

FIFTH EDITION

SCHAUM'S.
outlines

Electromagnetics

MAHMOOD NAHVI, PhD • JOSEPH A. EDMINISTER

480 practice problems with
step-by-step solutions

24 problem-solving videos online

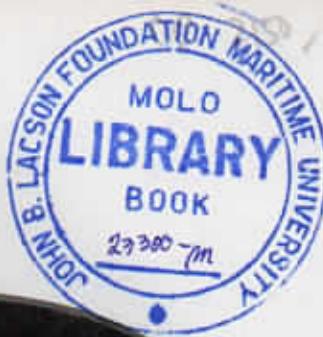
Concise explanations of all
course concepts



Use With These Courses:

Electromagnetics
Transmission lines
Wave propagation

SC
537.0202
NISU
2019



SCHAUM'S.
outlines

Electromagnetics

Fifth Edition

Mahmood Nahid, PhD
Professor, Department of Electrical Engineering
Clemson University, South Carolina

Joseph A. Edminister
Professor Emeritus, University of California, Berkeley
and a former member of the faculty at the University of Michigan

Published by Schaum's Outline Series

New York Chicago San Francisco
Atlanta Boston Dallas Montreal Toronto

Contents

CHAPTER 1	The Subject of Electromagnetics	1
1.1	Historical Background	1
1.2	Objectives of the Chapter	1
1.3	Electric Charge	2
1.4	Units	2
1.5	Vectors	4
1.6	Electrical Force, Field, Flux, and Potential	4
1.7	Magnetic Force, Field, Flux, and Potential	7
1.8	Electromagnetic Induction	9
1.9	Mathematical Operators and Identities	10
1.10	Maxwell's Equations	10
1.11	Electromagnetic Waves	11
1.12	Trajectory of a Sinusoidal Motion in Two Dimensions	14
1.13	Wave Polarization	15
1.14	Electromagnetic Spectrum	16
1.15	Transmission Lines	17
CHAPTER 2	Vector Analysis	31
2.1	Introduction	31
2.2	Vector Notation	31
2.3	Vector Functions	32
2.4	Vector Algebra	32
2.5	Coordinate Systems	34
2.6	Differential Volume, Surface, and Line Elements	35
CHAPTER 3	Electric Field	44
3.1	Introduction	44
3.2	Coulomb's Law in Vector Form	44
3.3	Superposition	45
3.4	Electric Field Intensity	45
3.5	Charge Distributions	46
3.6	Standard Charge Configurations	48
CHAPTER 4	Electric Flux	63
4.1	Net Charge in a Region	63
4.2	Electric Flux and Flux Density	63
4.3	Gauss's Law	65
4.4	Relation between Flux Density and Electric Field Intensity	65
4.5	Special Gaussian Surfaces	66

CHAPTER 5 Gradient, Divergence, Curl, and Laplacian	78
5.1 Introduction	78
5.2 Gradient	78
5.3 The Del Operator	79
5.4 The Del Operator and Gradient	80
5.5 Divergence	80
5.6 Expressions for Divergence in Coordinate Systems	80
5.7 The Del Operator and Divergence	82
5.8 Divergence of D	83
5.9 The Divergence Theorem	83
5.10 Curl	84
5.11 Laplacian	86
5.12 Summary of Vector Operations	86
CHAPTER 6 Electrostatics: Work, Energy, and Potential	97
6.1 Work Done in Moving a Point Charge	97
6.2 Conservative Property of the Electrostatic Field	98
6.3 Electric Potential between Two Points	99
6.4 Potential of a Point Charge	99
6.5 Potential of a Charge Distribution	99
6.6 Relationship between E and V	100
6.7 Energy in Static Electric Fields	101
CHAPTER 7 Electric Current	113
7.1 Introduction	113
7.2 Charges in Motion	113
7.3 Convection Current Density J	114
7.4 Conduction Current Density J	114
7.5 Conductivity σ	115
7.6 Current I	116
7.7 Resistance R	117
7.8 Current Sheet Density K	118
7.9 Continuity of Current	119
7.10 Conductor-Dielectric Boundary Conditions	120
CHAPTER 8 Capacitance and Dielectric Materials	131
8.1 Polarization P and Relative Permittivity ϵ_r	131
8.2 Capacitance	132
8.3 Multiple-Dielectric Capacitors	133
8.4 Energy Stored in a Capacitor	134
8.5 Fixed-Voltage D and E	135
8.6 Fixed-Charge D and E	135
8.7 Boundary Conditions at the Interface of Two Dielectrics	136
8.8 Method of Images	137
CHAPTER 9 Laplace's Equation	151
9.1 Introduction	151
9.2 Poisson's Equation and Laplace's Equation	151

CHAPTER 9	Harmonic Functions	151
9.3	Explicit Forms of Laplace's Equation	151
9.4	Uniqueness Theorem	152
9.5	Mean Value and Maximum Value Theorems	153
9.6	Cartesian Solution in One Variable	153
9.7	Cartesian Product Solution	154
9.8	Cylindrical Product Solution	155
9.9	Spherical Product Solution	156
CHAPTER 10	Magnetic Field and Boundary Conditions	172
10.1	Introduction	172
10.2	Biot-Savart Law	172
10.3	Ampère's Law	174
10.4	Relationship of J and H	174
10.5	Magnetic Flux Density B	175
10.6	Boundary Relations for Magnetic Fields	176
10.7	Current Sheet at the Boundary	177
10.8	Summary of Boundary Conditions	178
10.9	Vector Magnetic Potential A	178
10.10	Stokes' Theorem	179
CHAPTER 11	Forces and Torques in Magnetic Fields	193
11.1	Magnetic Force on Particles	193
11.2	Electric and Magnetic Fields Combined	194
11.3	Magnetic Force on a Current Element	195
11.4	Work and Power	195
11.5	Torque	196
11.6	Magnetic Moment of a Planar Coil	197
CHAPTER 12	Inductance and Magnetic Circuits	209
12.1	Inductance	209
12.2	Standard Conductor Configurations	211
12.3	Faraday's Law and Self-Inductance	212
12.4	Internal Inductance	212
12.5	Mutual Inductance	213
12.6	Magnetic Circuits	214
12.7	The B - H Curve	215
12.8	Ampère's Law for Magnetic Circuits	216
12.9	Cores with Air Gaps	217
12.10	Multiple Coils	217
12.11	Parallel Magnetic Circuits	218
CHAPTER 13	Time-Varying Fields and Maxwell's Equations	233
13.1	Introduction	233
13.2	Maxwell's Equations for Static Fields	233
13.3	Faraday's Law and Lenz's Law	233
13.4	Conductors' Motion in Time-Independent Fields	234
13.5	Conductors' Motion in Time-Dependent Fields	235
13.6	Displacement Current	236
13.7	Ratio of J_c to J_D	238
13.8	Maxwell's Equations for Time-Varying Fields	238

CHAPTER 14 Electromagnetic Waves	251
14.1 Introduction	251
14.2 Wave Equations	251
14.3 Solutions in Cartesian Coordinates	252
14.4 Plane Waves	253
14.5 Solutions for Partially Conducting Media	254
14.6 Solutions for Perfect Dielectrics	255
14.7 Solutions for Good Conductors; Skin Depth	255
14.8 Interface Conditions at Normal Incidence	256
14.9 Oblique Incidence and Snell's Laws	258
14.10 Perpendicular Polarization	259
14.11 Parallel Polarization	259
14.12 Standing Waves	260
14.13 Power and the Poynting Vector	261
CHAPTER 15 Transmission Lines	273
15.1 Introduction	273
15.2 Distributed Parameters	273
15.3 Incremental Models	274
15.4 Transmission Line Equation	275
15.5 Impedance, Admittance, and Other Features of Interest	275
15.6 Sinusoidal Steady-State Excitation	276
15.7 Lossless Lines	278
15.8 The Smith Chart	279
15.9 Admittance Plane	282
15.10 Quarter-Wave Transformer	282
15.11 Impedance Matching	283
15.12 Single-Stub Matching	284
15.13 Double-Stub Matching	285
15.14 Impedance Measurement	287
15.15 Transients in Lossless Lines	288
CHAPTER 16 Waveguides	316
16.1 Introduction	316
16.2 Transverse and Axial Fields	316
16.3 TE and TM Modes; Wave Impedances	318
16.4 Determination of the Axial Fields	318
16.5 Mode Cutoff Frequencies	319
16.6 Dominant Mode	320
16.7 Power Transmitted in a Lossless Waveguide	322
16.8 Power Dissipation in a Lossy Waveguide	322
CHAPTER 17 Antennas	335
17.1 Introduction	335
17.2 Current Source and the E and H Fields	335
17.3 Electric (Hertzian) Dipole Antenna	335
17.4 Antenna Parameters	336
17.5 Small Circular-Loop Antenna	338
17.6 Finite-Length Dipole	338
17.7 Monopole Antenna	339

17.8	Self- and Mutual Impedances	340
17.9	The Receiving Antenna	341
17.10	Linear Arrays	342
17.11	Reflectors	343
CHAPTER 18 Propagation of Electromagnetic Waves in the Atmosphere		354
18.1	Introduction and Summary	354
18.2	Plane Waves in Homogeneous Media	354
18.3	Propagation Parameters	355
18.4	Complex Dielectric Constant	357
18.5	Power Equation	358
18.6	Refraction	359
18.7	Reflection, Diffraction, and Scattering	360
18.8	The Atmosphere	361
18.9	Atmospheric Effects on Propagation of Radio Waves	362
18.10	Attenuation by Gaseous Absorption	362
18.11	Attenuation by Hydrometeors	363
18.12	Ground and Sky Waves	364
18.13	Models of the Troposphere	366
18.14	Tropospheric Refractivity	366
18.15	Tropospheric Excess Delay	367
18.16	Bending Effect of Tropospheric Refraction	368
18.17	Conductivity, Permittivity, and Refraction Index of the Ionosphere	369
18.18	Satellite Microwave Ranging	370
18.19	Ionospheric Range Error	371
18.20	Tropospheric Range Error	372
APPENDIX		384
INDEX		385

INDEX

- AC resistance, of transmission lines, 273
Air-gap line, negative, 224, 225
Air gaps, cores with, 217
Ampere (unit), 113, 216
Ampere turns (unit), 216
Ampere's law, 174
 for magnetic circuits, 216–217
Antenna parameters, 336–338
Antennas, 335–353
 available power of, 341
 directivity of, 337–338
 effective area for, 341
 effective length of, 339
 electric dipole, 335–336
 linear arrays of, 342–343
 monopole, 339–340
 ohmic loss of, 338
 power gain of, 338
 radiation efficiency of, 338
 receiving, 341–342
 self-impedance of, 340–341
 small circular-loop, 338
Army factor, 342
Arrays:
 endfire, 342
 linear, of antennas, 342–343
 uniform, 343
Associative law, 32
Atmosphere, 361–362
 attenuation by gaseous absorption, 362–363
 attenuation by hydrometeors, 363–364
 effects on radio waves propagation, 362
 layers of, 361
Attenuation of electromagnetic waves, 254, 255, 275, 323, 354, 358–359, 362–364, 373–374
 atmospheric, 362–364
 coefficient of, 255, 265, 354–356
 gaseous absorption, by 362–363
 homogeneous media, in, 354
 hydrometeors, by 363–364
 good conductors, in, 255, 373
 partially conducting media, in, 254, 374
 plane waves, 354
 power equation, 358–359
 transmission lines, in, 275
 wave guides, 323
Attenuation, per-meter, 291
Attenuation factor, 322–323
 total, 323
Available power of antennas, 341
Avogadro's number, 122
Axial components, transverse components from, 317–318
Axial fields, 316–318
 determination of, 318–319
B (*see* Magnetic flux density)
B-H curve, 215–216
Back-voltage in inductor, 212
Beam width, half-power, 337
Biot-Savart law, 172–174
Boundary, current sheet at, 177–178
Boundary conditions:
 across interface of two dielectrics, summary, 178
 at interface of two dielectrics, 136–137
 conductor-dielectric, 120–121
Boundary reflection coefficient, 277
Boundary relations, for magnetic fields, 176–177
Capacitance, 131–149
 definition of, 132–133
 equivalent, 133–134
 of transmission lines, 273
Capacitors:
 energy stored in, 134
 multiple-dielectric, 133–134
 parallel-plate, fringing of, 74–75
Cartesian coordinate system, 34–35
curl in, 85
del operator in, 79–80
differential displacement vector in, 97
divergence, curl, gradient, and Laplacian in, 354
divergence in, 81
electric flux density in, 70
field vector in, 317
gradient in, 78–79
Laplace's equation in, 152
 in one variable, 153–154
 product solution of, 154–155
Laplacian of vector in, 251
Maxwell's equations in, solutions for, 252–253
position vectors in, 36–37
Characteristic impedance, 276
Charge density, 46–47
 volume, 46
 surface, 47
 line, 47
Complex dielectric constant, 357
Conduction current, 114
Conduction current density, 114
Conductor:
 current-carrying, 194
 cylindrical, inductance of, 211
 good, Maxwell's equations solutions for, 255–256
 in motion:
 through time-dependent fields, 235–236
 through time-independent fields, 234–235
 parallel, inductance of, 211
 perfect, imaging in, 347–348
Conservative fields, 98
Conservative property of electrostatic field, 98
Constant currents, 113
Continuity of current, 119–120
 equation of, 119
Contour, closed, 98
Convection current, 114
Convection current density (J), 114
Coordinate system, divergence, curl, gradient, and Laplacian in, 354

- Coordinate systems, 34–35, (*see also* Cartesian coordinate system; Cylindrical coordinate system; Spherical coordinate system)
- Coordinates, 34
- Core lengths, 214
- Cores, with air gaps, 217
- Coulomb (unit), 2
- Coulomb forces, 44–62
- Coulomb's law:
- Scalar form of, 4, 138
 - Vector form of, 44, 45
- Critical wave number, 318
- Cross product of two vectors, 4, 33
- Curl, 80
- in coordinate systems, 354
 - divergence of, as zero scalar, 85
 - of gradient as zero vector, 85
 - of vector field, 84–85
- Current(s) (I), 116–117
- constant, 113
 - continuity of (*see* Continuity of current)
 - displacement (*see* Displacement current)
 - time-variable, 113
- Current density, 113
- conduction, 114–115
 - convection, 114
 - displacement, 11, 236–238
 - magnetic field strength and, 174–175
 - total, 238
- Current elements, magnetic force on, 195
- Current filament, vector magnetic potential for, 179
- Current law, Kirchhoff's, 119
- Current sheet, 118
- at boundary, 177–178
- Current sheet density, 118–119
- Current source, phasor fields outside, 335
- Cutoff frequency, 319–320
- Cutoff wavelength, 329
- Cylindrical conductors, inductance of, 211
- Cylindrical coordinate system, 34–35
- curl in, 85
 - del operator and, 80
 - differential displacement vector in, 97
 - divergence, curl, gradient, and Laplacian in, 354
 - divergence in, 81
 - electric flux density in, 71
 - field vector in, 312
 - gradient in, 79
 - Laplace's equation in, 152
 - product solution of, 155–156
- Cylindrical guides, 311, 321–324
- D (*see* Electric flux density)
- D'Arsonval meter movement, 200
- DC resistance, of transmission lines, 273
- Decibel (unit), 264
- Del operator, 10, 79–80
- Delay time, 288
- Density:
- charge (*see* Charge density)
 - current (*see* Current density)
 - energy, 107–108
 - flux (*see* Flux density)
- Depth of penetration, 256
- Determinants, 33
- Dielectric-conductor boundary conditions, 120–121
- Dielectric constant, 4
- complex, 365
- Dielectric free-space interface, 139
- Dielectric losses, 322–323
- Dielectrics:
- boundary conditions across interface of two, 178
 - boundary conditions at interface of two 136–137
 - perfect, Maxwell's equation solutions for, 255
- Dielectrics (*Cont.*):
- polarization of (*see* Polarization of dielectric materials)
 - two, in multiple-dielectric capacitors, 133–134
- Differential line element, 36
- Differential surface element, 36
- Differential volume, 35
- Diffraction, 360–361
- Diffusion, 315
- Dipole:
- finite-length, 338–339
 - magnetic, 338
- Dipole antennas, electric, 335–336
- Dipole moment, electric, 131
- Directivity, of antennas, 337–338
- Dispersive medium, 255
- Displacement current, 11
- definition of, 236–238
- Displacement current density, 237
- Displacement flux, 63
- Displacement vectors, 44
- Distributive law, 32
- Divergence, 10, 80–82
- in Cartesian coordinates, 81
 - in coordinate systems, 385
 - of curl as zero scalar, 85
 - definition of, 80
 - of electric flux density, 83
 - of gradient of potential function, 151–152
 - negative, 80
 - of zero, 88–89
- Divergence theorem, 83–84
- Dominant mode of waveguides, 315–316
- Dot product of two vectors, 32–33
- Double-stub matching, 285–286
- Drift velocity, 113
- E (*see* Electric field intensity)
- Effective area for antennas, 341
- Effective earth, 368
- Effective length of antennas, 339
- Electric component of force, 194
- Electric current (*see* Current entries)
- Electric dipole antennas, 335–336
- Electric dipole moment, 131
- Electric field intensity (E), 5, 44–62, 151
- definition of, 5, 45–46
 - due to point charges, 51–52
 - fixed-charge, 135–136
 - fixed-voltage, 135
 - flux density and, 65–66
 - motional, 234
 - potential function and, 100–101
 - tangential component of, 136
 - units of, 5, 46
- Electric fields:
- magnetic fields combined with, 194–195
 - point charges causing, 51–52
 - static, energy in, 101–102
 - work done against, 97
 - work done by, 97
- Electric flux, 63–77
- definition of, 63–64
- Electric flux density (D), 64–65
- antisymmetrical, 164–165
 - divergence of, 83
 - electric field intensity and, 65–66
 - fixed-charge, 135–136
 - fixed-voltage, 135
 - normal component of, 136
- Electric potential:
- of charge distributions, 99–100
 - definition of, 99
 - of point charges, 99
 - between two points, 99

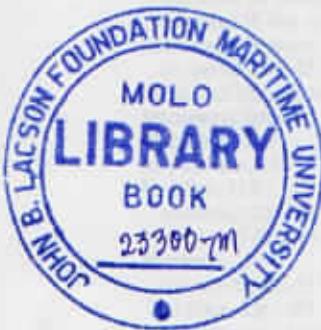
- Electric susceptibility, 132
 Electromagnetic waves, 251–261
 propagation of, 354–372
 spectrum of, 16
 propagation constant of, 252–253, 277, 354–357
 Electromotive force, 212
 Electron-gas theory, 113
 Electron-hole pairs, 115
 Electron mobility, 122
 Electrostatic field, 97–112
 conservative property of, 98
 Endfire arrays, 337
 Energy:
 instantaneous rate of, leaving volume, 261
 in static electric fields, 101–102
 stored in capacitors, 134
 Energy density, 107–108
 Energy differences, 109
 Equation of continuity for current, 119
 Equipotential surfaces, 79
 Equivalent capacitance, 133–134
 Excess delay, 370
- Farad (unit), 132
 Faraday homopolar generator, 244
 Faraday's law, 212
 integral form of, 233
 two-term form of, 235
 Ferromagnetic materials, 214
 Field lines, 330–321
 Field vector, 317
 Fields:
 axial (*see* Axial fields)
 conservative, 98
 electric (*see* Electric fields)
 electrostatic, 97–112
 magnetic (*see* Magnetic fields)
 radial, 184
 time-dependent, conductors in motion through, 235–236
 time-independent, conductors in motion through, 234–235
 transverse, 317–318
 vector (*see* Vector fields)
 Finite length dipole, 338–339
 First nulls, 342
 Fixed-charge electric field intensity and electric flux density, 135–136
 Fixed-voltage electric field intensity and electric flux density, 135
 Flux:
 displacement, 63
 electric (*see* Electric flux)
 magnetic, 175
 Flux density:
 electric (*see* Electric flux density)
 magnetic (*see* Magnetic flux density)
 Flux lines, 64
 Flux linkage, 209
 Forces:
 Coulomb, 4–5, 44–45
 electromotive, 212
 in magnetic fields, 193–208
 magnetomotive, 216
 moment of, 196–197
 Fourier sine series, 166–167
 Free charge, 120
 Free space, Maxwell's equation solutions in, 255
 Free-space interface, dielectric, 139
 Free-space permeability, 175
 Frequency of harmonic wave, 252
 Fringing of parallel-plate capacitors, 74–75
 Friis transmission formula, 342
 Gauss' divergence theorem, 83
 Gauss' law, 65
 Gaussian surfaces, special, 66–67
 Generator, Faraday homopolar, 244
 Geometrical factor, 273
 Gradient, 78–79
 in coordinate systems, 354
 curl of, as zero vector, 85
 divergence of, of potential function, 151–152
 Ground waves, 364–365
 Guide wavelength, 320
- H (*see* Magnetic field strength)
 Half-power beam width, 337
 Half-power points, 337
 Helical motion, 194–195
 Henry (unit), 209
 Hertzian dipole antennas, 335–336
 High-frequency lines, 287
 Homopolar generator, Faraday, 244
- I (*see* Current)
 Imaging in perfect conductor, 347–348
 Impedance:
 characteristic, 276
 intrinsic, 218, 254, 257
 mutual, of antennas, 340–341
 self-impedance, of antennas, 340–341
 wave, 313
 Impedance matching, 283–284
 Impedance measurement, transmission line, 287
 Incidence:
 angle of, 258
 normal, interface conditions at, 256–257
 oblique, 258
 plane of, 258
 Induced voltage, 212
 Inductance, 209–232
 definition of, 209–211
 internal, 212–213
 mutual, 213–214
 self-inductance, 212
 of transmission lines, 273–274
 Inductor, back-voltage in, 212
 Infinite line charge, 48
 Infinite plane charge, 49
 Infinity, zero reference at, 100
 Instantaneous power, 266–267
 Interface conditions at normal incidence, 256–257
 Internal inductance, 212–213
 Intrinsic concentration, 123
 Intrinsic impedance, 254, 257
 Intrinsic semiconductors, 115
 Inverse-square law of point charge, 48
 Ionosphere, 361–362
 conductivity of, 369–370
 height profile of, 362
 maximum usable frequency in, 365
 permittivity of, 369–370
 range error in, 371
 refraction index of, 365–366, 369–370
 two-frequency correction method for, 371
 Iron-core magnetics, 214
 Isotropic radiator, 332
- J (*see* Conduction current density; Convection current density)
- Kirchhoff's law, 119, 216
- Laplace's equation, 151–171
 in Cartesian coordinate system (*see* Cartesian coordinate system, Laplace's equation in)
 definition of, 151
 explicit forms of, 151–152

- Laplacian, in coordinate systems, 351
 Legendre polynomial:
 higher-order, 167
 of order n , 156
 Lenz's law, 233–234
 Lever arm, 196
 Line charge, 47
 infinite, 48
 Line charge density, 47
 Line element, differential, 36
 Linear arrays of antennas, 342–343
 Lorentz force, 194
 Lossless lines, 278
 transients in, 288–289
 Lossless waveguide, power transmitted in, 322
 Lossy waveguide, power dissipation in, 322–333
- Magnetic circuits, 214
 Ampere's law for, 214, 216–217
 parallel, 218
 Magnetic component of force, 194
 Magnetic dipole, 338
 Magnetic field strength (H), 172, 177
 current density and, 174
 tangential component of, 177
 Magnetic fields:
 boundary relations for, 176–177
 electric fields combined with, 194–195
 forces and torques in, 193–208
 static, 172
 time-variable, 236
 Magnetic flux, 175
 Magnetic flux density (B), 175–176
 normal component of, 177
 Magnetic force:
 on current elements, 195
 on particles, 193–194
 Magnetic moment:
 of planar coil, 197–198
 of planar current loop, 197
 Magnetic potential, vector, 178–179
 Magnetization curves, 215
 Magnetomotive force, 216
 Mass-action law, 123
 Matching:
 double-stub, 285–286
 impedance, 283–284
 single-stub, 284–285
 Maximum usable frequency, 365
 Maximum value theorem, 153
 Maxwell's equations, 10–11, 233, 238–239
 free-space set, 239
 general set, 239
 interface conditions at normal incidence, 256–257
 solutions for good conductors, 255–256
 solutions for partially conducting media, 254–255
 solutions for perfect dielectrics, 255
 solutions in free space, 255
 Mean value theorem, 153
 in special case, 157–158
 Method of images, 146–147
 Microwave ranging, 370
 Mho (unit), 117
 Mil, circular, 124
 Mobility, 113
 electron, 122
 Mode cutoff frequencies, 319–320
 Moment:
 electric dipole, 131
 of force, 196–197
 magnetic (see Magnetic moment)
 Monopole, quarter-wave, 340
- Monopole antennas, 339–340
 Motion:
 charges in, 113–114
 conductors in (see Conductors in motion)
 helical, 194–195
 Motional electric field intensity, 234
 Multiple coils, 217–218
 Multiple-dielectric capacitors, 133–134
 Mutual impedance, of antennas, 340–341
 Mutual inductance, 213–214
- n-type semiconductor materials, 115
 Negative air-gap line, 224
 Neper (unit), 224
 Neper to dB conversion, 264, 354
 Net charge, 119
 in region, 63
 Net charge density, 119–120
 Newton (unit), 4
 NI rise and NI drop, 216
 Nulls first, 342
- Oblique incidence, 258
 Ohmic loss of antennas, 338
 Ohm's law, 113
 point form of, 114
 Operating wave length, 315
 Operators, mathematical, 10, 78–96
 curl, 9–10, 84–85
 divergence 10, 13, 80–84
 gradient, 78–80
 Laplacian, 86
 Orthogonal surfaces, 34–35
- p-type semiconductor materials, 115
 Parallel conductors, inductance of, 211
 Parallel magnetic circuits, 218
 Parallel-plate capacitors, fringing of, 74–75
 Parallel plate geometrical factors, 274
 Parallel polarization, 259–260
 Parallel wire geometrical factors, 274
 Particles, magnetic force on, 193–194
 Pattern function, 332
 Penetration, depth of, 256
 Per-meter attenuation, 291
 Period of harmonic wave, 252
 Permeability, 175
 free-space, 175
 relative, 175
 Permittivity, 4
 relative, 4, 132
 Perpendicular polarization, 259
 Phasor fields, 335
 Phasors, 276
 Planar coil, magnetic moment of, 197–198
 Plane, of incidence, 258
 Plane charge, infinite, 258
 Plane waves, 12–14, 253, 354–357
 homogeneous media, in, 354–355
 polarization of, 15–16
 power flow and Poynting vector, 14, 261, 322–323, 355
 propagation parameters of, 355–357
- Point charges:
 causing electric fields, 51–52
 electric field intensity due to, 51–52
 electric potential of, 99
 inverse-square law of, 98
 in spherical coordinate system, 69
 work done in moving, 98
 Point form of Ohm's law, 114
 Points, 34
 electric potential between two, 99

- Poisson's equation, 151, 164–165
 Polar form, 276
 Polarity, 233–234
 Polarization of dielectric materials, 131–132
 parallel, 259–260
 perpendicular, 259
 Position vectors, 36
 Potential:
 electric (*see* Electric potential)
 vector magnetic, 178–179
 Potential difference, 99
 Potential function (V):
 divergence of gradient of, 151–152
 electric field intensity and, 100–101
 Power:
 available, of antennas, 341
 complex, 261
 dissipated in lossy waveguide, 322–323
 instantaneous, 266–267
 Poynting vector and, 261
 transmitted in lossless waveguide, 322
 work and, 195–196
 Power equation in atmospheric propagation, 358
 Power gain of antennas, 338
 Poynting vector, 261
 power and, 261
 Propagation constant, 252
 Propagation parameters, 355
 Quarter-wave monopole, 340
 Quarter-wave transformer, 296–297
- R (*see* Resistance)
 Radial fields, 184
 Radiation efficiency of antennas, 338
 Radiation intensity, 337
 Radiation resistance, 336
 Radiator, isotropic, 337
 Range error, 370–373
 Receiving antennas, 341–342
 Rectangular-guide formulas, 326
 Reflection:
 angle of, 258
 coefficient of, in transmission lines, 18, 275–277
 ionospheric, 365
 radio waves, 369
 Snell's law of, 258
 Reflectors, 343
 Refraction, 359–360
 index of 356–357
 ionospheric, 369–370
 tropospheric, 366, 368
 Snell's law of, 258
 Relative permeability, 175
 Relative permittivity, 4, 132
 Relaxation time, 120
 Reluctance, 216
 Resistance (R), 117–118
 radiation, 336
 surface, 323
 Resistivity, 113
 conductivity as reciprocal of, 124
 Right-hand rule, 173
- Satellite microwave ranging, 370
 Scalar function, gradient of, 78–79
 Scalar triple product, 38
 Scalars, 31
 zero, divergence of curl as, 85
 Scattering, 360–361
 Self-impedance, of antennas, 340–341
 Self-inductance, 212
- Semiconductors, 115–116
 Sheet charge, 47
 Sheet current, vector magnetic potential for, 179
 SI unit prefixes, 354
 SI units, rationalized, 4
 Side lobes, 343
 Siemens (unit), 114, 117
 Smith Chart, 279–281
 Single-stub matching, 284–285
 Sinks, 80
 Sinusoidal steady-state transmission-line excitation, 227–277
 Skin depth, 256
 Skin effect, 212–213
 Sky waves, 364–365
 Slotted lines, 287
 Small circular-loop antennas, 338
 Smith Chart, 279–281
 Snell's law:
 of reflection, 258
 of refraction, 258
 Solenoids, inductance of, 211
 Sources, 80
 Space, free (*see* Free space)
 Spherical coordinate system, 34–35
 curl in, 85
 differential displacement vector in, 97
 divergence, curl, gradient, and Laplacian in, 354
 divergence in, 81
 gradient in, 79
 Laplace's equation in, 152
 product solution of, 156
 point charge in, 69
 potential in, 101
 Spherical shells, concentric, 104
 Standing-wave ratio, voltage, 276, 278
 Standing waves, 260
 Static electric fields, energy in, 101–102
 Static magnetic field, 172
 Stokes' theorem, 179–180
 Surface charge density, 47
 Surface element, differential, 36
 Surface resistance, 323
 Surfaces:
 equipotential, 79
 orthogonal, 34–35
 Susceptibility, electric, 132
- TE (transverse electric) waves, 318
 Time constant, 120
 Time-dependent fields, conductors in motion through, 235–236
 Time-distance plots, 288–289
 Time-independent fields, conductors in motion through, 234–235
 Time-variable currents, 113
 Time-variable magnetic field, 236
 TM (transverse magnetic) waves, 318
 Toroids, inductance of, 211
 Torque:
 definition of, 196–197
 in magnetic fields, 193–208
 Transformer, quarter-wave, 282–283, 300
 Transients in lossless lines, 288–289
 Transmission, angle of, 258
 Transmission formula, Friss, 342
 Transmission lines, 273–315
 distributed parameters, 273–274
 double-stub matching, 285–286
 impedance matching, 283–284
 impedance measurement, 287
 incremental model, 274–275
 per-meter attenuation, 295



- Transmission lines (*Cont.*):
 single-stub matching, 284–285
 sinusoidal steady-state excitation, 276–278
 slotted, 287, 306
 uniform, 273
- Transverse components from axial components, 312–313
- Transverse electric (TE) waves, 318
- Transverse fields, 316–318
- Transverse length, unit, charge transport per, 118
- Transverse magnetic (TM) waves, 318
- Traveling waves, 262
- Triple product:
 scalar, 38
 vector, 38
- Troposphere, 361–362
 bending effect of, 368
 excess delay due to, 367
 models of, 366
 range error due to, 372
 refractivity of, 366
- Tuner circle, 285, 304
- Uniform arrays, 337
- Uniform transmission lines, 273
- Uniqueness theorem, 152–153
- Unit vectors, 4, 31, 35
- V (*see* Potential function)
- Vector(s), 4, 31
 absolute value of, 4, 31
 component form of, 4, 31
 cross product of two, 4, 33
 displacement, 44
 dot product of two, 4, 33
 position, 36
 Poynting (*see* Poynting vector)
 projection of one, on second, 37–38
 unit, 4, 31, 35
 zero, curl of gradient as, 85
- Vector algebra, 14, 32–33
- Vector analysis, 4, 31–43
- Vector fields, 4, 78–80
 curl of, 84–85
- Vector integral, 45, 46
- Vector magnetic potential, 178–179
- Vector notation, 4, 31
- Vector sum, 45
- Vector triple product, 38
- Vector wave equations, 251
- Velocity, drift, 113
- Voltage:
 around closed contour, 212
 induced, 212
 of self-inductance, 212
- Voltage drop, 117
- Voltage standing-wave ratio, 277
- Volume:
 differential, 35
 instantaneous rate of energy leaving, 261
- Volume charge, 46
- Volume current, vector magnetic potential for, 179
- Wall losses, 317–318
- Wave equations, 251–252
- Wave impedance, 318
- Wave number, 317
 critical, 318, 324
 of radiation, 335
- Waveguides, 316–334
 dominant mode of, 320–321
 lossless, power transmitted in, 322
 lossy, power dissipation in, 322–323
- Wavelength:
 cutoff, 329
 guide, 320
 of harmonic wave, 252
 operating, 320
- Waves:
 electromagnetic (*see* Electromagnetic waves)
 plane, 12–14, 253, 354
 polarization of, 15–16
 standing, 260
 traveling, 262
- Weber (unit), 175
- Work:
 definition of, 97
 done against electric field, 97
 done by electric field, 97
 done in moving point charges, 98
 power and, 195–196
- Zero, divergence of, 88–89
- Zero reference at infinity, 100
- Zero scalar, divergence of curl as, 85
- Zero vector, curl of gradient as, 85



7/18/19