EXPLORATION OF NEW INITIATIVES IN COMPUTER-AIDED ENGINEERING OF (M)MIC CIRCUITS

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Introduction

With the rapid development of monolithic microwave integrated circuit (MMIC) technologies in the recent years, the demand for fast and accurate software systems suitable for MMIC circuits is increasingly pressing. Industrial requirements for handling nonlinear and large-scale circuits, statistical variations and process/geometrical parameters are beyond the capabilities of currently available software products, since they were mostly created in the pre-MMIC period.

OSA's answer to those future needs is to create a software environment for general linear/nonlinear microwave circuit simulation and design, including statistics and in terms of electrical/process/geometrical parameters. State-of-the-art techniques in microwave computer-aided engineering (CAE) and a new software architecture will distinguish our products, in addition to a friendly user-interface and a comprehensive library of circuit components and devices.

Our knowledge of industrial demands with respect to microwave integrated circuits (MICs) as well as MMICs, our leading position in microwave computer-aided design (CAD) research, and our ability to implement advanced theory and techniques in the field contribute to our confidence in success.

This document is a proposal for support of acquisition of foreign technological innovation under the Technology Inflow Program (TIP) of the Canadian Department of External Affairs.

Objectives

The principal aim of this project is to work towards sharing of technology with the most prominent group in Europe in the process-oriented and field-theoretic approach to (M)MIC CAD technology. It is planned to initiate a joint OSA/Jansen Microwave venture to building a comprehensive software system suitable for yield- and cost-driven design of microwave circuits in terms of layout/geometrical and process/technological parameters. The goal is to plan a layout-oriented, process independent CAD system, based on a combined field/circuit theoretical approach. The system is to provide a direct link to geometry, physical parameters, field theory based process-oriented description of (M)MICs leading to design of circuits with optimal performance and optimal yield.

Significant activity is in progress in Canada in the design and manufacture of (M)MICs. Initiatives are being taken by ComDev Ltd. of Cambridge, Ontario, Bell-Northern Research of Ottawa, Ontario, BEL-TRONICS Ltd. of Mississauga, Ontario, the Communications Research Centre, Ottawa, Ontario, Gennum Corporation of Burlington, Ontario, MA Electronics Canada Ltd. of Mississauga, Ontario, Microtel Pacific Research Ltd. of Burnaby, BC, and Spar Aerospace Ltd. of Montreal, PQ.

Effective use by the Canadian microwave industry of state-of-the-art microwave CAE software products, including our own, will substantially improve productivity. Currently, all the most advanced products, except OSA's RoMPE™ and HarPE™, are purchased from the United States. Enhancing production yield will also make a substantial contribution to the viability of Canadian high-technology products.

As the U.S. gears up for serious production of MMICs, the need for efficient, user-friendly software will provide a significant export market for OSA's products.

Technology

It is our aim to gain a first hand understanding of techniques for CAD of strip type planar MICs and MMICs which overcome the limitations of analytical models of microwave circuit elements at high frequencies. Jansen Microwave has developed a novel CAD technology which differs considerably from other existing CAD approaches. Their approach makes direct, automated use of a very general, rigorous field theoretical approach to generate design information for a wide class of strip type structures with validity for complex substrate configurations and up to high mm-wave frequencies. OSA needs to understand and be in a position to work with Jansen's enhanced spectral-domain technique which computes the required design data in the form of multi-dimensional look-up tables.

Jansen Microwave has developed LINMIC+, which incorporates technology OSA is seeking to explore. LINMIC+'s development was directed at keeping abreast of emerging MIC process technologies. LINMIC+ can handle a wide class of strip type structures and complex substrate configurations into the high mm-wave region. This includes dispersion, loss and frequency-dependent multistrip and multimode behaviour.

In LINMIC+ optimization exploits look-up tables, which are used with fast interpolation. OSA needs to understand the details of this simulation technique, as it is the key to the shift away from analytical models. It realizes significant improvement in range of applicability and accurate circuit predictability.

OSA needs to understand the versatile, unrestricted and efficient, layout-oriented topology description of LINMIC+, which is based on a modified subnetwork growth approach in which the topology linker operates only on the unconnected ports of the incomplete network.

Circuit simulation and optimization in LINMIC+ is performed in terms of the geometrical data of the layout and the electrical specifications of available commercial hybrid components, i.e., the design parameters are the physical quantities, which actually are under the designer's control. Practical realizability of a design can be enforced by user-definable constraints. This structure is ideally relevant to the approach that OSA is planning for its future CAD development.

OSA also needs to understand the organization of the modular, file-oriented architecture with standardized, exchangeable component models within LINMIC+. This program allows continuous updating of models, thus keeping track of the latest developments and the insertion of new models.

Work Plan

One visit by Drs. Bandler, Biernacki and Chen to plan a schedule of cooperation and to work with Jansen Microwave engineers hands on with their latest software and technology. Finally, a three day visit by Dr. Bandler to plan future strategy and to tie down the details of proposed joint work.

The interactions will consist of state-of-the-art presentations by each participant, detailed analysis of the state of existing commercial products, their features, advantages and disadvantages. Technical requirements specifications for the joint future work will be drawn

up. We will plan the general structure of a new product. We will discuss the linear and nonlinear analysis capability, optimization and field theoretic analysis and look-up table principles. We will discuss elements and modeling techniques. We will sketch out features for a circuit file syntax. We will discuss user-friendly features expected of the new product. We will address compatibility issues between the existing codes and software architectures existing within each company. We will bring up ways of implementing our technology and programming languages, operating systems, computer platforms, etc. The dynamic, flexible memory structure organization will need to be addressed. Time-domain analysis capabilities via well-organized Fast Fourier Transform algorithms to general time-domain output will be addressed.

We will draw up an architectural/feature document. We will list the modules of a proposed new product. We will plan scheduling of a prototype and discuss ways of synchronizing our respective efforts.

We will discuss security aspects relating to data and access to technological parameters within data bases.

As the U.S. DoD MIMIC Program evolves, standards relating to interfaces between software will evolve. We will discuss ways of taking advantage of these standards to exploit layout schematic capture and other features to provide an integrated user-oriented system.

We will examine the possible creation of joint new products over the next few years. Consequently, we will explore

- possible long term joint goals

- define features for the possible products

- list possible milestones and deadlines

We will discuss ways of attracting funds and investments, attract potential customers, solicit technical interaction with the microwave industry, and to seek technical cooperation in the development of products.

Follow Up

The intention of the activities is to create a comprehensive software system suitable for yield- and cost-driven design of microwave circuits in terms of layout/geometrical and process/technological parameters. The main aim is to plan the sharing of the participants' technology, exploiting the latest research results of both parties. To that extent, close communication between the parties is envisaged over the next few years. Joint research and development will be carried out in several phases, to be planned within this project.

Participants

Dr. J.W. Bandler (manager responsible), Dr. R.M. Biernacki and Dr. S.H. Chen of OSA. Dr. Rolf Jansen and his staff of Jansen Microwave in West Germany.

Capabilities: OSA

OSA is a pioneer in circuit design with tolerances, circuit performance optimization, parametric design centering, statistical device modeling, robust parameter extraction, harmonic

balance simulation and large-scale optimization. OSA has to its credit benchmark microwave CAD technology and software architectures for (M)MIC simulation, modeling and design. OSA has originated features never previously offered by commercial microwave software houses.

OSA created the world's fastest multiplexer optimization software in 1984. OSA introduced powerful minimax optimizers into major CAD/CAE products in 1985. OSA embarked on large-scale microwave optimization in 1986. We laid the foundation of multi-circuit ℓ_1 modeling in 1986. The world's first yield-driven design features for major CAD/CAE products were produced in 1987. The world's first links between major linear/nonlinear microwave CAD/CAE products were forged in 1988. Computational enhancements of major CAD/CAE products were effected in 1988.

OSA pioneered a unified theory for frequency domain simulation and sensitivity analysis of linear and nonlinear circuits in 1988. Tests on sensitivity evaluation of nonlinear circuits indicate a 50 fold speed enhancement over the conventional perturbation technique.

In 1988, OSA evolved a robust model parameter extraction approach that simultaneously processes DC and RF measurements. The DC characteristics constrain bias-dependent parameters, thus improving the uniqueness and reliability of modeling from small-signal data. This is embodied into OSA's RoMPE™, the world's first commercial product of its kind.

The feasibility of yield-driven optimization of nonlinear circuits with statistically characterized devices was demonstrated in 1989. A general multi-dimensional normal distribution with correlations is used to describe the large-signal FET device statistics.

HarPE™, the world's first commercial product for harmonic balance driven FET parameter extraction was created in 1989. It features FAST™, a novel technique for high-speed sensitivity estimation. A powerful optimizer simultaneously processes multi-bias, multi-power-input, multi-frequency excitations and multi-harmonic measurements to uniquely reveal the parameters of the intrinsic FET.

From 1985, OSA worked with Raytheon to develop a design methodology for predictable, cost effective microwave CAD with tolerances. Since 1988, OSA has been contributing MIMIC/CAD technology to the Raytheon/Texas Instruments Joint Venture under the U.S. DoD's MIMIC Program, Phase 1. Software architectures for tolerance- and yield- driven design for linear and nonlinear MMIC circuits are under development. Methodologies for wafer/chip yield enhancement are considered.

OSA's specific competence includes the following. Microwave circuit analysis, design and optimization. Statistical estimation of production yield. Robust and statistical active and passive device modeling. Harmonic balance simulation of nonlinear circuits. Automated processing of direct current (DC), radio frequency (RF) and harmonic measurement data. Statistical modeling of devices. Powerful performance and yield driven optimizers. Manufacturing tolerance assignment and cost minimization. Customized gradient and minimax optimizers. Computer optimization of matching networks, filters and multiplexers. Algorithms for automated production alignment and tuning.

Capabilities: Jansen Microwave

Jansen Microwave has won international acclaim for its innovations in and applications of electromagnetic theory, microwave techniques and CAD, microwave measurement techniques, and active and passive integrated circuit modeling. The company has expertise in large-signal

transistor modeling and hybrid-mode analysis of arbitrarily shaped microstrip structures. It has expertise in the characterization of MIC components and the creation of benchmark CAD technology of microwave circuits. It has expertise in thin-film technology.

A variety of software and hardware projects have been undertaken by Jansen Microwave for the microwave and communications industry. Dr. Jansen developed, introduced and tested the first layout-oriented general-purpose microwave CAD package in a West German production-oriented environment. Industrial contacts include Standard Elektrik and Lorenz AG (SEL) in West Germany.

Jansen Microwave is currently undertaking the development of a novel engineering CAD workstation for GaAs MMICs with Plessey Research in England. This workstation project follows completely new design concepts.

Jansen Microwave developed LINMIC+. LINMIC+ can handle a wide class of strip type structures and complex substrate configurations into the high mm-wave region. This includes dispersion, loss and frequency-dependent multistrip and multimode behaviour. Of particular interest is LINMIC+'s analysis and optimization, featuring look-up tables and fast interpolation.

Jansen Microwave has grasped the significance of true integrated circuit design concepts very early in the development of the subject. In the area of GaAs MMICs they have made progress in modeling geometrically complex single and coupled MMIC components. A field theoretic treatment of structures with two metallization levels is invoked from the point of view of simulation and optimization. A hybrid mode dual metal level structure look-up table generator with spatial resolution and high computational efficiency has been developed using the spectral operator expansion technique. The approach is applicable to a wide class of MMIC components having two interconnect metal levels. In particular, Jansen Microwave is addressing the high packing density design problem.

Combined Expertise of OSA and Jansen Microwave

OSA/Jansen Microwave have long and extensive experience in CAE and a high level of technical and mathematical expertise. Both companies have implemented advanced theory and techniques in commercial software. They enjoy a high standard of professional programming. They have experience on many platforms and with several programming languages.

Of utmost importance is the fact that the two companies complement each other expertise, such that the joint expertise covers all the aspects of the planned venture.

Risks

We cannot rule out the possibility that Compact Software, EEsof, Hewlett-Packard or another company will initiate their own new generation of CAE software systems. These companies have financial and, especially EEsof, significant technical capabilities. EEsof's ACADEMY has several features that we plan to address. However, ACADEMY's technical capabilities appear to be limited to those inherent in Touchstone and Libra.

Compact Software, EEsof and Hewlett-Packard obviously have access to test equipment and other relevant hardware as well as established dominance in the market. We feel, however, that these companies are more likely to continue full exploitation of their existing product lines.

Costs

OSA's budget is currently tightly restricted to costs relating to development and support for RoMPE and HarPE. The cost of visiting Germany for short periods of time is quite prohibitive.

Visit 1: Drs. J.W. Bandler, R.M. Biernacki and S.H. Chen

Air Canada or Lufthansa, Toronto-Duesseldorf (Bandler)		$2,353.00
Air Canada or Lufthansa, Toronto-Duesseldorf (Biernacki)		$2,353.00
Air Canada or Lufthansa, Toronto-Duesseldorf (Chen)		$2,353.00
Ground Transportation (includes car rental)		$750.00
Hotel Accommodation (Bandler, 5 nights @ $90.00 per night)		$450.00
Hotel Accommodation (Biernacki, 12 nights @ $90.00 per night)		$1,080.00
Hotel Accommodation (Chen, 12 nights @ $90.00 per night)		$1,080.00
Meals (31 days @ $50.00 per day)		$1,550.00
	COST VISIT 1	$11,969.00

Visit 2: Dr. J.W. Bandler

Air Canada or Lufthansa, Toronto-Duesseldorf		$2,353.00
Ground Transportation (includes car rental)		$250.00
Hotel Accommodation (3 nights @ $90.00 per night)		$270.00
Meals (4 days @ $50.00 per day)		$200.00
	COST VISIT 2	$3,073.00
	TOTAL COST	$15,042.00

Biography: JOHN W. BANDLER

Ph.D., D.Sc.(Eng.), P.Eng., C.Eng., Fellow of the IEEE, Fellow of the IEE (London), Fellow of the Royal Society of Canada

Dr. Bandler is OSA Founder, President and Research Director. He is Professor of Electrical and Computer Engineering and Director of the Simulation Optimization Systems Research Laboratory, McMaster University, Hamilton, Ontario. He has 25 years of professional experience. He is an 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. He is recognized for his pioneering work in optimal design centering, tolerancing, tuning and yield optimization. Dr. Bandler is author of more than 220 publications. He is listed in Who's Who in Engineering, American Men and Women of Science, Who's Who in America and in Canadian Who's Who.

Biography: ROLF H. JANSEN

M.S., Ph.D., Fellow of the IEEE

Dr. Jansen was with RWTH Aachen Microwave Laboratory as a Senior Research Engineer. He directed the thin-film technology of the microwave laboratory. He worked as a research associate for radio communication at Standard Elektrik Lorenz AG (SEL). In 1979, he became Professor of Electrical Engineering at the University of Duisburg. His research topics included electromagnetic theory, microwave techniques and CAD, measurement techniques, and modeling. Dr. Jansen is author of 60 technical papers in the field of microwave CAD and related topics and the recipient of the outstanding publications award in 1979 from the German Society of Radio Engineers. He is cofounder of MCAD Software and Design Corp. He was one of the two Distinguished Microwave Lecturers appointed by the MTT-Society for the year 1987/88.

Biography: RADEK M. BIERNACKI

Ph.D., SMIEEE

Dr. Biernacki obtained his Ph.D. degree from Warsaw Technical University, Warsaw, Poland, in 1976. He is currently a Senior Research Engineer with OSA. He is also Professor (part-time) of Electrical and Computer Engineering, McMaster University, Hamilton. He has 20 years of professional experience. He is an expert in electronic circuits, computer-aided integrated circuit design, circuit theory, fault diagnosis of analog circuits, statistical analysis and in robust control. He is a leader in research and development in OSA. He is author of more than 50 publications.

Biography: SHAO HUA CHEN

Ph.D., MIEEE

Dr. Chen obtained his Ph.D. from McMaster University in 1987. He is currently a Research Engineer with OSA. Dr. Chen has 6 years of professional experience in optimization theory and algorithms, computer-aided circuit design, device modeling, statistical analysis and optimization, computer graphics, user-friendly software engineering and control systems. He is an expert in programming languages. He is the driving force behind OSA's current software innovations. He is author of 20 publications.