FINAL REPORT TO NSERC
on
Industrial Research Fellowship
for Dr. Qian Cai
(File IRF 800)

OSA-96-OS-1-R

February 28, 1996

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by
Optimization Systems Associates Inc.
P.O. Box 8083, Dundas, Ontario, Canada L9H 5E7
Tel 905 628 8228 Fax 905 628 8225

Duration of Support and Location of Tenure

In October 1993, Dr. Qian Cai was granted by NSERC an Industrial Research Fellowship to work on research and development of new techniques and approaches for device modelling, including statistical modelling and thermal effect modelling, as proposed by Optimization Systems Associates Inc. (OSA). The location of tenure was OSA's head office at 163 Watson's Lane, Dundas, Ontario. He joined OSA on December 1, 1993, and was with OSA until September 30, 1995. He left OSA on his own initiative and joined a US software company: Compact Software, Inc.

Work Done

The project concentrated on research and development of active device modelling, including statistical modelling and parameter extraction. This included development and testing new algorithms, device models and corresponding software modules. The software modules developed within this project were incorporated into our software systems HarPE™ and OSA90/hope™.

Specifically, the Fellow's research addressed new techniques for statistical modelling, accurate and robust physics-based statistical GaAs MESFET models, HEMT models, thermal effects in HBTs (heterojunction bipolar transistors), and physics-based cost-driven design of nonlinear circuits.

As a result, the following device models were developed:

HBT	heterojunction bipolar transistor model
HEMTAC	advanced Curtice HEMT model
HEMTC	Curtice HEMT model
HEMTG1	high order beta degradation HEMT model
HEMTG2	double parabolic HEMT model

These models are now included in the libraries of built-in device models in both OSA90/hope and HarPE.

The Fellow investigated techniques for statistical device modelling including indirect and direct methods. A novel approach to statistical modelling using cumulative probability distribution fitting and histogram fitting were developed. This new approach is based on a solid mathematical foundation and proves to be more reliable and robust than the previously existing methods. This new technique has been implemented into OSA's powerful device modelling software system HarPE.

Accurate statistical device models are very important to the success of yield-driven circuit design, particularly for the design of monolithic microwave integrated circuits. The Fellow has further investigated a robust physics-oriented statistical GaAs MESFET model which integrates the Khatibzadeh and Trew model for DC simulation with the Ladbrooke formulas for small-signal analysis.

Thermal effect modelling in microwave transistors is a significant new subject. This is particularly important for modelling HBTs. The Fellow investigated a new simulation technique where some circuit parameters, such as temperature, depend on the resulting solution of circuit equations. As a result a new HBT model has been developed. The model accounts for self-heating of the device. The dissipated power affects the operating temperature, which in turn affects the solution, including the power. The model can be used for DC, small-signal and large-signal simulation and optimization.

According to the increasing demands from industry for HEMT models the Fellow has researched various methods for HEMT modelling and implemented four published HEMT models in HarPE and OSA90/hope. The models were thoroughly tested.

The Fellow has researched techniques of analytical parameter extraction and implemented in HarPE a method of extracting the extrinsic parameters analytically from cold measurements (unbiased and pinched-off measurements) without optimization. It provides a fast way to determine the parasitic elements. This approach is very useful in two-stage parameter extraction of MESFET and HEMT models. The extrinsic parameters are first extracted analytically from cold measurements and then the intrinsic parameters are extracted from the "hot" measurements using optimization while keeping the extrinsic parameters fixed.

In the area of physics based large-signal device statistical modelling the Fellow has implemented a new analytic physics-based model for fast large-signal simulation and optimization. Cost-driven physics-based large-signal simultaneous device and circuit design where a cost function is minimized while maintaining specified yield has been investigated.

The Fellow has also participated in research on seamlessly integrating electromagnetic simulations into harmonic balance simulation and optimization of nonlinear circuits, mixed-domain multi-simulator statistical parameter extraction and yield-driven design and heterogeneous parallel yield-driven electromagnetic CAD.

Benefits

We are fully satisfied with the Fellow's work. It helped us to develop new techniques for statistical modelling and extend our built-in device library with a number of new models. The Fellow's work helped us to preserve and strengthen our leading edge in the area of active device modelling, including statistical modelling and parameter extraction.

OSA is not only committed to state of the art research, but also makes every effort to quickly incorporate new techniques into its commercial products. Therefore, commercialization of the research conducted within this project has already been done: the techniques, algorithms and models resulting from the Fellow's work are already implemented in the current releases of HarPE and OSA90/hope. This is a significant achievement.

There is no doubt that the Fellowship assisted OSA in developing an improved capability in research and development. It also provided the Fellow with an excellent opportunity to gain experience in research and development in an industrial environment where projects are driven by customer demands and have to be carried out in a timely fashion. Overall, it was very beneficial to his professional development.

Dr. Cai contributed to one journal publication [1], six conference publications [2-7], and numerous internal publications [8-32], including manuals [8-10, 24, 25].

List of Publications

Refereed Journal Papers

1. J.W. Bandler, R.M. Biernacki, Q. Cai and S.H. Chen, "Device statistical modelling and verification," *Microwave Engineering Europe*, May 1995, pp. 35–41.

Refereed Conference Contributions

2. J.W. Bandler, R.M. Biernacki, Q. Cai and S.H. Chen, "Cost-driven physics-based large-signal simultaneous device and circuit design," *IEEE Int. Microwave Symp. Digest* (Orlando, FL), 1995, pp. 1443–1446.

3. J.W. Bandler, R.M. Biernacki, Q. Cai, S.H. Chen, P.A. Grobelny and D.G. Swanson, Jr., "Heterogeneous parallel yield-driven electromagnetic CAD," *IEEE Int. Microwave Symp. Digest* (Orlando, FL), 1995, pp. 1085–1088.

4. J.W. Bandler, R.M. Biernacki, Q. Cai, S.H. Chen and P.A. Grobelny, "Integrated harmonic balance and electromagnetic optimization with Geometry Capture," *IEEE Int. Microwave Symp. Digest* (Orlando, FL), 1995, pp. 793–796.

5. J.W. Bandler, R.M. Biernacki, Q. Cai and S.H. Chen, "Compression analysis of a high power BJT amplifier," *Third Int. Workshop on Integrated Nonlinear Microwave and Millimeterwave Circuits INMMC'94, Digest* (Duisburg, Germany), 1994, pp. 173–178.

6. J.W. Bandler, R.M. Biernacki, Q. Cai and S.H. Chen, "A novel approach to statistical modelling using cumulative probability distribution fitting," *IEEE Int. Microwave Symp. Digest* (San Diego, CA), 1994, pp. 385–388.

7. J.W. Bandler, R.M. Biernacki, Q. Cai and S.H. Chen, "A robust physics-oriented statistical GaAs MESFET model," *Proc. European Gallium Arsenide Applications Symposium* (Turin, Italy), 1994, pp. 173–176.

OSA Internal Reports and Publications

8. "HarPE™ User's Manual, Version 2.0," Optimization Systems Associates Inc., Dundas, Ontario, Canada, August 1995.

9. "HarPE™ as a Child of OSA90/hope™, Version 2.0," Optimization Systems Associates Inc., Dundas, Ontario, Canada, August 1995.

10. "HarPE™ Applications Illustrated, Version 2.0," Optimization Systems Associates Inc., Dundas, Ontario, Canada, August 1995.

11. "Direct extrinsic parameter extraction from cold measurements," OSA-95-OS-12-R, September 6, 1995.

12. J.W. Bandler, R.M. Biernacki, Q. Cai, S.H. Chen and P.A. Grobelny, "Integrated harmonic balance and electromagnetic optimization with geometry capture," OSA-95-OS-8-V, May 10, 1995.

13. J.W. Bandler, R.M. Biernacki, Q. Cai and S.H. Chen, "Cost-driven physics-based large-signal simultaneous device and circuit design," OSA-95-OS-7-V, May 10, 1995.

14. J.W. Bandler, R.M. Biernacki, Q. Cai, S.H. Chen and P.A. Grobelny, "Automated EM optimization of linear and nonlinear circuits with geometry capture for arbitrary planar structures," OSA-95-OS-4-R, February 28, 1995.

15. J.W. Bandler, R.M. Biernacki, Q. Cai, S.H. Chen and P.A. Grobelny, "Electromagnetic design of microwave circuits integrated with spice device models," OSA-95-OS-3-R, February 8, 1995.

16. "Implementation of an HBT model," OSA-94-OS-31-R, November 2, 1994.

17. J.W. Bandler, R.M. Biernacki, Q. Cai, S.H. Chen, P.A. Grobelny and D.G. Swanson, Jr., "Heterogeneous parallel yield-driven electromagnetic CAD," OSA-94-OS-29-R, October 31, 1994.

18. J.W. Bandler, R.M. Biernacki, Q. Cai, S.H. Chen and P.A. Grobelny, "Mixed-domain multi-simulator statistical parameter extraction and yield-driven design," OSA-94-OS-28-R, October 31, 1994.

19. J.W. Bandler, R.M. Biernacki, Q. Cai, S.H. Chen and P.A. Grobelny, "Integrated harmonic balance and electromagnetic optimization with Geometry Capture," OSA-94-OS-27-R, October 31, 1994.

20. J.W. Bandler, R.M. Biernacki, Q. Cai and S.H. Chen, "Cost-driven physics-based large-signal simultaneous device and circuit design," OSA-94-OS-25-R, October 31, 1994.

21. J.W. Bandler, R.M. Biernacki, Q. Cai and S.H. Chen, "Compression analysis of a high power BJT amplifier," OSA-94-OS-24-V, September 12, 1994.

22. J.W. Bandler, R.M. Biernacki, Q. Cai and S.H. Chen, "Compression analysis of a high power BJT amplifier," OSA-94-OS-5-R, Revised July 26, 1994.

23. "Implementation of HEMT models and comparison with the measured data from Motorola," OSA-94-OS-19-R, July 19, 1994.

24. "OSA90/hope™ User's Manual, Version 3.0," Optimization Systems Associates Inc., Dundas, Ontario, Canada, July 1994.

25. "HarPE™ User's Manual, Version 1.8," Optimization Systems Associates Inc., Dundas, Ontario, Canada, July 1994.

26. J.W. Bandler, R.M. Biernacki, Q. Cai and S.H. Chen, "A novel approach to statistical modelling using cumulative probability distribution fitting," Report OSA-94-OS-13-V, April 25, 1994.

27. J.W. Bandler, R.M. Biernacki, Q. Cai and S.H. Chen, "A robust physics-oriented statistical GaAs MESFET Model," Report OSA-94-OS-11-V, April 20, 1994.

28. J.W. Bandler, R.M. Biernacki, Q. Cai and S.H. Chen, "Optimization of a class b frequency doubler enhanced by electromagnetic simulation," Report OSA-94-OS-6-R, March 29, 1994.

29. J.W. Bandler, R.M. Biernacki, Q. Cai and S.H. Chen, "Compression analysis of a high power BJT amplifier," Report OSA-94-OS-5-R, March 28, 1994.

30. "Nonlinear analysis of a class b frequency doubler", Report OSA-94-OS-4-R, March 23, 1994.

31. J.W. Bandler, R.M. Biernacki, Q. Cai and S.H. Chen, "A robust physics-oriented statistical GaAs MESFET model," Report OSA-93-OS-16-R, Revised February 22, 1994.

32. J.W. Bandler, R.M. Biernacki, Q. Cai and S.H. Chen, "A novel approach to statistical modelling using cumulative probability distribution fitting," Report OSA-93-OS-19-R, Revised February 8, 1994.