

Numerical and Asymptotic Techniques in Electromagnetics

Edited by R. Mittra

With Contributions by

F. J. Deadrick R. F. Harrington W. A. Imbriale

C. A. Klein R. G. Kouyoumjian E. K. Miller

R. Mittra W. V. T. Rusch

With 112 Figures

Springer-Verlag Berlin Heidelberg New York 1975

Professor RAJ MITTRA

University of Illinois at Urbana-Champaign, College of Engineering
Department of Electrical Engineering, Electromagnetics Laboratory
Urbana, IL 61801, USA

ISBN 3-540-07072-9 Springer-Verlag Berlin Heidelberg New York
ISBN 0-387-07072-9 Springer-Verlag New York Heidelberg Berlin

Library of Congress Cataloging in Publication Data. Mittra, Raj. Numerical and asymptotic techniques in electromagnetics. (Topics in applied physics; v. 3.) Includes bibliographical references and index. 1. Antennas (Electronics). 2. Electromagnetic waves. 3. Electric engineering – Mathematics. I. Deadrick, F. J. II. Title. TK7871.6.M59. 621.38'0283. 74-30146.

This work is subject to copyright. All rights are reserved, whether the whole or part of the material is concerned, specifically those of translation, reprinting, re-use of illustrations, broadcasting, reproduction by photocopying machine or similar means, and storage in data banks. Under § 54 of the German Copyright Law where copies are made for other than private use, a fee is payable to the publisher, the amount of the fee to be determined by agreement with the publisher.

© by Springer-Verlag Berlin Heidelberg 1975

Printed in Germany

The use of registered names, trademarks, etc. in this publication does not imply, even in the absence of a specific statement, that such names are exempt from the relevant protective laws and regulations and therefore free for general use.

Monophoto typesetting, offset printing and bookbinding: Brühlsche Universitätsdruckerei, Gießen

Preface

During the past two decades a large number of books have been written on the general subject of electromagnetics. Most of these publications have dealt with the classical approaches to solving electromagnetic boundary value problems. There are only a few notable exceptions to these, for instance, a monograph by HARRINGTON on the application of the moment method for the solution of field problems and a text by MITTRA on computer techniques for solving electromagnetic scattering and radiation problems. Since the appearance of these two books much progress has been made in the areas of computerated electromagnetics and the application of ray-optical techniques in the low-frequency and high-frequency regions, respectively. This book attempts to present a comprehensive description of some of these important recent developments and to illustrate the application of these techniques to a variety of problems of practical interest, e.g., design of dipole arrays and reflector antennas. Almost all of the material appearing in the book is relatively new and has not appeared elsewhere in any other publication except in the form of journal articles. It is hoped that the book will serve to fill the gap that exists in the current literature on numerical and asymptotic techniques in electromagnetics and will be found useful both as a convenient reference and as a practical tool for investigating electromagnetic radiation scattering problems. All of the contributing authors are well known throughout the world for their many contributions on moment methods, numerical aspects of computerated solution, ray-optical techniques and other topics covered in the book and they have made every attempt to present the material in the text in a coherent and easily readable form. It is their fervent hope that the reader will not only find the book useful as a tool for modern electromagnetic analysis and design, but will also enjoy the clarity of presentation of the advanced material discussed in the book.

Finally, the editor (R. M.) would like to thank all of the authors for their excellent cooperation and the publishers for their extremely efficient production schedule.

Urbana, Illinois, January 1975

R. MITTRA

Contents

1. Introduction. By R. MITTRA	1
2. Applications of the Method of Moments to Thin-Wire Elements and Arrays. By W. A. IMBRIALE (With 32 Figures)	
2.1. Method of Moments Applied to Wire Antennas	6
2.1.1. Basic Theory	7
2.1.2. Self-Impedance Evaluation	11
2.1.3. Convergence of Moments Solutions	13
2.1.4. Far-Field Evaluation	15
2.1.5. Arbitrarily Shaped Wires and Wire Junctions	15
2.2. Method of Moments Applied to Log-Periodic Dipole Antennas	17
2.2.1. Formulation of the Problem	19
The Transmission Line Admittance Matrix	21
The Dipole Elements Admittance Matrix	22
Far-Field Radiation Patterns	23
2.2.2. Single Log-Periodic Dipole Antenna	25
2.2.3. Coupled LPD Antennas	29
2.2.4. Effects of Feeder Boom	31
2.2.5. The Log-Periodic Fed Yagi	33
2.3. Wire Antennas as Feeds for Parabolic Reflectors	34
2.3.1. Scattering from Parabolic Reflectors	35
2.3.2. Optimum Design of LPD Feeds	37
Design Considerations	38
Optimum Design	42
Example Case	44
Experimental Correlation with Theory	45
2.3.3. Multiple LPD Feeds	47
References	49
3. Characteristic Modes for Antennas and Scatterers. By R. F. HARRINGTON (With 10 Figures)	
3.1. Characteristic Modes for Conducting Bodies	52
3.1.1. Characteristic Currents	53
3.1.2. Characteristic Fields	54

3.2. Modal Solutions	55
3.2.1. Linear Measurements	56
3.2.2. Application to Radiation Problems	57
3.2.3. Application to Scattering Problems	58
3.3. Scattering Matrices	59
3.4. Computation of Characteristic Modes	61
3.4.1. Computations for Bodies of Revolution	63
3.4.2. Convergence of Radiation Patterns	66
3.4.3. Computations for Wire Objects	68
3.5. Control of Modes by Reactive Loading	70
3.5.1. Modes of a Loaded Body	71
3.5.2. Resonating a Desired Real Current	72
3.5.3. A Scattering Example	74
3.5.4. Synthesis of Loaded Scatterers	75
3.6. Characteristic Modes for Dielectric Bodies	77
3.7. Characteristic Modes for N -Port Loaded Bodies	80
3.7.1. Formulation of the Problem	80
3.7.2. N -Port Characteristic Modes	82
3.7.3. Modal Solutions	83
3.7.4. Modal Resonance	84
3.7.5. Synthesis of Loaded N -Port Scatterers	85
3.8. Discussion	85
References	86
4. Some Computational Aspects of Thin-Wire Modeling.	
By E. K. MILLER and F. J. DEADRICK (With 8 Figures)	
4.1. Introduction	89
4.2. Current Expansions	91
4.2.1. Complete Domain Expansions	92
4.2.2. Sub-Domain Expansions	93
4.3. Structural Segmentation and Boundary Condition Matching	97
4.3.1. Structural Segmentation	98
4.3.2. Boundary Condition Matching	99
4.3.3. Impedance Loading	107
4.4. Multiple Junction Treatment	109
4.5. The Thin-Wire Approximation	112
4.6. Matrix Factorization Roundoff Error	114
4.7. Near-Field Behavior	115
4.8. Wire-Grid Modeling	118
4.9. Computer Time	122
4.10. Observations and Conclusion	123
References	126

5. Stability and Convergence of Moment Method Solutions.

By R. MITTRA and C. A. KLEIN (With 23 Figures)

5.1. Stability	129
5.1.1. Use of Condition Numbers	129
5.1.2. Scattering by Rectangular Conducting Cylinders	134
5.1.3. Waveguide Discontinuities	143
5.1.4. Wavefront Reconstruction	144
5.1.5. Thin-Wire Antennas	146
5.1.6. Remote Sensing	147
5.2. Convergence	149
5.2.1. Introduction	149
5.2.2. Testing Functions	151
5.2.3. Convergence of Impedance and Admittance	155
5.2.4. Convergence of Non-Local Parameters	160
5.3. Conclusions	162
References	163

6. The Geometrical Theory of Diffraction and Its Application.

By R. G. KOUYOUMJIAN (With 15 Figures)

6.1. Asymptotic Solution of Maxwell's Equations	166
6.1.1. Geometrical Optics	166
6.1.2. Reflection	168
6.1.3. Diffraction	170
6.2. Edge Diffraction	174
6.2.1. The Wedge	174
6.2.2. The General Edge Configuration	180
6.2.3. Higher-Order Edges	183
6.3. Diffraction by a Vertex	183
6.4. Surface Diffraction	184
6.4.1. The Shadow Region	185
6.4.2. The Parameters	190
6.4.3. Transition Regions	195
6.4.4. Two-Dimensional Problems	200
6.5. Applications	200
6.5.1. Reflector Antenna	201
6.5.2. Slot in an Elliptic Cylinder	205
6.5.3. Monopole Antenna Near an Edge	207
6.5.4. Discussion	210
6.6. Conclusions	212
References	213

7. Reflector Antennas. By W. V. T. RUSCH (With 24 Figures)

7.1. Formulation of the Field Equations	218
7.1.1. Free-Space Dyadic Green's Function	218
7.1.2. Physical Optics	219
7.1.3. Aperture Formulation	220
7.2. Numerical Integration Procedures	221
7.2.1. Physical-Optics Analysis of Radiation from a General Surface of Revolution	222
Convergence — An Example Using Dipole Illumination	227
Interval-Halving with Automatic Testing	228
7.2.2. Ludwig Algorithm	229
7.3. High-Frequency Reflectors with Stationary Points	229
7.3.1. Shadow-Region Cancellation	230
7.3.2. Geometrical Optics	231
7.3.3. Stationary Points of the Second Kind (Edge Rays)	235
7.3.4. Geometrical Theory of Diffraction for Reflectors in Free Space	235
Axially Symmetric Reflector for a Vector Spherical- Wave Point Source on Axis	235
Axially Symmetric Reflector for a Vector Spherical- Wave Point Source off Axis	240
Surface-Diffracted Rays	241
Applications	242
7.4. Application of Spherical-Wave Theory to Reflector Feed- System Design	245
7.4.1. NASA/JPL 64-m Antenna Dichroic Feed System	246
7.4.2. Shaped-Beam Pattern Synthesis Using Spherical- Wave Theory	250
7.5. Integral-Equation Analysis of Large Reflectors	250
References	255

Subject Index	257
--------------------------------	------------

Contributors

DEADRICK, FREDERICK J.

Lawrence Livermore Laboratory, P.O. Box 808, Livermore, CA 94550, USA

HARRINGTON, ROGER F.

Syracuse University, Electrical Engineering Department, Syracuse, NY 13210, USA

IMBRIALE, WILLIAM A.

TRW Systems Group, One Space Park, Redondo Beach, CA 90278, USA

KLEIN, CHARLES A.

University of Illinois at Urbana-Champaign, College of Engineering, Department of Electrical Engineering, Electromagnetics Laboratory, Urbana, IL 61801, USA

KOUYOUMJIAN, ROBERT G.

The Ohio State University, Department of Electrical Engineering, 2015 Neil Avenue, Columbus, OH 43210, USA

MILLER, EDMUND K.

Lawrence Livermore Laboratory, P.O. Box 808, Livermore, CA 94550, USA

MITTRA, RAJ

University of Illinois at Urbana-Champaign, College of Engineering, Department of Electrical Engineering, Electromagnetics Laboratory, Urbana, IL 61801, USA

RUSCH, WILLARD V. T.

University of Southern California, Department of Electrical Engineering, Los Angeles, CA 90007, USA