COMPUTER-AIDED ENGINEERING OF NONLINEAR MICROWAVE CIRCUITS: YIELD-DRIVEN DESIGN

OSA-91-OS-1-P

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1. Title of the Proposal

COMPUTER-AIDED ENGINEERING OF NONLINEAR MICROWAVE CIRCUITS: YIELD-DRIVEN DESIGN

2. Company Background

General Information

Optimization Systems Associates (OSA) was established in 1983 and was incorporated in 1986. OSA is privately owned.

OSA is driven by the microwave industry's growing demand for user-friendly, state-of-the-art software design tools. OSA has provided consulting services to several major microwave companies and software houses.

In 1988, OSA released its first product RoMPE™ - a program for FET parameter extraction. In 1989, OSA announced RoMPE's successor: HarPE™ - a software system for FET parameter extraction from DC, small-signal and large-signal measurements. It is marketed exclusively by OSA worldwide.

OSA's Facilities

Computers

1 DEC microVAX II
1 Apollo DN3500 workstation
5 IBM AT personal computers or compatibles

Operating Systems

BSD 4.2 UNIX, System V UNIX, VMS 4.5, DOS

Language Compilers

Fortran, C, Pascal

3. Company Commitment

The overall cost of the proposed project is estimated as follows.

1.	Technical personnel	$68,497.79
2.	Overhead	$66,794.78
	TOTAL ESTIMATED COST	$135,292.57

OSA is committed to contribute $68,192.57 to the project. This will be derived from operating profits and R&D Tax Credits.

4. Company Technical Capability

OSA's competence has been established by our substantial contributions to the literature, our innovations in several major commercial software in the microwave CAE, and by our product HarPE considered by the specialists as the most advanced and user-friendly software system for parameter extraction and statistical modeling commercially available.

OSA's Microwave CAE Innovations

OSA has originated features never previously offered by commercial microwave software houses.

In 1983, OSA developed a system for efficient simulation, sensitivity analysis and optimization of waveguide multiplexers. The leading manufacturer of multiplexers, namely, ComDev Ltd. (Cambridge, Ontario, Canada), commissioned this system.

OSA has reshaped EEsof's Touchstone by developing state-of-the-art optimizers, originally featured in Version 1.5, including minimax, quasi-Newton and generalized least pth optimizers.

From 1986 to 1989, OSA played a key role in the restructuring and enhancement of the popular microwave CAE products Super-Compact, Microwave Harmonica, Super-Compact PC and Microwave Harmonica PC, all for Compact Software, Inc.

Since 1985 OSA has supported Raytheon Company's initiatives towards the U.S. DoD's MIMIC (Microwave/Millimeter-Wave Monolithic Integrated Circuits) Program. From 1988 to 1989 OSA was a subcontractor on the Raytheon/Texas Instruments/Compact Software MIMIC team under a Phase 1 Subcontract. OSA was the only non-US group participating in this $300 million program.

OSA's first FET parameter extractor based on small-signal measurements - RoMPE™ - was released in 1988. In 1989 it was replaced by a new FET parameter extractor utilizing DC, small-signal and large-signal measurements - HarPE™ - the world's first commercial software for parameter extraction from harmonic measurements. It has been extremely well received by the microwave CAD community. Sales are slower than expected mostly due to recent cuts throughout the high tech microwave industry. In 1990, a statistical modeling option to HarPE has been released, with partial support by NRC through its IRAP-M program, making HarPE a complete system for FET device characterization.

OSA's Distinctive Competence

long and extensive experience in CAE

high level of technical and mathematical expertise

implementation of advanced theory and techniques in commercial software

high standard of professional programming

experience on many platforms: Apollo, Hewlett-Packard, Sun, CRAY, FPS, different mainframes and PCs

several programming languages

OSA's Recent R&D Activities

OSA's recent R&D activities concentrated on the following projects.

Project 1: ADVANCES IN MICROWAVE COMPUTER-AIDED-DESIGN (CAD)

- development and/or implementation of new nonlinear device models,
- investigation of seamlessly integrated, consistent DC/small-signal/large-signal circuit simulations and optimizations,
- efficiency and robustness of mathematical algorithms,
- open architecture and flexible data structures for user-friendly CAD tools, including accessing internal variables and processing capabilities of CAD systems,
- state-of-the-art CAD tools for GaAs FET small-signal, DC and large-signal model simulation, optimization and parameter extraction,
- 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.

This project comprises a number of on-going research activities with a common goal of reliable, efficient, robust, user-friendly and versatile CAD tools.

Project 2: YIELD-DRIVEN DESIGN OF NONLINEAR MICROWAVE CIRCUITS

- efficient yield-driven optimization of nonlinear microwave circuits with statistically characterized devices,
- fast gradient based techniques for yield optimization of nonlinear circuits,
- Monte Carlo statistical analysis option for HarPE featuring large-signal, DC and small-signal simulations.

The first two techniques have been tested using stand alone, specialized research programs. Their versatile, robust and user-friendly implementation into commercial software requires more research. The third technique is already implemented in HarPE.

Project 3: STATISTICAL MODELING OF MICROWAVE INTEGRATED CIRCUITS AND DEVICES

- study special aspects of GaAs integrated circuit FET devices related to statistical modeling,
- theory for an optimization approach to statistical modeling,
- implementing and testing the optimization approach to statistical modeling,
- a framework for a comprehensive statistical modeling system for monolithic integrated microwave devices,

- applying statistical modeling techniques to such devices reflecting fabrication parameters and response measurements,

- interact with process and fabrication engineers for measurement data and process information and test statistical modeling using real measurement data.

This research was supported in part by NRC through the IRAP-M program and led to the release of the statistical modeling option for HarPE [27-29].

OSA's Technical Personnel

JOHN W. BANDLER, Ph.D., D.Sc.(Eng.), P.Eng., C.Eng., FIEEE, FIEE (London), Fellow of the Royal Society of Canada

OSA Founder, President and Research Director; Professor of Electrical and Computer Engineering and Director of the Simulation Optimization Systems Research Laboratory, McMaster University, Hamilton, Ontario; more than 25 years of professional experience; expert in optimization methods and their applications to computer-aided network design, sensitivity analysis of electrical circuits, least pth and minimax optimization, fault location of analog circuits, optimal load flow in power systems, microwave filter and multiplexer design; recognized for his pioneering work in optimal design centering, tolerancing, tuning and yield optimization; author of more than 230 publications, listed in Who's Who in Engineering, American Men and Women of Science, Who's Who in America, the International Who's Who and in Who's Who in Canada.

RADEK M. BIERNACKI, Ph.D., SMIEEE

Senior Research Engineer with OSA; Professor (part-time) of Electrical and Computer Engineering, McMaster University, Hamilton, Ontario; 21 years of professional experience; expert in electronic circuits, computer-aided design, circuit theory, fault diagnosis of analog circuits, statistical analysis and in robust control; author of 60 publications.

SHAOHUA CHEN, Ph.D., MIEEE

Research Engineer with OSA; 6 years of professional experience in optimization theory and algorithms, computer-aided circuit design, device modeling, statistical analysis and optimization, computer graphics, and control systems; expert in programming languages; author of 20 publications.

5. Project Objectives

We plan to work towards a new generation comprehensive software system suitable for yield- and cost-driven design of RF and microwave circuits in terms of layout/geometrical and process/technological parameters. The ultimate goal of the proposed research is to develop a software system for yield-driven circuit design in the presence of device, process and other statistics. Our aim is to produce novel results and software relevant to the expanding area of monolithic microwave integrated circuits (MMICs). Software products exploiting such methods should be capable of designing high yield practical nonlinear circuits. Such software products will then be competitive commercially.

We propose to research the area of statistical design centering for computer-aided design of nonlinear RF and microwave circuits, in particular for design of high frequency analog integrated circuits. Based on the results of the research we will develop yield-driven design features to be included in a new, marketable packaging of OSA's technology: software system OSA90™. A number of user-oriented features will also be created in order to enable the users to utilize their existing software within the power of our new system.

6. Project Technical Background

Microwave analog circuits are essential elements in satellite communications, radar systems space technology, etc. Such circuits operate in the analog mode, similar to that of radio receivers and transmitters, but at much higher frequencies. High frequency circuits are much more difficult to design and manufacture than the low frequency ones. For example, the mutual coupling effects between two adjacent elements, negligible in low frequency operations, can substantially distort the circuit's performance in high frequency operations.

While silicon semiconductors are typically used in digital circuits and lower frequency circuits, microwave engineers have found Gallium Arsenide (GaAs) to be the material most suitable for microwave circuits. The GaAs development and wafer processing achieved in the past few years have made monolithic microwave integrated circuits (MMICs) practical. MMIC technology has been successfully applied to microwave circuits such as power amplifiers, mixers, oscillators, etc.

The production of MMIC chips is expected to become massive. In such production, devices and circuits are designed and manufactured in batches rather than individually. Random variations in the manufacturing process result in a portion of "bad" devices or circuits, which in this type of technology cannot be repaired and are simply thrown away. The yield, defined as the ratio between the number of "good" circuits and the total number of circuits, directly affects the cost of manufacturing. Consequently, the need for yield maximization has become more pressing.

Statistical circuit design, or yield optimization, is an approach to the yield problem that has yield maximization as an objective at the design stage. It involves mathematical algorithms and the corresponding software tools, and has been a subject of extensive research in the last decade. Yield optimization of practical nonlinear microwave circuits, however, constitutes a challenging task because of complexity and computational effort involved.

Analog circuits can be classified as linear or nonlinear. In linear (nonlinear) circuits, the level of the output signal changes proportionally (non-proportionally) with that of the input signal. Simulation of nonlinear circuits is much more complicated than that of linear ones since it involves iterative algorithms to solve nonlinear equations. For microwave circuits, whether a circuit is linear or nonlinear is typically decided according to the power level of the input signal. Small-signal circuits are linear while large-signal circuits are nonlinear. The pseudo-linear behaviour commonly existing in analog and microwave circuits and the intentional use of nonlinearities in circuits such as mixers are typical examples requiring nonlinear circuit CAD. Design optimization of nonlinear circuits is one of the most challenging tasks in the microwave computer-aided engineering (CAE) area. Yield optimization is even more challenging since many statistically related circuit outcomes must be optimized simultaneously.

Computer simulation of circuits needs mathematical models to describe the behaviour of devices in the circuit. Parameter extraction techniques are designed to determine the structure and parameters of device models. Statistical modeling techniques have evolved to determine the device model taking random process variations and other uncertainties into account.

The capabilities of parameter extraction and statistical modeling are already available in OSA's HarPE. Also available is statistical Monte Carlo analysis which allows design engineers to simulate statistical spreads of circuit parameters and see the resulting spreads of the circuit responses. The missing part is the capability of the software to automatically center the design in order to minimize, or totally eliminate, those "bad" circuits that may be manufactured due to the inherent statistical fluctuations in the manufacturing environment.

In the proposed research we want to concentrate our efforts on algorithms for statistical design of nonlinear circuits operating in the steady state under large-signal periodic excitations. OSA has already initiated research in this field (see: page 4, Project 2). For linear circuits, we have shown feasibility of an extremely efficient method for quadratic approximation of circuit response functions, including testing, reliability studies and, in particular, applying the methods to the yield optimization of a large-scale practical microwave circuit, namely a 5-channel multiplexer. We have pioneered yield optimization of nonlinear circuits operating in the steady-state under large-signal excitations. Two techniques for gradient approximation were exploited: the Integrated Gradient Approximation Technique and the Feasible Adjoint Sensitivity Technique. The resulting paper [30] has just been published in *IEEE Transactions on Microwave Theory and Techniques*, the most reputable journal in the field.

The proposed research is directed at a marketable software/hardware system for design of analog RF and microwave circuits that takes into account manufacturing tolerances, model uncertainties, variations of the process parameters, environmental uncertainties, etc. It is particularly important for large volume production of MMICs.

Recently, we have created a prototype software system under the name OSA90™. It is a superset of HarPE. We intend HarPE to preserve its parameter extraction orientation, consistent with its original promotion and the image already established on the market. The new system will be structured as a general purpose simulation and design software. It will be structured for easy customization that may or may not include HarPE, depending on particular customer needs. OSA90™ will be the vehicle for both the research and the development of the proposed product.

7. Proposed Investigation

Investigation Statement

With the aim of creating a new marketable software product, based on our prototype system OSA90, we will conduct research on numerical 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; we will develop and test software modules needed for yield optimization; we will integrate the new modules with the OSA90 system by developing new drivers, expanding menus and plotting capabilities, as needed for user-friendly operation and presentation of results; and we will work on the open architecture of the system in order to accommodate variety of already existing user's in-house programs.

Necessary research, development and milestones are outlined in the following subsections.

Research towards Yield-Driven Design System

1. Study and develop theory for yield optimization of nonlinear microwave circuits operating in the steady state under large-signal excitations.

2. Study and implement objective function formulations for yield-driven design of nonlinear microwave circuits operating in the steady state under large-signal excitations.

3. Study and implement the best approach to gradient estimation to facilitate the powerful gradient based optimizers.

4. Study the optimal time sample selection for generalized Discrete Fourier Transform in two-tone mixer and intermodulation harmonic balance analysis.

5. Study and implement efficient modeling techniques that can take advantage of available gradient information in constructing reliable approximate models which then will be used instead of actual circuit simulations.

6. Study and develop new methods and numerical algorithms aimed at improving efficiency of statistical design of analog microwave circuits.

7. Apply statistical design techniques to practical analog microwave circuits reflecting fabrication parameter spreads.

8. Interact with process and fabrication engineers for measurement data and process information.

9. Develop a framework for a comprehensive yield-driven design system for monolithic integrated microwave circuits.

Modules for Yield-Driven Design System

1. Module for User Interface and Command Processor for Yield Optimization.

2. Parser Module for Yield Optimization Information in the Circuit File.

3. Module for Error Function Formulation for Yield Optimization.

4. Driver Module for Yield Optimization.

5. Library Modules for new Active Device and Passive Component Models.

6. Modules for Inter-Process Communication.

7. Output Data Processor for Yield Optimization.

8. Graphics Interface for Yield Optimization.

Planned Features of Yield-Driven Design System

1. Handling window specifications for any combination of DC, small-signal and large-signal steady-state circuit responses.

2. Handling a number of predefined statistical distributions including uniform, normal, exponential and lognormal distributions.

3. Handling user-defined statistical distributions including discrete distributions.

4. Handling user-supplied random number generators.

5. Handling multi-level hierarchical statistical models including wafer, chip and device statistics described by multidimensional normal distributions with correlations.

6. Handling multiple nonlinear devices and multi-tone excitations.

7. Handling inter-process communication with user's own simulators, parametric black-boxes of user's components, etc.

8. Graphical display of statistical responses (for multiple outcomes) together with the window specifications imposed on the responses.

9. User-friendly features including a menu-driven command system, flexible input file syntax, interactive graphics for displaying statistical responses, user-formatted output, etc.

10. State-of-the-art yield-oriented one-sided ℓ_1 optimization technique.

11. Numerical efficiency achieved by implementing advanced adjoint sensitivity analysis, state-of-the-art optimizers and efficient approximation to circuit responses.

Nature and Method of the Research

The proposed 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.

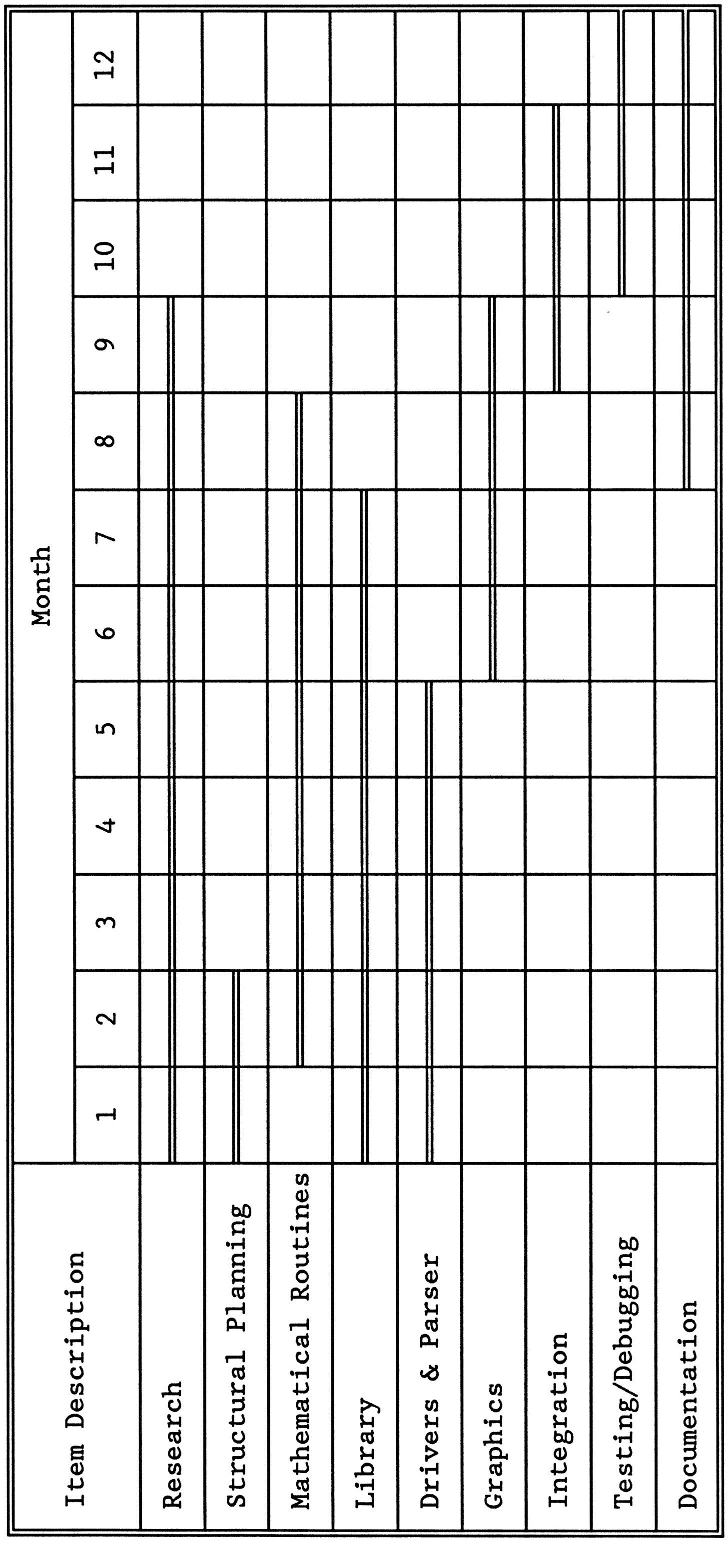
Accepted scientific methods will be employed. Since the team members have been actively working in this research area for a number of years no extra literature search will be necessary except for recent periodicals. According to our expectations, appropriate mathematical manipulations will be conducted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

Research and Development Schedule

Research and development schedule is illustrated by the bar chart in Table I.

TABLE I

BAR CHART FOR THE PROPOSED INVESTIGATION



Advance in Scientific Knowledge

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

Uncertainty of the Research

The main uncertainty of the project lies in the feasibility and reliability of the methods to be developed since they will be 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.

The uncertain future of statistical design of microwave integrated circuits, and a wide acceptance of the necessity of such 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.

8. Project Team

J.W. Bandler	35% time	Project Leader
R.M. Biernacki	70% time	Project Engineer
S.H. Chen	20% time	Project Engineer

For individual expertise relevant to the project please see section "OSA's Technical Personnel" on page 5.

9. Subcontractors and Consultants

No subcontractors or external consultants are planned for this project.

10. Projected Market

Introduction

The commercial market in the field of CAD software for nonlinear microwave circuit design is addressed mainly by: MDS by Hewlett-Packard; Libra by EEsof; Microwave Harmonica by Compact Software; and NANA by David Sarnoff Research Center. These simulation and design programs primarily solve simulation and performance-driven design problems for nonlinear microwave circuits. In Canada, all these products must be purchased from the United States.

The main CAD software systems offered to the microwave industry for either linear or nonlinear circuits: Super-Compact, Microwave Harmonica, Touchstone and Libra are currently gearing towards design centering and yield optimization features. Some yield capabilities are claimed by EEsof in the new releases of Libra. OSA's HarPE now has statistical modeling features. The statistical models are extracted from measurements taken on many devices, supposedly identical, but in practice different from one another. The main reason for statistical modeling is, however, to utilize such models in the design process.

We are convinced that OSA90 with its open architecture will provide the most versatile and efficient solution to yield-driven design of nonlinear circuits. For our competitors, it would require a significant investment effort to restructure their existing products in order to achieve the same level of versatility and efficiency. Furthermore, device models extracted using HarPE's statistical modeling features will consistently be utilized within the same software concept. Our competitors do not have any statistical modeling capabilities. Therefore, our achievements in the proposed research will contribute towards OSA's advantage over other software companies.

The product will meet the pressing need for statistical design of microwave integrated circuits. It will play a vital role in reducing the design cost. The product will substantially improve cost effectiveness and affordability in the manufacture of receive/transmit circuits. The ease with which the customer can acquire the skill to make use of the product is also crucial for product acceptance. Menu-driven user-friendly interaction will be available through very simple key strokes, allowing self paced, self directed learning to the user.

The product will be created in the context of OSA's long term plan to serve the microwave industry's needs for fast, accurate and user-friendly software systems capable of designing integrated circuits in new technologies for the 1990s. New technological developments and customer feedback will be used to upgrade the product in order to meet future needs of the industry as well as to attract more customers.

Target Market and its Segmentation

The product is designed to serve those larger corporations who have substantial manufacturing capabilities in the defence and communications market. It will also serve smaller corporations with a high volume of specialized products in the microwave, radar, communications and defence industry. The main customer locations are:

<u>Canada</u> The primary market in Canada is located in Montreal, Ottawa and Toronto. OSA is well positioned to serve these clients.

<u>U.S.A.</u> The primary United States locations are the Boston, Los Angeles and San Francisco areas. Secondary locations are in Texas, Florida and Washington, DC.

<u>Europe</u> Britain and Germany are expected to be the primary areas, followed by Italy, Benelux, Scandinavia and France.

<u>Japan</u>

The market consists of manufacturers of high frequency analog devices and circuits, and research laboratories working with analog circuits requiring advanced CAE tools. Of particular importance are companies planning manufacturing activities in monolithic microwave integrated circuits. Such companies have new requirements going beyond the capabilities of the existing products. OSA's innovations meet these as well as anticipated requirements of the industry.

The market can be divided into 3 segments: (A) companies already familiar with OSA's level of competence in CAD technology, (B) companies committed to advanced CAD technology, and (C) the remaining microwave companies.

A. Companies Familiar With OSA's Competence

The following companies will first acquire the new OSA's product. Personal and direct contacts should suffice in promoting the product.

Canada — Bell-Northern Research, BEL-Tronics, ComDev, Communications Research Centre, Microtel Pacific Research, Northern Telecom, Quantic Laboratories, Spar Aerospace,

USA — Avantek, Cascade Microtech, Comsat Laboratories, Ford Aerospace, General Dynamics, General Electric, Hughes Aircraft, Martin Marietta Orlando Aerospace, Raytheon, Rockwell International, Sandia National Laboratories, Texas Instruments, TriQuint Semiconductor, TRW,

Other — British Aerospace, British Telecom Research Laboratories, Bussan Electronic Systems Technology, Thorn-EMI, Filtronic Components, Marconi, Nippon Electric Company, Plessey Research Caswell, Siemens, Sony, Thomson Hybrides et Microondes.

B. Companies Committed to Advanced CAD Technology

The companies in this category are generally known to us, but they will have to be convinced that the product is to their advantage. Direct mail, personal visits and demonstrations will be given to them.

Canada — Andrew Antenna, Gennum Corporation, MA Electronics Canada, Mitec Electronics,

USA — AT&T Bell Laboratories, David Sarnoff Research Center, Deskin Research Group, Du Pont, Gamma-f Corp., Gazelle Microcircuits, Hewlett-Packard, IBM, M/A-COM, Menlo Industries, Microwave Associates, NYNEX Corporation, Satellite Technology Service, Stanford Electronics Laboratories, Tektronix, Teledyne Microwave, U.S. Army Electronics Command, United States Air Force, Watkins-Johnson, Westinghouse.

C. The Remaining Microwave Companies

The companies in the third category will be targeted through advertising in trade journals and at international conferences and exhibitions.

Size of Market and its Growth Rate

Depending on price, we expect to sell 35-70 units in the first two years. We estimate that approximately 10 corporations worldwide will purchase the product through their policy of acquiring one of every major high technology software innovation. As the industry is close knit word of mouth group sales are expected to increase in subsequent years at a 10% growth rate.

Distribution and Service

The product will be directly distributed by OSA. Distribution will be by direct mail and express courier from OSA. The software will be on diskettes or cartridge tapes, accompanied by manuals.

OSA will offer a one year maintenance option to customer. Reliability, technical competence and skill within OSA will guarantee high quality service to our customers. Because of OSA's plans to continually enhance its products it is expected that most of the clients will purchase the accompanying maintenance options. The purchase price referred to in this section reflects both the base price and the maintenance option. The maintenance service beyond the first year will have to be purchased at the 20% of the then current price of the product.

Sensitivity of Demand

US $5,000 At this price a CAD product is generally affordable and is likely to be within the budget control of a typical engineer. At this price we would expect 100 units to be sold. Expected Sales: US $500,000.

US $10,000 Some managerial approval required. At this price we would expect 70 units to be sold. Expected Sales: US $700,000.

US $20,000 At this price a CAD product requires not only a high level of approval by management but also its acquisition is considerably slower. At this price we would expect 35 units to be sold. Expected Sales: US $700,000.

US $30,000 The product must offer unique capabilities or significantly outperform other vendors' products, in particular well established, both in technical capabilities and in price. Market resistance expected. Only large companies are expected to buy at this price. We would expect 15 units to be sold. Expected Sales: US $450,000.

US $40,000 Considerable resistance by the market is expected at this price. Even large companies would consider such an acquisition very carefully. At this price we would expect 10 units to be sold. Expected Sales: US $400,000.

We conclude from the foregoing analysis that US $10,000 to US $15,000 is optimum.

External Factors

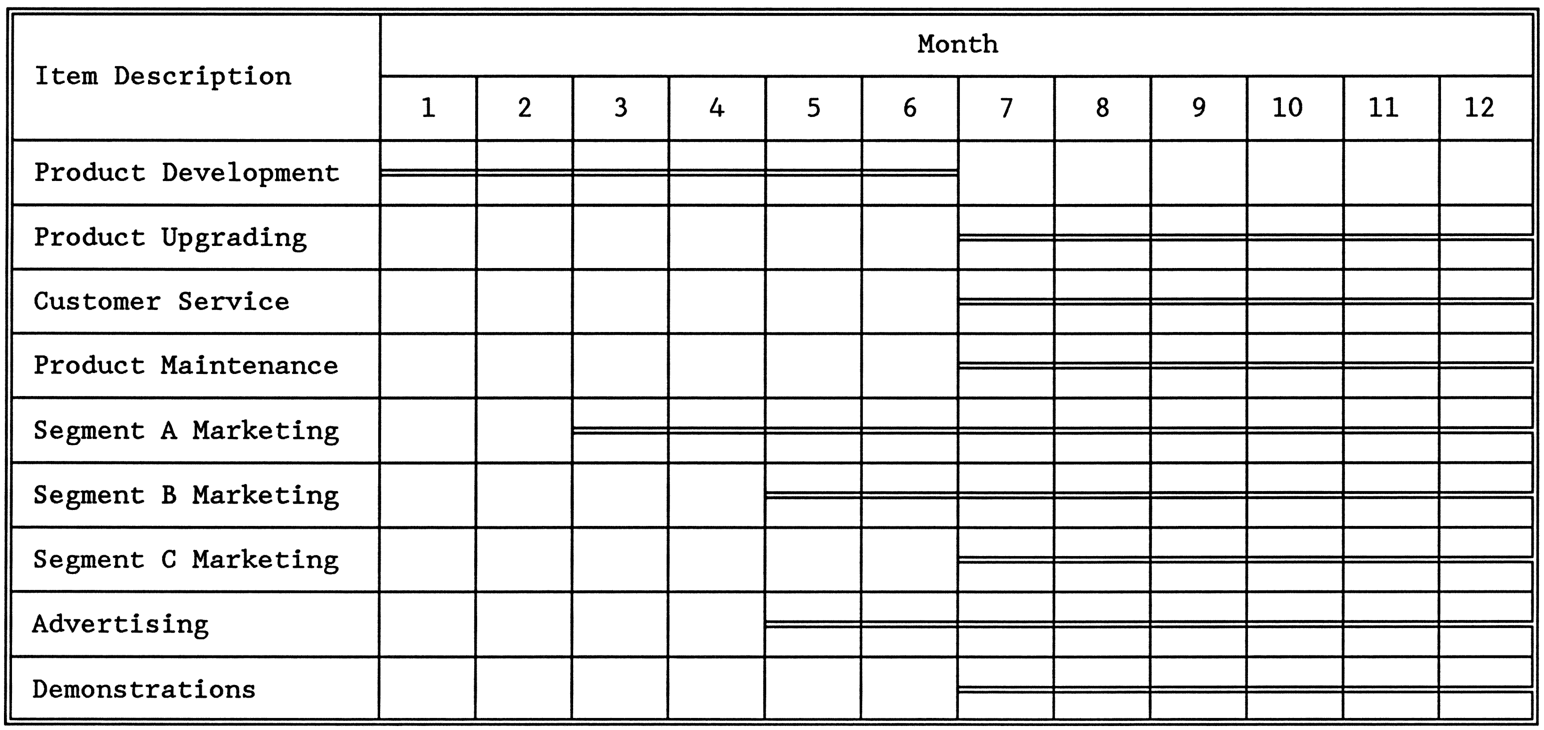
Success of the microwave industry in the present manufacture of monolithic microwave integrated circuits will affect the demand for this software. It has been estimated by Naegele in *Electronics*, November 1987, that the world wide market in 1997 for GaAs analog integrated circuits will be in the range of US $1.8 billion. With this rapid development in monolithic microwave integrated circuit technologies, the demand for fast and accurate software systems as created by OSA will be stimulated.

In spite of recent cuts in the defence and microwave industries, we are cautiously optimistic. We believe that the aforementioned prediction of the growth of the GaAs analog integrated circuit market is justifiable, especially if the industry is restructured from defence to commercial products.

Marketing Strategy, Scheduling and Promotion

See Table II for development, maintenance and marketing schedule during the last six months of research and development, and the first six months after product release.

TABLE II
BAR CHART FOR PRODUCT DEVELOPMENT AND MARKETING
DURING THE LAST SIX MONTHS OF R&D
AND THE FIRST SIX AFTER PRODUCT RELEASE



To ensure OSA's success, we are expanding technical cooperation with the microwave industry. We are continuing our high-level research to retain our image and leading position in technical areas. Our effort in advanced parameter extraction software contributes to the establishment of our influence and credibility in the market.

The main reason to acquire the OSA product will be the technical capabilities which meet the industry's demands. For customers, the features in our product will directly translate into more economical manufacturing, allowing the product to pay for itself rapidly. We believe that OSA's penetration of the marketplace and its positive feedback will create incentive for the remaining sector of the market to acquire OSA's products. The nature of the marketplace is such that users of existing CAE tools will not let their competitors have an edge with better CAE tools (OSA's product), and hence, will be motivated to acquire the same software. We forecast that the major share of this potential market will be captured by OSA.

Commercialization of the results will be by direct offering to prospective customers. Promotion of the final product will be by advertisement in trade journals, by demonstration at symposia and on site. Direct mail advertising to several thousand IEEE members who are also microwave engineers will be undertaken. Technical product summaries will be sent to all potential customers. Contacts in industry will assist in arranging on-site seminars and demonstrations in various companies.

Press releases, product announcements, product feature articles and full page colour advertisements will be sent to various trade journals including:

Microwave Journal
Microwaves & RF
Microwave Engineering Europe
Mikrowellen & HF Magazin

Appropriate announcements will also be sent to the following nonspecialist magazines:

Canadian Research
Electronics

The greatest impact on the market will be made in conjunction with the IEEE MTT-S International Microwave Symposium and Exhibition held annually in May or June. It is usually located in a significant geographical area. In 1991 it will be in Boston, Massachusetts, one of the major areas of concentration of microwave research, design and manufacturing. The exhibition attracts several thousand professional engineers, a large fraction of the world's microwave engineers. Virtually every company, world wide, is represented at these meetings. Other important international meeting, conferences and exhibitions will also be given considerable attention. Subject to budget constraints, booths will be reserved at exhibitions held in conjunction with appropriate conferences, including:

IEEE MTT-S International Microwave Symposium
GaAs IC Symposium
European Microwave Conference
MIOP
Technologie des Hyperfrequences

Demonstration versions of the product will be made available to the most prestigious and influential customers. We will cooperate with industrial and government laboratories, to explore ways of including their device models and fabrication statistics in our software and to ensure compatibility with their own hardware/software.

Detailed brochures and product summaries will be sent to the previously identified target market.

Competitor Evaluation

We estimate that we have a 12 month lead over possible competition. This is based on our knowledge of the state-of-the-art, our capabilities and our insight into the technical capabilities of the people involved in the competition. OSA is at the leading edge of microwave CAD technology. We are confident in our assessment of the competition. Our competitors, however, are aware of the needs in this area. Future developments by EEsof are considered to be potentially the most competitive.

Brand loyalty and barriers to entrance must be taken into account. EEsof has developed a significant customer loyalty. Our strength in penetrating their market relies upon two important strategies. (1) Our product will be made as compatible as possible with EEsof's so that our products will be complementary. (2) Approximately 30% of our sales will come from companies whose software inventory and budget makes possible the acquisition of a copy of every major software product. Technical superiority and compatibility with competitors' products are a fundamental element in OSA's designs.

Price and Financial Projections

We propose an initial fee for the final product of $10,000 per copy, and an annual maintenance fee of 20% of the then current price. The price for Europe will be 20% higher and for Japan 50% higher. Within the first two years after release we expect a sale of 5 to 15 copies in Canada and of 60 to 80 copies outside Canada. In order to contribute to Canadian competitiveness we will consider price discounts to Canadian companies, in particular, to those willing to cooperate, share measurement data, etc.

<u>Income Statement for Project (Year 1)</u>

Revenue from Direct Sales (15 @ US $20,000.00 @ 1.15)	$345,000.00
Revenue from Maintenance Agreements	0.00
Direct Costs	$5,000.00
Gross Margin	$340,000.00
Expenses:	
Advertising	$30,000.00
Demonstrations	$20,000.00
Manpower	$60,000.00
Overhead	$60,000.00
Research & Development Costs	$135,000.00
<u>Profit</u>	<u>$35,000.00</u>

Income Statement for Project (Year 2)

Revenue form Direct Sales (20 @ US $20,000.00 @ 1.15)	$460,000.00
Revenue form Maintenance Agreement	$69,000.00
Direct Costs	$5,000.00
Gross Margin	$524,000.00
Expenses:	
Advertising	$50,000.00
Demonstrations	$40,000.00
Manpower	$90,000.00
Overhead	$90,000.00
Profit	$254,000.00

11. Impact of Support

OSA has the technical expertise for the proposed project. However, without financial assistance the project could not be carried out. This project will generate one new opening on the job market right from the beginning of the research and development. Successful completion of the project will increase profitability and substantially contribute to development of OSA. The expected growth of the company will generate further jobs in Canada. Also, the algorithms and software modules created within this project will be extremely valuable in future OSA's products, thus reducing their development cost.

The project will contribute to Canadian competitiveness in the microwave CAE arena and in the high-tech industry in general, currently dominated by the Americans.

12. References

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