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SECURITY CLASSIFICATION OF THIS PAGE

AD-A191 511

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REPORT DOCUMENTATION PAGE

1a. REPORT SECURITY CLASSIFICATION: Unclassified

1b. RESTRICTIVE MARKINGS:

2a. SECURITY CLASSIFICATION AUTHORITY:

2b. DECLASSIFICATION / DOWNGRADING SCHEDULE:

3. DISTRIBUTION/AVAILABILITY OF REPORT: Approved for public release; distribution unlimited.

4. PERFORMING ORGANIZATION REPORT NUMBER(S):

5. MONITORING ORGANIZATION REPORT NUMBER(S): ARO 22634.6-EL

6a. NAME OF PERFORMING ORGANIZATION: Univ. of Illinois

6b. OFFICE SYMBOL (If applicable):

7a. NAME OF MONITORING ORGANIZATION: U. S. Army Research Office

6c. ADDRESS (City, State, and ZIP Code): Urbana, IL 61801

7b. ADDRESS (City, State, and ZIP Code): P. O. Box 12211, Research Triangle Park, NC 27709-2211

8a. NAME OF FUNDING/SPONSORING ORGANIZATION: U. S. Army Research Office

8b. OFFICE SYMBOL (If applicable):

9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER: DAAG29-85-K-0183

8c. ADDRESS (City, State, and ZIP Code): P. O. Box 12211, Research Triangle Park, NC 27709-2211

10. SOURCE OF FUNDING NUMBERS

PROGRAM ELEMENT NO.	PROJECT NO.	TASK NO.	WORK UNIT ACCESSION NO.

11. TITLE (Include Security Classification): Millimeter and Submillimeter Waves and Frequency Selective Surfaces

12. PERSONAL AUTHOR(S): Raj Mittra

13a. TYPE OF REPORT	13b. TIME COVERED	14. DATE OF REPORT (Year, Month, Day)	15. PAGE COUNT
Final	FROM 8/21/85 TO 12/31/87	January 1988	4

16. SUPPLEMENTARY NOTATION: The view, opinions and/or findings contained in this report are those of the author(s) and should not be construed as an official Department of the Army position, policy, or decision, unless so designated by other documentation.

17. COSATI CODES

FIELD	GROUP	SUB-GROUP

18. SUBJECT TERMS (Continue on reverse if necessary and identify by block number): Millimeter Waves, Submillimeter Waves, Integrated Circuits, Transmission Lines, Antennas, Frequency Selective Surfaces, Finite Element Method

19. ABSTRACT (Continue on reverse if necessary and identify by block number)

We have investigated two different class of problems in this effort. The first of these falls in the category of microwave and millimeter wave integrated circuits and the second is concerned with frequency selective surfaces, or FSS. Our research in the millimeter wave area has focused on the development of analytical and numerical techniques for determining the characteristics of planar transmission lines, as well as circuit components and antennas that are compatible with these lines. As for frequency selective surfaces, our investigation of the FSS screens dealt with the development of methodologies for predicting the transmission and reflection properties of these screens as a function of the frequency. Both the free-standing screens and those with a dielectric substrate or superstate have been studied. In addition, curved and finite screens have also been investigated.

20. DISTRIBUTION/AVAILABILITY OF ABSTRACT: ☐ UNCLASSIFIED/UNLIMITED ☐ SAME AS RPT. ☐ DTIC USERS

21. ABSTRACT SECURITY CLASSIFICATION: Unclassified

22a. NAME OF RESPONSIBLE INDIVIDUAL:

22b. TELEPHONE (Include Area Code):

22c. OFFICE SYMBOL:

DD FORM 1473, 84 MAR — 83 APR edition may be used until exhausted. All other editions are obsolete

SECURITY CLASSIFICATION OF THIS PAGE

UNCLASSIFIED

ARO 22634.6-EL

Millimeter and Submillimeter Waves and Frequency Selective Surfaces

FINAL REPORT

R. Mittra

January 1988

U.S. ARMY RESEARCH OFFICE

Grant No. DAAG29-85-K-0183

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INTRODUCTION

This Final Report summarizes the progress made on research into the topics of "Millimeter and Submillimeter Waves and Frequency Selective Surfaces," covering the period of August 21, 1985 to December 31, 1987.

STATEMENT OF THE PROBLEMS STUDIED

We have investigated two different class of problems in this effort. The first of these falls in the category of microwave and millimeter wave integrated circuits and the second is concerned with frequency selective surfaces, or FSS. Our research in the millimeter wave area has focused on the development of analytical and numerical techniques for determining the characteristics of planar transmission lines, as well as circuit components and antennas that are compatible with these lines. As for frequency selective surfaces, our investigation of the FSS screens dealt with the development of methodologies for predicting the transmission and reflection properties of these screens as a function of the frequency. Both the free-standing screens and those with a dielectric substrate or superstate have been studied. In addition, curved and finite screens have also been investigated.

SUMMARY

A. Quasistatic and Frequency-Dependent Analysis of Different Transmission-Line Configurations for Millimeter and Submillimeter Waves

We have carried out the development of the Finite Element Method (FEM) and the Spectral Domain approach for the computation of the characteristic impedance as well as the propagation characteristics of different transmission-line configurations that find application in the millimeter and submillimeter frequency range. The Spectral Domain approach is numerically very efficient and is, consequently, well suited for CAD design of planar integrated circuits. On the other hand, FEM is a versatile tool and is applicable to a much wider class of geometrical configurations than is the Spectral approach, e.g., transmission lines of arbitrary cross-section and with arbitrary fillings. The results of these studies have been described in the following reports:

1. Z. Pantic and R. Mittra, "Quasi-TEM analysis of microwave transmission lines by the finite element method," EMC Technical Report No. 86-2, February 1986.

2. T. Kitazawa, Y. Hayashi and R. Mittra, "Asymmetrical coupled coplanar-type transmission lines with anisotropic substrates," EMC Technical Report No. 86-3. February 1986.

3. Z. Pantic and R. Mittra, "Full-wave analysis of isolated and coupled microwave transmission lines using the finite element method," EMC Technical Report No. 87-1, February 1987.

4. T. Kitazawa, Y. Hayashi and R. Mittra, "Asymmetrical coupled coplanar-type transmission lines with anisotropic substrates," IEE Proceedings H, August 1986, vol. 133, no. 4, pp. 265-270, 1987.

5. C. Chan and R. Mittra, "Analysis of MMIC structures using an efficient iterative approach," IEEE Trans. Microwave Theory & Techniques, vol. MTT-36, no. 1, pp. 96-105, January 1988.

Although the Spectral Approach has been applied to problems involving planar integrated circuits, we have now modified it to make it more efficient by adding two important features. The first of these entails the combining of an FFT-based iterative procedure with the conventional spectral approach. The second involves the application of the transfer matrix approach to the construction of the spectral Green's function for multilayered dielectric substrates.

As for the finite element method, we have devised a modified formulation which eliminates the spurious modes that typically plague the FEM scheme when it is employed for the computation of the dispersion characteristics of wave-guiding structures, such as a shielded microstrip.

B. Discontinuity Problems in Planar Transmission Lines

The CAD design of millimeter-wave integrated circuits requires an accurate knowledge of the equivalent circuits of discontinuities, such as a change in the line width, a bend, or a dielectric discontinuity. We have investigated a number of different methods, including the mode matching approach, the spectral domain method and the FEM, for deriving these equivalent circuits. Some of these investigations have been described in the following publications:

1. Everett G. Farr, "An investigation of modal characteristics and discontinuities in printed circuit transmission lines," Ph.D. Dissertation, 1985.

2. Q. Xu, K. J. Webb and R. Mittra, "Study of modal solution procedures for microstrip step-discontinuities," submitted for publication in MTT.

3. C. Chan and R. Mittra, "Analysis of MMIC structures using an efficient iterative approach," IEEE Trans. Microwave Theory & Techniques, vol. MTT-36, no. 1, pp. 96-105, January 1988.

4. C. Chan, "Investigation of iterative and spectral Galerkin techniques for solving electromagnetic boundary value problems," Ph.D. Dissertation, 1987.

Although we have made some progress in deriving the equivalent circuits for complicated discontinuity configurations in planar transmission lines, we feel that there is a critical need for further work in this area and FEM appears to be the leading candidate for treating general discontinuity problems of interest.

C. Dielectric Antennas for Millimeter Wavelengths

In this effort we have investigated the characteristics of dielectric antennas that are compatible with planar dielectric waveguides suitable for millimeter wavelengths. The problem of excitation of these antennas has been studied and their radiation characteristics have been investigated. The results of this study have been described in the following report:

1. G. M. Wilkins and R. Mittra, "Dielectric antennas for millimeter-wave applications," EMC Technical Report No. 86-5, May 1986.

D. Frequency Selective Surfaces (FSS)

Frequency selective surfaces find wide applications as spatial filters, radomes, dichroic screens, components for infrared sensing devices, etc. The purpose of our investigation was to develop general purpose techniques for predicting the frequency response characteristics of single and multiple screens, either free-standing or printed on one or more layers of dielectric substrates.

A general formulation for the FSS problem has been derived, both for patch and aperture-type elements, by using a spectral domain formulation. The subdomain type of basis functions has been used to represent the current on the conducting surface, because the use of these functions allows one to handle arbitrarily-shaped elements. An equation for the unknown weight coefficients of these basis functions has been derived by applying the boundary condition on the screen which may be only partially conducting. To accurately model the current distribution on the screen, it is often necessary to use a large number of basis functions, going up to several hundreds or even thousands. Thus, conventional matrix elimination methods cannot always be employed to solve the FSS problem when the subdomain formulation is used and it becomes necessary to generate the solution using iterative techniques, such as the conjugate gradient method or the spectral iterative method. Descriptions of the formulation and solution of the FSS problem using the subdomain approach can be found in:

1. T. Cwik and R. Mittra, "Scattering from general periodic screens," EMC Technical Report No. 86-10, December 1986.
2. T. Cwik and R. Mittra, "Scattering from a periodic array of free-standing arbitrarily shaped perfectly conducting or resistive patches," to be published in AP-S.
3. C. Chan, "Investigation of iterative and spectral Galerkin techniques for solving electromagnetic boundary value problems," Ph.D. Dissertation, 1987.
4. C. H. Chan and R. Mittra, "Design of a dichroic surface for a reflector antenna system," to be published in AP-S.
5. C. H. Chan and R. Mittra, "On the analysis of frequency selective surfaces using subdomain basis functions," to be published in AP-S.

The case of screens printed on dielectric substrates has been solved using two different techniques. The first of these is based upon the use of the cascading procedure and has been described in:

1. T. Cwik and R. Mittra, "The cascade connection of planar periodic surfaces and lossy dielectric layers to form an arbitrary periodic screen," to be published in AP-S.

The second approach to the same problem is to employ the composite Green's function for the multilayered dielectric substrate. We have derived this Green's function in a convenient form using the transfer matrix method that avoids tedious algebraic manipulations. This approach to the dielectric-backed screen problem is given in the following publication:

1. C. Chan, "Investigation of iterative and spectral Galerkin techniques for solving electromagnetic boundary value problems," Ph.D. Dissertation, 1987.

Next, we have examined the practical FSS problem where the screen is truncated and/or curved. The solution of the truncated screen problem is made difficult by the fact that, unlike the infinite screen case, the current on each of the elements of the final screen must be considered as a separate unknown; thus, the number of unknowns in the problem becomes very large very rapidly with the increase in the size of the screen. We have used the entire domain basis functions to formulate this problem and have been able to obtain quite encouraging results for this challenging problem. This analysis is described in the following publications:

1. W. L. Ko and R. Mittra, "Scattering by a truncated periodic array," to be published in AP-S.

2. K. Merewether and R. Mittra, "Electromagnetic scattering from a crossed-dipole frequency-selective surface of finite width," paper presented at the 1987 IEEE/URSI International Symposium in Blacksburg, VA, June 1987.

The truncated and curved strip grating problems have been investigated using a locally planar approximation, and the validity of this approach has been demonstrated using the numerically rigorous solution of the curved grating problem. The above problem has been discussed in the following publication:

1. T. Cwik and R. Mittra, "The effects of the truncation and curvature of periodic surfaces: A strip grating," to be published in AP-S.

It appears that the above approach is extendable to two-dimensional planar truncated screens and to doubly-curved FSS screens. These problems are currently being investigated.

PERSONNEL

The following personnel devoted time to this project:

Dr. R. Mittra	Professor of Electrical Engineering
Dr. C. Chan (Ph.D.)	Visiting Assistant Professor
Dr. Z. Pantic	Research Associate
Dr. T. Cwik (Ph.D.)	Graduate Research Assistant
Mr. B. Halpern	Graduate Research Assistant
Dr. C. Smith (Ph.D.)	Graduate Student Air Force
Mr. K. Merewether	Graduate Research Assistant
Mr. P. Harms (M.S.)	Graduate Teaching Assistant
Mr. G. Wilkins	Graduate Student Fellow