Index

(5, 2) block code, 330, 333, 334
(6, 4) block code, 337
(7, 3) block code, 336
16-QAM, 361
4-PAM, 5, 30, 153, 202, 205, 208, 212, 223, 232, 258, 293, 326, 342
4-QAM, 360
6-PAM, 307
adapative components, 191
adapative deotation, 386
adaptive element, 55–56, 65, 114
Costas phase tracking, 208
CV clock recovery, 256
DD equalization, 288
DD for phase tracking, 212
DMA equalization, 291
LMS equalization, 285
LMS for AGC, 123
output power, 261
PLL for phase tracking, 203
SD for phase tracking, 198
simple AGC, 123
testing, 355
Aeneid, 314
AGC, 55, 120–128, 166, 175
aliasing, 28, 51, 52, 99, 102
alphabet, 4, 35, 152, 211, 291, 323
AM
large carrier, 81, 419
suppressed carrier, 84, 419
analog vs digital, 11, 28, 30, 121
Anderson, J. B., 39, 377, 380, 402
angle formulas, 405
automatic gain control, see AGC
averaging, 122–124, 199, 256, 261, 285, 442–450
averaging and LPF, 442
bandlimited, 18, 101, 418
bandpass filter, see BPF
bandwidth, 8, 18, 85, 101, 102, 155, 230, 414
bandwidth vs data rate, 319
bandwidth vs SNR, 320
Barry, J. R., 383, 396, 402
baseband, 9, 247, 251, 271, 285
Baum, Frank, 310
Bello, P. A., 79
binary arithmetic, 329
binary to text, 154
Bing, B., 356
Bingham, J. A. C., 356, 377, 392–393, 402
bit error rate, 36
bit error vs symbol error, 310
bits definition, 307
bits to letters, 4, 153
bits to text, 4, 153
blind equalization, 289, 290
block codes, 314
BPF, 22, 24, 46, 60, 63, 76, 141, 151, 377
phase shift, 196, 197, 203
Buracchini, E., 356
Burris, C. S., 151
capacity, see channel capacity
carrier
frequency, 17, 20, 22
recovery, 9, 33, 192–221, 367
recovery, tuning, 351
Carroll, Lewis, 310
CD encoding, 339
CDMA, 22
cell phones, 17
center spike initialization, 292
Cervantes, M., 314
chain rule, 410
channel, 5, 11, 62, 164, 179, 221, 237, 260, 266, 270, 272
channel capacity, 37, 318–323
CIRC encoder, 339
clock recovery, 33, 251–269
decision-directed, 256
output power, 261
tuning, 351
index

cluster variance, 174, 251, 254, 256
code division multiplexing, see CDMA
codeword, 333
coding, 4, 37, 303–340
block, 314, 328
channel, 328
efficiency, 324
instantaneous, 324
majority rules, 328
prefix, 324
source, 323–327, 339
variable length, 325
colored noise, 414
complex equalization, 282
complex-valued modulation, see modulation
codebook architecture, 15
compression
mp3, 327
uuencode, 327
zip, 327
calculators and meaning, 310
constellation diagram, 174, 379
convolution, 23, 70, 72, 131, 142, 156, 158, 275, 408
correlation, 152, 157–160, 172, 178, 245, 374, 426
correlation vs convolution, 160
Costas loop
PAM, 206
QAM, 367–374
Costas, J. P, 225
Couch, L. W. III, 39
data rate, 8, 102
data rate vs bandwidth, 319
DD, see decision-directed
decision, 35, 174
directed equalization, 288
directed phase tracking, 211
hard, 35
soft, 36, 176
decoder, 328
delay spread, 270, 272
δ function, 65
discrete, 67
sifting property, 66, 131
spectrum, 67
demodulation, see modulation
demodulation via sampling, 103
dependence of English text, 311
derotation, 385
design methodology, 345
destructive interference, 339
dice, 307
difference equation, 65, 430
differential encoding, 375
digital radio, 1, 14, 342
discrete frequencies, 132
dispersion minimization, 290, 386
distortionless, 238
DMA, see dispersion minimization
Don Quixote, 314
Doppler effect, 25, 64
downconversion, 25
via sampling, 103
downsampling, 51, 109, 161, 173, 185
dual PLLs, 218
duality, 23, 407
dynamic range, 121
efficiency, 324
electromagnetic transmission, 16
encoder, 328, 333
encoding a CD, 339
energy, 18, 409, 425
English
dependency, 311
frequency of letters, 311
random, 312
entropy, 315–318, 324
envelope, 81, 416–420
envelope detector, 416
equalization, 27, 34, 56, 270–302, 387–391
blind, 289, 290
complex, 282
dispersion minimization, 290
fractionally spaced, 283
initialization, 289, 292, 353
tuning, 352
error measures, 35
error surface, 118, 125, 200, 207, 213, 259, 261, 263
errors in transmission, 308
Euler’s formulas, 404
exclusive OR, 329
eye diagram, 173, 181, 185, 231–237, 241, 250, 435
fading, 10, 64, 127, 175
FDM, 22, 25, 29, 60
FFT, 18, 42, 131, 133–141, 422–424
frequency estimation, 194
of a sinusoid, 136
phase estimation, 195
vs DFT, 424
filter design, 76, 77, 130, 141, 146
filters, 23, 46, 62, 141, 275
final value theorem, 117, 408, 410, 431
firpm, see MATLAB firpm
fixes, overview, 191
flat fading, 175
Fourier transform, 18, 41, 131, 405–408
Index

meaning of, 422
vs DFT, 421
fractionally spaced equalization, 283
frame, 4
Franks, L. E., 225
frequency, 16
carrier, 20
content, 19, 20, 40
discrete, 132
division multiplexing, see FDM
domain, 23, 40, 72, 132, 140, 421
intermediate, 29, 93, 130, 192
measuring, 18
of letters in English, 311
offset, 85, 88, 179, 184, 266
radio, 9
resolution, 140
response, 23, 65, 74, 133, 432
scale, 408
selectivity, 27
shift, 407
synchronization, 85
tracking, 216, 218
translation, 9, 17, 20, 21, 24, 54, 80–97, 103, 192
freqz, see MATLAB freqz
gain of a linear system, 426
Galois fields, 339
generator matrix, 328
Gitlin, R. D., 397, 403
gong analysis, 139, 149
gradient, 34
gradient descent, 114
Gray code, 154, 361
Hamming
blip, 156, 169, 194, 228, 233
distance, 333
wide blip, 230
hard decision, 174
Haykin, S., 39, 56
HDTV, 102
header, 158, 344, 454
high-side injection, 93
highpass filter, see HPF
Hilbert transform, 407, 420
hill climbing, 115
HPF, 24, 46, 141
Huffman code, 37, 324
human hearing, 102
ideal
channel, 5
receiver, 4, 5, 13, 58, 165
transmitter, 165
important message, 167
impulse response, 23, 65, 70, 74, 131, 141, 142, 270
impulse sampling, 100
independence of English text, 311
independent events, 306
information, 37, 303
and complexity, 308
and uncertainty, 305
axioms, 306
definitions, 304
in a letter, 308
in digits of π, 308
vs meaning, 310
initialization, center spike, 292
instantaneous code, 324, 325
instructor, to the, vii
integration layer, 341
interference, 10, 59
intermediate frequency, 29, 93, 192, 342
interpolation, 11, 110, 257, 262
intersymbol interference, see ISI
iteration, 447
Jablon, N. K., 394, 403
Jayant, N., 356
jitter, visualizing, 231
Johnson, C. R. Jr., 129, 302
Lathi, B. P., 39
least mean square algorithm, 285, 388
least squares, 277
Lee, E. A., 375, 386, 395, 402
Leibniz rule, 410
letters to bits, 4, 153
linear, 20, 23, 407, 422
linear block codes, 37
linear filters, 59, 65, 70, 130–151
linear vs nonlinear codes, 335
LMS, see least mean squares
local minima, 118
logical AND, 329
lookfor, see MATLAB lookfor
low-side injection, 93
lowpass filter, see LPF
LPF, 23, 141, 171
LPF and averaging, 442
M6 receiver, 342–356
majority rules, 328, 332
marker, 162, 172, 178, 344, 454
matched filter, 242–249
mathematical prerequisites, v
<table>
<thead>
<tr>
<th>MATLAB</th>
<th>index</th>
</tr>
</thead>
<tbody>
<tr>
<td>AGC, 124</td>
<td></td>
</tr>
<tr>
<td>averaging, 124</td>
<td></td>
</tr>
<tr>
<td>block code, 331</td>
<td></td>
</tr>
<tr>
<td>clock recovery, 258, 262</td>
<td></td>
</tr>
<tr>
<td>convolution, 70, 237</td>
<td></td>
</tr>
<tr>
<td>correlation, 158</td>
<td></td>
</tr>
<tr>
<td>DMA equalizer, 292</td>
<td></td>
</tr>
<tr>
<td>equalizer</td>
<td></td>
</tr>
<tr>
<td>DD, 289</td>
<td></td>
</tr>
<tr>
<td>LMS, 286</td>
<td></td>
</tr>
<tr>
<td>LS, 278</td>
<td></td>
</tr>
<tr>
<td>error surface, 125, 213, 259</td>
<td></td>
</tr>
<tr>
<td>FFT, 135</td>
<td></td>
</tr>
<tr>
<td>filter, 47, 48, 70, 142, 237</td>
<td></td>
</tr>
<tr>
<td>firpm, vii, 47, 77, 146, 415</td>
<td></td>
</tr>
<tr>
<td>frequency response, 74</td>
<td></td>
</tr>
<tr>
<td>frequency tracking, 219</td>
<td></td>
</tr>
<tr>
<td>freqz, 143</td>
<td></td>
</tr>
<tr>
<td>help, 42</td>
<td></td>
</tr>
<tr>
<td>ideal receiver, 169</td>
<td></td>
</tr>
<tr>
<td>ideal transmitter, 168</td>
<td></td>
</tr>
<tr>
<td>interpolation, 112</td>
<td></td>
</tr>
<tr>
<td>lookfor, 42</td>
<td></td>
</tr>
<tr>
<td>matched filter, 244</td>
<td></td>
</tr>
<tr>
<td>mod, 329</td>
<td></td>
</tr>
<tr>
<td>noise, 413</td>
<td></td>
</tr>
<tr>
<td>phase tracking, 198, 204, 208, 212</td>
<td></td>
</tr>
<tr>
<td>plotspec, 42, 51</td>
<td></td>
</tr>
<tr>
<td>quantalph, 53, 161</td>
<td></td>
</tr>
<tr>
<td>rand vs randn, 414</td>
<td></td>
</tr>
<tr>
<td>random, 43</td>
<td></td>
</tr>
<tr>
<td>random sentences, 312</td>
<td></td>
</tr>
<tr>
<td>remez, 47</td>
<td></td>
</tr>
<tr>
<td>resample, 113</td>
<td></td>
</tr>
<tr>
<td>reshape, 233</td>
<td></td>
</tr>
<tr>
<td>sampling, 98, 108</td>
<td></td>
</tr>
<tr>
<td>source code, 326</td>
<td></td>
</tr>
<tr>
<td>spectrum of a pulse sequence, 228</td>
<td></td>
</tr>
<tr>
<td>timing recovery, 258, 262</td>
<td></td>
</tr>
<tr>
<td>toeplitz, 276</td>
<td></td>
</tr>
<tr>
<td>maximum phase, 430</td>
<td></td>
</tr>
<tr>
<td>maximum-length pseudo-noise sequence, 162</td>
<td></td>
</tr>
<tr>
<td>McClellan, J. H., 56, 151</td>
<td></td>
</tr>
<tr>
<td>mean, 413</td>
<td></td>
</tr>
<tr>
<td>Meyr, H., 268, 356, 394, 403</td>
<td></td>
</tr>
<tr>
<td>minimum distance, 333, 338</td>
<td></td>
</tr>
<tr>
<td>minimum phase, 430</td>
<td></td>
</tr>
<tr>
<td>Mitola, J. et al., 356</td>
<td></td>
</tr>
<tr>
<td>Mitra, S., 57</td>
<td></td>
</tr>
<tr>
<td>mixers, 53–54</td>
<td></td>
</tr>
<tr>
<td>mixing, 81</td>
<td></td>
</tr>
<tr>
<td>mod, see MATLAB mod</td>
<td></td>
</tr>
<tr>
<td>modular arithmetic, 329, 337</td>
<td></td>
</tr>
<tr>
<td>modulation, 9, 17, 20</td>
<td></td>
</tr>
<tr>
<td>complex-valued, 359</td>
<td></td>
</tr>
<tr>
<td>large carrier, 81</td>
<td></td>
</tr>
<tr>
<td>quadrature, 90–93, 283, 417</td>
<td></td>
</tr>
<tr>
<td>quadrature amplitude, 357–403</td>
<td></td>
</tr>
<tr>
<td>single sideband, 81</td>
<td></td>
</tr>
<tr>
<td>small carrier, 84–90</td>
<td></td>
</tr>
<tr>
<td>vestigial sideband, 81</td>
<td></td>
</tr>
<tr>
<td>Morse code, 323</td>
<td></td>
</tr>
<tr>
<td>moving average, 442</td>
<td></td>
</tr>
<tr>
<td>mp3 compression, 327</td>
<td></td>
</tr>
<tr>
<td>multipath, 10, 27, 34, 61, 179, 182, 270,</td>
<td></td>
</tr>
<tr>
<td>272–273, 435</td>
<td></td>
</tr>
<tr>
<td>mystery signal, 355</td>
<td></td>
</tr>
<tr>
<td>Nahin, P. J., 97</td>
<td></td>
</tr>
<tr>
<td>naive receiver, 12</td>
<td></td>
</tr>
<tr>
<td>Nevermind, 344</td>
<td></td>
</tr>
<tr>
<td>noise, 42, 77, 179</td>
<td></td>
</tr>
<tr>
<td>broadband, 60, 76, 180, 242, 412</td>
<td></td>
</tr>
<tr>
<td>colored, 414</td>
<td></td>
</tr>
<tr>
<td>in-band, 10, 60</td>
<td></td>
</tr>
<tr>
<td>narrowband, 61, 270, 412</td>
<td></td>
</tr>
<tr>
<td>out-of-band, 10, 60</td>
<td></td>
</tr>
<tr>
<td>simulating, 412–415</td>
<td></td>
</tr>
<tr>
<td>spectrum of, 413</td>
<td></td>
</tr>
<tr>
<td>thermal, 60, 76</td>
<td></td>
</tr>
<tr>
<td>white, 245, 412</td>
<td></td>
</tr>
<tr>
<td>nonlinear, 20</td>
<td></td>
</tr>
<tr>
<td>nonlinear vs linear codes, 335</td>
<td></td>
</tr>
<tr>
<td>nonlinearities, 52–53, 196, 197, 376, 416</td>
<td></td>
</tr>
<tr>
<td>nonreturn to zero, 236</td>
<td></td>
</tr>
<tr>
<td>number of particles in the Universe, 336</td>
<td></td>
</tr>
<tr>
<td>numerical approximation to derivative, 256,</td>
<td></td>
</tr>
<tr>
<td>262</td>
<td></td>
</tr>
<tr>
<td>Nyquist</td>
<td></td>
</tr>
<tr>
<td>frequency, 50</td>
<td></td>
</tr>
<tr>
<td>pulse, 237–242, 247</td>
<td></td>
</tr>
<tr>
<td>rate, 101</td>
<td></td>
</tr>
<tr>
<td>sampling theorem, 28, 101</td>
<td></td>
</tr>
<tr>
<td>open eye, 185, 232, 266, 278, 287, 290, 435</td>
<td></td>
</tr>
<tr>
<td>open-eye measure, 436</td>
<td></td>
</tr>
<tr>
<td>Oppenheim, A. V., 56</td>
<td></td>
</tr>
<tr>
<td>optimization, 34, 114</td>
<td></td>
</tr>
<tr>
<td>oscillators, 44–46, 192, 210</td>
<td></td>
</tr>
<tr>
<td>other users, 60, 270</td>
<td></td>
</tr>
<tr>
<td>output power, 251, 254</td>
<td></td>
</tr>
<tr>
<td>oversampling, 109, 156, 168, 194, 228, 236</td>
<td></td>
</tr>
<tr>
<td>PAM, 5</td>
<td></td>
</tr>
<tr>
<td>parity check, 328, 330</td>
<td></td>
</tr>
<tr>
<td>Parseval’s theorem, 133, 408, 425</td>
<td></td>
</tr>
<tr>
<td>passband, 141</td>
<td></td>
</tr>
<tr>
<td>pedagogical method, iv</td>
<td></td>
</tr>
<tr>
<td>performance function, 114, 263, 293, 381</td>
<td></td>
</tr>
</tbody>
</table>
Costas loop, 207
CV timing recovery, 256
DD carrier recovery, 211
DD equalization, 289
DMA equalization, 291
for QAM, 381–383
LMS equalization, 284
LMS for AGC, 122
LS equalization, 276
output power, 261
PLL carrier recovery, 203
SD carrier recovery, 198
simple AGC, 123
period offset, 185
periodicity, 49, 101, 406
phase ambiguity, 374
maximum, 430
minimum, 430
offset, 86, 87, 179, 183, 192
shift, 404
splitter, 366
synchronization, 86
phase tracking
analysis, 206
Costas loop, 206, 367, 376
decision-directed, 210
dual algorithm, 218
phase-locked loop, 55, 202, 375
squared difference, 197
PLL, see phase tracking
Porat, B., 57
power, 18, 76, 84, 120, 242, 409, 413, 425
and correlation, 426
power spectral density, 242, 245, 409,
425–427
PPM, 362
prefix code, 324, 325
Proakis, J. G., 39, 379, 403
probability, use of, v
properties of discrete-time signals, 132
pulse amplitude modulation, see PAM
pulse shaping, 30–32, 155, 160, 161, 172, 194,
226–249, 251, 273
pulse train, 68, 99
pulse-matched filtering, 160, 172
pulse-phase modulation, see PPM
QAM, 357–403
Q^3 AM receiver, 397, 398
QPSK, 361, 377, 383
quadrature phase shift keying, see QPSK
quantization, 36, 161, 211
Qureshi, S. U. H., 302
radio AM, 17, 21, 80
digital, 14, 342
FM, 17, 21
raised cosine pulse, 239, 240, 248, 406
rand, see MATLAB random
random numbers, 413
seed, 414
receive filtering, 160, 226–249, 251
receiver
AM^2, 342
Q^3 AM, 397, 398
design, 445
ideal, 165
smart, 16
testing, 350, 355
reconstruction, 110
rectangular pulse, 8, 31, 72, 111, 238, 248,
406
redundancy, 37, 304, 308–315
Reed, J. H., 356
Reed–Solomon codes, 339
replicas, 23, 24, 100, 103
resample, see MATLAB resample
reshape, see MATLAB reshape
resolution in time vs frequency, 140, 423
Robbins, T., xiii
sampling, 11, 28, 33, 49, 98–129, 251
for downconversion, 103
sampling theorem, 28
Schafer, R. W., 57
Schwarz’s inequality, 243, 245, 410
scrambling, 162
seed for random numbers, 414
Sethares, W. A., 302
Shannon, C., 3, 37, 305, 308, 312, 340
sifting property of impulse, 410
signal, 40, 41, 131
Signal Processing First, v
signal-to-noise ratio, see SNR
simple average, 442
simulating noise, 412–415
sinc function, 8, 31, 72, 111, 138, 236, 238,
248, 406
sine wave, 21
spectrum, 69
single-sideband modulation, 81
sketching frequency response, 432
SNR, 60, 76, 244
SNR vs bandwidth, 320
soft decision, 174
software-defined radio, 2, 14, 342, 356
source coding, 37
source recovery error, 251, 256, 261, 276, 285
source vs channel coding, 304
sources of error, 348
spectrum, 41, 132, 135
$\delta$ function, 67
magnitude, 18, 23
of a pulse sequence, 227
phase, 18
sine wave, 69
square-law mixing, 88
square-root raised cosine, see SRRC
squared error, 35
squaring, 52, 195, 207
SRRC, 113, 236, 240, 248, 344, 406
steepest descent, 114
Steiglitz, K., 151
step
1 to build a radio, 1
2 basic components, 15
3 idealized receiver, 58
4 adaptive components, 191
5 putting it all together, 341
step function, 407
Stonick, V., 57
stopband, 141
Stremler, F. G., 39
symbol error vs bit error, 310
symbol recovery error, 35, 271
symmetry, 132, 405, 407
synchronization, 7, 33–34
carrier, 9, 192
frame, 7, 34, 154, 161, 177, 344, 353, 454
frequency, 85
phase, 86
unnecessary, 84
syndrome table, 330, 336, 338
system, 40, 131
tapped-delay line, 275
Taylor, F. J., 56
TDM, 22
temperature in Wisconsin, average, 443
testing the receiver, 350
text to binary, 154
text to bits, 4, 153
Through the Looking Glass, 310
time, 250
delay operator, 428
division multiplexing, see TDM
domain, 23, 40, 132, 140, 421
resolution, 140
shift, 408, 410, 428
timing, 33
jitter, 7
offset, 6, 179, 185
recovery, 251–269, 380–384
Toeplitz matrix, 276, 278
tracking, 124
trade-offs, 350
training sequence, 273, 284, 344, 454
transfer function, 74, 133, 430
transition band, 142
probabilities, 313
transmitter
$BYG$, 187, 451
design, 343
ideal, 165
transpose, 411
Treichler, J. R., 394, 403
trial and error, 350
trigonometric identities, 404
tuning the receiver, 350
TV, 17
uniform sampling, 50
unit circle, 430
unit delay, 429
variable length code, 323
variance, 413
Vergil, 314
Verne, Jules, 314
vestigal sideband modulation, 81
wavelength, 16
what if?, 3, 167, 178
whatever, 344
widrow, B., 129
wiener, 168
Wizard of Oz, 310, 325, 327
zip compression, 327
$Z$-transforms, 409, 428–434