Contents

Preface xi
Acknowledgments xv

Part I Introduction 1

1. Categorization of Natural Materials and Metamaterials 3
   1.1 Natural and Metamaterial Antennas Discussed in This Book 3
   1.2 Some Antenna Examples 6
   References 8

2. Integral Equations and Method of Moments 11
   2.1 Basic Antenna Characteristics 11
   2.2 Integral Equation on a Straight-Wire Antenna 15
   2.3 Method of Moments 16
   2.4 Integral Equation for an Arbitrarily Shaped Wire Antenna in Free
      Space 19
   2.5 Point-Matching Technique 22
   2.6 Integral Equation N1 for an Arbitrarily Shaped Wire Antenna: Closed
      Kernel Expression 23
   2.7 Integral Equations N2 and N3 for an Antenna System Composed of an
      Arbitrarily Shaped Wire and an Arbitrarily Shaped Aperture and Their
      MoM Transformation 27
   2.8 Integral Equation N4 for an Arbitrarily Shaped Wire Antenna on a
      Dielectric Substrate Backed by a Conducting Plane and Its MoM
      Transformation 34
   2.9 Integral Equation N5 for an Arbitrarily Shaped Wire Antenna on a
      Dielectric Half-Space and Its Transformation Using a Finite-Difference
      Technique 41
   References 46
3. Finite-Difference Time-Domain Methods (FDTDMs) 49

3.1 Basis 49

3.2 LOD–FDTD Method 52

References 57

Part II Low-Profile Natural Antennas 59

Part II-1 Base Station Antennas 61

4. Inverted-F Antennas 63

4.1 Inverted-F Antenna with a Single Parasitic Inverted-L Element 63

4.2 Inverted-F Antenna with a Pair of Parasitic Inverted-L Elements 67

References 73

5. Multiloop Antennas 75

5.1 Discrete Multiloop (ML) Antennas 75

5.2 Modified Multiloop Antennas 78

5.3 Plate-Loop (PL) Antenna 82

References 83

6. Fan-Shaped Antenna 85

6.1 Wideband Input Impedance 85

6.2 Characteristics of The Fan-Shaped Antenna 86

6.3 Cross Fan-Shaped Antenna (X-Fan Antenna) 87

6.4 Cross Fan-Shaped Antenna Surrounded By a Wire (X-Fan-W) 89

6.5 Cross Fan-Shaped Antenna with Slots (X-Fan-S) 92

References 93

7. BOR–SPR Antenna 95

7.1 Configuration 95

7.2 Antenna Input Characteristics of Initial Patch, Patch-Slot, and PSP Antennas 97

7.3 Replacement of The Patch Island with a Conducting Body of Revolution (BOR) 99

References 103
Part II-2 Card Antennas for Mobile Equipment 105

8. Inverted LFL Antenna for Dual-Band Operation 107
   8.1 Configuration 107
   8.2 Design 107
   References 114

9. Fan-Shaped Card Antenna 117
   9.1 Configuration 117
   9.2 Antenna Characteristics 118
   References 123

10. Planar Monopole Card Antenna 125
    10.1 Ant-1 and Ant-2 125
    10.2 Ant-3 and Ant-4 127
    References 131

Part II-3 Beam forming Antennas 133

11. Inverted-F Antenna Above an Electromagnetic Band-Gap Reflector 135
    11.1 Inverted-F Array with an EBG Reflector (EBG-InvF Array) 135
    11.2 Antenna Characteristics 136
    References 140

12. Reconfigurable Bent Two-Leaf and Four-Leaf Antennas 143
    12.1 BeToL Antenna 143
    12.2 BeFoL Antenna 153
    References 160

13. Patch Antenna with a Nonuniform Loop Plate 163
    13.1 Antenna System 163
    13.2 Reference Gain and Broadside Radiation—Placement of a
        Homogeneous PerioAEs Plate 166
    13.3 Gradation Constant and Tilted Radiation Beam—Placement of a
        Nonhomogeneous PerioAEs Plate 168
    13.4 Gain 170
    References 173

14. Linearly Polarized Rhombic Grid Array Antenna 175
    14.1 Configuration 175
    14.2 Radiation Pattern and Gain 177
    14.3 VSWR Characteristic 183
    References 183
15. **Circularly Polarized Grid Array Antenna** 185

- 15.1 Configuration of a Prototype Loop-Based CP GAA\textsubscript{EDG} 185
- 15.2 Radiation Characteristics of The Prototype Loop-Based CP GAA\textsubscript{EDG} 188
- 15.3 Configuration of an Advanced Loop-Based CP GAA\textsubscript{EDG} 191
- 15.4 Radiation Characteristics of The Advanced Loop-Based CP GAA\textsubscript{EDG} 192

References 198

**Part II-4 Earth–Satellite and Satellite–Satellite Communications Antennas** 199

16. **Monofilar Spiral Antenna Array** 201

- 16.1 Tilted-Beam Monofilar Spiral Antenna 201
- 16.2 Tilted CP Fan Beam 206

References 209

17. **Low-Profile Helical Antenna Array** 211

- 17.1 Array Element 211
- 17.2 Array Antenna 213
- 17.3 Application Examples 219

References 221

18. **Curl Antennas** 223

- 18.1 High-Gain Normal-Beam Array Antenna Composed of Internal-Excitation Curl Elements 223
- 18.2 High-Gain Tilted-Beam Array Antenna Composed of External-Excitation Curl Elements 229

References 236

**Part III Low-Profile Metamaterial Antennas** 237

19. **Metaline Antenna** 239

- 19.1 Unit Cell 239
- 19.2 Natural Characteristic Impedance $Z_{\text{NTR}}$, Bloch Impedance $Z_B$, and Phase Constant $\beta$ 240
- 19.3 Two-Metaline Antennas 243

References 246
20. Metaloop Antenna for Linearly Polarized Radiation 247
   20.1 Metaloop Configuration 247
   20.2 Single- and Dual-Peak Beams 249
   References 253

21. Circularly Polarized Metaloop Antenna 255
   21.1 Configuration 255
   21.2 Counter-CP Radiation 255
   References 260

22. Metaspiral Antenna 261
   22.1 Circularly Polarized Radiation 261
   22.2 Linearly Polarized Radiation 266
   References 271

23. Metahelical Antennas 273
   23.1 Round Metahelical Antenna 273
   23.2 Rectangular Metahelical Antenna 276
   References 282

Index 283