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Modellierung, Simulation und Optimierung integrierter Schaltkreise

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Organizers:
Kurt Antreich, TU München
Roland Bulirsch, TU München
Albert Gilg, SIEMENS, München
Peter Rentrop, Univ. Karlsruhe

43 participants from mathematical departments, from departments of electrical engineering and from industry have joined the meeting. In their talks they try to bridge the gap between basic and applied research in mathematics, research in electrical engineering and the needs of industry. Most of the invited colleagues from electrical engineering disciplines have had strong mathematical connections in the past.The presentations cover several topics.

Basic modelling research for MOSFETs and diodes were presented by Anile and by Jüngel. A general approach for noise effects is studied by Mathis.

The simulation of electric circuits with noise effects were treated by Denk and by Winkler. Oscillating circuits are investigated by Houben and by ter Maten. The case of driven oscillators was studied by Bunse-Gerstner and by Pulch. Mathematical research of differential-algebraic equations (DAEs) related to circuit simulation was the content of the talks of Kværnø, of März, of Mehrmann, of Reißig and of Trajkovic. Feldmann discussed a road-map in chip industry, which covers the needs for the next 12 to 15 years. Numerical linear algebra for the large systems in circuit simulation algorithms are handled by Freund and by Grund.

Typical problems of Co-Simulation are presented by Bartel (circuit and heat equation), Günther (DAE and PDE coupling), Kahlert (circuit and telegraph equations), Schwarz (general approach in Co-Simulation), Schilders (circuit and interconnects), Tischendorf (circuit and devices). A general approach for Co-Simulation in microsystems was given by Wachutka.

The treatment of electromagnetic effects was central of the presentations of Dössel, of Hiptmair and of van Rienen. Hoppe presented a topology optimization procedure.

Special problems were discussed by Kärtner (Laser systems), by Pronath (test design), by Stehr (hierarchical simulation tool), and by Weigel (GSU and UMTS).

Additionally colleagues were invited who work on different areas than chip-design, but have developed methods which are useful in a future simulation chain: process - device - circuit simulation. Calvo presented her results on order reduction, Trigiante discussed special two-point boundary value problem solvers, Verwer handles splitting methods for coupled systems.

P. Rentrop

Abstracts

Hydrodynamical Modeling of Gunn Oscillations

Marcello Anile

The maximum entropy distribution function is used in order to close the system of moment equations (comprising particle, momentum, energy and energy flux balance equations) for a 2-population model for charge transport in GaAs. The resulting set of hyperbolic equations is then solved for the case of a $n^+ - n - n^+$ diode coupled to a RLC circuit. The occurrence and damping of Gunn oscillations is captured by the model.

Co-Modelling of Electric Networks and Heat Evolution

Andreas Bartel

Since dimensions of chip technologies shrink and functionality is enlarged, package density increases. Thus the semiconductor industry predicts power losses of up to 40 W/cm^2 in the near future. Therefore temperature evolution needs to be simulated, too, in order to guarantee functionality of the involved devices.

Starting from a benchmark, which includes basic effects of heat production, heat conduction and thermal dependence, we discuss the modelling and resulting structures for a more general setting which allows 0D-1D thermal elements. Thus the resulting structures are coupled systems of differential algebraic equations and parabolic partial equations. Finally, for a semi-discretised version a co-simulation strategy is presented. This type of simulation is not only desirable for the use of existing software, but also for exploiting the multirate behaviour of the coupled system.

An Embedding Method for Electronic Circuits with Widely Seperated Time Scales

Angelika Bunse-Gerstner

Widely seperated time scales appear in many electronic circuits, making analysis with the usual numerical methods very difficult and costly. In this talk we present a quasi-linear system of partial differential equations (PDE) of first order corresponding to the differential-algebraic equation (DAE) describing the circuit. The solution of the PDE restricted to one of its characteristics is the solution of the DAE. If the solution of the DAE is quasi-periodic or of a more general form of this type the solution of the PDE can be very smooth and numerical methods for its computation are very efficient. Conditions for the existence of the PDE solution are presented as well as new numerical methods for the DAE resulting from the methods of characteristics for the PDE.

An Efficient Way to Avoid the Order Reduction of Runge-Kutta Type Methods for Nonlinear Problems

Maria Paz Calvo

In [1] a strategy to avoid the order reduction of Runge-Kutta methods for linear initial boundary value problems has been proposed. In this talk we investigate the applicability of such a technique to deal with nonlinear problems. More precisely, we show how the order reduction phenomenon can be efficiently avoided for Burgers' equation when the time integration is performed using a linearly implicit Runge-Kutta method.

References:

[1] M. P. Calvo and C. Palencina: Avoiding the Order Reduction of Runge-Kutta Methods for Linear Initial Boundary Value Problems, Math. Comput. (to appear)

Transient Noise Simulation: Some Remarks on Modeling

Georg Denk

An important step in the design of integrated circuits is the simulation of the transient behavior of the chip. Normally, the transient simulation does not include noise. Due to the decreasing supply voltages and device sizes, however, noise is getting more and more important. In this talk some remarks on the modeling of noise and the influence on transient noise analysis are given.

Noisy devices are usually modeled as a noise source shunt in parallel to the ideal, non-noisy element. In the context of transient simulation, this leads to stochastic differential-algebraic equations. Thermal and shot noise are modeled as white noise sources. If such a noise source occurs in the constraint part of the differential-algebraic equations (direct noise), a unique solution process does no longer exist. Changing the modeling from white noise (Wiener process) to colored noise (Ornstein-Uhlenbeck process) avoids the problems.

The modeling of flicker noise cannot be done with white noise, as the derivative of the process has a spectrum proportional to $1/f$. Similar to the simulation of white noise, it can be shown that the increments of the fractional Brownian motion can be used in the computation of flicker noise. As the increments are not stochastically independent as in the case of Brownian motion, all time points enter the computation. Therefore, special approaches for the adaptive computation of the increments and performance improvements are necessary for an efficient implementation.

Finally, first numerical experiments are presented.

Modelling and Imaging of Bioelectric Sources in the Human Heart

Olaf Dössel

The Electrocardiogram ECG demonstrates, that beating of the heart is triggered by electrical signals that are produced by the heart itself: the bioelectric sources. Can we understand the origin of the bioelectric sources? Can we discover the origin of arrhythmias? Can we find a new medical imaging technique to visualize these bioelectric sources for diagnostic purposes?

Mathematical models are presented that are used to understand the electrophysiological behaviour of single myocardium cells: Large sets of coupled nonlinear differential equations have to be solved numerically. Modelling of cell patches and the complete heart leads to a Poisson equation with an extremely large number of nodes. Imaging of the source distribution brings us to an ill-posed inverse problem and adequate regularization techniques have to be found.

Actual Problems of Circuit Simulation in Industry

Uwe Feldmann
(joint work with Diana Estévez-Schwarz)

In the first part of the presentation actual trends in microelectronics are highlighted. Therefore topics of mathematical research are derived, which are desirable to be solved in order to cope with future circuit simulation problems.

In the second part a report is given about actual own work on mixed signal simulation, and on attempts to provide user oriented diagnostics in case of faulty circuit models, problems with coupling structural and functional circuit descriptions, and failure of numerical integration due to high DAE index.

Passive Reduced Order Models via Krylov-Subspace Methods and Optimization

Roland W. Freund
(joint work with Florian Jarre)

In recent years, there has been a lot of interest in using Krylov-subspace techniques, such as the Lanczos process, to generate reduced-order models of large-scale time-invariant linear dynamical systems, especially in circuit simulation [1]. However, in circuit simulation, these techniques are mostly applied to passive circuits or subcircuits, such as RLC networks that model the interconnect or the package of an integrated circuit, and usually, it is crucial that the reduced-order model preserves the passivity of the original system.

In this talk, we first review the family of PVL (Padé Via Lanczos) methods that employ the classical Lanczos process or extensions thereof to generate reduced-order models. The most accurate, in the sense of approximation in frequency domain, models that can be obtained via such Lanczos-type algorithms are Padé or matrix-Padé models. Unfortunately, these models do not preserve passivity in general. Next, we describe two techniques for turning these non-passive models into passive ones. The first approach uses a simple projection procedure onto the spaces generated by the underlying Lanczos-type method. While the resulting model is guaranteed to be passive, in general it is only half as accurate as the associated non-passive matrix-Padé model. The second approach attempts to restore passivity by means of low-rank modifications of the matrices describing the non-passive matrix-Padé model. The use of such low-rank modifications ensures that the new model is almost as accurate as the Padé model. In order to determine appropriate low-rank modifications that yield passive models, we first describe an extension of the classical positive real lemma for regular linear dynamical systems to general descriptor systems [2]. This extension characterizes passivity of a descriptor system via the solvability of a semi-definite programming problem. By determining the low-rank modifications such that this semi-definite program has a solution, one can guarantee passivity of the reduced-order model.

References:

[1] R. W. Freund: Krylov-subspace methods for reduced-order modeling in circuit simulation. J. Comput. Appl. Math., vol. 123, pp. 395- 421, 2000.
[2] R. W. Freund and F. Jarre (2000, Dec.): An extension of the positive real lemma to descriptor systems. Numerical Analysis Manuscript no. 00-3-09, Bell Laboratories, Murray Hill, N.J.
Available: http://cm.bell-labs.com/cs/doc/00 .

Solution of Linear Systems with Sparse Matrices

Friedrich Grund

For large scale problems in electric simulation as well as in chemical process simulation, the linear solver needs nearly 50-80 % of the total amount of the computing time. We consider direct methods for the numerical solution of linear systems with unsymmetric sparse matrices. In a new approach, at each step of the elimination, the algorithm is searching for columns with a minimal number of nonzero elements.

For solving several linear systems with the same structure of the coefficient matrix efficiently, we generate a pseudo code. The computing times for several linear solvers are compared.

Numerical Circuit Simulation

Michael Günther

The aim of this talk is twofold. The first part presents a short overview of current research activities in numerical circuit design, with the transient analysis of charge/flux-oriented networks equations as the starting point: limit cycle computations of oscillators, numerical simulation of multitone behavior in RF circuits, noise simulation based on stochastic DAE's and refined models using partial differential-algebraic equations.

The second part of the talk concentrates on an important task of the last point: analysis of PDAE models for interconnected networks, impact of semidiscretization and pitfalls for co-simulation based on dynamic iteration schemes.

Coupling of Fields and Circuits

Ralf Hiptmaier

A circuit with compact elements is to be coupled with a device whose function can only be modelled appropriately on the level of electromagnetic fields. In my talk I am going to focus on devices for which the magnetoquasistatic eddy current model offers an adequate description of the electromagnetic phenomena. An example is an arrangement for inductive heating along with its driving circuit.

The coupling is based on the two lumped quantities I (current) and U (voltage), of which one provides the excitation for the field device, whereas the other takes care of the feedback to the circuit.Therefore both current and voltage excitation have to be examined. I am going to discuss how to realize them in the case of both the E-based and H-based variational formulation arising from the eddy current model. The current will be introduced through the relationship $P = U \cdot I$, where P is the power fed into the device.

Topology Optimization of High Power Electronic Devices

Ronald H. W. Hoppe

We consider the layout and design of high power electronic devices whose operational behavior is largely determined by the occurrence of electromagnetic fields. In mathematical terms, this often leads to an optimization problem with a highly nonlinear, non-convex objective functional and with equality and inequality constraints for the design, and state variables the latter ones being subject to Maxwell's equations.

The efficient solution of the optimization problem requires a proper combination of advanced nonlinear programming techniques and efficient numerical solution methods for the appropriately discretized field equations. In this contribution, we focus on primal-dual Newton interior-point methods with a hierarchy of merit functions for convergence monitoring. The discretization of Maxwell's equations is taken care of by curl-conforming edge elements. For the numerical solution we consider domain decomposition techniques on nonmatching grids (mortur edge element methods) featuring multigrid with hybrid smoothing and adaptive grid refinement/coarsening based on efficient and reliable residual type a posteriori error estimators.

In particular, we consider the optimal design of electric drives for high power electromotors giving rise to the minimization of parasitic inductivities caused by eddy currents.

Time-Domain Simulation Techniques for Finding the PSS of Electric Oscillators

Stephan Houben

There are nowadays several efficient methods for finding a Periodic Steady State (PSS) of a driven (non-autonomous) circuit. Such methods include

- Harmonic Balance (frequency-domain method)
- Finite-Difference Methods
- Shooting Methods
- Wave-form Newton (mix of Shooting & FDM)

For autonomous oscillators, which have the period T as an additional unknown, it has been suggested to scale the equation to a fixed domain and add the period T as an additional state variable. In this talk, it is shown that the resulting problem may be very ill-conditioned with respect to T. Therefore, an alternative approach based on Poincaré-mapping is used. This approach avoids the ill-conditioned of T and leads to fast convergence on the problems tested.

Numerical Simulation of Submicron Semiconductor Devices

Ansgar Jüngel

Submicron semiconductor devices, like submicron MESFET devices or resonant tunneling diodes, need to be modeled by advanced semiconductor models. Two of these advanced models are presented: the quantum drift-diffusion equations and the energy-transport model.

The quantum drift-diffusion model consists of a nonlinear fourth-order parabolic equation for the electron density coupled to the Poisson equation for the electrostatic potential. The model can be derived from the hydrodynamic formulation of a mixed-state Schrödinger-Poissson-system together with a momentum-relaxation-time limit in the hydrodynamic equations. A positivity-preserving numerical scheme is developed, the numerical convergence of the corresponding semi-discretization in time is shown by means of energy/entropy estimates, and a one-dimensional resonant tunneling diode is simulated. The static current-voltage characteristic shows negative differential effects which indicates the resonant behavior of the diode.

The energy-transport model consists of the conservation laws for the electron density and the thermal energy and of the Poisson equation for the electrostatic potential. The particle flux and the energy flux are given by constitutive relations in drift-diffusion form. With these relations the time-dependent equations are of parabolic type. The model can be derived from the Boltzmann equation by first assuming dominant electron-phonon interactions and then by assuming dominant electron-electron collisions. An exponentially fitted mixed finite-element discretization of the two-dimensional stationary equations is developed. For this approximation, P_2 elements of Marini-Pietra are used in order to get a stiffness-matrix which is also a M-matrix. Finally, a 2D MESFET device is simulated and the electron densities and electron temperatures are computed. The devices shows the expected depletion region for the electron density near the gate contact.

References:
[1] A. Jüngel and R. Pinnau: A positivity preserving numerical scheme for a nonlinear fourth-order parabolic equation. SIAM J. Num. Anal. 39 (2001), 385-406.
[2] S. Holst, A. Jüngel and P. Pietra. A mixed finite-element discretization of the energy-transport equations for semiconductors. Submitted for publication, 2001

Noise in Optical Systems

Franz Kärtner

A brief introduction into the priniciples of noise in optical systems is presented. Then the noise behavior of mode-locked lasers is derived and the timing jitter in different laser systems is discussed.

Parasitics Reduction in Analog Circuit Simulation

Martin Kahlert

A method for parasitics reduction based on direct eigenvalue calculation is presented. Differences to Padé like methods are pointed out and criticism of current generation of lumped elements is given. RCL lumped elements can be shown to be an unstable discretization of the telegrapher's equations in all cases but DC analysis.

Order Reduction in Operator Splitting Methods

Anne Kværnø

Operator splitting methods are quite popular integration schemes for problems involving different physical processes. However, for combinations of physical processes involving different time scales, order reduction might occur. This phenomenon is in this talk analyzed by means of a singular perturbation approach.

Differential Algebraic Systems with Properly Stated Leading Terms

Roswitha März

Differential algebraic systems with properly stated leading terms are equations of the form $A(x(t),t)(d(x(t),t))'+b(x(t),t) = 0$, with in some sense well matched coefficient functions A and d, as they arise e.g. in circuit simulation. In comparison with standard form differential algebraic systems $E(x(t),t)x'(t)+f(x(t),t) = 0$, by means of properly stated leading terms more information is built into the model. It is precisely figured out which derivatives are actually involved. Amazing symmetries concerning adjoint equations and Hamiltonians in optimal control theory, an easier sensitivity and stability analysis as well as a better performance of numerical integration methods are shown to be the resulting benefits.

Periodic Steady-State, AC, Noise

E. Jan W. ter Maten

Special, dedicated, RF-simulation techniques are important for speeding up the designs of several wireless producers. When dealing with RF, different signals can be recognized such as a highly oscillating carrier, of which the modulation comes from another signal. Because of non-linearity of several modular building blocks intermodulation distortion results. Stochastic noise sources generate noise like thermal noise, shot noise, flicker noise. In all these cases one is interested how effects occuring in one frequency band affect the solution in other frequency bands, or the other way round: How immune is the solution w.r.t. disturbances.

A complete RF simulation tool usually is built up from several other simulation analysis phases: DC, transient, nert periodic-steady state (PSS), nert periodic AC (PAC) and/or noise analysis (PNOISE). In developing such a tool re-usability of implementations is very important. When dealing with PAC for driven oscillator problems (i.e. the oscillator frequency is determined by the external sources), several parts of the code developed for the PSS problem (large signal) can be re-used. Also the noise analysis part can re-use several parts from the PAC analysis. Here, however, there still is only consensus about the validity of the modelling expressions for noise in the RF-PSS case. In the more specialized transistor models one even has to approximate these by so-called “elementary noise sources”. Renewed modelling is really needed here, validated by experiments.

In the case of autonomous, free oscillating circuits, the oscillator frequency is determined by the system itself in the absence of external (time-dependent sources). Here phase noise (along the orbit) occures, of which a proper analysis requires a non-linear perturbation technique using elements from Floquet theory. For each deterministic perturbation source a non-linear differential equation has to be solved for the time-dependent phase shift function $\alpha(t)$. For stochastic noise the standard deviation $\sigma^2(t)$ of $\alpha(t)$ can be directly related to the power density spectrum of the particular source, which makes an efficient algorithm possible. In all these cases several assumptions simplify things. Here a more rigid mathematical analysis (combining Floquet theory and stochastic diff. equation knowledge) is welcomed.

In addition to the phase noise, the orbital deviation represents so-called amplitude noise. As in the driven case, this component can be analysized by a linearization around the phase-shifted orbit function. This, however, is not periodical. By this one can reuse much less code then in the driven case.

Noise Analysis of Nonlinear Electrical Circuits and Devices

Wolfgang Mathis

The Langevin Approach that was developed by P. Langevin around 1905 is until now mainly used in noise analysis of linear and nonlinear circuits. Maybe one of the reasons is that it leads to stochastic differential equations which is a well-developed area of mathematics. In my presentation I showed that the Langevin approach has only a useful physical interpretation in the case of linear circuits and it leads to the Brillouin paradoxon (doesn’t satisfy the second law of thermodynamics). Therefore a more general concept is presented that based on nonlinear non-equilibrium thermodynamics of Stratonovich. L. Weiss, a former member of my research group developed a revised version which is useful for a large class of nonlinear reciprocal circuit. Using this new approach a noise description of these circuits can be derived where the second law of thermodynamics is fullfilled. Furthermore the thermal noise behaviour of many semiconductor devices can be derived in a correct manner. Finally we showed that several relations of deterministic circuit theory become invalid in noise regime.

Numerical Simulation and Control of Large Scale Differential Algebraic Systems

Volker Mehrmann

A new index reduction technique is discussed for the treatment of large scale differential-algebraic systems for which extra structured information is available. Based on this information ordered derivative arrays are formed and instead of using expensive subspace computations the index reduction is obtained by introducing new variables. The approach is discussed for circuit simulation.

Test Design for Parametric Faults in Analog Integrated Circuits

Michael Pronath

A fault model for parametric faults in analog integrated circuits is presented, followed by a brief introduction to worst-case points and their applications in circuit design and test. Two methods for optimization of test criteria and analysis of the influence of measurement error on test quality are demonstrated.

PDE Methods to Extract the Quasi-Periodic Steady State Response of Oscillators

Roland Pulch

In radio frequency applications of electric circuits, the coupling of analogue and digital components leads to oscillatory signals with widely separated time scales. Since the integration step size is restricted by the fastest rate, transient analysis becomes costly in this context.

For such circuits, we present a PDE model, which decouples the largely differing time scales and therfore yields more efficient methods. Consequently, we apply this approach to determine quasi-periodic steady state responses of source driven oscillators. Thereby, the ring modulator serves as test example.

Calculating Structural Indices

Gunther Reissig

It is shown that there is a dual solution (y, z) of the assignment problem for the bipartite graph derived from the zero-nonzero pattern of a regular linear DAE with constant coefficients such that $-y_k$ equals the structural index of equation k, for any k. It is also shown that Pantelides' algorithm is the Hungarian method applied to the same assignment problem, with a specific initial feasible point of the dual.

Simulation of Electromagnetic Fields with the Finite Integration Technique

Ursula van Rienen

The Finite Integration Technique (FIT) is based on Yu's FDTD-Method (1966). It was introduced by Weiland as a general solution method transfering Maxwell's equations in the so-called Maxwell-Grid-Equations (MGE). The linear operators in MGE correspond one-to-one to the vectorial differential operators: curl, div and grad. This method is introduced and basic properties ensuring consistency are given. Some actual and future applications, especially from electroquasistatics and in connection with the human body model HUGO are presented. Also an approach of Weiland's group is shown for parameter extraction from time domain simulation.

Reduced Order Modelling for Circuits and Interconnects

Wil Schilders

In this talk, techniques for reduced order modelling will be discussed, both from a mathematical point of view and in its application to circuits and interconnects. First a short review of existing techniques will be given, followed by more recent developments, such as the promising method based on an expansion in Laguerre functions. Examples will be given from the area of circuit simulation and for some interconnect problems.

Hierarchical Simulation of Heterogen Continuous Systems and Analog Circuits

Peter Schwarz
(joint work with Christoph Clauß)

Heterogeneous systems have to be modeled and simulated very often in application areas like electronics, telecommunication, automation, mechatronics or micro-electro-mechanical systems (MEMS). They are mostly "multi-physics systems" and each subsystem should be simulated by its own "optimal" simulator. Therefore, coupling of different simulators has to be investigated. The characteristics of heterogeneous systems are:

- large complexity
- mixed-domain: mechanical, electrical, pneumatic, optical, ...
- distributed and lumped (= concentrated) elements $\longrightarrow$ PDE and ODE/DAE
- in electronics: analog and digital subsystems $\longrightarrow$ "mixed-signal" simulation
- partially tight coupling between the subsystems
- partially temporal latency of subsystems
- continuous subsystems with extremely different time constants (stiff differential equations)

Sometimes it is possible to transform all subsystem's models into one homogeneous description (e.g. generalized KIRCHHOFFIAN networks). But other properties remain, e.g. the spread of time constants. Therefore, we developed algorithms for simulating large continuous systems composed of subsystems with different properties. These algorithms should be also expandable to the simulation of mixed continuous-discrete systems, the more general case in modelling of heterogeneous systems. In detail, we investigated the problems arising in the simulation of electronic circuits.

The simulation of large electronic circuits on transistor level is both time and memory consuming. However, extremely large electronic circuits are mostly composed of subcircuits. Therefore, a **hierarchical** simulation algorithm which takes into account the subcircuit structure offers the opportunity to handle larger circuits.

In mathematical terms the problem to be solved is a partitioned DAE system like this:

$$
\begin{aligned}
0 &= H(x_1, x_2, \ldots, x_n, y) \\
0 &= F_1(x_1, y) \\
\ldots & \\
0 &= F_n(x_n, y),
\end{aligned}
$$

H, F include differentiation operations with respect to time; x, y are time-dependent variables which are to be computed. A restriction on ODE systems is not possible because most of the equations-setting-up formalisms in electronics lead directly to nonlinear DAE, but not to ODE systems.

Important solution methods are relaxation methods or NEWTON type methods. If the F_i-equations (subcircuits) are able to be solved for x_i, after one solution step of the $H-$equation the F_i-equations can be solved simultaneously. Moreover, each F_i-equation can be solved using its own error tolerances and stepsize control, which is more economical than the usage of the smallest stepsize (determined by the fastest subsystem) to each equation. Furthermore, each F_i-equation can be solved by its own simulation tool (simulator coupling).

Via the $H-$equation, the F_i-equations are connected, y is the vector of the coupling variables. Depending on the simplicity of H and on the solution methods used, different methods of simulator coupling can be derived. In the paper the "block-oriented" circuit analysis is discussed, which uses the Jacobians of the F_i for the solution of the $H-$equation. Therefore, it is a two-stage Newton method which offers better properties of convergence than relaxation methods. The method becomes practicable because the number of the coupling variables y is usually very low compared with the number of internal variables x_i.

The solution scheme of the proposed modified NEWTON method for structured DAEs (in function space or at a specific timepoint t_k) may be summarized as:

1. $j = 0$, guess y^0
2. for $i = 1(1)n$: solve <u>nonlinear</u> systems: $F_i(x_i^{j+1}, y^{j+1}) = 0 \qquad \longrightarrow x_i^{j+1}$
3. solve <u>linear</u> system
$\left[\sum_{i=1}^{n} \partial_1 H * (\partial_1 F_i)^{-1} * \partial_2 F_i - \partial_{n+1} H\right] * (y^{j+1} - y^j) = H(x_1^j, \ldots, x_n^j, y^j) \qquad \longrightarrow y^{j+1}$
4. if convergent, then stop; else $j := j + 1$, goto **2**

In coupling different simulation algorithms, it is not useful to carry out this procedure at any timepoint. Instead of, small time intervals are considered and the coupling variables $y_i(t)$ are approximated by linear (or low-order polynomial) functions of t.

There are several approximation methods to calculate the Jacobians of F_i effectively. All these methods are heuristical. Therefore, an "observer and controller module" should be included into the simulator which has to carry out:

- statistical analysis,
- supervision of convergence properties,
- calculation of the Jacobian, eigenvalue check,
- organization of NEWTON's method.

The method has been implemented as a first version in a simulator KOSIM (applied in the design of integrated circuits) and is under improvement in the context of distributed simulation of heterogeneous systems.

References:
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[4] Elst, G.; Poenisch, G.: On two-level newton methods for the analysis of large-scale nonlinear networks. Proc. ECCTD'85, Prag, 1985, pp. 165-169
[5] Schulte, S.: Modulare und hierarchische Simulation gekoppelter Probleme. Fortschrittberichte VDI, Reihe 20: Rechnerunterstützte Verfahren, Nr. 271, VDI Verlag GmbH, Düsseldorf, 1998

A Hierarchical Optimization Approach for Analog and Mixed-Signal Systems

Guido Stehr

Circuit-level simulation examines analog circuits based on transistor models. A dramatic speedup can be achieved by system-level simulation. On this abstraction level the main functional blocks are described behaviorally. In hierarchical simulation quick circuit-level simulations are used to calibrate the models for system-level simulation.

Optimization to some extent mirrors simulation. Since no reverse mapping is available, an iterative simulation-based optimization is necessary. In hierarchical optimization the results from a single system-level optimization turn into the specifications for several circuit-level optimizations. Without special care it is likely that these specifications are not realistic. This means that no solutions can be found on circuit level. A so-called feasibility region is a means to properly link the abstraction levels. This feasibility region comprises all achievable performances of the functional blocks. It can be derived from circuit-level design knowledge.

A method to obtain a linear approximation of the feasibility region is described. A real-life example is used to visualize an actual feasibility region and its linear approximation.

Verzweigungen bei grundlegenden Digitalschaltungen

Klaus Taubert

Unterschiedliche Technologien (DTL, CMOS und Bi(MOS)) führen bereits bei den grundlegenden Digitalschaltungen (NAND-Gatter, Flip-Flop und bistabile Kippstufe) zu interessanten mathematischen Aufgabenstellungen; nämlich: Singuläre Gleichungssysteme, Umkehrpunkte, Pitchfork- und Transkritische Verzweigungen und Hopf-Verzweigungen.

Index Concept for Circuit Systems Coupled with Semiconductor Model Equations

Caren Tischendorf

Integrated circuits contain mainly semiconductor elements. Various simulation packages for integrated circuits use so-called compact models which describe the voltage-current or voltage-charge characteristics of semiconductors. The resulting circuit equations represent differential-algebraic equations (DAEs). Due to the miniaturization of devices, the refinement of compact models has reached a level, where a lot of parameters are needed for a correct model description. This provides an unwished high complexity for circuit design since most of the parameters are only slightly related to real physical parameters. Therefore, we are interested in the usage of original semiconductor models instead of compact models for circuit simulation. This way we obtain DAEs with PDEs via boundary conditions. The coupled systems can be considered as abstract differential-algebraic systems (ADAS) operating in real Hilbert spaces. In this talk we will describe the coupling conditions of circuit equations with semiconductor equations and the resulting ADAS structure. Furthermore, we present an index concept for ADAS that extends the (tractability) index of DAEs. Finally we demonstrate the extended index concept by an example that combines the MNA equations for a circuit with the semiconductor model equations of a diode.

Application of Homotopy Methods for Solving Equations Describing Nonlinear Circuits

Ljiljana Trajković

Finding dc operating points, steady-state, and transient responses of electronic circuits are essential tasks in electrical circuit simulation and involve solving nonlinear differential algebraic equations. Traditional methods for solving such systems of equations often fail, are difficult to converge, and often may not find all the solutions. In this talk, I described the application of homotopy methods to solving nonlinear equations describing circuits consisting of bipolar junction and MOS transistors that traditionally pose simulation difficulties.

I described implementations of homotopy methods for dc and steady-state analysis of non-autonomous and autonomous (oscillatory) circuits. Past implementations of homotopy algorithms in industrial circuit simulators proved that they were a viable option to resolving convergence difficulties when finding circuits' dc operating points. Even their simple implementations using MATLAB proved successful in finding dc operating points of benchmark circuits. We have also implemented homotopies in the public domain SPICE simulator by interfacing it to the HOMPACK homotopy solver. By using homotopy solver within the shooting method, we successfully found steady-state solutions of various nonlinear circuits (including oscillators) that could not be otherwise simulated. Our experiments with homotopies led to better understanding of the algorithmus and the behavior of nonlinear circuits, and, ultimately, to the development of more robust circuit simulation tools.

Numerical Methods for Boundary Value Problems

Donato Trigiante

An overview of the difficulties arising when dealing with BVP is presented. The problem of mesh strategy is presented in more details. In particular a strategy based on the use of two measures of the conditioning of the problem seems the most promising. The methods used are the symmetric schemes in the class of Boundary Value Methods. Results and comparisons with existing codes are presented.

Splitting Methods for Advection-Diffusion-Reaction Problems

Jan Verwer

This talk focuses on the time integration of advection-diffusion-reaction problems by means of splitting methods. Advection-diffusion-reaction problems are an example of multi-process problems where for the different processes and scales involved different numerical techniques should be used. For example, advection problems can be efficiently integrated by means of explicit method whereas diffusion and stiff reaction problems require implicit time stepping. This distinction calls for splitting methods. Another, practical reason to advocate splitting methods is that advection-diffusion-reaction problems are mostly too large to be handled efficiently with a single implicit method. Such problems are for example found in atmospheric air pollution studies where one typically works with 50 to 100 trace gases and for each of which an advection-diffusion-reaction equation is to be solved.

In this talk splitting will be discussed at three levels: at the level of operators leading to the popular operator splitting approach, at the level of methods leading to various kinds of implicit-explicit methods, and at the level of linear system solutions leading to the technique of approximate matrix factorization. The implicit-explicit methods we consider are derived from low order linear multistep methods and approximate matrix factorization will be discussed in the context of low order Rosenbrock methods. Our aim is to review the basic principles and to illustrate some of the methods by means of concrete examples.

Modelling of Energy-Coupled Microdevices and Microsystems

Gerhard Wachutka

Miniaturized sensors and actuators are co-integrated with electronic circuitry to form hybrid or monolithic microsystems which have application in many industrial fields such as automation, transportation (in particular automative), consumer electronics and many others. Application in cars, for instance, comprise airbag accelerometers, pressure monitors, mass flow sensors, gyroscopes etc.

Modeling and numerical analysis of the "internal life" of integrated microdevies is based on continuous field theory, where several physical field quantities are used as distributed state variables in the respective energy domains interacting in the transducer units of a microsystem. A "generic model" of microdevices is proposed which combines the basic equations of each individual energy domain in a physically consistent way, relying on the concepts of irreversible thermodynamics and Onsagers phenomenological transport theory.

Modeling on system level requires order reduction in the device models, leading to compact ("lumped") models which describe the device behavior in terms of appropriately chosen terminal variables (fluxes and driving forces). Assembling the compact device models in the framework of generalized Kirchhoffian network theory leads to macromodels which provide a full system description amenable to hardware description languages and standard system simulation tools.

RFK-Design for GSM and UMTS

Robert Weigel

An overview of the current status and future developments of radio frequency integrated circuits (RFIC's) for mobile radio terminal applications is given. Emphasis is laid on the impact of system simulation on the RFIC design. Recent results of the design activities in Linz are discussed.

Stochastic Differential Algebraic Equations in Circuit Simulation

Renate Winkler

The increasing scale of integration, high tact frequencies and low supply voltages cause smaller signal-to-noise-ratios. In several applications linear noise analysis is no longer satisfactory and transient noise analysis becomes necessary.

We deal with the thermal noise of resistors as well as the short noise of semiconductors modeled by additional sources of additive or multiplicative white noise currents. The resulting system is described by a stochastic differential algebraic equation. The leading Jacobian is a constant singular matrix which is determined by the topology of the electrical network. One has to deal with a large number of equations as well as of noise sources. We assume that the noise sources do not disturb the constraints of the differential algebraic equation and express this in terms of the network topology. We derive existence and uniqueness for the solutions as well as convergence results for certain drift-implicit methods for systems with index 1 or 2.

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