

Contents

Preface *xiii*

1 Maxwell's Equations 1

- 1.1 Maxwell's Equations, 1
- 1.2 Lorentz Force, 2
- 1.3 Constitutive Relations, 3
- 1.4 Negative Index Media, 7
- 1.5 Boundary Conditions, 7
- 1.6 Currents, Fluxes, and Conservation Laws, 9
- 1.7 Charge Conservation, 10
- 1.8 Energy Flux and Energy Conservation, 11
- 1.9 Harmonic Time Dependence, 13
- 1.10 Simple Models of Dielectrics, Conductors, and Plasmas, 16
- 1.11 Dielectrics, 17
- 1.12 Conductors, 20
- 1.13 Charge Relaxation in Conductors, 22
- 1.14 Power Losses, 23
- 1.15 Plasmas, 25
- 1.16 Energy Density in Lossless Dispersive Dielectrics, 25
- 1.17 Kramers-Kronig Dispersion Relations, 26
- 1.18 Group Velocity, Energy Velocity, 29
- 1.19 Problems, 31

2 Uniform Plane Waves 36

- 2.1 Uniform Plane Waves in Lossless Media, 36
- 2.2 Monochromatic Waves, 42
- 2.3 Energy Density and Flux, 45
- 2.4 Wave Impedance, 46
- 2.5 Polarization, 46
- 2.6 Uniform Plane Waves in Lossy Media, 53
- 2.7 Propagation in Weakly Lossy Dielectrics, 59
- 2.8 Propagation in Good Conductors, 60
- 2.9 Propagation in Oblique Directions, 61
- 2.10 Complex or Inhomogeneous Waves, 64
- 2.11 Doppler Effect, 66
- 2.12 Propagation in Negative-Index Media, 70

- 2.13 Problems, 73

3 Pulse Propagation in Dispersive Media 82

- 3.1 Propagation Filter, 82
- 3.2 Front Velocity and Causality, 84
- 3.3 Exact Impulse Response Examples, 87
- 3.4 Transient and Steady-State Behavior, 90
- 3.5 Pulse Propagation and Group Velocity, 94
- 3.6 Group Velocity Dispersion and Pulse Spreading, 97
- 3.7 Propagation and Chirping, 102
- 3.8 Dispersion Compensation, 103
- 3.9 Slow, Fast, and Negative Group Velocities, 105
- 3.10 Chirp Radar and Pulse Compression, 112
- 3.11 Further Reading, 122
- 3.12 Problems, 122

4 Propagation in Birefringent Media 131

- 4.1 Linear and Circular Birefringence, 131
- 4.2 Uniaxial and Biaxial Media, 132
- 4.3 Chiral Media, 134
- 4.4 Gyrotropic Media, 137
- 4.5 Linear and Circular Dichroism, 138
- 4.6 Oblique Propagation in Birefringent Media, 139
- 4.7 Problems, 146

5 Reflection and Transmission 152

- 5.1 Propagation Matrices, 152
- 5.2 Matching Matrices, 156
- 5.3 Reflected and Transmitted Power, 159
- 5.4 Single Dielectric Slab, 162
- 5.5 Reflectionless Slab, 165
- 5.6 Time-Domain Reflection Response, 173
- 5.7 Two Dielectric Slabs, 175
- 5.8 Reflection by a Moving Boundary, 177
- 5.9 Problems, 180

6 Multilayer Structures 185

- 6.1 Multiple Dielectric Slabs, 185
- 6.2 Antireflection Coatings, 187
- 6.3 Dielectric Mirrors, 192
- 6.4 Propagation Bandgaps, 203
- 6.5 Narrow-Band Transmission Filters, 203
- 6.6 Equal Travel-Time Multilayer Structures, 208
- 6.7 Applications of Layered Structures, 222
- 6.8 Chebyshev Design of Reflectionless Multilayers, 225
- 6.9 Problems, 233

7 Oblique Incidence 240

- 7.1 Oblique Incidence and Snell's Laws, 240
- 7.2 Transverse Impedance, 242
- 7.3 Propagation and Matching of Transverse Fields, 245
- 7.4 Fresnel Reflection Coefficients, 247
- 7.5 Maximum Angle and Critical Angle, 249
- 7.6 Brewster Angle, 258
- 7.7 Complex Waves, 260
- 7.8 Total Internal Reflection, 263
- 7.9 Oblique Incidence on a Lossy Medium, 264
- 7.10 Zenneck Surface Wave, 269
- 7.11 Surface Plasmons, 271
- 7.12 Oblique Reflection from a Moving Boundary, 274
- 7.13 Geometrical Optics, 278
- 7.14 Fermat's Principle, 281
- 7.15 Ray Tracing, 283
- 7.16 Snell's Law in Negative-Index Media, 294
- 7.17 Problems, 297

8 Multilayer Film Applications 302

- 8.1 Multilayer Dielectric Structures at Oblique Incidence, 302
- 8.2 Lossy Multilayer Structures, 304
- 8.3 Single Dielectric Slab, 306
- 8.4 Frustrated Total Internal Reflection, 308
- 8.5 Surface Plasmon Resonance, 312
- 8.6 Perfect Lens in Negative-Index Media, 321
- 8.7 Antireflection Coatings at Oblique Incidence, 329
- 8.8 Omnidirectional Dielectric Mirrors, 332
- 8.9 Polarizing Beam Splitters, 343
- 8.10 Reflection and Refraction in Birefringent Media, 345
- 8.11 Brewster and Critical Angles in Birefringent Media, 349
- 8.12 Multilayer Birefringent Structures, 352
- 8.13 Giant Birefringent Optics, 354
- 8.14 Problems, 359

9 Waveguides 361

- 9.1 Longitudinal-Transverse Decompositions, 362
- 9.2 Power Transfer and Attenuation, 367
- 9.3 TEM, TE, and TM modes, 369
- 9.4 Rectangular Waveguides, 372
- 9.5 Higher TE and TM modes, 374
- 9.6 Operating Bandwidth, 376
- 9.7 Power Transfer, Energy Density, and Group Velocity, 377
- 9.8 Power Attenuation, 379
- 9.9 Reflection Model of Waveguide Propagation, 382
- 9.10 Resonant Cavities, 384
- 9.11 Dielectric Slab Waveguides, 386
- 9.12 Problems, 395

10 Transmission Lines 397

- 10.1 General Properties of TEM Transmission Lines, 397
- 10.2 Parallel Plate Lines, 403
- 10.3 Microstrip Lines, 404
- 10.4 Coaxial Lines, 408
- 10.5 Two-Wire Lines, 413
- 10.6 Distributed Circuit Model of a Transmission Line, 415
- 10.7 Wave Impedance and Reflection Response, 417
- 10.8 Two-Port Equivalent Circuit, 419
- 10.9 Terminated Transmission Lines, 420
- 10.10 Power Transfer from Generator to Load, 423
- 10.11 Open- and Short-Circuited Transmission Lines, 425
- 10.12 Standing Wave Ratio, 428
- 10.13 Determining an Unknown Load Impedance, 430
- 10.14 Smith Chart, 434
- 10.15 Time-Domain Response of Transmission Lines, 438
- 10.16 Problems, 445

11 Coupled Lines 456

- 11.1 Coupled Transmission Lines, 456
- 11.2 Crosstalk Between Lines, 462
- 11.3 Weakly Coupled Lines with Arbitrary Terminations, 465
- 11.4 Coupled-Mode Theory, 467
- 11.5 Fiber Bragg Gratings, 469
- 11.6 Diffuse Reflection and Transmission, 472
- 11.7 Problems, 474

12 Impedance Matching 476

- 12.1 Conjugate and Reflectionless Matching, 476
- 12.2 Multisection Transmission Lines, 478
- 12.3 Quarter-Wavelength Chebyshev Transformers, 479
- 12.4 Two-Section Dual-Band Chebyshev Transformers, 485
- 12.5 Quarter-Wavelength Transformer With Series Section, 491
- 12.6 Quarter-Wavelength Transformer With Shunt Stub, 494
- 12.7 Two-Section Series Impedance Transformer, 496
- 12.8 Single Stub Matching, 501
- 12.9 Balanced Stubs, 505
- 12.10 Double and Triple Stub Matching, 507
- 12.11 L-Section Lumped Reactive Matching Networks, 509
- 12.12 Pi-Section Lumped Reactive Matching Networks, 512
- 12.13 Reversed Matching Networks, 519
- 12.14 Problems, 521

13 S-Parameters 525

- 13.1 Scattering Parameters, 525
- 13.2 Power Flow, 529
- 13.3 Parameter Conversions, 530

- 13.4 Input and Output Reflection Coefficients, 531
- 13.5 Stability Circles, 533
- 13.6 Power Gains, 539
- 13.7 Generalized S-Parameters and Power Waves, 545
- 13.8 Simultaneous Conjugate Matching, 549
- 13.9 Power Gain Circles, 554
- 13.10 Unilateral Gain Circles, 555
- 13.11 Operating and Available Power Gain Circles, 557
- 13.12 Noise Figure Circles, 563
- 13.13 Problems, 568

14 Radiation Fields 571

- 14.1 Currents and Charges as Sources of Fields, 571
- 14.2 Retarded Potentials, 573
- 14.3 Harmonic Time Dependence, 576
- 14.4 Fields of a Linear Wire Antenna, 578
- 14.5 Fields of Electric and Magnetic Dipoles, 580
- 14.6 Ewald-Oseen Extinction Theorem, 585
- 14.7 Radiation Fields, 590
- 14.8 Radial Coordinates, 593
- 14.9 Radiation Field Approximation, 595
- 14.10 Computing the Radiation Fields, 596
- 14.11 Problems, 598

15 Transmitting and Receiving Antennas 601

- 15.1 Energy Flux and Radiation Intensity, 601
- 15.2 Directivity, Gain, and Beamwidth, 602
- 15.3 Effective Area, 607
- 15.4 Antenna Equivalent Circuits, 611
- 15.5 Effective Length, 613
- 15.6 Communicating Antennas, 615
- 15.7 Antenna Noise Temperature, 617
- 15.8 System Noise Temperature, 621
- 15.9 Data Rate Limits, 627
- 15.10 Satellite Links, 629
- 15.11 Radar Equation, 632
- 15.12 Problems, 634

16 Linear and Loop Antennas 637

- 16.1 Linear Antennas, 637
- 16.2 Hertzian Dipole, 639
- 16.3 Standing-Wave Antennas, 641
- 16.4 Half-Wave Dipole, 645
- 16.5 Monopole Antennas, 646
- 16.6 Traveling-Wave Antennas, 648
- 16.7 Vee and Rhombic Antennas, 650
- 16.8 Loop Antennas, 653
- 16.9 Circular Loops, 655

- 16.10 Square Loops, 657
- 16.11 Dipole and Quadrupole Radiation, 658
- 16.12 Problems, 660

17 Radiation from Apertures 661

- 17.1 Field Equivalence Principle, 661
- 17.2 Magnetic Currents and Duality, 663
- 17.3 Radiation Fields from Magnetic Currents, 665
- 17.4 Radiation Fields from Apertures, 666
- 17.5 Huygens Source, 669
- 17.6 Directivity and Effective Area of Apertures, 671
- 17.7 Uniform Apertures, 673
- 17.8 Rectangular Apertures, 673
- 17.9 Circular Apertures, 675
- 17.10 Vector Diffraction Theory, 678
- 17.11 Extinction Theorem, 682
- 17.12 Vector Diffraction for Apertures, 684
- 17.13 Fresnel Diffraction, 685
- 17.14 Knife-Edge Diffraction, 689
- 17.15 Geometrical Theory of Diffraction, 697
- 17.16 Rayleigh-Sommerfeld Diffraction Theory, 703
- 17.17 Plane-Wave Spectrum Representation, 706
- 17.18 Fresnel Diffraction and Fourier Optics, 711
- 17.19 Lenses, 716
- 17.20 Problems, 722

18 Aperture Antennas 726

- 18.1 Open-Ended Waveguides, 726
- 18.2 Horn Antennas, 730
- 18.3 Horn Radiation Fields, 732
- 18.4 Horn Directivity, 737
- 18.5 Horn Design, 740
- 18.6 Microstrip Antennas, 743
- 18.7 Parabolic Reflector Antennas, 749
- 18.8 Gain and Beamwidth of Reflector Antennas, 751
- 18.9 Aperture-Field and Current-Distribution Methods, 754
- 18.10 Radiation Patterns of Reflector Antennas, 757
- 18.11 Dual-Reflector Antennas, 766
- 18.12 Lens Antennas, 769

19 Antenna Arrays 771

- 19.1 Antenna Arrays, 771
- 19.2 Translational Phase Shift, 771
- 19.3 Array Pattern Multiplication, 773
- 19.4 One-Dimensional Arrays, 783
- 19.5 Visible Region, 785
- 19.6 Grating Lobes, 787
- 19.7 Uniform Arrays, 789

- 19.8 Array Directivity, 793
- 19.9 Array Steering, 794
- 19.10 Array Beamwidth, 797
- 19.11 Problems, 799

20 Array Design Methods 802

- 20.1 Array Design Methods, 802
- 20.2 Schelkunoff's Zero Placement Method, 805
- 20.3 Fourier Series Method with Windowing, 807
- 20.4 Sector Beam Array Design, 808
- 20.5 Woodward-Lawson Frequency-Sampling Design, 812
- 20.6 Discretization of Continuous Line Sources, 817
- 20.7 Narrow-Beam Low-Sidelobe Designs, 821
- 20.8 Binomial Arrays, 825
- 20.9 Dolph-Chebyshev Arrays, 826
- 20.10 Taylor One-Parameter Source, 839
- 20.11 Prolate Array, 843
- 20.12 Taylor Line Source, 845
- 20.13 Villeneuve Arrays, 849
- 20.14 Multibeam Arrays, 850
- 20.15 Problems, 853

21 Currents on Linear Antennas 855

- 21.1 Hallén and Pocklington Integral Equations, 855
- 21.2 Delta-Gap, Frill Generator, and Plane-Wave Sources, 858
- 21.3 Solving Hallén's Equation, 859
- 21.4 Sinusoidal Current Approximation, 861
- 21.5 Reflecting and Center-Loaded Receiving Antennas, 862
- 21.6 King's Three-Term Approximation, 865
- 21.7 Evaluation of the Exact Kernel, 872
- 21.8 Method of Moments, 877
- 21.9 Delta-Function Basis, 880
- 21.10 Pulse Basis, 884
- 21.11 Triangular Basis, 889
- 21.12 NEC Sinusoidal Basis, 891
- 21.13 Hallén's Equation for Arbitrary Incident Field, 894
- 21.14 Solving Pocklington's Equation, 899
- 21.15 Problems, 903

22 Coupled Antennas 905

- 22.1 Near Fields of Linear Antennas, 905
- 22.2 Improved Near-Field Calculation, 908
- 22.3 Self and Mutual Impedance, 916
- 22.4 Coupled Two-Element Arrays, 922
- 22.5 Arrays of Parallel Dipoles, 925
- 22.6 Yagi-Uda Antennas, 934
- 22.7 Hallén Equations for Coupled Antennas, 939
- 22.8 Problems, 947

23 Appendices 949

- A Physical Constants, 949
- B Electromagnetic Frequency Bands, 950
- C Vector Identities and Integral Theorems, 952
- D Green's Functions, 955
- E Coordinate Systems, 958
- F Fresnel, Exponential, Sine, and Cosine Integrals, 960
- G Gauss-Legendre Quadrature, 966
- H Lorentz Transformations, 972
- I MATLAB Functions, 980

References 985

Index 1033