RESEARCH PROJECTS
DECEMBER 1997 - OCTOBER 1998

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INTRODUCTION

Commercial CAE systems for high-speed, wireless and microwave circuits and systems are no longer regarded as complete without a variety of design automation capabilities. Computer-integrated manufacturing, including CAD, CAM, information management and decision support systems will be a reality facing the design engineer in the next century.

CAE practices such as active and passive device, circuit and system design are expected to be physically and electromagnetically based, to include electrical, mechanical and thermal effects. Future developments in integrated CAE tools will concurrently link geometry, layout, physical, electromagnetic (EM) and process simulations, with performance, yield, cost, system specifications, manufacturability and testability in a manner transparent to the designer.

In our research we focus upon exciting concepts, which we believe will play important roles in the next generation optimization methodologies including device modeling through artificial neural network technology and Space Mapping optimization. These technologies are targeted at the design of high-speed VLSI interconnects, large-scale mixed frequency/time domain simulation, chip design, package design, design of multichip modules, printed circuit boards and backplanes, as well as low cost, high-performance RF, microwave and millimeter wave components for system applications.

During the fiscal year 1997/1998 we conducted scientific research work on the research project "Next Generation Methodologies for RF, Wireless and Microwave Computer-aided Engineering (CAE).

Our overall research effort and net financial contribution were as follows:

Project No. 1	100%	$140,298
Total claimed for the Investment Tax Credit in respect of Scientific Research and Experimental Development (SR & ED)		$140,298

RESEARCH PROJECT:

NEXT GENERATION METHODOLOGIES FOR RF, WIRELESS AND MICROWAVE COMPUTER-AIDED ENGINEERING (CAE)

Starting Date

The starting date for this project was November 20, 1997.

Objective of the Research

The main objective of the project is to conduct research in the field of microwave CAE and to research and implement advanced features and techniques as either extensions to state-of-the-art existing software systems or as a basis for new software systems. This includes pioneering novel theories and developing new algorithms for parameter extraction, simulation and design optimization of both linear and nonlinear microwave circuits.

Software products exploiting such new features and techniques will be able to meet a continually strong industrial demand for efficient and reliable tools for nonlinear device modeling, parameter extraction, and automated design optimization coupled to sufficiently fast linear/nonlinear, accurate physical and electromagnetic circuit simulation. Such products should then be more competitive.

Nature of the Research

This research is essentially applied. However, many aspects of basic research are involved. The fields of science involved are mathematics: numerical methods, optimization theory, Fourier transforms; system theory: system identifiability; engineering: electrical circuit theory, electromagnetic field theory; and computer science: software architecture, parsers, data structures, graphics. Engineering applications are found in all aspects of linear and nonlinear analog electrical circuit design. Many concepts are strongly rooted in engineering practice and hence should find application in other branches of engineering.

Reference Material

Many references can be cited. A few important ones are:

J.W. Bandler and S.H. Chen, "Circuit optimization: the state of the art", (invited), IEEE Trans. Microwave Theory Tech., vol. 36, 1988, pp. 424-443.

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Q.J Zhang, "Neural network paradigm for microwave modeling, simulation and optimization," IEEE MTT-S Int. Microwave Symp., Workshop on Applications of ANN to Microwave Design (Denver, CO, 1997).

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Uncertainty of the Research

The main uncertainty of the project lies in the feasibility of implementation, mathematical robustness and reliability of the methods being developed. They are computationally intensive and partially heuristic in nature. We will not be able to fully implement them if they turn out to be unreliable, highly sensitive to computational accuracy or fail to provide satisfactory results for a large variety of circuits. Fast PCs and workstations, large-scale optimization techniques and parallel computation may be required, which introduces further risk and uncertainty.

It is not clear how large the improvement in efficiency will eventually be and whether the methods will be sufficiently cost-effective in their implementation. Many of the features being developed will be buried deeply in new software products, and as such may be appreciated by more advanced users only. Uncertain future developments in statistical design of microwave integrated circuits, and acceptance of the necessary software tools by wireless, RF and microwave engineers also makes this a high risk project.

Novelty of the Research

This research represents new work directed at state-of-the-art software systems. Our group has achieved world recognition and has an excellent track record in this area. As such our contributions are novel.

Advance in Scientific Knowledge

After this research is successfully completed, the advanced features and techniques developed will constitute a true breakthrough in CAE tools available to wireless, RF and microwave circuit and system design engineers. In particular, design optimization employing electromagnetic simulations of passive structures, as well as physical simulations of high speed/high frequency active devices, all in a user-friendly CAE environment, are of utmost importance.

Method of Research

Accepted scientific methods are employed. Since the team members and their collaborators in academic and industrial institutions have been actively working in relevant research areas for a number of years no additional literature search was necessary except for recent periodicals. Existing state-of-the art CAE software systems are continually studied.

Long-term and short-term goals are carefully defined and milestones are scheduled. Theoretical investigations are conducted and then the new concepts are implemented in computer programs and verified through numerical examples. Promising algorithms are further tested on a number of industrial examples. The project particularly requires interaction with integrated circuit process and fabrication engineers to determine and obtain relevant measured data. Interaction with industry also provides important feedback.

Software, Hardware and Documentation Facilities

During the fiscal year, there have been several acquisitions in the computing and software facilities at Bandler Corporation. There have been many acquisitions or upgrades of software and hardware in order to facilitate continued work in the chosen area of research.

A powerful new PC machine was purchased and installed due to the need for significantly more computing power to run the current releases of state-of-the-art electromagnetic simulation software. This machine is a Pentium II-400 with 256MB of RAM.

Significant effort was directed at beta software installation and upgrades, particularly prerelease software made available by Hewlett-Packard (HP). We have installed several versions of HP HFSS (High Frequency Structure Simulator) and HP Empipe3D (formerly OSA's Empipe3D) over the course of the year in order to stay current. There have been several changes made to the network configuration to accommodate the new software and to allow a smooth transitions from old hardware to newer units. Beta software is notoriously prone to bugs: significant effort has been expended documenting and fixing bugs, or finding work-arounds so that research could continue as smoothly as possible.

There has also been a change in the primary documentation preparation software which required the re-working of many existing documents. This change was necessary in order to ensure a smooth progression to the future, as the old software fails to meet the expectations placed on documents today.

Reports

The papers [1-30] and reports [31-40], as well as many seminars, workshops and panels [41-] contain results of our work within the framework of this project. Much of our work is published in the *IEEE Transactions on Microwave Theory and Techniques*, which is the most reputable journal in the field, and the *IEEE MTT-S International Microwave Symposium*, which is the most reputable conference in the field.

Selected Highlights of Progress to Date

We worked on incorporating accurate electromagnetic simulations into the yield-driven circuit design process, and on exploiting Space Mapping for statistical circuit design (design centering). The results appeared in publications listed in the previous section ("Reports").

Our work involves developing new methods as well as enhancing existing techniques. To this end, our research efforts have been concentrated on efficiency and robustness of mathematical algorithms, as well as direct electromagnetic field simulation and optimization for accurate circuit design taking into account electromagnetic effects such as radiation and coupling.

We continued our exciting work on the novel Space Mapping optimization technique. The method addresses an efficient way for engineers to solve optimization problems when the simulation time of the underlining simulator (such as an electromagnetic field solver) may be prohibitively long. Using Space Mapping, circuit design can be carried out at the speed of circuit-level optimization while retaining the accuracy of CPU intensive simulations. New developments in the aggressive strategy for Space Mapping were applied to novel electromagnetic design problems, results of which were published.

Important collaborators in this work are M.H. Bakr of McMaster University and Dr. K. Madsen of the Technical University of Denmark in Lyngby, Denmark. Our recent research has led us to the conclusion that a dedicated "Space Mapping software engine" needs to be developed in its own right.

We have continued investigations on applying Space Mapping to 3D structure optimization (various papers) and to signal integrity (interconnect design) in digital circuits [16]. The concept and theory of Space Mapping have been presented on several other occasions, including review papers, workshops and numerous seminars.

We concentrated our efforts on improving the robustness of the parameter extraction process, which is key to the success of Space Mapping implementations. Following our previously exploited idea of multi-circuit optimization we devised a new multi-point parameter extraction procedure [13, 18]. When single-point parameter extraction is carried out the Space Mapping algorithm exhibits unwanted oscillations and the convergence is either degraded or may even not be achieved.

One of the promising research directions is the integration of trust region methods [13, 18] with the Space Mapping technique. These methods construct a quadratic approximation of the function to be minimized in a certain region called the trust region. The optimization step taken at each iteration is limited to this trust region. The size of the trust region is updated at each iteration according to the goodness of the quadratic approximation. These methods enjoy excellent convergence properties and can improve the Space Mapping technique [13, 18].

Highlights of the Aggressive Space Mapping Technique

Space Mapping involves the interplay between two representations of a circuit or device. Here, the aim is to align two different simulation models: the so-called "coarse" model, typically an empirical circuit simulation and a "fine" model, typically a full wave electromagnetic simulation. The coarse model is called the "optimization" model and the fine model is identified as the "validation" model.

The technique combines the accuracy of the fine (validation) model with the speed of the coarse (optimization) model during the circuit optimization process. Parameter extraction is a crucial part of the technique. During this step the parameters of the coarse model whose response matches the fine model response are obtained. The extracted parameters may not be unique, causing the technique to fail to converge to the optimal design.

An algorithm for Aggressive Space Mapping (ASM) electromagnetic optimization (see section on "Reference Material" above) has been introduced. ASM has been applied to a number of design examples exploiting full wave electromagnetic simulators. The Sonnet electromagnetic solver ***em*** has been used to optimize various filters, including the design of a high temperature superconducting filter. The finite element solvers Ansoft HFSS (from Ansoft Corporation) and HP HFSS (from Hewlett-Packard) have been used to design various 3D structures such as waveguide transformers and filters. Coarse models for these examples exploited coarse grid electromagnetic models or circuit-theoretic/analytical models. Coarse models, decomposed into subnetworks, have even consisted of a mixture of electromagnetic based subnetworks and empirical elements connected through circuit theory.

A new ASM algorithm called TRASM (Trust Region Aggressive Space Mapping) automates the selection of fine model points used in a multi-point parameter extraction process [13, 18, 24].

Research into Artificial Neural Network Technology for Device Modeling

This work is conducted in collaboration with Dr. Q.J. Zhang of Carleton University, Ottawa.

The need for statistical analysis and yield optimization coupled with the desire to use accurate models such as physics-based and electromagnetic-based models leads to tasks that are computationally intensive using conventional approaches. Exploitation of microelectronics CAE models that are both accurate and fast has been a contradictory requirement until neural based models for active and passive elements were introduced (see section on "Reference Material" above).

Neural networks have the ability to learn from and generalize patterns in data, and to model nonlinear relationships. Neural models can be much faster than original detailed models, more accurate than polynomial and empirical models, allow more dimensions than table lookup models and are easier to develop for a new device/new technology. These appealing features make the neural network a good choice for overcoming some of the difficulties in standard device/circuit modeling and optimization.

Theoretically, a multilayer perceptron neural network can model any arbitrary nonlinear relationship. At the model development stage training data is generated from electromagnetic simulation or measurement. The neural model is then trained to learn relevant mathematical relationships from the training data. Specifically, training is to determine neural model parameters, i.e., neural network internal weights, such that the neural model predicted output best matches that of the training data. In the model testing stage, a new set of input-output samples, called the testing data, is used to test the accuracy of the neural model.

The ability of neural models to predict results not seen during training is called the generalization ability. A trained and tested neural model can then be used online during the design stage, providing fast model evaluation replacing original slow electromagnetic/device simulators. The benefits of the neural model approach are especially significant when the model is repetitively used such as in circuit optimization, statistical analysis and yield maximization.

Neural networks have been used to develop models for passive components, e.g., coupled transmission lines, and active components, e.g., physics-based MESFETs, in high-speed/high-frequency circuits and systems. Electromagnetic simulation of coupled transmission lines is slow especially if it needs to be carried out repetitively in the analysis of high speed VLSI interconnects. Neural networks can relate physical parameters, such as conductor width, conductor thickness, directly to electrical parameters, such as cross-sectional RLCG parameters.

In addition to modeling a device or a circuit element, neural networks can also model the entire circuit with the circuit responses as outputs of the models, e.g., a high-speed VLSI interconnect network. A neural model can be developed to predict the signal integrity responses such as signal propagation delays at the terminations.

Research into novel neural based modeling techniques for high-speed/high-frequency circuits and systems has been initiated during the fiscal year. We began to investigate approaches that combine engineering empirical knowledge with the learning power of neural networks. With the ultra fast recalling speed of neural models, this promises to have significant impact on the development of interactive CAE tools.

Electromagnetic Optimization

Advances in computational electromagnetics and optimization technology allow direct exploitation of electromagnetic simulation techniques in circuit design optimization. We have researched recent advances in electromagnetic optimization of microwave components and circuits. Increasingly, more complex structures need to be accurately simulated in their entirety for design purposes. Decomposition into substructures should be considered only if no significant couplings are neglected.

We solved some illustrative examples involving direct optimization using commercial electromagnetic simulators. Examples solved include the electromagnetic optimization of microstrip T-junctions, a high temperature superconducting filter, waveguide transformers, a dielectric-filled waveguide section and a double folded stub bandstop filter. See for example, relevant reports [38-40].

We exploited HP HFSS, Sonnet's ***em***, MATLAB, OSA90, Datapipe, interpolation and database techniques and Geometry Capture.

TECHNICAL PERSONNEL

Director of Research

Dr. J.W. Bandler is President of Bandler Corporation, established in 1997, and Director of Research.

Dr. Bandler studied at Imperial College of Science and Technology, London, England, from 1960 to 1966. He 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. Dr. Bandler joined McMaster University, Hamilton, Canada, in 1969, where he is currently Professor of Electrical and Computer Engineering. He has served as Chairman of the Department of Electrical Engineering and Dean of the Faculty of Engineering. He currently directs research in the Simulation Optimization Systems Research Laboratory. He is a member of the Micronet Network of Centres of Excellence.

Dr. Bandler was President of Optimization Systems Associates Inc. (OSA), which he founded in 1983, until November 20, 1997, the date of acquisition of OSA by Hewlett-Packard Company (HP). OSA implemented a first-generation yield-driven microwave CAD capability for Raytheon in 1985, followed by further innovations in linear and nonlinear microwave CAD technology for the Raytheon/Texas Instruments Joint Venture MIMIC Program. OSA introduced the CAE systems RoMPE™ in 1988, HarPE™ in 1989, OSA90™ and OSA90/hope™ in 1991, Empipe™ in 1992, Empipe3D™ and EmpipeExpress™ in 1996. OSA created the product ***empath***™ in 1996 which was marketed by Sonnet Software, Inc., USA. Dr. Bandler is President of Bandler Corporation, which he founded in 1997.

Dr. Bandler was an Associate Editor of the IEEE Transactions on Microwave Theory and Techniques (1969-1974), and has continued serving as a member of the Editorial Board. He was Guest Editor of the Special Issue of the IEEE Transactions on Microwave Theory and Techniques on Computer-Oriented Microwave Practices (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 (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 was Guest Editor, International Journal of Microwave and Millimeter-Wave Computer-Aided Engineering, Special Issue on Optimization-Oriented Microwave CAD (1997), and Guest Editor, IEEE Transactions on Microwave Theory and Techniques, Special Issue on Automated Circuit Design Using Electromagnetic Simulators (1997). He is currently Co-Chairman of the MTT-1 Technical Committee on Computer-Aided Design.

Dr. Bandler has published more than 300 papers from 1965 to 1998. He contributed to Modern Filter Theory and Design, Wiley-Interscience, 1973 and to Analog Methods for Computer-aided Analysis and Diagnosis, Marcel Dekker, Inc., 1988. Four of his papers have been reprinted in Computer-Aided Filter Design, IEEE Press, 1973, one in each of Microwave Integrated Circuits, Artech House, 1975, Low-Noise Microwave Transistors and Amplifiers, IEEE Press, 1981, Microwave Integrated Circuits, 2nd ed., Artech House, 1985, Statistical Design of Integrated Circuits, IEEE Press, 1987 and Analog Fault Diagnosis, IEEE Press, 1987.

Dr. Bandler is a Fellow of the Royal Society of Canada, a Fellow of the Institute of Electrical and Electronics Engineers, 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. He received the Automatic Radio Frequency Techniques Group (ARFTG) Automated Measurements Career Award in 1994.

Senior Research Personnel

Dr. Natalia Georgieva received the Diploma in Engineering (Electronics) from the Technical University of Varna, Bulgaria, in 1989, and the Doctor of Engineering degree from the University of Electro-Communications, Tokyo, Japan, in 1997.

From August 1997 until April 1998 she was a postdoctoral fellow with the Department of Electrical and Computer Engineering, DalTech, Dalhousie University, Halifax, Nova Scotia. During this period she was involved in teaching and in research projects concerning time-domain electromagnetic field simulation, modeling and design of RF/microwave multilayer passive structures, printed circuit boards and printed antennas.

In March 1998, she was granted a Postdoctoral Fellowship by the Natural Sciences and Engineering Research Council of Canada (NSERC). Since May 1998, she has been with the Simulation Optimization Systems Research Laboratory, McMaster University, Canada, where she is involved in projects concerning the implementation and development of novel highly efficient optimization algorithms for microwave structure design.

Research Personnel

Mr. Steve Porter, Software Specialist, is a professional programmer with 6 years of experience developing on the PC platform. His skills include proficiency in Fortran, C, C++, Object Oriented Design, Java and Assembler. In addition Mr. Porter is skilled in PC hardware installation, network installation and planning. His personal achievements include the development of his own database engine and well as a real time 3D engine. More recently he has been involved with an ongoing distributed computing effort.

He played a key role in porting OSA software from the UNIX platform to the PC while working with Optimization Systems Associates Inc. before its acquisition by Hewlett-Packard. He was responsible for many user interface and other platform specific design decisions, such as correct use of the system registry, system IPC (inter-process communication), proper use of multithreading and general PC specific code optimizations. In addition to porting, he was responsible for several important additions to the PC products, including the ability to print results and plots from within the application itself. Other responsibilities included documentation and technical support.

Currently, he works as a Research Assistant with the Simulation Optimization Systems Research Laboratory, McMaster University.

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[37] "Parameterization of structures through geometry capture" BC-98-8-V, September 1998.
[38] "Optimization of an inhomogeneous two-section waveguide transformer" BC-98-9-R, September 1998.
[39] "Optimization of a dielectric-filled waveguide section" BC-98-10-R, September 1998.
[40] "Parameter extraction of dielectric constant" BC-98-11-R, September 1998.

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[47...] *Many additional R&D seminars were delivered by Dr. Bandler.*