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Simulation of Microstrips on Printed Circuit Boards

INTRODUCTION

The data rate in digital electronics increases rapidly and thus, the influence of interconnects have to be considered, too. Wireless telecommunication, for instance with a bluetooth antenna in a laptop, has recently gained great importance. On the other hand steadily growing demands on the electromagnetic compatibility, for instance signal integrity, require tools allowing a fast and accurate assessment of printed circuit boards already in the design phase. Analytic approximate techniques may fail to simulate complex structures correctly. Therefore, efficient tools considering the full set of Maxwell's equations in a comprehensive numerical model of the complex structure are required.
In previous works [1, 2] the finite element method in the frequency domain (FEFD) with two potential formulations (**A**v and **T**Phi, [3]) has been used to study excitation models and the computational effort by means of a microstrip (MS). 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 the finite difference time domain method (FDTD) and the finite element method in the time domain (FETD, [4]) using an adequate Gauss pulse representing the frequency range to be considered as excitation. An input impedance is calculated from the Fourier transforms of the input voltage and the input current.
The input impedance of a spiral shaped MS has been investigated by FETD, FDTD and FEFD, the radiation of a bluetooth antenna has been studied by FEFD and FDTD. For both problems the necessity to apply absorbing boundary conditions (ABCs) has been analyzed.

NUMERICAL SIMULATIONS

A) Spiral Shaped Microstrip:

The geometry of the spiral shaped MS with its dimensions shown is plotted in Fig. 1. According to the specifications of the manufacturer of the board, the relative electric permittivity ε_r decreases from 4.475 at a frequency f of 100MHz to 4.4 at 1GHz practically linearly. The loss factor $\tan\delta=\sigma/(2\pi f\ \varepsilon_r\varepsilon_0)$ was assumed to be 0.0195, wherein ε_0 means the electric permittivity of vacuum and σ the electric conductivity. The width of the MS is 1.014mm and its thickness 35.98µm. The thickness of the board equals 1.5mm. For the simulations with FDTD and FETD average values of the material properties for the board have been selected. The electric conductivity σ was assumed to be 2.594mS/m and the relative electric permittivity ε_r was chosen to be 4.425. The smallest dimension of the cells / finite elements was selected as 7.089µm, which is about 2.5 times the penetration depth for copper at 1GHz. The tangential component of the electric field intensity has been set on the far boundary. Hexahedral edge and nodal finite elements have been used with **A**v formulation in both the time and the frequency domain.

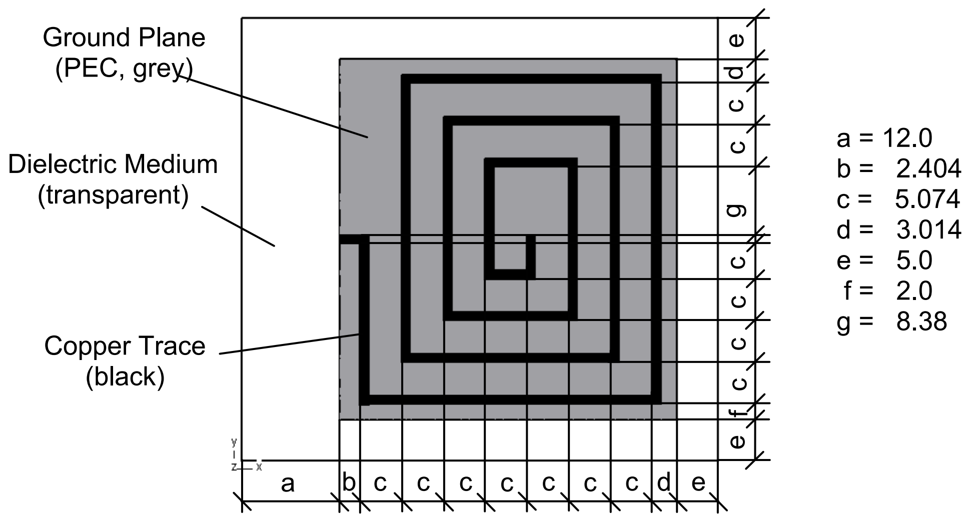

Fig. 1: Geometry of the spiral shaped MS with the dimensions in millimeter, top view.

The ground plane has been considered as a perfect electric conductor (PEC). This simplification in the model has been examined by a couple of simulations with the ground plane made of copper using FEFD. It turned out, that the deviation of the input impedance obtained by the simplified model from that by the accurate one is negligibly small.

The input impedance of the spiral shaped MS obtained by using once a finite element model and once a finite difference model have been compared with measurement data (see Fig. 2). In general all simulated input impedances are close to the measurement and to each other.

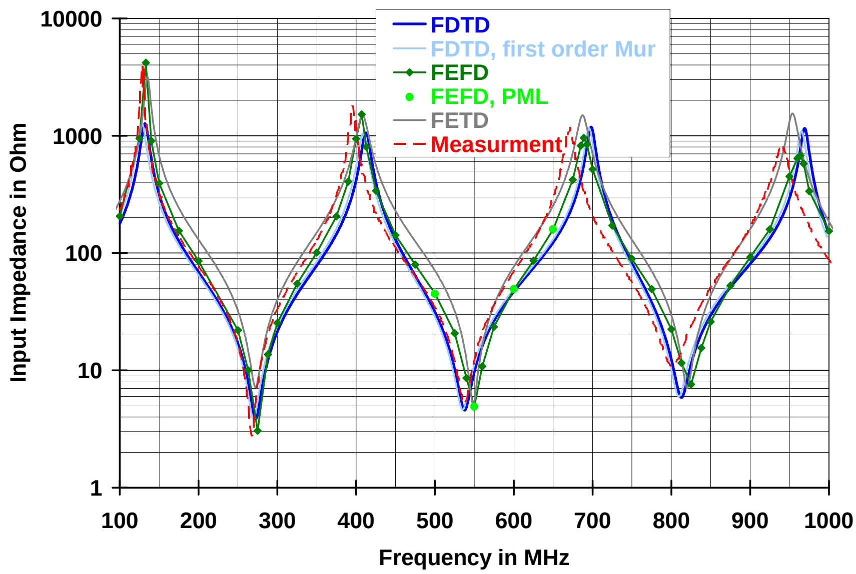

Fig. 2: The input impedance obtained by different methods is compared with measurement data.

The electric conductivity of the board varies within the analyzed frequency range strongly. Its influence on the input impedance is clearly visible comparing the results obtained by FDTD with those obtained by FEFD, for which the frequency dependent material parameters have been used. The higher electric conductivity damps the peaks of the input impedance at the resonance frequencies.
The necessity to apply ABCs on the far boundary has also been investigated. In case of FDTD Mur's first order ABCs [5] have been used, for FEFD perfectly matched layers (PMLs, [6]) have been applied. A comparison of the results obtained with ABCs with those without ABCs shows that the results are practically identical. This means that the radiation of the electromagnetic field is negligibly small.
Some numerical data are summarized in Table I. The simulation in the time domain has been carried out in a time interval of 10ns for FDTD and 7ns for FETD.

TABLE I: NUMERICAL DATA

Method	ABC	[a] FEYC	[b] DOF	[c] NOC	[d] NOI	[e] CT
FDTD	no	95,284	527,450	2 366,156	-	16,590
FETD	no	46,080	658,387	41 014,976	166,461	85,170
FEFD	no	46,080	658,387	41 014,976	[f] 5,987	[g] 8,670
FDTD	Mur of first order	95,284	582,146	2 584,224	-	17,048
FEFD	PML	76,032	1 123,003	72 715,999	[f] 5,987	[g] 43,567

[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.

B) Bluetooth Antenna:

A bluetooth antenna has been selected as an example where the radiation of the electromagnetic field has to be taken into accont in the numerical model. Fig. 3 shows the investigated bluetooth antenna with the dimensions. The ground plane and the antenna have been modeled as a PEC. The antenna is 1.0mm above the ground. The specific shape facilitates its mounting on metallic objects. The relative electric permittivity ε_r as well as the relative magnetic permeability μ_r in the entire region have been assumed to be 1.0.

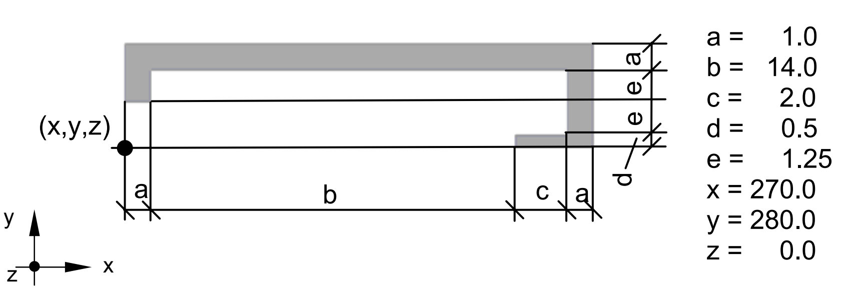

Fig. 3: Geometry of the bluetooth antenna (gray) with the dimensions in millimeter, top view.

Investigations have been carried out by FEFD and by FDTD applying a sinusoidal excitation. To approximate the steady state in case of FDTD, 4 periods have been simulated.The simulations with FDTD and FEFD have shown a good agreement. It can be easily seen from Fig. 4 that the antenna radiates at a frequency of 2.5GHz practically uniformly in the upper half space.

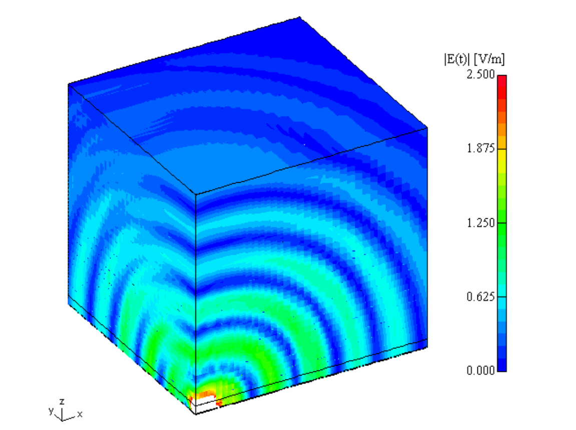

Fig. 4: Distribution of the magnitude of the electric field intensity on the surface of one fourth of the problem region, FDTD.

Perfectly matched layers have been applied for FEFD. Mur's first order ABCs have been used for FDTD. The z-component of the electric field intensity E_z is shown in Fig. 5. The graph is plotted up to the position of the ABCs. No visible refelections could be detected analysing its time behavior. A simulation with Mur's second order ABCs with the same model has shown strong reflections.

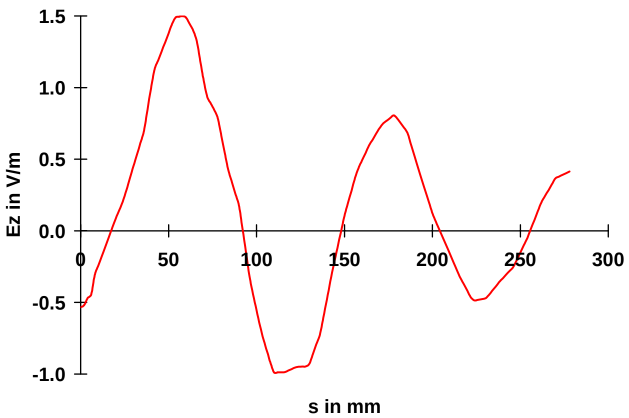

Fig. 5: Electric field intensity E_z along the line s (300.0mm<x<600.0mm, y=340.5 and z=10.0mm) at the time t=1.4ns, see also Fig. 3, FDTD.

CONCLUSIONS

In case of the spiral shaped MS, the computation times for FDTD and FETD are substantially different. The memory requirement during solution is essentially smaller for FDTD than that for FETD.

One simulation by FEFD for the bluetooth antenna took about one day, whereas FDTD required about 2 hours for 4 periodes on a common PC.

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