LINEAR/NONLINEAR/STATISTICAL MODELING FOR COMPUTER-AIDED ENGINEERING OF MICROWAVE INTEGRATED CIRCUITS

Interim Report

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1. Title of the Project

LINEAR/NONLINEAR/STATISTICAL MODELING FOR COMPUTER-AIDED ENGINEERING OF MICROWAVE INTEGRATED CIRCUITS

2. Project IRAP Code

CAEMICMOD 8-5145-M-15

3. IRAP Funding

June 18, 1989 - April 30, 1990:	$45,000.00
May 1, 1990 - June 30, 1990:	$15,000.00
TOTAL IRAP FUNDING	$60,000.00

4. Project Team

P1.	J.W. Bandler	Research Director
P2.	R.M. Biernacki	Project Consultant
P3.	S.H. Chen	Project Co-Leader
P4.	M.L. Renault	Project Engineer
P5.	Q.J. Zhang	Project Co-Leader

5. Project Objectives

The purpose of the project is to research the area of microwave device modeling including extraction of small-signal and large-signal model parameters in the presence of device statistics. Based on the results of the research develop a new software system for parameter extraction of linear/nonlinear statistical models of microwave devices.

6. Progress to-date

The ultimate goal of the project is to develop a software system for device parameter extraction and modeling including statistics. We have decided that the system will consist of two components: a master program, which we call HarPE-S, organizing and processing statistical information, and a parameter extractor that will be invoked by the master program and run in the background as a batch job as many times as the number of statistical outcomes being processed. As the latter we adapt our existing software HarPE.

Research and development carried out within the framework of the project and their status are outlined in the following subsections.

Research towards Parameter Extraction and Statistical Modeling System

1. Study special aspects of GaAs FET integrated circuit devices related to statistical modeling.

   We have studied the subject of GaAs FET modeling both at the equivalent circuit level and using physical parameters. Currently, we handle the following equivalent circuit FET models: the Curtice and Ettenberg model, the Materka and Kacprzak model and the Raytheon model. A physics-based FET model follows Khatibzadeh and Trew. This is a large-signal analytic model derived from basic semiconductor equations, especially suitable for process-oriented simulation, pre-fabrication design optimization and modeling. User-specified parameters include gate length and width, channel thickness, doping density, dielectric coefficient, saturation velocity, low-field mobility, high-field diffusion coefficient, and gate Schottky voltage.

2. Develop theory for an optimization approach to statistical modeling.

   We have studied various congruential random number generators and means to break sequential correlations. As a result we have selected a generator for further use and implementation within the system. We have studied the suitability of mathematical eigenvalue algorithms for multidimensional distributions. A multidimensional normal random number generator has been developed and tested. We have also investigated consistency between small-signal linear analysis and large-signal harmonic balance simulation for the purpose of parameter extraction from simultaneously processed small- and large-signal data.

3. Implement and test the optimization approach to statistical modeling.

   To be done.

4. Develop a framework for a comprehensive statistical modeling system for monolithic integrated microwave devices.

   We are investigating the ways to employ a data base software system for processing large quantities of measurement data.

5. Apply statistical modeling techniques to such devices reflecting fabrication parameters and response measurements. Test statistical modeling using real measurement data.

   To be done during the testing stage.

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

   We have established contacts and initiated interaction with a few leading companies including Cascade Microtech, TriQuint Semiconductor, and Plessey. We have studied the output data format from the automated wafer probe and measurement system MicroCAT from Cascade Microtech. We have studied the file compatibility aspects with Measurement Data Interchange Format (MDIF) by EEsof and Cascade Microtech.

Modules for Parameter Extraction and Statistical Modeling System

1. User Interface and Command Processor.

   We have completed structural planning of the overall product architecture: global modules, modular interface and interlanguage specifications, and global data structure. We have developed the input file syntax for statistical variables including one-dimensional uniform and normal distributions and multidimensional normal distributions with correlations. In progress is the development of the data syntax for storing and selecting sets of statistical data.

   Design of user interface layout including menus and windows has been completed for the parameter extraction part of the project and a "point-and-click" mouse-driven pull-down menu driver has been implemented. We have developed a version of HarPE suitable for background batch execution.

2. File Parser.

   We have worked on model description and element parameters, preprocessor for file blocks, "include file" handler, comment lines, expression parser and evaluator, and on handling user-defined labels and optimizable variables. The work on other modules of the circuit file parser continues.

3. Editor.

   HarPE's screen editor is adapted.

4. Memory Manager.

   We have implemented data structure definitions: data deposit, retrieval and memory management. Also, a structured description of circuit topology, parameters and variables are incorporated. Work continues on the part of the data structure dealing with statistical information.

5. Circuit Element Library.

   We have developed modules for the library of linear elements allowing the user to create the linear device environment with no restriction on circuit topology. This includes modules handling transmission lines, resistors, capacitors, series and parallel connections of resistors, inductors and capacitors. Also, we have developed a module for handling a generic "black-box" n-terminal element, thus enabling the user to import measurement or simulation data for whole subcircuits.

6. Linear Simulator.

   The general linear simulator has been completed, including programming, testing and debugging. It has the capability of handling arbitrary topology allowing the user to define his own linear device environment reflecting measurement setup, and parasitic and packaging effects. We have worked on general complex, frequency dependent and user-defined terminations, as well as on user-defined reference resistance for S-parameter calculations. We have developed modules for calculation of the stability factor and maximum available gain.

7. Harmonic Balance Simulator.

   HarPE's harmonic balance simulator has been adapted with modifications of the convergence criteria for the nonlinear solver.

8. Optimizers.

   In addition to HarPE's ℓ_1 and ℓ_2 optimizers we incorporated a state-of-the-art minimax optimizer.

9. Library of Parasitic and Packaging Models.

   Specialized linear simulators for extrinsic device parasitic models have been developed. In addition to HarPE's Extrinsic1 and Extrinsic2 we have developed two new specialized simulators. All these simulators are optimized for speed, especially important for statistical modeling. Also, all of these parasitic models have been implemented in the form of connectable elements within the general circuit topology, which together with the transmission lines provides the means to model packaging effects.

10. Library of Intrinsic Device Models.

    In addition to HarPE's FET models (the Curtice and Ettenberg model, the Materka and Kacprzak model, and the Raytheon model) we have implemented the Khatibzadeh and Trew physics-based FET model. Also, the Gummel and Poon models of NPN and PNP bipolar transistors have been added. In progress is the development of semiconductor diode models.

11. Drivers for Multi-Circuit Simulation and Error Functions for Modeling.

    HarPE's drivers are adapted.

12. Statistical Processor of Extracted Parameters.

    The driver processing statistical data for histograms and scattering diagrams is almost finished. Also, we have developed a module for statistical estimates of the means, standard deviations and correlations from a sample of outcomes.

13. Interface to Measurement Equipment.

    We have implemented data entry compatibility with MicroCAT by Cascade MicroTech and MDIF by Cascade MicroTech and EEsof. Measurement data files in these formats are accepted without any modification.

14. Output Data Processor.

    We have developed postprocessing capability allowing the user to define arbitrary response functions for both graphical and numerical output. The work on processing the statistical data for output is to be done.

15. Graphics Interface.

We have implemented graphics modules for plotting histograms and scattering diagrams to graphically illustrate statistical distributions of user selected parameters. We have implemented graphics hardcopy capabilities and investigated the compatibility of graphics libraries for Apollo, Hewlett-Packard and Sun workstations.

We have expanded HarPE's graphical display and numerical output to include conventional small-signal parameters (such as the transconductance g_m) analytically linearized from the nonlinear (large-signal) model at selected bias points. We added a graphical display of parameter sensitivities and made some other improvements on graphics, such as VG-ID curves, and Smith chart and polar plots on a single display.

7. Delays and Anticipated Difficulties

The project has been carried out to date according to the planned schedule. Delays have not been experienced so far. We do not anticipate insurmountable obstacles for the remainder of the project.

8. Impact of Support

OSA has the technical expertise for the proposed project. IRAP funding helps the project to be carried out. Successful completion of the project will substantially contribute to profitability and development of OSA. Thus, the expected growth of the company will generate jobs in Canada, for example, to create a technical support department for customers of OSA products. Also, the algorithms and software modules will be extremely valuable in future products, thus reducing their development cost.

Upon completion 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.