RESEARCH PROJECTS

DECEMBER 1990 - NOVEMBER 1991

OSA-92-RC-6-R

July 10, 1992

INTRODUCTION

During the fiscal year 1990/1991 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	30%	$46,079
Project No. 2	40%	$61,440
Project No. 3	30%	$46,079
Total claimed for the Investment Tax Credit in respect of Scientific Research and Experimental Development (SR & ED)		$153,598

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

(1) National Research Council's IRAP-M contribution towards the salaries of our staff (July 1991 to November 1991).

(2) Natural Sciences and Engineering Research Council's contribution to the salary of Industrial Research Fellow Dr. Shen Ye (July 1991 to November 1991).

INDEX

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 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; 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:

Libra, 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. 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. 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.

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 physics equations, consistent models for all types of circuit simulation and design, and field theory based component analysis, all in a user-friendly CAD environment, are of utmost importance.

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 November 1990 we had already developed, released and started marketing a computer program called HarPE for nonlinear device parameter extraction. We demonstrated the feasibility of the parameter extraction method based on large-signal power spectrum measurements and the harmonic balance simulation technique. We laid a foundation for analytical unification of DC, small-signal and large-signal circuit simulations and optimizations. We developed adjoint sensitivity technique for harmonic balance simulations.

Between December 1, 1990 and November 30, 1991 we developed and released a novel, state-of-the-art general purpose CAD software system called OSA90/hope. Its design optimization engine OSA90 features open architecture achieved through our research on high speed interprocess data communication. We also continued work on different components of the project to enhance efficiency and robustness of mathematical algorithms.

Reports

The papers [21-25] and manuals [18-20] summarize our achievements within the framework of this project. Reference [21] was published in *IEEE Transactions on Microwave Theory and Techniques*, the most reputable journal in the field. An invited paper [22] was submitted to the 1992 IEEE International Symposium on Circuits and Systems. Our research results on open architecture CAD software systems were presented at the 8th COMPUMAG Conference on the Computation of Electromagnetic Fields in Sorrento, Italy [23]. A comprehensive new paper [24] was submitted to the Special Issue of *IEEE Transactions on Microwave Theory Techniques* on Process-Oriented Microwave CAD and Modeling.

Description of the Project

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. 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 [1-4,7-14,17].

The harmonic balance method has become an important tool for the analysis of nonlinear circuits. The work of Rizzoli et al. [1], Gilmore and Rosenbaum [2], Curtice and Ettenberg [4], Gilmore [6], Curtice [12] stimulated work on harmonic balance in the microwave CAD community. The excellent paper of Kundert and Sangiovanni-Vincentelli [5] provided systematic insight into the harmonic balance method. Our achievements in the adjoint sensitivity analysis technique [15] and its expedient implementation in general purpose CAD software [16] has made the harmonic balance method attractive for design optimization.

Our research efforts have been concentrated on the following subjects:

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

(2) investigation of seamlessly integrated, consistent DC/small-signal/large-signal circuit simulations and optimizations,

(3) efficiency and robustness of mathematical algorithms,

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

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

(6) user-friendliness of CAD tools,

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

(8) work towards a new generation comprehensive software system suitable for yield and cost driven design of microwave circuits in terms of layout/geometrical and process/technological parameters.

To date we have made progress in all of these subjects. Implementation of these features and techniques has been made within the software system HarPE [18] as well as within our new software systems OSA90 [19] and OSA90/hope [20] which we released in June 1991. Continuous research on the subjects (2) to (8) was involved in creation of these new programs.

Our previous work on consistency of the harmonic balance simulations under small-signal excitations with the traditional DC/small-signal simulation technique based on local linearizations at the operating points [21] was published in *IEEE Transactions on Microwave Theory and Techniques*. Also, an invited paper [22] on our previous results was submitted to the 1992 International Symposium on Circuits and Systems (San Diego, CA, May 1992).

We have continued our work on different computer scientific solutions needed for the new generation CAD tools for design of MMICs in the 1990s. We have investigated and developed an inter-program pipe communication technique for high speed numerical interactions between independent programs. This provides architectural foundation for a new generation of large-scale CAD software systems and has been implemented in our new CAD software systems OSA90 and OSA90/hope. Reference [23] was presented at the 8th COMPUMAG Conference on the Computation of Electromagnetic Fields held in Sorrento, Italy, in July 1991. We have also contributed to subject (1) by creating an new GaAs MESFET model called KTL [25]. It is described in more detail within Research Project 3.

Currently we are developing models for microstrip structures to expand our library of linear elements. In our future work we will continue to concentrate on (1) further theoretical developments, including mathematical algorithms for simulation and optimization, (2) researching and implementing nonlinear device models and linear library elements, (3) extensive testing.

Technical Personnel

Dr. J.W. Bandler, Director of Research

Dr. R.M. Biernacki

Dr. S.H. Chen

Dr. S. Ye

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[19] "OSA90™ User's Manual, Version 1.1", Optimization Systems Associates Inc., Dundas, Ontario, Canada, August 1, 1991.

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[23] J.W. Bandler, R.M. Biernacki and S.H Chen, "Design optimization with external simulators", (invited), *COMPUMAG 8th Conf. on the Computation of Electromagnetic Fields* (Sorrento, Italy), 1991, pp. 1061-1064.

[24] J.W. Bandler, R.M. Biernacki, Q. Cai, S.H. Chen, S. Ye and Q.J. Zhang, "Integrated physics-oriented statistical modeling, simulation and optimization," submitted to the Special Issue of *IEEE Trans. Microwave Theory Tech.* on Process-Oriented Microwave CAD and Modeling.

[25] J.W. Bandler, S. Ye, Q. Cai, R.M. Biernacki and S.H. Chen, "Predictable yield-driven circuit optimization," submitted to *IEEE MTT-S Int. Microwave Symp.* (Albuquerque, NM), 1992.

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. 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, or fast workstations, 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., [1,2,5,7-13]. 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 November 1990 we have successfully demonstrated feasibility of an extremely efficient method for quadratic approximation of circuit response functions, including testing, reliability studies and, especially, applying these methods to yield optimization of a large-scale practical microwave circuit, namely a 5-channel multiplexer. We developed a fast gradient based technique for yield optimization of nonlinear circuits operating in the steady-state under large-signal excitations. We also introduced Monte Carlo analysis into HarPE [14].

Between December 1, 1990 and November 30, 1991 we continued our work on this project. We have researched yield optimization of MMIC circuits in terms of physical and geometrical parameters of active devices and passive components, including correlations. We have developed a quadratic modeling technique based on both simulated responses and their gradients. We have started development of yield optimization capabilities for our new CAD software systems OSA90 [15] and OSA90/hope [16]. This work was supported in part by the National Research Council of Canada through its IRAP-M program. We have devised a new algorithm for yield optimization, more suitable for gradient based optimizers because of the smoothness of the objective function. We have also investigated the predictability of simulated yield as compared to yield determined directly from device measurements.

Reports

The papers [17-21], report [22] and manuals [15,16] summarize our achievements within the framework of this project. Two papers [17] and [18] (based on our earlier work) were presented at the 1991 IEEE MTT-S International Microwave Symposium and the 1991 European Microwave Conference, respectively. A comprehensive new paper [19] whose one section deals with the subjects of this project was submitted to the Special Issue of *IEEE Transactions on Microwave Theory Techniques* on Process-Oriented Microwave CAD and Modeling. New papers [20] and [21] were submitted to the 1992 IEEE MTT-S International Microwave Symposium.

Description of the Project

Statistical circuit design, or yield optimization has been a subject of extensive research in the last decade, e.g., [1-13]. High production costs of present MMICs due to fluctuations in the manufacturing process demand yield-driven design CAD [6]. It is important to truly reflect the actual statistical spreads during computer simulations. Therefore, the primary physical and geometrical parameters must be available. Unfortunately, device simulation in terms of such parameters is extremely slow. This makes yield optimization of practical nonlinear microwave circuits a challenging task because of complexity and computational effort involved. In this research we concentrate our efforts on algorithms for statistical design of nonlinear circuits operating in the steady state under large-signal periodic excitations. In particular, we investigate the feasibility and practical implementation of yield optimization techniques in terms of physical parameters of both active devices and passive components. The following is a brief description of our results.

We finalized our previous work on a new approach to modeling of circuit responses and their gradients. We exploit multidimensional quadratic approximation and take full advantage of available gradient information in order to replace expensive repeated actual circuit simulations and gradient calculations by approximate model evaluations. This may significantly speed up the simulation process. Efficiency and accuracy of the new technique have been tested by gradient-based yield optimization of a filter and an MMIC amplifier. A research paper [17] was presented at the 1991 IEEE MTT-S International Microwave Symposium, held in Boston, MA, in June 1991.

We have initiated research on physics-based design and yield optimization of MMICs. Multidimensional statistical models are considered for the physical, geometrical and process-related parameters of active devices and passive components. We concentrate our efforts on feasibility studies of this extremely complex and computationally involved problem. We are experimenting with efficient gradient-based yield optimization technique. Our preliminary results were reported at the 1991 European Microwave Conference, held in Stuttgart, Germany, in September 1991 [18]. This subject has been further advanced by relevant physics-based statistical modeling of active devices. Our statistical implementations use models originated by Ladbrooke and by Khatibzadeh and Trew. We embed these physics-based statistical models in the yield optimization process for MMICs using appropriate multidimensional statistical distributions (including correlations). A large new paper [19] (our results within this area are contained in one section which by itself could be published as a separate regular paper) has been submitted to the Special Issue of *IEEE Transactions on Microwave Theory and Techniques* on Process-Oriented Microwave CAD and Modeling.

A massive research and development effort has been initiated to incorporate the advanced yield optimization features into our new software systems OSA90 [15] and OSA90/hope [16]. This work is supported in part by the National Research Council of Canada through its IRAP-M program [23,24]. An abstract mathematical formulation of yield optimization problem is given in [22]. It has been extended to a new and elegant formulation suitable for gradient-based optimization. The conventional discrete Monte Carlo estimate of yield is replaced by a continuous yield probability function. The merit of the new method has been demonstrated by applications to an amplifier and a nonlinear FET doubler. A new paper [20] has been submitted to the 1992 IEEE MTT-S International Microwave Symposium (Albuquerque, NM, June 1992).

Of particular interest in our investigations has been the problem of predictability of simulated yield as compared to yield determined directly from device measurements. This subject is closely related to the problem of statistical modeling considered in Project 3. Here we have researched utilization of the new KTL model. Our experiments led to significantly improved yield of a broadband amplifier. More importantly, yield predicted over a range of specifications has been verified by device data. We have also devised a scheme for yield sensitivity analysis which proves to be of great assistance in selecting optimization variables, identifying critical specifications, etc. A new paper [21] has been submitted to the 1992 IEEE MTT-S International Microwave Symposium (Albuquerque, NM, in June 1992).

In the future we will concentrate our efforts on further improvements of the algorithms and methods for statistical design of analog and microwave circuits.

Technical Personnel

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Dr. S.H. Chen

Dr. S. Ye

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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

The uncertain future of statistical modeling and design of microwave integrated circuits, and acceptance of the necessary software tools by microwave engineers makes this a high risk project. The prognosis for the affordable manufacture of monolithic microwave integrated circuits (MMICs) is particularly uncertain. Recent cuts throughout the high-tech microwave industry may slow down these developments.

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 develop new techniques otherwise. As such, this research is novel.

Advance in Scientific Knowledge

The methods and algorithms developed within this project will help the microwave engineers to investigate, better understand, and, as a consequence, to utilize device statistics in the process of circuit design. This research is aimed at establishing 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 this research area for a few years no extra literature search was necessary except for recent periodicals. 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.

Progress to Date

The starting date for the project was June 1, 1988. By November 1990 we had reviewed the state-of-the-art in statistical modeling; we had developed the theory for combined discrete/normal statistical modeling; and we had developed the theory for optimization based statistical modeling, tested it, and implemented it in a commercial software product HarPE Version 1.4+S (the current version is 1.5+S [8]). We had also experimented with the Ladbrooke model and processed wafer measurement data from Plessey Research Caswell Ltd. Encouraging results have been obtained.

Between December 1, 1990 and November 30, 1991 we continued our research on physics based statistical modeling. We have concentrated our efforts on two physics-based models originated by Ladbrooke and by Khatibzadeh and Trew. Our experiments have indicated that statistical representation of device statistics by the Khatibzadeh and Trew model is not satisfactory. This has led us to investigate the possibility of combining the two models into one model exploiting their respective advantages.

Reports

The papers [9-11] and report [12] summarize our achievements within the framework of this project. The paper [9] (based on our earlier work) was presented at the 1991 IEEE MTT-S International Microwave Symposium. A comprehensive new paper [10] whose one section deals with the subjects of this project was submitted to the Special Issue of *IEEE Transactions on Microwave Theory Techniques* on Process-Oriented Microwave CAD and Modeling. A new scientific paper [11] was submitted to the 1992 IEEE MTT-S International Microwave Symposium.

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., [3-7].

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.

Our work concentrates on the following on-going activities:

(1) investigate direct use of data bases of both measured and extracted parameters,

(2) investigate physics based model statistical properties,

(3) continue to interact with process and fabrication engineers for measurement data and process information,

(4) continue to test statistical modeling using real measurement data.

During the reported period we have made progress in all of these subjects. We continued interaction with a few leading companies, in particular GEC Marconi Materials Technology Limited, England. We have processed real S-parameter measurement data from a sample of devices from two wafers manufactured by Plessey.

Our main effort within this project has been devoted to subject (2). We have continued our study of the Ladbrooke physics based model. Our previous encouraging results [9] were presented at the 1991 IEEE MTT-S International Microwave Symposium, held in Boston, MA, in June 1991. We have investigated statistical properties of the Khatibzadeh and Trew model and concluded that the model is deficient for the purpose of statistical modeling. These results have been reported in a comprehensive paper [10] submitted to the Special Issue of *IEEE Transactions on Microwave Theory and Techniques* on Process-Oriented Microwave CAD and Modeling.

Since the Ladbrooke model provides quite a reliable estimate of device statistics, but it lacks the DC simulation capabilities needed to determine its parameters we have combined it with the Khatibzadeh and Trew model. The latter is used to evaluate the DC operating point, and, therefore, provides the missing link for the completeness of the Ladbrooke model. The resulting combined model, which we call KTL, proves to be the best known model for statistical characterization of GaAs MESFETs. We have published this extremely important result in a report [12], and in [11], a scientific paper submitted to the 1992 IEEE MTT-S International Microwave Symposium (Albuquerque, NM, June 1992).

Furthermore, we have investigated the predictability of yield estimation using our new KTL model by comparing the simulation results employing the model against the results obtained by using directly device measurements (subject 2). That research is reported within Project 2.

In the future we will continue research in all of the aforementioned subjects.

Technical Personnel

Dr. J.W. Bandler, Director of Research

Dr. R.M. Biernacki

Dr. S.H. Chen

Dr. S. Ye

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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 some 250 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 more than 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 70 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 25 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. S. Ye received the B.Eng. and M.Eng. degrees from Shanghai University of Technology, Shanghai, China, in 1982 and 1984, respectively, and the Ph.D. degree from McMaster University, Hamilton, Canada, in 1991, all in electrical engineering.

Dr. Ye was a teaching and research assistant in the Department of Electrical Engineering, Shanghai University of Technology from 1984 to 1986. He joined the Simulation Optimization Systems Research Laboratory and the Department of Electrical and Computer Engineering, McMaster University as a graduate student in 1986. He held an Ontario Graduate Scholarship for the academic year 1989/90.

In 1991 Dr. Ye was awarded an NSERC Industrial Research Fellowship and joint Optimization Systems Associates Inc., Dundas, Canada, as Research Engineer. His research interests include circuit CAD software design, simulation and optimization techniques, active and passive device modeling and parameter extraction and statistical circuit design.

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