Simulation of Simple Topologies on a PCB by a Frequency and a Time Domain Method

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Abstract – **The aim of this work is to investigate numerical methods to simulate the electromagnetic field of simple structures on printed circuit boards accurately. Finite elements in the frequency domain and finite differences in the time domain have been studied. The input impedance of a simple microstrip on a test board has been simulated. Some numerical results compared with measurement data are presented.**

1 INTRODUCTION

Due to steadily growing demands on the electromagnetic compatibility, i.e. humans being unintentionally exposed to electromagnetic fields on one hand and the signal integrity on the other hand [1, 2], it is absolutely necessary to have a tool allowing an accurate assessment of PCBs already in the design phase or to validate fast approximate techniques.

In a previous work [3] two potential formulations [4] were used to study excitation models [5] and the computational effort in the frequency domain. The input impedance of the microstrip shown in Fig. 1 obtained once by using a comprehensive finite element model and once exploiting some simplifications were compared with measurement data. The investigations carried out showed a high memory requirement and long computation times in general.

The motivation of the present work has been to compare a frequency domain method realized by the finite element method (FEM) with the finite difference time domain method (FDTD) to simulate the electromagnetic field of structures on a printed circuit board (PCB) considering the full set of Maxwell's equations accurately.

In case of the time domain method the input voltage and the input current have been Fourier transformed afterward to obtain the input impedance as a function of the frequency.

The input impedance of the microstrip [6] obtained once by using a comprehensive finite element model and once exploiting FDTD are compared with measurement data. A good agreement between simulations in the frequency and time domain could be observed. The feasibility of coupling a circuit with a field simulation by FDTD has been also investigated.

2 FREQUENCY DOMAIN METHOD

Hexahedral edge finite elements using the potential formulation $\mathbf{A}, V$ have been employed. The vector potential is approximated by edge basis functions of second order, the scalar potential is represented by nodal ones. The formulation used is not gauged. The time derivative in the frequency domain means, simply speaking, a multiplication by $j\omega$. The arising singular linear complex algebraic equation system is solved by incomplete Cholesky conjugate gradient technique iteratively.

For each single frequency, a separate calculation has to be done. This means, that for a large frequency range, numerous calculations have to be carried out leading to high computational times and high memory requirements.

3 FINITE DIFFERENCE DOMAIN METHOD

One common possible method to simulate the electromagnetic field in the time domain is FDTD which has been implemented for test purposes [7]. Discrete values of the electric field intensity $\mathbf{E}$ and magnetic field intensity $\mathbf{H}$ represent the degrees of freedom, are assigned to two interleaved grids and are calculated in interleaved time instants explicitly, well known as the "leapfrog scheme". To keep the memory requirement small the FDTD model can be built by non-continuous grids of so called Yee-cells on one hand, and on the other hand, only an arbitrary subset of time instants can be stored.

According to the Courant stability condition the largest admissible time step is determined by the smallest dimension of a cell in the entire grid and depending on the material properties. Since the penetration depth is also considered in the model, an extremely small time step has to be selected which leads to relatively long simulation times.

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4 NUMERICAL SIMULATIONS

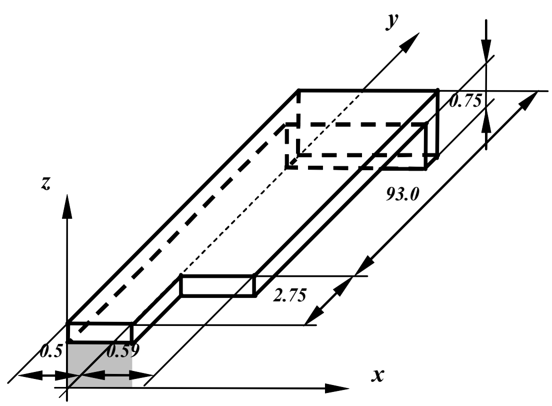

Figure 1: One fourth of the microstrip, all dimensions are in millimeter, thickness of the conductor equals to $35.0 \cdot 10^{-3} mm$.

Since $x = 0$ and $z = 0$ are planes of symmetry, only one fourth of the entire problem region has been modeled as shown in Figure 1 and simulations have been carried out. The conductivity of the microstrip is assumed to be $5.8 \cdot 10^7 S/m$. The microstrip is mounted on a board symmetric with respect to the $z = 0$ plane and is considered to be infinite. The relative electric permittivity has been set to 4.2 and a loss factor of $\tan\delta = 0.02$ has been selected. A comprehensive 3D model using a dense mesh was created taking also account of eddy currents in the microstrip. The smallest dimension in the model was assumed to be $\delta \approx 1.2 \mu m$. The same discretizations were used for FEM and FDTD models. The penetration depth for copper at $f = 1GHz$ is equal to $\delta \approx 2 \mu m$. This leads to a time increment of $\Delta t \le 2.3 \cdot 10^{-15} s$ according to the Courant stability condition to be on the save side in vacuum. A time increment of $\Delta t = 2.0 \cdot 10^{-15} s$ was selected. The simulation time was chosen to be $t_{sim} = 4.0 \cdot 10^{-9} s$. To obtain practically a rapidly vanishing input current, a damping resistor of $R_d = 100\Omega$ was used modeled by a suitable conductivity in a negligibly small section of the microstrip adjacent to the excitation.

Since the field is concentrated close to the conductor and decays rapidly with the distance from the board no absorbing boundary conditions have been necessary on the far boundary.

Using FEM with $\mathbf{A}, V$ [4] an electric voltage was prescribed by specifying the impressed electric field intensity with the aid of the tangential component of $\mathbf{A}$ on the grey surface in Figure 1. V was enforced to be zero on the same surface. In case of FDTD the input voltage has been modelled with the tangential component of the electric field intensity $\mathbf{E}$ also on the grey surface. On the opposite end of the excitation the microstrip is short circuited.

The model can be simplified by considering the microstrip to be ideally conducting. To this end, the tangential component of the electric field intensity has been set to zero on its surface. This model obviously neglects eddy current losses in the microstrip.

A possibility to reduce the computational effort drastically, is to take the microstrip to be an infinitely long line whose parameters R', L', G' and C' have been determined by a 2D finite element model, a very fast method what the computation times and memory requirements are concerned. Primes refer to quantities per unit length.

5 RESULTS

5.1 Microstrip

Using FEM in the frequency domain the input impedance has been calculated with the aid of the losses and energies stored in the magnetic and electric field and using the prescribed voltage in the frequency domain. In case of the FDTD the input impedance has been calculated by a Fourier transformation of the input current and input voltage in the time domain.

The input impedance and the associated phase angle are shown in Figures 2 and 3 in the vicinity of one resonance frequency. Measurement data are represented by a solid line. All simulated results are close to each other, except those from the 2D approximation. Nevertheless, the results of the 2D approximation may serve at least as a first rough estimation. Some numerical details obtained on the same PC are summarized in Table 1. The savings concerning memory requirement and computation time of the model with an ideally conducting microstrip are considerable compared to those where the microstrip is assumed to be a real conductor. In case of the ideal conductor the smallest dimension of the grid was selected with $\Delta x = 4.8 \mu m$ and the time increment was chose with $\Delta t = 8.0 \cdot 10^{-15} s$. The computational effort of the 2D finite element model is negligible compared to the 3D ones.

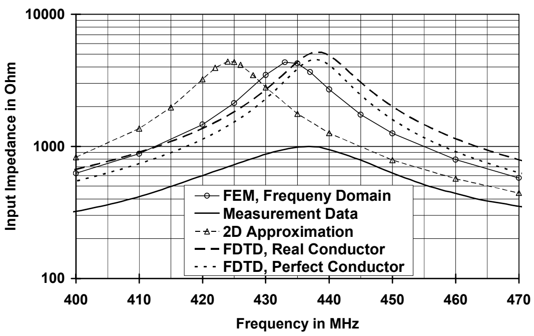

Figure 2: Input impedance as a function of the excitation frequency.

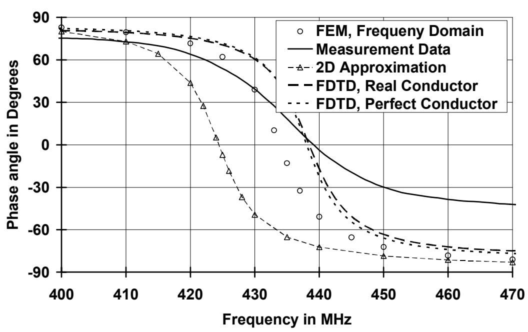

Figure 3: Phase angle as a function of the excitation frequency.

Model	[a]DOF	[b]NOSS	[c]NOI	[d]NOTS	[e]CT
FEM	562,768	1	13,655	-	18,811
FDTD, Real Cond.	230,447	200	-	2 000,000	45,259
FDTD, Ideal Cond.	86,165	200	-	500,000	3,877

[a] No. of Degrees of Freedom, [b] No. of stored Solutions, [c] No. of ICCG Iterations, [d] No. of Time Steps, [e] Computation Time in Seconds.

Table 1: Numerical Data.

5.2 Coupling Circuits with Field Simulation

Contrary to FEM coupling a circuit with a field simulation is straightforward in case of FDTD [7]. This might be rather helpful in practical problems, where the field solution is required somewhere away from the board and the circuit is built for instance by surface mounted devices, which would be very complex to be modeled. A comparison of FDTD results and a 2D approximation is shown in Figures 4 and 5. A circuit consisting of a parallel connection of a resistor $\left(R = 500\Omega\right)$, an inductor $\left(L = 24mH\right)$ and a capacitor $\left(C = 1\mu F\right)$ is assumed to be clamped at the end of the microstrip replacing the short circuit. Simulation results by FDTD for the short circuit and open circuit are represented for comparison, too.

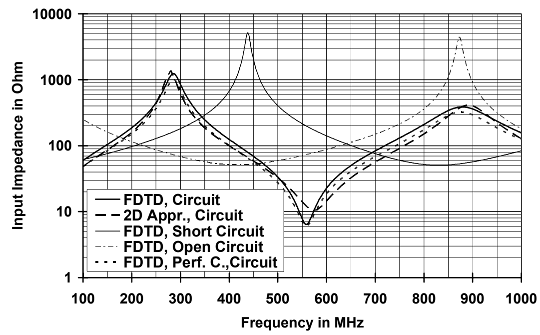

Figure 4: Input impedance as a function of the excitation frequency.

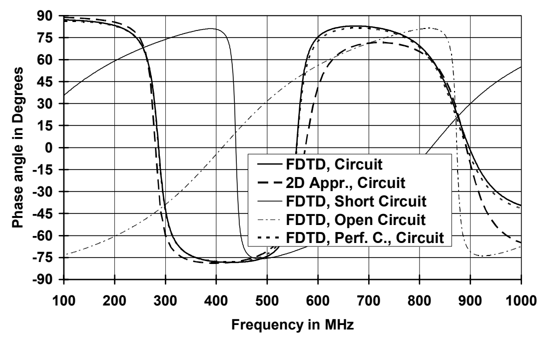

Figure 5: Phase angle as a function of the excitation frequency.

6 CONCLUSIONS

The reason for the relative large deviations of the simulated data from the measured ones are expected to be caused by the uncertain material quantities, i.e. the relative electric permittivity of the board and its losses, as well as geometric dimensions of the structure on the test board.

The computation times are essentially smaller for the time domain method compared with that in the frequency domain. Approximating the microstrip by a 2D model reduces the computational effort drastically what the computation times and memory requirements concerns.

Acknowledgments

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