MACSI-net event

MACSI-NET Working Groups 2 & 13

“Electromagnetics in Telecommunication”

“Coupled Problems and Model Reduction”

Annual meeting and workshop

on

Model Reduction in Electromagnetics
Coupling of Field Models and Circuits

May, 2-3, 2003

Swiss Federal Institute of Technology (ETH)
Zürich, Switzerland

Programme

Friday, May 2, 2003:

09:00-09:15	Welcome and opening	
09:15-10:00	Invited presentation: **P. Dular**	*Dual Finite Element Formulations and Associated Global Quantities for Field-Circuit Coupling*
10:00-10:45	Invited presentation: **C. Tischendorf**	*Numerical Analysis of Coupled Circuit and Device Models*
10:45-11:30	Coffee break	
11:30-12:15	Invited presentation: **S. Kurz**	*Field-Circuit Coupling for Mechatronic Systems: Some Trends and Techniques*
12:15-13:30	Lunch in Mensa	
13:30-14:15	Invited presentation: **Z. Andjelic**	*Coupled Problems in Power Device Simulation*
14:15-15:00	Invited presentation: **H. De Gersem**	*Finite Element Models for Eddy Current Effects in Windings: Application to Superconductive Rutherford Cable*
15:00-15:45	Coffee break	

Programme

Friday, May 2, 2003 (continued):

15:45-16:15	Contributed presentation: **O. Sterz**	*Current and Voltage Excitations for the Eddy Current Mode*
16:15-16:45	Contributed presentation: **P. Ledger**	*Parameterised Electromagnetic Scattering Solutions for a Range of Incident Wave Angles*
16:45-17:15	Contributed presentation: **P. Heres**	*Reduction and Realization Techniques in Modelling of Passive Electronic Structures*
19:00	**Conference dinner** in *Jimmy's Pizzeria*	

Saturday, May 3, 2003:

09:00-09:45	Invited presentation: **P.B.L. Meijer**	*Compact behavioural modelling of electromagnetic effects in on-chip interconnect*
09:45-10:30	Invited presentation: **R. Liebmann**	*CAD-based Modeling of On-Chip Spiral Inductors*
10:30-11:15	Coffee break	
11:15-12:00	Invited presentation: **A. Witzig**	*Eigenmode Analysis of Vertical-Cavity Lasers*
12:00-12:45	MACSI-NET Working Group meeting and discussion	
12:45	Closing	
13:00	Lunch in "Polysnack" (Level F)	

Invited presentation

Dual Finite Element Formulations and Associated Global Quantities for Field-Circuit Coupling

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Both general families of magnetodynamic formulations, i.e. h- and b-conform formulations, are studied in the frame of the finite element method, as well in 2D as in 3D. These dual formulations are respectively weak forms of the Faraday and Ampere equations, and respectively use unknowns directly associated with the magnetic field h (e.g. magnetic field - magnetic scalar potential h-formulations) and with the magnetic flux density b (e.g. magnetic vector potential a-formulations).

When such formulations are applied to systems coupled with electric circuits, not only local quantities, characterizing the unknown field, are involved, but also electric global quantities, i.e. currents and voltages. The conducting regions carrying these global quantities can be of massive or stranded types, each type necessitating a particular treatment depending on the formulation. The mathematical and numerical tools for naturally coupling local and global quantities are studied for all these variants. The results of this coupling are circuit relations characterizing the conducting regions, i.e. relations relating currents and voltages.

The developed methods use edge and nodal coupled finite elements and benefit from their properties to define currents and voltages in strong or weak senses, in accordance with the considered weak formulations, i.e. with no additional approximation. For that, in some cases, they make use of well defined source fields as mathematical tools. In particular, when dealing with a stranded conductor, an h-formulation needs a source magnetic field. The same kind of source field can also be used in a-formulations. Other source fields, source electric scalar potentials, are proposed for massive conductors in a-formulations. Finally, a global function of another type is used in h-formulations for massive conductors. Convenient forms of such source fields are proposed for efficient analyses. An extension of the methods for dealing with foil winding inductors is also done.

Invited presentation

Numerical Analysis of Coupled Circuit and Device Models

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The increase of performance of high-frequency circuits bases on higher complexity of integrated systems, increasing frequencies and smaller geometries of circuit elements. The behavior of high-frequency elements is more and more influenced by the surrounding circuit. Furthermore, a high modeling precision is important for a reliable evaluation of the circuit function. Therefore, we are interested in circuit simulation including distributed semiconductor device models. Using the instationary drift-diffusion model, the device equations represent a system of elliptic and parabolic differential equations. The network is described by a differential-algebraic system. Both systems are mutually coupled via boundary conditions and integral relations.

The arising coupled system can be analyzed as an abstract differential algebraic system in proper Hilbert spaces. From the theory of differential algebraic equations we know that the sensitivity of circuits with respect to perturbations depends mainly on the DAE-index. We will introduce an index concept that extends the DAE-index to abstract differential-algebraic systems describing the coupled system. Finally, we will present network topological criteria for the index of the coupled systems.

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Invited presentation

Field-Circuit Coupling for Mechatronic Systems: Some Trends and Techniques

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The first point to be addressed in this contribution is the question why mechatronic systems should be described on different levels of abstraction. It turns out that the most important levels are the field level (described by partial differential equations) and the circuit level (described by systems of differential algebraic equations). Since some parts of the system are usually modelled on the field level and others on the circuit level, the necessity of field-circuit coupling arises.

Therefore it is important to recall how the circuit elements can be derived from the more general field theory. Consequently, quasi-static electromagnetic field systems are considered and the concept of terminals is addressed. This concept allows the definition of terminal voltages and currents, which occur at the interfaces between the field and circuit models.

Field-circuit coupling can be grouped into three main categories. One approach consists of parameter extraction, where the electromagnetic field device is described by an equivalent circuit and the system simulation is carried out on the network level. Field simulations can be employed to obtain both the topology and the parameters of an equivalent circuit. A good account on this topic can be found in [14].

Another common approach is the so-called direct coupling, where the field and the circuit equations are collected in one overall matrix and solved together. This can be done either under control of the field or the circuit simulator. Typically, a finite element matrix is augmented by the circuit equations [18], or the finite element equations are represented in the circuit simulation as a multiport device [19]. From the mathematical point of view, the direct coupling algorithms frequently rely on Schur complement methods.

In contrast, indirect coupling keeps both simulations separated. They communicate with each other by coupling matrices. The overall problem has to be solved by iteration in this case [3].

The various coupling techniques are briefly discussed and compared to each other. Finally, some technical issues for analog-analog simulator coupling are pointed out and some trends that have emerged in literature during the last years are summarised.

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Invited presentation

Coupled Problems in Power Device Simulation

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The presentation covers some solution aspects of the practical power device simulation with ABB corporationn. The design of real world power devices like power transformers or switchgears is inevitably requires advanced 3D simulation techniques that are able to capture simultaneously both complex physical phenomena and complex geometry. We shall restrict our presentation to techniques and examples showing simulation-supported solutions in dielectric design (single-physics problem) and electromagnetic-thermal/electromagnetic-mechanical design (multi-physics problems). The focus is on advanced techniques used in connection with the boundary element method for the simulation of 3D electromagnetic problems, as well as on the weak coupling with modules for thermal and structural mechanics simulation.

Invited presentation

Finite Element Models for Eddy Current Effects in Windings: Application to Superconductive Rutherford Cable

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Various types of windings are used in electrotechnical devices: e.g. solid bars and three-phase windings in squirrel-cage asynchronous machines, foil windings in transformers and Rutherford cables in superconductive magnets. Eddy currents within and between the individual strands may have a significant influence on system's behaviour. Due to the large differences in size of conductor constituents, the meshing of the detailed inner coil geometry in an overall magnet model is not an option. Numerical cable models are discussed which accurately describe the cable eddy current behaviour without the necessity to consider the inner cable geometry in full detail.

The numerical scheme is based on the formulation $\nabla \times (\nu \nabla \times \mathbf{A}) + \sigma \frac{\partial}{\partial t}\mathbf{A} = \mathbf{J}_s$ where $\mathbf{A}$ is the magnetic vector potential, $\mathbf{J}_s$ is the applied current density, ν is the reluctivity and σ is the conductivity. Winding models prescribe particular paths to be followed by the currents and specific volumes in which current redistribution occurs. In most cases, this can be modelled by an anisotropic conductivity tensor [1] in combination with a particular treatment for the electric voltage [2, 3]. The voltage is discretized by nodal shape functions which reflect the particular eddy current mechanism but not necessarily resolve the coil inner geometry itself, e.g. for foil windings, shape functions are applied which only vary in the direction perpendicular to the foils. Although the discretization for the voltage is substantially coarser than the true coil geometry, a technically sufficient accuracy is achieved at a small additional computation cost.

In the Rutherford cable, the strands are arranged in two layers and are fully transposed [4]. To prevent quench, only limited insulation is applied between the individual strands. Time-varying magnetic fields induce *adjacent strand eddy currents* migrating between adjacent strands and *cross-over strand eddy currents* forming diamond-shaped paths inside the cable [5]. An eddy current effect with such complicated current paths is conveniently represented by the magnetization $\mathbf{M} = \tau_{\mathrm{ruth}} \frac{\partial}{\partial t}\mathbf{B}$ of the Rutherford cable when submitted to a time-varying magnetic flux density $\mathbf{B}$ where the *cable time constant* τ_{ruth} is given by measurements. The additional magnetization term $\nabla \times \left(\nu \tau_{\mathrm{ruth}} \nabla \times \frac{\partial}{\partial t}\mathbf{A}\right)$ is added to the formulation [6]. The Rutherford cable model is applied in a 2D finite element and 3D finite integration model of a superconductive accelerator magnet planned for the new test facilities at the heavy-ion research center ('Gesellschaft für Schwerionenforschung' (GSI)) in Darmstadt, Germany.

The developed winding models are combined with the models of resistors, capacitors, inductors and sources in an electric circuit coupled which is coupled to the field discretization. A tree-cotree decomposition is applied to uniquely determine an independent set of voltage and current unknowns which yields a symmetric field-circuit coupled system of equations without fill-in of the sparse field equations [7]. Based on the algebraic properties of the coupled system, appropriate iterative solution techniques are selected [8].

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Invited presentation

Compact behavioural modelling of electromagnetic effects in on-chip interconnect

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Obtaining accurate circuit-level simulation models of very high speed on-chip interconnect can be very difficult. Distributed resistive, capacitive and inductive effects need to be accounted for, as well as the frequency dependent skin effect. In this talk, a new modelling flow is outlined for obtaining compact and accurate interconnect models that can be readily used in analog circuit simulators like Philips' Pstar, Berkeley SPICE or Cadence Spectre, while including automatic model generation support for simulators that use the modelling languages VHDL-AMS and/or Verilog-A. The modelling flow makes use of detailed electromagnetic simulations obtained through numerically solving the Maxwell Equations in the time domain, e.g., using FDTD-like methods [6]. Next, linear state space models are obtained from the time domain data using subspace methods like 4SID/MOESP [3,4,5]. The resulting linear state space models form a subset of the class of models that can be represented and optimized by our generalized dynamic neural network modelling formalism [1,2]. A software implementation of this formalism is applied to remove undesirable modelling artifacts from the subspace method outcomes, as well as to subsequently and automatically generate simulation models for a range of supported circuit simulation languages. Preliminary results of the use of the modelling flow will be illustrated by means of simple interconnect examples.

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Invited presentation

CAD-based Modelling of On-Chip Spiral Inductors

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Characterization of integrated inductors based on 3D simulation is of great importance in industry, as it reduces considerably time and cost of libraries for new technologies. Here we report experiences with a commercial full Maxwell field solver (Ansoft/HFSS [1]). Results agree quite well with measurements for low-resistive CMOS substrates. The dependence of different loss mechanisms and of the frequency-dependent quality factor on geometry and material properties is discussed [2], useful for optimization in RF applications. Also some numerical aspects are addressed.

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Invited presentation

Eigenmode Analysis of Vertical-Cavity Lasers

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Vertical-cavity surface-emitting lasers (VCSELs) are promising devices for applications in optical communication networks. In this work, the optical modes supported by these devices are calculated rigorously. The complex vectorial Helmholtz equation is discretized by edge-elements, resulting in a large sparse generalized non-hermitian matrix eigenvalue problem. The algebraic eigenvalue problem is solved by the Jacobi-Davidson QZ algorithm. In VCSEL engineering, real and imaginary part of the eigenvalue are key design parameters. Furthermore, the optical eigenvalue problem is integrated into an electro-thermal device simulator. As a result, comprehensive modeling of the fully-coupled opto-electro-thermal device characteristics is performed, and an example is given for the optimization of single-mode stability of a realistic VCSEL application.

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Contributed presentation

Current and Voltage Excitations for the Eddy Current Mode

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We present a systematic study of how to take into account external excitation in the eddy current model. Emphasis is put on mathematically sound variational formulations and on lumped parameter excitation through prescribed current and voltages. We distinguish between local excitation at known contacts and non-local variants that rely on topological concepts. The latter case entails the violation of Faraday's law at so-called cuts and prevents us from reconstructing a meaningful electric field.

Parameterised Electromagnetic Scattering Solutions for a Range of Incident Wave Angles

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This presentation is concerned with the numerical simulation of 2D electromagnetic wave scattering problems and it will describe the construction of a reduced order model which will enable the rapid prediction of the scattering width distribution for a range of incident wave directions. The construction of associated certainty bounds which ensure confidence in the results of the computed approximation will also be described. In addition, numerical examples will be included to demonstrate the performance of the proposed procedure.

Contributed presentation

Reduction and Realization techniques in modelling of passive electronic structures

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Modelling of passive structures can be done in different ways. Many methods (TLM, PEEC, FIT, FDTD) lead to a formulation which can be represented as a large RLC-circuit model. Given this model, a set of terminals and a frequency range of interest, model order reduction techniques can be applied.

Especially Krylov subspace methods are well-suited for this area of application. In our research we investigated, applied and improved some of these methods. Especially the orthogonalization of the Krylov-space is of interest.

Once a reduced formulation of the problem is obtained, it has lost its physical meaning, so finding a circuit with the same behaviour is not straightforward. We found a way to do this and also this subject will be addressed during my talk.

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