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

OSA-94-OS-3-R

February 17, 1994

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by
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Duration of Support and Location of Tenure

In June 1991, Dr. Shen Ye was granted by NSERC an Industrial Research Fellowship to work on research and development of numerical models for passive microwave integrated circuit components as proposed by Optimization Systems Associates Inc. (OSA). He joined OSA on July 1, 1991, and was with OSA until March 12, 1993, when, on his own initiative, he decided to join Com Dev Ltd. of Cambridge, Ontario. The location of tenure was OSA's head office at 163 Watson's Lane, Dundas, Ontario.

Work Done

The project concentrated on research and development of numerical models (or simulation) of a wide variety of passive microwave integrated circuit components. This included development and testing software modules implementing the models. The software modules developed within this project were incorporated into our software systems HarPE™, OSA90/hope™ and Empipe™.

Specifically, the Fellow's research addressed efficient, robust, accurate and reliable numerical modeling of microstrip structures, lossy and dispersive, including: (1) discontinuities: steps, bends, open and short-circuited stubs, tee and cross junctions, microstrip gaps, slits, (2) transmission lines, coupled transmission lines, (3) Lange couplers; and (4) interdigital capacitors.

As a result, the following component models were created:

MAGAP	microstrip asymmetric gap
MBEND1	microstrip 90 degree bend
MBEND2	microstrip chamfered 90 degree bend
MBEND3	microstrip optimally-chamfered 90 degree bend
MBEND3A	microstrip optimally-chamfered 90 degree bend
MCROSS	microstrip cross-junction
MGAP	microstrip symmetric gap
MLANG4	four-finger microstrip Lange coupler
MLANG6	six-finger microstrip Lange coupler
MLANG8	eight-finger microstrip Lange coupler
MOPEN	microstrip open stub
MSCL	two-conductor symmetrical coupled microstrip lines
MSHORT	microstrip short stub
MSL	microstrip line
MSLIT	narrow transverse slit in microstrip
MSTEP	microstrip step
MSUB	microstrip substrate definition
MTEE	microstrip T-junction

These models are now included in the libraries of built-in components in both OSA90/hope and HarPE. All models use material and geometrical parameters as inputs. Simulation of individual components provides the admittance matrices which are automatically incorporated into the overall circuit simulation for calculating various circuit responses such as *S* parameters or power. The aforementioned models are so called analytical models, that is, they are based on different approximations and partially heuristic formulas devised to match experimental results. The formulas were searched for and implemented, with some modifications, by the Fellow.

Analytical models are faster, but may not be accurate enough, especially at higher frequencies. As a more costly but more accurate alternative, numerical models were considered. To this end the Fellow worked on an interface between OSA90/hope and a state-of-the-art electromagnetic simulator *em* from Sonnet Software, Inc. The method of modified moments is utilized to solve the field equations for predominantly planar structures. Accuracy of the models is increased at microwave frequencies, extending their validity to millimetre-wave frequencies. At first, the simulator *em* was used for reference, testing and verification of analytical models developed by the Fellow. Satisfactory results were obtained.

Of particular interest was direct circuit-level optimization carried out by OSA90/hope with microstrip components simulated by *em*. To achieve it, the Fellow developed techniques for geometrical interpolation, parameterization and database management to handle the results of *em* simulations. Research assisted by Dr. Ye led to breakthrough results in electromagnetic optimization. For the first time, we were able to optimize microwave and millimetre-wave filters with microstrip components of those filters simulated by an electromagnetic simulator. The Fellow significantly contributed to the development of Empipe, a new product offered by OSA to RF and microwave designers. In particular he developed the following models:

EM_AGAP	microstrip asymmetrical gap
EM_APAS	microstrip all-pass filter structure
EM_BEND1	microstrip bend
EM_BEND2	mitered microstrip bend
EM_CROSS	microstrip cross junction
EM_DCAP1	microstrip interdigital capacitor model 1
EM_DCAP2	microstrip interdigital capacitor model 2
EM_DPCAP	microstrip double patch capacitor
EM_DSTB1	symmetrical microstrip double stub
EM_DSTB2	asymmetrical microstrip double stub
EM_FDST1	symmetrical microstrip folded double stub
EM_FDST2	asymmetrical microstrip folded double stub
EM_GAP	microstrip symmetrical gap
EM_MSL	microstrip line
EM_ODPC1	microstrip overlay double patch capacitor 1
EM_ODPC2	microstrip overlay double patch capacitor 2
EM_ODPC3	microstrip overlay double patch capacitor 3
EM_ODPC4	microstrip overlay double patch capacitor 4
EM_ODPC5	microstrip overlay double patch capacitor 5
EM_ODPC6	microstrip overlay double patch capacitor 6
EM_OPEN	microstrip open stub
EM_RECT	microstrip rectangular structure
EM_SPIND	microstrip spiral inductor
EM_STEP	microstrip step junction
EM_TEE	microstrip T-junction

These models are parameterized microstrip structures that are recognized by Empipe. They are simulated by *em* and can be incorporated into the overall circuit description for simulation and

optimization like any other built-in library components. A sophisticated mechanism of database management of already simulated structures was also developed by the Fellow. This is crucial for eliminating unnecessary duplicate simulations by *em*, in particular during optimization.

In addition to parameterized microstrip structures the Fellow's work established the means for handling arbitrarily shaped microstrip structures, simulated by *em* and incorporated into OSA90/hope's overall circuit-level simulation.

Benefits

We are more than satisfied with the Fellow's work. It helped us to create a comprehensive library of built-in microstrip component models and opened up an entirely new avenue in electromagnetic design optimization.

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, OSA90/hope and Empipe. This is a very 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. Ye contributed to three journal publications [1-3], three conference publications [4-6], and numerous internal publications [7-26], including manuals [12,13,15,24].

List of Publications

Refereed Journal Papers

1. 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," *IEEE Trans. Microwave Theory Tech.*, vol. 40, 1992, pp. 1374-1400.

2. J.W. Bandler, R.M. Biernacki, S.H. Chen, P.A. Grobelny and S. Ye, "Yield-driven electromagnetic optimization via multilevel multidimensional models," *IEEE Trans. Microwave Theory Tech.*, vol. 41, 1993, pp. 2269-2278.

3. J.W. Bandler, R.M. Biernacki, S.H. Chen, D.G. Swanson, Jr. and S. Ye, "Microstrip filter design using direct EM field simulation," *IEEE Trans. Microwave Theory Tech.*, vol. 42, July 1994.

Refereed Conference Contributions

4. J.W. Bandler, S. Ye, Q. Cai, R.M. Biernacki and S.H. Chen, "Predictable yield-driven circuit optimization," *IEEE MTT-S Int. Microwave Symp. Digest* (Albuquerque, NM), 1992, pp. 837-840.

5. J.W. Bandler, S. Ye, R.M. Biernacki, S.H. Chen and D.G. Swanson, Jr., "Minimax microstrip filter design using direct EM field simulation," *IEEE MTT-S Int. Microwave Symp. Digest* (Atlanta, GA), 1993, pp. 889-892.

6. J.W. Bandler, R.M. Biernacki, S.H. Chen, S. Ye and P.A. Grobelny, "Multilevel multidimensional quadratic modeling for yield-driven electromagnetic optimization," *IEEE MTT-S Int. Microwave Symp. Digest* (Atlanta, GA), 1993, pp. 1017-1020.

OSA Internal Reports and Publications

7. J.W. Bandler, S. Ye, Q. Cai, R.M. Biernacki and S.H. Chen, "Predictable yield-driven circuit optimization", OSA-91-MT-6-R, December 2, 1991, Revised February 17, 1992.

8. J.W. Bandler, R.M. Biernacki, Q. Cai, S.H. Chen and S. Ye, "PhorsFET: A new physics-oriented statistical GaAs MESFET model", OSA-91-MT-5-R, December 2, 1991.

9. J.W. Bandler, R.M. Biernacki, Q. Cai, S.H. Chen and S. Ye, "Predictable yield-driven circuit design exploiting a novel statistical GaAs MESFET model," Report OSA-92-MT-2-R, March 25, 1992.

10. "Interconnecting the electromagnetic field simulator Em with OSA90/hope," Report OSA-92-OS-3-R, April 7, 1992.

11. "Statistical physics-based modeling and yield-driven design of microwave circuits," Report OSA-92-OS-4-V, April 28, 1992.

12. "OSA90/hope™ User's Manual, Version 2.0," Optimization Systems Associates Inc., Dundas, Ontario, Canada, May 25, 1992.

13. "HarPE™ User's Manual, Version 1.6," Optimization Systems Associates Inc., Dundas, Ontario, Canada, July 1992.

14. J.W. Bandler, S. Ye, Q. Cai, R.M. Biernacki and S.H. Chen, "Predictable yield-driven circuit optimization," Report OSA-92-MT-10-V, August 12, 1992.

15. "Empipe™ Installation Instructions and User's Guide," Report OSA-92-OS-11-R, September 2, 1992.

16. "Empipe™ connection between OSA90/hope™ and *em*™," Report OSA-92-OS-13-V, October 1, 1992.

17. J.W. Bandler, S. Ye, R.M. Biernacki and S.H. Chen, "Microstrip circuit simulation and optimization using electromagnetic field simulator," Report OSA-92-OS-14-R, November 11, 1992.

18. J.W. Bandler, S. Ye, R.M. Biernacki, S.H. Chen and D.G. Swanson, Jr., "Minimax microstrip filter design using direct EM field simulation," Report OSA-92-MT-16-R, November 25, 1992, Revised February 19, 1993.

19. J.W. Bandler, R.M. Biernacki, S.H. Chen, S. Ye and P.A. Grobelny, "Multilevel multidimensional quadratic modeling for yield-driven electromagnetic optimization," Report OSA-92-MT-17-R, November 28, 1992, Revised February 23, 1993.

20. "Empipe Version 1.0 Technical Brief," December 15, 1992.

21. S. Ye, "Design of a double patch microstrip filter," Report OSA-92-OS-18-R, December 4, 1992.

22. J.W. Bandler, R.M. Biernacki, S.H. Chen, D.G. Swanson, Jr. and S. Ye, "Microstrip filter design using direct EM field simulation," Report OSA-93-MT-3-R, March 25, 1993, Revised July 6, 1993, Second Revision January 10, 1994.

23. J.W. Bandler, R.M. Biernacki, S.H. Chen, P.A. Grobelny and S. Ye, "Yield-driven electromagnetic optimization via multilevel multidimensional models," Report OSA-93-MT-4-R, March 26, 1993, Revised June 11, 1993.

24. "Empipe™ User's Manual, Version 1.1," Optimization Systems Associates Inc., Dundas, Ontario, Canada, May 1993.

25. J.W. Bandler, S. Ye, R.M. Biernacki, S.H. Chen and D.G. Swanson, Jr., "Minimax microstrip filter design using direct EM field simulation," Report OSA-93-MT-8-V, June 10, 1993.

26. J.W. Bandler, R.M. Biernacki, S.H. Chen, S. Ye and P.A. Grobelny, "Multilevel multidimensional quadratic modeling for yield-driven electromagnetic optimization," Report OSA-93-MT-9-V, June 28, 1993.