

# Index

## A

- American Digital Cellular and Japanese Digital Cellular systems, 138
- Amount of fading (AF)
  - cascaded fading channels, 233, 235
  - Gaussian pdf, 366
  - lognormal shadowing channel, 364, 366
  - MRC diversity, 362
  - Nakagami fading, 211
  - Nakagami parameter, 364, 366
  - Rayleigh fading, 200–201
  - Rician fading, 203, 204
  - shadowing models, 216
  - short term faded Nakagami channel, 362
  - SSC, 363
  - two channel selection combining
    - diversity, 363
- Amplitude shift keying (ASK), 121–122
- Arnold and Strauss's bivariate gamma distribution, 76

## B

- Bayes theorem, 86–87
- BER. *See* Bit error rate
- Bessel function, 221, 303
- Beta distribution, 11–13
- Binary phase shift keying (BPSK)
  - digital signal spectra, 127
  - gray encoding, 129, 130
  - M-ary signals, 128–129
  - MQAM, 139–141
  - null-to-null criterion, 127
  - QPSK
    - modulator, 131, 132
    - offset-QPSK scheme, 133, 134
    - phase constellation, 131

- $\pi/4$ -QPSK, 133–136
        - time domain waveforms, 131, 132
        - waveforms, 130
  - signal space, 129
  - symbol error
    - coherent MPSK, 137, 138
    - equivalent bit error rate, 137
    - generic MPSK constellation, 136, 137
    - k bits encoding/mapping, 136
    - spectral efficiencies and SNR, 138, 139
- Binomial distribution, 13–15
- Bit error rate (BER), 255, 256, 307
  - BPSK, 256–259
  - CDF, 259
  - fading channel, 259
  - moderately shadowed channel, 260, 262
  - MRC, 448–450
  - Nakagami channels
    - average error probability, 442, 444, 445
    - hypergeometric function, 443
    - MeijerG function, 443
  - pdf, 449
  - Rayleigh channels, 441–442
  - severely shadowed channel, 260, 261
  - shadowed fading channels
    - average error rates, 446, 447
    - CCI effect, 446
    - cochannels, 448
    - N Nakagami interferers, 445
- BPSK. *See* Binary phase shift keying

## C

- Cascaded channels, 306
- Cascaded fading channels
  - AF, 233, 235
  - average SNR, 233

- Cascaded fading channels (*cont.*)
  - CDF, 235, 236
  - density function, 233, 234
  - gamma-distribution, 232
  - MeijerG function, 232–233
  - Nakagami-gamma model, 234
- Cascaded Nakagami channels
  - AF, 395, 400, 401
  - average error probabilities, 405, 406
  - BER, 401, 402
  - CDFs, 396–401, 404, 405
  - density function, SNR, 395
  - Matlab, 396
  - M-fold convolution, 403, 404
  - MGF, 404, 405
  - MRC diversity, AF, 403–404
  - multihop relayed communication system, 395
  - order statistics, 400
  - outage probability, 401, 403, 405, 407
  - pdfs, SNR, 396, 398–400, 402
  - received signal power, 395
  - threshold SNR, 404
- Cauchy distribution, 15–16
- CDFs. *See* Cumulative distribution functions
- Central limit theorem (CLT), 46–47
- Characteristic function (CHF), 10–11, 57
- Chebyshev inequality, 94–95, 323
- Chi-squared distribution, 16–18
- Cochannel interference, 5
- Coherent binary phase shift keying (CBPSK), 367
- Cumulative distribution functions (CDFs), 8–9, 207–208, 322, 330–331
- D**
- Decision theory and error rates
  - channel noise, 85–86
  - Gaussian case
    - Bayes theorem, 86–87
    - binary channel, 86
    - conditional density functions, 87
    - conditional probability, 87
    - error probability, 87, 89, 90
    - false alarm probability, 89
    - hypothesis testing, 86, 88
    - likelihood ratio, 89
    - probability of miss, 89
  - non-Gaussian case
    - false alarm probability, 91
    - hypothesis testing, 91, 93
    - probability of miss, 91, 92
    - Q function, 92
    - Rayleigh densities, 90
    - Rician densities, 90
- Differential phase shift keying (DPSK), 154
- Digital frequency modulation (DFM)
  - block diagram, 142, 143
  - CPFSK, 144
  - frequency deviation, 143
  - pulse shape, 143
- Diversity techniques, 1
  - AF
    - Gaussian pdf, 366
    - lognormal shadowing channel, 364, 365
    - MRC diversity, 363
    - Nakagami parameter, 364, 366
    - short term faded Nakagami channel, 362
    - SSC, 364
    - two channel selection combining diversity, 363
  - average error probability
    - average error rate, 366–367
    - CBPSK, 367
    - CDF, 369
    - density functions, 373–377
    - dual branch correlated MRC, 372
    - dual branch MRC, 375, 377–379
    - dual branch SC, 371, 372, 378, 379
    - four-branch diversity, 371
    - four channel MRC, 375, 378
    - GSC algorithm, 371, 373
    - hybrid diversity approach, 375
    - Laplace transform, 367
    - MGF, 367–368
    - MRC algorithm, 369
    - Nakagami channel, 368, 373
    - Nakagami-lognormal model, 373
    - Nakagami- $m$  channel, MRC, 370, 371
    - Q function, 368
    - shadowed fading channels, 375, 377, 378, 379
  - branch correlation effects
    - correlated SC and SSC receiver, 337
    - exponential correlation, 334
    - joint CDF, 339
    - Marcum's Q function, 337
    - modified Bessel function, 337, 339
    - MRC algorithm (*see* Maximal ratio combining algorithm)
    - Nakagami parameter, 337, 338
    - pdf, SC algorithm, 339
  - cascaded Nakagami channels (*see* Cascaded Nakagami channels)

- CDF, 325
  - diversity receivers, 321
  - EGC algorithm, 324
  - frequency diversity, 318
  - gamma shadowing, 362
  - generalized gamma and Weibull channels
    - AF, 386
    - average error probability, 391, 392
    - BER, dual diversity, 393, 394
    - CDFs, 387–389, 391
    - coherent BPSK modem, 389
    - complementary incomplete gamma function, 390
    - detection scheme, 390
    - dual MRC, 392
    - dual SC, BER, 394
    - “keyhole” scattering, 395
    - MGF, 392
    - modulation type, 389
    - Nakagami- $m$  distribution, 385
    - Nakagami pdf, 385
    - SNR, pdfs, 385, 387, 388, 391
  - GSC algorithm, 361
    - average error probabilities, 408, 409
    - average SNR, 357
    - CDFs, 357–359, 408, 409
    - CDMA system, 353
    - densities and distributions, 359–360
    - gamma random variables, 359
    - joint pdf, 354–356
    - $M_c$  signals, 354
    - Nakagami channels, 358, 360
    - Nakagami- $m$  faded channels, 360, 361
    - normalized peak values, 360
    - outage probabilities, 407, 410
    - output SNR, pdfs, 408
    - RAKE reception, 353
    - Rayleigh channel, 354–356
    - three-branch diversity receiver, pdfs, 358, 359
  - macrodiversity (*see* Macrodiversity techniques)
  - MRC algorithm (*see* Maximal ratio combining algorithm)
  - multipath diversity, 320
  - Nakagami- $m$  distribution (*see* Nakagami- $m$  distribution)
  - noise power, 315
  - outage probability
    - CDF, 381
    - MRC algorithm, 382, 384
    - Nakagami fading channels, 382
    - SC algorithm, 382
    - sensitivity, 381
    - shadowed fading channel, 383–385
      - short-term faded channel, 381
      - pdf, 314
      - polarization diversity, 318–319
      - Rayleigh faded channel, 315
      - received signal power, 315
  - SC algorithm
    - CDFs, 322
    - SNR expression, 321–322
    - SSC algorithm (*see* Switched and stay combining algorithm)
  - signal processing methods, 313
  - SNR, 316
  - space diversity, 317–318
  - time diversity, 319
  - types, 316
- E**
- Equal gain combining (EGC) algorithm, 324
  - Ergodic channel capacity
    - additive white Gaussian noise, 284, 285
    - cascaed short-term fading channel, 287
    - channel bandwidth, 285
    - density function, generalized K distribution, 289–290
    - double Nakagami cascaded channels, 288
    - MeijerG function, 285
    - Nakagami faded channel, 285, 286
    - Nakagami-Hoyt channels, 287, 288
    - normalized average channel capacity, 285
    - quadruple cascaded channels, 287, 289
    - Rayleigh fading, 286
    - Rician faded channel, 286, 287
    - shadowed fading channels, 290, 291
    - triple cascaded channels, 287, 289
  - Erlang distribution, 18
  - Exponential distribution, 18–20
- F**
- F (Fisher-Snedecor) distribution, 20–21
  - Frequency diversity, 318
  - Frequency shift keying (FSK), 124–126, 141–142
- G**
- Gamma distribution, 21–23
  - Gaussian distribution, 33–35
  - Gaussian function, 301
  - Gaussian minimum shift keying (GMSK), 146–149
  - Generalized Bessel K (GBK) distribution, 65
  - Generalized gamma distribution, 25
    - definition, 22

- Generalized gamma distribution (*cont.*)
  - generalized gamma pdf, 24
  - normalization factor, 25
  - random variable, 24
  - scaling factor, 25
  - Stacy distribution, 24
  - two-sided generalized gamma pdf, 26
- Generalized K (GK) distribution, 344, 345
- Generalized selection combining (GSC)
  - algorithm, 361
  - average error probabilities, 408, 409
  - average SNR, 357
  - CDFs, 357–359, 408, 409
  - CDMA system, 353
  - densities and distributions, 359–360
  - gamma random variables, 359
  - joint pdf, 354–356
  - $M_c$  signals, 354
  - Nakagami channels, 358, 360
  - Nakagami- $m$  faded channels, 360, 361
  - normalized peak values, 360
  - outage probabilities, 407, 410
  - output SNR, pdfs, 408
  - RAKE reception, 353
  - Rayleigh channel, 354–356
  - three-branch diversity receiver, pdfs, 358, 359
- GK distribution. *See* Generalized K distribution
- GMSK. *See* Gaussian minimum shift keying
  
- K**
- Kibble's bivariate gamma distribution, 76
- Kurtosis coefficient, 10
  
- L**
- Laplace distribution, 27–28
- Laplace transforms, 11, 307
- 8-Level phase shift keying (8PSK)
  - demodulator, 158
  - modulator, 158
  - phase constellation, 156, 157
  - phase encoding, 156, 157
  - waveform, 159
- Lognormal distribution, 28–29
  
- M**
- Macrodiversity techniques
  - microdiversity systems
    - CDFs, 352
    - density functions, 348, 349
    - gamma pdf, 344
    - GK distribution, 344, 345
    - joint pdf, 345–346
    - MeijerG functions, 351
    - MRC diversity, 348, 349
    - MRC–SC, 345–347, 350–351
    - pdfs, 352, 353
    - shadowed fading channel, 349
    - short-term fading effects, 343
    - SNR, SC, 349–350
  - shadowing mitigation
    - CDF, SC algorithm, 341
    - dual correlated Nakagami channels, 342
    - multiple base stations, 340
    - normalized Gaussian variable, 341
    - SNR, 340, 342, 343
    - three-base station arrangement, 340, 341
- Marcum's Q functions, 3, 179–182
- M-ary phase shift keying (MPSK). *See* Binary phase shift keying
- M-ary quadrature amplitude modulation (MQAM), 139–141
- Matlab and Maple, 5
- Maximal ratio combining (MRC) algorithm, 448–450
  - Chebyshev inequality, 323
  - correlation coefficient
    - correlated branch expression, 334
    - density functions, 335, 336
    - SNR, fractional decline, 337
  - noise power, 323
  - processing algorithm, 322
  - signal power, 323
- McKay's bivariate gamma distribution, 76
- Meijer G function, 67, 68, 299–301, 304
- MGF. *See* Moment generating function
- Minimum shift keying (MSK)
  - modulator, 144, 145
  - power spectrum, 144
  - waveform, 144–146
- Modems
  - bandwidth requirement, 174
  - bit energy, 163
  - carrier regeneration and synchronization, 166–168
  - channel capacity, 175
  - complementary error function, 176–179
  - correlator, 114
  - cos() and sine() functions, 119
  - differentially encoded signals
    - coherent vs. noncoherent modems, 156

- DPSK, 154
  - error probability, 152
  - 8-level PSK (*see* 8-Level phase shift keying)
  - modified Bessel function, 153
  - noise variance, 153
  - noncoherent detection, 152
  - noncoherent receiver, 154, 155
  - non-Gaussian statistics, 152
  - phase encoding, 155
  - Rician statistics, 153
  - digital communication system, 110
  - digital modulation techniques, 117–118
  - digital signal bandwidth, 164–166
  - digital transmission, 110, 111
  - error function, 176
  - Euclidian distance, 120
  - gamma functions, 177–178
  - Gaussian Q function, 112
  - general nonlinear modulation schemes
    - DFM (*see* Digital frequency modulation)
    - error rates, 151
    - FSK, 141–142
    - GMSK, 146–149
    - MSK (*see* Minimum shift keying)
    - orthogonal M-ary FSK, 147, 149–151
  - gray coding, 110
  - inter symbol interference
    - cosine pulse shape, 183–185
    - eye pattern, 185, 186
    - impulse response, 182
    - roll-off factor, 183
  - Kronecker delta function, 118
  - Marcum's Q functions, 179–182
  - M-ary signaling, 110
  - M-ary transmission system, 118
  - matched filter, 114
  - modulation techniques
    - ASK, 121–122
    - BPSK (*see* Binary phase shift keying)
    - FSK, 124–126
    - PSK, 122–124
    - QAM, 125
  - N-dimensional orthogonal space, 118
  - noise power, 163
  - noise variance, 112
  - Nyquist criteria, 115, 117
  - OFDM
    - digital Fourier transforms principle, 161, 162
    - fast Fourier transform algorithm, 162
    - frequency domain representations, 160
    - inter channel interference, 160, 162
    - inverse fast Fourier transform approach, 162
    - subcarrier frequencies, 160–161
    - transmitter and receiver, 160, 161
  - optimum filter, impulse response, 113
  - phase mismatch
    - angular mismatch, 168, 169
    - coherent QPSK, 172
    - correlation function, 171
    - fixed phase mismatch, 168, 169
    - jitter, 170
    - matched filter, 170
    - normalized timing offset, 171–172
    - random phase mismatch, 168, 170
    - timing offset, 170
  - power spectral density, 113
  - probability of error, 119–121
  - probability density function, 112
  - pulse shapes, 114–116
  - Q functions, 176, 179
  - Shannon's channel capacity theorem, 174
  - signal-to-noise ratio, 163
  - sin c pulse, 116
  - spectral and power efficiencies, 174
  - symbol energy, 163
  - zero mean Gaussian white noise, 111
  - Moment generating function (MGF), 11, 367
  - MQAM. *See* M-ary quadrature amplitude modulation
  - MRC algorithm. *See* Maximal ratio combining algorithm
  - MSK. *See* Minimum shift keying
  - Multipath diversity, 320
  - Multipath propagation phenomenon, 3
- N**
- Nakagami channels, 426–427
    - bit error rates
      - average error probability, 442, 444, 445
      - hypergeometric function, 443
      - MeijerG function, 443
    - pdf, 436
  - Nakagami distribution, 30–32
  - Nakagami fading
    - AF, 211
    - CDF, 207–208
    - channel, 303
    - chi-square density function, 208–209
    - clustering/bunching concept, 208
    - density moments, 207
    - Gaussian densities, 209, 210

Nakagami fading (*cont.*)

- Nakagami- $m$  pdf moments, 208, 209
- received signal envelope, 206–207
- Rician envelope densities, 209–211

## Nakagami-inverse Gaussian distribution, 226

Nakagami- $m$  distribution

- CDF, 325, 328–330
- density functions, 328–329
- EGC algorithm, 327
- Matlab, 328
- MRC algorithm, 325–327
- received signal power, 325
- SC algorithm, 325, 326
- SNR improvement, 329
- statistical model, 324

## Nakagami-N-gamma channels, 4

## Natural logarithm, 303

## Non-central chi-squared distribution, 32–33

## Nyquist criteria, 115, 117

**O**

## Orthogonal frequency division multiplexing (OFDM), 3

- digital Fourier transforms principle, 161, 162
- fast Fourier transform algorithm, 162
- frequency domain representations, 160
- inter channel interference, 160, 162
- inverse fast Fourier transform approach, 162
- subcarrier frequencies, 160–161
- transmitter and receiver, 160, 161

**P**pdf. *See* Probability density function

## Phase shift keying (PSK), 122–124

## Poisson distribution, 35

## Polarization diversity, 318–319

## Probability and statistics concepts

- bivariate correlated distributions
  - gamma pdf, 76–77
  - generalized gamma pdf, 77–78
  - Nakagami pdf, 75–76
  - normal pdf, 73–75
  - Rician distribution, 79
  - Weibull pdf, 78
- CDF, 8–9
- Chebyshev inequality, 94–95
- Chernoff bound, 96–97
- CHF, 10–11, 57
- CLT, 46–47
- conditional densities, 44

## correlation coefficient, 45

## covariance, 45

decision theory and error rates (*see*

Decision theory and error rates)

## expected value, random variables, 44–45

## independent random variables, 45

## joint densities, 43

## joint pdf, multiple random variable

- CDF differentiation, 56, 57
- diversity combining algorithm, 53
- Jacobian, 51, 52
- Leibniz's rule, 55
- probability volume calculation, 55
- region of interest, 53, 54
- two-scaled random variables, 52

## Laplace transforms, 11

## marginal densities, 43–44

## moment generating functions, 11

## order statistics

- bivariate correlated pdf, 83
- bivariate lognormal densities, 84
- bivariate Nakagami pdf, 82
- bivariate Rayleigh pdf, 82–83
- exponential pdf, 82
- generalized Bernoulli trial, 81
- joint CDF, 80
- lognormal random variables, 85
- Marcum Q function, 83
- selection combining algorithm, 79
- short-term fading, indoor wireless channels, 84

## orthogonality, 45

## pdf, 10

- beta distribution, 11–13
- binomial distribution, 13–15
- Cauchy distribution, 15–16
- chi-squared distribution, 16–18
- Erlang distribution, 18
- exponential distribution, 18–20
- F distribution, 20–21
- gamma distribution, 21–23
- Gaussian distribution, 33–35
- generalized gamma distribution (*see* Generalized gamma distribution)
- Laplace distribution, 27–28
- lognormal distribution, 28–29
- Nakagami distribution, 30–32
- non-central chi-squared distribution, 32–33
- Poisson distribution, 35
- Rayleigh distribution, 36–38
- rectangular/uniform distribution, 38–40

- student's *t* distribution (*see* Student's *t* distribution)
    - Weibull distribution, 41–43
  - random variable transformations
    - Bessel function, 59, 63
    - doubling formula, 62
    - gamma random variable sum, 62, 66
    - Gaussian, chi-squared and student *t* distributions relationship, 72–73
    - GBK distribution, 65
    - K distribution, 64
    - lognormal fading conditions, 68
    - marginal density function, 58
    - Meijer's G function, 67, 68
    - monotonic transformation property, 63
    - Nakagami-*m* distributed envelope values, 69
    - phase statistics, 59
    - Rician factor, 60–61
    - SNR, 70, 71
  - stochastic processes, 97
    - autocovariance, 99
    - ergodicity concept, 100
    - first order density function, 98
    - higher-order density functions, 99
    - power spectral density, 100
    - second order density function, 98
    - spectral density, 101
    - thermal noise, 101
    - time domain function, 97
    - wide stationary sense process, 100
  - $Y = g(X)$ , pdf and CDF derivation
    - filter, input-output relationship, 47, 48
    - many-to-one transformation, 49, 50
    - monotonic transformation, 47, 48
    - non-monotonic transformation, 48, 49
  - $Z = X + Y$ , pdf, 50–51
  - Probability density function (pdf), 10, 198
    - beta distribution, 11–13
    - binomial distribution, 13–15
    - Cauchy distribution, 15–16
    - chi-squared distribution, 16–18
    - Erlang distribution, 18
    - exponential distribution, 18–20
    - F distribution, 20–21
    - gamma distribution, 21–23
    - Gaussian distribution, 33–35
    - Gaussian pdf, 215
    - generalized gamma distribution (*see* Generalized gamma distribution)
    - Laplace distribution, 27–28
    - lognormal distribution, 28–29
    - Nakagami channels, 436
    - Nakagami distribution, 30–32
    - Nakagami-Hoyt pdf, 282, 283
    - Nakagami-*m* pdf, 201
    - non-central chi-squared distribution, 32–33
    - Poisson distribution, 35
    - Rayleigh channels, 434–435
    - Rayleigh distribution, 36–38
    - rectangular/uniform distribution, 38–40
    - Rician fading, 206
    - second order statistics
      - conditional pdf, 293
      - envelope pdf, 296
      - SNR, joint pdf, 292
    - shadowed fading channels
      - N interfering channels, 439
      - probability density functions, 437, 438, 440, 441
      - signal-to-CCI ratio, 437, 438
      - SNR, density function, 436, 437, 439
    - student's *t* distribution (*see* Student's *t* distribution)
    - Weibull distribution, 41–43
  - PSK. *See* Phase shift keying
- Q**
- Quadrature amplitude modulation (QAM), 125
  - Quaternary phase shift keying (QPSK)
    - modulator, 131, 132
    - offset-QPSK scheme, 133, 134
    - phase constellation, 131
    - $\pi/4$ -QPSK, 133–136
    - time domain waveforms, 131, 132
    - waveforms, 130
- R**
- RAKE receiver, 320
  - Rayleigh channels
    - bit error rates, 421, 441–442
    - N cochannels, 419
    - outage probability, 418, 419
      - CCI channels, 425, 426
      - desired signal power, 424, 425
      - multiple cochannels, 424
      - SIR/q, 422
      - $Z_0/Z_T$ , 423
    - pdf, 434–435
    - Poisson random variable, 424
    - protection ratio, 420
    - signal-to-interference, 420
    - threshold and protection factor, 421
  - Rayleigh distribution, 36–38

- Rayleigh fading
  - AF, 200–201
  - amplitude, 197
  - exponential densities, 198, 199
  - Gaussian random variables, 198
  - histogram, 198–200
  - inphase and quadrature notation, 197
  - multipath phenomenon, 197
  - Nakagami- $m$  pdf, 201
  - pdf, 198
  - Rayleigh density function, 200
- Rayleigh-lognormal channel, 221
- Rectangular/uniform distribution, 38–40
- Rician factor, 60–61
- Rician fading
  - AF, 203, 204
  - average power, 203, 204
  - density function, 201, 202, 206
  - error function, 206
  - Gaussian statistics, 204–205
  - Marcum Q function, 203
  - mean and second moments, 202–203
  - phase, pdf, 206
  - received power, 201
  - Rician factor, 202, 205
- S**
- Selection combining (SC) algorithm, 321–322
- Shadowed fading channels
  - AF, 225–226
  - BER, 255, 256
    - average error rates, 446, 447
    - BPSK, 256–259
    - CCI effect, 446
    - CDF, 259
    - cochannels, 448
    - fading channel, 259
    - moderately shadowed channel, 260, 262
    - Nakagami interferers, 445
    - severely shadowed channel, 261
  - cascaded approach
    - AF, 242, 243
    - CDF, 242, 244, 245
    - central limit theorem, 237
    - density function, 238, 240, 241
    - digamma and trigamma function, 238
    - gamma parameter, 239
    - gamma random variables, 238
    - GK distribution, 236
    - inverse Gaussian distribution, 237
    - MeijerG function and Bessel function, 238, 240
    - Nakagami- $N$ -gamma distribution, 237
    - outage probabilities and error rates, 241
    - shadowing, higher level, 240, 241
  - conditional density function, 429
  - equivalent gamma model, 429
  - generalized gamma model, 223–225
  - Nakagami-gamma/generalized K models, 220–222
  - Nakagami-inverse-Gaussian model, 221–223
  - Nakagami-lognormal models
    - average power, 218
    - density functions, 219
    - vs. short term fading, 219, 220
  - outage probability
    - CDF, 271, 273
    - density function, 271, 272
    - multiple interfering shadowed fading channels, 432, 433
    - Nakagami-cascaded gamma channel, 268, 270
    - Nakagami inverse Gaussian channel, 271
    - Nakagami-lognormal channel, 267–271
    - Nakagami- $m$  distributed cochannel, 429, 430
    - Nakagami parameter, 268, 269
    - single interfering channel, 431, 432
  - pdf, 440, 441
  - $N$  interfering channels, 439
  - signal-to-CCI ratio, 437, 438
  - SNR, density function, 436, 437, 439
  - shadowing density, 429
- Shannon's channel capacity theorem, 174
- Short-term fading, 194
  - attenuation, 195
  - average power, gamma pdf moments, 211
  - CDF, 213
  - gamma fading channel, 211, 214, 215
  - generalized gamma channel, 212–215
  - Nakagami fading
    - AF, 211
    - CDF, 207–208
    - chi-square density function, 208–209
    - clustering/bunching concept, 208
    - density moments, 207
    - Gaussian densities, 209, 210
    - Nakagami- $m$  pdf moments, 208, 209
    - received signal envelope, 206–207
    - Rician envelope densities, 209–211

- Rayleigh fading
    - AF, 200–201
    - amplitude, 197
    - exponential densities, 198, 199
    - Gaussian random variables, 198
    - histogram, 198–200
    - inphase and quadrature notation, 197
    - multipath phenomenon, 197
    - Nakagami- $m$  pdf, 201
    - pdf, 198
    - Rayleigh density function, 200
  - Rician fading
    - AF, 203, 204
    - average power, 203, 204
    - density function, 201, 202, 206
    - error function, 206
    - Gaussian statistics, 204–205
    - Marcum Q function, 203
    - mean and second moments, 202–203
    - phase, pdf, 206
    - received power, 201
    - Rician factor, 202, 205
    - statistical characteristics, 196
    - Weibull fading model, 213–215
  - Signal transmission and deterioration, 1
  - Skewness coefficient, 10
  - Space diversity, 317–318
  - SSC algorithm. *See* Switched and stay combining algorithm
  - Stacy distribution, 24
  - Statistical decision theory, 3
  - Statistical distributions, 2
  - Stochastic processes, 97
    - autocovariance, 99
    - ergodicity concept, 100
    - first order density function, 98
    - higher-order density functions, 99
    - power spectral density, 100
    - second order density function, 98
    - spectral density, 101
    - thermal noise, 101
    - time domain function, 97
    - wide stationary sense process, 100
  - Student's  $t$  distribution, 41
    - cumulative distributions functions, 41, 42
    - Gaussian and Cauchy distributions, 39
    - moments of, 40
    - random variable, 40
  - Switched and stay combining (SSC) algorithm
    - CDFs, 330–331
    - logic and switching circuits, 329
    - Nakagami parameter, SNR improvement, 332, 333
    - vs. SC dual branch, density functions, 331, 332
    - vs. SC SNR enhancement, 333, 334
- T**
- Thermal noise, 101
  - Time diversity, 319
  - Time domain function, 97
- W**
- Weibull distribution, 41–43
  - Weibull fading model, 213–215
  - Wireless channels, 1, 2, 193
    - attenuation, 195
    - average probability of error
      - bit error rate (*see* Bit error rate)
      - coherent BPSK modem, 433
      - probability density function (*see* Probability density function)
    - cascaded models
      - cascaded fading channels (*see* Cascaded fading channels)
      - cooperative diversity, 231
      - double Rician channels, 245–246
      - multiple scattering, 231
      - $N^*$ Weibull channels, 245
      - shadowed fading channels (*see* Shadowed fading channels)
    - composite model
      - cluster power, 227
      - double Nakagami fading and Nakagami- $m$  fading, 228–229
      - double Rayleigh and Rayleigh densities, 228
      - gamma-Weibull/Weibull-Weibull channel, 230
      - “miniclusters,” 230
      - received signal power, 226–227
      - scaling factors, 227
      - signal-to-noise ratio, 230–231
    - Doppler fading, 196
    - ergodic channel capacity
      - additive white Gaussian noise, 284, 285
      - cascaded short-term fading channel, 287
      - channel bandwidth, 285
      - density function, generalized K distribution, 289–290
      - double Nakagami cascaded channels, 288
      - MeijerG function, 285
      - Nakagami faded channel, 285, 286

Wireless channels (*cont.*)

- Nakagami-Hoyt channels, 287, 288
- normalized average channel capacity, 285
- quadruple cascaded channels, 287, 289
- Rayleigh fading, 286
- Rician faded channel, 286, 287
- shadowed fading channels, 290, 291
- triple cascaded channels, 287, 289
- error rates
  - cascaded channels, 253, 255, 256
  - complimentary error function, 248
  - generalized gamma channel, 252–254
  - ideal Gaussian channel, 247
  - lognormal channel, 252, 253
  - lognormal random variable, 251–252
  - lognormal shadowing, 251
  - Nakagami channels, 250–251
  - Nakagami-Hoyt channels, 283, 284
  - power penalty, 247, 249
  - Rayleigh fading channel, 248
  - Rician channel, 251
  - shadowed fading channels (*see* Shadowed fading channels)
  - signal-to-noise ratio, 249
  - SNR correction factor, 252
  - Weibull channels, 253, 254
- fading channel, 304
- frequency selective fading channels, 196
- general fading models
  - AF, 283
  - central limit theorem, 274
  - cluster based scattering model, 274, 275
  - Gaussian random variables, 279
  - generalized Nakagami pdf, 282
  - $\eta$ - $\mu$  densities, 276
  - $\alpha$ - $\eta$ - $\mu$  distributions, 273
  - Hoyt fading channel, 278–279
  - $\kappa$ - $\mu$  density, 280, 281
  - $\alpha$ - $\lambda$ - $\mu$  distributions, 273
  - modified Bessel function, 277
  - Nakagami-Hoyt distribution, 276
  - Nakagami-Hoyt pdf, 282, 283
  - Nakagami parameter, 277, 278
  - Rice distribution, 279
  - total power, 280
  - unified model, 273
- long-term fading, 195
- multipath transmission, 194
- multiple scattering, 195
- outage probability
  - cascaded  $N^*$ -Nakagami channel, 266, 267
  - CDF, 265
  - generalized gamma fading channel, 264, 265
  - Nakagami channels, 426–428
  - Nakagami-Hoyt channels, 283, 284
  - Nakagami- $m$  faded channel, 263
  - Rayleigh channels (*see* Rayleigh channels)
  - shadowed fading channels (*see* Shadowed fading channels)
  - SNR, 262
  - Weibull channels, 265, 266
- second order statistics
  - average fade duration, 292, 294, 296
  - conditional pdf, 293
  - envelope pdf, 296
  - level crossing rates, 292
  - maximum Doppler frequency shift, 293
  - Nakagami fading channel, 297
  - Rayleigh faded channel, 292–293
  - Rician channel, LCR, 295
  - shadowed fading channels, 297, 298
  - SNR, joint pdf, 292
  - temporal characteristics, 291
  - transmitter and receiver effects, 290–291
  - Weibull fading, 295–296
- shadowed fading channels, 196 (*see also* Shadowed fading channels)
- shadowing models
  - AF, 216
  - definition, 215
  - gamma distribution, 216
  - Gaussian pdf, 215
  - lognormal density function, 216, 217
  - shadowing parameter vs. gamma parameter, 217, 218
- short-term fading (*see* Short-term fading)
- variance ratio, inphase and quadrature component, 275, 278