considerable larger than the accumulated communication time between each two clients operating on adjacent sub meshes. In Fig. 1 the performance of a workstation cluster measured by accumulation of cpu-plus user-time increases nearly linear with increasing number of computing nodes, whereas the performance measured by the occupation time saturates due to collisions and other communication bottlenecks. Modern networking technologies like Switched Ethernet or FDDI networks reduce this problem considerably. As a workaround we limit concurrent communication to one pair of clients during each communication phase between the TLM time steps. We use a hybrid model for the embedding of the existing computer codes, attributing most of communication directly to the clients and introduce only a small overhead managed by a master program as shown in Fig. 2. Even the embedding of machines with very different architecture like MIMD-and/or SIMD-computers is straightforward requireing only minor changes in the computer code.

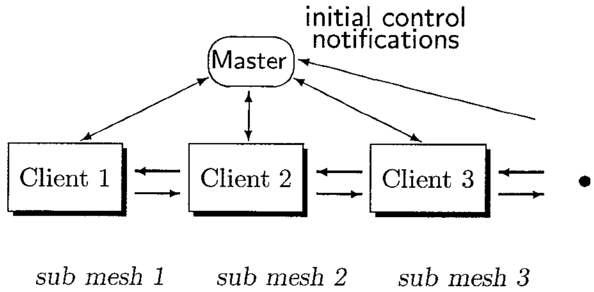

Fig. 2: Parallelization model

SIMULATION OF PLANAR CIRCUITS

Next we demonstrate the application of distributed computing for the modeling of the electromagnetic field in coplanar circuits. The investigation of structures with metalic boundaries requires also an accurate modeling of the skin effect surface impedance taking into account its $f^{\frac{1}{2}}$ dependence. A conventional TLM scheme is not applicable for the modeling of thin conducting sheets, since a very high number of nodes within the TLM mesh would be required. Previously we have introduced a surface impedance model for thin conducting sheets enclosed in a TLM mesh [6]. Under the assumption that the surface area and its curvature are large compared to the skin effect penetration depth over the considered frequency range, the electromagnetic field components inside the metallic conductor are parallel to the surface. The conductor surface is subdivided into surface elements according the discretization of the adjacent TLM mesh. In the direction normal to the conductor surface an independent discretization is introduced. Under each surface element cell the electromagnetic field is modeled by an attenuated plane electromagnetic wave propagating into the metal in perpendicular direction. This plane wave model neglects the coupling of adjacent cells inside the metallic conductor. Therefor the skin effect surface impedance can be modeled with arbitrary accuracy by lumped element ladder networks consisting of cascaded L-R - sections as depicted in Fig. 3. Since the high frequency spectral components of the signal exhibit a lower skin penetration depth a fine discretization of the metal layers is only required close to the surface. With increasing depth the layer spacing is increased, covering the penetration depths of the lower frequency spectral components. The L-R - sections are described by discrete time state equations. The model with a nonuniform discretization yields optimum accuracy within a broad frequency range.

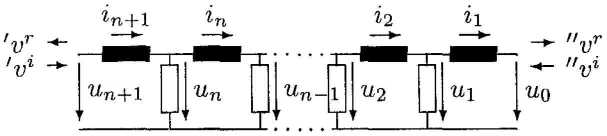

Fig. 3: Skin effect ladder model

For the extraction of S-Parameters high-quality absorbing boundary conditions are necessary. Less stable one-way absorbing boundary conditions often limit the length of the observable time response, whereas global boundary conditions require a lot of nonlocal communication between several nodes. This will introduce a bottleneck and will decrease the computational performance considerably. An alternative approach is the use of absorbing materials for modeling accurate boundary conditions. Berenger [7] found that non-physical materials complying with the relation

$$\frac{\sigma_e}{\epsilon} = \frac{\sigma_m}{\mu}, \tag{1}$$

yield absorbing material for incident waves at arbitrary angles. Perfect matching layers (PMLs) are constructed utilizing several layers with quadratically increasing electric conductivity σ_e and magnetic conductivity σ_m, and yield return losses considerable below 50dB.

SIMULATION EXAMPLES

First a CPW structure consisting of cascaded CPW sections of different widths was investigated (Fig. 4). The width of the center conductor is stepped down from 500μm to 200μm and back to 500μm, whereas the width of the gap is increased from 200μm to 350μm. The length of the high impedance section is 4.36mm. The substrate has the dielectric constant $\epsilon = 12.9$. The thickness of the aluminium metalization is 35μm and the conductivity is $2 \cdot 10^7 S/m$. The structure was enclosed in a WR28-rectangular waveguide. The mesh is terminated by matched layers consisting of ten individuell layers, yielding very low reflections.

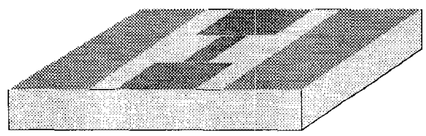

Fig. 4: Schematic of CPW element (not to scale)

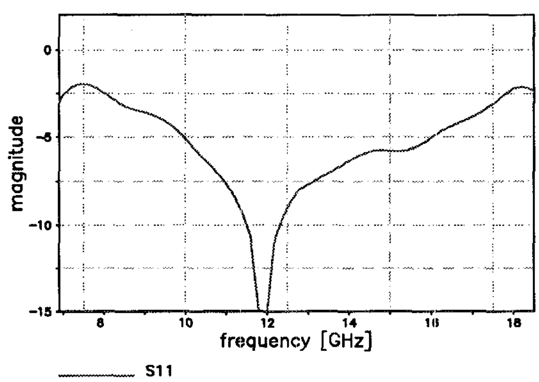

Fig. 5: Input reflection coefficient

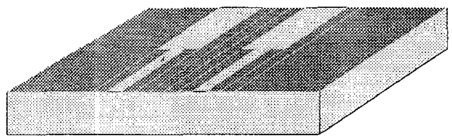

Fig. 6: Schematic of CPW 35-to-50Ω-transition

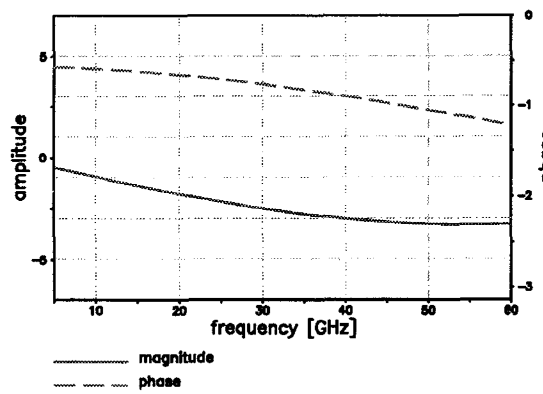

Fig. 7: Input reflection coefficient of CPW 35-to-50Ω-transition

The simulation task was distributed among three workstations and took about 3 cpu hours on a HP-720 cluster. Fig. 5 depicts the input reflection coefficient of the CPW element. In Fig. 6 the schematic of a coplanar 35-to-50Ω-transition is given. The geometrical parameters at the first port are given by the width of the center conductor $w_1 = 20\mu$m and the gap width $s_1 = 5\mu$m, whereas the parameters at the second port are given by $w_2 = 15\mu$m and $s_2 = 10\mu$m. The simulation was performed for a GaAs substrate with a dielectric constant $\epsilon = 12.9$. The input reflection coefficient is shown by Fig. 7. Currently we are working on the simulation of interconnecting structures and multilayer structures.

CONCLUSION

We have presented an extremely cost–effective approach for the time–domain simulation of coplanar circuit structures with the TLM method utilizing a parallel software environment. The use of matched layers, skin effect model and performance aspects have been discussed. The feasibility of the approach has been demonstrated by the analysis of coplanar structures.

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