

- Foreword p. xix
- Preface p. xxi
- 1 Microstrip Radiators p. 1
- 1.1 Introduction p. 1
- 1.1.1 Advantages and Limitations of Microstrip Antennas p. 2
- 1.1.2 Radiation Mechanism of a Microstrip Antenna p. 3
- 1.2 Various Microstrip Antenna Configurations p. 8
- 1.2.1 Microstrip Patch Antennas p. 8
- 1.2.2 Microstrip or Printed Dipole Antennas p. 9
- 1.2.3 Printed Slot Antennas p. 13
- 1.2.4 Microstrip Traveling-Wave Antennas p. 13
- 1.3 Feeding Techniques and Modeling p. 14
- 1.3.1 Coaxial Feed/Probe Coupling p. 16
- 1.3.2 Microstrip (Coplanar) Feeds p. 19
- 1.3.3 Proximity (Electromagnetically) Coupled Microstrip Feed p. 28
- 1.3.4 Aperture-Coupled Microstrip Feed p. 28
- 1.3.5 Coplanar Waveguide Feed p. 29
- 1.4 Radiation Fields p. 31
- 1.4.1 Vector Potentials and Radiation Field Formulation p. 33
- 1.4.2 Microstrip Antenna Characteristics Calculations p. 40
- 1.5 Surface Waves and Photonic Bandgap Structures p. 43
- 1.5.1 Surface Waves p. 43
- 1.5.2 Photonic Bandgap Structures p. 47
- 1.6 Applications p. 54
- 1.6.1 Mobile and Satellite Communications Applications p. 57
- 1.6.2 Radar Antennas p. 66
- 1.6.3 Patch Applicators for Medicine p. 67
- References p. 68
- 2 Analytical Models for Microstrip Antennas p. 73
- 2.1 Introduction p. 73
- 2.2 Transmission Line Model p. 78
- 2.2.1 Simple Transmission Line Model p. 80
- 2.2.2 Transmission Line Model With Mutual Coupling p. 82
- 2.2.3 Generalized Transmission Line Model p. 85
- 2.2.4 Lossy Transmission Line Model p. 88
- 2.3 Cavity Model p. 90
- 2.4 Generalized Cavity Model p. 97
- 2.5 Multiport Network Model p. 103
- 2.6 Radiation Fields p. 108
- 2.7 Aperture Admittance p. 110
- 2.7.1 Aperture Conductance,  $G_s$  p. 111
- 2.7.2 Edge Susceptance,  $B_s$  p. 116
- 2.8 Mutual Admittance,  $Y_m$  p. 118
- 2.8.1 Mutual Conductance,  $G_m$  p. 118
- 2.8.2 Mutual Susceptance,  $B_m$  p. 120
- 2.9 Model for Coaxial Probe in Microstrip Antennas p. 121

- 2.10 Comparison of Analytical Models p. 126
- Appendix 2A Theoretical Background of the Generalized Transmission Line Model p. 128
- Appendix 2B Eigenfunctions, Equivalent Dimensions, and Effective Permittivities for Some Patch Shapes With Separable Geometries p. 144
- References p. 150
- 3 Full-Wave Analysis of Microstrip Antennas p. 157
- 3.1 Spectral-Domain Full-Wave Analysis p. 159
- 3.1.1 Input Impedance and Radiation Efficiency p. 164
- 3.1.2 Radiation Patterns p. 166
- 3.1.3 Numerical Evaluation of Matrix Elements and Voltage Vector p. 169
- 3.1.4 Basis Functions p. 174
- 3.1.5 Mathematical Model of Excitation p. 179
- 3.1.6 Applications of the Spectral-Domain Technique to Microstrip Antennas p. 185
- 3.2 Mixed-Potential Integral Equation Analysis p. 186
- 3.2.1 Potential Green's Functions in the Spectral Domain p. 187
- 3.2.2 Potential Green's Functions in the Space Domain p. 189
- 3.2.3 Results for Potentials for a Single-Layer Microstrip Structure p. 190
- 3.2.4 Integral Equation Solution Using Method of Moments p. 191
- 3.2.5 Applications of the MPIE Technique to Microstrip Antennas p. 197
- 3.3 Finite-Difference Time-Domain Analysis p. 197
- 3.3.1 Formulation of FDTD p. 199
- 3.3.2 Stability Criteria p. 203
- 3.3.3 Numerical Dispersion p. 203
- 3.3.4 Absorbing Boundary Conditions p. 205
- 3.3.5 Excitation and Source Modeling p. 214
- 3.3.6 Extraction of Frequency-Domain Characteristics From Time-Domain Data p. 217
- 3.3.7 Propagation in a Microstrip Line p. 220
- 3.3.8 Applications of the FDTD Technique to Microstrip Antennas p. 221
- Appendix 3A Derivation of Green's Functions in the Spectral Domain p. 224
- Appendix 3B Moment Method Solution p. 231
- Appendix 3C Derivation of Potential Green's Functions p. 234
- Appendix 3D Numerical Evaluation of Scalar and Vector Potentials p. 240
- References p. 246
- 4 Rectangular Microstrip Antennas p. 253
- 4.1 Introduction p. 253
- 4.2 Models for Rectangular Patch Antennas p. 254
- 4.2.1 Transmission Line Model Analysis p. 255
- 4.2.2 Cavity Model Analysis p. 257
- 4.3 Design Considerations for Rectangular Patch Antennas p. 265
- 4.3.1 Substrate Selection p. 265
- 4.3.2 Element Width and Length p. 265
- 4.3.3 Radiation Patterns and Radiation Resistance p. 269
- 4.3.4 Losses and Q Factor p. 279
- 4.3.5 Bandwidth p. 282
- 4.3.6 Radiation Efficiency,  $e_r$  p. 285

- 4.3.7 Feed Point Location p. 287
- 4.3.8 Polarization p. 289
- 4.3.9 RCS of a Rectangular Patch p. 290
- 4.3.10 Effects of a Dielectric Cover p. 291
- 4.3.11 Effects of Finite Size Ground Plane p. 293
- 4.3.12 Computer-Aided Design p. 297
- 4.4 Tolerance Analysis of Rectangular Microstrip Antennas p. 299
- 4.5 Mechanical Tuning of Patch Antennas p. 302
- 4.5.1 Mechanical Tuning Using Stubs p. 303
- 4.5.2 Mechanical Tuning Based on Shorting Posts or Pins p. 303
- 4.5.3 Mechanical Tuning Using an Adjustable Air Gap p. 306
- 4.6 Quarter-Wave Rectangular Patch Antennas p. 306
- 4.6.1 Quarter-Wave Patch With Shorting Pins p. 308
- 4.6.2 Stacked Quarter-Wave Antennas p. 311
- References p. 314
- 5 Circular Disk and Ring Antennas p. 317
- 5.1 Introduction p. 317
- 5.2 Analysis of a Circular Disk Microstrip Antenna p. 317
- 5.2.1 Cavity Model p. 318
- 5.2.2 Mode Matching With Edge Admittance p. 329
- 5.2.3 Generalized Transmission Line Model for a Circular Disk p. 337
- 5.3 Design Considerations for Circular Disk Antennas p. 339
- 5.3.1 Substrate Selection and Disk Radius p. 339
- 5.3.2 Radiation Patterns p. 342
- 5.3.3 Quality Factor and Impedance Bandwidth p. 349
- 5.3.4 Radiation Efficiency p. 351
- 5.3.5 Feed Point Location p. 352
- 5.3.6 Polarization p. 354
- 5.3.7 Circular Disk Antenna With an Air Gap p. 356
- 5.3.8 Effects of a Dielectric Cover or Superstrate p. 357
- 5.3.9 RCS of a Circular Disk Antenna p. 358
- 5.3.10 Computer-Aided Design p. 359
- 5.4 Semicircular Disk and Circular Sector Microstrip Antennas p. 360
- 5.5 Comparison of Rectangular and Circular Disk Microstrip Antennas p. 364
- 5.6 Circular Ring or Annular Ring Microstrip Antennas p. 366
- 5.6.1 Fields and Currents p. 368
- 5.6.2 Resonant Frequency p. 371
- 5.6.3 Radiation Fields p. 374
- 5.6.4 Losses, Q, and Resonant Resistance p. 379
- 5.6.5 Input Impedance p. 381
- 5.6.6 Circular Microstrip Ring Antenna With a Dielectric Cover or Superstrate p. 385
- 5.6.7 Circular Microstrip Ring Antenna With an Air Gap p. 387
- 5.7 Circular Sector Microstrip Ring Antennas p. 387
- 5.8 Microstrip Ring Antennas With Noncircular Shapes p. 388
- References p. 394
- 6 Dipoles and Triangular Patch Antennas p. 399

- 6.1 Microstrip Dipole and Center-Fed Dipoles p. 399
- 6.1.1 Feed Design Considerations p. 403
- 6.1.2 Input Impedance of a Dipole p. 409
- 6.1.3 Radiation Patterns p. 416
- 6.1.4 Design of a Printed Dipole and a Microstrip Dipole p. 416
- 6.1.5 Mutual Coupling Between Dipoles p. 422
- 6.2 Triangular Microstrip Patch Antennas p. 425
- 6.2.1 Field Representation p. 425
- 6.2.2 Resonant Frequency p. 429
- 6.2.3 Input Impedance p. 430
- 6.2.4 Radiation Patterns p. 432
- 6.2.5 Design of an Equilateral Triangular Patch Antenna p. 433
- References p. 436
- 7 Microstrip Slot Antennas p. 441
- 7.1 Introduction p. 441
- 7.2 Microstrip-Fed Rectangular Slot Antennas p. 441
- 7.2.1 Equivalent Circuit p. 446
- 7.2.2 Determination of Network Quantities p. 447
- 7.2.3 Inclined Slot p. 453
- 7.2.4 Design of Microstrip-Fed Slot Antenna p. 455
- 7.2.5 Radiation Patterns p. 457
- 7.3 CPW-Fed Slot Antennas p. 463
- 7.4 Annular Slot Antennas p. 470
- 7.5 Tapered Slot Antennas p. 480
- 7.5.1 Beamwidth p. 481
- 7.5.2 Input Impedance p. 483
- 7.5.3 Excitation of TSA p. 486
- 7.6 Comparison of Slot Antennas With Microstrip Antennas p. 487
- References p. 488
- 8 Circularly Polarized Microstrip Antennas and Techniques p. 493
- 8.1 Introduction p. 493
- 8.2 Various Types of Circularly Polarized Printed Antennas p. 493
- 8.2.1 Microstrip Patch Antennas p. 494
- 8.2.2 Other Types of Circularly Polarized Antennas p. 500
- 8.3 Singly Fed Circularly Polarized Microstrip Antennas p. 503
- 8.3.1 Rectangular-Type Circularly Polarized Microstrip Antennas p. 505
- 8.3.2 Circularly Polarized Circular Microstrip Antennas p. 513
- 8.4 Dual-Orthogonal Feed Circularly Polarized Microstrip Antennas p. 515
- 8.4.1 The Quadrature Hybrid p. 516
- 8.4.2 The 180-Degree Hybrid p. 518
- 8.4.3 The Wilkinson Power Divider p. 518
- 8.4.4 The T-Junction Power Divider p. 519
- 8.4.5 Design Procedure p. 520
- 8.5 Circularly Polarized Traveling-Wave Microstrip Line Arrays p. 520
- 8.5.1 Rampart Line Antenna and Crank-Type Microstrip Line Antenna p. 521
- 8.5.2 Chain Antenna p. 522

- 8.5.3 Square-Loop-Type Microstrip Line Antenna p. 523
- 8.6 Bandwidth Enhancement Techniques p. 524
- 8.6.1 Utilization of Wide-Band Microstrip Antennas p. 524
- 8.6.2 Sequentially Rotated Arrays p. 525
- References p. 530
- 9 Broadbanding of Microstrip Antennas p. 533
- 9.1 Introduction p. 533
- 9.2 Effects of Substrate Parameters on Bandwidth p. 534
- 9.3 Selection of Suitable Patch Shape p. 538
- 9.4 Selection of Suitable Feeding Technique p. 538
- 9.4.1 Aperture-Coupled Microstrip Antennas p. 539
- 9.4.2 Transmission Line Model of Aperture Coupling p. 540
- 9.4.3 Modal Expansion Model of Aperture Coupling p. 544
- 9.5 Multimoding Techniques p. 551
- 9.5.1 Broadbanding Using Stacked Elements p. 552
- 9.5.2 Broadbanding Using Coplanar Parasitic Elements p. 570
- 9.5.3 Other Multimoding Techniques p. 576
- 9.6 Other Broadbanding Techniques p. 578
- 9.6.1 Impedance Matching p. 580
- 9.6.2 Resistive Loading p. 583
- 9.7 Multifrequency Operation p. 585
- References p. 586
- 10 Loaded Microstrip Antennas and Applications p. 591
- 10.1 Introduction p. 591
- 10.2 Polarization Diversity Using Microstrip Antennas p. 592
- 10.3 Frequency Agile Microstrip Antennas p. 595
- 10.3.1 Varactor-Tuned Microstrip Antennas p. 595
- 10.3.2 Optical Tuning of Patch Antennas p. 598
- 10.4 Radiation Pattern Control of Microstrip Antennas p. 599
- 10.5 Loading Effect of a Short p. 599
- 10.5.1 Shorting Pin at the Radiating Edge p. 601
- 10.5.2 Shorting Pin on the Center Line of the Patch p. 605
- 10.6 Compact Patch Antennas p. 607
- 10.6.1 Compact Linearly Polarized Antennas p. 607
- 10.6.2 Compact Circularly Polarized Antennas p. 610
- 10.7 Planar Inverted-F Antenna p. 620
- 10.8 Dual-Frequency Microstrip Antennas p. 625
- 10.8.1 Dual-Frequency Slotted Patch Antennas p. 626
- 10.8.2 Dual-Frequency Dual-Linearly Polarized Microstrip Antennas p. 630
- 10.8.3 Dual-Frequency Circularly Polarized Microstrip Antennas p. 633
- 10.8.4 Dual Circularly Polarized Microstrip Antennas p. 636
- 10.9 Dual-Frequency Compact Microstrip Antennas p. 637
- 10.9.1 Pin-Loaded Dual-Frequency Antennas p. 637
- 10.9.2 Slot-Loaded Dual-Frequency Antennas p. 643
- 10.9.3 Dual-Frequency PIFA p. 646
- References p. 654

- 11 Active Integrated Microstrip Antennas p. 659
- 11.1 Introduction p. 659
- 11.2 Classification of Active Integrated Microstrip Antennas p. 659
- 11.2.1 Oscillator Type p. 660
- 11.2.2 Amplifier Type p. 661
- 11.2.3 Frequency Conversion Type p. 663
- 11.3 Theory and Design of Active Integrated Microstrip Antenna Oscillators p. 666
- 11.3.1 One-Port Active Integrated Microstrip Antenna Oscillators p. 666
- 11.3.2 Active Patch Antennas Integrated With Diodes p. 668
- 11.3.3 Active Patch Antennas Integrated With Two-Port Devices p. 675
- 11.4 Theory and Design of Active Integrated Microstrip Antenna Amplifiers p. 696
- 11.4.1 Analysis and Design of Active Integrated Microstrip Antenna Amplifiers p. 697
- 11.4.2 Specified Gain Active Integrated Microstrip Antenna Amplifier Design p. 700
- 11.4.3 Low-Noise Active Integrated Microstrip Antenna Amplifier Design p. 706
- 11.5 Frequency Conversion Active Integrated Microstrip Antenna Theory and Design p. 709
- 11.5.1 Operational Principle of Transconductance Mixers p. 711
- 11.5.2 Self-Oscillating Mixer Active Integrated Microstrip Antennas p. 712
- References p. 714
- 12 Design and Analysis of Microstrip Antenna Arrays p. 719
- 12.1 Introduction p. 719
- 12.2 Parallel and Series Feed Systems p. 719
- 12.2.1 Parallel Feed for One and Two Dimensions p. 720
- 12.2.2 Series Feeding of Microstrip Arrays p. 722
- 12.3 Mutual Coupling p. 727
- 12.4 Design of Linear Arrays p. 728
- 12.4.1 Linear Array Design With Microstrip Patches p. 728
- 12.4.2 Linear Array Design With Capacitively Coupled Fingers p. 732
- 12.4.3 Design of Comb-Line Arrays With Microstrip Stubs p. 733
- 12.5 Design of Planar Arrays p. 737
- 12.5.1 Infinite Arrays of Printed Dipoles p. 737
- 12.5.2 Infinite Arrays of Rectangular Microstrip Patches p. 742
- 12.5.3 Finite Planar Arrays of Printed Dipoles p. 746
- 12.6 Monolithic Integrated Phased Arrays p. 750
- 12.6.1 Design Considerations p. 751
- 12.6.2 Array Architectures p. 753
- References p. 756
- Appendix A Substrates for Microstrip Antennas p. 759
- A.1 Substrate Characteristics for Microstrip Antenna Design p. 759
- A.1.1 Ceramic Substrates p. 760
- A.1.2 Semiconductor Substrates p. 760
- A.1.3 Ferrimagnetic Substrates p. 760
- A.1.4 Synthetic Substrates p. 763
- A.1.5 Composite Material Substrates p. 763
- A.1.6 Low-Cost Low-Loss Substrates p. 763
- A.1.7 Substrate Anisotropy p. 765

- A.2 Desirable Substrate Characteristics for Antenna Fabrication p. 768
- References p. 770
- Appendix B Design of Planar Transmission Lines and Discontinuities p. 771
- B.1 Microstrip Line Design p. 771
- B.2 Suspended and Inverted Microstrip Line Design p. 779
- B.3 Design of Microstrip Line With a Superstrate p. 781
- B.4 Parallel Strips Line Design p. 782
- B.5 Strip Line Design p. 783
- B.6 Slot Line Design p. 786
- B.7 Coplanar Waveguide Design p. 789
- B.7.1 CPW With an Infinitely Thick Substrate p. 791
- B.7.2 CPW With Finite Dielectric Thickness p. 791
- B.7.3 CPW With Finite Dielectric Thickness and Finite Width Ground Planes p. 791
- B.7.4 CPW With Finite Dielectric Thickness and a Cover Shield p. 792
- B.7.5 Conductor-Backed CPW With a Cover Shield p. 792
- B.7.6 Conductor-Backed CPW p. 792
- B.7.7 Asymmetric CPW Without Dielectric Substrate p. 792
- B.7.8 Asymmetric CPW With Finite Dielectric Thickness p. 792
- B.8 Coplanar Strips Design p. 793
- B.8.1 Symmetric CPS With Infinitely Thick Substrate p. 793
- B.8.2 Asymmetric CPS With Infinitely Thick Substrate p. 793
- B.8.3 Asymmetric CPS With Finitely Thick Substrate p. 794
- B.8.4 Symmetric CPS With Finite Dielectric Thickness p. 795
- B.8.5 Asymmetric CPS With an Infinitely Wide Strip p. 795
- B.9 Coupled Microstrip Lines Design p. 795
- B.10 Coupled Strip Lines Design p. 798
- B.11 Characterization of Discontinuities in Microstrip Lines p. 800
- B.11.1 Open Ends p. 800
- B.11.2 Gaps in Microstrips Lines p. 804
- B.11.3 Notch p. 805
- B.11.4 Steps in Width p. 806
- B.11.5 Bends in Microstrips p. 807
- B.11.6 Symmetric T-Junctions p. 807
- B.11.7 Short-Circuited Posts in Microstrips p. 809
- B.11.8 Shorted Ends p. 809
- B.12 Open-End Discontinuity in Coupled Microstrip Lines p. 810
- References p. 810
- About the Authors p. 813
- Index p. 817