Comparison of FETD and FDTD to Simulate Micro-strip Structures on PCBs

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Abstract

The aim of this paper has been to investigate the numerical effort to simulate the electromagnetic field of simple structures on printed circuit boards (PCB) fast and accurately by the finite difference time domain (FDTD) and by the finite element time domain (FETD) method. In case of FDTD an approximate solution of the unknown electromagnetic field is determined with the aid of Yee-cells and by applying the "leapfrog scheme" in an explicit time stepping procedure. For FETD edge and nodal finite elements of second order are employed to approximate the magnetic vector potential **A** and the electric scalar potential *V*, respectively. A preconditioned conjugate gradient method is used to solve the algebraic system of equations. A micro-strip structure has been studied between 100MHz and 1GHz. Simulations and measurement data are presented and the numerical effort is discussed.

1 Introduction

The motivation of the present work is to find a method to simulate efficiently the electromagnetic field of simple structures on PCBs considering the full set of Maxwell's equations in a comprehensive numerical model. These accurate computations shall serve to examine approximate techniques.

In a previous work [1] two potential formulations [2] have been used to study excitation models and the computational effort in the frequency domain. The input impedance of a micro-strip obtained once by using a comprehensive finite element model and once exploiting some simplifications have been compared with measurement data. The investigations carried out have shown a high memory requirement and long computation times for a frequency sweep. For each single frequency, a separate calculation has to be done.

To reduce the computation times significantly simulations are carried out in the present work with FDTD and FETD using an adequate Gauss pulse with respect to the frequency range to be determined as excitation. The input impedance is calculated by the input voltage and the input current after a Fourier transformation.

Simulations and measurement data are presented. A loop shaped lossy micro-strip structure serves as a benchmark. The numerical effort of FDTD and FETD is compared and discussed.

2 Numerical Methods

2.1 Finite Difference Time Domain

One common possible method to simulate the electromagnetic field in the time domain is FDTD which has been implemented for test purposes [3]. Discrete values of the electric field intensity $\mathbf{E}$ and magnetic field intensity $\mathbf{H}$ representing the degrees of freedom, are assigned to two spatially interleaved grids, i.e. Yee cells, and are calculated in interleaved time instants explicitly. This is well known as the "leapfrog scheme". To keep the memory requirement small, the FDTD model can be built by non-continuous grids on one the hand, and on the other hand, only a subset of time instants is stored.

2.2 Finite Element Time Domain

Another accurate method for solving electromagnetic wave equations is the FETD method [4]. The whole region is discretized by hexahedral finite elements. To describe the electromagnetic field, a potential formulation using the magnetic vector potential $\mathbf{A}$ and the electric scalar potential V is used. $\mathbf{A}$ is approximated by edge basis functions of second order and V is represented by nodal ones. The formulation used is not gauged. For the time discretization the Newmark method is used. To be unconditionally stable the parameters of the Newmark method have to be chosen appropriately. For this work the average acceleration has been used. At every time step a singular system of linear equations is solved iteratively by a conjugate gradient method with symmetric Gauss-Seidel preconditioning.

3 Numerical Simulations

The numerical benchmark is sketched in Fig. 1. The relative permittivity of the board has been assumed to be $\varepsilon_r = 4.45$ and the electric conductivity to be $\sigma = 0.99 mS/m$. The thickness of the dielectric medium equals $1.5mm$ and that of the ground plane and the conducting track is $35.0mm$. The modeling of a voltage excitation using the $\mathbf{A}, V$ formulation is described in [1]. To obtain a rapidly vanishing input current, the real part of the wave impedance Z_w has been used as the resistance R_i. The per unit length parameters for Z_w have been determined by appropriate 2D FEM calculations. In case of FEDT, R_i was modeled by a suitable conductivity in a negligibly small section of the micro-strip adjacent to the excitation. For FDTD a discrete series connection of the voltage source and R_i has been used.

To compare the simulations, numerical models have been created with almost equal number of degrees of freedom (DOF). Since the order of approximation for FDTD and FETD is different, the smallest subdivision selected for FDTD equals $5.0 \mu m$ and for

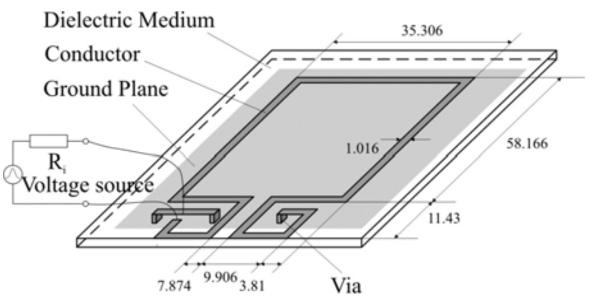

Fig. 1 Loop shaped PCB track, dimensions are in mm.

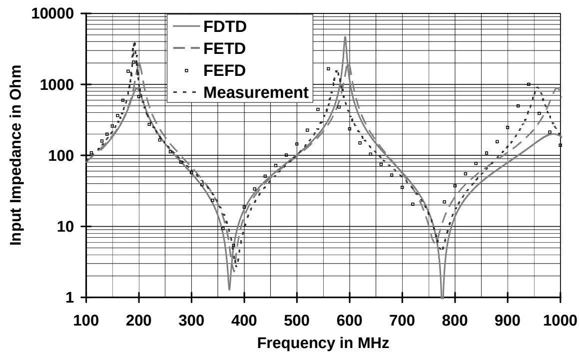

Fig. 2 Frequency sweep of the input impedance.

FETD $10.0 \mu m$.

The input impedance obtained by the different methods and by measurement is shown in Fig. 2. The finite element frequency domain (FEFD) solution is also presented. The simulation in the time domain has been carried out in a time interval of $5.0ns$. According to the Courant stability condition 330,000 time steps has been required for FDTD. The number of time steps chosen for FDTD and FETD was 100. Additional numerical data are summarized in Tab. I.

TABLE I: NUMERICAL DATA

Method	[a] FEYC	[b] DOF	[c] NOC	[d] NOI	[e] CT
FDTD	91,630	525,420	2 360,371	-	18,514
FETD	34,320	513,487	33 787,804	39,916	17,659
FEFD	34,320	513,487	33 788,804	[f] 3,356	[g] 3,571

[a] No. of Finite Elements or Yee Cells, [b] No. of DOF, [c] No. of Coefficients, [d] No. of ICCG Iterations, [e] Comp. Time in Seconds on an Intel® Pentium® 4 processor 660, [f] Average No. of ICCG Iterations, [g] Comp. Time in Seconds for one single frequency.

4 Conclusions

A good agreement between simulation results and measurement data can be observed. Although the number of time steps required by FDTD is extremely large the simulation time by FDTD and FETD is almost equal. The number of coefficients for FDTD is clearly smaller than that for FETD.

5 Acknowledgement

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6 Literature

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