
CONTENTS

Preface	xi
Abbreviations and Acronyms	xiii
1 INTRODUCTION	1
1.1 The Definition of a Conformal Antenna	1
1.2 Why Conformal Antennas?	2
1.3 History	4
1.4 Metal Radomes	9
1.5 Sonar Arrays	9
References	11
2 CIRCULAR ARRAY THEORY	15
2.1 Introduction	15
2.2 Fundamentals	16
2.2.1 Linear Arrays	16
2.2.2 Circular Arrays	19
2.3 Phase Mode Theory	23
2.3.1 Introduction	23
2.3.2 Discrete Elements	27
2.3.3 Directional Elements	29
2.4 The Ripple Problem in Omnidirectional Patterns	34
2.4.1 Isotropic Radiators	37
2.4.2 Higher-Order Phase Modes	40
2.4.3 Directional Radiators	40
2.5 Elevation Pattern	41
2.6 Focused Beam Pattern	41
References	46
3 THE SHAPES OF CONFORMAL ANTENNAS	49
3.1 Introduction	49
3.2 360° Coverage	52

vi CONTENTS

3.2.1	360° Coverage Using Planar Surfaces	52
3.2.2	360° Coverage Using a Curved Surface	54
3.3	Hemispherical Coverage	57
3.3.1	Introduction	57
3.3.2	Hemispherical Coverage Using Planar Surfaces	58
3.3.3	Half Sphere	60
3.3.4	Cone	60
3.3.5	Ellipsoid	62
3.3.6	Paraboloid	63
3.3.7	Comparing Shapes	64
3.4	Multifaceted Surfaces	67
3.5	References	70

4 METHODS OF ANALYSIS 73

4.1	Introduction	73
4.2	The Problem	75
4.3	Electrically Small Surfaces	76
4.3.1	Introduction	76
4.3.2	Modal Solutions	76
4.3.2.1	Introduction	76
4.3.2.2	The Circular Cylinder	77
4.3.2.3	A Unit Cell Approach	79
4.3.3	Integral Equations and the Method of Moments	80
4.3.4	Finite Difference Time Domain Methods (FDTD)	81
4.3.4.1	Introduction	81
4.3.4.2	Conformal or Contour-Patch (CP) FDTD	82
4.3.4.3	FDTD in Global Curvilinear Coordinates	83
4.3.4.4	FDTD in Cylindrical Coordinates	84
4.3.5	Finite Element Method (FEM)	87
4.3.5.1	Introduction	87
4.3.5.2	Hybrid FE-BI Method	88
4.4	Electrically Large Surfaces	89
4.4.1	Introduction	89
4.4.2	High-Frequency Methods for PEC Surfaces	90
4.4.3	High-Frequency Methods for Dielectric Coated Surfaces	93
4.5	Two Examples	95
4.5.1	Introduction	95
4.5.2	The Aperture Antenna	95
4.5.3	The Microstrip-Patch Antenna	98
4.6	A Comparison of Analysis Methods	100
Appendix 4A	—Interpretation of the ray theory	100
4A.1	Watson Transformation	103
4A.2	Fock Substitution	103
4A.3	SDP Integration	104
4A.4	Surface Waves	105
4A.5	Generalization	107
References		108

5	GEODESICS ON CURVED SURFACES	123
5.1	Introduction	123
5.1.1	Definition of a Surface and Related Parameters	125
5.1.2	The Geodesic Equation	127
5.1.3	Solving the Geodesic Equation and the Existence of Geodesics	128
5.2	Singly Curved Surfaces	130
5.3	Doubly Curved Surfaces	135
5.3.1	Introduction	135
5.3.2	The Cone	135
5.3.3	Rotationally Symmetric Doubly Curved Surfaces	137
5.3.4	Properties of Geodesics on Doubly Curved Surfaces	139
5.3.5	Geodesic Splitting	141
5.4	Arbitrarily Shaped Surfaces	149
5.4.1	Hybrid surfaces	150
5.4.2	Analytically Described Surfaces	152
	References	152
6	ANTENNAS ON SINGLY CURVED SURFACES	155
6.1	Introduction	155
6.2	Aperture Antennas on Circular Cylinders	157
6.2.1	Introduction	157
6.2.2	Theory	157
6.2.3	Mutual Coupling	158
6.2.3.1	Isolated Mutual Coupling	158
6.2.3.2	Cross Polarization Coupling	168
6.2.3.3	Array mutual coupling	168
6.2.4	Radiation Characteristics	173
6.2.4.1	Isolated-Element Patterns	175
6.2.4.2	Embedded-Element Patterns	176
6.3	Aperture Antennas on General Convex Cylinders	192
6.3.1	Introduction	192
6.3.2	Mutual Coupling	193
6.3.2.1	The Elliptic Cylinder	193
6.3.2.2	The Parabolic Cylinder	194
6.3.2.3	The Hyperbolic Cylinder	194
6.3.3	Radiation Characteristics	194
6.3.3.1	The Elliptic Cylinder	196
6.3.3.2	End Effects	196
6.4	Aperture Antennas on Faceted Cylinders	200
6.4.1	Introduction	200
6.4.2	Mutual Coupling	207
6.4.3	Radiation Characteristics	209
6.5	Aperture Antennas on Dielectric Coated Circular Cylinders	209
6.5.1	Introduction	209
6.5.2	Mutual Coupling	213
6.5.2.1	Isolated Mutual Coupling	213
6.5.2.2	Array Mutual Coupling	215
6.5.3	Radiation Characteristics	221

viii CONTENTS

	6.5.3.1 Isolated-Element Patterns	221
	6.5.3.2 Embedded-Element Patterns	223
6.6	Microstrip-Patch Antennas on Coated Circular Cylinders	230
	6.6.1 Introduction	230
	6.6.2 Theory	231
	6.6.3 Mutual Coupling	232
	6.6.3.1 Single-Element Characteristics	232
	6.6.3.2 Isolated and Array Mutual Coupling	232
	6.6.4 Radiation Characteristics	237
	6.6.4.1 Isolated-Element Patterns	237
	6.6.4.2 Embedded-Element Patterns	238
6.7	The Cone	245
	6.7.1 Introduction	245
	6.7.2 Mutual Coupling	246
	6.7.2.1 Aperture Antennas	246
	6.7.2.2 Microstrip-Patch Antennas	247
	6.7.3 Radiation Characteristics	248
	6.7.3.1 Aperture Antennas	248
	6.7.3.2 Microstrip-Patch Antennas	257
	References	258
7	ANTENNAS ON DOUBLY CURVED SURFACES	265
	7.1 Introduction	265
	7.2 Aperture Antennas	267
	7.2.1 Introduction	267
	7.2.2 Mutual Coupling	267
	7.2.2.1 Isolated Mutual Coupling	269
	7.2.2.2 Array Mutual Coupling	282
	7.2.3 Radiation Characteristics	283
	7.3 Microstrip-Patch Antennas	289
	7.3.1 Introduction	289
	7.3.2 Mutual Coupling	289
	7.3.2.1 Single-Element Characteristics	291
	7.3.2.2 Isolated Mutual Coupling	294
	7.3.3 Radiation Characteristics	297
	References	302
8	CONFORMAL ARRAY CHARACTERISTICS	305
	8.1 Introduction	305
	8.2 Mechanical Considerations	306
	8.2.1 Array Shapes	306
	8.2.2 Element Distribution on a Curved Surface	308
	8.2.3 Multifacet Solutions	308
	8.2.4 Tile Architecture	309
	8.2.5 Static and Dynamic Stress	312
	8.2.6 Other Electromagnetic Considerations	312
	8.3 Radiation Patterns	313
	8.3.1 Introduction	313

8.3.2	Grating Lobes	315
8.3.3	Scan-Invariant Pattern	319
8.3.4	Phase-Scanned Pattern	319
8.3.5	A Simple Aperture Model for Microstrip Arrays	323
8.4	Array Impedance	327
8.4.1	Introduction	327
8.4.2	Phase-Mode Impedance	330
8.5	Polarization	336
8.5.1	Polarization Definitions	336
8.5.2	Cylindrical Arrays	337
8.5.2.1	Dipole Elements	337
8.5.2.2	Aperture elements	337
8.5.3	Polarization in Doubly Curved Arrays	340
8.5.3.1	A Paraboloidal Array	341
8.5.4	Polarization Control	348
8.6	Characteristics of Selected Conformal Arrays	351
8.6.1	Nearly Planar Arrays	351
8.6.2	Circular Arrays	351
8.6.3	Cylindrical Arrays	351
8.6.4	Conical Arrays	351
8.6.5	Spherical Arrays	354
8.6.6	Paraboloidal Arrays	356
8.6.7	Ellipsoidal Arrays	358
8.6.8	Other Shapes	359
	References	359

9	BEAM FORMING	365
9.1	Introduction	365
9.2	A Note on Orthogonal Beams	366
9.3	Analog Feed Systems	366
9.3.1	Vector Transfer Matrix Systems	367
9.3.2	Switch Matrix Systems	367
9.3.3	Butler Matrix Feed Systems	370
9.3.4	RF Lens Feed Systems	374
9.3.4.1	The R-2R Lens Feed	374
9.3.4.2	The R-kR Lens Feed	375
9.3.4.3	Mode-Controlled Lenses	376
9.3.4.4	The Luneburg Lens	377
9.3.4.5	The Geodesic Lens	378
9.3.4.6	The Dome Antenna	380
9.4	Digital Beam Forming	380
9.5	Adaptive Beam Forming	384
9.5.1	Introduction	384
9.5.2	The Sample Matrix Inversion Method	384
9.5.3	An Adaptive Beam Forming Simulation Using a Circular Array	385
9.6	Remarks on Feed Systems	388
	References	389

x CONTENTS

10	CONFORMAL ARRAY PATTERN SYNTHESIS	395
10.1	Introduction	395
10.2	Shape Optimization	397
10.3	Fourier Methods for Circular Ring Arrays	397
10.4	Dolph-Chebysjev Pattern Synthesis	398
	10.4.1 Isotropic Elements	398
	10.4.2 Directive Elements	399
10.5	An Aperture Projection Method	401
10.6	The Method of Alternating Projections	404
10.7	Adaptive Array Methods	406
10.8	Least-Mean-Squares Methods (LMS)	407
10.9	Polarimetric Pattern Synthesis	409
10.10	Other Optimization Methods	409
10.11	A Synthesis Example Including Mutual Coupling	411
10.12	A Comparison of Synthesis Methods	414
	References	418
11	SCATTERING FROM CONFORMAL ARRAYS	421
11.1	Introduction	431
11.2	Definitions	422
11.3	Radar Cross Section Analysis	423
	11.3.1 General	423
	11.3.2 Analysis Method for an Array on a Conducting Cylinder	424
	11.3.3 Analysis Method for an Array on a Conducting Cylinder with a Dielectric Coating	426
11.4	Cylindrical Array	427
	11.4.1 Analysis and Experiment—Rectangular Grid	427
	11.4.2 Higher-Order Waveguide Modes	430
	11.4.3 Triangular Grid	432
	11.4.4 Conclusions from the PEC Conformal Array Analysis	433
11.5	Cylindrical Array with Dielectric Coating	435
	11.5.1 Single Element with Dielectric Coating	436
	11.5.2 Array with Dielectric Coating	437
11.6	Radiation and Scattering Trade-off	446
	11.6.1 Introduction	446
	11.6.2 Single-Element Results	449
	11.6.3 Array Results	454
11.7	Discussion	458
	References	459
	Subject Index	463
	About the Authors	471