SIMULATION OPTIMIZATION SYSTEMS
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OPTIMIZATION TECHNOLOGY FOR MICROWAVE CIRCUIT MODELING AND DESIGN

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SOS-95-2-R

February 1995

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Invited Paper (Summary)

Microwave circuit designers have become more enthusiastic and at the same time more critical users of numerical optimization techniques in the strive for first-pass success. Among their current needs and expectations for CAD tools are electromagnetic (EM) simulation, integrated and concurrent design environment, mixed-domain multi-level hierarchical optimization, physical and physics-based modeling, intelligent and robust optimizers, yield and cost optimization, and visualization.

The thrust for faster and smaller circuits has raised EM field-theoretical studies to new prominence in the simulation of MMICs, interconnects, component packaging and housings, etc. However, the prevailing use of EM simulators for validation of designs obtained through traditional techniques does not fully exploit their predictive power. Furthermore, the widespread use of EM simulators for ad hoc design is highly wasteful of human and computer resources. We pioneered direct and automated EM optimization with successful applications to designing matching circuits, filters, attenuators and amplifiers, including statistical analysis and yield optimization. Recent advances reported by Zoltan Cendes of Ansoft Corporation promise substantial acceleration of frequency sweeps by a 3D EM solver, motivating us to further intensify the work on automated 3D EM optimization.

Another challenge is to integrate optimization technology into a design environment with a diversified set of CAD tools, which may include digital, analog time-domain, analog frequency-domain, EM, mechanical and thermal simulators. Our success with Datapipe™ demonstrates that this can be achieved without immensely complicated syntax and protocols. We have developed a novel approach to capturing design data from external simulators in their native format. One application of this approach is Geometry Capture™, which automates the parameterization of arbitrary microstrip structures for EM optimization.

Very recently Chris Snowden noted that the advent of more powerful computers has increased the drive in using physical models and physics-based models for microwave and mm-wave CAD to meet the requirement of predictability and economization. Physical and physics-based models permit statistical characterization at the geometrical/process parameter level, and also offer the opportunity of device optimization. A methodology of integrating EM analyses of passive structures and physical simulations of active devices will have a tremendous impact on reducing the cost and time required for design cycles.

In EM optimization, the field solver, not the optimization algorithm, is the true bottleneck. This is especially significant when gradients are estimated by perturbations or when yield is estimated from many Monte Carlo outcomes. We promote parallel computing as an effective means of speeding up CPU intensive EM optimization. Parallel computing does not necessarily require an expensive multiprocessor system. It can be realized by distributing the computational load over a network of heterogeneous computers. We can further improve the efficiency by combining parallelization with data interpolation and response function modeling.

Our recent exploitation of Space Mapping™ (SM), a totally new concept in engineering optimization, roused great excitement. It opens new horizons of optimization linking engineering models of different types and levels of complexity, including empirical, EM-based, analytic, numerical, physics-based and even direct lab measurement, which represent the same physical design.

SM not only accelerates the speed of design optimization exploiting EM simulators but also makes it tractable. As a result, we are convinced that CAD and modeling of engineering devices, circuits and systems will reach a level of precision and computational efficiency previously undreamed of.

The SM concept is founded on the computational expediency of empirical engineering models (which embody expert knowledge accumulated over many years) and the acclaimed accuracy of EM simulators to facilitate automated design optimization within a practical time frame. The expansion of SM to hierarchically structured, optimization-oriented, CAD systems promises to integrate optimization technology with field theory, circuit theory and system theory based simulators for process-oriented linear, nonlinear and statistical CAD.

Traditional iterative optimization techniques use local information about the objective and constraint functions at the current iterate to find the next iterate. Function approximations are at best quadratic and estimated at a single point. Our feasibility studies indicate that functions derived from physical and engineering models embody substantial information, which can be utilized for effective modeling over a much larger range of design parameter values, essentially global w.r.t. the solution sought.

A key step in SM is to determine pairs of corresponding EM and empirical models through parameter extraction. The "empirical" model can even be a coarse EM simulation! From the EM simulation results, we need to extract the parameter values of the corresponding empirical model. This can be a serious challenge, especially at the starting point, when the responses produced by EM analysis and by the empirical model may be severely misaligned. We discovered a method for applying SM to parameter extraction and introduced the concept of automated Frequency Space Mapping™. It leads to a powerful means of overcoming problems of local minima and data misalignment.

We introduced a novel approach to "robustizing" circuit optimization using Huber functions. Robust handling of both large and small measurement errors, bad starting points and statistical uncertainties can now be automated, as validated by FET modeling from data contaminated with "wild points". We developed a statistical verification procedure for device models, using yield as the statistical estimator. Our new cumulative probability distribution fitting technique directly determines statistics such as the mean values and standard deviations in a single optimization.

One aspect in urgent need of attention is an accepted set of benchmark standards for comparing the accuracy, efficiency and robustness of different optimization techniques and methods. The establishment of such standards will contribute greatly to the understanding of the strength and weakness of optimization technology by microwave engineers at large.

John W. Bandler received the B.Sc.(Eng.), Ph.D. and D.Sc.(Eng.) degrees from the University of London, London, England, in 1963, 1967 and 1976, respectively. He joined Mullard Research Laboratories, Redhill, Surrey, England in 1966. From 1967 to 1969 he was a Postdoctorate Fellow and Sessional Lecturer at the University of Manitoba, Winnipeg, Canada. He joined McMaster University, Hamilton, Canada, in 1969, where he is currently Professor of Electrical and Computer Engineering. He is President of Optimization Systems Associates Inc. which he founded in 1983. Dr. Bandler contributed to Modern Filter Theory and Design, Wiley-Interscience, 1973 and to Analog Methods for Computer-aided Analysis and Diagnosis, Marcel Dekker, Inc., 1988. He has published more than 270 papers. He was an Associate Editor of the IEEE Transactions on Microwave Theory and Techniques (1969-1974), Guest Editor of the Special Issue of the IEEE Transactions on Microwave Theory and Techniques on Computer-Oriented Microwave Practices (March 1974) and Guest Co-Editor with Rolf H. Jansen of the Special Issue of the IEEE Transactions on Microwave Theory and Techniques on Process-Oriented Microwave CAD and Modeling (July 1992). He joined the Editorial Boards of the International Journal of Numerical Modelling in 1987, and the International Journal of Microwave and Millimeterwave Computer-Aided Engineering in 1989. He received the ARFTG Automated Measurements Career Award with the citation "For a career of meritorious achievement and outstanding technical contribution in the field of Automated Microwave Techniques" from the Automatic Radio Frequency Techniques Group (ARFTG), 1994. Dr. Bandler is a Fellow of the Royal Society of Canada, a Fellow of the IEEE, a Fellow of the Institution of Electrical Engineers (Great Britain), a member of the Association of Professional Engineers of the Province of Ontario (Canada) and a Member of the MIT Electromagnetics Academy.

Radoslaw M. Biernacki received the Ph.D. degree from the Technical University of Warsaw, Warsaw, Poland, in 1976. He became a Research and Teaching Assistant in 1969 and an Assistant Professor in 1976 at the Institute of Electronics Fundamentals, Technical University of Warsaw, Warsaw, Poland. From 1978 to 1980 he was on leave with the Research Group on Simulation, Optimization and Control and with the Department of Electrical and Computer Engineering, McMaster University, Hamilton, Canada, as a Postdoctorate Fellow. From 1984 to 1986 he was a Visiting Associate Professor at Texas A&M University, College Station, TX. He joined Optimization Systems Associates Inc., Dundas, Ontario, Canada, in 1986, where he is currently Vice President Research and Development. At OSA he has been involved in the development of commercial CAE software systems HarPE™, OSA90™ and OSA90/hope™, and related research on parameter extraction, statistical device modeling, simulation and optimization, including yield-driven design, of linear and nonlinear microwave circuits. Since 1988 he has been a Professor (part time) in the Department of Electrical and Computer Engineering, McMaster University, Hamilton, Canada. His research interests include system theory, optimization and numerical methods, computer-aided design of integrated circuits and control systems. He has more than 80 publications and has been awarded several prizes for his research and teaching activities.

Shao Hua Chen received the B.S.(Eng.) degree from the South China Institute of Technology, Guangzhou, China, in 1982 and the Ph.D. degree in electrical engineering from McMaster University, Hamilton, Canada, in 1987. From July 1982 to August 1983, he was a Teaching Assistant in the Department of Automation at the South China Institute of Technology. He was a graduate student in the Department of Electrical and Computer Engineering at McMaster University from 1983 to 1987, during which time he was awarded an Ontario Graduate Scholarship for two academic years. He joined Optimization Systems Associates Inc., Dundas, Ontario, Canada, in 1987 and engaged in commercial CAD software development. He has made major contributions to the development of CAD algorithms and the CAE systems HarPE™ and OSA90/hope™. He is a Consulting Engineer with OSA and a Research Engineer in the Simulation Optimization Systems Research Laboratory at McMaster University. He has published more than 30 technical papers. His professional interests include optimization theory, numerical methods, CAD software architecture, device modeling, statistical simulation, circuit design centering, sensitivity analysis, computer graphics and user interfaces.