FINAL REPORT TO NSERC
on
Industrial Research Fellowship
for Dr. Dževat Omeragić
PIN #177617

OSA-97-OS-15-R

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by

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Duration of Support and Location of Tenure

In November 1996, Dr. Dževat Omeragić was granted by NSERC an Industrial Research Fellowship to work on research and development of new techniques and approaches for advanced electromagnetic (EM) optimization, 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 February 1, 1997, and was with OSA until April 18, 1997. He left OSA on his own initiative and joined a US company: Schlumberger-Houston Product Center, Electrical and Nuclear Department, located in Houston, Texas.

Work Done

The planned project concentrated on research and development of advanced techniques for design optimization of microwave circuits utilizing the most accurate techniques for circuit simulation which are based on solving numerically the EM field problems. This was to include development and testing of new algorithms, and to be followed by development of corresponding software modules. The short duration of the Fellow tenure allowed only preliminary study to be completed.

Specifically, the Fellow's research addressed: (1) testing several components of the mode-matching (MM) based library RWGMM [1] integrated with our OSA90/hope CAD software system [2], (2) study of decomposition of 3D structures using a finite-element solver Maxwell Eminence [3], and (3) initial issues related to optimization-oriented intelligent mesh generation using Maxwell Eminence. The following briefly describes his findings.

Testing the Mode-Matching (MM) Based Library RWGMM

A number of components from the MM based library RWGMM (developed by F. Arndt, University of Bremen, Germany) can be directly called from OSA90/hope. Results of simulation of individual components can be combined for overall circuit analysis and optimization. Examples published in a recent paper by Arndt *et al.* [4] were tried. This set of examples, extended for direct optimization, was augmented to handle multi-section waveguide transformers from classic Bandler's paper [5]. In most of the cases the circuits were successfully optimized.

Examples included:

(a) four resonator H-plane iris filter

(b) two and three-section waveguide transformer WR75 to WG 0.75"x0.1875"

(c) two, three and seven-section waveguide transformers [5]

(d) five resonator symmetrical WR62 filter [4, Fig. 4]

(e) multiaperture iris WR62 filter [4, Fig. 5]

(f) circular waveguide filter [4, Fig. 6]

(g) two section waveguide transformer, WR62 to WR42, from [4, Fig.7]

(h) five resonator asymmetrical WR62 filter [4, Fig. 10]

(i) six resonator asymmetrical WR62 filter [4, Fig. 11]

They combined the following elements from the library:

single rectangular waveguide iris (RWGMM code 1, RWGIR1)

quadruple rectangular waveguide iris (RWGMM code 4, RWGIR4)

single rectangular waveguide step (RWGMM code 9, RWGST1)

empty rectangular waveguide (RWGMM code 19, RWGEMP)

circular waveguide iris (RWGMM code 24, CIRIR)

empty circular waveguide (RWGMM code 29, CIREMP)

circular iris with centered rectangular and circular ports (RWGMM code 34, RCC_IR)

Some difficulties were experienced with problem (f) and element 34. Structures (d), (e) and (i) did not give the same responses as reported in [4].

Decomposition of 3D Structures Using Maxwell Eminence Finite-Element Solver

In order to efficiently carry out EM optimization using our software system Empipe3D [2], the Fellow investigated decomposition of some more complex 3D structures. Decomposed blocks were analyzed individually using Maxwell Eminence and treated as circuit elements in OSA90/hope. Higher order modes were included in a manner similar to the MM technique. De-embedding of S parameters was used where appropriate.

The approach was tested on a simple corrugated waveguide structure, suggested by Weisshaar *et al.* [6] and shown in Fig. 1(a). The geometry is decomposed into two inductive irises, each simulated separately. The equivalent circuit model is presented in Fig. 1(b). A two-port iris is modelled as a multiport element, where each port corresponds to one mode. Since higher order (evanescent) modes have to be taken into account, the ports of the substructure are defined close to the discontinuity and appropriately defined in the EM field solver. If ports are far from the discontinuity, the S parameters corresponding to evanescent modes have small magnitudes and are inaccurate (since the convergence criterion is defined in terms of allowable $|\Delta S|$ in two subsequent steps). It is also important in analyzing higher order modes to model the ports in their entirety, i.e., not to use any symmetry (perfect electric or magnetic walls). Fig. 2 depicts the responses when (a) only the dominant mode is considered, and (b) using four interacting modes (TE_{m0}). It is important to note that the four modes are extracted from first 12 modes. The simulation results for the decomposed structure are in a very good agreement with responses when the structure was modelled in its entirety.

Initial implementation work (programming) was carried out to capture the desired S parameters for higher-order modes from Maxwell Eminence output data.

The Fellow discovered that Maxwell Eminence did not properly perform de-embedding of the non-propagating (evanescent) modes. He also investigated calculation of the modal waveguide impedances, needed for denormalization of the S matrix. By comparing the results with analytically known data for rectangular homogeneous waveguides he noticed that while the dominant mode impedances computed using Z_{pv} algorithm had high accuracy there were significant differences for higher-order modes between computed Z_{pv}, Z_{pi} and the theoretical values.

Intelligent Mesh Generation for Efficient EM Optimization

Initial study of potentially very useful intelligent exploitation of meshing and mesh control in EM simulations for efficient optimization of 3D structures was carried out. When a finite-element based simulator is run in the optimization loop, only one adaptive solution (full mesh generation) should be needed for the entire optimization process. This may be achieved by automatic parameterization of the mesh, and generation of topologically similar meshes in each subsequent step. Within the current "encapsulation" method, the latter will have to be performed externally to the EM simulator. The Fellow identified the Maxwell Eminence data files that would be involved in such an external mesh generation and proposed how to proceed.

<u>Benefits</u>

We are fully satisfied with Dr. Omeragić's work. We only wish he could have stayed with us to continue his excellent work.

Further research is needed to complete the project planned for the Fellow. Commercialization of the results should then follow. 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.

The Fellowship assisted OSA in opening up new avenues in research and development, particularly related to computational electromagnetics, the area of Dr. Omeragić's expertise. 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. Although short, it was surely beneficial to his professional development.

Dr. Omeragić contributed to one journal publication [7], one conference publications [8], and a few internal publications [9-12]. The paper [7] and the first version of [8] were prepared before he joined OSA. The digest version of [8] (contained in [9]) and all other items were done afterwards.

References

[1] *RWGMM*, Microwave Department, University of Bremen, P.O. Box 330 440, Kufsteiner Str., NW1, D-28334 Bremen, Germany, 1996.

[2] *OSA90/hope*™, *Empipe*™ and *Empipe3D*™, Optimization Systems Associates Inc., P.O. Box 8083, Dundas, Ontario, Canada L9H 5E7, 1996.

[3] *Maxwell*™ *Eminence*, Ansoft Corporation, Four Station Square, Suite 660, Pittsburgh, PA 15219.

[4] F. Arndt, T. Sieverding, T. Wolf and U. Papziner, "Optimization-oriented design of rectangular and circular waveguide components using efficient mode-matching simulators in commercial circuit CAD tools," *Int. J. Microwave and Millimeter-Wave Computer-Aided Engineering*, vol. 7, 1997, pp. 37-51.

[5] J.W. Bandler, "Computer optimization of inhomogeneous waveguide transformers," *IEEE Trans. Microwave Theory Tech.*, vol. MTT-17, 1969, pp. 563-571.

[6] A. Weisshaar, M. Mongiardo, A. Tripathi and V. Tripathi, "CAD-oriented fullwave equivalent circuit models for waveguide components and circuits," *IEEE Trans. Microwave Theory Tech.*, vol. 44, 1996, pp. 2564-2570.

List of Publications

Refereed Journal Paper

[7] J.W. Bandler, R.M. Biernacki, S.H. Chen, L.W. Hendrick and D. Omeragić, "Electromagnetic optimization of 3D structures," *IEEE Trans. Microwave Theory Tech.*, vol. 45, 1997, pp. 770-779.

Refereed Conference Contribution

[8] J.W. Bandler, R.M. Biernacki, S.H. Chen and D. Omeragić, "Space mapping optimization of waveguide filters using finite element and mode-matching electromagnetic simulators," *IEEE MTT-S Int. Microwave Symp.* (Denver, CO), 1997, pp. 635-638.

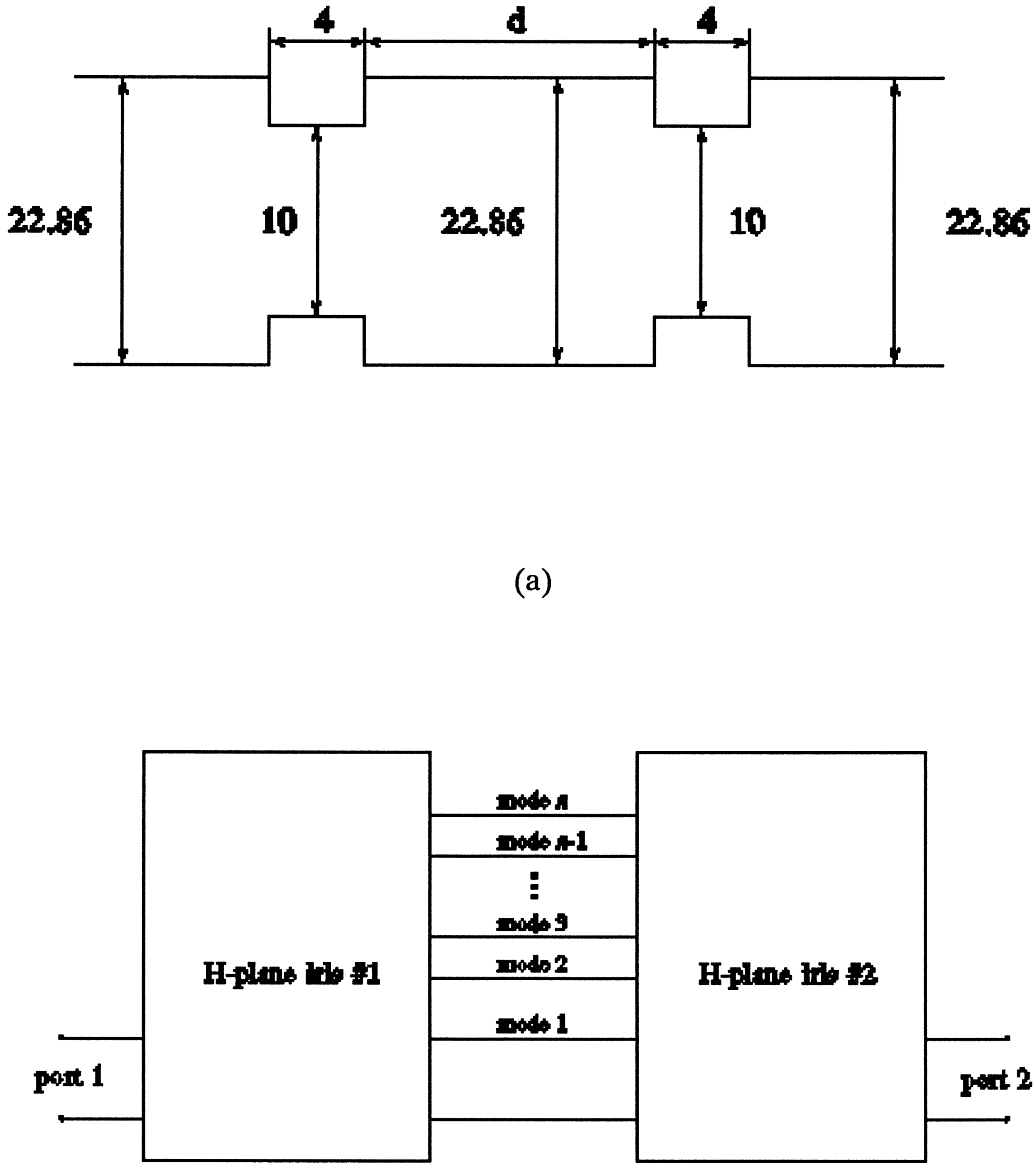
OSA Internal Reports

[9] J.W. Bandler, R.M. Biernacki, S.H. Chen and D. Omeragić, "Space mapping optimization of waveguide filters using finite element and mode-matching electromagnetic simulators," OSA-96-MT-23-RR, November 30, 1996, revised February 26, 1997.

[10] J.W. Bandler, R.M. Biernacki, S.H. Chen and D. Omeragić, "Space mapping optimization of waveguide filters using finite element and mode-matching electromagnetic simulators," OSA-97-OS-3-V, March 11, 1997.

[11] J.W. Bandler, R.M. Biernacki, S.H. Chen and D. Omeragić, "Space mapping optimization of waveguide filters using finite element and mode-matching electromagnetic simulators," OSA-97-MT-7-R, March 21, 1997.

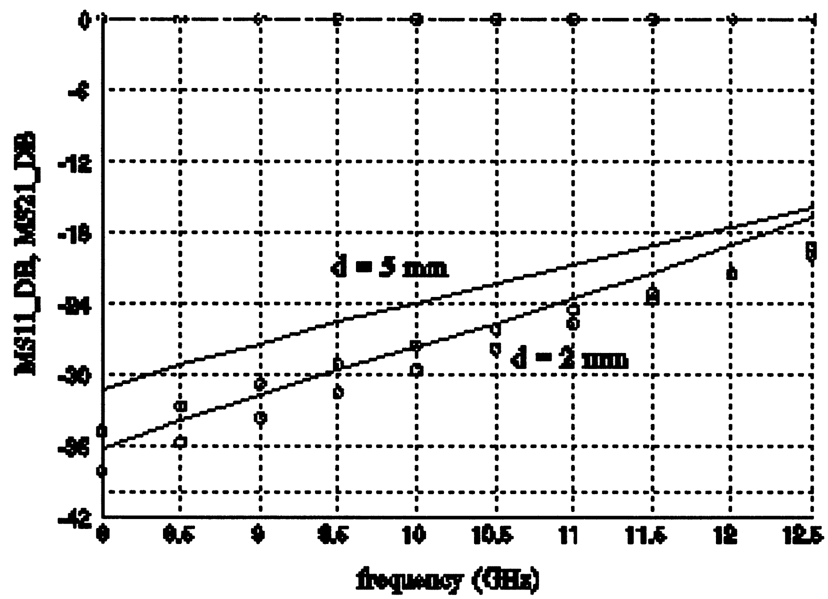
[12] J.W. Bandler, R.M. Biernacki, S.H. Chen and D. Omeragić, "Space mapping optimization of waveguide filters using finite element and mode-matching electromagnetic simulators," OSA-97-MT-10-V, June 4, 1997.



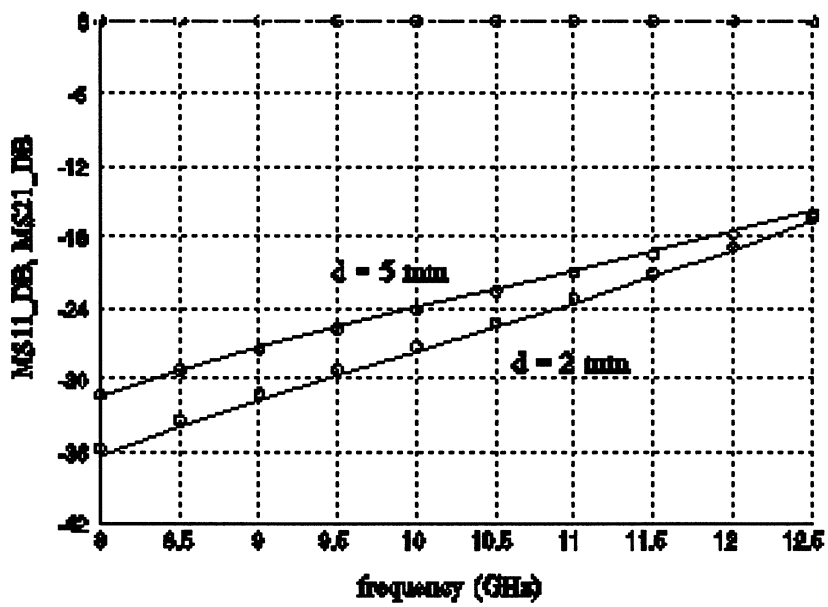
(a)

(b)

Fig. 1. Analyzed structure of two cascaded H-plane irises separated by distance *d*: (a) geometry (dimensions are in mm); (b) equivalent circuit of the decomposed structure.



(a)



(b)

Fig. 2. Two cascaded H-plane irises. Responses for two different separation distances *d* for the structure simulated in its entirety (lines) and when it is decomposed (circles). (a) only the dominant mode is considered; (b) four interacting modes are included. *S* parameters are de-embedded from ports located 3 mm from discontinuity.