Index

A

absorbing boundary condition, *see* radiation boundary condition
absorbing material, 483–484, 494, 511
addition theorem for Hankel functions, 142
adjoint operator, 163, 220
anisotropy due to FDTD grids, 505–506
antenna, 28–30, 331, 440–443
antenna feed model, 29, 35, 440–443
aperture formulation, 22–24, 281–282
area coordinates, *see* local area coordinates
augmented field integral equation, *see* integral equation
axisymmetric problems, 301, 323–332, 475, 484, 493

B

backward error analysis, 148
banded matrix algorithm, 156
bandwidth, matrix, 151
base vectors, 399
basis, 188–190
basis/testing functions
  bilinear, 349–350, 408
  biquadratic, 351–352, 408
  CN/LT, 395, 415, 425, 434, 451, 456
  CT/LN, 372, 393, 410, 493
  cubic Lagrangian, 408
  curl-conforming, 367, 463
  curved-cell, 354–359, 409
  divergence-conforming, 395, 416–432, 451
  fully interpolatory vector, 395, 399
  Hermitian, 195, 229, 342, 475
  higher-order, 200, 337
  Lagrangian, 193, 197, 339–342, 475, 487
  linear pyramid, 71–72, 102–103, 314, 338
  LN/QT, 397, 423–424, 456, 493
  loop, 381, 435
  LT/QN, 374–375, 393, 411, 415
  mapped, 349–359, 409
  mixed-order vector, 371
  on hexahedral cells, 359, 394
  on quadrilateral cells, 353–354, 379–380, 416–424
  on rectangular cells, 349–352, 379–380, 416–424
  on tetrahedral cells, 359–361, 392–395, 451, 463–469
  on triangular cells, 70–72, 95, 103–115, 290–296, 313–323, 338–349, 362–378, 395–398
  parametric, 349–359, 409
  piecewise-constant, *see* pulse
  piecewise-linear, *see* triangle, *see* linear pyramid
  pulse, 33, 38, 46, 50–52, 60, 192, 203, 242, 267, 286
  QT/CuN, 378, 393, 411
  quadratic Lagrangian, 194, 228, 340–341, 347–348, 355, 358

basis/testing functions (*Continued*)
quadratic spline, 192, 203, 419
Rao–Wilton–Glisson (RWG), 397, 425–429, 436
razor-blade, 418, 431, 522
rooftop, 397, 416–417, 431–432, 444
sinusoidal-triangle, 33, 196, 442, 522
spline, 192, 204–205, 218
star, 381, 435
three-term sinusoid, 196, 442
triangle, 32, 52, 120, 192, 197, 203, 218, 280, 281, 440
triangular-rooftop, 397, 425–429, 436
vector, 337, 367–382
Bessel functions, 7, 61, 326, 335
asymptotic form, 207, 230
of complex argument, 252
biconjugate gradient algorithm, 161, 474
bifactorization, 145
bilinear interpolation, *see* basis functions
biquadratic interpolation, *see* basis functions
blind angles, 277
block-Toeplitz matrix, 172–173, 421
body of revolution, *see* axisymmetric problems
boundary conditions
absorbing, *see* radiation boundary conditions
at conducting surface, 2
at dielectric interface, 2
Dirichlet, 97–100, 130–132, 138, 230, 254, 319, 332, 385, 463
error in the satisfaction of, 63–65, 67–68
essential, 100, 463
impedance, 80–84, 98, 139, 511
natural, 100, 362, 463
Neumann, 97–100, 130–132, 138, 254, 319, 332, 463
perfect electric, 2, 506–507
perfect magnetic, 509–510
radiating, *see* radiation boundary condition
resistive, 93
boundary element method, *see* method of moments

C

cascaded periodic surfaces, 282–284
cavity, resonant, 135, 234, 361, 463–468
charge density, induced, 5
charge doublet, 54, 426
Cholesky factorization, 149–150
CN/LT basis functions, *see* basis functions
comb function, 262–263, 297
combined source integral equation, *see* integral equation
combined-field integral equation, *see* integral equation
compact operator, *see* operator
complementary error function, 275, 445
complete elliptic integral, 328
completeness, 188
complexification of the wavenumber, 252
condensation, 387, 411
condition number, 146, 166, 184, 205, 235–239, 253, 255
conjugate direction method, 164
conjugate gradient (CG) algorithm, 143, 161–170, 185
conjugate gradient fast Fourier transform (CG-FFT) algorithm, 143, 161, 186, 170–175, 421, 451
connectivity matrix, 57–58, 106–107, 345, 370, 384
continuity conditions, *see* boundary conditions
continuity equation, 16
contravariant components, 400–405
control region methods, 499
convergence
of iterative algorithms, 166–170
of numerical results, 187–191, 200–205, 212–224
of periodic Green's function, 269–277
convolution, 7, 8, 34, 262, 271, 313, 418–420, 448, 507
convolution theorem, 201, 262, 271, 303
corrugated surface, 288, 294
coupled azimuthal potentials, 484
coupled-wave formulation, 288, 293–294
Courant condition, 503–504
Courant ratio, 505
covariant components, 400–405
Crout's method, 145
CT/LN basis functions, *see* basis functions
curl-conforming basis functions, *see* basis functions
curl-curl equation, *see* Helmholtz equation, vector
current sheet superposition, 278, 446
curved cells, *see* basis functions
Cuthill–McKee algorithm, 151, 154, 184
cutoff wavenumber, 253, 259
cylinder
infinite, 3
perfectly conducting, 25, 37
cylindrical harmonics, 118, 128, 141, 257, 301, 320, 325, 475

D

Debye materials, 508
degenerate kernels, 214–216
delta gap antenna feed, 441
determinant, 253–254
dielectric cylinder, 59–80, 106–110, 313–323, 386–389, 439
dielectric-loaded waveguides, 388–392
differentiability requirements for basis functions, 191, 200
differential equation formulation, *see* Helmholtz equation, *see* finite difference time domain
diffraction grating, *see* strip grating, *see* frequency-selective surface
dipole antennas, 29, 35, 336
Dirichlet boundary condition, *see* boundary conditions
discrete convolutional symmetry, 170–174
discrete Fourier transform, 171, 264
discretization errors, 40, 62, 235, *see also* interpolation error
dispersion analysis
  finite difference, 229
  finite difference time domain, 504–506
  scalar finite element, 198, 230
  vector finite element, 381
divergence conservation in FDTD, 500
divergence theorem, 11, 96, 222, 318, 361, 462
divergence-conforming basis functions, *see* basis functions
domain of an operator, *see* operator
Doolittle's method, 145
dual surface integral equation, *see* integral equations
duality principles, 10, 91, 92, 282, 287
dummy cells, 174
dummy nodes, 292
dummy unknowns, 111
dyadic Green's function, *see* Green's functions

E

echo width, *see* scattering cross section, two-dimensional
edge elements, *see* basis functions
edge singularity, 88, 228, 423
eigenfunction, 205, 230, 234, 241, 247, 250
eigenfunction expansion, 100, 108, 128, 141, 257, 320, 411, 469
eigenvalue projection theory, 205–206, 234
eigenvalues, 147, 168, 205–211, 215, 230, 234–241, 247, 250, 389, 431
eigenvalues of CFIE, 241, 259
eigenvalues of EFIE, 207–209, 230, 234
eigenvalues of MFIE, 211, 230, 235
eigenvectors, 168, 206
electric field integral equation
  eigenvalues of, 207–209, 230, 234
  low-frequency treatment, 209, 433–435
  mixed potential form, 52, 324, 425, 433, 449
  normal-field, 35
  thin wire, 440
  three-dimensional surface, 17, 21, 324, 404–405, 416, 425, 435
  three-dimensional volume, 19, 404, 450
  two-dimensional surface, 35, 37, 50, 77, 81–82, 92, 93, 126, 201, 202, 233
  two-dimensional volume, 60, 66, 91, 313
electrically small scatterers, treatment of, 209, 433–435
element matrix
  one-dimensional, 120–121, 141, 229, 385, 408, 412
  three-dimensional vector, 403–404, 412, 464–467
  two-dimensional scalar, 107, 112–115, 292, 322, 343–345, 351, 353–354, 356
  two-dimensional vector, 363, 370, 374–375, 403, 410–411
elements, *see* basis functions
envelope of a sparse matrix, 151, 156
equivalence principle
  surface, 10–23, 37, 284, 510
  volume, 4–5, 18–19
equivalent exterior problem, 15–17, 20, 125, 247, 435
equivalent interior problem, 20, 247, 435
equivalent polarization current density, *see* polarization current density
error function, 274, 445
error function transformation, 274–276, 445
essential boundary conditions, *see* boundary conditions
Ewald transformation, 445
expansion functions, *see* basis functions
exponential convergence, 272–277
exponential integral, 276
extended boundary condition method, 443
extinction theorem, 14

F

far-field approximation, 25–28, 176
far-field projections in FDTD, 518–520

fast Fourier transform (FFT), 171, 186, 264, 304, 334
fast multipole method, 161, 175–178
feed region modeling, 440, 443
fictitious charges, 51, 70, 76, 426
field singularities at edges, *see* edge singularity
fill-in, 150, 159
finite difference method, 191, 228, 496
finite difference time domain (FDTD), 495–523
finite element mesh, 102
finite element method, 102, 190
finite integration method, 499
finite volume method, 499
flat p.e.c. plate, 421–424
flat p.e.c. strip, 57
Floquet harmonics, 264–268, 282–284, 293, 298, 300
Floquet periodicity condition, 266, 280, 285, 289, 443
Fourier series, 325
Fourier spectrum, 101, 304
Fourier transform, 34, 201, 261, 269–271, 287, 297, 302, 446–448
Fredholm alternative, 240
frequency selective surface, 282, 443, 458
frontal method of solution, 159–160
functional analysis, 187, 207
functionals, 161, 168, 185, 219–223

G

Galerkin's method, 212, 218, 221, 455
Gauss–Kronrod quadrature rules, 528
Gauss–Legendre quadrature, 527–528
Gaussian elimination, 143
Gaussian quadrature, 527–530
  for tetrahedrons, 530
  for triangles, 529
  with logarithmic singularity, 528–529, 537, 548
generalized functions, 4
generalized matrix eigenvalue equation, 206, 362, 370, 390, 464
generalized minimal residual (GMRES) algorithm, 161
Gram–Schmidt orthogonalization, 212, 218, 227
Green's functions
  dielectric slab grating, 278–280, 299
  dyadic, 9, 34
  integration of 3D singularity, 420
  microstrip, 445–449
  periodic, 261, 267–281, 286, 298–299, 444
  three dimensional, 7, 33, 298–299, 415
  two dimensional, 7, 101, 303

H

Hankel function, 7, 61, 119, 335
  asymptotic form of, 25, 36, 39, 50, 101, 177, 201, 207, 230, 269
  of complex argument, 78, 252
Harwell library, 158
Helmholtz equation
  scalar, 3, 95, 117, 138, 158, 198, 212–213
  vector, 2, 5, 139, 389, 461
  weak form for scalar, 96, 126, 290
  weak form for vector, 362, 462
Hermitian basis functions, *see* basis functions
Hermitian matrix, 165
hexahedral elements, *see* basis functions
higher-order elements, *see* basis functions
homogeneous dielectric scatterer, 76–80
homogeneous solutions, 208, 234

I

identity-plus-compact operators, *see* operators
image theory, 23, 34
impedance boundary condition, 80–84, 98, 258–259
impedance matrix, 39
incident field, 5
incomplete LU factorization, 179
initial estimate of solution, 169
inner product, 161, 188, 201, 226
inner product space, 188, 212
instabilities in volume EFIE, 68–70, 75
integral equation
  augmented field, 248, 307–310
  combined field, 240–246, 259, 305, 430
  combined source, 246–248, 259
  dual surface, 250–251
  electric field, *see* electric field integral equation
  magnetic field, *see* magnetic field integral equation
interior resonances, 234, 304–307, 335, 430, 435
interpolation error, 109, 197–199, 204, 228, 342, 352, 380
interpolation functions, *see* basis functions
invisible region, 265, 304, 335
inward-looking formulations, 102, 130, 142, 255, 473–475
isoparametric expansion, 355, 357
iterative methods, 160–179

J

Jacobian, 114, 344, 351–358, 400–405, 430
junctions between conductors, 57, 443

K

k-space, *see* spectral domain, *see* Fourier transform
Kirchhoff's current law, 59
Kummer's transformation, 270, 272

L

Lagrangian interpolation functions, *see* basis functions
LAPACK, 146
Laplace transform, 273
Laplacian, vector, 6
leapfrog time integration, 500–501
Leibnitz's rule, 8–9
LINPACK, 146, 149, 156, 238
LN/QT basis functions, *see* basis functions
local area coordinates, *see* simplex coordinates
loop basis functions, *see* basis functions
Lorentz gauge condition, 34
Lorentz reciprocity theorem, 11
LT/QN basis functions, *see* basis functions
LU factorization, 127, 145, 170, 175, 184, 473

M

magnetic field integral equation
  applicability to thin conductors, 17–18
  eigenvalues of, 211, 230, 235
  normal-field, 35, 90
  three-dimensional surface, 17, 22, 24, 428, 430, 435, 456–458
  three-dimensional volume, 19, 452
  two-dimensional surface, 35, 45, 82, 89, 126
  two-dimensional volume, 71, 91, 313
magnetic frill feed model, 29, 35, 336, 441
mapping to curved cells
  scalar, 354–359
  vector, 399–405
matrix-vector product, 174
Maxwell's equations, 1, 33, 496
method of averages, 449
method of moments, 38, 102, 190–191
microstrip patch antennas, 445–450
minimum cell density, 40, 62, 68–70
MININEC, 442
mixed potential formulation, 8, 52, 425, 433, 449
mixed-order basis functions, *see* basis functions
modeling errors, 40, 62
moment method, *see* method of moments
monopole antennas, 29, 331
multiple incident fields, treatment of, 174–175
mutual admittance function, 311

N

natural boundary conditions, *see* boundary conditions
near-to-far field transformation, 518–520
NEC, 196, 203
Nedelec constraints, 371–374, 377, 392–393, 463
Neumann boundary conditions, *see* boundary conditions
Neumann function, 42
node renumbering algorithms, 150–156
node-based finite elements, *see* basis functions, Lagrangian
nodes of the mesh or model, 57
norm, 188
normal equations, 165
nullspace eigenfunctions, 371, 373, 382, 409, 462, 480
nullspace of curl-curl operator, 364–367, 378, 391, 462
nullspace of divergence operator, 396
numerical integration, *see* quadrature

O

oblique scattering, 301
one-way wave equations, 511–515
operator
  compact, 207, 213, 215–216, 218
  domain of, 187, 191, 202
  identity-plus-compact, 209, 214, 218
  linear, 187, 207
  positive definite, 212
  projection, 217
  pseudo-differential, 482, 512–513
  range of, 187, 191, 202
  unbounded, 209, 216
  weakly singular, 201, 213, 214
orthogonal projection, 189, 212–216
orthogonality, 188
outward-looking formulations, 102–106, 120, 130, 255, 289–295, 322, 472–476

P

parametric basis functions, *see* basis functions
Pascal triangle, 352
perfectly matched layer (PML), 483–484, 494, 516–517, 523

periodic Green's function, *see* Green's functions
permeability, 1
permittivity, 1
phased array antennas, 449–450
phasor, 1
physical optics, 243–246, 330
piecewise constant basis functions, *see* basis functions
pivoting, 146, 150, 156
plane wave spectrum, 301, 310
point collocation method, *see* point matching
point matching, 50, 72
Poisson sum transformation, 269, 272, 287, 297, 444
polarization
  TE, 3, 25, 45, 65
  TE-to-r, 478
  TM, 3, 24, 37
  TM-to-r, 478
polarization current density
  electric, 4–5, 60, 66
  magnetic, 4–5
positive definite operator, *see* operator
postprocessing, 40
potential function
  electric scalar, 8–9
  electric vector, 6–9, 519
  magnetic scalar, 8–9
  magnetic vector, 6–9, 519
preconditioning, 178–179
preprocessing, 40
projecting between curl and divergence-conforming functions, 480
projection methods, 217–219
pseudo-differential operators, 482, 512–513
pulse basis functions, *see* basis functions
pyramid basis function, *see* basis functions

Q

QT/CuN basis functions, *see* basis functions
quadratic elements, *see* basis functions
quadrature, 7, 40, 42, 204, 525–530
quadrilateral elements, 353–354, 378–382
quadruple indices for Lagrangian bases, 360
quasi-minimal residual (QMR) algorithm, 161

R

radar cross section, *see* scattering cross section
radiation boundary condition, 6, 95, 98, 463
  Bayliss–Turkel, 104, 115–124, 140, 158, 255, 335, 342, 348–349
  Engquist–Majda, 140, 482, 511
  exact, 100–102, 122, 128, 320, 335, 411, 469–470
  fictitious absorber, 483–484
  global, 104
  integral equation, 125–128, 290–293, 300, 470–473
  Lindman, 511
  local vector, 332, 336, 383, 476–483
  Mur, 511–515
  perfectly matched layer, 483–484, 494, 516–517, 523
  Sommerfeld, 98, 115, 139
Rao–Wilton–Glisson functions, *see* basis functions
Rayleigh–Ritz method, 138, 190
razor-blade functions, *see* basis functions
reciprocal base vectors, 399
reciprocal lattice, 266, 298
reciprocity, reciprocity theorem, 11–12, 222, 239, 258
rectangular brick element, *see* basis functions
reduced kernel approximation, 442
reflection coefficient, 268, 277, 283
reflector antenna, 30
residual norm, 166
residual polynomial, 168
residual vector, 162
resistive boundary condition, 93
resolution limit, 40
reverse Cuthill–McKee algorithm, 154
Richardson extrapolation, 88, 252, 526
Romberg integration, 525–527, 537, 544
rooftop basis functions, *see* basis functions
rotation matrices, 345
rounding error, 147

S

scalar basis functions, *see* basis functions
scalar Helmholtz equation, *see* Helmholtz equation
scalar product, *see* inner product
scattered field, 5
scattered field formulation, 139–140, 509
scatterer
  layered dielectric, 35–36, 74, 92, 132–134
  perfectly conducting, 16, 37
  thin p.e.c., 18
scattering cross section
  three-dimensional, 27–28, 421
  two-dimensional, 24–27, 36, 40, 44, 47–48, 56, 61, 67, 73, 78, 108, 111–112, 122, 223, 235, 243, 306–307, 315

scattering matrix, 28, 282
scattering parameters, generalized, 282–284
Schwartz inequality, 147
self-adjoint operator, 212
shape functions, *see* basis functions
Silvester polynomials, 340–341
simplex coordinates, 113, 322, 338, 359–360
single point approximation of integrals, 38, 40–41, 46, 48–49, 87, 537
sinusoidal triangle basis function, *see* basis functions
slot antennas, 310
Sommerfeld integral, 279, 299, 449
source-field relations, 6–9, 531–536
sparse matrix techniques, 104, 124
spatial lattice, 266, 298
spectral domain, 272, 302, 446–448
spherical Hankel functions, 469
spherical vector wave functions, 469–470, 478, 492–493
spline functions, *see* basis functions
spurious eigenvalues, 364
spurious eigenvalues, elimination of, 370, 382
stability of FDTD, 503–504
staircase approximation, 70
star basis functions, *see* basis functions
strip grating, 261, 264
subdomain basis function, *see* basis functions
subparametric expansion, 355
subsectional basis functions, *see* basis functions
superconvergence, 198
symmetric inner product, 223
symmetry, exploiting geometrical, 428, 456

T

TE polarization, *see* polarization
testing functions, 52
tetrahedral finite elements, *see* basis functions
thin wire approximations, 440–443
three-term sinusoid basis function, *see* basis functions
TM polarization, *see* polarization
TM-TE decomposition, 32
Toeplitz matrix, 86, 161, 171–173, 186, 329, 421, 451
transmission coefficient, 268–277
transmission line analogy, 278–279, 446–449, 459
transmission matrices, 284
trapezoidal rule, 525
trial functions, *see* basis functions
triangle basis function, *see* basis functions
triangular cell mesh, 70–71, 95
triangular finite elements, *see* basis functions
triangular-rooftop basis function, *see* basis functions
triple indices for Lagrangian bases, 339

U

unbounded operator, 209, 216
unimoment method, 130–135
uniqueness, 18, 233, 241

V

variational finite element method, 138
vector basis functions, *see* basis functions
vector finite elements, *see* basis functions
vector Helmholtz equation, *see* Helmholtz equation
Veysoglu's acceleration, 273–277
visible region, 265, 304, 334
volume integral equations, 19, 60, 66, 71, 91, 313, 404, 450–452

W

wave equation, 496, 502
waveguide modes, 252, 330, 388
waveguide, dielectric-loaded, 254, 388–392, 412
wavelength, in dielectric, 62
wavelets, 196
wavenumber, 3
weak equation, 96
weakly singular kernel, 52
weighted residual methods, 102, 190
Wilcox expansion, 476
Wilkinson's growth factor, 148
wire grid modeling of scatterers, 440–443
Wood's anomalies, 277
Wronskian, 101

Y

Y12M, 158, 346
Yagi antenna, 30
Yale Sparse Matrix Package, 158
Yee lattice, 501

Z

zero padding, 171–174