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We dedicate this book to our friend and colleague,
Professor Anthony J. Ferraro of The Pennsylvania State University,
who has served as a mentor and an inspiration to many undergraduate as well as
graduate students during his long and distinguished career in academia.

CONTENTS

PREFACE xxi

LIST OF CONTRIBUTORS xxiii

PART I GEOMETRY, TOPOLOGY, AND GROUPS

CHAPTER 1 FRACTAL ELECTRODYNAMICS: SURFACES AND SUPERLATTICES 1

Dwight L. Jaggard, Aaron D. Jaggard, and Panayiotis V. Frangos

- 1.1 Introduction 1
 - 1.1.1 Background 1
 - 1.1.2 Overview 2
- 1.2 Introduction to Fractals 3
 - 1.2.1 What are Fractals? 3
 - 1.2.1.1 Fractal Characteristics 3
 - 1.2.1.2 Bandlimited Fractals and Prefractals 5
 - 1.2.1.3 Bandlimited Weierstrass Function 6
 - 1.2.1.4 Triadic Cantor Set 6
 - 1.2.2 Fractal Dimension 7
 - 1.2.2.1 Motivation 7
 - 1.2.2.2 Definition 7
 - 1.2.2.3 Extensions 8
 - 1.2.3 Fractals and Their Construction 9
 - 1.2.3.1 Bandlimited Weierstrass Function 9
 - 1.2.3.2 Sierpiński Gasket 10
 - 1.2.3.3 Polyadic Cantor Bars—Minimal Lacunarity 11
 - 1.2.4 Lacunarity 12
 - 1.2.4.1 Concept 12
 - 1.2.4.2 Examples—Polyadic Cantor Bars with Variable Lacunarity 13
 - 1.2.4.3 Definition 14
 - 1.2.5 Fractals and Waves 15
- 1.3 Scattering from Fractal Surfaces 15
 - 1.3.1 Problem Geometry 16

1.3.2	Approximate Scattering Solution	17
1.3.2.1	Formulation of Approximate Surface Scattering Solution	17
1.3.2.2	Scattering Cross Sections for the Approximate Case	19
1.3.2.3	Observations on the Approximate Case	22
1.3.3	Exact Scattering Solution	22
1.3.3.1	Formulation of Exact Surface Scattering Solution	23
1.3.3.2	Scattering Cross Sections for the Exact Case	24
1.3.3.3	Observations on the Exact Case	29
1.4	Reflection from Cantor Superlattices	29
1.4.1	Problem Geometry	30
1.4.2	Doubly Recursive Solution	30
1.4.3	Results	32
1.4.3.1	Twist Plots	32
1.4.3.2	Nulls and Their Structure	33
1.4.3.3	Polarization	35
1.4.4	Fractal Descriptors: Imprinting and Extraction	37
1.4.4.1	Frequency-Domain Approach	37
1.4.4.2	Time-Scale Approach	39
1.4.5	Observations on Superlattice Scattering	41
1.5	Conclusion	42
	References	42

CHAPTER 2 FRACTAL-SHAPED ANTENNAS 48

Carles Puente, Jordi Romeu, and Angel Cardama

2.1	Introduction	48
2.2	Fractals, Antennas, and Fractal Antennas	50
2.2.1	Main Fractal Properties	50
2.2.1.1	Fractal Self-Similarity	50
2.2.1.2	The Fractal Dimension	53
2.2.2	Why Fractal-Shaped Antennas?	54
2.2.2.1	Multifrequency Fractal Antennas	55
2.2.2.2	Small Fractal Antennas	57
2.3	Multifrequency Fractal-Shaped Antennas	59
2.3.1	The Equilateral Sierpiński Antenna	59
2.3.1.1	The Sierpiński Gasket	59
2.3.1.2	Input Impedance and Return-Loss	59
2.3.1.3	Radiation Patterns	62
2.3.1.4	Current Density Distribution	62
2.3.1.5	Iterative Transmission Line Network Model	64
2.3.2	Variations on the Sierpiński Antenna	67
2.3.2.1	Variations on the Flare Angle	68
2.3.2.2	Shifting the Operating Bands	75
2.3.3	Fractal Tree-Like Antennas	78
2.4	Small Fractal Antennas	81
2.4.1	Some Theoretical Considerations	81
2.4.1.1	About the Koch Curve	81

2.4.1.2 Theoretical Hypothesis	82
2.4.2 The Small but Long Koch Monopole	83
2.4.2.1 Antenna Description	83
2.4.2.2 Input Parameters	84
2.4.2.3 The Quality Factor	86
2.4.2.4 Current Distributions	89
2.4.3 Conclusion	90
References	91

CHAPTER 3 THE THEORY AND DESIGN OF FRACTAL ANTENNA ARRAYS 94

*Douglas H. Werner, Pingjuan L. Werner, Dwight L. Jaggard,
Aaron D. Jaggard, Carles Puente, and Randy L. Haupt*

3.1 Introduction	94
3.2 The Fractal Random Array	96
3.2.1 Background and Motivation	96
3.2.2 Sample Design of a Fractal Random Array and Discussion	98
3.3 Aperture Arrays or Diffractals	100
3.3.1 Calculation of Radiation Patterns	101
3.3.2 Symmetry Relations	102
3.3.3 Cartesian Diffractals	103
3.3.3.1 Cantor Square Diffraction	104
3.3.3.2 Purina Square Diffraction	105
3.3.3.3 Sierpiński Square Diffraction	105
3.3.3.4 Discussion	105
3.3.4 Cantor Ring Diffractals	113
3.3.4.1 Triadic Cantor Ring Diffractal	114
3.3.4.2 Polyadic Cantor Diffractal	116
3.3.4.3 Discussion	120
3.4 Fractal Radiation Pattern Synthesis Techniques	122
3.4.1 Background	122
3.4.2 Weierstrass Linear Arrays	123
3.4.3 Fourier-Weierstrass Line Sources	130
3.4.4 Fourier-Weierstrass Linear Arrays	137
3.4.5 Weierstrass Concentric-Ring Planar Arrays	140
3.5 Fractal Array Factors and Their Role in the Design of Multiband Arrays	142
3.5.1 Background	142
3.5.2 Weierstrass Fractal Array Factors	144
3.5.3 Koch Fractal Array Factors	153
3.5.3.1 Reducing the Number of Elements: Array Truncation	156
3.5.3.2 Koch-Pattern Construction Algorithm	157
3.5.3.3 The Blackman-Koch Array Factor	161
3.6 Deterministic Fractal Arrays	163
3.6.1 Cantor Linear Arrays	164
3.6.2 Sierpiński Carpet Arrays	170

3.6.3	Cantor Ring Arrays	176
3.6.3.1	Formulation	176
3.6.3.2	Results and Discussion	177
3.7	The Concentric Circular Ring Sub-Array Generator	181
3.7.1	Theory	181
3.7.2	Examples	184
3.7.2.1	Linear Arrays	184
3.7.2.2	Planar Square Arrays	186
3.7.2.3	Planar Triangular Arrays	189
3.7.2.4	Hexagonal Arrays	193
3.8	Conclusion	200
	References	200

CHAPTER 4 TARGET SYMMETRY AND THE SCATTERING DYADIC 204

Carl E. Baum

4.1	Introduction	204
4.2	Reciprocity	208
4.3	Symmetry Groups for Target	208
4.4	Target Symmetry	210
4.5	Symmetry in General Bistatic Scattering	211
4.6	Symmetry in Backscattering	212
4.7	Symmetry in Forward-Scattering	216
4.8	Symmetry in Low-Frequency Scattering	222
4.9	Preliminaries for Self-Dual Targets	226
4.10	Duality	227
4.11	Scattering by Self-Dual Target	228
4.12	Backscattering by Self-Dual Target	229
4.13	Forward-Scattering by Self-Dual Target	231
4.14	Low-Frequency Scattering by Self-Dual Target	233
4.15	Conclusion	234
	References	235

CHAPTER 5 COMPLEMENTARY STRUCTURES IN TWO DIMENSIONS 237

Carl E. Baum

5.1	Introduction	237
5.2	Quasi-Static Boundary Value Problems in Two Dimensions	238
5.3	Two-Dimensional Complementary Structures	240
5.4	Lowest-Order Self-Complementary Rotation Group: C_{2c} Symmetry	241
5.5	N -Fold Rotation Axis: C_N Symmetry	243
5.6	Self-Complementary Rotation Group: C_{Nc} Symmetry	247
5.7	Reciprocation of Two-Dimensional Structures	250
5.8	Reflection Self-Complementarity	254
5.9	Conclusion	255
	References	256

CHAPTER 6 TOPOLOGY IN ELECTROMAGNETICS 258*Gerald E. Marsh*

- 6.1 Introduction 258
- 6.2 Magnetic Field Helicity 262
- 6.3 Solar Prominence Helicity 263
- 6.4 Twist, Kink, and Link Helicity 265
- 6.5 Helicity and the Asymptotic Hopf Invariant 270
- 6.6 Magnetic Energy in Multiply Connected Domains 276
 - 6.6.1 Gauge Invariance 282
- 6.7 Conclusion 282
- Appendix: The Classical Hopf Invariant 284
- References 286

CHAPTER 7 THE ELECTRODYNAMICS OF TORUS KNOTS 289*Douglas H. Werner*

- 7.1 Introduction 289
- 7.2 Theoretical Development 291
 - 7.2.1 Background 291
 - 7.2.2 Electromagnetic Fields of a Torus Knot 294
 - 7.2.3 The Torus Knot EFIE 299
- 7.3 Special Cases 302
 - 7.3.1 Small Knot Approximation 302
 - 7.3.2 The Canonical Unknot 304
- 7.4 Elliptical Torus Knots 304
 - 7.4.1 Background 304
 - 7.4.2 Electromagnetic Fields 307
- 7.5 Additional Special Cases 308
 - 7.5.1 Circular Torus Knots 308
 - 7.5.2 Small-Knot Approximation 309
 - 7.5.2.1 General Case 309
 - 7.5.2.2 Special Case when $p = q$ 310
 - 7.5.2.3 Special Case when $p = 2q$ 310
 - 7.5.3 Small-Knot Approximations for Circular Torus Knots 311
 - 7.5.3.1 Special Case when $p = q$ and $\gamma = \alpha$ 311
 - 7.5.3.2 Special Case when $p = 2q$ and $\gamma = \alpha$ 311
 - 7.5.4 Small-Knot Approximation 312
 - 7.5.4.1 General Case 312
 - 7.5.4.2 Special Case when $p/q = 2n$ 313
 - 7.5.4.3 Special Case when $p/q = 2n - 1$ 315
 - 7.5.4.4 Special Case when $p/q = (2n - 1)/2$ 317
 - 7.5.5 Circular Loop and Linear Dipole 319
- 7.6 Results 320
- 7.7 Conclusion 325
- Appendix 326
- References 327

PART II OPTIMIZATION AND ESTIMATION

CHAPTER 8 BIOLOGICAL BEAMFORMING 329

Randy L. Haupt, Hugh L. Southall, and Teresa H. O'Donnell

- 8.1 Biological Beamforming 329
- 8.2 Genetic Algorithm Beamforming 330
- 8.3 Low Sidelobe Phase Tapers 332
- 8.4 Phase-Only Adaptive Nulling 335
- 8.5 Adaptive Algorithm 337
- 8.6 Adaptive Nulling Results 339
- 8.7 Neural Network Beamforming 344
- 8.8 Neural Networks 345
- 8.9 Direction Finding 346
 - 8.9.1 Analogy Between the Neural Network and the Butler Matrix 346
 - 8.9.2 Single-Source DF: Comparison to Monopulse 352
 - 8.9.2.1 Network Architecture for Single-Source DF 352
 - 8.9.2.2 Network Training 353
 - 8.9.2.3 Rapid Convergence 354
 - 8.9.2.4 Monopulse Direction Finding 355
 - 8.9.2.5 Experimental DF Results 355
 - 8.9.3 Multiple-Source Direction Finding 357
- 8.10 Neural Network Beamsteering 358
 - 8.10.1 Network Architecture for Beamsteering 358
 - 8.10.2 The Experimental Phased-Array Antenna 360
 - 8.10.3 Experimental Beamsteering Results in a Clean Environment 360
 - 8.10.4 Neural Beamsteering in the Presence of a Near-Field Scatterer 364
 - 8.10.4.1 Neural Network Beamsteering 365
 - 8.10.4.2 Theoretical Predictions 365
 - 8.10.4.3 Description of the Scattering Experiment 367
 - 8.10.4.4 Experimental Beamsteering Results with a Near-Field Scatterer 368
- References 368

CHAPTER 9 MODEL-ORDER REDUCTION IN ELECTROMAGNETICS USING MODEL-BASED PARAMETER ESTIMATION 371

Edmund K. Miller and Tapan K. Sarkar

- 9.1 Background and Motivation 371
- 9.2 Waveform-Domain and Spectral-Domain Modeling 373
 - 9.2.1 Selecting a Fitting Model 376
- 9.3 Sampling First-Principle Models and Observables in the Waveform Domain 377
 - 9.3.1 Waveform-Domain Function Sampling 377

9.3.2	Waveform-Domain Derivative Sampling	380
9.3.3	Combining Waveform-Domain Function Sampling and Derivative Sampling	381
9.4	Sampling First-Principle Models and Observables in the Spectral Domain	384
9.4.1	Spectral-Domain Function Sampling	384
9.4.2	Spectral-Domain Derivative Sampling	386
9.4.3	Adapting and Optimizing Sampling of the GM	387
9.4.3.1	Possible Adaptive Sampling Strategies	388
9.4.3.2	Estimating FM Error or Uncertainty as an Adaptation Strategy	389
9.4.4	Initializing and Updating the Fitting Models	391
9.5	Application of MBPE to Spectral-Domain Observables	391
9.5.1	Non-Adaptive Modeling	392
9.5.2	Adaptive Modeling	395
9.5.3	Filtering Noisy Spectral Data	399
9.5.4	Estimating Data Accuracy	399
9.6	Waveform-Domain MBPE	402
9.6.1	Radiation-Pattern Analysis and Synthesis	403
9.6.2	Adaptive Sampling of Far-Field Patterns	404
9.6.3	Inverse Scattering	407
9.7	Other EM Fitting Models	407
9.7.1	Antenna Source Modeling Using MBPE	408
9.7.2	MBPE Applied to STEM	409
9.8	MBPE Application to a Frequency-Domain Integral Equation, First-Principles Models	410
9.8.1	The Two Application Domains in Integral-Equation Modeling	413
9.8.2	Formulation-Domain Modeling	414
9.8.2.1	Waveform-Based MBPE in the Formulation Domain	414
9.8.2.2	Modeling Frequency Variations: Antenna Applications	415
9.8.2.3	Modeling Frequency Variations: Elastodynamic Scattering	417
9.8.2.4	Modeling Spatial Variations: The Sommerfeld Problem	417
9.8.2.5	Modeling Spatial Variations: Waveguide Fields	420
9.8.2.6	Modeling Spatial Variations: Moment-Method Impedance Matrices	421
9.8.3	Using Spectral MBPE in the Solution Domain	424
9.8.3.1	Modeling the Admittance Matrix	424
9.8.3.2	Sampling Admittance-Matrices Derivatives	425
9.9	Observations and Concluding Comments	427
Appendix 9.1:	Estimating Data Rank	429
Appendix 9.2:	Using the Matrix Pencil to Estimate Waveform-Domain Parameters	431
References		433

CHAPTER 10 ADAPTIVE DECOMPOSITION IN ELECTROMAGNETICS 437*Joseph W. Burns and Nikola S. Subotic*

- 10.1 Introduction 437
- 10.2 Adaptive Decomposition 438
- 10.3 Overdetermined Dictionaries 440
 - 10.3.1 Physics-Based Dictionaries 441
 - 10.3.2 Data-Based Dictionaries 443
- 10.4 Solution Algorithms 443
 - 10.4.1 Method of Frames 444
 - 10.4.2 Best Orthogonal Basis 444
 - 10.4.3 Basis Pursuit 445
 - 10.4.3.1 Basis Pursuit Decomposition Example 446
 - 10.4.4 Matching Pursuit 448
 - 10.4.4.1 Matching Pursuit Decomposition Example 449
 - 10.4.5 Reweighted Minimum Norm 450
 - 10.4.5.1 Reweighted Minimum Norm Decomposition Example 451
- 10.5 Applications 453
 - 10.5.1 Scattering Decomposition for Inverse Problems 454
 - 10.5.1.1 Identification of Scattering Centers in Range Profiles 454
 - 10.5.1.2 Identification of Scattering Centers in SAR Imagery 457
 - 10.5.2 Decompositions for Data Filtering 460
 - 10.5.2.1 Measurement Contamination Mitigation 461
 - 10.5.3 Current Decomposition for Forward Problems 468
 - 10.5.3.1 Basis Transformation 468
 - 10.5.3.2 Adaptive Construction of Basis Functions 469
- 10.6 Conclusion 470
- References 470

PART III ANALYTICAL METHODS**CHAPTER 11 LOMMEL EXPANSIONS IN ELECTROMAGNETICS 474***Douglas H. Werner*

- 11.1 Introduction 474
- 11.2 The Cylindrical Wire Dipole Antenna 476
 - 11.2.1 The Cylindrical Wire Kernel 478
 - 11.2.2 The Uniform Current Vector Potential and Electromagnetic Fields 481
- 11.3 The Thin Circular Loop Antenna 486
 - 11.3.1 An Exact Integration Procedure for Near-Zone Vector Potentials of Thin Circular Loops 489
 - 11.3.2 Examples 490

11.3.2.1	Fourier Cosine Series Representation of the Loop Current	490
11.3.2.2	The Uniform Current Loop Antenna	495
11.3.2.3	The Cosinusoidal Current Loop Antenna	498
11.3.2.4	General Far-Field Approximations	501
11.3.2.5	The Traveling-Wave Current Loop Antenna	501
11.4	A Generalized Series Expansion	509
11.5	Applications	514
11.6	Conclusion	519
	References	520

CHAPTER 12 FRACTIONAL PARADIGM IN ELECTROMAGNETIC THEORY 523

Nader Engheta

12.1	Introduction	523
12.2	What is Meant by Fractional Paradigm in Electromagnetic Theory?	524
12.2.1	A Recipe for Fractionalization of a Linear Operator \underline{L}	528
12.3	Fractional Paradigm and Electromagnetic Multipoles	529
12.4	Fractional Paradigm and Electrostatic Image Methods for Perfectly Conducting Wedges and Cones	536
12.5	Fractional Paradigm in Wave Propagation	540
12.6	Fractionalization of the Duality Principle in Electromagnetism	543
12.7	Summary	547
	Appendix	547
	References	548

CHAPTER 13 SPHERICAL-MULTIPOLE ANALYSIS IN ELECTROMAGNETICS 553

Siegfried Blume and Ludger Klinkenbusch

13.1	Introduction	553
13.2	Sphero-Conal Coordinates	556
13.3	Spherical-Multipole Analysis of Scalar Fields	558
13.3.1	Scalar Spherical-Multipole Expansion in Sphero-Conal Coordinates	558
13.3.2	Scalar Orthogonality Relations	565
13.3.2.1	Orthogonality of Lamé Products	565
13.3.2.2	Orthogonality of Scalar Multipole Functions	566
13.3.3	Scalar Green's Functions in Sphero-Conal Coordinates	567
13.4	Spherical-Multipole Analysis of Electromagnetic Fields	568
13.4.1	Vector Spherical-Multipole Expansion of Solenoidal Electromagnetic Fields	568
13.4.2	Vector Orthogonality Relations	571
13.4.2.1	Orthogonality of the Transverse Vector Functions	571
13.4.2.2	Orthogonality of the Vector Spherical-Multipole Functions	573

13.4.3	Dyadic Green's Functions in Sphero-Conal Coordinates	576
13.4.4	Plane Electromagnetic Waves in Sphero-Conal Coordinates	581
13.5	Applications in Electrical Engineering	584
13.5.1	Electromagnetic Scattering by a PEC Semi-Infinite Elliptic Cone	584
13.5.2	Electromagnetic Scattering by a PEC Finite Elliptic Cone	587
13.5.3	Shielding Properties of a Loaded Spherical Shell with an Elliptic Aperture	594
Appendix 13.1	Solutions of the Vector Helmholtz Equation	599
Appendix 13.2	Paths of Integration for the Eigenfunction Expansion of the Dyadic Green's Function	602
Appendix 13.3	The Euler Summation Technique	604
References		606

PART IV NUMERICAL METHODS

CHAPTER 14 A SYSTEMATIC STUDY OF PERFECTLY MATCHED ABSORBERS 609

Mustafa Kuzuoglu and Raj Mittra

14.1	Introduction	609
14.2	Systematic Derivation of the Equations Governing Perfectly Matched Absorbers	612
14.2.1	Different PML Realizations for a TM Model Problem	613
14.2.1.1	The Split-Field Realization	614
14.2.1.2	The Anisotropic Realization	615
14.2.1.3	The Bianisotropic Realization	616
14.2.2	Cartesian Mesh Truncations and Corner Regions	617
14.2.3	Example of FEM Implementation of the Cartesian PML	619
14.2.4	Interpretation of the Cartesian PML in Terms of Complex Coordinate Stretching	620
14.2.5	PMLs in Curvilinear Coordinates	622
14.2.5.1	Split-Field (Non-Maxwellian) Realization	623
14.2.5.2	Anisotropic Realization	623
14.2.5.3	Bianisotropic Realization	624
14.3	Causality and Static PMLs	624
14.3.1	Constitutive Relations of a Causal PML	625
14.3.2	Non-Causal PML Media	627
14.3.3	Static PMLs	629
14.4	Reciprocity in Perfectly Matched Absorbers	632
14.4.1	Verification of Reciprocity in the Anisotropic and Bianisotropic Realizations	632
14.4.2	Example of a Non-Reciprocal PML	636
14.5	Conclusion	638
References		639

CHAPTER 15 FAST CALCULATION OF INTERCONNECT CAPACITANCES USING THE FINITE DIFFERENCE MODEL APPLIED IN CONJUNCTION WITH THE PERFECTLY MATCHED LAYER (PML) APPROACH FOR MESH TRUNCATION 644

Vladimir Veremey and Raj Mittra

- 15.1 Introduction 644
- 15.2 Finite Difference Mesh Truncation by Means of Anisotropic Dielectric Layers 646
 - 15.2.1 Perfectly Matched Layers for Mesh Truncation in Electrostatics 647
- 15.3 α -Technique for FD Mesh Truncation 649
- 15.4 Wraparound Technique for Mesh Truncation 652
- 15.5 Two-Step Calculation Method 653
- 15.6 Numerical Results 654
 - 15.6.1 Microstrip Line Over a Conducting Plane 654
 - 15.6.2 Coupled Microstrip Bends Over a Conducting Plane 655
 - 15.6.3 Crossover 655
 - 15.6.4 Combinations of Bends and Crossovers Above a Conducting Plane 659
 - 15.6.5 Two-Comb Structure Over a Ground Plane 662
- 15.7 Efficient Computation of Interconnect Capacitances Using the Domain Decomposition Approach 662
- 15.8 Conclusion 665
- References 665

CHAPTER 16 FINITE-DIFFERENCE TIME-DOMAIN METHODOLOGIES FOR ELECTROMAGNETIC WAVE PROPAGATION IN COMPLEX MEDIA 666

Jeffrey L. Young

- 16.1 Introduction 666
- 16.2 Maxwell's Equations and Complex Media 667
- 16.3 FDTD Method 669
- 16.4 Non-Dispersive, Anisotropic Media 671
- 16.5 Cold Plasma 674
 - 16.5.1 Direct Integration Method One: CP-DIM1 675
 - 16.5.2 Direct Integration Method Two: CP-DIM2 676
 - 16.5.3 Direct Integration Method Three: CP-DIM3 676
 - 16.5.4 Direct Integration Method Four: CP-DIM4 677
 - 16.5.5 Direct Integration Method Five: CP-DIM5 677
 - 16.5.6 Recursive Convolution Method One: CP-RCM1 677
 - 16.5.7 Recursive Convolution Method Two: CP-RCM2 679
 - 16.5.8 Comparative Analysis 680
- 16.6 Magnetoionic Media 682
- 16.7 Isotropic, Collisionless Warm Plasma 683
- 16.8 Debye Dielectric 686

16.8.1	Direct Integration Method One: D-DIM1	687
16.8.2	Direct Integration Method Two: D-DIM2	688
16.8.3	Direct Integration Method Three: D-DIM3	689
16.8.4	Recursive Convolution Method One: D-RCM1	689
16.8.5	Recursive Convolution Method Two: D-RCM2	690
16.8.6	Comparative Analysis	690
16.8.7	Parameter Selection	692
16.9	Lorentz Dielectric	693
16.9.1	Direct Integration Method One: L-DIM1	694
16.9.2	Direct Integration Method Two: L-DIM2	695
16.9.3	Direct Integration Method Three: L-DIM3	695
16.9.4	Recursive Convolution Method One: L-RCM1	696
16.9.5	Recursive Convolution Method Two: L-RCM2	696
16.9.6	Comparative Analysis	697
16.9.7	Numerical Results	698
16.10	Magnetic Ferrites	699
16.11	Nonlinear Dispersive Media	702
16.12	Summary	704
	References	705

CHAPTER 17 A NEW COMPUTATIONAL ELECTROMAGNETICS METHOD BASED ON DISCRETE MATHEMATICS 708

*Rodolfo E. Diaz, Franco Deflaviis, Massimo Noro,
and Nicolaos G. Alexopoulos*

17.1	Introduction	708
17.2	The Fitzgerald Mechanical Model	710
17.3	Extension to Debye Materials	713
17.4	The Simulation of General Ponderable Media	721
17.4.1	Non-Linear Dielectrics	721
17.4.2	How Should Moving Ponderable Media be Modeled?	723
17.4.3	Collisions Between Pulses and Objects	726
17.5	Conclusion	729
	References	730
	Glossary	731

CHAPTER 18 ARTIFICIAL BIANISOTROPIC COMPOSITES 732

Frédéric Mariotte, Bruno Sauviac, and Sergei A. Tretyakov

18.1	Introduction	732
18.2	Chiral Media and Omega Media	734
18.2.1	Classification of Bianisotropic Composites	734
18.2.2	Constitutive Equations and Electromagnetic Properties of Chiral Media	735
18.2.2.1	The Three General Formulations	736
18.2.2.2	Energy Considerations for Material Parameters	738
18.2.3	Wave Propagation in Chiral Materials	738

18.2.4	Field Equations for Uniaxial Omega Regions	741
18.2.5	Plane Eigenwaves, Propagation Factors, and Wave Impedances of Omega Media	741
18.3	Electromagnetic Scattering by Chiral Objects and Medium Modeling	743
18.3.1	Baseline to Model Bianisotropic Composites	743
18.3.2	Analytical Integral Equation Method for a Standard Helix	743
18.3.3	Numerical Integral Equation Method Using the Thin-Wire Approximation	744
18.3.4	Dipole Representation and Equivalent Polarizabilities for Chiral Scatterers	748
18.3.4.1	Calculation of Dipole Moments	748
18.3.4.2	Polarizabilities Calculation	749
18.3.5	Analytical Antenna Model for Canonical Chiral Objects and Omega Scatterers	750
18.3.5.1	Antenna Representation for the Chiral Scatterer—Polarizability Dyadic	751
18.3.5.2	Antenna Representation for the Omega Scatterer	753
18.3.6	Composite Modeling: Effective Medium Parameters	754
18.3.6.1	Isotropic Chiral Composites	754
18.3.6.2	Bianisotropic Composites	755
18.3.6.3	A Relation Between the Polarizabilities	756
18.4	Reflection and Transmission in Chiral and Omega Slabs: Applications	756
18.4.1	Continuity Problems with a Chiral Medium	756
18.4.2	Properties of a Single Slab	760
18.4.3	Properties of a Chiral Dällenbach Screen	764
18.4.4	Reflection and Transmission in Uniaxial Omega Slabs	765
18.4.5	Zero-Reflection Condition. Omega Slabs on Metal Surface	766
18.5	Future Developments and Applications	767
	References	769

INDEX 771

ABOUT THE EDITORS 785

PREFACE

The topics covered in this book are all relatively new and emerging areas of research in the field of electromagnetics. These topics were carefully selected not only because of their innovative nature, but also because they have the potential to make a significant impact on future directions in electromagnetics research. The chapters are designed to be as self-contained as possible with ample references provided for the benefit of interested readers. Many chapters also contain a brief tutorial intended to acquaint the unfamiliar reader with the mathematical foundations and fundamental concepts which form the basis for the more advanced material that follows.

The book contains 18 chapters that are organized into four sections. The first section (Chapters 1–7) addresses recent progress toward combining electromagnetic theory with concepts originating from several branches of mathematics including geometry, topology, and groups. State-of-the-art techniques in electromagnetic optimization and estimation are discussed in the second section of the book (Chapters 8–10). A variety of new developments in analytical and numerical methods for solving electromagnetics problems are considered in sections three (Chapters 11–13) and four (Chapters 14–18), respectively.

Fractal electrodynamics is the area of research that combines fractal geometric concepts with Maxwell's theory of electromagnetism in order to study a new class of radiation, scattering, and propagation problems. Recent advancements in fractal electrodynamics research are presented in Chapters 1–3. Chapter 1 starts out with an introduction to the properties of fractals, followed by an overview of research into the fundamental nature of electromagnetic wave interactions with fractal surfaces and superlattices. Applications of fractals to the design of antenna elements and arrays are discussed in Chapters 2 and 3, respectively. Chapters 4 and 5 deal with applications of group theory to the solution of electromagnetic problems that possess certain geometrical symmetries. The impact of reciprocity and geometrical symmetry of a target on the associated scattering dyadic is considered in Chapter 4. Chapter 5 introduces a generalized theory of self-complementary structures that is based on conformal and stereographic projections. The application of some topological results from knot theory to electromagnetics is addressed in Chapters 6 and 7. In Chapter 6, particular emphasis is placed on investigating the topological features of twisted or knotted field line configurations. The electromagnetic radiation and scattering properties of thin, knotted wires are discussed in Chapter 7.

Genetic algorithms are a group of powerful optimization methods that are based on the processes of procreation and natural evolution. Chapter 8 describes some novel approaches to antenna array beamforming based on genetic algorithms and neural networks. An approach for model-order reduction, known as *model-based*

parameter estimation, has been successfully applied to expedite the solution of a wide variety of computational electromagnetics problems. Chapter 9 includes a brief background discussion of model-based parameter estimation techniques followed by several examples illustrating its many practical uses in computational electromagnetics. Wavelets have received a considerable amount of recent attention for the potential advantages they offer in the solution of many electromagnetics problems. A newly developed wavelet-based method for the adaptive decomposition of electromagnetic signals into a wide range of physically meaningful mechanisms is presented in Chapter 10.

A technique for finding analytical solutions to a special class of electromagnetics problems which relies on Lommel expansions is outlined in Chapter 11. Several examples are presented in Chapter 11 including the derivation of an exact representation for the cylindrical wire kernel, and of useful near-field expansions for the circular loop antenna. Fractional calculus is the branch of mathematics that deals with a generalization of the well-known operations of differentiation and integration to non-integer orders. Chapter 12 explores applications as well as physical interpretation of non-integer order differential and integral operators in electromagnetics. A vector spherical-multipole analysis technique is presented in Chapter 13 that may be used for deriving analytical solutions to a wide range of interesting scattering and diffraction problems.

The recently introduced concept of perfectly matched layers and their application to the general problem of mesh truncation in finite methods for computational electromagnetics analysis are discussed in Chapter 14. A new method for the rapid calculation of interconnect capacitances is introduced in Chapter 15 which combines an electrostatic finite differencing scheme with a perfectly matched layer approach for mesh truncation. Chapter 16 examines the most recent and popular advances in finite-difference time-domain algorithm development for analysis of wave propagation in complex media. A new discrete mechanics approach to computational electromagnetics is introduced in Chapter 17. This new computational method offers several advantages over conventional approaches for the simulation of the interaction between electromagnetic fields and physically realistic media. Chapter 18 begins with a background discussion on the classification of bianisotropic composites, which are formed by embedding miniature complex-shaped inclusions, such as helices or omegas, in a host medium. This is followed by a more in-depth coverage of both analytical and numerical methods for modeling the electromagnetic properties of individual bianisotropic inclusions as well as composites.

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