RESEARCH PROJECTS

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INDEX

INTRODUCTION

At the beginning of the fiscal year 1988/1989 we have restructured our research projects in order to avoid too much overlapping which would otherwise be unavoidable. Out of five previously reported research projects:

(1) Robust Model Parameter Extraction (RoMPE),

(2) Harmonic Balance Analysis and Optimization,

(3) Efficient Statistical Circuit Design of Integrated Circuits,

(4) Statistical Modeling of Microwave Integrated Circuits and Devices,

(5) Advances in Microwave Computer-Aided Design (CAD)

we have created 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.

Original Project No. 4 on statistical modeling has not changed and now is reported as Project No. 3. Original Project No. 3 on statistical design has been limited to yield optimization of nonlinear circuits (now Project No. 2) and its other components have been moved to a new project which combines the rest of our research activities. Original Project Nos. 1, 2 and 5 have all been merged, as our aim is to integrate all techniques that are mature enough into one state-of-the-art and versatile software system.

Our overall research effort was divided between the three projects as follows:

Project No. 1	50%
Project No. 2	20%
Project No. 3	30%

The only Canadian funding of our research was limited to IRAP-H contribution towards the salaries of our Engineering Students: R. Csermak, G. Simpson (August 1988) and M. Fletcher (May 1989 to July 1989).

RESEARCH PROJECT 1:

ADVANCES IN MICROWAVE COMPUTER-AIDED-DESIGN (CAD)

Objective of the Research

The main objective of the project is to survey the field of microwave CAD 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 the new features and techniques will be able to meet a strong industrial demand for efficient and reliable tools for nonlinear device parameter extraction (in particular GaAs FETs) coupled to sufficiently fast nonlinear circuit simulation and design (including yield-driven design). Such product 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; electrical circuit theory; and computer science: software architecture, parsers, data structures, graphics. Engineering applications are found in all aspects of linear and nonlinear analog circuit design.

Reference Material

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

SUPER-COMPACT, Compact Software Inc., Paterson, NJ 07504.

TOUCHSTONE, EEsof Inc., Westlake Village, CA 91362.

A. Materka and T. Kacprzak, "Computer calculation of large-signal GaAs FET amplifier characteristics", *IEEE Trans. Microwave Theory Tech.*, vol. MTT-33, 1985, pp. 129-135.

K.S. Kundert and A. Sangiovanni-Vincentelli, "Simulation of nonlinear circuits in the frequency domain", *IEEE Trans. Computer-Aided Design*, vol. CAD-5, 1986, pp. 521-535.

Uncertainty of the Research

The main uncertainty of the project lies in the mathematical robustness and reliability of the methods being developed. While they seem to be attractive and quite promising at the present stage of development, we will not be able to implement them if they turn out to be unreliable, highly sensitive to computational accuracy or the starting point of the iterative numerical solution process, or fail to provide satisfactory results.

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. Most of the features being developed will be buried deeply in new software products, and as such will be appreciated by more advanced users only.

Novelty of the Research

This research represents new work on state-of-the-art software systems. Our group has achieved world recognition 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 CAD tools available to microwave circuit design engineers. In particular, parameter extraction of microwave active devices based on easy-to-take power spectrum measurements and availability of consistent models for all types of circuit simulation and design will open up a new avenue in CAD practices.

Method of Research

Accepted scientific methods are employed. Since the team members have been actively working in this research area for a number of years no extra literature search was necessary except for recent periodicals. Existing CAD 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.

Progress to Date

The starting date for this project in its present form was August 1, 1988. However, different components of the project had been carried out within the framework of other projects since early 1987. By July 1988 we had developed and demonstrated a prototype computer program called RoMPE for nonlinear device parameter extraction; we introduced advanced features and techniques including a highly-interactive graphical user-interface, a mathematical decomposition technique for design of large-scale systems and a statistical design option for general CAD systems. We had also developed a unified theory for harmonic balance simulation and sensitivity analysis.

Between August 1, 1988 and July 31, 1989 we continued our work on different components of the project. The work to date demonstrates the feasibility of the parameter extraction method based on large-signal power spectrum measurements and harmonic balance simulation technique. We have implemented and tested new FET models, namely, the Curtice model and the Raytheon (Statz) model. We have substantially enhanced basic mathematical algorithms by taking advantage of features offered by the C language and results of our earlier research. We have made progress in designing open architecture, user-friendly software which is a must for the new generation CAD tools for design of MMICs in the 1990s.

Our future work includes (1) further theoretical developments, (2) researching and implementing new device models, and (3) extensive testing.

Reports

The reports [23-47] and papers [48-50] summarize our achievements within the framework of this project. References [48,49] were presented at the IEEE MTT-S International Microwave Symposium held in Long Beach, CA, in June 1989. An extended version of [48], namely [50], has been accepted for publication in IEEE Transactions on Microwave Theory and Techniques, the most reputable journal in the field.

Description of the Project

Within the framework of this project we make an effort to combine different techniques, in particular device model parameter extraction and harmonic balance simulation, with the aim of integrating them into one versatile, user-friendly and state-of-the-art software system. It involves developing new methods as well as enhancing some of the existing techniques. In addition to the mathematical aspect of the algorithms considerable effort is devoted to the computer science aspects arising from the requirements for the new generation of CAD systems.

The advances in GaAs material development and wafer processing achieved in the past few years have made monolithic microwave integrated circuits (MMICs) practical. The modeling of MMIC devices is recognized as a subject of fundamental importance [1-9,13,16-18,20,21,27].

The harmonic balance method has become an important tool for the analysis of nonlinear circuits. The work of Rizzoli et al. [4], Gilmore and Rosenbaum [6], Curtice and Ettenberg [9], Gilmore [11], Camacho-Penalosa and Aitchison [15], Curtice [18] stimulated work on harmonic balance in the microwave CAD community. The excellent paper of Kundert and Sangiovanni-Vincentelli [10] provided systematic insight into the harmonic balance method.

Our research efforts are presently concentrated on the following subjects:

(1) theoretical framework for optimization based robust parameter extraction and unique identifiability,

(2) implementable algorithms for harmonic balance based large-signal device model parameter extraction,

(3) efficient sensitivity analysis of nonlinear circuits,

(4) efficiency and robustness of mathematical algorithms,

(5) development and/or implementation of new nonlinear device models,

(6) input syntax for the new generation microwave CAD,

(7) accessing internal variables and processing capabilities of CAD systems,

(8) highly interactive CAD user interfacing,

(9) user-friendliness of CAD tools,

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

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

(12) statistical design option for general purpose CAD systems.

To date we have made progress in all of these subjects. Implementation of these features and techniques has been made within the new software system HarPE [45] or in the context of general CAD systems [47]. The following is a brief description of our results.

Our work on the first two subjects demonstrates the feasibility of the parameter extraction method based on large-signal power spectrum measurements and the harmonic balance simulation technique. Powerful nonlinear adjoint-based optimization [12,14] simultaneously processes multi-bias, multi-input-power, multi-harmonic measurements to uniquely reveal the parameters of the intrinsic FET. A state-of-the-art research paper [32,48] emerging from our investigations has been presented and enthusiastically received at the 1989 IEEE MTT-S International Microwave Symposium held in Long Beach, CA, in June 1989. A full scientific paper has been accepted for publication in the IEEE Transactions on Microwave Theory and Techniques [41,50].

We have continued our work on efficient sensitivity analysis of nonlinear circuits. Our investigations led to a revolutionary approach to adjoint sensitivities which combines the efficiency of exact adjoint sensitivity calculations [22] with the simplicity and implementability of the traditional perturbation approach. A paper on the subject [33,49] has been presented at the 1989 IEEE MTT-S International Microwave Symposium held in Long Beach, CA, in June 1989. A full scientific paper is currently being prepared for publication.

We have enhanced some of the mathematical algorithms by converting the existing Fortran routines to the C language and by taking advantage of some specific features offered by the C language and results of our earlier research. In particular, we have worked on a partial elimination technique and incorporated it into both dense and sparse matrix solvers. We have also developed techniques for a robust DC analysis and a general n-port analysis [31,36].

We have implemented and tested new FET models: the Curtice and Ettenberg model [9,30], and the Raytheon (Statz) model [13]. A number of enhancements w.r.t. the published results have been introduced for the purpose of improved robustness. The first model was introduced to both RoMPE [40] and HarPE [45] and the second one to HarPE only. Exhaustive testing has been performed.

We have carefully investigated both potentials and limitations of the existing CAD software products in the context of growing industrial demands for user friendly, flexible and powerful software needed for monolithic microwave integrated circuit (MMICs) design. In particular, we studied possibilities of yield- and cost-driven design techniques [19], especially for nonlinear circuits. Based on this research we have created a flexible and expandable syntax for input files for the new generation CAD software [28,29].

We have extensively studied, experimented and tested different computer scientific solutions needed for the new generation CAD tools for design of MMICs in the 1990s. We have made progress in all items (7) to (9). No reports have been published on these subjects since our solutions contain proprietary information. Our work included flexible, easily expandable data structures, expression interpreting, modular, open software architecture, minimizing system dependent coding, and window and menu driven user interfacing.

Work on item (11) involved integration of all items (1) to (10) into one state-of-the-art software system [35,45].

Work on item (12) involved research and implementation of state-of-the-art algorithms for statistical design, including multidimensional and hierarchical distributions, in the context of a general purpose software system and was performed on behalf of the MIMIC Raytheon/Texas Instruments Joint Venture [23-26,29,31,34,37-39,42-44,46,47].

Technical Personnel

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RESEARCH PROJECT 2:

YIELD-DRIVEN DESIGN OF NONLINEAR MICROWAVE CIRCUITS

Objective of the Research

The main objective of the project is to develop new methods and algorithms suitable for statistical design of analog electrical circuits, in particular nonlinear microwave circuits operating in the steady state under large-signal periodic excitations. Our aim is to produce novel results and software relevant to the emerging area of monolithic microwave integrated circuits (MMICs). Software products exploiting such methods should be capable of designing high yield practical nonlinear circuits. These software products will then be competitive commercially.

Nature of the Research

This research is both basic and applied. It is our aim to extend specific techniques and methods by applying them to a larger class of microwave circuits. The fields of science involved are mathematics: optimization theory, statistical analysis; and electrical circuit theory. Engineering applications are specifically found in all aspects of nonlinear analog circuit design including analysis, optimization, parameter extraction, statistical design and modeling.

Reference Material

Many references can be cited. An important contribution is:

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

Uncertainty of the Research

The main uncertainty of the project lies in the feasibility and reliability of the methods being developed since 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. Supercomputers and large-scale optimization techniques are likely to be required, which introduces further risk and uncertainty.

The uncertain future of statistical design of microwave integrated circuits, and acceptance of the necessary software tools by microwave engineers also makes this a high risk project. The prognosis for the affordable manufacture of monolithic microwave integrated circuits (MMICs) is particularly uncertain.

Novelty of the Research

This research is a followup of state-of-the-art published works by members of the team, e.g., [1,2,5,7-10]. As such it is novel.

Advance in Scientific Knowledge

If this research is successfully completed, the algorithms may constitute a true breakthrough in the numerical approach to the simulation and statistical analysis and yield optimization of large and nonlinear engineering systems.

Method of Research

Accepted scientific methods are employed. Since the team members have been actively working in this research area for a number of years no extra literature search was necessary except for recent periodicals. According to our expectations, appropriate mathematical manipulations are conducted and then the new concepts are programmed. The algorithms being developed are then tested on a number of circuit examples.

Progress to Date

The starting date for the project was August 1, 1986. By July 1988 feasibility of an extremely efficient method for quadratic approximation of circuit response functions had been successfully demonstrated, including testing, reliability studies and, especially, applying the methods to the yield optimization of a large-scale practical microwave circuit, namely a 5-channel multiplexer. Between August 1, 1988 and July 31, 1989 we continued our work on this project. The work included a comprehensive treatment of yield optimization of nonlinear microwave circuits with statistically characterized devices. We exploited an advanced technique of one-sided ℓ_1 circuit centering and efficient harmonic balance simulation with exact Jacobians. The work to date confirms applicability of the methods proposed to the statistical design of large microwave circuits.

In the future we plan to combine the efficient approximation methods with nonlinear harmonic balance simulations, and, in general, concentrate on new methods and algorithms aimed at improving efficiency of statistical design of analog and microwave circuits.

Reports

The reports [11,12] and paper [13] summarize our achievements within the framework of this project. Reference [13] was presented at the IEEE MTT-S International Microwave Symposium held in Long Beach, CA, in June 1989. An extended version of that paper is being prepared for submission to IEEE Transactions on Microwave Theory and Techniques, the most reputable journal in the field.

Description of the Project

Statistical circuit design, or yield optimization has been a subject of extensive research in the last decade, e.g., [1-10]. However, yield optimization of practical nonlinear microwave circuits remained unaddressed hitherto. On the other hand, because of high production costs of present MMICs due to various fluctuations in the manufacturing process, yield-driven design should become an indispensable tool in the microwave CAD area [6].

In this research we concentrated our efforts on algorithms for statistical design of nonlinear circuits operating in the steady state under large-signal periodic excitations. To date, the feasibility of combining yield optimization algorithms with harmonic balance simulation has been successfully shown. The following is a brief description of our results.

We studied an approach to efficient yield-driven optimization of nonlinear microwave circuits with statistically characterized devices. A powerful and robust one-sided ℓ_1 optimization algorithm for design centering recently proposed by Bandler et al. [8] was adopted. The harmonic balance simulation technique was implemented with exact Jacobian matrices for fast convergence and improved robustness. Independent and/or correlated normal distributions and uniform distributions describing large-signal FET model parameters and passive elements were fully accommodated.

We tested our approach on the example of a microwave frequency doubler. The performance yield was increased from 25% to 61%. To the best of our knowledge this was the first comprehensive demonstration of yield optimization of statistically characterized nonlinear microwave circuits operating under large-signal steady state periodic conditions.

In the future we plan to combine the efficient approximation methods [5,10] with nonlinear harmonic balance simulations. Also, we plan to incorporate possible gradient information to even further reduce the number of actual circuit simulations needed for constructing a reliable quadratic model. In general, we concentrate on new methods and algorithms aimed at improving efficiency of statistical design of analog and microwave circuits.

Technical Personnel

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RESEARCH PROJECT 3:

STATISTICAL MODELING OF MICROWAVE INTEGRATED CIRCUITS AND DEVICES

Objective of the Research

The main objective of the project is to establish the mathematical theory and algorithms aimed at modeling the statistical behaviour of manufactured microwave integrated devices. Software products implementing such algorithms should provide reliable statistical device models for yield analysis and optimization. These software products will build the bridge between process engineers and circuit designers in a volume production environment.

Nature of the Research

This research is both basic and applied. It is our aim to solve specific practical problems in microwave circuit modeling and design. In that sense it is applied. However, many aspects of basic research are involved. The fields of science involved: numerical methods, electrical circuit theory, microwave theory and techniques, statistical analysis, physics. Engineering applications will be found in all engineering areas involving mathematical modeling and volume production.

Reference Material

Two important papers can be cited:

S. Liu and K. Singhal, "A statistical model for MOSFETs", *IEEE Int. Conf. on Computer-Aided Design* (Santa Clara, CA), 1985, pp. 78-80.

J. Purviance, D. Criss and D. Monteith, "FET model statistics and their effects on design centering and yield prediction for microwave amplifiers", *IEEE Int. Microwave Symp. Digest* (New York, NY), 1988, pp. 315-318.

Uncertainty of the Research

One important uncertainty of the project lies in the identification of critical process/geometrical parameters and establish physical/empirical formulas for such parameters. The second uncertainty is the reliability of statistical descriptions for electrical model parameters.

A scientific risk lies in the robustness and reliability of the methods being developed. We will not be able to properly implement them if they turn out to be unreliable, or unable to provide usable results.

The uncertain future of statistical modeling and design of microwave integrated circuits, and acceptance of the necessary software tools by microwave engineers also makes this a high risk project. The prognosis for the affordable manufacture of monolithic microwave integrated circuits (MMICs) is particularly uncertain.

Novelty of the Research

Statistical modeling of microwave integrated circuit devices is being pioneered by only a few research groups worldwide, including OSA. This research extends, where possible, statistical modeling techniques used in VLSI digital circuits to microwave circuits. We will develop new techniques otherwise. As such, this research is novel.

Advance in Scientific Knowledge

If this research is successfully completed, the result will significantly enhance microwave engineers' understanding of device statistics. It will establish a framework for complete statistical characterization and design of microwave integrated circuits.

Method of Research

Accepted scientific methods are employed. Since the team members have been actively working in device modeling, parameter extraction and statistical design areas for a number of years, we have a solid background in this research. A relevant literature search has been carried out. Interaction with relevant industry is also providing important feedback.

The project particularly requires interaction with integrated circuit process and fabrication engineers to determine and obtain relevant measured data. The mathematical algorithms being developed will then be tested on a number of practical devices using real measurement data.

Progress to Date

The starting date for the project was June 1, 1987. By July 1988 a comparative review of the state of the art in statistical modeling had been completed. Between August 1988 and July 1989 the theory for combined discrete/normal statistical modeling has been developed. Interaction with industry has also been initiated.

In June 1989, OSA was awarded a one year IRAP-M grant from the National Research Council of Canada for "Linear/Nonlinear Statistical Modeling for Computer-Aided Engineering of Microwave Integrated Circuits" [7,9], starting June 18, 1989. No support, however, was received from NRC within the fiscal year ending July 31, 1989.

Reports

The reports [5-9] and paper [10] summarize our achievements within the framework of this project. Reference [10] was presented at the European Microwave Conference held in London, England, in September 1989.

Description of the Project

Statistical modeling is a prerequisite to using statistical design techniques. Such a procedure has been successfully used in the design of MOSFET devices, CMOS and other types of VLSI digital circuits [1,2].

GaAs integrated circuits now play an important role in microwave engineering. How to obtain the statistical models is a vital step towards effective use of yield analysis and optimization. However, such modeling techniques are relatively new to most microwave engineers. The literature on this subject in the microwave community is very sparse, e.g., [3,4].

Generally speaking, statistical modeling is to find a model and the statistical distribution of the model parameters. The available information are measurements of the external behaviour of circuits or devices, and possibly process/geometrical measurements. Different levels of information may be hierarchically classified, from top to bottom, as response level, electrical model parameter level, intermediate parameter level and basic process/geometrical parameter level.

Within the fiscal year our activities concentrated on three subjects:

(1) study discretized arbitrary statistical distributions and combined discrete/normal statistical modeling of microwave devices,

(2) research towards IRAP-M proposal and start working on the project,

(3) interaction with industry.

To date the first two subjects have been successfully completed. The third is an on-going activity. The following is a brief description of our results.

We studied the problem of approximating arbitrary multidimensional joint probability density functions (pdf's) by discretization. Weights are assigned to discretization cells according to the frequency of outcomes falling into the cells, and then they are used in generating pseudo random outcomes. The limitation of this approach comes from limited sizes of the samples (leading to poor approximations) as well as from the exponential growth of the number of cells with the number of variables. To alleviate these limitations we devised a combined discrete/normal approach. The approach is based on the fact that a multidimensional normal distribution is justified for most of the equivalent circuit parameters. For parameters exhibiting sample distributions substantially different from normal our method provides random outcomes that preserve the means, standard deviations, correlations and marginal distributions derived from the sample. FET statistical modeling at the equivalent circuit level was carried out. A bi-modal distribution of one of the parameters was successfully recovered. Within the scope of this subject we also studied the problem of the optimal size of the sample needed for statistical device modeling.

We studied different aspects of statistical modeling needed for a successful implementation in the form of a CAD system. We identified research subtasks to work on and software modules to be developed. An IRAP-M proposal was accepted and we started working on the project in June 1989. By July 31, 1989, we completed structural and architecture planning, defining data structure and started research on device modeling using physical parameters.

Interaction with industry included a number of Canadian companies in the Ottawa area (January 1989), AT&T Bell Laboratories (initiated in February 1989) and continuous discussions with the Raytheon Company, Research Division.

Future work will be carried out according to the IRAP-M proposal and will include:

(1) study special aspects of GaAs FET integrated circuit devices related to statistical modeling,

(2) develop theory for an optimization approach to statistical modeling,

(3) implement and test the optimization approach to statistical modeling,

(4) interact with process and fabrication engineers for measurement data and process information,

(5) test statistical modeling using real measurement data.

Technical Personnel

Dr. J.W. Bandler, Director of Research

Dr. R.M. Biernacki

Dr. S.H. Chen

Mr. J.F. Loman

Ms. M.L. Renault

Dr. Q.J. Zhang

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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 230 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 from the Technical University of Warsaw in 1976. He has 20 years of professional experience which includes several academic and research positions.

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

Dr. Biernacki's research interests include system theory, optimization and numerical methods, computer-aided design of integrated circuits and control systems. He has more than 50 publications in IEEE journals and proceedings of IEEE and other conferences.

Dr. Biernacki is a Senior Member of the Institute of Electrical and Electronics Engineers.

Research Personnel

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.

Dr. Chen's professional interests include optimization theory and algorithms, computer-aided microwave circuit design, statistical analysis and yield optimization, robust device modeling, and user-friendly computer graphics. He has contributed to 15 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". During his stay in McMaster University he contributed to 20 technical reports.

Ms. M.L. Renault received the B.Eng. and M.Eng. degrees, both in electrical engineering from McMaster University in 1982 and 1988, respectively.

Ms. Renault has been employed by Optimization Systems Associates Inc. on a project basis since 1983 and on a regular part-time basis since July 1986. She joined Optimization Systems Associates Inc. as a full time Research Engineer in 1988.

Ms. Renault's research interests include statistical circuit design and identification of circuit model parameters.

Dr. Qi-jun Zhang received the B.Eng. degree from the East China Engineering Institute, Nanjing, China in 1982. 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. Zhang was a research assistant in Tianjin University, Tianjin, China in 1982 and 1983. He was a Postdoctoral Fellow in the Department of Electrical and Computer Engineering, McMaster University from September 1987 to March 1988. He joined Optimization Systems Associates Inc. in 1988 as Research Engineer. In 1989 he became Assistant Professor of Electrical and Computer Engineering (part-time) at McMaster University, Hamilton, Canada.

Dr. Zhang's professional interests include large-scale optimization techniques for design and modeling of microwave circuits, analysis and optimization of nonlinear microwave circuits, sensitivity analysis, diagnosis and tuning of analog circuits. He has published 19 technical papers.

<u>Assistant Research Personnel</u>

Mr. J.F. Loman received the B.Sc.E.E. degree in electrical engineering from the University of Calgary in 1986. He worked for National Semiconductor Canada Ltd. in workstation ASIC design automation from 1987 to 1988. Mr. Loman was employed by Optimization Systems Associates Inc. as Software Engineer from May 1988 to May 1989.

Currently, Mr. Loman is pursuing an M.Eng. degree in the Department of Electrical and Computer Engineering at McMaster University.

<u>Engineering Students</u>

Mr. R. Csermak was employed by Optimization Systems Associates Inc. as an Engineering Assistant in August 1988. He graduated in 1989 with a B.Eng.Mgt. from the Department of Electrical and Computer Engineering, McMaster University.

Mr. G.R. Simpson was employed by Optimization Systems Associates Inc. as an Engineering Assistant in August 1988. He graduated with a B.Eng. in Computer Engineering from the Department of Electrical and Computer Engineering, McMaster University, in 1989.

Mr. M. Fletcher was employed by Optimization Systems Associates Inc. as an Engineering Assistant from May to August 1989. He is presently a student at McMaster University, where he expects to graduate in 1991.

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