INDEX

A (*see* Magnetic vector potential)
Acceptor, 340, 342
Addition:
  of complex numbers, 22
  of vectors, 3, 4
Admittance:
  characteristic, 399
  input, 364
  line, 399
Air gap, 367, 368
Ampere, definition of, 450
Ampere turn, 367
Ampere's circuital law:
  illustration of, 74
  in differential form, 92, 95
  in integral form, 62, 64, 90
  statement of, 74
Ampere's law of force, 30-32
Amplitude modulated signal, 270
  group velocity for, 271
Anisotropic dielectric:
  effective permittivity of, 170
  example of, 386
  wave propagation in, 386-87
Anisotropic dielectric materials, 169
Anisotropic magnetic material:
  effective permeability of, 195
  example of, 387
Antenna:
  directivity of, 306
  equiangular spiral, 411
  frequency-independent, 411
  half-wave dipole (*see* Half-wave dipole)
  Hertzian dipole (*see* Hertzian dipole)
  image, 316
  loop (*see* Loop antenna)
  radiation pattern, 304
  radiation resistance of, 304
  short dipole, 327
Antenna array:
  group pattern for, 313
  log-periodic dipole, 412
  of two current sheets, 141
  principle of, 141-42, 311
  resultant pattern for, 313
Antenna arrays:
  of two Hertzian dipoles, 311-14
  radiation patterns for, 313-16
Antennas:
  in sea water, 188
  receiving properties of, 318
Antiferromagnetic material, 171
Apparent phase velocity, 252, 284
Apparent wavelength, 252, 284
Array (*see* Antenna array)
Array factor, 313

Atom, classical model of, 162
Attenuation, 179
Attenuation constant, 179
  for good conductor, 186
  for imperfect dielectric, 185
  units of, 179
Automobile, Doppler shift due to, 145

B (*see* Magnetic flux density)
B–H curve, 176
Biot-Savart law, 33
Bound electrons, 162, 164
Boundary condition:
  at transmission line short circuit, 220
  for normal component of **B**, 203, 229
  for normal component of **D**, 202, 229
  for tangential component of **E**, 199, 228
  for tangential component of **H**, 201, 228
Boundary conditions:
  at dielectric interface, 229, 239
  at transmission line junction, 232
  on perfect conductor surface, 203, 236
Brewster angle, 409
Broadside radiation pattern, 313

Cable, coaxial (*see* Coaxial cable)
Candela, definition of, 450
Capacitance:
  definition of, 208
  for parallel-plate arrangement, 346
Capacitance per unit length:
  for arbitrary line, 215, 216, 238
  for coaxial cable, 218, 238
  for parallel-plate line, 209, 237
  for parallel-wire line, 422
  related to conductance per unit length, 209
  related to inductance per unit length, 209
  units of, 208
Cartesian coordinate system, 9-14
  arbitrary curve in, 13
  arbitrary surface in, 13
  coordinates for, 10
  curl in, 89, 114
  differential length vector in, 12, 37
  differential lengths, 12
  differential surfaces, 12, 37
  differential volume, 13, 37
  divergence in, 104, 114
  gradient in, 332, 370
  Laplacian in, 340
Cartesian coordinate system (*Cont.*):
  orthogonal surfaces, 10
  unit vectors, 10
Cavity resonator, 279
  frequencies of oscillation, 280, 286
Characteristic admittance, 399
Characteristic impedance, 219, 238
  for coaxial cable, 219
  for lossless line, 219, 238
Characteristic polarizations, 170, 386, 388
Charge, 2, 24
  conservation of, 72
  line, 41
  magnetic, 70
  of an electron, 24
  point (*see* Point charge)
  surface, 42
  unit of, 24
Charge density:
  line, 41
  surface, 42
  volume, 70
Circuit:
  distributed, 210, 211
  magnetic (*see* Magnetic circuit)
Circuit parameters, 208
Circuit theory, 210
  validity of, 227
Circuital law, Ampere's (*see* Ampere's circuital law)
Circular polarization, 20-21
Circulation, 49
  per unit area, 97, 99
Closed path, line integral around, 49
Closed surface integral, 55
Coaxial cable, 217
  capacitance per unit length of, 218
  characteristic impedance of, 219
  conductance per unit length of, 218
  field map for, 217
  inductance per unit length of, 217
  parameters for, 238
Communication:
  from earth to moon, 150
  from earth to satellite, 383-84
  ground-to-ground, 384
  under water, 188
Commutative property of vector dot product, 5
Complete standing waves, 223
Complex number, conversion into exponential form, 22

Complex numbers, addition of, 22
Computer solution of Laplace's equation, basis for, 354, 372
Conductance:
  definition of, 209
  for parallel-plate arrangement, 346
Conductance per unit length:
  for arbitrary line, 216, 238
  for coaxial cable, 218, 238
  for parallel-plate line, 209, 237
  related to capacitance per unit length, 209
  units of, 209
Conduction, 162
Conduction current, 162
  power dissipation due to, 211
Conduction current density, 162
  relationship with **E**, 163, 177, 189
Conductivities, table of, 163
Conductivity:
  definition of, 163
  for conductors, 163
  for semiconductors, 163
  units of, 163
Conductor:
  decay of charge placed inside, 194
  good (*see* Good conductor)
  perfect (*see* Perfect conductor)
  power dissipation density in, 184, 191
Conductors, 162, 189
  good, 191
  perfect, 192
Conservation of charge, 72
  law of, 72, 76
Conservative field, 336
Constant of universal gravitation, 24
Constant phase surfaces:
  far from a physical antenna, 145
  for uniform plane wave, 249
Constant SWR circle, 399
Constitutive relations, 161, 177, 190
Continuity equation, 109, 113
Coordinate system:
  Cartesian, 9-14
  cylindrical, 433-35
  spherical, 435-37
Coordinates:
  Cartesian, 10
  cylindrical, 433
  relationships between, 437-38
  spherical, 436
Corner reflector, 328
Coulomb, as unit of charge, 24, 450
Coulomb's law, 25
Critical angle, 282, 287
Critical frequency, 383
Cross product of vectors, 6
  distributive property of, 7, 8
Curl, 95-99
  definition of, 96, 113
  divergence of, 114, 423–24
  in Cartesian coordinates, 89, 114
  in cylindrical coordinates, 443
  in spherical coordinates, 445
  of **E**, 90, 112, 177
  of gradient of scalar, 332
  of **H**, 95, 113, 177
  physical interpretation of, 97-99
Curl meter, 97
Current:
  conduction, 162
  crossing a line, 123-24
  crossing a surface, 30, 63
  displacement, 63
  magnetization, 174
  polarization, 167
  unit of, 450
Current density:
  conduction, 162, 163
  definition of, 30
  displacement, 95
  due to motion of electron cloud, 29-30
  surface, 123
  volume, 63
Current element:
  magnetic field of, 32-33, 37
  magnetic force on, 33
Current enclosed by closed path, uniqueness of, 64-67
Current loop (*see also* Loop antenna):
  dipole moment of, 170
  vector potential due to, 427
Current reflection coefficient, 233, 240
Current sheet, infinite plane (*see* Infinite plane current sheet)
Current transmission coefficient, 233, 240
Curve, equation for, 13
Curvilinear squares, 216, 217
Cutoff condition, 260, 273, 274
Cutoff frequencies:
  determination of, 277-79
  for $TE_{m,0}$ modes, 260, 285
  for $TE_{m,n}$ modes, 277
  for $TM_{m,n}$ modes, 277

Cutoff frequency, 260
of dominant mode, 278
Cutoff wavelength, 260
Cutoff wavelengths:
for $TE_{0,n}$ modes, 274
for $TE_{m,0}$ modes, 260, 273, 285
for $TE_{m,n}$ modes, 274, 286
for $TM_{m,n}$ modes, 277, 286
Cylindrical coordinate system:
coordinates for, 433
curl in, 443
differential length vector in, 435
differential lengths, 435
differential surfaces, 435
differential volume, 435
divergence in, 443
gradient in, 444
limits of coordinates, 433
orthogonal surfaces, 433
unit vectors, 433

D (*see* Displacement flux density)
Degree Kelvin, definition of, 450
Del operator, 89
Density:
charge (*see* Charge density)
current (*see* Current density)
Depletion layer, 342
Depth, skin, 187
Derived equation, checking the validity of, 450-51
Diamagnetic materials, values of χ_m for, 175-76
Diamagnetism, 171
Dielectric:
imperfect (*see* Imperfect dielectric)
perfect (*see* Perfect dielectric)
Dielectric constant, 169
Dielectric interface:
boundary conditions at, 229, 239
oblique incidence of uniform plane waves on, 281, 404
Dielectrics, 162, 189
anisotropic, 169
imperfect, 191
linear isotropic, 169
perfect, 191
polarization in, 164
table of relative permittivities for, 169
Differential:
net longitudinal, 104
Differential (*Cont.*):
net right-lateral, 88, 89
right-lateral, 88
Differential length vector:
in Cartesian coordinates, 12, 37
in cylindrical coordinates, 435
in spherical coordinates, 436
Differential lengths:
in Cartesian coordinates, 12
in cylindrical coordinates, 435
in spherical coordinates, 436
Differential surface, as a vector, 12
Differential surfaces:
in Cartesian coordinates, 12, 37
in cylindrical coordinates, 435
in spherical coordinates, 437
Differential volume:
in Cartesian coordinates, 13, 37
in cylindrical coordinates, 435
in spherical coordinates, 437
Dimensions, 450
table of, 451-53
Diode:
tunnel, 344
vacuum, 374
Dipole:
electric (*see* Electric dipole)
half-wave (*see* Half-wave dipole)
Hertzian (*see* Hertzian dipole)
magnetic (*see* Magnetic dipole)
short, 327
Dipole moment:
electric, 164, 339
magnetic, 170
of current loop, 170
per unit volume, 165, 172
Dipole moment per unit volume:
electric (*see* Polarization vector)
magnetic (*see* Magnetization vector)
Direction lines, 17
for electric dipole field, 339
for point charge field, 27
Directivity:
definition of, 306
of half-wave dipole, 311, 323
of Hertzian dipole, 306, 323
of loop antenna, 429
Discharge tube, in gas lasers, 409
Dispersion, 181, 266
Dispersion diagram, 269
Displacement current, 63
Displacement current density, 95

Displacement flux, 63
Displacement flux density, 63
  divergence of, 104, 113
  due to point charge, 71-72
  relationship with **E**, 76, 113, 168, 177
  units of, 63
Displacement vector (*see* Displacement flux density)
Distributed circuit, 210
  physical interpretation of, 210-11
Distributive property:
  of vector cross product, 7, 8
  of vector dot product, 6
Divergence, 107-10
  definition of, 108, 113
  in Cartesian coordinates, 104, 114
  in cylindrical coordinates, 443
  in spherical coordinates, 446
  of **B**, 107, 113
  of curl of a vector, 114, 423-24
  of **D**, 104, 113
  of gradient of scalar, 340
  of **J**, 109, 113
  physical interpretation of, 109-10
Divergence meter, 109
Divergence theorem, 110, 114
  verification of, 110-12
Division of vector by a scalar, 5
Dominant mode, 277, 286
  cutoff frequency of, 278
Donor, 340, 342
Doppler shift, 143
  due to automobile, 145
  due to changing ionosphere, 384
  due to rocket, 160
  due to satellite, 145-47
Doppler-shifted frequency, 143, 144
Dot product of vectors, 5
  commutative property of, 5
  distributive property of, 6
Drift velocity, 162

E (*see* Electric field intensity)
Effective permeabilities, of ferrite medium, 388
Effective permeability, of anisotropic magnetic material, 195
Effective permittivity:
  of anisotropic dielectric, 170
  of ionized medium, 381
Electrets, 165
Electric dipole, 164, 338
  dipole moment of, 164, 339
  direction lines for the field of, 339
  electric field of, 339
  equipotential surfaces for, 339
  potential field of, 339
  schematic representation of, 164
  torque on, 164, 194
Electric dipole moment, definition of, 164
Electric energy density:
  in free space, 151, 153
  in material medium, 184, 191
Electric field, 24
  energy density in, 151, 153, 184, 191
  energy storage in, 211
  far from a physical antenna, 149
  Gauss' law for, 70, 104
  induced, 60
  motion of electron cloud in, 29-30
  source of, 26
  static (*see* Static electric field)
Electric field intensity:
  curl of, 90, 112, 177
  definition of, 26
  due to charge distribution, 105-6
  due to dipole, 339
  due to point change, 26, 37
  due to point charges, 26-28
  relationship with **D**, 76, 113, 168, 177
  unit of, 25
Electric force:
  between two point charges, 24, 25
  on a test charge, 25
Electric polarization (*see* Polarization in dielectrics)
Electric potential, 335; *see also* Potential field
Electric potential difference (*see* Potential difference)
Electric susceptibility, 165
Electromagnetic field:
  due to current sheet, 138, 152
  due to Hertzian dipole, 301, 322
  power flow density in, 148
Electromagnetic waves:
  guiding of, 247; *see also* Waveguide
  propagation of, 121, 293; *see also* Wave propagation
  radiation of, 121, 293; *see also* Radiation
  transmission of, 293; *see also* Transmission lines
Electromotive force, 50, 57, 58
  motional, 61

Electron:
charge of, 24
mobility of, 163
Electron cloud, motion in electric field, 29-3(
Electron density, related to plasma frequency, 381
Electronic orbit, 170
Electronic polarization, 164
Electrons:
bound, 162
conduction, 162
free, 162
Elliptical polarization, 21
Emf (*see* Electromotive force)
Endfire radiation pattern, 142, 314
Energy density:
in electric field, 151, 153, 184, 191
in magnetic field, 152, 153, 184, 191
Energy storage:
in electric field, 150, 211
in magnetic field, 150, 211
Equiangular spiral antenna, 411
Equipotential surfaces, 334
between parallel plates, 345
for electric dipole, 338-39
for line-charge pair, 420
for point charge, 337

Fabry-Perot resonator, 409
Faraday rotation, 390
Faraday's law, 57
illustration of, 74
in differential form, 85, 90, 112
in integral form, 59, 74, 84
statement of, 74
Ferrimagnetic material, 171
Ferrites, 387
characteristic polarizations for, 388
effective permeabilities for, 388
wave propagation in, 387-90
Ferroelectric materials, 165
Ferromagnetic materials, 171
Field:
definition of, 14
electric (*see* Electric field)
gravitational, 14, 24
magnetic (*see* Magnetic field)
Field intensity:
electric (*see* Electric field intensity)
magnetic (*see* Magnetic field intensity)
Field map, 212
for arbitrary line, 212-14
Field map (*Cont.*):
for coaxial cable, 217
Field mapping, determination of line parameters from, 212-16
Fields:
conservative, 336
quasistatic, 357-64
radiation, 302; *see also* Radiation fields
scalar, 14-17; *see also* Scalar fields
sinusoidally time-varying, 18-24
static, 15-16; *see also* Static fields
time-varying, 16-17
vector, 17-18; *see also* Vector fields
Flux:
displacement, 63
magnetic, 51-53
Flux density:
displacement (*see* Displacement flux density)
magnetic (*see* Magnetic flux density)
Flux lines, 17
Force:
Ampere's law of, 30-32
electric (*see* Electric force)
gravitational, 15, 24
magnetic (*see* Magnetic force)
unit of, 449-50
Free electrons, 162
Free space:
intrinsic impedance of, 140
permeability of, 31
permittivity of, 25
velocity of light in, 136
wave propagation in, 135-47
Frequencies of oscillation, for cavity resonator, 280, 286
Frequency:
cutoff, 260, 277, 285
plasma, 381
times wavelength, 140
Frequency-independent antenna, 411

Gas lasers, 409
Gauss' law for the electric field:
illustration of, 75
in differential form, 104, 113
in integral form, 70, 75, 102
statement of, 69, 75
Gauss' law for the magnetic field:
illustration of, 75
in differential form, 107, 113
in integral form, 69, 75, 106

Gauss' law for the magnetic field (*Cont.*):
physical significance of, 70
statement of, 70, 75
Good conductor:
attenuation constant for, 186
definition of, 184
intrinsic impedance for, 187
phase constant for, 187
skin effect in, 188
wave propagation in, 186-89
Good conductors, 191
Gradient, 332
curl of, 332
divergence of, 340
in Cartesian coordinates, 332, 370
in cylindrical coordinates, 444
in spherical coordinates, 446
physical interpretation of, 332-34
Gravitational field, 14, 24
Gravitational force, 15, 24
Ground, effect on antenna, 316
Group pattern, 313
Group patterns, determination of, 313-14
Group velocity:
concept of, 266
for a pair frequencies, 269
for amplitude modulated signal, 271
for narrowband signal, 270
in ionized medium, 385
in parallel-plate waveguide, 270
Guide impedance, 263, 285
compared to characteristic impedance, 264
Guide wavelength, 261, 285

H (*see* Magnetic field intensity)
Half-wave dipole:
directivity of, 311, 323
evolution of, 307
radiation fields for, 309, 323
radiation patterns for, 310
radiation resistance for, 310, 323
Hertzian dipole, 294
above perfect conductor surface, 316-18
charges and currents associated with, 295
directivity of, 306, 323
electromagnetic field for, 301, 322
radiation fields for, 302, 322
radiation patterns for, 304–6
radiation resistance for, 304, 322
retarded potential for, 426
time-average radiated power, 303, 322
Hertzian dipoles, array of, 311
Holes, 163, 340
mobility of, 163
Hysteresis, 176
Hysteresis curve, 176

Image antennas, 316
illustration of, 317
Impedance:
characteristic, 219, 238
guide, 263, 285
input, 224
intrinsic, 140; *see also* Intrinsic impedance
line, 394
Imperfect dielectric:
attenuation constant for, 185
definition of, 184
intrinsic impedance for, 185
phase constant for, 185
wave propagation in, 185-86
Imperfect dielectrics, 191
Incident wave, 221, 231, 263, 281, 404
Induced electric field, 60
Inductance, definition of, 208
Inductance per unit length:
for arbitrary line, 214, 216, 237
for coaxial cable, 217, 238
for parallel-plate line, 208, 237
related to capacitance per unit length, 209
units of, 208
Infinite plane current sheet, 123
as an idealized source, 123, 293
electromagnetic field due to, 138, 152, 182, 190
magnetic field adjacent to, 126
radiation from, 139, 183
Input behavior, for low frequencies, 225-27, 357-64
Input impedance:
low frequency behavior of, 225-27
of short-circuited line, 224, 239
Input reactance, of short-circuited line, 224
Insulators, 162
Integral:
closed line (*see* Circulation)
closed surface, 55
line, 48
surface, 54
volume, 70-71
Integrated optics, 272
Interferometer, 328
International system of units, 24, 449

Intrinsic impedance:
  definition of, 140
  for free space, 140, 152
  for good conductor, 187
  for imperfect dielectric, 185
  for material medium, 181, 191
  for perfect dielectric, 184
Ionic polarization, 164
Ionized medium:
  condition for propagation in, 381
  effective permittivity of, 381
  example of, 380
  group velocity in, 385
  phase velocity in, 382
  wave propagation in, 380-85
Ionosphere, 380
  condition for reflection of wave, 383
  description of, 382-83
Iteration technique, 355

J (*see* Volume current density)
$\mathbf{J}_C$ (*see* Conduction current density)
Joule, definition of, 450
Junction, *p–n*, 340

Kelvin degree, definition of, 450
Kilogram, definition of, 449
Kirchhoff's current law, 210
Kirchhoff's voltage law, 210

Laplace's equation, 347, 371
  application for field mapping, 347
  applications of, 345-46, 348-52
  computer solution of, 352-57
  in one dimension, 345-46
  in two dimensions, 347
  solution for steady current condition, 344
  solution of, 345, 347-48, 418-19
Laplacian, 340
  in Cartesian coordinates, 340
Laser beam, 390
Lasers, gas, 409
Law of conservation of charge, 72, 76, 108
  in differential form, 109, 113
Law of reflection, 282
Law of refraction, 282, 286
Leakage flux, 366
Lenz's law, 60, 62
Light, velocity of (*see* Velocity of light)
Line admittance, 399
  from the Smith chart, 399-400
  normalized, 399
Line charge, 41
  infinitely long, 418
  potential field of, 418-19
Line charge density, 41
  units of, 41
Line current, magnetic field due to, 64-65
Line impedance, 394
  from the Smith chart, 398-99
  normalized, 395
Line integral, 48
  around closed path, 49
  evaluation of, 48-49
  to surface integral, 99, 114
Line integral of **E**, physical meaning of, 49
Linear isotropic dielectrics, 169
Linear polarization, 19-20
Linear quadrupole, 374
Lines:
  direction (*see* Direction lines)
  transmission (*see* Transmission lines)
Log-periodic dipole array, 412
  design of, 413-17
Longitudinal differential, net, 104
Loop antenna, 319, 426
  directivity of, 429
  magnetic vector potential for, 427
  power radiated by, 428
  radiation fields of, 428
  radiation resistance of, 429
  receiving properties of, 319-21
Lorentz force equation, 35, 38
Loss tangent, 180
Low frequency behavior, determination of, 225-27, 357-64
Lumped circuits, 210

Magnetic charge, 70
Magnetic circuit:
  analysis of, 367-69
  example of, 365
  reluctance of, 367
Magnetic dipole, 170
  schematic representation of, 171
  torque on, 171, 194
Magnetic dipole moment, definition of, 170
Magnetic dipole moment per unit volume (*see* Magnetization vector)

Magnetic energy density:
in free space, 152, 153
in material medium, 184, 191
Magnetic field:
energy density in, 152, 153, 184, 191
energy storage in, 150, 211
far from a physical antenna, 149
Gauss' law for, 69, 107
inside a good conductor, 189
realizability of, 107
source of, 35
Magnetic field intensity, 63
adjacent to current sheet, 126
curl of, 95, 113, 177
due to current distribution, 93-94
due to infinitely long wire of current, 64-65
relationship with **B**, 76, 113, 175, 177
units of, 64
Magnetic flux, crossing a surface, 51-53
Magnetic flux density:
definition of, 34
divergence of, 107, 113
due to current element, 32-33, 37
from **A**, 424
relationship with **H**, 76, 113, 175, 177
units of, 32
Magnetic force:
between two current elements, 31
in terms of current, 33
on a moving charge, 34
Magnetic materials, 170, 189
anisotropic, 175
Magnetic susceptibilities, values of, 176
Magnetic susceptibility, 172
Magnetic vector potential, 424
application of, 426
due to current element, 425
for circular loop antenna, 427
for Hertzian dipole, 426
relationship with **B**, 424
Magnetization, 170
Magnetization current, 174
Magnetization current density, 174
Magnetization vector:
definition of, 172
in magnetic iron-garnet film, 390, 392
relationship with **B**, 172
units of, 172
Magnetomotive force, 64, 68, 366
Magneto-optical switch, 390, 392
Magnitude of vector, 5
Mass, 24
unit of, 449
Matching, transmission line, 400-402
Materials:
antiferromagnetic, 171
classification of, 161, 189
conductive (*see* Conductors)
constitutive relations for, 177
diamagnetic (*see* Diamagnetic materials)
dielectric (*see* Dielectrics)
ferrimagnetic, 171
ferroelectric, 165
ferromagnetic, 171
magnetic (*see* Magnetic materials)
paramagnetic (*see* Paramagnetic materials)
Maxwell's curl equations:
for material medium, 177, 190
for static fields, 332,
successive solution of, 128-31, 153
Maxwell's equations:
as a set of laws, 1, 45
for static fields, 370
in differential form, 112-13
in integral form, 74-75, 198
independence of, 76, 114-15
Meter, definition of, 449
Mho, 163
MKSA system of units, 449
Mmf (*see* Magnetomotive force)
Mobility, 163
Mode, Dominant (*see* Dominant mode)
Modes:
TE (*see* TE modes)
TM (*see* TM modes)
Moment:
electric dipole, 164
magnetic dipole, 170
Moving charge, magnetic force on, 34
Moving observer:
frequency viewed by, 143, 145
phase of the wave viewed by, 142
Multiplication of vector, by a scalar, 5

Newton, definition of, 449-50
Newton's law of gravitation, 24
Newton's third law, 32
Normal component of **B**, boundary condition for, 203, 229
Normal component of **D**, boundary condition for, 202, 229

Normal vector to a surface:
from cross product, 13-14
from gradient, 334
Normalized line admittance, 399
Normalized line impedance, 395
Nucleus, 162

Observer:
moving, 142, 143, 145
stationary, 144-45
Ohm, 163
Ohm's law, 163
$\omega - \beta_z$ diagram, 269
Operator, del, 89
Optical fiber, 282
Optical waveguides, principle of, 281
Orbit, electonic, 170
Orientational polarization, 164
Origin, 10
Orthogonality property, of sine functions, 352

Paddle wheel, 97
Parallel-plate transmission line, 205
capacitance per unit length for, 209
conductance per unit length for, 209
inductance per unit length for, 208
parameters for, 237
power flow along, 207
voltage and current along, 206
Parallel-plate waveguide, 259
cutoff frequencies for, 260
cutoff wavelengths for, 260
discontinuity in, 262-65
group velocity in, 270
guide wavelength in, 261
phase velocity along, 261
$TE_{m,0}$ mode fields in, 261
$TE_{m,0}$ modes in, 259
Parallel polarization, 406
Parallel-wire line, 243, 418
capacitance per unit length of, 422
Parallelepiped, volume of, 40
Paramagnetic materials, 171
values of χ_m for, 176
Paramagnetism, 171
Partial standing waves, 235
standing wave patterns for, 235-36
Pattern multiplication, 314
Perfect conductor:
boundary conditions, 203, 236
definition of, 189
Perfect conductors, 192
Perfect dielectric:
boundary conditions, 229, 239
definition of, 184
intrinsic impedance for, 184
phase constant for, 184
phase velocity in, 184
wave propagation in, 184
Perfect dielectrics, 191
Permanent magnetization, 171
Permeability:
effective, 195, 388
of free space, 31
of magnetic material, 175
relative, 175
units of, 31
Permeability tensor, 195
Permittivity:
effective, 170, 381
of dielectric material, 169
of free space, 25
relative, 169
units of, 25
Permittivity tensor, 169, 194, 386
Perpendicular polarization, 405
Phase, 18
Phase constant:
for free space, 138, 152
for good conductor, 187
for ionized medium, 381
for imperfect dielectric, 185
for material medium, 180
for perfect dielectric, 184
Phase shift, 179
Phase velocity:
along guide axis, 261, 285
apparent, 252
in free space, 138, 152
in good conductor, 187
in imperfect dielectric, 185
in ionized medium, 382
in material medium, 180
in perfect dielectric, 184
Phasor, 22
Phasor technique, review of, 21-24
Plane surface, equation for, 13
Plane wave, uniform (*see* Uniform plane wave)
Plasma frequency:
definition of, 381
related to electron density, 381
p–n junction semiconductor, 340
analysis of, 340-43

Point charge:
electric field of, 26, 37
equipotential surfaces for, 337
potential field of, 337, 371
Point charges, 24
electric field of, 26-28
Poisson's equation, 340, 371
application of, 340-44
Polarization current, 167
Polarization current density, 168
Polarization in dielectrics, 164
electronic, 164
ionic, 164
orientational, 164
Polarization of vector fields:
circular, 20-21
elliptical, 21
linear, 19-20
parallel, 406
perpendicular, 405
Polarization vector:
definition of, 165
relationship with **E**, 165
units of, 165
Polarizer, 392
Polarizing angle, 409
Position vector, 250, 284, 439
Potential:
electric (*see* Electric potential)
magnetic vector (*see* Magnetic vector potential)
retarded, 426
Potential difference, 335
compared to voltage, 336
Potential field:
of electric dipole, 339
of line charge, 418-19
of pair of line charges, 419-20
of point charge, 337, 371
Power:
carried by an electromagnetic wave, 148
dissipated in a conductor, 182
radiated by half-wave dipole, 309
radiated by Hertzian dipole, 303
radiated by loop antenna, 428
time-average, 303, 310, 428
Power balance, at junction of transmission lines, 234
Power density, associated with an electromagnetic field, 148, 151
Power dissipation density, 184, 191
Power flow:
along parallel-plate line, 207
Power flow (*Cont.*):
along short-circuited line, 221
in parallel-plate waveguide, 257
Poynting theorem, 151
for material medium, 184
Poynting vector, 148-51, 153
for half-wave dipole fields, 309
for Hertzian dipole fields, 302
for loop antenna fields, 428
for TE waves, 257
surface integral of, 151, 207, 302
time-average, 257
units of, 148
Propagating modes, determination of, 262, 277-79
Propagation:
sky wave mode of, 384
waveguide mode of, 384
Propagation constant:
for material medium, 179, 190
for transmission line, 218, 238
Propagation vector, 250, 284

Quadrupole, linear, 374
Quasistatic behavior:
determination of, 358-60, 360-64
equivalent circuit for, 364
Quasistatic extension:
analysis beyond, 377
of static field, 358, 360, 372
Quasistatic fields, 331, 357-64

Radiation:
far from a physical antenna, 149
from current sheet, 139, 183
principle of, 123
Radiation fields:
definition of, 302
for half-wave dipole, 309, 323
for Hertzian dipole, 302, 322
for loop antenna, 428
Radiation pattern, 304
broadside, 313
endfire, 142, 314
Radiation patterns:
for antenna above perfect conductor, 318
for antenna arrays, 313-16
for half-wave dipole, 310
for Hertzian dipole, 304-6
Radiation resistance:
definition of, 304

Radiation resistance (*Cont.*):
for half-wave dipole, 310, 323
for Hertzian dipole, 304, 322
for loop antenna, 429
Radio communication, 383
Rationalized MKSA units, 448
Receiving properties:
of Hertzian dipole, 318-19
of loop antenna, 319-21
Reciprocity, 318
Rectangular coordinate system (*see* Cartesian coordinate system)
Rectangular waveguide, 272
determination of propagating modes in, 277-78
field expressions for TE modes in, 274-76
TE modes in, 274
TM modes in, 277
Reflected wave, 221, 231, 263, 281, 404
Reflection coefficient:
at waveguide discontinuity, 265
current, 233, 240
for oblique incidence, 406, 407
from the Smith chart, 398
voltage, 232, 239, 395
Reflection condition, for incidence on ionosphere, 383
Refractive index, 282
Relative permeability, 175
for ferromagnetic materials, 176
Relative permittivity, 169
table of values of, 169
Reluctance, definition of, 367
Resistance, 194, 212
Resonator, cavity (*see* Cavity resonator)
Resultant pattern, 313
Resultant patterns, determination of, 314-16
Retarded potential, 426
Right-hand screw rule, 59, 85, 87, 91
illustration of, 59
Right-handed coordinate system, 10
Right-lateral differential, net, 88, 89

Satellite, Doppler shift due to, 145-47
Satellite navigational systems, 384
Scalar:
definition of, 2
gradient of (*see* Gradient)
Laplacian of, 340
Scalar fields, 14-17
graphical representation of, 15-16
sinusoidally time-varying, 18
Scalar product (*see* Dot product of vectors)
Scalar triple product, 8
Scalars, example of, 2
Second, definition of, 449
Semiconductor, p–n junction, 340
Semiconductors, 163
conductivity of, 163
Separation of variables technique, 132, 133
Shielding, 188
Short circuit, location of, 225
Short-circuited line:
input impedance of, 224, 239
instantaneous power flow down, 221
standing wave patterns for, 223
voltage and current on, 221
Short dipole, 327
Signal source, location of, 321
Sine functions, orthogonality property of, 352
Sinusiodally time-varying fields, 18-24
Skin depth, 187, 191
for copper, 187
Skin effect, 188
Smith chart:
applications of, 397-402
construction of, 395-96
use as admittance chart, 400
Snell's law, 282, 286
Space charge layer, 340, 342
Spherical coordinate system:
brief review of, 296-97
coordinates for, 436
curl in, 445
differential length vector in, 436
differential lengths, 436
differential surfaces, 437
differential volume, 437
divergence in, 446
gradient in, 446
limits of coordinates, 436
orthogonal surfaces, 435-36
unit vectors, 436
Standing wave patterns, 223
for partial standing wave, 236
for short-circuited line, 223-24
Standing wave ratio:
definition of, 235, 240, 394
from the Smith chart, 399, 400
Standing waves, 204
complete, 223
partial, 235
Static electric field:
conservative property of, 336
determination of, 72

Static electric field (*Cont.*):
in terms of potential, 336, 370
of electric dipole, 339
Static fields, 331
Maxwell's equations for, 370
Static magnetic field, determination of, 65
Steady current condition, 344
Stokes' theorem, 99-100, 114
verification of, 100-101
Stream lines, 17
Strip line, 244
Stub, 401, 402
Subtraction of vectors, 4
Surface:
differential (*see* Differential surface)
equation for, 13
Surface charge, 42
Surface charge density, 42
units of, 42
Surface current density, 123
units of, 123
Surface integral, 54
closed, 55
evaluation of, 55-57
of **E** x **H**, 148
to volume integral, 110, 114
Surfaces:
constant phase (*see* Constant phase surfaces)
differential (*see* Differential surfaces)
equipotential (*see* Equipotential surfaces)
Susceptibility:
electric, 165
magnetic, 172
SWR (*see* Standing wave ratio)

Table:
of conductivities, 163
of dimensions, 451–53
of relative permittivities, 169
of units, 451–53
Tangential component of **E**, boundary condition for, 199, 228
Tangential component of **H**, boundary condition for, 201, 228
$TE_{0,n}$ modes, 273, 274
$TE_{m,0}$ modes, 259
cutoff frequencies for, 260, 285
cutoff wavelengths for, 260, 273, 285
field expressions for, 261
guide impedance for, 263, 285
in parallel-plate waveguide, 259
in rectangular waveguide, 272
$TE_{m,n}$ modes, 274
cutoff frequencies for, 277
cutoff wavelengths for, 274, 286
field expressions for, 274-76
$TE_{m,n,l}$ modes, in cavity resonator, 280
TE wave, 257, 285
TEM wave, 212
Thin film waveguide, 292
Time-average power:
radiated by half-wave dipole, 310
radiated by Hertzian dipole, 303, 322
radiated by loop antenna, 428
Time-average power flow:
along short-circuited line, 223
for TE wave, 257
Time-average Poynting vector, 257
Time constant, for decay of charge inside a conductor, 194
$TM_{m,n}$ modes, 277
cutoff frequencies for, 277
cutoff wavelengths for, 277, 286
$TM_{m,n,l}$ modes, in cavity resonator, 280
TM wave, 276
Toroidal magnetic core, 365
Torque:
on electric dipole, 164, 194
on magnetic dipole, 171, 194
Total internal reflection, 282, 287, 408
Transmission coefficient:
at waveguide discontinuity, 265
current, 233, 240
for oblique incidence, 406, 407
voltage, 233, 240
Transmission line:
characteristic impedance of, 219, 238
coaxial (*see* Coaxial cable)
compared to waveguide, 197, 247
field mapping, 212-16
location of short circuit in, 225
parallel-plate (*see* Parallel-plate line)
parallel-wire (*see* Parallel-wire line)
propagation constant for, 218, 238
short-circuited (*see* Short-circuited line)
Transmission-line admittance (*see* Line admittance)
Transmission-line discontinuity:
boundary conditions at, 232
reflection coefficients, 232-33
transmission coefficients, 233
Transmission-line equations, 208, 218, 237
circuit representation of, 209-10
in phasor form, 218, 238

Transmission-line equivalent, for waveguide discontinuity, 264
Transmission-line impedance (*see* Line impedance)
Transmission-line matching, 400-402
Transmission-line parameters:
  for arbitrary line, 237-38
  for coaxial cable, 238
  for parallel-plate line, 237
Transmission lines, power balance at junction of, 234
Transmitted wave, 231, 263, 281, 404
Transverse electric wave, 257, 285
Transverse electromagnetic wave, 212
Transverse magnetic wave, 276
Transverse plane, 206, 207
Traveling wave, 136
  negative going, 136
  positive going, 136
  velocity of, 136
Tunnel diode, 344

Uniform plane wave:
  guided between perfect conductors, 205
  oblique incidence on a dielectric, 281, 404
  parameters associated with, 140-41
  radiation from current sheet, 139, 183
  terminology, 138
Uniform plane wave fields:
  magnetization induced by, 172
  polarization induced by, 165
Uniform plane wave in three dimensions:
  apparent phase velocities, 252, 284
  apparent wavelengths, 252, 284
  electric field vector of, 250
  expressions for field vectors, 284
  magnetic field vector of, 251, 252
  propagation vector for, 250, 284
Uniform plane wave propagation (*see* Wave propagation)
Uniform plane waves:
  bouncing obliquely of, 259
  superposition of, 255
Unit conductance circle, 401
Unit pattern, 313
Unit vector, 3, 5
Unit vector normal to a surface:
  from cross product, 13-14
  from gradient, 334
Unit vectors:
  cross products of, 7
  dot products of, 5, 438
Unit vectors (*Cont.*):
  in Cartesian coordinates, 10
  in cylindrical coordinates, 433
  in spherical coordinates, 436
  left-handed system of, 3
  right-handed system of, 3
Units:
  International system of, 24, 449
  MKSA rationalized, 449
  table of, 451-53

V (*see* Electric potential; and Voltage)
Vacuum diode, 374
Vector:
  circulation of, 49
  curl of (*see* Curl)
  definition of, 2
  divergence of (*see* Divergence)
  division by a scalar, 5
  graphical representation of, 2
  magnitude of, 5
  multiplication by a scalar, 5
  position, 250, 284, 439
  unit, 3, 5
Vector algebra, summary of rules of, 36
Vector fields, 17-18
  graphical description of, 17-18
  sinusoidally time-varying, 18-21
Vector potential (*see* Magnetic vector potential)
Vector product (*see* Cross product of vectors)
Vectors:
  addition of, 3, 4
  cross product of, 6
  dot product of, 5
  examples of, 5
  scalar triple product of, 8
  subtraction of, 4
  unit (*see* Unit vectors)
Velocity:
  drift, 162
  group (*see* Group velocity)
  phase (*see* Phase velocity)
Velocity of light, in free space, 136
Velocity of propagation, 138
Volt, definition of, 25, 450
Voltage, 49
  compared to potential difference, 336
Voltage reflection coefficient, 232, 239, 395
Voltage transmission coefficient, 233, 239
Volume, differential (*see* Differential volume)

Volume charge density, 70
  units of, 70
Volume current density, 63; *see also* Current density
Volume integral, evaluation of, 71

Watt, definition of, 450
Wave:
  incident, 221, 231, 263, 281, 404
  reflected, 221, 231, 263, 281, 404
  TE, 257, 285
  TEM, 212
  TM, 276
  transmitted, 231, 263, 281, 404
  traveling (*see* Traveling wave)
Wave equation, 132
  for ionized medium, 380-81
  for material medium, 179
Wave motion, 121
  as viewed by moving observer, 144
  as viewed by stationary observer, 144
Wave propagation:
  in anisotropic dielectric, 386-87
  in ferrite medium, 387-90
  in free space, 135-47
  in good conductor, 186-89
Wave propagation (*Cont.*):
  in imperfect dielectric, 185-86
  in ionized medium, 380-85
  in material medium, 176-84
  in perfect dielectric, 184
  in terms of voltage and current, 208
Waveguide:
  compared to transmission line, 197, 247
  optical, 282
  parallel-plate (*see* Parallel-plate waveguide)
  rectangular (*see* Rectangular waveguide)
  thin-film, 292
Wavelength:
  apparent, 252
  definition of, 138
  guide, 261, 285
  in free space, 138, 152
  in good conductor, 187
  in imperfect dielectric, 185-86
  in material medium, 181
  in perfect dielectric, 184
  times frequency, 140
Waves:
  electromagnetic (*see* Electromagnetic waves)
  standing (*see* Standing waves)
Work, in movement of charge in electric field, 46-48