MODIFICATION OF THE 3D-TLM SCATTERING MATRIX TO MODEL NONLINEAR DEVICES IN GRADED AND HETEROGENEOUS REGIONS

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ABSTRACT

In this paper we propose a modification of the TLM stub-loaded SCN scattering matrix to analyze three-dimensional problems including nonlinear active and passive devices in graded and heterogeneous regions. The nonlinear behavior of the lumped circuit is decoupled from the impulse scattering at the nodes, yielding a general and systematic methodology to embed arbitrary nonlinear devices into the TLM mesh.

The method has been validated for both one-dimensional examples with traditional CAD circuit simulators (SPICE) and 3D problems. The modeling results have been compared with measurements available in the literature.

INTRODUCTION

The increase in clock rate and integration density in modern IC technology leads to complex interactions among different parts of the circuit. These interactions are poorly represented with traditional lumped circuit design methodologies. Traditional CAD tools, such as SPICE [1], 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.

On the other hand, the application of a full-wave numerical method for the analysis of a complete device containing nonlinear elements is not sustainable with the present computer capabilities. The spatial and time discretization steps required to accurately model the nonlinear part of the device are much smaller than those necessary to describe the distributed part of the circuit [2].

A feasible solution consists in embedding the nonlinear devices in the form of equivalent circuits into a full-wave field solver [3-10].

A general procedure to connect the standard 3D-TLM symmetrical condensed node (SCN) [11] and lumped element circuits have been presented in [10]. The procedure consisted in linking the nonlinear devices to the nodes of the TLM network by means of stubs of length $\Delta l/2$. The stubs related to the electric field components, traditionally employed to model the material dielectric properties, have been used for this purpose. The new stub voltages incident upon the nodes are modified by the presence of the lumped circuit connected to TLM cell.

In order to apply this procedure to the case of graded meshes and heterogeneous problems, additional stubs are required. In this paper, a modification of the stub-loaded SCN scattering matrix is proposed, to accommodate the presence of the additional stubs.

MODIFICATION OF THE STUB-LOADED SCN SCATTERING MATRIX

The technique for introducing lumped elements across a set of TLM-SC nodes has been introduced in [10].

If a lumped device is connected to the node, then only one of the field components is affected by its presence; the TLM cell must thus be modified “anisotropically”. In general, assuming that the device can be oriented in any one of the three Cartesian directions, three stubs with appropriate admittances must be added to the node; only one of them will the be effectively used in connection with the device, while the others will be eliminated by setting their admittance to zero (anisotropic modification of the node).

The scattering matrix of the new node, now taking into account the interaction between 21 lines (12 link lines and 9 stubs), must be determined according to the laws of energy conservation, and assumes a form similar to that of the SCN for the modeling of electrical losses [11]. In that case, since the additional lossy stubs are assumed to be matched, no incident voltages are coming from them towards the node, and a 18x21 matrix is sufficient to describe the situation.

When using the device stubs to connect the lumped element equivalent circuit, voltages will travel from the device to the node, hence the interaction between these impulses and the rest of the node must be taken into consideration. A full 21x21 matrix[1] is therefore needed to model the material properties of the node in conjunction with the presence of the lumped device.

The coefficients of the new scattering matrix are given by:

$$a = -\frac{\hat{Y} + \hat{Y}_s}{2(4 + \hat{Y} + \hat{Y}_s)} + \frac{\hat{Z}}{2(4 + \hat{Z})}$$

$$b = \frac{4}{2(4 + \hat{Y} + \hat{Y}_s)}$$

$$c = -\frac{\hat{Y} + \hat{Y}_s}{2(4 + \hat{Y} + \hat{Y}_s)} - \frac{\hat{Z}}{2(4 + \hat{Z})}$$

$$d = \frac{4}{2(4 + \hat{Z})}$$

$$e = b \qquad f = \hat{Z}d \qquad g = \hat{Y}b \qquad (1)$$

$$h = \frac{\hat{Y} - \hat{Y}_s - 4}{4 + \hat{Y} + \hat{Y}_s} \qquad i = d \qquad j = \frac{4 - \hat{Z}}{4 + \hat{Z}}$$

$$m = \frac{\hat{Y}_s - \hat{Y} - 4}{4 + \hat{Y} + \hat{Y}_s} \qquad n = \hat{Y}_s b$$

where $\hat{Y}$ and $\hat{Z}$ are respectively the normalized stub admittance and impedance, necessary to describe the permittivity, permeability, and spatial properties of the region [11]. $\hat{Y}_s$ is the normalized device stub admittance, which is different for the three directions ($\hat{Y}_{sx}$, $\hat{Y}_{sy}$, $\hat{Y}_{sz}$), according to the orientation of the device.

The value of the stub admittance must be appropriately chosen in order to decouple the incident and reflected voltages traveling in the device stubs [4]. For example, assuming that the feeding voltage is oriented along the *y* axis, this is given by: $\hat{Y}_{sy} = 4 + \hat{Y}_y$.

NUMERICAL RESULTS

We have modeled the dynamic behavior of a pn-junction diode, having a saturation current of 10^{-14} A and placed at one extremity of a partially filled transmission line (Fig. 1). The normalized device stub admittance was then given by: $\hat{Y}_{ys} = 16$. The excitation was a matched resistive voltage source, providing a 2-volt, 200MHz sinusoid. The characteristics of the stripline were: *l* = 20 mm, *h*

1.

[S] =

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
1	*a*	*b*	*d*						*b*		-*d*	*c*	*g*					*i*	*n*		
2	*b*	*a*				*d*			*c*	-*d*		*b*	*g*				-*i*		*n*		
3	*d*		*a*	*b*				*b*			*c*	-*d*		*g*				-*i*		*n*	
4			*b*	*a*	*d*		-*d*	*c*			*b*			*g*		*i*				*n*	
5				*d*	*a*	*b*	*c*	-*d*		*b*					*g*	-*i*					*n*
6		*d*			*b*	*a*	*b*		-*d*	*c*					*g*		*i*				*n*
7				-*d*	*c*	*b*	*a*	*d*		*b*					*g*	*i*					*n*
8			*b*	*c*	-*d*		*d*	*a*			*b*			*g*		-*i*				*n*	
9	*b*	*c*				-*d*			*a*	*d*		*b*	*g*				*i*		*n*		
10		-*d*			*b*	*c*	*b*		*d*	*a*					*g*		-*i*				*n*
11	-*d*		*c*	*b*				*b*			*a*	*d*		*g*				-*i*		*n*	
12	*c*	*b*	-*d*						*b*		*d*	*a*	*g*					-*i*	*n*		
13	*e*	*e*							*e*			*e*	*h*						*n*		
14			*e*	*e*				*e*			*e*			*h*						*n*	
15					*e*	*e*	*e*			*e*					*h*						*n*
16				*f*	-*f*		*f*	-*f*								*j*					
17		-*f*				*f*			*f*	-*f*							*j*				
18	*f*		-*f*								*f*	-*f*						*j*			
19	*e*	*e*							*e*			*e*	*g*						*m*		
20			*e*	*e*				*e*			*e*			*g*						*m*	
21					*e*	*e*	*e*			*e*					*g*						*m*

= 3 mm and w = 3 mm. The dynamic characteristics were described by $C_j(0)$=0.1pF, and a transit time of 0.1ns.

The TLM analysis of the given structure has been compared with the results obtained using SPICE (Fig. 2), showing a very good agreement. The little discrepancy is due to the parasitic capacitance introduced by the stubs.

The procedure has also been validated for a fully 3D problem in the presence of a graded mesh and heterogeneous media. The capacitively coupled bandpass filter of Fig. 3.a has been examined [12]. The two capacitors, of value 0.16 pF have been modeled with the lumped device approach. The S-parameters of the structure have been computed with a TLM analysis and compared with the measurements available in the literature [12], showing a good agreement (Fig. 3.b).

CONCLUSIONS

We have presented an extension of the TLM method to analyze three-dimensional hybrid problems, consisting of distributed and lumped components. In order to model arbitrary geometries and media properties, as well as nonlinear devices, a modification of the stub-loaded SCN scattering matrix has been proposed.

The accuracy of the proposed method has been validated by comparing the results of our approach with SPICE simulations and against measurements available in the literature.

In the future, the ability of embedding lumped elements in structures having arbitrary geometries and media properties will be coupled with a lumped circuit solver such as SPICE, thus exploiting the advantages of both the TLM and the lumped circuit simulators.

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FIGURES

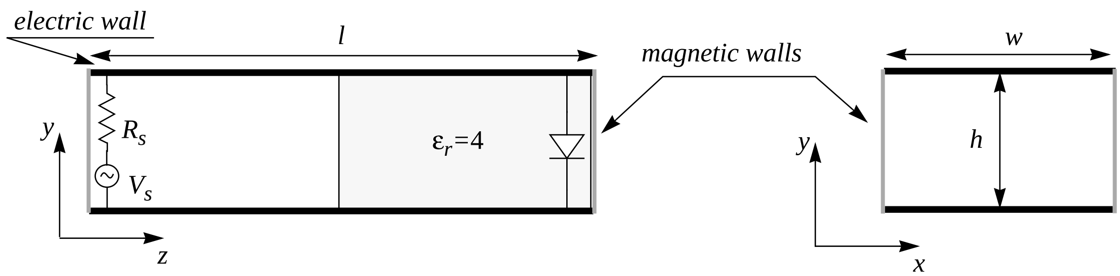

Fig. 1 One-dimensional test structure: partially filled transmission line ended by a pn junction diode

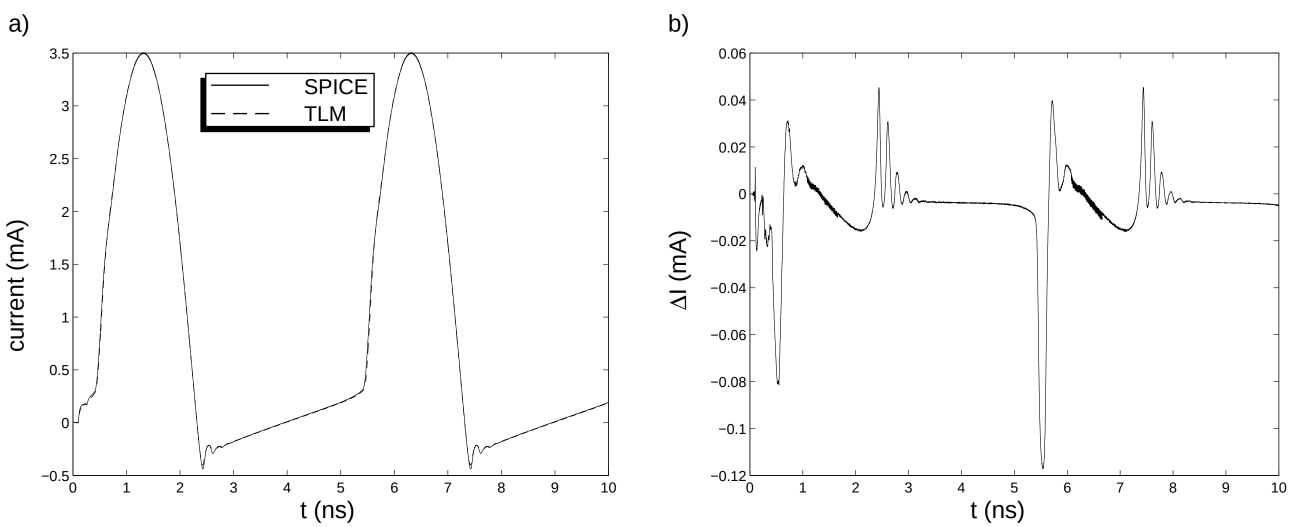

Fig. 2 a) Diode current for the circuit shown in Fig. 1. b) Time-domain difference between the SPICE and TLM results

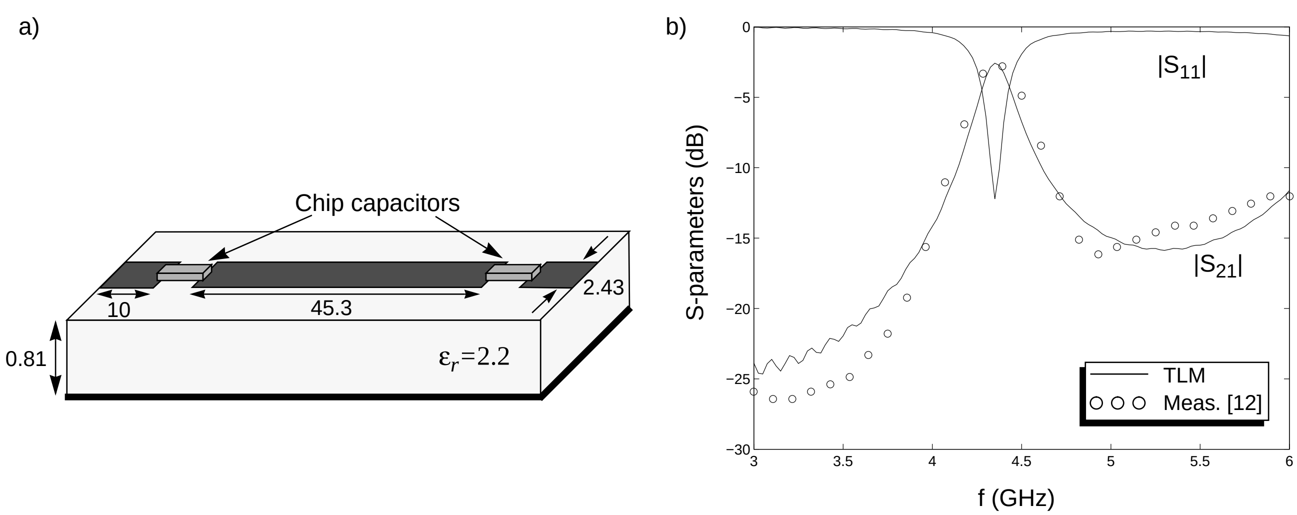

Fig. 3 Capacitively coupled bandpass filter: a) Geometry of the problem (dimensions in mm). b) Comparison of the computed S-parameters with the measurements available in the literature [12].