

Index

- AACI (alternate adjacent channel interference) requirement, 88, 104, 131
- ACI (adjacent channel interference) requirement, 88, 104
- AD (amplitude distortion), 96, 97
- Adjacent channel interference (ACI) requirement, 88, 104, 131
- AFC (automatic frequency control), 165–171
- All-white-Gaussian-noise (AWGN) channel, 196–197
- Alternate adjacent channel interference (AACI) requirement, 88, 104
- AM-AM distortion, 96–99, 121, 123
- AM-PM distortion, 96–99, 121, 123
- Amplifiers. *See* Differential amplifiers; HPVGAs (high pass variable-gain amplifiers); LNAs (low-noise amplifiers); PAs (power amplifiers)
- Amplitude distortion (AD), 96, 97
- Amplitude modulation (AM). *See* AM-AM distortion; AM-PM distortion
- Antennas:
 - and direct-conversion receivers, 56, 57, 91
 - and FCC requirements, 33
 - and IEEE 802.11a/g receivers, 87
 - and LO leakage, 75–76, 77
 - and low IF receivers, 52
 - multiple, 197–200, 212, 214
 - and receiver phase noise, 129
 - and superheterodyne receivers, 44, 50
- Autocalibration, 119, 161–163, 178–179, 207. *See also* Calibration
- Automatic frequency control (AFC), 165–172
- AWGN (all-white-Gaussian-noise) channel, 196–197
- Backoff, 89, 98, 116, 122–123, 148
- Baluns, 94, 149, 178, 179, 203, 205
- Band-select filters, 44, 45–46, 47, 48, 52, 56, 77, 103
- Bandpass filters, 52–54, 61, 65, 84, 91, 104, 105–106
- Baseband blocks:
 - HD-related interference, 119–121
 - in receiver architecture, 59, 82–83
 - in transceiver case study, 178
 - in transmitter architecture, 65–66, 119
- Baseband filters, 44–45, 47, 49, 51, 52, 61, 165
- Bias current calibration, 175–176
- BiCMOS (bipolar CMOS), 70
- Bipolar devices:
 - comparison of SiGe transistors with CMOS transistors, 67–71
 - comparison with MOSFET devices, 81–82, 154–155
 - flicker noise, 81–82
- Calibration:
 - bias current, 175–176
 - closed-loop, 164
 - in CMOS 802.11a/b/g/n MIMO transceiver case study, 209–210
 - for CMOS-based transmitters, 177
 - DSP-assisted, 161, 163
 - filter time-constant, 176–177
 - open-loop, 164–165
 - self-contained, 161, 163
 - VCO, 163–165
 - WLAN radio overview, 161–177

- Calibration (*continued*)
 - in WLAN transmitter case study, 189–196
- Cascodes:
 - folded, 144, 146
 - in low-noise amplifier design, 140–141, 142
 - and mixers, 144, 146
 - in power amplifiers, 148, 151
 - and VCO pulling, 126
 - in WLAN transmitter case study, 190
- CCDF (complementary CDF), 97, 98, 100, 134
- CDF (cumulative distribution function), 97, 134
- CDMA (cellular code division multiple-access) standard, 11, 18, 31, 61, 90, 91, 129
- Channel allocations:
 - IEEE 802.11a, 13–15
 - IEEE 802.11b, 10–12
 - IEEE 802.11g, 10–12
- Channel-select filters, 44, 46, 47, 52, 104
- Closed-loop calibration, 164
- CMOS (complementary metal-oxide-semiconductor):
 - comparison with BiCMOS, 70–71
 - comparison with bipolar SiGe transistors, 67–71
 - flicker noise in devices, 81
 - in low-noise amplifiers, 139–142
 - in mixers, 143–144
 - in power amplifier design, 149–153
 - power-level calibration, 177
 - three-stage PA example, 148–149
 - transceiver case study, 178–189
 - in VCO design, 154–155
- CMOS 802.11a transceiver case study:
 - architecture, 178–180
 - block diagrams, 179–180
 - circuit implementation, 179–180
 - performance characteristics, 187–189
 - receiver, 181–183
 - transmitter, 183–185
- Code rates, 21, 22, 23
- Complementary CDF (CCDF), 97, 98, 100, 134
- Constellation diagrams:
 - IEEE 802.11a, 34, 35, 36, 37
 - and polar modulators, 66–67
 - and quadrature balance, 110–114
 - transmitter output, 66–67, 110–114, 185–186
 - VSA examples, 34–41
- Cumulative distribution function (CDF), 97, 134
- Data rates:
 - and automatic frequency control, 171
 - in CMOS 802.11a/b/g/n MIMO transceiver case study, 201
 - CMOS 802.11a transceiver case study, 182–183, 184
 - and far-out phase noise, 130
 - in history of IEEE 802.11, 6–8
 - IEEE 802.11a, 8–9, 21–23
 - IEEE 802.11b, 5, 8–9, 11–12
 - IEEE 802.11g, 5, 8–9, 21–23
 - and multipath fading, 17
 - receiver issues, 26, 74, 75, 88, 89, 107, 182–183
 - transmitter issues, 28, 123–124, 184
- DC offsets, receiver-related, 75–79
- Differential amplifiers, 151, 158–160
- Direct-conversion architecture:
 - advantages and disadvantages, 56–59
 - example, 55, 56
 - overview, 44, 55–56
 - and receiver flicker noise, 82–83
 - and receiver image rejection, 106–107
 - receivers, 44, 55–59, 76–79, 91–92
 - transmitters, 44, 64–66, 117–119
- Direct sequence spread spectrum (DSSS), 6, 7, 11
- Diversity, 149, 181, 199–200, 201, 219
- DSB (double-sideband) NF vs. SSB (single-sideband) NF, 46, 103
- DSSS (direct sequence spread spectrum), 6, 7, 11
- EVM (error vector magnitude):
 - receiver, 169, 170
 - relationship to image rejection, 114–116
 - relationship to quadrature balance, 109–116
 - transmitter, 26–28
- Fading, multipath, 15–17

- Far-out phase noise, 130–131
- FCC (Federal Communications Commission), 10, 13, 31, 33, 75, 77, 104, 119, 129
- Feedback techniques vs. open-loop transductance, 158–160
- FER (frame error rate), 88
- FHSS (frequency hopping spread spectrum), 6, 11
- Filters:
- band-select, 44, 45–46, 47, 48, 52, 56, 77, 103
 - bandpass, 52–54, 61, 65, 84, 91, 104, 105–106
 - baseband, 44–45, 47, 49, 51, 52, 61, 165
 - channel-select, 44, 46, 47, 52, 104
 - front-end, 48, 104
 - high pass, 36, 50, 54, 58, 77, 78, 165–166, 169
 - RF, 102–106
 - time-constant calibration techniques, 176–177
- Flicker noise, 79–83
- Frame error rate (FER), 88
- Frequency control, automatic (AFC), 165–171
- Frequency conversion. *See* Mixers
- Frequency errors, effect on OFDM systems, 132–135
- Frequency hopping spread spectrum (FHSS), 6, 11
- Front-end filters, 48, 104
- GaAs (gallium arsenide) devices, 68, 70, 123, 149–150, 153
- Gain control:
- in CMOS 802.11a transceiver case study, 183–185
 - implementing in low-noise amplifiers, 141–142
 - providing in transmitters, 118–119
 - switched-resistance scheme, 141–142
- Gilbert quads, 143, 144, 146
- GSM (Global System for Mobile) communication, 54, 55, 58, 75, 83, 90
- HD (harmonic distortion), 30, 83–84, 119–121, 151, 159–160
- High pass filters. *See* HPFs (high-pass filters)
- High pass variable-gain amplifiers. *See* HPVGAs (high pass variable-gain amplifiers)
- HPFs (high-pass filters), 36, 50, 54, 58, 77, 78–79, 165–166, 169, 205
- HPVGAs (high pass variable-gain amplifiers), 181–182, 203, 205
- IEEE 802.11 standard:
- comparison with HyperLAN standard, 6
 - comparisons among PHY versions, 8–10, 12, 13
 - data rates, 6, 11–12, 21–23
 - history, 6–8
 - MAC layer, 6, 22, 24
 - overview, 6–8
 - PHY extensions, 6–8, 24
 - structure, 6–8
 - system requirements, 24–33
 - working groups, 7–8
- IEEE 802.11a:
- channel allocations, 13–15
 - constellation diagrams, 34, 35, 36, 37
 - extension, 6, 7, 8–10, 12, 21–23
 - OFDM coding, 15, 20–21
 - OFDM packet construction, 24, 25
- IEEE 802.11b:
- channel allocations, 10–12
 - extension, 6–7, 8–12
- IEEE 802.11g:
- channel allocations, 10–12
 - extension, 7, 8–10, 12, 21–23
 - OFDM coding, 15, 20–21
 - OFDM packet construction, 24, 25
- IEEE 802.11n:
- need for, 195–200
 - working group, 7–8
- IF (intermediate frequency). *See also* Low IF receivers
- choosing in superheterodyne receivers, 47–51
 - and image rejection, 104
 - zero, 43
- IIPs. *See* Input IPs (IIPs); Intercept points (IPs)
- Image rejection:
- direct-conversion receivers, 106–107

- Image rejection (*continued*)
 filter use, 45–46, 47
 in low IF architecture, 104–106
 and quadrature balance, 107–109
 relationship to EVM, 114–116
 superheterodyne receivers, 45–46, 47, 102–104
- IMD (intermodulation distortion):
 characterizing circuit nonlinearity, 83–84
 product nonsymmetry, 121
 and spectral regrowth, 30–31, 32
- Inductors, 138–139, 141, 146
- Input IPs (IPs), 86–87
- Intercept points (IPs), 59, 84–96, 144, 145
- Intermediate frequency (IF). *See also* Low IF receivers
 choosing in superheterodyne receivers, 47–49
 and image rejection, 104
 zero, 43
- Intermodulation distortion (IMD):
 characterizing circuit nonlinearity, 83–84
 product nonsymmetry, 121
 and spectral regrowth, 30–31, 32
- IPs. *See* Intercept points (IPs)
- IS-95 CDMA standard, 11. *See also* CDMA (cellular code division multiple-access) standard
- LANs (local area networks), wired vs. wireless, 1–3. *See also* Wireless LANs
- LC-based oscillators, 153–154
- Linearity:
 in circuit building blocks, 158–160
 feedback techniques vs. open-loop transductance, 158–160
 in low-noise amplifiers, 139–140, 141, 142, 143, 144, 145–146
 in power amplifiers, 148, 150, 153
 as receiver issue, 91–96
 as transmitter issue, 121–124
- LNAs (low-noise amplifiers):
 in CMOS 802.11a/b/g/n MIMO transceiver case study, 203
 in CMOS 802.11a transceiver case study, 178
 defined, 137
 in direct-conversion receivers, 55, 56, 57, 59, 106
 in IEEE 802.11 standards, 22
 implementing gain control, 141–142
 linearity, 139–140, 141, 142, 143, 144, 145–146
 in low IF receivers, 52, 53, 104–105
 overview, 137–138
 as receiver building block, 137–142
 in superheterodyne receivers, 44–46, 102–104
 and transceiver impairments, 75, 76, 77, 79, 91, 102–106, 117
- LO generation circuitry, 57, 111, 114, 157, 167–169, 173, 175, 203, 207–209
- Local oscillators (LOs):
 and automatic frequency control, 167–168
 buffers for mixers, 146–147
 in direct-conversion receivers, 106
 leakage and DC offsets, 75
 leakage and receiver DC offsets, 75–79
 PLLs pulling, 124–126
 in superheterodyne receivers, 102
- LOFT (LO feedthrough):
 calibration case study, 189–196
 direct-conversion transmitter issue, 117–119
 and MI>IQ imbalances, 174–175
 and quadrature error, 172–175
 as transmitter impairment, 116–119
- LOGEN, 60, 147–148, 157, 159
- Low IF receivers:
 advantages and disadvantages, 52, 54
 and band-select filters, 77
 examples, 52–53
 image rejection, 104–106
 overview, 44, 51–52
 suitability for WLAN systems, 55
- Low IF transmitters, 44, 64
- Low-noise amplifiers. *See* LNAs (low-noise amplifiers)
- MAC layer, 6, 22, 24, 70, 181, 188, 205, 218–219
- Maximum ratio combining (MRC), 200, 214, 217
- MIMO (multi-in, multi-out) systems, 200, 201, 202–217

- Mixers:
- as building block in wireless transceivers, 142–148
 - CMOS, 143–144
 - LO generation, 167–168
 - multifrequency, 157–158
 - role of Gilbert quad, 142–148
 - stacked, 157–158, 169
 - symbol, 142
 - transmit-side variable gain, 145–146
- MOSFET (MOS field effect transistor) devices:
- comparison with bipolar devices, 81–82, 154–155
 - flicker noise, 80–81
 - and power consumption issues, 93
 - in VCO design, 154–155
- MRC (maximum ratio combining), 200, 214, 217
- Multi-in, multi-out (MIMO), 200, 201, 202–217
- Multifrequency mixers, 157–158
- Multipath propagation, 15–21
- Multiple antennas, 199–204, 214, 216
- NF (noise figure):
- in CMOS 802.11a transceiver case study, 180–181
 - and flicker noise, 83
 - impact of band-select filter, 45
 - impact of image-reject filter, 46
 - linearity tradeoff, 26
 - and low-noise amplifiers, 137–140, 142
 - and receiver impairments, 92, 93
 - and receiver sensitivity, 73–75
 - and superheterodyne receiver image rejection, 102–104
- NMOS devices, 81–82, 144, 146, 155
- Noise figure. *See* NF (noise figure)
- Nonconstant envelope signals, 29, 30–31, 121
- OFDM (orthogonal frequency division multiplexing):
- comparison with CDMA, 18
 - data rates, 21–23
 - effect of frequency errors, 132–135
 - effect of phase noise, 131–132
 - and IEEE 802.11n, 199, 200–201
 - modulated signals, 88–89
 - and multipath propagation, 15–21
 - overview, 15
 - packet construction, 24, 25
 - and quadrature signals, 107, 109, 110–111
 - and subcarrier overlaps, 18–21
 - and transmitter spectral masks, 32
- OIPs. *See* Output IPs (OIPs)
- OOBs (out-of-band blockers), 103
- Open-loop calibration, 164–165
- Orthogonal frequency division multiplexing. *See* OFDM (orthogonal frequency division multiplexing)
- Oscillators, LC-based, 153–154. *See also* Local oscillators (LOs); VCOs (voltage-controlled oscillators)
- Out-of-band blockers (OOBs), 103
- Out-of-band phase noise, 130–131
- Output IPs (OIPs), 86–87
- P1dB compression point, 95–96, 98, 99, 123
- PAPR (peak-to-average power ratio), 12. *See also* PAR (peak-to-average ratio)
- PAR (peak-to-average ratio):
- defined, 121
 - OFDM signals, 19–20, 88, 121, 148, 182
 - overview, 19–20, 29, 31, 32
 - and polar modulators, 67
 - relationship to transmitter linearity and efficiency, 121–124
 - signal differences, 88, 96, 97–98
- PAs (power amplifiers):
- analyzing signal distortion, 97–98, 99, 100–102
 - CMOS devices in, 149–151
 - designing for WLAN applications, 149–153
 - linearity, 148, 150, 153
 - linearization and efficiency enhancement techniques, 123–124
 - overview, 148
 - as radio building block, 148–153
 - three-stage CMOS example, 148–149
- PD (phase distortion), 96, 97

- Peak-to-average power ratio (PAPR), 12.
See also PAR (peak-to-average ratio)
- Peak-to-average ratio (PAR). *See* PAR (peak-to-average ratio)
- PGAs (programmable gain amplifiers), 44, 52, 56, 82
- Phase distortion (PD), 96, 97
- Phase-locked loops (PLLs):
 block diagram, 186
 in CMOS 802.11a transceiver case study, 186–189
 local oscillator pulling, 124–126
 measured phase noise, 184–185
 phase noise behavior, 126–130
- Phase noise:
 close-in vs. far-out, 129–130
 effect on OFDM systems, 131–132
 far-out, 130–131
 out-of-band, 130–131
 in PLLs, 126–130, 186–187
 in VCOs, 154–155
- PHY layer, 6–8, 24
- PLLs. *See* Phase-locked loops (PLLs)
- PMOS devices, 81, 144, 145, 155
- Polar modulators, 66–67
- Power amplifiers. *See* PAs (power amplifiers)
- Power detectors, 174–175, 184
- Programmable gain amplifiers (PGAs), 44, 52, 56, 82
- Quadrature balance:
 calibrating imbalances, 172–175
 constellation diagrams, 110–114
 and direct-conversion receivers, 106–107
 in low IF architecture, 104, 106
 relationship to error vector magnitude, 109–116
 relationship to image rejection, 102, 104, 107–109
 in WLAN transmitter case study, 189–196
- Receive signal strength indicators (RSSIs), 26, 182, 205
- Receivers:
 architectural overview, 43–44
 automatic frequency control, 165–172
 in CMOS 802.11a/b/g/n MIMO transceiver case study, 202–205
 in CMOS 802.11a transceiver case study, 181–183
 comparison of architectures, 49–51, 59–60, 76–77
 DC offsets, 75–79
 direct-conversion, 44, 55–59, 76–79, 91–92
 flicker noise, 79–83
 frequency offsets and multipath distortion, 169–172
 image rejection, 45–46, 47, 102–107
 linearity issue, 91–96
 LO leakage, 75–79
 low IF, 44, 51–55, 104–106
 noise figure, 73–75, 92, 93, 102–104
 nonlinearities, 83–102
 PLL and PCO phase noise, 129
 sensitivity, 24, 26, 73–75
 superheterodyne, 43, 44–51, 60, 76, 77, 102–104
- Reciprocal mixing, 128, 129, 130–131
- RF filters:
 in low-IF architecture, 51, 104–106
 in superheterodyne architecture, 48, 102–104
- Root-mean-square (RMS) delay, 17, 18, 28, 116, 154, 169
- RSSIs (receive signal strength indicators), 26, 182, 205
- SAW (surface acoustic wave) filters, 44, 46, 52, 56, 60
- Semiconductors. *See also* CMOS (complementary metal-oxide-semiconductor); SiGe (silicon germanium) devices
 BiCMOS, 67–71
 WLAN chipset market, 3–6
- SiGe (silicon germanium) devices:
 in bipolar buffers, 147
 in power amplifiers, 67–69, 70, 123, 139, 149, 150, 153
- Signal-to-noise plus interference ratio (SNIR), 104, 130
- Signal-to-noise ratio (SNR), 11, 23, 73–75, 79, 137, 198–201

- Silicon germanium (SiGe) devices:
 in bipolar buffers, 147
 in power amplifiers, 67–69, 70, 123, 139, 149, 150, 153
- SIMO (single-in, multi-out) systems, 200
- SISO (single-in, single-out) systems, 200–201
- Sliding IF architecture, 48–49, 63
- SNIR (signal-to-noise plus interference ratio), 104, 130
- SNR (signal-to-noise ratio), 11, 23, 73–75, 79, 137, 198–201
- Spectral masks, 10, 13, 28–33, 61, 64, 98, 100–101, 184–185
- Spurious emissions, 33, 129–130
- SSB (single-sideband) NF vs. DSB (double-sideband) NF, 46, 103
- Stacked mixers, 157–158, 169
- Superheterodyne receivers:
 advantages and disadvantages, 49–51
 band-select filters, 44, 45–46, 47, 48, 77
 baseband filters, 44–45, 47, 49, 51
 channel-select filters, 44, 46, 47, 52, 104
 choosing intermediate frequency, 47–51
 comparison with direct-conversion receivers, 60, 76, 77
 and flicker noise, 82
 image rejection, 45–46, 47, 102–104
 overview, 44–45
 role of filters, 44–45
 sliding IF option, 48–49
- Superheterodyne transmitters:
 advantages and disadvantages, 62
 example, 62–64
 overview, 43–44, 60
 role of filters, 61
- Surface acoustic wave (SAW) filters, 44, 46, 52, 56, 60
- Temperature sensors, 177
- Through-wafer via technology, 150
- Transceivers. *See also* Receivers;
 Transmitters
 in CMOS 802.11a/b/g/n MIMO case study, 200–215
 in CMOS 802.11a case study, 178–189
- Transconductance:
 in CMOS power amplifier design, 151–153
 in WLAN transmitter case study, 189–196
- Transmitters:
 architectural overview, 43–44
 baseband blocks, 65–66, 119
 in CMOS 802.11a/b/g/n MIMO transceiver case study, 205–207
 in CMOS 802.11a transceiver case study, 183–186
 constellation diagrams, 66–67, 110–114, 185–186
 current leakage problem, 116–119
 direct-conversion, 44, 64–66, 117–119
 error vector magnitude, 26–28
 gain control, 118–119
 in high performance WLAN case study, 187–194
 impairments, 116–121
 and LO feedthrough, 116–119
 low IF, 44, 64
 PLL and PCO phase noise, 129
 and polar modulators, 66–67
 relationship of PAR to transmitter linearity and efficiency, 121–124
 spectral mask passing, 28–33
 superheterodyne, 43–44, 60–64
 transmit output power vs. data rate, 182–183
- U.S. Federal Communications Commission (FCC), 10, 13, 31, 33, 75, 77, 104, 119, 129
- VCOs (voltage-controlled oscillators):
 in automatic frequency correction, 167, 168
 buffers for mixers, 146–147
 calibration techniques, 163–165
 in CMOS 802.11a/b/g/n MIMO transceiver case study, 207–209
 CMOS design topology, 155–156
 in direct-conversion receivers, 57
 in direct-conversion transmitters, 65
 fully integrated, 153–157
 in low IF transmitters, 64
 in multifrequency stacked mixers, 157–158
 phase noise overview, 154–155
 and PLL phase noise, 126–129

- VCOs (*continued*)
 - and PLL pulling phenomenon, 124–126
 - in superheterodyne transmitters, 62, 63
 - tuning range requirements, 156
- Vector signal analysis (VSA):
 - constellation diagrams, 34–41
 - defined, 34
 - overview, 33–34
- Viterbi decoding, 21, 22, 23, 24, 74, 181
- VoIP (voice-over-Internet Protocol), 5, 7
- Voltage-controlled oscillators. *See* VCOs (voltage-controlled oscillators)
- VSA. *See* Vector signal analysis
- Wireless CDMA (cellular code division multiple-access) standard, 31, 61, 90, 91, 129
- Wireless LANs:
 - advantages and disadvantages, 1–3
 - communication speed issues, 2, 8, 15, 17
 - comparison with wired LANs, 1–3
 - defined, 1
 - market trends, 3–6
 - network example, 1, 2
 - overview, 1–3
 - radio design trends, 218–219