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13. ABSTRACT (Maximum 200 words)

This contract studied 5 principal topics: (1) Full wave analysis of microstrip crossovers, (2) Dynamic and quasi-dynamic analysis of printed circuits, (3) User-friendly computer programs for multiconductor transmission lines, (4) Theory of printed circuits for multilayered dielectrics, and (5) Full-wave analysis of transmission lines in a layered uniaxial medium.

14. SUBJECT TERMS

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FINAL REPORT

for the period

1 August 1988 - 31 July 1991

by

Roger F. Harrington

December 10, 1991

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I. STATEMENT OF THE PROBLEM STUDIED

The general problem studied was theoretical and computational full-wave analysis of microwave integrated circuits using the surface integral formulation. The following specific topics were considered:

(1) Analysis of Microstrip Crossovers. These were analyzed by both the quasi-static method and the full-wave method. The quasi-static analysis gives a three-element capacitive equivalent network for the crossover, and the full-wave analysis gives a four-port impedance network. The full wave analysis resulted in difficult integrals to evaluate, which were evaluated numerically.

(2) Dynamic and Quasi-Dynamic Analysis of Printed Circuits. This solution uses the Green's function approach and the Sommerfeld integral. It treats the general problem of integrated circuits on a dielectric substrate backed by a ground plane. Numerical application of this solution to specific printed circuits is still being studied.

(3) Publication of User-Friendly Computer Programs. Although the original work was not supported by ARO, we have published two user-friendly computer programs in the area of integrated circuits. The first program and manual are entitled "Matrix Parameters for Multiconductor Transmission Lines," by A. Djordjević, R. F. Harrington, T. K. Sarkar, and M. Bazdar. The second program and manual are entitled "Time-domain Response of Multiconductor Transmission Lines," by the same authors. These programs are published by Artech House, 685 Canton Street, Norwood, MA.

(4) The theory of printed circuits has been extended to two or more dielectric layers over a ground plane. This makes the evaluation of the Sommerfeld integrals more difficult. Some work on numerical evaluation of the integrals for two dielectric layers has been performed.

(5) Full-wave analysis of a multiconductor transmission line embedded in a layered uniaxial medium using a mixed potential formulation. This work has resulted in new methods of computation for multilayered media.

II. SUMMARY OF THE MOST IMPORTANT RESULTS

(1) Dr. Chung-I Gavin Hsu finished his Ph.D. Thesis in September 1991. The title of his thesis is "Analysis of a Multiconductor Transmission Line Embedded in a Multilayered Uniaxial Medium using Mixed Potential Integral Equation Approach."

The work of Dr. Hsu, which appears in his thesis, is a generalization of the approach introduced by Dr. Juan Mosig in his Ph.D. thesis at the Ecole Polytechnique Federale de Lausanne, Switzerland, in 1983. It allows one to separate the scalar potential from the vector potential for charge and current in a dielectric sheet region. This work was extended to layered media by K. Michalski and D. Zheng of Texas A&M University. Dr. Hsu has succeeded in extending the theory to uniaxial layered media. An abstract of this thesis follows:

A surface integral equation in conjunction with the method of moments is formulated for a transmission-line system which consists of multiple conducting cylinders of arbitrary cross section embedded in a stratified medium with or without top and/or bottom ground planes. Each layer of the medium is possibly uniaxially anisotropic, with its optical axis perpendicular to the dielectric interfaces. The contours of the conductor cross sections are approximated by a set of linear segments. Pulse and triangular basis functions are assumed for, respectively, the longitudinal and the transverse surface currents on the conductors in the moment method procedure. A mixed-potential form of the electric field equation is adopted. Therefore, direct computation of the more singular electric field is avoided in the testing process. Numerical results are presented and, wherever possible, are compared with data available in the literature. Propagation constants and current distributions are computed for a variety of configurations, in which the number of conductors ranges from one to five and that of layers of dielectrics from two to six. In particular, the Goubau modes, in which all the longitudinal modal currents flow in the same direction for the systems without the ground planes, have been found. Possible ways of further improving the computational efficiency are also discussed.

(2) The work on microstrip crossovers was the Ph.D. thesis, "Electromagnetic Coupling between Two Nonintersecting, Orthogonal, and Infinitely Long Microstrip Lines Parallel

to a Ground Plane," by Stilianos Papatheodorou. He passed his final Ph.D. Thesis Exam in September 1989. The following is an abstract of the dissertation.

A full-wave analysis of a microstrip crossover above a conducting plane is carried out. The crossover excites higher order modes in the form of evanescent waves near the discontinuity, while further away only the dominant (TEM) modes exist. The higher order mode currents are modelled by triangle functions and the dominant modes by outgoing traveling waves. The method of moments is employed to reduce the boundary conditions on the surface of each strip to matrix equations, the solution of which determines the currents on each strip. Then the impedance and scattering matrices of the four port are found along with the equivalent circuit. The results obtained using this full-wave solution are in agreement with results obtained using a quasi-static analysis, which at low frequencies is a very good approximation.

(3) Full-wave analysis of a three-dimensional printed circuit has been studied. Because of the Green's function, which involves a Sommerfeld integral, this requires a numerical analysis which can be made using the method of moments. A preliminary quasi-static solution has been developed theoretically, and a numerical treatment outlined. It is hoped that the quasi-static computer program developed will provide data for comparion to the full-wave analysis.

(4) A user-friendly computer program for the scattering parameters of microwave networks with multiconductor transmission lines has been published by Artech House in December 1989. This program uses as input the output data from a previously published software package, "Matrix Parameters of Multiconductor Transmission Lines." This new program allows one to compute the coupling between more than two signal lines in a printed circuit. The multiconductor transmission line can be fed by an arbitrary active network and terminated by an arbitrary passive network. These networks can consist of resistors, inductors, capacitors, and generators. The outputs of the program are the scattering parameters, the impedance matrix, and the admittance matrix. The format of the output is the same as that given by a network analyzer, used for experimental measurements.

(5) A full-wave analysis of microstrip crossover above a conducting plane has been carried out. Higher order modes are excited in the form of evanescent waves in the vicinity of the discontinuity, while further away only the dominant (TEM) modes exist. The higher order mode currents are modelled by triangle functions and the dominant modes by outgoing traveling

waves. The method of moments is employed to reduce the integral equations on the surface of each strip to matrix equations, the solution of which determines the currents on each strip. The impedance and scattering matrices of the four port follow from the equivalent circuit. The results obtained using this full-wave solution are in agreement with results obtained from a quasi-static analysis, which at low frequencies is a very good approximation.

III. PUBLICATIONS, TECHNICAL REPORTS, AND THESES

1. S. Papatheodorou, R. F. Harrington, and J. R. Mautz, "The Equivalent Circuit of a Microstrip Crossover," Applied Computational Electromagnetics Journal, vol. 4, No. 1, pp. 69-95, Spring 1989.

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3. J. A. Gerald and R. F. Harrington, "Scattering from Waveguide Backed Apertures in an Infinite Conducting Cylinder," accepted for publication in the IEEE Trans. AP.

4. T. Wang, R. F. Harrington, and J. R. Mautz, "Electromagnetic Scattering from and Transmission through Arbitrary Apertures in Conducting Bodies," IEEE Trans. on Antennas and Propagation, vol. 28, No. 11, pp.1805-1814, Nov. 1990.

5. S. Papatheodorou, "Electromagnetic Coupling Between Two Nonintersecting, Orthogonal, and Infinitely Long Microstrip Lines Parallel to a Ground Plane," Ph.D. Thesis, Syracuse University, Dec. 1989.

6. S. Papatheodorou, J. R. Mautz, and R. F. Harrington, "Full-Wave Analysis of a Strip Crossover," IEEE Trans. on Microwave Theory and Techniques, vol. 38, No. 10, pp. 1439-1447, Oct. 1990.

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10. M.J. Povinelli and R. F. Harrington, "A Volume and Surface Source Integral Formulation for Electromagnetic Scattering from Printed Circuit Antennas," accepted for publication in the IEEE Trans. on Magnetics.

11. C-I Gavin Hsu, "Analysis of a Multiconductor Transmission Line Embedded in a Layered Uniaxial Medium Using a Mixed Potential Integral Equation Approach," Ph.D. Thesis, Syracuse University, Sept. 1991.

IV. PARTICIPATING SCIENTIFIC PERSONNEL

The following persons have participated in the conduction of this research:

1. Roger F. Harrington, Professor, Principal Investigator.

2. Joseph R. Mautz, Ph.D. Research Associate.

3. Stilianos Papatheodorou, Research Assistant. Dr. Papatheodorou earned his Ph.D. degree in December, 1989.

4. Tawfic Rahal Arabi, Research Assistant. Dr. Rahal Arabi earned his Ph.D. degree in March 1991.

5. Enming Zheng, Research Assistant.

6. Mouloud Meghezzi, Research Assistant.

7. Chung-I Gavin Hsu, Research Assistant. Dr. Hsu earned his Ph.D. degree in Sept. 1991.

8. Ardalan Taaghol, Research Assistant.

Respectfully submitted,

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