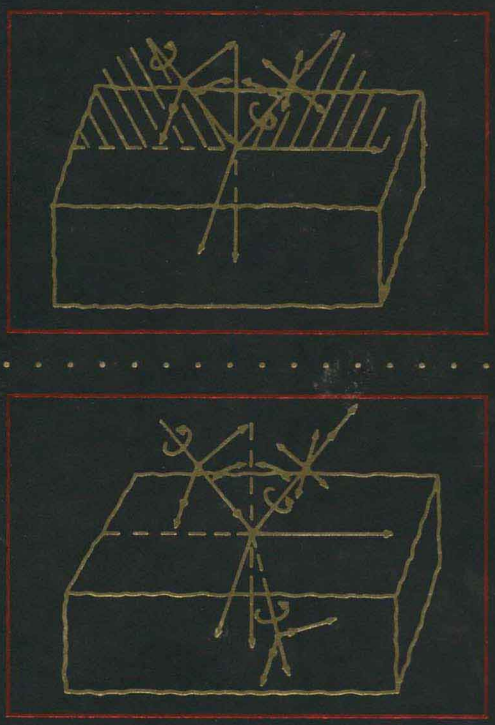
ADVANCED ENGINEERING ELECTROMAGNETICS



CONSTANTINE A. BALANIS

ADVANCED ENGINEERING ELECTROMAGNETICS

CONSTANTINE A. BALANIS
Arizona State University

JOHN WILEY & SONS
New York • Chichester • Brisbane • Toronto • Singapore

Copyright © 1989, by John Wiley & Sons, Inc.

All rights reserved. Published simultaneously in Canada.

Reproduction or translation of any part of
this work beyond that permitted by Sections
107 and 108 of the 1976 United States Copyright
Act without the permission of the copyright
owner is unlawful. Requests for permission
or further information should be addressed to
the Permissions Department, John Wiley & Sons.

Library of Congress Cataloging in Publication Data:

Balanis, Constantine A., 1938–
Advanced engineering electromagnetics.

Bibliography: p.
1. Electromagnetism. I. Title.
QC760.B25 1989 537 88-33846
ISBN 0-471-62194-3

Printed in the United States of America

10 9 8 7 6 5 4 3 2 1

ADVANCED ENGINEERING ELECTROMAGNETICS

To Helen, Renie, and Stephanie

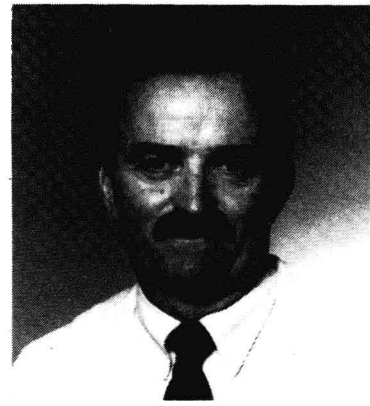
此为试读,需要完整PDF请访问: www.ertongbook.com

ABOUT THE AUTHOR

Constantine A. Balanis was born in Trikala, Greece. He received his B.S.E.E. degree from Virginia Polytechnic Institute, Blacksburg, in 1964, his M.E.E. degree from University of Virginia, Charlottesville, in 1966, and his Ph.D. degree in electrical engineering from Ohio State University, Columbus, in 1969.

From 1964 to 1970 he was with the NASA Langley Research Center in Hampton, Virginia. In 1970 he joined the Department of Electrical Engineering, West Virginia University, Morgantown, and held the positions of Associate and Full Professor. He is now a Full Professor of Electrical and Computer Engineering and Director of the Telecommunications Research Center, Arizona State University, Tempe. He teaches graduate and undergraduate courses in electromagnetic theory, antennas, and microwave circuits. His research interests are in low- and high-frequency numerical antenna and scattering techniques, reconstruction (inversion) methods, and electromagnetic wave propagation in microwave-integrated circuit transmission lines. He received the Graduate Teaching Excellence Award, School of Engineering, Arizona State University for 1987–1988.

Dr. Balanis is a member of IEEE (Institute of Electrical and Electronics Engineers), ASEE (American Society for Engineering Education), Sigma Xi, Tau Beta Pi, Eta Kappa Nu, and Phi Kappa Phi. He has served as the Associate Editor of the *IEEE Transactions on Antennas and Propagation* (1974–1977) and *IEEE Transactions on Geoscience and Remote Sensing* (1982–1984), Editor of the Newsletter for the IEEE Geoscience and Remote Sensing Society (1982–1983), and as Second Vice-President of the IEEE Geoscience and Remote Sensing Society (1984). He is also the author of *Antenna Theory: Analysis and Design* (John Wiley & Sons, New York, 1982), and "Horn Antennas," Chapter 8 in *Antenna Handbook: Theory, Applications, and Design* (Y. T. Lo and S. W. Lee, Editors), Van Nostrand Reinhold Co., New York, 1988.



PREFACE

This book is designed for a two-semester sequence in time-harmonic electromagnetics that is beyond an introduction to electromagnetostatics. Although the first part of the book is intended primarily for undergraduates and beginning graduates in electrical engineering and physics, the last part is intended for advanced graduate students and practicing engineers and scientists. The majority of Chapters 1 to 10 can be covered in the first semester, and most of Chapters 11 to 14 can be covered in the second semester. To cover all of the material in the proposed time frame would be, in many instances, a very ambitious task. Sufficient topics have been included, however, to make the text complete and to allow the instructor the flexibility to emphasize, de-emphasize, or omit sections or chapters.

The discussion presumes that the student has a general knowledge of vector analysis, differential and integral calculus, and electromagnetostatics either from an introductory electrical engineering or physics course. Mathematical techniques required for understanding some advanced topics, mostly in the later chapters, are incorporated in the individual chapters or are included as appendixes.

This is a very detailed student-oriented book. The analytical detail, rigor, and thoroughness allows many of the topics to be traced to their origin. In addition to the coverage of traditional classical topics, the book includes state of the art advanced topics on Integral Equations (IE), Moment Method (MM), Geometrical Theory of Diffraction (GTD), and Green's functions. Electromagnetic theorems, as applied to the solution of boundary-value problems, are also included and discussed.

The material is presented in a sequential and unified manner, and each chapter is subdivided into sections or subsections for which the individual heading clearly identifies the topic discussed, examined, or illustrated. The book also includes numerous examples, illustrations, references, and end-of-chapter problems. The examples and end-of-chapter problems have been designed to illustrate basic principles and to challenge the knowledge of the student. An exhaustive list of references is included at the end of each chapter to allow the interested reader to research each topic. A number of appendixes of mathematical identities and special functions, some represented also in tabular and graphical forms, are included to aid the student in the solution of the examples and assigned problems. Moment Method (MM) and Geometrical Theory of Diffraction (GTD) FORTRAN computer programs are included, respectively, at the end of Chapters 12 and 13, and they can be used for the solution of simple and complex problems. Also, information is provided about other national moment method computer programs. A solutions manual for all end-of-chapter problems is available for the instructor.

In Chapter 1 the book covers the classical topics on Maxwell's equations, constitutive parameters and relations, circuit relations, boundary conditions, and power and energy relations. The electrical properties of matter, both direct-current and alternating-current, are covered in Chapter 2, and the wave equation and its solution in rectangular, cylindrical and spherical coordinates are discussed in Chapter 3. Electromagnetic wave propagation and polarization is introduced

in Chapter 4. Reflection and transmission at normal and oblique wave incidences are considered in Chapter 5. Chapter 6 covers the auxiliary vector potentials and their use toward the construction of solutions for radiation and scattering problems. The theorems of duality, uniqueness, image, reciprocity, reaction, volume and surface equivalences, induction, and physical and physical optics equivalents are introduced and applied in Chapter 7. Rectangular cross section waveguides and cavities, including dielectric slabs, striplines, and microstrips, are discussed in Chapter 8. Those of circular cross section, including the fiber optics cable, are examined in Chapter 9, and those of spherical geometry are introduced in Chapter 10. Scattering by strips, plates, circular cylinders, wedges, and spheres is analyzed in Chapter 11. Chapter 12 covers the basics and applications of Integral Equations (IE) and Moment Method (MM) and also includes a computer program for wire radiation and scattering. The techniques and applications for the Geometrical Theory of Diffraction (GTD) are introduced and discussed in Chapter 13, including computer programs for diffraction coefficients of conducting wedges. The classic topic of Green's functions is introduced and applied in Chapter 14.

Throughout the book an $e^{j\omega t}$ time convention is assumed, and it is suppressed in almost all of the chapters. The International System of Units, which is an expanded form of the rationalized MKS system, is used throughout the text discussion. In some instances, the units of length are given in meters (or centimeters) and feet (or inches). Numbers in parentheses ( ) refer to equations, whereas those in brackets [ ] refer to references. For emphasis, the most important equations, once they are derived, are boxed.

I acknowledge the invaluable suggestions, corrections, and constructive criticisms of the reviewers of this book: Roger D. Radcliff of Ohio University, Christos G. Christodoulou of University of Central Florida, Prabhakar H. Pathak of Ohio State University, and Thomas E. Tice of Arizona State University. The writing of this book has been a very ambitious task, and its completion would not have been possible without the contributions of many of my graduate students. It is a pleasure to acknowledge those of Kefeng Liu for the development of the moment method computer programs and for the proofreading of parts of the manuscript, and those of Leslie A. Polka, Frank L. Whetten, Mark S. Frank, James P. Gilb, and Craig R. Birtcher for proofreading parts of the manuscript. A special tribute is owed to Thuy Griesser for the expert typing of all phases of the entire manuscript. I am also grateful to Christina Kamra, Wiley editor of electrical engineering and computer science, for her interest in the production and publication of this book. To the companies and authors that provided the copyright permissions, I am most appreciative. In a book of this size, there inevitably will be errors that have been overlooked. I would appreciate having any errors brought to my attention.

Constantine A. Balanis

Tempe, Arizona

CONTENTS

1 TIME-VARYING AND TIME-HARMONIC ELECTROMAGNETIC FIELDS 1

1.1 INTRODUCTION 2
1.2 MAXWELL'S EQUATIONS 2
1.2.1 Differential Form of Maxwell's Equations 2
1.2.2 Integral Form of Maxwell's Equations 5
1.3 CONSTITUTIVE PARAMETERS AND RELATIONS 7
1.4 CIRCUIT-FIELD RELATIONS 8
1.4.1 Kirchhoff's Voltage Law 8
1.4.2 Kirchhoff's Current Law 9
1.4.3 Element Laws 11
1.5 BOUNDARY CONDITIONS 13
1.5.1 Finite Conductivity Media 13
1.5.2 Infinite Conductivity Media 16
1.5.3 Sources along Boundaries 19
1.6 POWER AND ENERGY 20
1.7 TIME-HARMONIC ELECTROMAGNETIC FIELDS 23
1.7.1 Maxwell's Equations in Differential and Integral Forms 24
1.7.2 Boundary Conditions 24
1.7.3 Power and Energy 28
REFERENCES 32
PROBLEMS 32

2 ELECTRICAL PROPERTIES OF MATTER 42

2.1 INTRODUCTION 42
2.2 DIELECTRICS, POLARIZATION, AND PERMITTIVITY 44
2.3 MAGNETICS, MAGNETIZATION, AND PERMEABILITY 51
2.4 CURRENT, CONDUCTORS, AND CONDUCTIVITY 59
2.4.1 Current 59
2.4.2 Conductors 60
2.4.3 Conductivity 63
2.5 SEMICONDUCTORS 63
2.6 SUPERCONDUCTORS 68
2.7 LINEAR, HOMOGENEOUS, ISOTROPIC, AND NONDISPERSIVE MEDIA 71
2.8 A.C. VARIATIONS IN MATERIALS 72
2.8.1 Complex Permittivity 73

2.8.2 Complex Permeability 84
2.8.3 Ferrites 85
REFERENCES 94
PROBLEMS 96

3 WAVE EQUATION AND ITS SOLUTIONS 104

3.1 INTRODUCTION 104
3.2 TIME-VARYING ELECTROMAGNETIC FIELDS 104
3.3 TIME-HARMONIC ELECTROMAGNETIC FIELDS 106
3.4 SOLUTION TO THE WAVE EQUATION 107
3.4.1 Rectangular Coordinate System 108
A. Source-Free and Lossless Media 108
B. Source-Free and Lossy Media 113
3.4.2 Cylindrical Coordinate System 116
3.4.3 Spherical Coordinate System 121
REFERENCES 126
PROBLEMS 127

4 WAVE PROPAGATION AND POLARIZATION 129

4.1 INTRODUCTION 129
4.2 TRANSVERSE ELECTROMAGNETIC MODES 129
4.2.1 Uniform Plane Waves in an Unbounded Lossless Medium—Principal Axis 131
A. Electric and Magnetic Fields 131
B. Wave Impedance 133
C. Phase and Energy (Group) Velocities, Power, and Energy Densities 135
D. Standing Waves 136
4.2.2 Uniform Plane Waves in an Unbounded Lossless Medium—Oblique Angle 138
A. Electric and Magnetic Fields 139
B. Wave Impedance 142
C. Phase and Energy (Group) Velocities 143
D. Power and Energy Densities 144
4.3 TRANSVERSE ELECTROMAGNETIC MODES IN LOSSY MEDIA 145
4.3.1 Uniform Plane Waves in an Unbounded Lossy Medium—Principal Axis 145
A. Good Dielectrics $[(\sigma/\omega\varepsilon)^2 \ll 1]$ 149
B. Good Conductors $[(\sigma/\omega\varepsilon)^2 \gg 1]$ 151
4.3.2 Uniform Plane Waves in an Unbounded Lossy Medium—Oblique Angle 151

4.4 POLARIZATION 154
4.4.1 Linear Polarization 156
4.4.2 Circular Polarization 158
A. Right-Hand (Clockwise) Circular Polarization 158
B. Left-Hand (Counterclockwise) Circular Polarization 161
4.4.3 Elliptical Polarization 163
4.4.4 Poincaré Sphere 168
REFERENCES 173
PROBLEMS 174

5 REFLECTION AND TRANSMISSION 180

5.1 INTRODUCTION 180
5.2 NORMAL INCIDENCE—LOSSLESS MEDIA 180
5.3 OBLIQUE INCIDENCE—LOSSLESS MEDIA 185
5.3.1 Perpendicular (Horizontal or E) Polarization 185
5.3.2 Parallel (Vertical or H) Polarization 189
5.3.3 Total Transmission–Brewster Angle 193
A. Perpendicular (Horizontal) Polarization 193
B. Parallel (Vertical) Polarization 194
5.3.4 Total Reflection–Critical Angle 196
A. Perpendicular (Horizontal) Polarization 196
B. Parallel (Vertical) Polarization 206
5.4 LOSSY MEDIA 206
5.4.1 Normal Incidence: Conductor–Conductor Interface 207
5.4.2 Oblique Incidence: Dielectric–Conductor Interface 210
5.4.3 Oblique Incidence: Conductor–Conductor Interface 214
5.5 REFLECTION AND TRANSMISSION OF MULTIPLE INTERFACES 220
5.5.1 Reflection Coefficient of a Single Slab Layer 220
5.5.2 Reflection Coefficient of Multiple Layers 229
A. Quarter-Wavelength Transformer 230
B. Binomial (Maximally Flat) Design 231
C. Tschebyscheff (Equal-Ripple) Design 233
D. Oblique-Wave Incidence 235
5.6 POLARIZATION CHARACTERISTICS ON REFLECTION 236
REFERENCES 243
PROBLEMS 244

6 AUXILIARY VECTOR POTENTIALS, CONSTRUCTION OF SOLUTIONS, AND RADIATION AND SCATTERING EQUATIONS 254

6.1 INTRODUCTION 254
6.2 THE VECTOR POTENTIAL **A** 256

此为试读,需要完整PDF请访问: www.ertongbook.com

6.3 THE VECTOR POTENTIAL **F** 257
6.4 THE VECTOR POTENTIALS **A** AND **F** 259
6.5 CONSTRUCTION OF SOLUTIONS 261
6.5.1 Transverse Electromagnetic Modes: Source-Free Region 261
A. Rectangular Coordinate System 261
B. Cylindrical Coordinate System 266
6.5.2 Transverse Magnetic Modes: Source-Free Region 269
A. Rectangular Coordinate System 269
B. Cylindrical Coordinate System 272
6.5.3 Transverse Electric Modes: Source-Free Region 273
A. Rectangular Coordinate System 274
B. Cylindrical Coordinate System 275
6.6 SOLUTION OF THE INHOMOGENEOUS VECTOR POTENTIAL WAVE EQUATION 276
6.7 FAR-FIELD RADIATION 280
6.8 RADIATION AND SCATTERING EQUATIONS 282
6.8.1 Near Field 282
6.8.2 Far Field 285
A. Rectangular Coordinate System 288
B. Cylindrical Coordinate System 300
REFERENCES 305
PROBLEMS 305

7 ELECTROMAGNETIC THEOREMS AND PRINCIPLES 310

7.1 INTRODUCTION 310
7.2 DUALITY THEOREM 310
7.3 UNIQUENESS THEOREM 312
7.4 IMAGE THEORY 314
7.4.1 Vertical Electric Dipole 318
7.4.2 Horizontal Electric Dipole 321
7.5 RECIPROCITY THEOREM 323
7.6 REACTION THEOREM 326
7.7 VOLUME EQUIVALENCE THEOREM 327
7.8 SURFACE EQUIVALENCE THEOREM: HUYGENS'S PRINCIPLE 329
7.9 INDUCTION THEOREM (INDUCTION EQUIVALENT) 334
7.10 PHYSICAL EQUIVALENT AND PHYSICAL OPTICS EQUIVALENT 338
7.11 INDUCTION AND PHYSICAL EQUIVALENT APPROXIMATIONS 341
REFERENCES 346
PROBLEMS 347

8 RECTANGULAR CROSS-SECTION WAVEGUIDES AND CAVITIES 352

8.1 INTRODUCTION 352

8.2 RECTANGULAR WAVEGUIDE 352

8.2.1 Transverse Electric (TE^z) 353

8.2.2 Transverse Magnetic (TM^z) 362

8.2.3 Dominant TE_{10} Mode 366

8.2.4 Power Density and Power 374

8.2.5 Attenuation 376

A. Conduction (Ohmic) Losses 376

B. Dielectric Losses 381

C. Coupling 384

8.3 RECTANGULAR RESONANT CAVITIES 388

8.3.1 Transverse Electric (TE^z) Modes 388

8.3.2 Transverse Magnetic (TM^z) Modes 392

8.4 HYBRID (LSE AND LSM) MODES 394

8.4.1 Longitudinal Section Electric (LSE^y) or Transverse Electric (TE^y) or H^y Modes 395

8.4.2 Longitudinal Section Magnetic (LSM^y) or Transverse Magnetic (TM^y) or E^y Modes 397

8.5 PARTIALLY FILLED WAVEGUIDE 398

8.5.1 Longitudinal Section Electric (LSE^y) or Transverse Electric (TE^y) 398

8.5.2 Longitudinal Section Magnetic (LSM^y) or Transverse Magnetic (TM^y) 404

8.6 TRANSVERSE RESONANCE METHOD 410

8.6.1 Transverse Electric (TE^y) or Longitudinal Section Electric (LSE^y) or H^y 413

8.6.2 Transverse Magnetic (TM^y) or Longitudinal Section Magnetic (LSM^y) or E^y 413

8.7 DIELECTRIC WAVEGUIDE 414

8.7.1 Dielectric Slab Waveguide 414

8.7.2 Transverse Magnetic (TM^z) Modes 416

A. TM^z (even) 418

B. TM^z (odd) 420

C. Summary of TM^z (even) and TM^z (odd) Modes 420

D. Graphical Solution for TM^z (even) and TM^z (odd) Modes 423

8.7.3 Transverse Electric (TE^z) Modes 427

8.7.4 Ray-Tracing Method 431

A. Transverse Magnetic (TM^z) Modes (Parallel Polarization) 436

B. Transverse Electric (TE^z) Modes (Perpendicular Polarization) 439

8.7.5 Dielectric Covered Ground Plane 441

8.8 STRIPLINE AND MICROSTRIP LINES 444

8.8.1 Stripline 445

8.8.2 Microstrip 449

8.8.3 Microstrip: Boundary-Value Problem 455
8.9 RIDGED WAVEGUIDE 457
REFERENCES 461
PROBLEMS 463

9 CIRCULAR CROSS-SECTION WAVEGUIDES AND CAVITIES 470

9.1 INTRODUCTION 470
9.2 CIRCULAR WAVEGUIDE 470
9.2.1 Transverse Electric (TE^z) Modes 470
9.2.2 Transverse Magnetic (TM^z) Modes 477
9.2.3 Attenuation 485
9.3 CIRCULAR CAVITY 492
9.3.1 Transverse Electric (TE^z) Modes 492
9.3.2 Transverse Magnetic (TM^z) Modes 494
9.3.3 Quality Factor Q 495
9.4 RADIAL WAVEGUIDES 499
9.4.1 Parallel Plates 499
A. Transverse Electric (TE^z) Modes 499
B. Transverse Magnetic (TM^z) Modes 502
9.4.2 Wedged Plates 504
A. Transverse Electric (TE^z) Modes 505
B. Transverse Magnetic (TM^z) Modes 505
9.5 DIELECTRIC WAVEGUIDES AND RESONATORS 506
9.5.1 Circular Dielectric Waveguide 506
9.5.2 Circular Dielectric Resonator 517
A. TE^z Modes 520
B. TM^z Modes 521
C. $TE_{01\delta}$ Mode 522
9.5.3 Optical Fiber Cable 524
9.5.4 Dielectric Covered Conducting Rod 527
A. TM^z Modes 528
B. TE^z Modes 534
REFERENCES 535
PROBLEMS 537

10 SPHERICAL TRANSMISSION LINES AND CAVITIES 543

10.1 INTRODUCTION 543
10.2 CONSTRUCTION OF SOLUTIONS 543
10.2.1 The Vector Potential $\mathbf{F}$ ($\mathbf{J} = 0$, $\mathbf{M} \neq 0$) 544
10.2.2 The Vector Potential $\mathbf{A}$ ($\mathbf{J} \neq 0$, $\mathbf{M} = 0$) 546
10.2.3 The Vector Potentials $\mathbf{F}$ and $\mathbf{A}$ 546
10.2.4 Transverse Electric (TE) Modes: Source-Free Region 547
10.2.5 Transverse Magnetic (TM) Modes: Source-Free Region 549
10.2.6 Solution of the Scalar Helmholtz Wave Equation 550

10.3 BICONICAL TRANSMISSION LINE 552
10.3.1 Transverse Electric (TE^r) Modes 552
10.3.2 Transverse Magnetic (TM^r) Modes 554
10.3.3 Transverse Electromagnetic (TEM^r) Modes 554
10.4 THE SPHERICAL CAVITY 557
10.4.1 Transverse Electric (TE^r) Modes 557
10.4.2 Transverse Magnetic (TM^r) Modes 560
10.4.3 Quality Factor Q 562
REFERENCES 565
PROBLEMS 565

11 SCATTERING 570

11.1 INTRODUCTION 570
11.2 INFINITE LINE-SOURCE CYLINDRICAL WAVE RADIATION 571
11.2.1 Electric Line Source 571
11.2.2 Magnetic Line Source 573
11.2.3 Electric Line Source above Infinite Plane Electric Conductor 574
11.3 PLANE WAVE SCATTERING BY PLANAR SURFACES 577
11.3.1 TM^z Plane Wave Scattering from a Strip 578
11.3.2 TE^x Plane Wave Scattering from a Flat Rectangular Plate 586
11.4 CYLINDRICAL WAVE TRANSFORMATIONS AND THEOREMS 595
11.4.1 Plane Waves in Terms of Cylindrical Wave Functions 595
11.4.2 Addition Theorem of Hankel Functions 597
11.4.3 Addition Theorem for Bessel Functions 600
11.4.4 Summary of Cylindrical Wave Transformations and Theorems 602
11.5 SCATTERING BY CIRCULAR CYLINDERS 602
11.5.1 Normal Incidence Plane Wave Scattering by Conducting Circular Cylinder: TM^z Polarization 603
A. Small Radius Approximation 606
B. Far-Zone Scattered Field 606
11.5.2 Normal Incidence Plane Wave Scattering by Conducting Circular Cylinder: TE^z Polarization 608
A. Small Radius Approximation 610
B. Far-Zone Scattered Field 611
11.5.3 Oblique Incidence Plane Wave Scattering by Conducting Circular Cylinder: TM^z Polarization 614
A. Far-Zone Scattered Field 618
11.5.4 Oblique Incidence Plane Wave Scattering by Conducting Circular Cylinder: TE^z Polarization 620
A. Far-Zone Scattered Field 624
11.5.5 Line-Source Scattering by a Conducting Circular Cylinder 626
A. Electric Line Source (TM^z Polarization) 626
B. Magnetic Line Source (TE^z Polarization) 630
11.6 SCATTERING BY CONDUCTING WEDGE 634
11.6.1 Electric Line-Source Scattering by a Conducting Wedge: TM^z Polarization 635

A. Far-Zone Field 637
B. Plane Wave Scattering 638
11.6.2 Magnetic Line-Source Scattering by a Conducting Wedge: TE^z Polarization 639
11.6.3 Electric and Magnetic Line-Source Scattering by a Conducting Wedge 642
11.7 SPHERICAL WAVE ORTHOGONALITIES, TRANSFORMATIONS, AND THEOREMS 645
11.7.1 Vertical Dipole Spherical Wave Radiation 645
11.7.2 Orthogonality Relationships 647
11.7.3 Wave Transformations and Theorems 648
11.8 SCATTERING BY A CONDUCTING SPHERE 650
REFERENCES 658
PROBLEMS 660

12 INTEGRAL EQUATIONS AND THE MOMENT METHOD 670

12.1 INTRODUCTION 670
12.2 INTEGRAL EQUATION METHOD 671
12.2.1 Electrostatic Charge Distribution 671
A. Finite Straight Wire 671
B. Bent Wire 675
12.2.2 Integral Equation 677
12.2.3 Radiation Pattern 680
12.2.4 Point-Matching (Collocation) Method 681
12.2.5 Basis Functions 683
A. Subdomain Functions 683
B. Entire-Domain Functions 685
12.2.6 Application of Point Matching 687
12.2.7 Weighting (Testing) Functions 689
12.2.8 Moment Method 689
12.3 ELECTRIC AND MAGNETIC FIELD INTEGRAL EQUATIONS 695
12.3.1 Electric Field Integral Equation 696
A. Two-Dimensional EFIE: TM^z Polarization 698
B. Two-Dimensional EFIE: TE^z Polarization 702
12.3.2 Magnetic Field Integral Equation 707
A. Two-Dimensional MFIE: TM^z Polarization 709
B. Two-Dimensional MFIE: TE^z Polarization 710
C. Solution of the Two-Dimensional MFIE TE^z Polarization 712
12.4 FINITE DIAMETER WIRES 717
12.4.1 Pocklington's Integral Equation 718
12.4.2 Hallén's Integral Equation 720
12.4.3 Source Modeling 722
A. Delta Gap 722
B. Magnetic Frill Generator 722
12.5 COMPUTER CODES 726
12.5.1 Two-Dimensional Radiation and Scattering 727

A. Strip 727
B. Circular, Elliptical, or Rectangular Cylinder 728
12.5.2 Pocklington's Wire Radiation and Scattering 729
A. Radiation 729
B. Scattering 729
12.5.3 Numerical Electromagnetics Code 729
12.5.4 Mini-Numerical Electromagnetics Code 730
12.5.5 Electromagnetic Surface Patch Code 730
REFERENCES 731
PROBLEMS 733
COMPUTER PROGRAM: PWRS 737

13 GEOMETRICAL THEORY OF DIFFRACTION 743

13.1 INTRODUCTION 743
13.2 GEOMETRICAL OPTICS 744
13.2.1 Amplitude Relation 746
13.2.2 Phase and Polarization Relations 751
13.2.3 Reflection From Surfaces 753
13.3 GEOMETRICAL THEORY OF DIFFRACTION: EDGE DIFFRACTION 765
13.3.1 Amplitude, Phase, and Polarization Relations 765
13.3.2 Straight Edge Diffraction: Normal Incidence 769
A. Modal Solution 771
B. High-Frequency Asymptotic Solution 772
C. Method of Steepest Descent 777
D. Geometrical Optics and Diffracted Fields 782
E. Diffraction Coefficients 785
13.3.3 Straight Edge Diffraction: Oblique Incidence 807
13.3.4 Curved Edge Diffraction: Oblique Incidence 814
13.3.5 Equivalent Currents in Diffraction 824
13.3.6 Slope Diffraction 828
13.3.7 Multiple Diffractions 830
13.4 COMPUTER CODES 834
13.4.1 Wedge Diffraction Coefficients 834
13.4.2 Fresnel Transition Function 835
13.4.3 Slope Wedge Diffraction Coefficients 835
REFERENCES 835
PROBLEMS 838
COMPUTER PROGRAM: WDC 848
COMPUTER PROGRAM: SWDC 849
COMPUTER PROGRAM: FTF 850

14 GREEN'S FUNCTIONS 851

14.1 INTRODUCTION 851
14.2 GREEN'S FUNCTIONS IN ENGINEERING 852
14.2.1 Circuit Theory 852
14.2.2 Mechanics 855

此为试读,需要完整PDF请访问: www.ertongbook.com