EXPERIMENTAL STUDY ON PARALLELIZATION ANALYSIS OF THE PEEC-BASED SOLVER

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Abstract

The BEM-based PEEC modeling approach proved to be useful for the analysis of the electromagnetic behavior of 3D interconnects and traces on PCBs. As the main shortcomings in EMC simulation in the context of a BEM discretization approach, the memory requirements as well as the total simulation times severely limit the performance and therefore the managable problem sizes. The application of direct methods together with dense matrices leads to a time complexity of O(n3) and a storage complexity of O(n2) with n DOF. Consequently, only small problems could be solved in the past. Even simple iterative solution logarithms usually can only reduce the complexity to O(n1.5) by ensuring convergency. MOR techniques often proved to be not efficient enough to enable simulations of real-life problems on system level. The two existing bottlenecks are the modeling as well as the solving processes.

Keywords: PEEC, Hierarchical Matrices, Electromagnetic Compatibility.

Introduction

The PEEC method was originally developed at IBM for 3D inductance extraction, but it is now used for general EM modeling. The principle favorable position of the strategy is the proportional circuit plan, which gives a good insight to the electrical behaviour of the original problem and transfers the problem from the EM to the circuit domain, which makes further analysis more efficient. In addition, the PEEC method is a suitable technique for combined EM and circuit analysis, e.g. power electronic systems, since the external circuitry (consisting of active and passive components) is directly included in the EM analysis without reformulation. Research on the PEEC method and computer simulations has been done continuously over the years. An earlier implementation of the PEEC method is known as Fast Henry. Fast Henry is used for inductance extraction and is accelerated using non-uniform mesh, the fast multiple method (FMM), and iterative solvers.

More recently, hierarchical matrices (H-matrices) have been utilized together with the reluctance technique to improve the performance of a PEEC-based solver by converting a dense system into sparse system.

Additionally, some other extensions to the classic PEEC were made to include non-orthogonal structures, magnetic materials, and round wire formulations. Extensive work has also been done and is still ongoing to apply model order reduction (MOR) algorithms to the PEEC method. MOR is used to extract a macro model of a structure with respect to frequency. Moreover, over the current years, parameterized display arrange diminishment (PMOR) has been proposed, which can lessen huge arrangement of conditions regarding recurrence and other outline parameters of the circuit, for example, geometrical format or substrate qualities. Recently, an efficient scheme has been proposed for skin effect modeling using the PEEC method for round wires by connecting partial inductance for a shell in series.

Electromagnetic Simulation Approaches

Using electromagnetic simulation for product verification and optimization has become essential.As the operational recurrence and unpredictability of electronic frameworks increment, the need to predict the behaviour of the design and ensure whether the design complies with electromagnetic compatibility (EMC) regulations becomes vital. In high frequency and high current electrical systems, capacitive and inductive couplings between parts of the circuit will exist and cannot be disregarded. Furthermore, other phenomena such as skin- and proximity effects need to take into account. Therefore, classic circuit analysis is not enough to model a high frequency system correctly.

Electromagnetic simulation is generally performed by solving Maxwell's equations. Maxwell's conditions comprise of four conditions which can be communicated either in differential or essential frame. The conditions relate the electric and attractive fields to charge and current thickness.

Partial Element Equivalent Circuit (PEEC)

The incomplete component comparable circuit (PEEC) is a fundamental condition based full-wave way to deal with take care of consolidated circuit and electromagnetic issues in the time and recurrence spaces. The PEEC plan utilizes an indispensable condition arrangement of Maxwell's conditions, which is deciphered as a proportionate circuit. The model comprises of fractional inductances, capacitances and volume cell protections. The traditional PEEC strategy is gotten from the condition for the aggregate electric field at a point composed as

$$E^T (r, t) = E^i (r, t)\frac{-\partial A(r,t)}{\partial t} - \nabla\varphi(r, t).$$

is an occurrence electric field, Ĵ is a present thickness, An is the attractive vector potential, φ is the scalar electric potential, and σ the electrical conductivity, all at perception point . Utilizing PEEC, the electromagnetic problem translated into the equivalent circuit. Thus, the solution is done in the circuit domain, where additional lumped elements can easily be added to the system. The next section describes the PEEC method in more detail.

The PEEC strategy is a 3D full-wave displaying technique suitable for joined electromagnetic and circuit investigation, which is legitimate from dc to the greatest recurrence dictated by the cross section. In the PEEC strategy, the basic condition is deciphered as Kirchhoff's voltage law connected to an essential PEEC cell, which brings about a total circuit answer for 3D geometries. The equal circuit definition takes into account extra SPICE-type circuit components to be effectively included. Moreover, the models and the examination apply to both the time and the recurrence space. The circuit conditions coming about because of the PEEC display are effortlessly built utilizing an altered circle examination (MLA) or an adjusted nodal investigation (MNA) detailing. The strategy can be connected to both orthogonal and non-orthogonal geometries.

The PEEC technique's detailing is gotten from the condition for the aggregate electric field at a point. The electric field at any given point, as far as scalar and vector possibilities, because of charge and current thickness is communicated as

$$\vec{E}(\vec{r}, t) = -\frac{\partial \vec{A}(\vec{r},t)}{\partial t - \nabla\varphi\ (\vec{r},t)} \qquad (1.1)$$

In the event that there is no awed source, at that point the aggregate electric field at the surface of a conduit will progress toward becoming

$$\vec{E}\ \ (\vec{r}, t)\ = \frac{\vec{J}(\vec{r},t)}{\sigma} \qquad (1.2)$$

Substituting (1.2) into (1.1) will yield

$$0 = \frac{\vec{J}(\vec{r},t)}{\sigma} + \frac{\partial \vec{A}(\vec{r},t)}{\partial t} + \nabla\varphi\ (\vec{r}, t) \qquad (1.3)$$

where$\vec{J}$ is the current density, $\vec{A}$ is the magnetic vector potential, φ is the scalar electric potential, and σ the electrical conductivity, all at observation point$\vec{r}$. The vector potential $\vec{A}$ for a conductor at a point $\vec{J}$ in space is given by

$$\vec{A}\ (\vec{r}, t) = \mu \int_{v\iota} G\ (\vec{r},\vec{r\iota})\ \vec{J}\ (\vec{r\iota}, t_d)\ dv\iota, \qquad (1.4)$$

This is the movement time from guide r toward r` with speed of light. So also, the scalar potential is characterized as

$$\varphi\ (\vec{r}, t) = \frac{1}{\varepsilon O} \int_{v\iota} G\ (\vec{r},\vec{r\iota})\ q\ (\vec{r\iota}, t)\ dv\iota, \qquad (1.5)$$

where the free space Green's function in (1.4) and (1.5) is

$$G(\vec{r},\vec{r_\iota}) = \frac{1}{4\pi}\frac{1}{(\vec{r}-\vec{r_\iota})|} \tag{1.6}$$

By substituting (1.3) and (1.4) in (1.5), the basic condition for the electrical field at given point r is figured as

$$O = \frac{\vec{J}(\vec{r},t)}{\sigma} + \mu \int_{v\iota} G(\vec{r},\vec{r_\iota})\, \vec{J}\,(\vec{r_\iota}, t_d)\, dv\iota + \frac{1}{\varepsilon O}\int_{v\iota} G(\vec{r},\vec{r_\iota})\, q\,(\vec{r_\iota}, t)\, dv\iota, \tag{1.7}$$

, the electric field integral equation is re-written as

$$O = \frac{\vec{J}(\vec{r},t)}{\sigma} \tag{1.8}$$

$$+ \mu \int_{v\iota} G(\vec{r},\vec{r_\iota})\, \frac{\partial \vec{J}(\vec{r_\iota},td)}{\partial t}\, dv\iota$$

$$+ \frac{\nabla}{\varepsilon O}\int_{v\iota} G(\vec{r},\vec{r_\iota})\, q\,(\vec{r_\iota}, t)\, dv\iota,$$

Sequential Code for EM Analysis Using PEEC Theory

A program for EM investigation, in light of the hypothesis and references illustrated above, has been created. The solver can deal with both the customary orthogonal PEEC demonstrate and the recently presented non-orthogonal plan. In this paper, just orthogonal models are considered while non-orthogonal outcomes will be introduced in a future paper since various issues emerge when working with non-orthogonal PEEC models. The program makes a proportional circuit and figures the relating protections, fractional inductances, capacitances, and coupled voltage and current sources (to represent electromagnetic couplings) for the given geometrical format (CAD-information as determined in an info record). The client includes outside electronic (sub-) frameworks and examination mode as depicted by the SPICE punctuation.

The PEEC-Based Solver

The solver's main role is to orchestrate the solution process within different phases, which are explained in detail in this section. First of all, by feeding the solver with a geometrical layout, the mesh on the surface and volume will be applied, which will discretize the structure. In the next step, the solver makes an identical circuit and computes the relating protections, fractional inductances, capacitances, and coupled voltage and current sources (to represent shared couplings). Sources and extra lumped components like resistors, inductors, capacitors, and any other linear/non-linear elements can simply be added to the model. The reproduction should be possible in both the time and recurrence spaces with the correct work as indicated by the most astounding recurrence of intrigue.

In the last advance, the MNA framework, which depends on Kirchhoff's present law (KCL) and Kirchhoff's voltage law (KVL) at nodes and within loops of the equivalent circuit and describes the behaviour of the PEEC circuit, is formed and then solved using numerical methods. The solution of the MNA system will be as current within each volume cell and potential at each node. The profiling has been done by running a quasi-static frequency domain simulation within 10 frequency steps. The number of unknowns for both tested models was 9 451. Partial element calculation is a set of tasks to calculate coefficient of potential (P), partial inductance (L_p), and the resistance (R) matrices. In the solution phase, the system of equations is solved and unknowns are extracted, and in the post-processing the field values are calculated. It is evident that in an orthogonal model the most time is consumed in the solution phase, whereas partial element calculation is done very fast. Post-processing is an optional process, and this is also fast for both test cases. However, in a non-orthogonal simulation, the time needed for partial element calculation is increased dramatically, becoming comparable to the solution time. This is because of the cumbersome calculations necessary in non-orthogonal formulations for partial elements.

Conclusion

The consistent research concerning the PEEC technique would bring about a strategy completely equipped for dealing with a considerable lot of the confounded issues looked by the business today. The suite of apparatuses that could be founded on the PEEC strategy would enhance demonstrating of a substantial assortment of wave based issues both single and consolidated wave compose issues. We are able to identify by this analysis where some of the frequencies are generated. This analysis helps to design better printed circuit boards which do not exhibit these coupling behaviors. This in turn should lead to reduced coupling and EM1 radiation.

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