Comparison of the Efficiency of Electromagnetic Solvers in the Time-and Frequency-Domain for the Accurate Modeling of Planar Circuits and MEMS

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Abstract - **In this contribution we present an accurate investigation of three different techniques for the modeling of complex planar circuits. The em analysis is performed by means of different electromagnetic full-wave solvers in the time-domain and in the frequency-domain. The first one is the Transmission Line Matrix (TLM) method. In the second one the TLM method is combined with the Integral Equation (IE) method. The latter is based on the Generalized Transverse Resonance Diffraction (GTRD). In order to test the methods we model different structures and compare the calculated S-parameters to measured results, with good agreement.**

I. INTRODUCTION

The goal of our outgoing joint effort is the development and the application of efficient numerical tools for the analysis and modeling of complex open planar circuits such as antennas, filters and Micro-Electro-Mechanical-System (MEMS).

The above structures usually exhibit several geometrical details, finite dielectric layers, losses and thick metals and in the case of MEMS, also strongly critical "aspect-ratios". Typically, it is very difficult to deal with all these structures using the same method or solver. The use of semi-analytical methods like the integral equation method (IE) in connection with the method of moments (MoM) is usually restricted to strictly planar structures, [1]. However GTRD allows setting up an integral equation for truly 3D structures, complementing the known advantages of MoM techniques (such as speed and reliability) with the flexibility of 3D full-wave approach in the frequency domain.

Its disadvantage lies in the need for some hypothesis on the structure, as it relies on knowledge of the Green Function describing the structure under test.

In [2] a 3D GTRD formulation for boxed multilayer structures was presented that exploited the Green's function of a loaded box and was shown to be especially suited for MMIC and MEMS analysis. Space discretizing methods like the TLM method allow the numerical field modeling of structures with nearly arbitrary geometry [3,4]. Their disadvantages appear when dealing with free space regions which increases considerably the 3D-spatial domain of computation, thus increasing the number and the size of the elementary cells for the field modeling. The hybrid TLM-IE method combines the advantages of the TLM method in modeling nearly arbitrary complex structures and the advantages of the IE method in dealing with wide homogeneous regions, [6]. A minor drawback is the need of storing the time-evolution of the tangential field where TLM is coupled to the Green's function-based Integral Equation.

Three full-wave numerical tools were developed based to the aforementioned techniques:

i) A solver based on the TLM method, which involves computer visualization [5].
ii) A solver based on the TLM-IE method [6].
iii) A general-purpose commercial program, including tools for pre and post processing, EM3DS, distributed by MEM Research, based on our GTRD method [2].

In order to compare accuracy and efficiency of the above three methods we have modeled several structures. In this contribution we discuss three examples: a patch antenna in order to highlight features of the open environment, a microstrip filter, as example of typical purely planar circuit and a MEMS switch, that is known to be challenging structure [7,8]. Theoretical S-parameters are compared to experimental ones with very good agreement.

II. THEORY

In the TLM method the evolution of the discretized electromagnetic field is modeled by wave pulses propagating on a mesh of transmission lines and scattered at the mesh nodes [3,4].

In the TLM-IE method the 3D space is segmented into different sub-regions, where the best suited method, be it TLM or IE is applied. Inside the TLM-regions, the e.m. field is modeled by the TLM method. In IE-regions the e.m. field is analytically by means of the appropriate Green's function. The continuity of the field is applied

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at the interfaces between regions, providing appropriate integral equations for the tangential field.
The tangential field solution represents the exact boundary condition for the TLM algorithm [6]. In the GTRD approach the Green's function of a multilayer dielectric stack is calculated [2]: the Green's function links fields within the stack to arbitrary current source distributions. Currents are defined in volumes describing lossy conductor regions, and by imposing Ohm's law to hold, an eigenvalue equation is obtained. The final step is to select appropriate excitation so as to transform the eigenvalue equation into a deterministic one. In our case, excitations were selected to be standard delta-gap field sources, while the source discontinuity was removed by appropriate de-embedding.

III. RESULTS

Figure 1 shows the patch antenna described in [7] and the comparison between the different methods and the experimental values of [7].

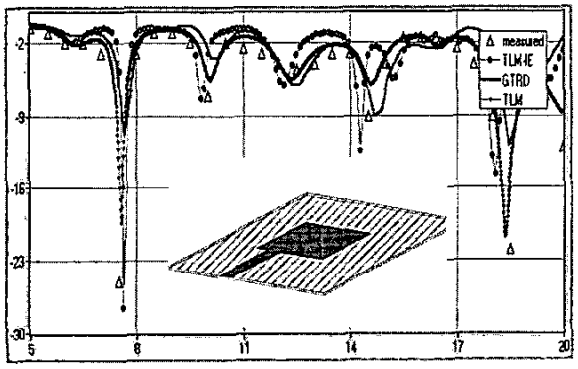

Fig. 1: Line-fed rectangular microstrip antenna reported in [5]: S11 (dB) versus frequency [GHz].

Fig.2 shows the microstrip filter reported in [7], while Fig.3 reports the return loss as obtained by the different approaches.
The three methods show high accuracy and agreement with experimental data. The TLM-IE and GTRD simulations have been performed by a 512 Mb-RAM 300 MHz PC, while TLM over a HP-9000 C360.
TLM-IE simulation requires about 15 minutes for each structure. For the microstrip filter, for example, a Symmetrical Condensed Node (SCN) was used resulting in a grid of 120 x 120 x 12 cells, with homogeneous mesh (Δl=0.25 mm). GTRD took a few minutes for the patch antenna, involving only 195 expansion functions, and just seconds for the filter (127 expansion functions). TLM required two hours on the C360 workstation for the patch antenna; the discretization was 100 x 165 x 53 cells.
It should be remarked, however, that GTRD is a frequency-domain approach, so that the simulation time is dependent of the number of frequency points required, while TLM and TLM-IE obtain the frequency-domain response as FFT of a time-domain evolution, implying advantages for broad band simulations.
It has to be mentioned that TLM and TLM-IE have their strongest point in the ability to model very complex structures, with nearly arbitrary shaped object in space.

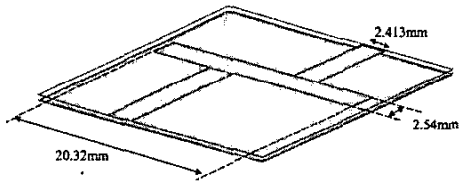

Fig. 2: The microstrip filter reported in [7].

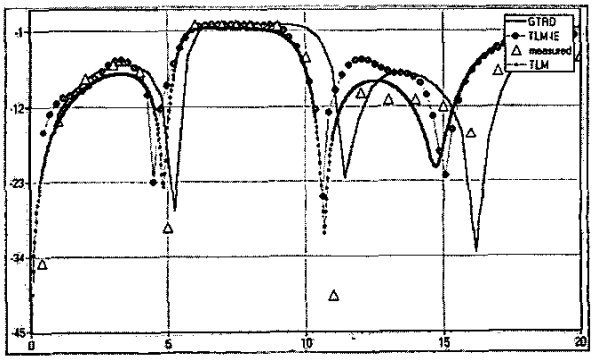

Fig. 3: Return Loss (dB) for the structure of fig.2.

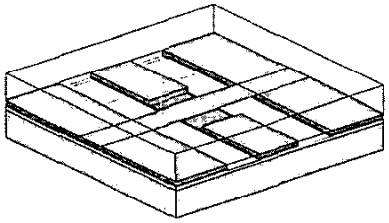

Fig. 4:MEMS switch

Fig.4 shows the MEMS switch reported in [9]. Fig.5 shows a comparison between TLM, TLM-IE, GTRD and experimental data for the "on" state. Fig.6 shows the same comparison for the "off" state. In both cases GTRD computation required roughly 3 hours CPU-time; the TLM-IE simulation requires about 2 hours CPU-time. It is remarkable to observe that by using the TLM-IE method both the bulk Si-region and the free-space regions are modeled by means of the appropriate Green's function, thus drastically reducing the 3D spatial domain of computation for the TLM algorithm.

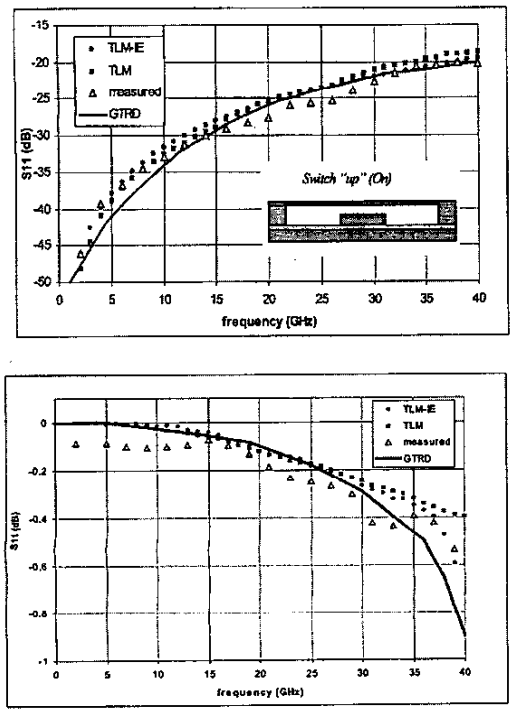

Fig. 5. On State. S_{11} (above) and S_{21} (below) vs. freq. (GHz).

A comparison of TLM method, TLM-IE method and GTRD method with experimental data shows a very good agreement in any analyzed structure. Slight differences on the accuracy are mostly due to the selection running parameters (mesh size, number of time steps for TLM/TLM-IE, number of expansion functions for GTRD).

Any method has its own advantages and drawbacks. TLM-IE, due to its hybrid nature, seems to offer a good trade-off between flexibility, accuracy and computation time.

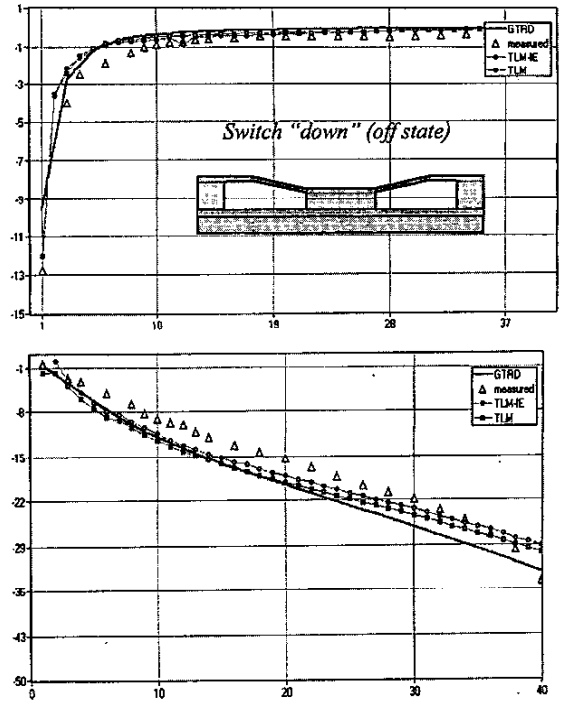

Fig. 6. Off State. S_{11} (above) and S_{21} (below) vs. freq. (GHz).

Fig. 7 to 10 show the time domain simulation of the electric field in the MEMS switch according to fig. 4. The structure is excited with a Gaussian pulse of 1.6 ps width. Due to the symmetry of the problem only half of the structure is depicted. Fig.7 and 8 show the field distribution of the "on" state, fig. 9 and 10 the field distribution in the "off" state.

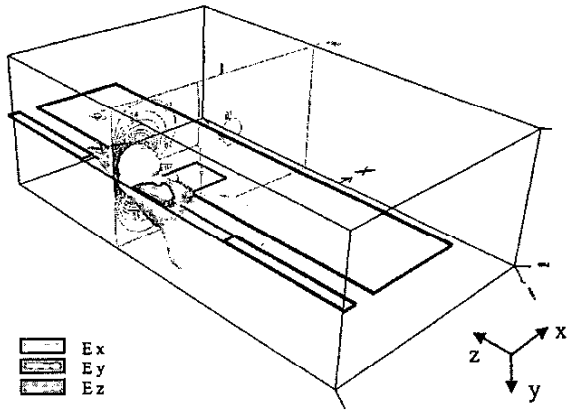

Fig. 7 On State – $t=t_0$

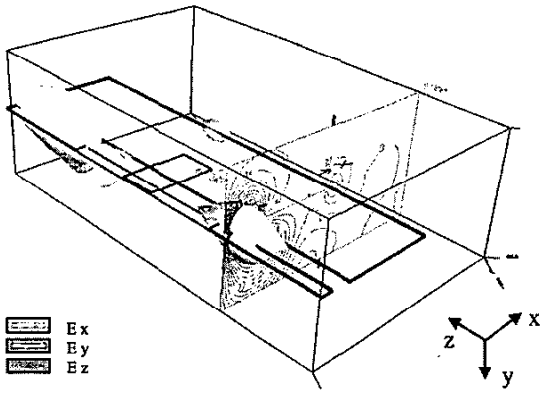

Fig. 8 On State – $t=t_0+2.5ps$

The shaded surfaces are the isopheres of E_x , E_y und E_z . In the xz-plane and in the yz-plane respectively the isoclinal lines of E_x are depicted.
Fig. 7 and 9 show the field distribution at $t=t_0$ when the pulse passes the bridge. Fig. 8 and 10 show the field distribution 2.5 ps later.

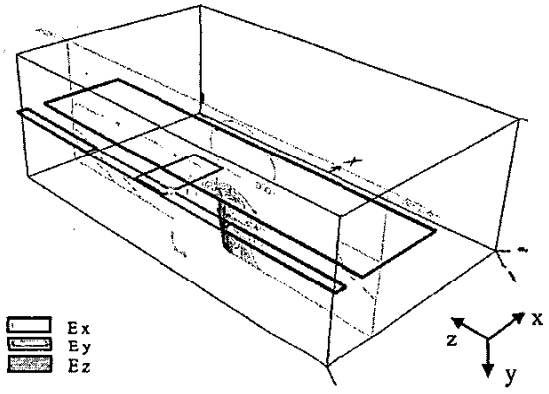

Fig. 9 Off State – $t=t_0$

IV. CONCLUSIONS

The performances of the three full-wave approaches, TLM, TLM-IE and GTRD, have been compared for the case of planar and quasi-planar structures. Comparison with experimental results shows very good agreement. Besides the high accuracy a further advantage of TLM is its high flexibility with respect to general structures. A reduction of computation time by up to one order of magnitude with pure TLM can be achieved using system identification methods [10].

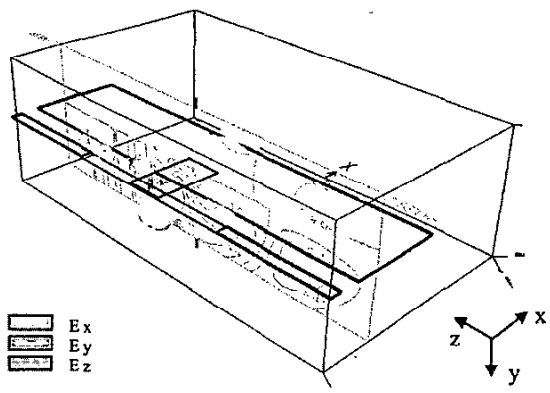

Fig. 10 Off State – $t=t_0+2.5ps$

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