Appendix

Description of Research Projects

1) Modeling of Nonlinear Active and Passive Devices in Three-Dimensional TLM Networks

(Lucia Cascio, Giampaolo Tardioli and Wolfgang J.R. Hoefer)

The increase in clock rate and integration density in modern IC technology leads the designer to deal with problems for which traditional lumped circuit design methodology fails to accurately account for the complex interactions among different parts of the circuit. Traditional CAD tools, such as SPICE, provide very accurate models for a large variety of active devices, but their description of the passive part of the circuit is progressively becoming insufficient as the frequencies of the signals increase. Problems such as dispersion, crosstalk and package effects require a full electromagnetic approach in order to predict their impact on the final response of the circuit.

The TLM method is particularly suitable for interfacing lumped circuits to distributed structures: the electromagnetic fields are directly related to the voltages and currents propagating in the TLM transmission lines, and it is straightforward to interpret the connection between the distributed electromagnetic problem and the lumped devices in terms of circuit theory. Moreover, unlike FDTD, the TLM method is very stable at low frequencies, particularly in the presence of one-way absorbing boundary conditions.

We have thus developed a technique for introducing lumped elements in a set of TLM-SC nodes. To incorporate the circuit into the TLM mesh, we consider an equivalent region extending over the device volume, and we assume that the behavior of the device depends on the local field in all the cells in that volume. This is particularly important in the case of nonlinear active elements, such as Tunnel diodes, because the connection of the cells in the direction of the feeding voltage would have the effect of a series of diodes, which is DC-unstable. A second advantage is that when modeling nonlinear devices such as pn-junction diodes or bipolar transistors, we will need to solve only a single nonlinear equation at each iteration.

To connect the device to the TLM mesh we add n series-connected capacitive stubs in the direction of the feeding voltage. The inclusion of the circuit into the TLM mesh is performed by expressing the equation relating the voltage across the element, v, and the current flowing into it, i, as a function of the voltages traveling in the TLM stubs:

$$v = \sum_{m=1}^{n} v_m = \sum_{m=1}^{n} (v_m^i + v_m^r)$$

$$i = i_m = Y_r(v_m^r - v_m^i) \qquad m = 1, \dots, n$$

Substituting the expressions for the current and for the voltage in the equation describing the lumped circuit, and applying an appropriate discretization scheme, we obtain a recursive formulation for the new incident voltages traveling in the stubs. For first-order circuits this can be written as:

$$ {}_kV^i_{s1} = F\left[{}_kV^r_{s1} \ , \ {}_{k-1}V^i_{s1} \ , \ {}_{k-1}V^r_{s1} \ , \ \sum_{m=2}^{n} {}_kV^r_{sm} \ , \ \sum_{m=2}^{n} {}_{k-1}V^r_{sm} \right] $$

$$ {}_kV^i_{sm} = {}_kV^r_{sm} - {}_kV^r_{s1} + {}_kV^i_{s1} \qquad m = 2, \ldots, n $$

The proposed technique has been specialized for several kinds of circuits, and has proven to be capable of correctly describing the transient response of nonlinear devices, including the DC behavior of active elements..

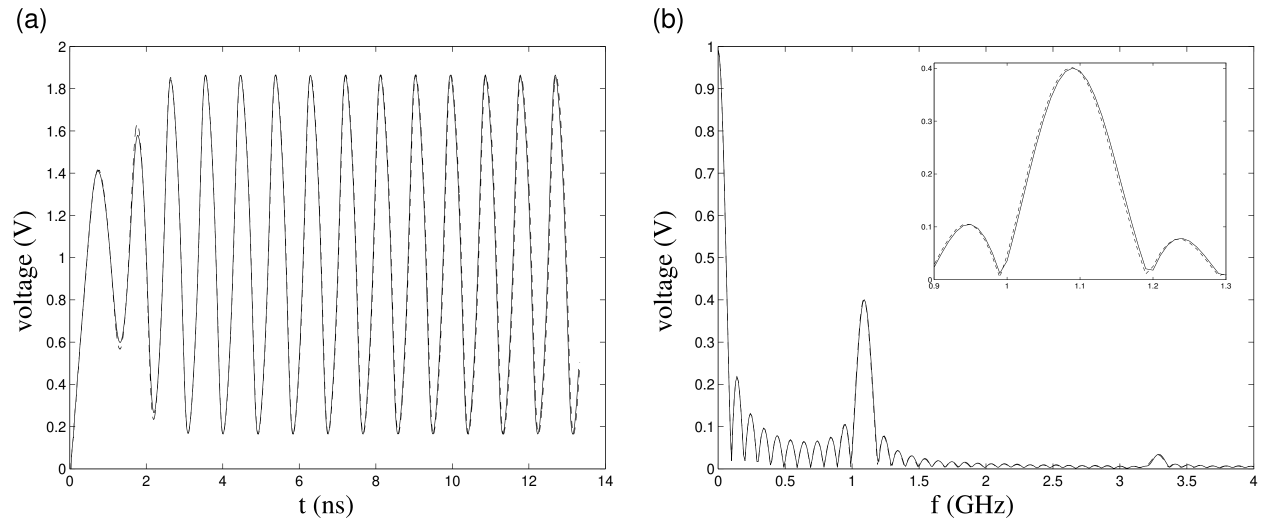

Fig. 1 Time (a) and frequency (b) response for one of the diodes in the stripline oscillator (Solid line: SPICE, dashed line: TLM)

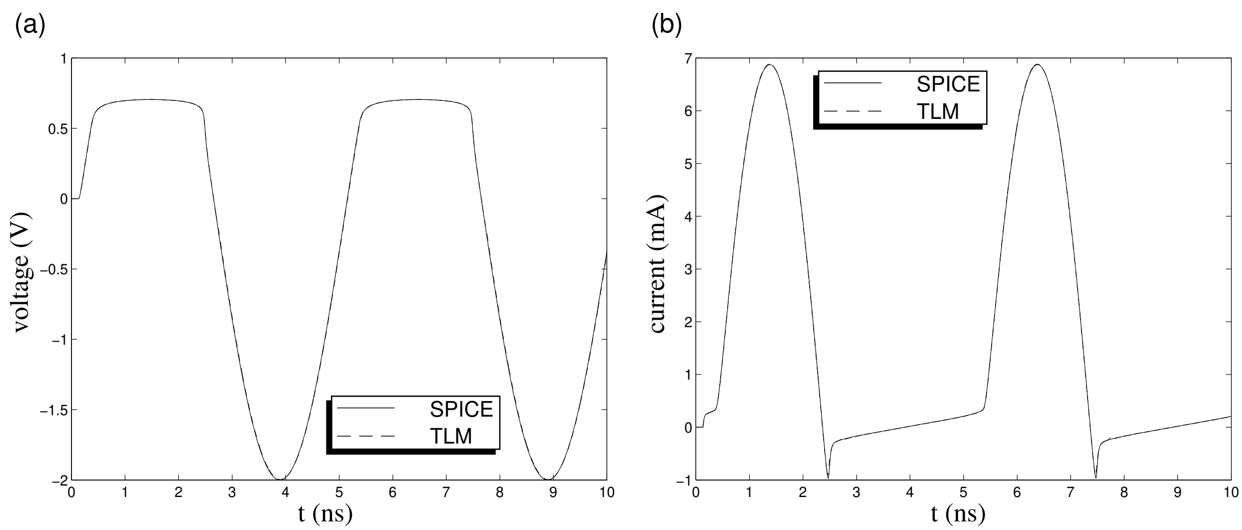

Fig. 2 Voltage (a) and current (b) behavior for the pn-junction diode: comparison between the TLM simulation and SPICE results

We have simulated an air-filled stripline oscillator with its DC biasing circuit. The time and frequency behavior of the oscillator, determined with the TLM analysis, has been compared with a SPICE simulation

(Fig. 1). The difference between the SPICE and the TLM simulations during the transient period is due to the adaptive time-step used by SPICE. The frequency response in Fig. 1 Fig. 1(b) has been evaluated after the steady-state condition has been reached (t > 2.915 ns).

As a second example we have modeled the dynamic behavior of a pn-junction diode placed at one extremity of a stripline. The TLM analysis of the given structure has been compared with the results obtained using SPICE (Fig. 2Fig. 2), showing an excellent agreement both for the voltage and current behavior

Further details can be found in:

L. Cascio, G. Tardioli and W. J. R. Hoefer, “Modeling of Nonlinear Active and Passive Devices in Three-Dimensional TLM Networks”, in IEEE Intl. Microwave Symp. Dig, pp. 383-386, Denver, Colorado, June 8-13, 1997.

2) Special 3D-TLM Corner Nodes for Singular Field Regions

(Giampaolo Tardioli, Lucia Cascio, Mario Righi, and Wolfgang J.R. Hoefer)

Introduction

Space discrete methods such as Finite Difference Frequency Domain (FDFD), Finite Difference Time Domain (FDTD), Transmission Line Matrix (TLM) and Finite Element Methods (FEM), are currently used for solving a wide variety of fields problems. The computational domain is discretized in a finite number of elementary cells where the electromagnetic field is assumed to have a simple behavior, very often linear. This assumption fails to accurately model sharp features, where highly nonuniform fields are present. This is typically the case of corners and edges, where the electromagnetic fields are singular. We refer to the resulting error as “coarseness error”.

In time domain methods, a comparison between the dispersion and the coarseness error reveals that the coarseness error is the dominant source of inaccuracies in most of the practical cases and represents the most severe limitation to the maximum admissible cell size.

A direct solution to reduce the coarseness error is to use an extremely fine mesh, but this quickly leads to unacceptable memory and time requirements. A better approach is to use a variable or multigrid mesh, so that a higher resolution can be obtained in that region. In this case the resources would be still larger than those of a uniform coarser mesh fixed by the dispersion error only.

We present a novel approach to incorporate knowledge of the static field behavior in the vicinity of singularities in a three-dimensional TLM mesh. The procedure is systematic and does not require optimization of the correcting elements. As a result, relatively coarse TLM meshes may be used to obtain highly accurate results, within the dispersion error, across a wide frequency range.

Theoretical Background

Close to edges (Fig. 1) the spatial derivatives of the fields are much larger than the time derivatives, so that the latter may be neglected in Maxwell’s equations. Therefore the propagation effects are negligible and the electromagnetic field is quasi-static. The finite energy condition imposes that the **E** and **H** field