RESEARCH PROJECTS

DECEMBER 1995 - NOVEMBER 1996

OSA-97-RC-12-R

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INTRODUCTION

During the fiscal year 1995/1996 we continued our research work on the following three projects:

(1) Advances in Microwave Computer-Aided Design (CAD),

(2) Yield-Driven Design of Nonlinear Microwave Circuits,

(3) Statistical Modeling of Microwave Integrated Circuits and Devices.

Our overall research effort and net financial contribution were divided between the three projects as follows:

Project No. 1	80%	$134,660
Project No. 2	5%	$8,419
Project No. 3	15%	$25,250
Total claimed for the Investment Tax Credit in respect of Scientific Research and Experimental Development (SR & ED)		$168,329

The Canadian partial funding of our research (not included in the aforementioned figures) during the fiscal year was:

(1) Natural Sciences and Engineering Research Council's contribution to the August and September 1995 salary of Industrial Research Fellow Dr. Q. Cai (payment received in March 1996).

(2) Student Opportunities for Workterms (SOW) contribution to the summer employment of Junior Research Engineer, McMaster University student Craig French.

RESEARCH PROJECT 1:

ADVANCES IN MICROWAVE COMPUTER-AIDED-DESIGN (CAD)

Introduction

The starting date for this project in its present form was August 1, 1988. However, different components of the project had been carried out since early 1987.

For objectives, nature, uncertainty, novelty and method of the research, as well as reference material, description of advance in scientific knowledge and past progress please see [33].

Reports

The manuals [6-8], papers [10-24] and reports [25-52] contain new results of our work within the framework of this project. Our earlier work [9] on the Aggressive Space Mapping technique was published in the *IEEE Transactions on Microwave Theory and Techniques* which is the most reputable journal in the field.

Work on the Project from December 1995 to November 1996

Within the framework of this project we make an effort to combine different techniques with the aim of integrating them into versatile, user-friendly and state-of-the-art software systems. It involves developing new methods as well as enhancing some of the existing techniques. To this end, our research efforts have been concentrated on the following aspects:

(1) efficiency and robustness of mathematical algorithms,

(2) open architecture and flexible data structures for CAD tools,

(3) user-friendliness of CAD tools,

(4) state-of-the-art CAD tools for GaAs FET small-signal, DC and large-signal model simulation, optimization and parameter extraction,

(5) work towards new generation comprehensive software systems suitable for designing microwave circuits in terms of layout/geometrical and process/technological parameters,

(6) direct electromagnetic (EM) field simulation and optimization for accurate circuit design taking into account electromagnetic effects such as radiation and coupling.

Between December 1, 1995 and November 30, 1996, we have made substantial progress on all items. Item (6), which strictly speaking is a part of item (5), was the main focus of our research. Implementation of new features and techniques has been made within a new release of our software system Empipe [3,8] and two new products introduced in 1996, namely EmpipeExpress [4,7] and Empipe3D [5,6].

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. Our aggressive strategy for Space Mapping developed earlier was published in the December 1995 issue of the *IEEE Transactions on Microwave Theory and Techniques* [9]. We also revised a full journal paper [16,32] accepted for publication in the Proceedings of the Institute of Mathematical Applications on Large-Scale Optimization, a book to be published by Springer Verlag. New results are contained in the papers [11,15,19-22] and reports [26,40,43,44,46,49,51,52].

We found the aggressive Space Mapping strategy more suitable for full automation than our original algorithm. The generic update loop and the model-specific parameter extraction loop can be automated using a two-level Datapipe architecture. This idea was presented at the 1996 IEEE MTT-S International Microwave Symposium held in San Francisco, CA, June 1996, [11,26,40].

A new design methodology was developed by combining decomposition with Space Mapping [15,20,43,46,49]. In this procedure, the accurate but computationally intensive full-wave EM model (Empipe [3] driving the electromagnetic simulator ***em*** from Sonnet Software, Inc.) is used sparingly only to calibrate less accurate, but computationally much more efficient models (the fast models). Decomposition is employed to further accelerate the fast model simulation. As the fast model we use a combination of empirical models and coarse EM simulations applied to different decomposed substructures. For interdigital filter design, a desirable filter response is obtained requiring only three accurate EM model simulations. These results were presented at the M+RF96 Microwaves and RF Conference in London, England, in October 1996 [15,46,49], and included in a comprehensive paper accepted for publication in the *IEEE Transactions on Microwave Theory and Techniques* [20,43].

We have also investigated applying Space Mapping to 3D structure optimization [19,22,44,51] and to signal integrity in digital circuits [52]. Two new papers have been accepted for publication. The concept and theory of Space Mapping have been presented on several other occasions, including two review papers [17,21,29,42], workshop [12] (report [30]) and numerous seminars.

We have continued our work on the novel Geometry Capture technique. The technique makes optimization of arbitrary geometrical structures a reality. Designable parameters are captured graphically from the layout, and the layout is directly optimized without the need of any schematic translation. We worked on the mathematical foundation of the method and on extending it from planar to 3D structures. Our findings were presented at the 1996 IEEE MTT-S International Microwave Symposium (San Francisco, CA, June 1996) [10,25,41]. An extended, comprehensive treatment of the subject, yet to be published, is included in [45].

Perhaps the most substantial development within the fiscal year was our work on direct EM optimization of 3D structures, particularly waveguide components. As a result, for the first time, complicated 3D structures can be made fully optimizable. We created a significant new software system Empipe3D [5,6], revealed at the 1996 IEEE MTT-S International Microwave Symposium in San Francisco, CA, in June 1996. This new product interfaces OSA90/hope [2] and finite-element based 3D EM solvers HFSS and Maxwell Eminence offered by Hewlett-Packard Co. and Ansoft Corp., respectively. Our research on Geometry Capture and experience derived from Empipe [3] were crucial to this new successful development. In order to arrive at a comprehensive solution we also needed to advance the integrated interpolation/modeling/database technique. Our findings on this subject are described in the paper [19,44] accepted for publication in the *IEEE Transactions on Microwave Theory and Techniques* and reviewed in [21]. The theoretical foundation of 3D EM optimization with Empipe3D has been presented on several other occasions, including the invited paper [14], workshop [12] and many presentations [53,55-70] (reports [30,35,36,38,47,48]).

Empipe3D has allowed us to investigate Space Mapping optimization between finite-element based models and mode-matching fast EM simulations. Here, the capabilities of mode-matching simulations are extended to irregular shapes that could not be normally handled by that method (the waveguides considered have round corners, reflecting less expensive machining in the manufacture). In the course of this work we also needed to address robustness of the parameter extraction process, extending our earlier approaches [11,26,40]. The new "statistical parameter extraction" technique is elaborated in more detail in the description of Project 3. Our preliminary results have been accepted for presentation at the 1997 IEEE MTT-S International Microwave Symposium (Denver, CO) [22,51].

Following a small pilot project entitled "A Feasibility Study for Porting OSA's CAD Software from UNIX X-Windows to a PC Environment" carried out in the previous year we continued our investigation into cross-platform portability [34,50]. Of particular interest was the development of the Datapipe technology under Windows NT. We originally developed this capability using UNIX interprocess pipe communication. Our unique Datapipe technology (e.g., reviewed in [21]) is central to the open architecture of OSA90/hope [2] and is the basis for all the Empipe products. This task has been successfully completed which paves the way to porting OSA's software from X-Windows to a PC environment (both Windows NT and Windows 95 can be accommodated). This work will further contribute to user-friendliness of OSA's CAD tools.

Other activities related to this project included two important workshop presentations [12,13] (reports [30,31]) and a panel session (J.W. Bandler, Organizer and Moderator) [39,54] at the 1996 IEEE MTT-S International Microwave Symposium (San Francisco, CA, June 1996), and prestigious editorial work (J.W. Bandler, Guest Editor) for two most important journals in the field: *IEEE Transactions on Microwave Theory Techniques* [24], and *International Journal of Microwave and Millimeter-Wave Computer-Aided Engineering* [18,23].

For the latter special issue we have prepared a comprehensive review paper [17,29,42]. We reviewed relevant concepts, formulations and algorithms for microwave circuit optimization. Emphasis was given to recent advances in the state of the art, particularly automated EM design in an integrated CAD environment. Noted by the reviewers: "This is an excellent paper" and "... an excellent review of microwave optimization techniques ... explains the underlying concepts in a coherent and systematic way. In addition there are several new contributions ...". Among those new contributions was first reporting, in a journal paper, of our significant research on integrating EM and harmonic balance large-signal simulations which was carried out in the previous fiscal year.

Technical Personnel

Dr. J.W. Bandler, Director of Research

Dr. R.M. Biernacki

Dr. S.H. Chen

Ms. J. Tripp

Mr. C. French

RESEARCH PROJECT 2:

YIELD-DRIVEN DESIGN OF NONLINEAR MICROWAVE CIRCUITS

Introduction

The starting date for the project was August 1, 1986.

For objectives, nature, uncertainty, novelty and method of the research, as well as reference material, description of advance in scientific knowledge and past progress please see [33].

Reports

The papers [12,17] and reports [28,29,30,42] contain results relevant to this project. In particular, the use of optimization technology for yield-driven design was reviewed in an important paper submitted to and accepted for publication in the *International Journal of Microwave and Millimeter-Wave Computer-Aided Engineering* [17] (reports [29,42]).

Work on the Project from December 1995 to November 1996

Since our main research focus during the fiscal year was Item (6) of Project 1 and because our existing algorithms for yield-driven design have significantly matured, we devoted only limited effort to this project. Nevertheless, we need to continue our work in this area, particularly on incorporating accurate EM simulations into the yield-driven design process, and on exploiting Space Mapping for statistical design.

Between December 1, 1995 and November 30, 1996, we continued our work on parallel and distributed computation using a network of heterogeneous computers. Yield optimization is particularly suitable for parallelization of computation. Many statistically perturbed circuit outcomes need to be simulated to estimate yield by Monte Carlo analysis. Once the perturbed parameter values are determined, these simulations are independent of each other. Therefore they can be carried out simultaneously on a number of computers. Our work on parallel/distributed computation included investigation of the following aspects: server verification and acquisition, job posting and queuing, remote execution and delivery of results, as well as detection and recovery from lost connection [28].

Other activities related to this project included an important workshop presentation [12] (report [30]) at the 1996 IEEE MTT-S International Microwave Symposium (San Francisco, CA, June 1996), and prestigious editorial work (J.W. Bandler, Guest Editor) for two most important journals in the field: *IEEE Transactions on Microwave Theory Techniques* [24], and *International Journal of Microwave and Millimeter-Wave Computer-Aided Engineering* [18,23].

Technical Personnel

Dr. J.W. Bandler, Director of Research

Dr. R.M. Biernacki

Dr. S.H. Chen

Ms. J. Tripp

RESEARCH PROJECT 3:

STATISTICAL MODELING OF MICROWAVE INTEGRATED CIRCUITS AND DEVICES

Introduction

The starting date for the project was June 1, 1988.

For objectives, nature, uncertainty, novelty and method of the research, as well as reference material, description of advance in scientific knowledge and past progress please see [33].

Reports

The papers [11,22] and reports [26,40,51] contain new results of our work within the framework of this project. Techniques for statistical modeling were reviewed for an important workshop presentation [13] (report [31]) at the 1996 IEEE MTT-S Int. Microwave Symposium (San Francisco, CA, June 1996), as well as in an important paper submitted to and accepted for publication in the *International Journal of Microwave and Millimeter-Wave Computer-Aided Engineering* [17] (reports [29,42]).

Work on the Project from December 1995 to November 1996

Since our main research focus during the fiscal year was Item (6) of Project 1 we devoted only limited effort to this project. Nevertheless, we need to continue our work in this area.

Between December 1, 1995 and November 30, 1996, we concentrated our efforts on improving the robustness of the parameter extraction process, particularly for Space Mapping applications. Following our previously exploited idea of multi-circuit optimization we devised a new multi-point parameter extraction procedure. 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. In the design of a two-section waveguide transformer the multi-point approach has sharpened the uniqueness of parameter extraction and dramatically improved the overall convergence. This result was presented at the 1996 IEEE MTT-S International Microwave Symposium held in San Francisco, CA, June 1996, [11,26,40].

We developed a statistical parameter extraction procedure to overcome potential pitfalls arising out of inaccurate or nonunique solutions. A number of starting points is randomly selected and the corresponding parameter extraction optimizations are carried out. The resulting solutions (expected to be multiple) are then categorized into clusters and ranked according to the achieved values of the objective function. Employing the penalty function concept was also investigated. This approach can be automated using a three-level Datapipe architecture. It can also be parallelized since the parameter extractions considered can be carried out independently. These new concepts are demonstrated by EM optimization of an H-plane resonator filter using the Space Mapping technique using hybrid mode-matching/network theory simulations and models based on finite-element simulations. A new paper [22,51] describing our preliminary results was submitted to the 1997 IEEE MTT-S International Microwave Symposium and was accepted for presentation.

Other activities related to this project included prestigious editorial work (J.W. Bandler, Guest Editor) for two most important journals in the field: *IEEE Transactions on Microwave Theory Techniques* [24], and *International Journal of Microwave and Millimeter-Wave Computer-Aided Engineering* [18,23].

Technical Personnel

Dr. J.W. Bandler, Director of Research

Dr. R.M. Biernacki

Dr. S.H. Chen

Ms. J. Tripp

CAPITAL EQUIPMENT

Expenditures

(1)	Micron Millenia PC	$7,971
(2)	IBM Aptiva S78 PC	$6,448
(3)	Software for (1) and (2)	$761
Total		$15,180

Role of the Equipment

The equipment is needed for our work on cross-platform portability, in particular our research and implementation on porting OSA's software to the PC platform (see Project 1). After our feasibility study we were able to determine the software, operating systems, disk and memory requirements, etc., needed to continue our development. The previously existing facilities were found to be inadequate.

The new software and hardware will also be used for documentation, replacing obsolete tools.

TECHNICAL PERSONNEL

Director of Research

Dr. J.W. Bandler is President of Optimization Systems Associates Inc., established in 1983, 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.

Dr. Bandler 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 a 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 has more than 280 research publications. Dr. Bandler is a Fellow of the Royal Society of Canada, a Fellow of the Institute of Electrical and Electronics Engineers and a Fellow of the Institution of Electrical Engineers (Great Britain). He is a member of the Association of Professional Engineers of the Province of Ontario (Canada).

Senior Research Personnel

Dr. R.M. Biernacki received the Ph.D. degree with distinction from the Technical University of Warsaw in 1976. He has more than 25 years of professional experience which includes several academic and research positions.

Dr. Biernacki joined Optimization Systems Associates Inc., in 1986, as Senior Research Engineer. He is now Vice President Research and Development. In 1988 he was appointed Professor of Electrical and Computer Engineering (part-time) at McMaster University, Hamilton, Canada.

Dr. Biernacki has more than 100 publications in IEEE journals and proceedings of IEEE and other conferences. Dr. Biernacki is a Fellow of the Institute of Electrical and Electronics Engineers.

Dr. S.H. Chen received the B.S.(Eng.) degree from the South China Institute of Technology, Guangzhou, China, with top class honours, in 1982. Between 1983 and 1987, he pursued his graduate studies in the Department of Electrical and Computer Engineering, McMaster University, Hamilton, Canada, where he received the Ph.D. degree in 1987.

Dr. Chen joined Optimization Systems Associates Inc. in 1987 as Research Engineer. He is responsible for developing state-of-the-art CAD mathematics, algorithms and software. He is now Consulting Engineer with Optimization Systems Associates Inc.

Dr. Chen has contributed to some 60 technical papers, including an invited paper for the 1988 Special Issue on Computer-Aided Design of the IEEE Transactions on Microwave Theory and Techniques entitled "Circuit optimization: the state of the art". Dr. Chen is a Senior Member of the Institute of Electrical and Electronics Engineers.

Research Personnel

Ms. J. Tripp joined Optimization Systems Associates Inc. in September 1995. Her position at OSA is Assistant to the President (Research and Administration). She is responsible for researching and maintaining computer resources, particularly software, and for software comparison and evaluation. She executes technical documentation and presentation material for scientific conferences and journals. She also assists in projecting OSA's hi-tech research profile to potential users and collaborators around the world by means of the Internet. She participated in creating OSA's Internet link and web home page, as well as responding to inquiries. By regularly searching the Internet and gathering relevant technical data, she makes an important contribution to OSA's knowledge base of the latest technical advances and trends.

Ms. Tripp has 19 years of experience in working with DOS and UNIX operating systems, both hardware and software. She has worked as UNIX System Administrator responsible for general maintenance, software upgrades, training and supervising junior personnel. She has also been responsible for hardware installations.

Junior Research Personnel

Mr. C. French, a McMaster University fourth year student, was employed by OSA during summer of 1996, following his prior successful contribution to OSA's work during summer of 1995 (which was partially supported by NRC's IRAP Technology Enhancement program). In 1996, his work was partially supported by Student Opportunities for Workterms (SOW), a private initiative administered by Engineering Career Services of McMaster University.

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[56-70] *Additional 15 seminars were delivered by Drs. Bandler, Biernacki and Chen.*