Electromagnetic Modeling of Composite Metallic and Dielectric Structures

Branko M. Kolundzija Antonije R. Djordjević



ş

Artech House Boston • London www.artechhouse.com

Contents

.

1	Introduction	1
1.1	MoM as a General Approach to Solving Electromagnetic-Field Problems	2
1.2	MoM/SIE, MoM/VIE, and FEM	4
1.3	Basic Classes of Composite Metallic and Dielectric Structures (Material Structures)	6
1.4	Methods for the Analysis of Thin-Wire Structures	8
1.5	Methods for the Analysis of Metallic Structures	11
1.6	Methods for the Analysis of Composite Metallic and Dielectric Structures	14
1.7	What Is New in This Book?	15
1.8	Survey of Chapters References	18 20
2	MoM	27
2.1	Formulation of Deterministic-Field Problems	27

2.2	Linear Operator Equation	30
2.3	Solution of Integral Equations	33
2.3.1	Approximation of Unknown Function	33
2.3.2	Point-Matching Method	35
2.3.3	Data Postprocessing	36
2.3.4	Estimation of the Solution Quality	39
2.3.5	Least-Squares Method	43
2.3.6	Inner Product	45
2.3.7	Rayleigh-Ritz Method	47
2.3.8	Galerkin Method	49
2.3.9	MoM	54
2.3.10	Weighted Point-Matching Method	55
2.3.11	Memory and Analysis-Time Requirements	57
2.3.12	Choice of Test Procedure	59
2.3.13	Choice of Basis Functions	60
2.3.14	Adaptive Methods	63
2.4	Solution of Differential Equations	66
2.4.1	Approximation of Unknown Function	66
2.4.2	FD Method	70
2.4.3	Sparse Matrices	73
2.4.4	Iterative Procedure	75
2.4.5	FEM Via the Galerkin Method	79
2.5	Choosing the Optimal Method	82
2.6	Summary	83
	References	84
3	Electromagnetic Theory	87
3.1	Maxwell's Equations	87
3.1.1	Maxwell's Equations in the Frequency Domain	89
3.2	Retarded Potentials	93

3.3	Field Vectors	95
3.3.1	Basic Integral Expressions	95
3.3.2	Alternative Expressions for the Electric Field	97
3.3.3	Definition of L and K Operators	100
3.3.4	Expressions for Fields Due to Surface Current	100
3.3.5	Far-Field Expressions	104
3.4	Volume Equivalence Principle	105
3.5	Duality Relations Between Electric and Magnetic Quantities	107
3.6	Boundary Conditions	108
3.7	Formulation of the Basic Field Problem in the Frequency Domain	113
3.8	Poynting Theorem	115
3.9	Surface Equivalence Principle	116
3.10	Uniqueness Theorem	119
3.10.1	Single Region	119
3.10.2	Multiple Region	123
3.11	Summary	125
	References	126
4	Field Integral Equations	127
4.1	BIEs for Metallic Structures	128
4.1.1	EFIEs and MFIEs	132
4.1.2	Generalized Scalar Formulation of the EFIE and MFIE	134
4.1.3	Equivalent Sources and EBCs	136
4.1.4	Spurious Resonances	139
4.1.5	AFIE	143
4.1.6	CFIE	144
4.1.7	Generalized Scalar Formulation of CFIE	146

	4.1.8	CSIE	149
	4.1.9	Thin-Plate Approximation	151
	4.1.10	Thin-Wire Approximation	154
	4.1.11	Hallén Equation	158
4	4.1.12	IBC-IE	160
	4.1.13	Optimal Choice of BIEs for Analysis of Metallic	
		Structures	161
	4.2	BIEs for Combined Metallic and Dielectric	
		Structures	162
	4.2.1	EFIE, MFIE, and CFIE for Multiple-Region	
		Problems	167
	4.2.2	CRIEs	169
	4.2.3	Muller Formulation	170
	4.2.4	PMCHW Formulation	171
	4.2.5	Thin Plate at an Interface Between Two Regions	174
	4.2.6	Optimal Choice of BIEs for Analysis of	
		Multiple-Region Problems	175
	4.3	CIEs	176
	4.3.1	VIEs	178
	4.3.2	Metallic Surfaces with Distributed Loadings	179
	4.3.3	Wires with Distributed Loadings	182
	4.3.4	Wires with Concentrated Loadings	185
	4.4	Hybrid Methods	188
	4.4.1	Surface/Volume Integral Formulation	188
	4.4.2	MoM and FEM	189
	4.4.3	MoM and Green's-Function Techniques	190
	4.4.4	MoM and Asymptotic High-Frequency	
		Techniques	193
	4.5	Summary	196
		References	197
	5 -	Geometrical Modeling	203
	5.1	Wire Structures	204
	5.1.1	Generalized Wires	201
	~ • * • *		

5.1.2	Approximation of Wires by Spline Curves	205
5.1.3	Right Truncated Cones	207
5.1.4	Piecewise Cylindrical (Conical) Approximation of Wires	210
5.1.5	Equivalent Radius of Wire Curvature	210
5.2	Metallic and Dielectric Surfaces	214
5.2.1	Generalized Quadrilaterals and Triangles	214
5.2.2	Unitary Vectors and Related Quantities	217
5.2.3	Exact Modeling of Surfaces by Generalized Quadrilaterals	218
5.2.4	Approximations of Surfaces by Spline Quadrilaterals	219
5.2.5	Bilinear Surfaces and Flat Triangles	221
5.2.6	Piecewise Almost-Flat Approximation of Surfaces	223
5.2.7	Concept of Equivalent Radius for Surfaces	224
5.3	Dielectric Volumes	226
5.4	Wire-to-Plate Junctions and Related Structures	229
5.4.1	Attachment Modes	230
5.4.2	General Localized Junction Model	231
5.4.3	Protrusion of a Wire Through a Dielectric Surface	233
5.5	Automatic Parameterization of 3-D Geometries	234
5.6	Automatic Segmentation of Electrically Large Surface Patches	238
5.7	Summary	243
	References	245
6	Approximation of Currents and Fields	251
6.1	Approximation of Currents Along Wires	252
6.1.1	Subdomain Basis Functions	253
6.1.2	Entire-Domain Basis Functions	258

6.1.3	Inclusion of KCL into Basis Functions	260
6.1.4	Combined Polynomial and Trigonometric Expansions	264
6.1.5	Quasistatic Treatment of Wire Ends and	
	Interconnections	266
6.1.6	Basis Functions in Terms of Simplex	
	Coordinates	269
6.2	Approximation of Currents over Generalized	
	Quadrilaterals	271
6.2.1	Subdomain Approximation	272
6.2.2	Approximate and Exact Formulation of Surface	275
())	Doublets	275
6.2.3	Rooftop Basis Functions (Exact Formulation)	277
6.2.4	Entire-Domain Basis Functions	27.8
6.2.5	Inclusion of Continuity Equation into Basis Functions	280
6.2.6	Single and Multiple Metallic Junctions	283
6.2.7	Single and Multiple Dielectric Junctions	285
6.2.8	Composite Metallic and Dielectric Junctions	289
6.2.9	Inclusion of Quasistatic Relation (Edge Effect)	
	into Basis Functions	291
6.2.10	Square Scatterer Benchmark	293
6.3	Approximation of Currents over (Generalized)	
	Triangles	297
6.3.1	Doublets and Rooftop Basis Functions	297
6.3.2	Entire-Domain Approximation in Simplex	
	Coordinates	299
6.4	Generalized Hexahedrons	304
6.4.1	Basis Functions That Maintain Normal	
	Continuity (VIE)	304
6.4.2	Basis Functions That Maintain Tangential	_
	Continuity (FEM)	307
6.5	Generalized Tetrahedrons	210
U.J	Generalized Tetranedrons	310

6.6	Approximation of Currents and Fields Across Junctions of Incompatible Building Elements	311
6.7	Comparison of MoM/SIE, MoM/VIE, and FEM Based on Topological Analysis	314
6.8	Summary	318
	References	319
7	Treatment of Excitations	323
7.1	Free-Space Waves	323
7.2	Voltage and Current Generators	325
7.2.1	Delta-Function Generator	326
7.3	Guided Waves	329
7.3.1	Exact Modeling	329
7.3.2	TEM Magnetic-Current Frill	333
7.4	Transfer of Excitation	337
7.5	Summary	339
	References	339
8	Test Procedure	341
8.1	Testing of Vector Equations in Nonorthogonal	
	Coordinate Systems	341
8.2	Weighted Point-Matching Method	344
8.2.1	Choice of Matching (Integration) Points and	
	Weighting Coefficients	345
8.2.2	Field Integrals of Currents over Generalized Quadrilaterals	348
8.2.3	Reduced Kernel in Field Integrals of Currents	
	Along Generalized Wires	350
8.3	Galerkin Method	354
8.3.1	Choice of the SIE Form	354

xi

	Index	393
	About the Authors	391
	References	388
9.6	Summary	388
9.5	Base-Station Antenna with Cosecant Characteristic at 60 GHz	383
9.4	Stacked Patch Antenna Mounted on an Airplane	380
9.3	Paraboloidal Reflector Antenna with Feed and Feed Struts	377
9.2	Horn Antennas	373
9.1	TV-UHF Panel Antenna with Radome	370
9	Practical Examples	369
8.5	Summary References	367 367
8.4	Choice of Optimal Test Procedure	365
8.3.3	Simplified Testing Based on Generalized Scalar Formulation of SIEs	362
8.3.2	Impedance Integrals Due to Currents over Generalized Quadrilaterals	357