

SUBJECT INDEX

KEY

page number font	boldface	main subject treatment
	<i>italic</i>	figure
	f	figure
suffixes	ff	“and pages following”
bold suffixes	ff	“main entry, and pages following”
	(box)	boxed item
	g	graph
	n	footnote
	p	photograph
	r	review section
	s	screen shot ('scope or spectrum analyzer)
	t	tabular
	T	table

1-wire bus, *see* computer, data bus
1/f, *see* noise
 1TIC cell, 1019
 2's complement, *see* number, codes
 3-state, *see* logic
 3-terminal regulator, *see* voltage regulator
 3-way switch, *see* switch
 3.58MHz subcarrier, *see* video, composite
 6T cell, 1016
 8b/10b code, 1041
 555, *see* one-shot, *see* oscillator
 8051, *see* microcontroller
 abbreviations, 1166
 ABEL, *see* programmable logic device (PLD)
 absolute temperature sensor, *see* PTAT, *see* sensor, temperature
 absolute-value circuit, 257, 257, 288r
 abuse, *see* argument
 ac line filter, 629ff
 fuse mandatory, 630
 ac power, *see* power, powerline
 ac power control
 microcontroller, 1062–1065
 ac powered
 dc power supply topologies, 630
 ac solid-state relay, *see* SSR
 academics, 332n
 acceleration, *see also* sensor
 algorithm, 1069
 accelerometer, *see* sensor
 acoustic ranging, 207

acquisition time, *see* ADC, *see* aperture time,
 see sample-and-hold
 acronyms, 1166
 active
 ballast, 113, 113, 213, 214
 clamp, *see* clamp
 device, 71
 filter, *see* filter
 load, *see also* load, 85, 98, 105, 123, 147,
 158, 167, 243, 266, 266, 496
 rectifier, *see also* op-amp, 238ff, 289r, 634
 resistor, *see also* AoE 2nd ed., p 257, 416,
 416
 active-HIGH, active-LOW, *see* logic
 Adafruit, 1082, 1095r
 ADC, *see also* converter, AD/DA, 879,
 900–955, 1053, 1061, 1070, 1071, 1082,
 1087, 1095r
 ac monitor, **943**
 acquisition time, *see* aperture time
 analog switches in, 916
 application examples, 907, 910, 932, 936,
 946, 987r
 bridge-sensor oriented, 945, 947
 charge redistribution, 909, 950n
 choosing, **938**, 987r
 comparison, **938**
 data-acquisition system (DAQ), **946–955**
 isolated SPI, 950
 multiplexed 16-channel SAR, **946ff**, 948
 parallel 8-channel $\Delta\Sigma$, **952**, 954
 parallel 8-channel SAR, **950**, 951–953
 delta-sigma, *see* delta-sigma
 differential-input, 374, 380, 382
 flash, 902, 903, **903–908**, 986r
 driving (design example), 906, 904–907
 folding, 904
 for thermocouple, 1084
 half-flash, 903
 integrating, **912–938**
 as lowpass filter, 940
 dual-slope, 902, **914ff**, 915, 986r
 multislope, 902, 919, 921t, **918–922**
 normal-mode rejection, 915
 powerline rejection, 915, 919
 single-slope, 902, 914, **914**, 986r
 introduction, 879–881
 latency time, *see* latency
 low-power shootout, 941
 micropower, 916t, 941
 noise
 filtering out-of-band, 911
 sampling vs integrating, **940**
 parallel, **903–908**
 pipelined, 904
 pipelined flash, 903
 precision, in microcontroller, 1071
 resolution
 effective, 935n
 noise-free, 935n
 RF
 driving (design example), 906, 904–907
 selected, 905t
 sequencer, 945

shootout, 939t
 ADCs, SAR vs $\Delta\Sigma$, 939
 low-power, 941
 specialty, 942, 942t
 subsystem, 1084
 successive approximation, 902, 908, 908s, 910t, **908–912**, 986r
 block diagram, 911
 design example, 912, 910–912
 SPI timing, 911
 switched-capacitor, *see* ADC, charge redistribution
 system design examples, **946–955**
 tables, 905t, 910t, 916t, 921t, 937t, 939t, 942t
 techniques, 902
 timing example, 1088, 1088g
 pseudocode, 1089
 touchscreen digitizer, 944
 tracking, 909
 transformer input coupling, 382
 undersampling
 deliberate, 907
 V to f , 434, 902, **912ff**, 986r
 nonlinearity, 914g
 adder, *see* logic
 admittance, 69, 90n
 aging
 crystal, 451, 471r
 MOV, 632
 voltage reference, **683**
 alias, *see also* filter, 395, 901, 931g
 digital oscilloscope, 442n, 1164
 in switched-capacitor filter, 417
 undersampling conversion, 907
 AM radio, 55, 56s
 waveforms, 55g, 56s
 amp, 2
 amplifier
 autonulling, 298
 autonulling (design example), 297
 input errors, 306
 balanced audio, 376
 clamping output, 383
 class-A, 106n, **107**
 class-AB, 108, **108**, 310
 class-B, 107n
 distortion, 309
 class-D, 109, 109s, 673
 CMRR, 347ff
 common-base, 91, 549, 549
 common-emitter, **87ff**, 91, 128r
 biasing, **95**, **96ff**
 bootstrapping, **112**
 bypassed emitter resistor, 96
 distortion, 95s
 emitter resistor as feedback, 96
 gain of, 93
 input impedance of, 95

maximum gain of, 98
 nonlinearity, 94, 94–96s
 revisited (Ebers-Moll), 93
 composite, 332, 333, 365, 543–547, 920, 920
 slew rate of, 920
 vs single-stage, 546
 current, *see* transimpedance amplifier
 current-feedback, 375t, 378, 384–386, 513, 544
 current-sensing, 278
 difference, 348, **347–387**, 390r
 applications, 349ff
 as current source, 350, 351
 bandwidth, 355
 BJT, **102ff**
 CMRR, 355g
 CMRR trim, 356, 357
 common-mode input range, 354
 configurations, 356
 current sensing, 349, 350
 filter node, 355
 ground-loop isolation, 349, 350, 584
 input impedance, 352, 354
 line driver, 351
 offset trim, 355, 357
 performance parameters, 352ff
 tricks, 349
 differential, 115, 124, 129r, **373ff**, 375t, **347–387**, 390r, 1070
 as comparator, 105
 as dc amplifier, 104
 bandwidth, 385
 bias pin, 378
 biasing, 104
 BJT, **102ff**
 choosing, **383ff**
 CMRR, 347, 376, 384
 common-mode input range, 378, 381, 384
 common-mode output impedance, 379
 common-mode output voltage, 380
 compensation, 378
 current-feedback, 375t
 current-mirror load, 105, 105, 153, **496**
 distortion, 386, 386g
 filtering, 385
 gain of, 103
 gain setting, 384
 gain-setting resistor, 378
 input impedance, 384
 input impedance matching, 382
 input impedance of, 376
 JFET, **152ff**
 no Miller effect in, 114
 noise, 386, 496, 520
 offset voltage, 384
 output voltage, 383
 phase splitter, 105
 settling time, 385

single-ended output, 377
 slew rate, 385
 speed, 385
 supply voltage, 383
 use with ADCs, **380**, 382
 use with single-ended input, 376
 distortion
 barn-roof, 95
 SPICE simulation, 1148
 equalization, 380, 381
 error, 598, 604 (box), 642, 699, 700r
 in linear regulator, 597
 in switchmode regulator, 646, 651
 fully differential, *see* amplifier, differential
 funnel, 376n
 gain, predictability of, 117
 general purpose, 274
 grounded-base, 115
 grounded-emitter, 94
 high-voltage, 209, 696
 hybrid, low-noise, 534
 input errors, 301, 388r
 input impedance
 effect of feedback on, 118
 input protection, 210
 instrumentation, *see* instrumentation amplifier
 isolation, **585ff**, **847**
 capacitive, 586
 JFET, **146ff**
 differential, 152
 low noise, **509–520**
 op-amp hybrid, 151, 153g, 155g, 343, 344, 534
 series-feedback pair, 150, 151g
 with cascode, 148
 laboratory, 298
 laboratory, general-purpose, 274
 logarithmic, *see* AoE 2nd ed., pp 212–216
 low-noise, 496, 498, 500, 505, 506
 MOSFET power, 221r
 noise, *see also* noise, 481
 in inverting amplifier, 521
 in noninverting amplifier, 520
 measurement, **555ff**
 total, vs R_s , 526g
 total, vs frequency, 531g
 noise model, 481, 492
 op-amp, *see* op-amp
 BJT hybrid, 534
 JFET hybrid, 153g, 534, 545
 low-noise, 522–524t
 low-noise, choosing, **525–533**
 single-supply, 261
 operational transconductance, *see* OTA
 (operational transconductance amplifier)
 output errors, 307
 output impedance
 effect of feedback on, 119

- inductive, 120n
 patch clamp, 552
 peaking, 152, 153g, 154, 154g, 378, 385, 385g
 photodiode, 233, 547, 548
 photomultiplier, 843
 piezo, 208, 209
 programmable gain (PGA), 946
 programmable-gain (PGA), **370**, 370, 371t
 sense, 1016, 1018
 STM, 553
 summing, 234
 switchable gain, 182
 switching, 109, 109s, 673
 transconductance, *see* transconductance
 transformer in feedback, 285, 536
 transimpedance, *see* transimpedance amplifier
 video and RF, 274, 351, 374, 380, 381, 533, 862, 862
 voltage, 90
 voltage-feedback, 378
 wideband analog link, 352, 380
 world's quietest, 505, 507g, 508t
 amplitude
 modulation, *see* modulation
 peak-to-peak, 14
 rms, 14, 47, 68r
 do not add, 479
 noise, 474ff, 475t
 square wave, 16
 analog multiplexer, *see* analog switch, multiplexer, *see* multiplexer
 analog multiplier, *see* multiplier
 analog switch, 176t, 946
 4053-style, 916ff, 917t
 charge injection, *see also* charge injection, 176t, **180**, 181g
 vs R_{ON} , 182g
 FET, **171–184**
 applications, 182–184
 capacitance, 178–181
 charge injection, **180**
 CMOS, 172
 feedthrough, 179g
 gate drive, **173**
 JFET, 172
 latchup, 174
 leakage current, 181, 256, 947, 948
 limitations, 174
 multiplexer, 173, 946
 nonlinearity, 177
 ON resistance, 171, 172, 173g, 177g, 178g, 175–178
 protected, 175
 speed, 178
 substrate effects, 173n
 T-switch, 179
 in ADCs, **916ff**
 in conversion applications, **916ff**
 logic-family, 916ff
 multiplexer, 173, 361, **361**, 413, 945, 1062
 nonlinearity, 177
 transmission gate, *see* logic
 analog vs digital, 703
 analog-to-digital, *see* ADC
 anti-alias, *see* filter
 antisaturation, *see also* comparator
 antisaturation circuit, 717n, 812
 aperture time, 904, 911, 940
 in Hororan circuit, 982
 jitter, 905t
 apodization, 420
 arbitrary function generator, 18, 1152
 Arduino, *see also* microcontroller, 1053, 1087n, **1092**, 1094, 1095, 1096r
 argument, *see also* abuse, *see also* computer, 993
 immediate, 993
 ARM, *see* microcontroller
 Armstrong, Edwin, 969n
 Art of Electronics
 logo wristwatch, 448p
 ASCII, 706
 ASCII code, 1039, 1040t
 ASIC, 714, 777, 787, 788r
 assertion-level logic, 713
 assign, in Verilog, 777
 ASSP, 714, 788r, 1031, 1093
 asynchronous, *see also* logic, *see also* memory, 1016
 communication, 771
 RS-232, **1038ff**
 ATSC, 1133, 1137n
 attenuator, 17
 digital, 1067
 matched impedance, 1123, 1124t
 audio
 analog, 1131
 balanced driver, 351, **351**, 376, 380, 383
 balanced impedances, 355n
 balanced line, 348
 digital, 1131
 sampling rate, 902
 autocorrelation
 of LSFR, 977
 of PRBS, 978g
 autozero, *see* op-amp
 avalanche, *see also* MOSFET
 in BJT, 982, 988r
 in diodes, 70r
 in JFETs, 199
 in zener diodes, 674n
 photodiode, 609, 831 (box), 877
 AVR, *see* microcontroller
 Ayrton-Perry winding, *see* Chapter 1x
 backlight, *see* LED
 balanced amplifier, *see* amplifier
 balanced line, *see* audio
 ballast, 113, 113, 138, 146, 192, 201, 214
 balun, 379, 380
 bandgap, *see* voltage reference
 bandwidth
 limit, 1162, 1165
 narrowing, **574ff**
 lock-in detection, 398, 563, 576, **575–578**, 593r, 852
 lock-in modulation, 577
 modulation feedthrough, 577
 synchronous detection, 852
 of difference amplifier, 355
 of noise, 477
 of op-amp, 308
 signal averaging, 576
 bang-bang control, 608, 644n, 645, 645, 649, 650, 700r, 1070
 base resistance, *see* BJT, r_{bb}
 base spreading resistance, *see* BJT, r_{bb}
 baseband, 395
 BASIC Stamp, 1087
 battery, 2, 9, **686ff**, 688p
 alkaline, 196n, 753
 backup, 36
 characteristics, 687, 689t
 choosing, 688
 Diehard, 983
 discharge curves, 687g
 energy density
 vs capacitor, 690g
 energy storage
 vs capacitor, 690t
 Li-ion
 charging, 688
 power density
 vs capacitor, 690g
 primary, 686
 choices, 687
 rechargeable, *see* battery, secondary
 secondary, 686
 charging, 687
 choices, 687
 series resistance of, 8
 baud, 872
 Baudot, 708
 BCD, *see* number
 bead, *see* ferrite
 BeagleBoard, 1053n
 bench instrument favorites, 1152
 Bessel, *see* filter
 beta, *see* BJT
 BGA, 789r
 bias cancellation, *see* op-amp
 bias tee, 836
 bias-current cancellation, *see* op-amp
 biasing
 bad, 85, 125

- of emitter follower, 83
 with compensated V_{BE} drop, 97
 with dc feedback, 98
 with LED, 86n
bibliography, 1154ff
bifilar, 656n
binary
 number, *see* number
 search, 908
biology
 electrical engineer's view of, 805
biphase code, 1041, 1041
bipolar transistor, *see* BJT
bit
 effective number of, 928, 929g
 error rate, 975
 grooming, 1138n
 hidden, 1048
 scrambling, 975
 stuffing, 1041, 1044
bitstream, *see* delta-sigma
BJT (bipolar junction transistor), 71ff
 active ballasting, 113, 113
 amplifier building blocks, 105ff
 as transconductance amplifier, 90
 base resistance, *see* BJT, r_{bb}
 base-emitter breakdown, 77n, 82, 238, 535, 815
 basic circuit topologies, 90
 basic circuits, 91
 beta, 72, 74g, 501, 502t, 504g
 capacitance, 74t, 113ff, 114, 130r, 548ff
 collector output resistance, 93n
 current noise, 483, 493g
 vs current, 484g
 vs frequency, 484g
 current ratio, 102g
 current sharing in, 112
 current source, 128r
Darlington, 109ff, 129r, 610, 752, 817, 1081
 beta vs current, 110g
 complementary, *see* Sziklai connection
 optocoupler, 845
 saturation, 109, 752, 752
Early effect, *see* Early effect
Ebers–Moll model, 90ff, 127r
 emitter ballast, *see* ballast
 emitter ballasting, 113, 113, 138, 146, 192, 201, 214, 495, 508
 emitter follower, *see* emitter follower
 emitter impedance of, 92
 emitter resistance
 intrinsic, 92–99, 122, 128r, 148
 not a real resistor, 481n
 gain-bandwidth product, 549g
 I_C vs V_{CE} , 92
 improved model, 90ff
 inductive load, 74
 LED driver, 76
 logic with, 123
low-noise, 501t
 challenge, 505ff
 replace with JFET, 500
 selecting, 500–505, 507
low-noise amplifier, *see also* amplifier, 495, 496, 498, 500, 505, 506
 challenge, 507g, 508t
low-noise design with, 492–509
 example, 495
low-noise dual, 502t
 manufacturing spread, 508g
noise, 481ff, 591, 592r
 from NF, 489–492
 measuring, 508
 model, 481, 488
 resistance, 494
 test circuit, 557
 vs JFET, 517
noise resistance, *see* noise resistance
 operating modes, 126r
 paralleling, 112
 pin labels, 126r
 pinouts, 72, 502
 polarities, 126r
 power, 106t
 pulse generator, 458, 459s
 r_{bb} , 481ff, 483g, 501, 502t, 503, 505ff, 535
 representative, 74t
 rules of thumb, 91, 127r
 saturation, 73ff, 81, 115, 123, 165n
 vs FET R_{on} , *see* MOSFET, R_{ON}
 saturation current, I_S , 91
 series connection of, 697
 simple model, 72
 limitations of, 90
 single-stage voltage gain, 93n, 98, 105n
 storage time, 458
 superbeta, 111, 252, 303t, 323, 326
 switch, 73ff, 91, 126, 127r
 Sziklai connection, 110ff, 111, 129r, 148, 207, 214n, 229, 600n, 610
 table of, 74t, 106t, 501, 502t
 terminal notation, 71
 transconductance, 126, 127r
 V_{BE} spread, 508g
 V_{BE} tempco, 92
 voltage noise, 481ff, 493g
 calculation (circuit example), 486
 charting, 493ff, 494, 495g, 504g
 figure of merit, 505n
 from i_n through R_s , 483
 vs r_{bb} , 483g
 vs current, 481–483g, 485, 486g
 vs frequency, 485, 486g, 504g, 519g
 vs power MOSFET and IGBT, 201, 202t, 208t
Black, Harold, *see also* feedback, 116, 118
 Blackman's impedance relation, 120
 Blackman-Harris, *see* window, sampling
 bleeder resistor, 211, 634
 blocking capacitor, *see* capacitor
 Blu-ray, 703n, 852, 992, 1135
 Bluetooth, 1053, 1061, 1077
BNC, *see* connector
 Bode plot, 247g, 281g, 280–285, 311g, 899, 961g, 963g
boost, *see* switchmode
bootstrap, 111ff
 cascode, in TIA, 550
 leakage cancellation, capacitor, 897
 of capacitor, 682, 683
 of collector load, 112
 of guard shield, 359, 548, 587
 of JFET drain, 343, 344
 of op-amp follower, 233
 of power supply, 359
 of TIA, 547, 550
 twin-T filter, 414
bounce, *see* switch
 boxcar integration, *see* bandwidth, narrowing
 branch
 you're sitting on, sawing off, 1091
breakdown, *see also* second breakdown, 627
 base-emitter, 82
 MOSFET gate, 199
brickwall, *see* filter
bridge, *see also* diode, *see also* rectifier
 ac drive, 946
 amplifier for, 306, 372n, 1070
 converter, 656, 659, 700r
 diode, 454, 612
 in oscillator, 431
 full, *see also* H-bridge, 655, 889, 1077, 1085
 half, 655
 inductance, 405
 measurement system, 945
 ratio metric, 884
 rectifier, 630, 699r, 805
 active, 634n
 dual-voltage input, 660
 resistive, 297, 608, 945, 1070
 strain gauge, 347, 364, 941
 switch configuration, 206, 655
 Wheatstone, 123
 Wien, 436ff, 437, 438, 452t, 847
brownout, 1064
buck, *see* switchmode
buffer
 logic, 23, 218t
 ring, 747n
 unity-gain, 275, 311, 588, 843
bulk capacitor, *see* capacitor, storage
burn-in, 683
burst mode, 643n
bus, *see also* computer, 1029t
 multidrop, 990
 point-to-point, 990

- Butterworth, *see* filter
 byte, 706, 990
- cable
 cat-5, 352, 380, 381, 864, 1117
 cat-6, 352, 864
 coax, 380, **1116–1122**
 counterwound helix, 1130p, 1130s
 driving with logic, 859, 859s, 860, 860s, 861s, 862, 862s, 863, 863s, 864s, **858–864**, 1120
 driving with video, 862
 pre-emphasis, 864
 reflections, 859, 859s, 860, 860s, 861s, 862, 862s, 863, 863s, 864s, **858–864**, 1116g, 1118, 1119s
 terminating, 859, 859s, 860, 860s, 861s, 862, 862s, 863, 863s, 864s, **858–864**, **1117ff**
 video, 1140
 differential, **864–870**
 digital signals through, **856ff**, 877r
 driving, **856ff**, 877r
 equalization, 864
 pre-emphasis, 864
 shielded, *see also* cable, coax, 587
 STP, 864
 television, 1134
 terminated
 capacitance disappears, 860
 termination
 back, 739, **862**, **1118**, 1122
 double-ended, **861**, 1122
 far end, **860**
 series, 739, **862**, **1118**
 twisted-pair, **864–870**
 UTP, 352, 864
 velocity factor, 1117
 calculus, 1099
 calibration
 data in EEPROM, 1067
 CALL, 996
 CAN bus, *see also* computer, data bus, 1043, **1043ff**, 1044, 1061, 1081
 isolated, **1045**
 levels, 1044
 capacitance, *see also* BJT; FET; JFET
 bootstrapped, 542, 548
 CMOS switch, **178ff**
 disappears in terminated cable, 860, 1116
 effective power-dissipation, 754
 equivalent (switching), 719
 feedback, *see also* Miller effect, 113
 gate, 197g, **197**
 isolation, 843, 849
 JFET, 153, 157, 164, 170
 JFET switch, **178ff**
 junction, 114, 130r, 153, 157
- MOSFET, 164, **165**, 187, 188–191t, 197g, **197ff**, 205
 multiplier, 537, 557, 578, 579g
 of analog switch, 178–181
 of current source, 150n
 of op-amp, 532
 power-dissipation, 719, 719g
 sensor, 1086
 transmission line, **1116ff**
 trimmer, *see* trimmer
- capacitive
 coupling, 581
 isolator, 586
 capacitive load, *see* load
 capacitor, **18ff**, 20p, 68r
 active, 645n
 air, 326
 as microphone, 682n
 blocking, 19, 43, 69r
 in H-bridge, 659
 bootstrap to suppress leakage, 682, 683
 bulk, *see* capacitor, storage
 bypass, 19, 54, 69r, 222, 758, 759, 857, 1056
 resonances, 857n
 ceramic, 438
 ESR and stability, 561, 617n
 compensation, 283, 307, 308, 700r
 current through, 19, 46
 dielectric absorption, 28, **300**, 301g, 326, 388r, 422, 915, 920
 digital, 1082
 double-layer, *see* AoE 2nd ed., pp 820, 934, 689
 electrolytic, 20p, 232n, 301g, 393, 579, 599, 633ff, 661, 690t, 856
 dc coupling eliminates, 496
 energy density
 vs battery, 690g
 energy storage
 vs battery, 690t
 energy storage in, 19, 671, 688
 ESL, 28, 646
 ESR, 28, 561, 599n, 611, 646, 671, 689
 filter attenuation, effect on, 393g
 increased ripple from, 639n
 film, 19, 20p, 279, 300, 326, 422, 438, 631p
 flying
 driving MOSFETs, 822, 847
 in power conversion, 184, **638ff**
 HV discharge circuit, 211
 international notation, 5n
 leakage, 260, 300, 682, 683, 897
 bootstrap cure, 897
 leakage compensation, 298, 298
 Miller, 282, 283, 597
 multiplier, *see* capacitance
 mylar, 19, 20p
 non-ideal, 28, 388
 in filter, 392
- parallel, 21
 piezoelectric effect in, 682n
 power density
 vs battery, 690g
 powerline rated, 631, 631p, 664p, 668, 671
 discharge resistor, 632
- RC circuit, **21ff**
 reactance of, 42, **45**, 49g
 reactive current, 47g
 ripple current, *see also* current, 634, 635s, 659
 series, 21
 speedup, 74n, 808s
 storage, 32, 55, 69r, 665, 699r
 ripple current, 634
 storage, in power supply, 633
 super, 689
 surface-mount, 20p, 65, 66p, 758, 759
 switched, *see* filter, switched-capacitor
 switched, filter, **415ff**, 436
 timing, 55, 69r
 types, 20
 variable, 64
 “X” and “Y” types, *see* capacitor, powerline rated
- CAPZero, 632
 CAS, 1020
 cascode, 102, 114, **115**, **146**, **148ff**, 345, 369, 377, 502, 534, 544, 548, 549, 550
 folded, **149**, 377, 498, 537
 in TIA, 548
 inverted, *see* cascode, folded
 regulated (RGC), 551, 552
 regulator, for HV, 693
 series, for HV, 697
 catalogs, 1153
 cathode
 ray tube (CRT), 1142
 CD audio, 902
 CDMA, 975
 CDR, 971
 ceramic resonator, 450, 1063
 cesium, *see* oscillator, atomic
 CFB, *see* op-amp, current feedback
 chain rule, 1100
 charge
 injection
 in autozero op-amp, 334, 339
 integrator (Coulomb counter), *see also* AoE
 2nd ed., pp 640–643, 933
 MOSFET gate, 197g, 198s, 221r
 pump, *see also* capacitor, flying, *see also* switchmode, 175n, 183, 638, 699r, 872
 redistribution
 ADC, 909, 950n
 charge injection
 absence of, 843
 in ADC, 911

- in analog switch, 176t, **180**, 181g, 300, 947, 948n
 vs R_{ON} , 182g
 in integrator, 918
 in sample-and-hold, 256g
 in switched-capacitor filter, 418
 charge transfer, *see* charge injection
 Chebyshev, *see* filter
 choke, *see also* inductor, 29
 common-mode, 585
 chopper, *see* op-amp
 chrominance, *see* video, composite
 cigar, *see* cigar
 circuit
 BJT, basic, 90, 91
 breaker, 630
 diagram
 how to draw, **1101ff**
 integrated, *see* IC
 linear, 14
 loading, *see* loading
 parallel, 2
RC
 discharge waveform, 21g
 Thévenin simplification, 23
 resistor
 shortcuts, 6
 resonant, **52ff**
 series, 2
 parallel, 5
 resistor, 5
 clamp, *see also* SCR, 257
 active, 257
 active reset, in SMPS, 657
 diode, 36
 input transient, in SMPS, 669
 op-amp, 912, 913
 power supply, 692
 Clapp, *see* oscillator
 clearance, 663, 663
 clipping, 81
 clock
 and data recovery (CDR), 971
 feedthrough, 417
 generation with PLL, 972
 inputs and hysteresis, 808
 real-time, 1061, 1084
 recovery, 1037
 skew, 757, 757, 759
 clock skew, *see also* logic
 CMOS, *see* analog switch, *see* logic, *see* op-amp, *see* oscillator
 CMRR, 103, 388r, 515, 583
 and source impedance, 365
 at high-frequency, preserving, 359
 differential amplifier, 376
 ground-loop isolation, 583
 instrumentation amplifier, 364, 364g, 367
 vs frequency, 364
 trim, 356, 361, 515
 coax, *see* cable
 digital signals through, 1116ff
 driving, 1116ff
 codec, 1140n
 coil driver, precision, **897**, 898
 cold atoms, 365
 Coldfire, *see* microcontroller
 collector, *see also* BJT
 open, *see* open collector
 saturation, 73ff
 color burst, *see* video, composite
 command bit, *see* computer, programmed IO
 command register, *see* computer, programmed IO
 common-mode, *see also* amplifier, *see also* choke, *see also* comparator, *see also* op-amp, *see also* transmission line, differential
 pickup, *see also* CMRR, 583
 torture test, 866s, 869s
 common-mode rejection ratio, *see* CMRR
 compact disc (CD), 992, 1131
 Compact Flash, 1061
 comparator, *see also* Schmitt trigger, 23, 129r, 173, 173, 236, 267, 289r, 700r, 812t, 813t, **809–817**, 876r, 1061, 1081
 antisaturation circuit, 812
 cautions, 816
 digital magnitude, 728, 728
 driving logic from, 806ff
 hysteresis
 internal, 815
 input
 common-mode range, 812
 input characteristics, **812ff**
 input current, 814, 814g
 input stage, 814
 output current, 811, 811g
 output stage, 811
 output swing, 810
 response time, 816g
 saturation voltage, 811g
 schematic, LM393, 270
 speed, 815
 supply voltage, 815
 voltage
 differential, 815
 offset, 812
 window, *see also* AoE 2nd ed., p 669, 429
 with hysteresis, 237
 without hysteresis, 237
 zero-crossing, *see* zero-crossing
 compensation
 active
 of op-amp phase error, 314, 315g, 315t
 dominant-pole, **282ff**
 of transimpedance amplifier (TIA), 537, **539ff**, 540–542g, 545
 pole-zero, 284, 545
 complex
 conjugate, 1098
 numbers, **1097**
 plane, 1098
 compliance, *see also* current source, 8
 components
 best avoided, 63p
 confusing markings, 65p
 itty-bitty, 65p, 269, 627p, 712n, 821n, 500, 601, 603, 617, 714, 715, 715p, 720, 769, 772, 782, 785, 786, 788, 789r
 where to buy, 1150
 composite amplifier, *see* amplifier, composite
 composite video, *see* video, composite
 compression, 1136
 artifacts, 1137n
 bitrate reduction, 1137
 lossless, 1137
 lossy, 1137
 computer, *see also* microcontroller, 1053
 architecture, 990–993
 Harvard, 991
 von Neumann, 991
 assembly language, 993, 1087
 BASIC, 1087
 block diagram, 991
 bus-oriented, 991
 C/C++, 1087
 CPU, 990
 data bus, 990, 992, 1029t, 1049r
 1-wire, 1035, 1036, 1082
 2-wire, 1061
 ADDRESS, 992, 997
 ATA, 1027, 1062
 bidirectional, 1001
 bridge, 1089
 CAN bus, 1043, **1043ff**, 1044, 1045, 1050r, 1061
 contention, 721
 control lines, 992
 DATA, 992, 997
 differential, 1031n
 EISA, 1027n
 eSATA, 1028, 1037, 1050r
 Ethernet, **1045ff**, 1050r, 1053, 1061
 Fastbus, 1027n
 FireWire, 1042, 1050r
 Firewire, 871n, 992, 1027
 Front Side, 990n
 Futurebus, 1027n
 GPIB, 1031, 1050r
 I²C, **1034**, **1034ff**, 1035, 1036, 1051r, 1053, 1061, 1095r
 I²C vs SPI, 1035
 IDE, 1027, 1050r, 1062
 IEEE-488, 1031

- ISA, 990n
 JTAG, 1036, *1036*, 1051r
 MicroChannel, 1027n
 Multibus, 1027n
 multidrop, *1014*, 1027
 NuBus, 1027n
 overview, 1027
 parallel, 1027, 1028, 1050r
 PATA, 1027, 1031, 1050r
 PC104/ISA, 992, 1012, 1027, 1044, 1049r
 PCI, 990n, 992, 1027, 1030, 1050r, 1053, 1061
 PCIe, 990n, 992, 1027, 1030, 1037, 1041, 1044, 1050r, 1053, 1061
 PCMCIA, 1044, 1053, 1061
 PLD address decoder, *1000*
 point-to-point, 1027
 printer port (Centronics), 1031
 Q-bus, 1027n
 read cycle, *see* memory
 RS-232, 771, 804, 1027, 1051r
 SAS, 1027, 1028, 1037, 1050r
 SATA, 1027, 1031, 1037, 1041, 1050r, 1053, 1062
 SCSI, 1031
 serial, 1027, **1032–1046**
 signals, 1013t, **997–1013**
 signals, summary of, 1012
 SPI, *1032*, **1032ff**, 1033, 1036, 1051r, 1053, 1061, 1095r
 SPI vs I²C, 1035
 STD bus, 1027n
 STROBE, 997
 Unibus, 990n, 1027n
 USB, 871n, 992, 1027, 1042, *1042*, 1044, 1050r, 1053, 1059, 1061, 1062
 VAX BI, 1027n
 write cycle, *see* memory
 direct memory access (DMA), 1010, 1050r
 flags, 990, 1049r
 IBM60, 1n
 instruction, 990
 instruction decoder, 990, 1049r
 instruction set, 1049r
 addressing modes, 994
 argument, 993
 jump, 996
 POP, 995
 PUSH, 995
 subroutine, 996, 997
 x86, simplified, 994t, **993–997**
 interrupt, **1005–1010**, 1050r
 acknowledgment, 1009
 autovectored, 1009
 handler, 1006, 1064, 1096r
 hardware, *1006*
 mask, 1010
 polling, 1008
 shared, 1008
 software, 1010
 Java, 1088
 keyboard bus interface, 1002, 1003, 1005, *1006*
 machine language, 993
 mass memory, 991
 memory, *see also* memory, 991, **1014–1027**, 1051r, 1061
 cache, 991, 1049r
 read cycle, *1017*, *1019*, *1021*, *1022*
 SD, 1061
 write cycle, *1017*, *1019*, *1021*, *1022*
 multidrop bus, *1014*
 number storage in memory, 1048
 object code, 993, 996
 PC104, 997p, 1013, *1014*, 1015p
 signals, summary of, 1012
 port, 992
 program
 counter, 990, 1049r
 example, 996
 programmed IO, **998–1005**
 command bit, 1050r
 command register, 1004
 data in, 1001
 data out, 998, 999
 read cycle, *1001*, 1049r
 status bit, *1002*, 1050r
 status register, 1002
 write cycle, 998, 1049r
 progress in, 990p
 pseudo-op, 996
 Python, 1088
 real-time IO, 992
 register, 990, 994, 1049r
 SBC, 997p, 1013
 serial port, 1038
 software interrupt, 1010
 source code, 996
 stack, 995
 pointer, 990, 995, 1049r
 subroutine, 996, 997
 terminology, 989
 UART, *see* UART
 word, 990
 xy vector display, 999, 999
 block diagram, *1000*
 conductance, **6**
 conduction
 angle, 613, 631, 633, 635, 662s
 continuous mode, 637n, 642, 644ff
 discontinuous mode, 637n, 642, 645, 666
 confusion central, 65p
 connector
 audio, 62p
 avoid these, 63p
 banana, 61p
 BNC, 56, 59, 62p, 264, 1116
 insulated, 274, 275, 555, 583, 805
 card-edge, 61
 circular, 61p
 DIN, 61p
 DisplayPort, 1145
 DVI, 1145
 HDMI, 1144
 Lemo, 61, 62p
 MHV, 62p
 microphone, 61p
 Microtech EP-7S, 61p
 miniDIN, 61p, 1144
 MS, 61p
 multipin, 61
 phono, 63p
 photographs of, 60–62p, 1144p
 pin jack, 61p
 RCA, 62p, 1143
 rectangular, 60p
 RF and shielded, 62p
 RJ45, 1064
 SC (fiber), 62p
 shielded-cable, 59
 SHV, 62p
 SMA, 62p
 SMB, 62p
 ST (fiber), 62p, 841p
 Supericon, 61p
 TNC, 62p
 type N, 62p
 type-F, 63p
 UHF, 62, 63p
 video, **1143ff**, 1144p
 XLR, 61, 62p, 348
 continuous mode, *see* conduction, *see also* switchmode
 control
 bang–bang, 608, 644n, 645, 645, 649, 650, 700r, 1070
 proportional, 1070
 control loop
 block diagram, *1069*
 PID, 1069
 converter, *see also* ADC, *see also* DAC, *see also* power, 30
 AD/DA
 errors, 880
 linearity, **899**
 performance parameters, 879–880, 985
 power, *see* power supply, *see* switchmode,
 see voltage regulator
 boost, *see also* switchmode, 30
 buck, *see also* switchmode, 30
 charge-pump, 183
 flying-capacitor, 183
 time-to-amplitude, *see also* AoE 2nd ed., p 1035, 914
 V to f, 912
 nonlinearity, 914g
 correlated double sampling, 553, 571n

- coulomb, *see also* charge, integrator, 2, 18
 counter, 933
 counter, *see also* logic, 733
 timing with, 465
 cow
 spherical, 804
 cPLD, *see* programmable logic device (PLD)
 creepage, 663, 663, 664
 crest factor, 568, 981
 crossover distortion, *see* distortion
 crossover, input, *see* op-amp
 crosstalk, 581, 588
 crowbar, *see also* voltage regulator, 598
 overvoltage, 598, 672, **690ff**, 691, 700r, 702r
 crystal, *see* oscillator
 Ćuk converter, *see* switchmode
 CUPL, *see* programmable logic device (PLD)
 current, **1**, 68r
 class-A, 754, 1073
 comparator input, 814, 814g
 comparator output, 811, 811g
 conveyor, 99
 critical, in SMPS, *see* switchmode
 dark, 537n, 1059
 defined, 2
 differential drive, 865
 discontinuity
 in switchmode converters, 649, 651
 divider, 698
 dynamic, 164, 186, 186, 793
 of digital logic, 186, 186, 719
 feedback, *see* feedback
 gate leakage, 163
 impact-ionization, 164
 input
 of digital logic, 795
 of instrumentation amplifier, 362
 of op-amp, 244
 inrush, 637, 651, 661, 668
 Junction leakage, 253
 junction leakage, 70r, 91, 109
 Kirchhoff's current law, 2
 leakage, *see also* analog switch, FET, *see also* capacitor, *see also* FET, gate current, *see also* FET, leakage, *see also* JFET, gate current, *see also* MOSFET, gate leakage, *see also* op-amp, input current, 163g, 327 cancelling, 894
 CMOS logic, 463, 466, 795
 diode, 70r, 160, 294, 294n, 634
 FET, 163
 floating gate, 1023
 gold doping, 458
 guarding, 572, 573n, 587
 JFET, 163
 measuring, 299n
 MOSFET, 163
 PCB, 554n
 photodiode, 841, 877r
 PIN diode, 497, 500
 ridiculously low, 1023, 1025
 solid-state relay, 1062
 specifications too conservative, 296, 388r, 1055n
 limiting, 286, 351, 597, 700r, 823, 824
 foldback, 286, 693, 694, 694g, 823, 824, 824g
 of outboard pass transistor, 695
 load-sensing, 277
 loop, 1038, 1084
 mirror, *see* current mirror
 mode, *see* switchmode
 noise, *see* noise
 probe, 1161
 pulsation in SMPS, 650, 651
 pulsation in switchmode converters, 649
 quiescent, 83
 BJT, 84ff
 blocking capacitor preserves, 182
 JFET, 145, 156
 lateral MOSFET, 215
 of logic families, 719
 stabilized with emitter resistor, 96
 reactive, 41
 ripple, 634, 635s
 in boost converter, 647
 in bridge converter, 659
 in buck converter, 644
 in storage capacitor, 634
 in zener bias, 598
 saturation, 132, 165n
 sensing, 278, 349, 350, 365, 754, 760
 shoot-through, 186, 186, 222, 660, 754, 760, 760g, 856, 942n
 shunt, 277, 365, 944, 944
 source, *see* current source
 spy, 754, 754
 steering, *see also* DAC
 sawtooth generator, 917
 suppression, 573
 transfer ratio, 844, 1062
 transformer, 944, 944
 transient
 output-stage, 856
 current limiting, *see also* power supply, *see also* voltage regulator, linear, *see also* voltage regulator
 current mirror, 99, 100, **101ff**, 123, 124, 128r, 146, 369, 431, 960
 active load, 105, 153, 496, 544
 compliance, 101, 104
 Early effect in, 101
 fix, 102, 102, 148
 IC, 622
 input offset adjust, 244
 VCO programming, 960
 Wilson, 102, 102, 146, 546
 current source, 8, **85ff**, 431, **620ff**, 623g, 702r
 2-terminal, 622
 3-terminal regulator as, 620, 620, 621g
 bandwidth of, 254
 bipolarity, *see also* current source, Howland, 229, 230, 894, 896
 BJT, 85, 87, 91, 146, 534
 compliance, 8, 27, 28, 86, 895
 deficiencies of, 87
 depletion-mode
 FET as, 211, 622, 623g, 696
 difference amplifier as, 350, 351
 discrete, 622
 floating, 895, 894–897
 high voltage, 622, 696
 high-voltage floating, 897
 Howland, 229, 230
 IC, 621, 622g
 instrumentation amplifier as, 367
 JFET, 142, 623g
 JFET and BJT compared, 145
 nanoamp
 programmable wide-compliance, 894, 896
 pulsed, 555
 noise of, **487ff**
 op-amp, **228–230**, 242, 254, 344, 367, 622, 623, 895
 oscillation in, 442
 output resistance, 93n
 precision, 351, 367, **897**, 898
 resistor as, 85
 slew rate of, 367
 symbols, 9
 transistor, *see* current source, BJT/JFET/depletion-mode
 current transformer, *see* transformer
 curve tracer, 1115
 cut-and-try, 597, 835, 963
 DAC, *see also* converter, AD/DA, 879, **881–900**, 1053, 1061, 1065, 1081, 1095r
 1-bit, *see* delta-sigma
 application examples, **891–899**, 985r
 audio, 939t
 charge redistribution, 904, 909, 909, 911
 choosing, 891, 986r
 code-change glitch, 892
 current-steering, 883, **883–886**, 985r
 generating voltage output from, 885, **885**
 delta-sigma, *see* delta-sigma
 exemplary, six, 886, 887, 889t
 for DDS, 1065
 for offset correction, 949
 for zero correction, 949
 frequency-to-voltage, 890, 985r
 introduction, 879–881
 multiplying, 413, **884**, 894t, 985r
 PWM as, 888, 888, 890, 985r
 PWM to, converter, 889

- R–2R*, **882**, 883, 985r
 resistor string, **881**, 882, 985r
 selected, 893t
 switched-capacitor, 904, 909
 tables, 889t, 893, 894t
 types, 985r
 video, 885, 1086
- Darlington, *see* BJT
 photo, 842
- data bus, *see* bus, *see* computer
 data-acquisition system, *see* ADC
 datasheet
 too big, 1063n
 dB, 15ff, 68r, 351
 desert island, 15
 dB per octave, 51–52
 dB\$, 15n
 dBm, 15
 dc
 blocking capacitor, 43
 power switching, 202
 restoration, 37
 supply splitter, 262
 dc-dc converter, *see* power supply, *see also* switchmode
 DCE, 1038
 DDR, 1021
 DDR2, 1021
 DDR3, 1021
 DDR4, 1021
 DDS, *see also* oscillator, 1066, 1067
 phase control, 1068
 debouncer, *see also* switch, 1064
 debugging
 microcontroller, in-circuit, 1092
 decibel, *see* dB
 decoder, *see* logic
 decompensated, *see* op-amp
 degeneration, *see* emitter, *see* source
 delay equalizer, 415
 delay line
 lumped element, 1126, 1128p, 1129
 impedance of, 1127
 transmission line, 1128p, 1130s
 delay time, of filter, 400
 delta-sigma, 902, 987r
 20-bit ADC, 934, 934
 24-bit ADC, 934, 936, 936, 937, 937
 ADC, 935t, **922–941**
 digital filter in, 924, 926
 micropower, 941
 application examples, **932ff**
 audio ADC, 902n, 937t
 block diagram, 924
 charge integrator, 933
 DAC, 888, **930**, 931, 938, 985r
 demystifying, **923–930**
 dynamic range, 925
 vs OSR and *m*, 929g
- ENO, 928, 929g
 even simpler, 932
 fast multichannel IC, 955, 956
 idle tones, 931, **932**, 932t
 mitigating, 932
 simulation, 933g
 “industrial” ADC, 936, 937
 magic in the modulator, 927
 microcontroller, implemented with, 932, 933
 modulator, 924, 925
 higher order, 928, 929
 monotonicity, 931
 noise shaping, 927g, **927ff**
 powerline rejection, 953–955, 955g
 pro-audio ADC, **936**, 940
 pros and cons, **931ff**
 simplest, 922
 simulation, 929g, 930g, **928–930**
 spectrum, 930g
 suntan monitor, 922ff
 the paradox, 924
 time delay, 931
 vs the competition, **938**
- DeMorgan’s theorem, 713
 depletion mode, *see* current source, *see also* MOSFET
 derivative, 1099
 desaturation protection, 847, 847
 desensitivity, 117, 118
 design review, 1059
 Designs by the masters
 instrumentation amplifier, 359
 Keysight’s multislope converters, 919, 918–922
 nanoamp programmable current source, 896
 paralleling MOSFETs, 213, 214
 powerline SMPS, 595p, 667s, 665–672
 precision DMM, **342ff**
 SR560 preamp, 512ff, 514
 desoldering station
 favorite, 1152
 detector
 AM, 970
 demodulation, 969
 FM, 969
 homodyne, 970
 optical, *see* optoelectronics
 phase, *see* PLL
 quadrature FM, 969
 device programmer, 769
 diac, 428
 diagram, ugly, **1102**
 Dicke switch, 577
 dielectric
 absorption, *see also* capacitor, **300**, 301g
 constant, 18, 1116
 isolation, 175
 difference amplifier, *see* amplifier, *see also* op-amp
 differential, *see also* amplifier
- cable, **864–870**
 logic signal, 705n
 output, creating, 372, 373
 pseudo, 583, 947
 signal, 347ff
- differential amplifier, *see* amplifier
 configurations, 376–378
- differentiation, 1099
- differentiator
 bridged, 415
 op-amp, 260
RC, 25, 26s, 51
- digital, *see also* logic
 conquest over analog, history of, 703, 703n
 filtering, 419
 measurement, 140g
 meets analog, **879–988**
 multimeter, 10
 potentiometer, 63, 184
 signal processing (DSP), **418ff**
 sampling, 419
- television
 broadcast, 1138
 cable, 1138
 satellite, 1139
 spectrum, 1136s
 vs analog, 703
- digital-to-analog, *see* DAC
- DIN
 rail mount, 686
- diode, *see also* rectifier, 12, 31, **31ff**, 70r
 AND gate, 711
 as log converter, 37
 back, *see also* diode, tunnel, *see* AoE 2nd
 ed., pp 49, 891, 904
 bridge, 431
 catch, 642
 clamp, 36
 current-regulator, 143g, 623g
 drop compensation, 35
 fast recovery, 671
 fault protection, 606, 607, 619
 forward current, 294, 295g
 forward drop, 31
 freewheeling, 642
 gate, 36
I vs *V*, 92
 inductive clamp, 38
 input protection, 37, 37, 159, 160, 210, 266,
 269, 294, 362, 362, 532, **804**
 JFET as, 294
- laser, *see* laser diode
 leakage current, *see* current, leakage
 LED, *see* optoelectronics
 limiter, 37
 MOSFET body, 199
 operating point, 1112
 photo, 537n, 539, **841**, 841p, 842
 amplifier, 547, 548

- wideband amplifier, 540
PIN, 837p
protection array, 805
representative, 32t
reverse current, *see* current, leakage
reverse recovery, 634, 635n, 670, 671
Schottky, 32t, 35, 199n, 222, 608, 634, 642, 643, 645–649, 651, 655, 657, 665, 666, 671, 696, 717, 757, 792, 912, 913
protection with, *see* input, *see also* op-amp, input protection
suppression, 75
tunnel, 7, 1113
varactor, 64, 435, 440, 441, 960, 969, 971
capacitance vs voltage, 441g
zener, *see also* voltage reference, 12ff, 82, 199, 670, 674, 696–698, 701
3-terminal, 680
as voltage regulator, 595
biasing, 675
buried, 546
compensated, 674
dissipation, 82
drift, 675
dynamic resistance, 13, 675g
for crowbar, 690
IC, 676ff
low voltage, 13g
noise, 676n
programmable, 677t, 680
tempco, 675g
the astonishing LTZ1000, 675
DIP (dual in-line package), *see* IC, packages
direct digital synthesis, *see* oscillator, DDS
direct memory access, *see* computer
discharge
curves, of battery, 687g
of high-voltage supply, 211
RC, 21
discontinued parts, 273 (box)
discontinuous mode, *see* conduction, *see also* switchmode
display
LCD
interface timing, 1028
xy vector
interface, 999, 999
display devices, *see* optoelectronics
DisplayPort, *see* connector
distortion, *see also* op-amp, distortion
barn-roof, 95, 95s
crossover, 286, 309, 311
effect of feedback, 235s
in push-pull follower, 107
of differential amplifier, 386, 386g
of filtered sinewave, 436
of modified sinewave, 674
of op-amp, 329ff, 331, 332g
rail-to-rail, 318
- of phase-shift oscillator, 439
of photoconductive cell, 437
of switched-capacitor sinewave, 436
of Wien-bridge oscillator, 437, 438
test circuit, 332
ultra-low, oscillator, 437, 438
dithering, 382n, 636s, 658t, 968, 969
divider
Kelvin-Varley, *see* AoE 2nd ed., p 1025
voltage, 7
DMM, 10, 1152
Agilent's accurate, 342ff
block diagram, 343
current sink, 344
front end, 343, 344
gain block, 345
ranging, 345
favorites, 1152
Dobkin, Bob, 604 (box), 679
dogs, 63p
dominant pole
compensation, 282ff
double buffering, 1000
doughnut, 29
DPCP, 1145
drain, *see also* FET, *see also* JFET, *see also* MOSFET
open, *see* open-drain
output impedance, *see* JFET, output conductance, *see* JFET, output resistance
DRAM, *see* computer, *see* memory, dynamic dry switching, *see* switch
DSL, 1141
DTE, 1038
DTL, *see* logic
dual-slope
conversion, *see* ADC
dual-tracking, *see* voltage regulator
duty cycle, 643
duty-cycle
limiting, 465
DVD, 703n, 852, 992, 1135
DVI, *see also* connector, 1062
dynamic RAM, *see* memory
dynamic range
of delta-sigma converter, 925
of numbers, 1048
of switched-capacitor filters, 418
vs precision, 292
- Early effect, 92, 93n, 99, 99n, 101g, 127r, 151n
configurations that avoid, 102, 127r, 148
in current mirror, 101
Early voltage, *see* voltage, 502
Ebers-Moll model, *see also* BJT, 90ff
ECL, *see* logic
Eden
garden of, 549
edge
detector, 26
leading, 25
trailing, 25
triggered, 458ff, 957, 1010
flip-flop, *see* logic
EEPOT, *see also* potentiometer, 63, 1067
EEPROM, *see* memory
egg
Easter, *see* if you can find all eight
electrical engineer
view of biology, 805
electrical tape, 63p
electrolytic capacitor, *see* capacitor
electromagnetic interference, *see* EMI
electrometer, 10n, 259, 297, 570ff
electromotive force, *see* EMF
electrostatic discharge, *see* ESD
elliptic filter, *see* filter
EMF, 2
back, 28
EMI, 649, 668
in instrumentation amplifiers, 365
emitter, *see also* BJT, *see also* optoelectronics
degeneration, 88, 96, 98, 116, 126r, 128, 129r, 308, 502
emitter ballast resistor, *see* BJT, *see* resistor
emitter follower, *see also* BJT, 79, 79–85, 91, 128r
ability to source/sink, 81
ac coupled, 84
as voltage regulator, 82
base-emitter breakdown, 77n
biasing, 83
canceling offset, 85, 87
current flow in, 81
example, 84
gain, 93
impedances of, 80
JFET current-sink pulldown, 144
noise of, 487ff
output impedance, 84
output impedance of, 94
push-pull, 81, 106–108
revisited (Ebers-Moll), 93
with split supplies, 84
 e_n , *see* noise, density, voltage, *see* noise
 e_nC , *see* transimpedance amplifier
encoder, *see also* logic
flash, 903
Gray code, 708
keyboard, 803
logic, 727
quadrature, 844p
rotary, 844p, 852, 1066
video, 1030, 1030
- energy
density
battery vs capacitor, 690g
in capacitor, 19

- in inductor, 28
 storage
 battery vs capacitor, 690t
 ENOB (effective number of bits), 900, 905t, 928, 929g, 985r
 envelope, 54, 55, 55g, 55s, 970, 973, 974, 978, 979, 1163
 EPROM, *see* memory
 equalization, *see also* amplifier, 40g, 223, 284, 380, 381, 864, 870, 870, 871s, 873g
 equivalent series inductance, *see* capacitor, *see also* resistor
 equivalent series resistance, *see* capacitor
 error
 budget, 293, 295–299, 307, 388r
 component, 299, 388r
 eSATA, *see* computer, data bus
 ESD, *see also* human body model, *see also* spike, 200, 200t, 804
 input protection, 258, 362
 ESL, *see* capacitor, *see* resistor
 ESR, *see* capacitor
 Ethernet, *see also* computer, data bus, 867, 992, 1027, 1041, **1045ff**, 1061, 1064, 1081, 1089, 1095r
 3-level signaling in, 1040n, 1046
 4b/5b coding in, 1040n, 1046
 8b/10b coding in, 1041, 1046
 Manchester coding in, 1040
 power over (PoE), 1046n
 Euler, Leonhard, 1098
 excluded state, *see* logic
 exclusive-OR, *see* logic, gates
 eye diagram, 870, 870, 871, 872s, 975, 988r, 1027, 1028s

 failure
 pattern sensitive, 857
 fan, *see also* AoE 2nd ed., p 858, 627
 fanout, *see* logic
 farad, 18
 feature size
 scaling, 793n
 feedback, **115ff**, 130r, **223ff**
 BJT examples, 121
 Blackman's impedance relation, 120
 closed-loop gain, 117
 compensation, 120
 current, *see also* op-amp, 118–120, 150, 308, 378, 513, 521, 524t, 527, 544, 593
 effect on amplifier circuits, **117ff**
 effect on input impedance, 118
 effect on output impedance, 119
 gain equation, 116
 improved frequency response, 118
 in PLL, 960, 961
 loading by the feedback network, 120
 nonlinear, 276
 nonlinear control, 1075

 output-current sensing, 120
 PID, 1069, **1069**, 1074, 1077
 circuit, **1075**
 convergence, 1076g
 tuning, 1069, 1074
 predictability of gain, 117
 series, 118
 shunt, 119
 split, 263, 286, **913**
 stability, 120
 in switchmode converters, 650
 with inductive load, 899
 ferrite, 29, 29p, 51, 579, 581, 584, 585, 655, 670
 bead, 51, 212, 366, 582, 669–672, 696–698, 921
 FET, *see also* JFET, MOSFET, 115, **131ff**
 analog switch, *see* analog switch
 basic circuits, 140
 capacitance, 132, 148, 163, 164, 170, **178**, 187, 188–191t, 192ff, 194, **197ff**, 202t, 204, 206t, 207, 222, 511, 516t, 662, 670
 depletion-mode
 as current source, *see also* current source, 622
 drain characteristics, 137g, **137**, 139g
 dynamic gate current, 164
 enhancement and depletion, 135, 219r
 family tree, 134, 136
 gate current, **163**, 220r
 gate drive, 137
 gate leakage current, 163, 303
 G_{\max} , 141t
 interdigitation, 140
 JFET and MOSFET, 134
 leakage, 530
 circuit cure for, 259ff
 linear region, 137, 137g, 220r
 linear switch, *see* analog switch
 manufacturing spread, 140g, 138–140, 145g, 157, 158, 169, 169g
 matching, 139
 operating regions, 219r
 polarities, 131, 136, 219r
 probe, 810p
 quadratic region, 132, 137, 137g, 138, 147, **165ff**
 resistive region, 132
 saturation current, I_{DSS} , 136, 139g, 361
 saturation region, 132, 137g, **137**, 147, **165ff**, 219r
 similarity to BJT, 132
 square law, 137ff, 165
 subthreshold region, 138, 139g, 166, 167g, 168, 220r
 switch, 132, **171**, 220r
 tempco of I_D , 138g, 138n
 terminal nomenclature, **131**
- threshold voltage (V_{th}), 136n, 137ff, 137, 138g, 147
 transconductance (g_m), 132, 141t, **146**, 219r
 transfer characteristics, 135g, 137g, 139g, 142g
 types, 134
 $V-I$ curves, 132, 133g
 V_{GS} spread, 140g
 FEXT (far-end crosstalk), 581
 FFT, 422, 560s
 fiber optics, **852ff**, 853p, 877r
 integrated transceiver, 853p, 855, 856
 ST/SC, 853p, 855
 TOSLINK (EIAJ), 852, 853, 853p, 854s
 Versatile Link, 853p, 854
 field-effect transistor, *see* FET
 FIFO, *see* logic
 filter
 active, **396–399**, **405–415**, 423r
 bandpass, 411ff
 lowpass, 241, 400ff
 Sallen and Key, 242g
 universal, 416, 417, 417, 418
 allpass, 415
 analog FIR, 983
 anti-alias, 395, 901ff
 attenuation
 degraded by ESR, 393g
 bandpass
 noise bandwidth, 564t, 565g
 Bessel, 402g, 403, 409g, 423r
 VCVS, 408
 biquad, 411, 423r
 brickwall, 391g, 477, 902
 equivalent bandwidth, 477, 561, **561**, **563ff**
 bridged differentiator, 415
 Butterworth, 401, 401, 402g, 409g, 423r, 902
 LC, **1109ff**, 1110t
 VCVS, 408
 Cauer, 402
 characteristics, 400, 401g, 423r
 Chebyshev, 401, 402g, 409g, 423r
 phase and amplitude, 400g
 VCVS, 408
 vs RC , 396g
 comparison, 402g
 continuous-time, 397, 406, 423r
 delay equalizer, 415
 delay time, 400
 digital, 419ff, 424r
 in delta-sigma, 924, 926
 of PRBS, 979
 response, 421g
 discrete-time, 418, 423r
 eco-friendly, 1073
 effect of component tolerances, 402g
 effect of non-ideal capacitors, 392

- electrically tunable, 412
 elliptic, 402, 403g, 1068
 equiripple, 401, 402
 finite-impulse-response (FIR), 419, 421g, 424r
 frequency response
 comparison, 409g
 frequency-domain characteristics, 399
 Gaussian, 404
 highpass
 approximate, 43
 exact, 48
 VCVS, 408
 implementation, 405–418, 423r
 inductorless, *see* filter, active
 infinite-impulse-response (IIR), 419, 424r
LC, 54g, 54p, 55s, 393, 423r
 brickwall bandwidth, 561
 multisection, 394
 linear-phase, 400, 404
 linearity, 422
 lowpass
 after transimpedance amplifier, 542
 anti-alias, 395
 approximate, 42
 dc-accurate, 418
 exact, 50
 FIR, 420
 IIR, 420
 in switching amplifier, 109, 673
 of PRBS, 979
 VCVS, 407
 maximally flat, 401
 multiple-feedback, 413
 effect of op-amp Z_{out} , 414g
 node of difference amplifier, 355
 noise bandwidth, 564t, 565g
 notch, 53g, 414, 423r
 overshoot, 400
 passive, 391–396, 423r
 performance parameters, 399
 phase shift, 404g
 phase-sequence, 455, 456, 456g
 power-supply, 32, 699r
 powerline, *see also* ac line filter, 631
RC highpass, 69r
 approximate, 43
 exact, 48
RC lowpass, 69r
 approximate, 42g
 exact, 50
 phase shift of, 50g
 phasor diagram, 51
 switchable, 182
RC, 402g, 423r
 brickwall bandwidth, 561
 loading by, 44
 phase shift, 393g
 response, 392g
 worst-case impedance of, 44
 recursive, 419
 ringing, 400
 ripple, 399
 rise time, 400
 Sallen and Key, 399, 409, 423r
 settling time, 400
 skirt, 399
 specifying, 403g
 state-variable, 410ff, 423r
 bandpass, 411
 step response, 405g, 406t
 comparison, 405g, 406t
 switched-capacitor, 397, 406, 415ff, 423, 424r, 436
 advantages, 416
 configurations, 417
 drawbacks, 417
 noise, 418g
 sine from square, 436, 436s
 Thomson, 403
 time delay, 404g
 time-domain characteristics, 400
 tracking, 436, 577
 twin-T, 414, 423r
 types, 400ff
 VCVS, 407, 408, 408t, 407–410, 423r
 effect of op-amp Z_{out} , 414g
 highpass, 408
 finite state machine (FSM), *see* logic
 FIR, *see* filter, digital
 FireWire, *see* computer, data bus
 firmware, 1056
 first-in, first-out, *see* logic
 flash
 conversion, *see* ADC
 memory, *see* memory
 flicker, *see also* noise, 1/f
 of ADC code, 935
 flip-flop, *see* logic
 floating gate, *see* memory, non-volatile, *see*
 voltage reference, MOSFET floating gate
 floating point, *see* number
 flowchart, 1056
 fluctuation-dissipation theorem, 475
 flyback, *see* inductor, *see* switchmode
 flying
 amplifier, 367
 capacitor, *see* capacitor
 foldback, *see* power supply, *see* voltage regulator
 follower, *see* emitter follower, *see* op-amp, *see* source follower
 forgettery, 991
 forward
 converter, *see* switchmode
 Fourier transform, 395n
 FPGA, 788, 789r, 1031, 1036, 1053n, 1060, 1090p, 1093, 1096
 frequency
 analysis of reactive circuits, 41ff
 angular, 14
 beat, 973, 974
 compensation, 280ff
 in linear regulator, 597
 dithering, 649n, 969
 intermediate (IF), 562, 1139
 log sweep, 1069
 modulation, *see* modulation
 multiplier, 961, 962
 shifting, 395
 spurs, 966, 967, 971, 1066, 1067
 synthesis, 394, 451, 471r, 966–969
 synthesizer, 17, 1082, 1152
 microcontroller, 1065–1069
 to voltage converter, 890
 translation, 562
 unity-gain, *see* op-amp
 f_T , *see* op-amp, gain vs frequency, *see* op-amp, unity-gain frequency
 full duplex, 1033, 1042, 1051
 function generator, 17
 arbitrary, 18
 favorites, 1152
 low-distortion, 1152
 fuse, 630, 699r
 rating, 631
 GaAs, 135n, 793, 841p
 gain
 amplifier, *see* amplifier, *see* BJT, *see* JFET, *see* op-amp
 loop, *see* loop gain
 GAL, *see* programmable logic device (PLD)
 galvanic isolation, 843, 873
 CAN bus, 1045
 Garwin, R. L., 571n
 gate
 charge, *see* JFET, *see* MOSFET
 delay
 vs power, 792g
 vs voltage, 794g
 input current, 795g
 logic
 as pulse generator, 459
 CMOS, 185
 speed
 vs power, 719g, 792g
 vs voltage, 719g, 794g
 universal, 715, 717
 Gaussian, *see* filter, *see* noise
 GBW, *see* BJT, gain-bandwidth product, *see* op-amp, gain vs frequency
 generalized impedance converter, 398
 op-amp bandwidth, effect on, 399g
 Gilbert cell, 162
 glitch, *see also* logic, *see also* runt pulse, 738
 ground-bounce, 856

- in 555 output, 429
 in active clamp, 238
 in analog switch, 180
 in counter, 743s
 in crowbar, 691
 in DAC, 882, 892, 893t, 939
 in logic MUX, 756
 in logic one-shot, 463, 759
 in logic race, 738
 with slow transitions, 808
GLONASS, 451n
glossary, 1166
GPIB, *see* computer, data bus
GPIO, 1084
GPS, 451, 1053, 1061
Gray code, 708
 binary conversion, 711
ground, 2
 bounce, 758s, 759, 793, 856, 856, 877r
 inductance, 758
 loop, 442, 582
 isolation, 349, 350
 mecca, 582
 noise, 856, 856
 oscilloscope probe, 1161
 plane, 581, 758, 759, 857, 1117
 sensing, 316
 separate analog and digital, 915
 grounded coplanar waveguide, 1117
 grounding, 579ff, 582ff, 593r, 758
 between instruments, 583
 blunders, 582
 group delay, 400
 guard, *see also* current, leakage, 358, 360, 587
Gummel plot, 92g, 127r, 500
Gummel-Poon, 93n
gyrator, 393n, 397ff
- H-bridge**, 655, 659, 889, 1077, 1084, 1085
half duplex, 1034, 1042, 1084, 1084n
Hall effect, 1161
Hamming, *see also* window, sampling, 975
handshake, 1017, 1029t, 1031, 1033, 1038, 1039t
Hanning, *see* window, sampling
hard disk (hdd), 1135
Hartley, *see* oscillator
Harvard architecture, *see* computer, architecture
HDCP, 1145
HDL, *see* programmable logic device (PLD)
HDMI, *see also* connector, 1041
HDTV, 1137
headroom, *see also* voltage regulator, low-dropout, 195, 277, 351, 497, 579, 600, 600n, 604 (box), 636, 936
heat, 623ff, 701r
heatsink, 236, 600, 623ff, 625p, 701r, 834
 air flow, 627
- insulating, 626
LED, 834, 835p
 PCB foil as, 626, 627g
 sizing, 626g
 sizzle test, 625
 thermal resistance of, 626g
- heel**
 Achilles', 536n
- henry**, *see* inductor
- heterodyne**, 562, 563
- Hewlett**, William, 437n
- hex file**, 1059
- hex number**, *see* number
- hexadecimal**, *see* number
- hibernate**, 755
- high side**, *see* MOSFET, power, *see also* switching
- high voltage**
 amplifier, 696, 696
 clearance distance, 663
 creepage barrier, 665p
 creepage distance, 663, 664, 665p
 current source, *see also* current source
 current source in SMU, 897
 discharge circuit, 211
 electrostatic, 200, 200t
 in SMPS, 662
 MOSFET isolated switches, 205
 op-amps, 272t
 pulse generator, 333, 917, 918
 regulator, 609, 609, 693, 693, 695ff, 696
 resistor, *see* resistor
- high-voltage**
 amplifier, 209
- hold time**, *see* logic, flip-flop
- hot carrier diode**, *see* diode, Schottky
- hour of power**, 466, 467, 469
- hour of power (design example)**, 466
- Howland current source**, *see* op-amp, current source
- human**
 body model (HBM), 200, 804ff, 805, 872, 875r
 system interface (HI), 1059, 1096r
- humidity**
 and MOSFET damage, 200
 effect on ICs, 684
- hybrid**
 signal isolator, 1046
- hysteresis**, *see also* Schmitt trigger, 237
 clock inputs, 808
 in tunnel diode, 1114
 thermal, 683
- hysteretic**
 SMPS, *see* switchmode
- IC**
 discontinued, 273 (box)
 packages
 DIP, 3p, 57p, 65p, 73p, 224p, 225, 269, 340, 443p, 664, 715p, 758, 765p, 861, 1059
 SMT, 73p, 224p, 225, 269, 340, 443p, 715p, 758, 765p, 861
- parallel interface**, *see also* computer, data bus
 bus, 1028, 1030
 example, 1028, 1030
- serial interface**, *see also* computer, data bus, 1032–1046
- IEC power entry**, 629
- IEEE 1394 (FireWire)**, *see* computer, data bus
- IEEE 488 bus (GPIB)**, *see* computer, data bus
- IEEE number format**, 1047
- IGBT** (insulated-gate bipolar transistor), 207, 222r, 695
 desaturation, 847
- I²C**, *see also* computer, data bus, 887, 1028, 1030, 1061, 1081, 1089, 1094
 address selection, 952, 953
 bridge, 1084
 in DAQ, 954
 microcontroller peripherals, 1085, 1084–1086
- immediate argument**, 993
- impedance**, 40ff, 68r
 audio, 351
 characteristic, of transmission line, 1116
 converter, generalized (GIC), 398
 op-amp bandwidth, effect on, 399g
 converter, negative (NIC), 397
- in parallel**, 46
- in series**, 46
- input**
 of difference amplifier, 352, 354
 of differential amplifier, 376
 of op-amp, 245
- loading effect** of, 11, 11g, 69r, 99, 105, 861, 862
- matching**, 1120
- of **LC**, 52, 444n
- of **RC**, 49g
- of common-emitter amplifier, 88
- of emitter follower, 80
- of sources and loads, 79
- of transmission line, 1120
- output**
 of op-amp, 309
 of RRO op-amp, 316
- output, of op-amp, 246
- small-signal, 12, 50, 81
- transmission-line matching, 1122
- i_n*, *see* noise, density, current
- in-phase**, 395n
- inductance**
 leakage, 30, 633–635, 656, 659, 664, 667, 667n, 668
 disadvantages, 633n
 energy in, 669
 in powerline transformer, 633

snubber, 634, 656, 659, **669**
 spike, 634, 659
 spike from, 667
 symbols, 665n
 magnetizing, 30, 656, 666, 667, 669
 of coil, 28
 of op-amp output, 250g
 sensor, 1084
 inductive
 kick, *see also* spike, 38
 loads, 38
 inductor, *see also* ferrite, **28ff**, 29p, 68r
 active, 397, 398, 399g, 645n
 A_L value, 670
 drawbacks of, 396
 flyback, transformer as, 655, 656
 international notation, 5n
 reactance of, 44, **45**, 49g
 some magic with, 29
 stored energy, 689, 700r
 in switchmode converter, 636, 655, 666
 variable, 64
 volt-second balance, 30, 643
 input
 protection, 37, **37**, 159, 160, 175, **175**, 210,
 266, 269, 294, 294, 362, 532, **804**, 805,
 946, 949
 logic, **804**, **804**
 robust, 362
 inrush current, *see* current
 instrumentation amplifier, 273, 288r, 297, 306,
 363t, 390r, 512, 1070, **1071**
 accuracy, 306
 as current source, 367
 autozero, 342, 370
 bootstrapped power supply, 359, 359
 classic, 357
 CMRR, 306, 347, 358, 363t, 364, 364g, 367
 vs frequency, 364
 CMRR depends on gain, 358
 CMRR vs R_{source} mismatch, 366g
 common-mode range, 367, 1071
 configurations, 357, 368, 368ff, 369
 discrete, 361
 EMI, 365
 hybrid, 513
 in DAQ, 948
 input current, 362
 JFET-input, 512
 miscellany, 362
 noise, 362
 noise depends on gain, 358
 offset drift, 306
 offset trim, 366, 366
 offset voltage, 306
 PGA, **370**, 370, 371t
 resistor matching, 358
 roll-your-own, 359
 signal guards, 358

integrated circuit, *see* IC
 integrating
 ADC, *see* ADC
 conversion, *see* ADC
 integrator
 droop, 257–260
 in active filter, 406
 in PLL, 960
 in quadrature oscillator, 453
 op-amp, 230, 231s, 257–260
 RC, 26, 51
 reset, 230, 231, 288r, 388r, 552
 amusing story, 573
 switched-capacitor, 416
 interdigitation, 140, 515
 interface, *see* computer, data bus, *see also* logic
 interference, 478, 579ff
 intersymbol, 870
 interlace, 1133n
 Internet
 video streaming, 1140
 interrupt, *see* computer
 inverter
 ac power converting, 673, 673s
 charge-pump, 183
 flying-capacitor, 183
 logic
 CMOS, 185
 nMOS, 185
 op-amp, 225
 optional, 232
 pMOS, 185
 inverting
 switchmode converter, *see* switchmode
 IP, *see* programmable logic device (PLD)
 ISA, *see* computer, data bus
 isolation
 amplifier, **585ff**, **847**
 barrier in offline SMPS, 663
 coupler, *see also* optocoupler, **847**
 power switch, **203**, 205
 jam-load, *see also* logic, counter, *see also*
 logic, flip-flop, *see also* logic, register,
 730, 742, 748, 751
 jetpack, 1095r
 JFET
 source ballasting, 547n
 JFET (junction field-effect transistor)
 bootstrapped drain, 343, 344
 JFET (junction field-effect transistor), *see also*
 FET, 134, 217t
 1/f noise, 510, 517g
 amplifier
 biasing, 220r
 common-source, 149
 g_{os} gain error, 167
 instrumentation, 512, 513
 low noise, 346, **509–520**

maximum gain G_{\max} , 166
 with cascode, 148
 as diode, 294
 as variable resistor, **161ff**, 437, 438
 linearizing, 161, 162, 162g
 biasing, 150, 150n, 156, 513
 capacitance, 157, 164, 170, 510, 519
 care and feeding of, 346
 characteristic curves, 143g
 current noise, 511g, **511**, 591r
 current source, 142, 623g
 as BJT follower pulldown, 144
 self-biased, 143g, 145g
 deep subthreshold region, 166, 167g
 differential amplifier, 152, 343, 512, **513**
 dual, 139, 515
 dynamic gate current, 164
 gate charge, 164
 gate current, 146, 157, 163g, 325, 509, 511,
 511g, 591r, 593r
 impact ionization, 164g, 546
 G_{\max} , 141t
 hybrid amplifier, 151, 153g, 155g, 343, 344,
 512, 513, 544
 compensation, 154, 154g
 vs FET op-amp, 155
 impact-ionization current, 164, 538
 in Wien bridge oscillator, 437, 438
 leakage, *see* JFET gate current
 linear circuits, **142ff**
 low distortion, 346
 low noise
 hybrid op-amp, 534
 low-noise, 516t
 selecting, **515**
 manufacturing spread, 140g, 138–140, 145g,
 157, 158, 169, 169g
 mini-table, 141t
 noise, 346, 500, **509–520**, 591r, 593r
 reduction by paralleling, 509
 vs BJT, 517
 op-amp, *see also* op-amp
 fast, 155t
 operating point, 156, 1112
 oscillator, 155, 441
 in PLL, 395
 spectrum, 442g
 output conductance, 148n, 166
 output resistance, 148n, 166, 517
 pinch-off reference, 680, **680**
 pinch-off voltage tester, 240
 pinch-off voltage, V_p , 136
 schematic symbols, 135
 series-feedback pair, 150, 151g
 source follower, *see* source follower
 subthreshold region, 166g, 167g, 168g,
 166–170
 switch, 220r

- threshold voltage (V_{th}), 137, 147, 166, 167g, 169g
 transconductance, 132, 141t, 146
 vs drain current, 168g, 169, 169g
 vs drain voltage, 170, 517
 within a family, 169, 169g
 transfer characteristics, 135g, 137g, 139g, 142g, 165ff, 166–169g
 trimming offset with DAC, 345
 V_{GS} spread, 140g
 voltage noise, 346, 509–511, 518–520g
 theory vs measurement, 509g
 vs frequency, 510g
 vs transconductance, 509g
 voltage reference, 680, 680
 vs MOSFET, 170g
 jitter, *see also* oscillator, *see also* slew rate, 427, 457g, 457, 464, 870, 907, 964, 966, 971
 rejection in PLL, 974
 Johnson noise, 474ff, 475g, 475t, 482g, 494g, 526g, 569, 590r
 as noise source, 557
 calculation example, 486
 gain resistor contribution, 152, 352, 358, 379, 384, 906
 greater at low gain, 387
 in differential amplifier, 520
 in JFET channel, 509
 in TIA feedback resistor, 537ff
 eliminating, 552
 joule, 2
 joy
 and pain, 65
 JTAG, *see also* computer, data bus, *see also* memory, nonvolatile, *see also* microcontroller, 764, 769, 787r, 1028, 1036, 1061
 bootloader, 1091
 jump, 996
 junction
 capacitance, *see* capacitance
 leakage current, *see* current
 Karnaugh map, *see* logic
 KCL, KVL, *see* Kirchhoff's laws
 Kelvin connection, 277, 294n, 350, 365, 898, 1070
 Kelvin-Varley divider, *see* AoE 2nd ed., p 1025
 keyboard, 1064
 parallel bus interface, 1003, 1005
 keypad, 1081
 hex, 1068, 1069
 Kirchhoff's laws, 2, 68r, 1107
 L network, 1123
 laboratory power supply, *see* power supply
 ladder
 R–2R, 234
 DAC, 882, 883
 replaced by charge redistribution, 909
 lamp, 62, 437
 as a problem load, 694
 neon, 428
 Lantronix XPort, 1064
 Larkin, John, 360
 laser diode, 830p, 834, 835, 836s, 973, 973
 current, 835s
 driver, 835n, 836
 linearizing, 836s
 modulating, 836
 laser trimming, 244, 305, 352, 357, 416
 latch, *see* logic
 latchup
 in analog switch, 174
 in CMOS, 754, 759
 latency
 in ADCs, 903ff, 905t, 931, 937, 938, 940, 985–987r
 none, 903, 916t
 in FIFOs, 747
 in processors, 1011
 in RAM, 1014n, 1021, 1021ff
 LC, *see also* filter, 52
 Butterworth filter, 1109ff, 1110t
 damped oscillation, 53g
 filter, 54g, 54p, 55s
 filter examples, 1109ff
 impedance of, 52, 444n
 notch, 53
 oscillator, *see* oscillator
 parallel, 52
 resonant circuit, 52, 69r
 series, 52
 tank, 53
 trap, 441n
 LC
 series, 394
 LCD, *see* optoelectronics
 LCR meter, 1152
 LDO, *see* voltage regulator, low-dropout
 leakage, *see also* capacitor, *see also* current, *see also* JFET, 420, 1062
 cancellation, 298, 897, 898
 spectral, 420
 leakage inductance, *see* inductance
 leap year, 967n
 Lebowksi, *see* egg
 LED, 13, 62, 575, 830p, 829–834, 876r, 1062
 angular illumination, 830g, 832g
 arrays, 832
 as bias reference, 86n
 backlight, 1084
 BJT driver, 76
 constant-current drive, 832
 current-source drive, 622
 desklamp, 834, 835p
 driver, 1086
 driver ICs, 833t
 driving
 series string, 832
 driving from comparator, 13, 14
 driving from logic, 817ff, 833
 driving from MOSFET, 206, 465, 466
 driving from TTL, 718n
 forward drop, 76g, 827g
 high-current driver, 835s
 lamp (design example), 833
 multiplexed display, 751, 751–752
 multiplexed drive, 744n
 organic, *see* OLED
 panel-mount, 832t
 pulsed, 466, 835s
 synchronous detection of, 577
 voltage budget, 752
 wavelength, 76
 Lehrer, Tom, 1099
 LFSR, 558, 771, 771, 975, 975ff
 Li-ion battery, *see* battery
 lighting, *see also* LED, *see also* optoelectronics
 theater, 1081
 lightning detector (design example), 497
 limiter
 diode, 37
 line driver
 difference amplifier, 351
 linear
 circuit, 14, 68r
 linearity
 converter, 880, 899
 DNL warning, 900
 INL vs DNL, 899, 899
 linearizing
 JFET resistor, 162
 optocoupler, 849
 via lookup table, 1067, 1096r
 Little Logic, *see* mini-logic
 LMOS, *see* mini-logic
 LO, *see* oscillator, local
 load
 active, *see also* active load, 85, 105, 158, 266, 266, 496
 capacitive
 logic, 857, 857
 op-amp, 263s, 264, 264
 dump, 618
 inductive, 38
 load lines, 145g, 156, 156g, 1112ff
 loading, 10ff, 11g, 69r, 79
 lock-in, *see* bandwidth, narrowing
 lockup, *see* logic, pathology
 logarithmic
 amplifier, *see* amplifier
 frequency sweep, 1069
 logic
 0 and 1, 704
 1-of-8 decoder, 727

- 4-bit full adder, 728
 Verilog code for, 729
- 5V-tolerant, 798
- 8-input multiplexer, 726
- active-HIGH, active-LOW, 704, 714
- adder, 728
- arithmetic logic unit (ALU), 728, 990, 1049r
- assertion-level, 713
- asynchronous, 733, 734, 734s, 743s
- BiCMOS, 714, 717n
- buffer, *see* buffer
- capacitive load, 857, 857
- class-A current, 186, 186, 754
- clock
- global, 777
- clock skew, 757, 757, 759, 801
- CML, 874
- CMOS, 221r, 714, 790–794
- characteristics, 718ff
 - circuits, 791
 - failure modes, 760
 - input current, 795g
 - minimizing power, 754
 - open inputs with, 759, 760
 - output current, 798g
 - output voltage, 797g
 - pathology, 759
 - shoot-through current, 760, 760g
 - speed vs power, 792g
 - speed vs voltage, 794g
 - threshold skew, 760
 - threshold voltage, 797g
 - transfer characteristics, 796g
 - weak outputs, 827
- combinational, 708–728, 762r
- combinatorial, 708
- contention, 721, 722, 730
- counter, 742t, 741–744, 762r
- asynchronous, 733, 734, 734s
 - modulo-*n*, 748ff, 750
 - modulo-*n*, timing, 750g
 - ripple, 733, 734, 734s
 - synchronous, 737, 737s
 - up-down, 736, 742, 909
- current
- class-A, 754, 760, 760g
- D-register
- Verilog code for, 741
- data bus, 720, 721
- DCL, 790
- decoder, 726, 751, 838
- expansion, 727
 - Verilog code for, 727
- delay
- vs power, 792g
 - vs voltage, 794g
- demultiplexer, 726
- digital vs analog, 703
- diode, 711
- divide-by-2, 731, 732
- divide-by-3, 734, 743, 743s
- asynchronous glitch, 743s
 - synchronous, 735
 - Verilog code for, 736
- double transitions, 759
- driving
- external loads, 721, 818, 817–829, 875r
 - from comparator, 806
 - from op-amp, 808
 - pre-emphasis, 864
 - driving ac loads from, 821, 822
 - driving negative loads from, 821, 822
 - DTL, 790
 - dynamic current, 186
 - ECL, 714, 717n, 718, 718, 722, 750, 790
 - edge rate, 801, 801s
 - enable, 720, 752
 - encoder, *see also* encoder, 727
 - excluded states, 735
 - expansion, 726, 726, 727
 - families, 704n, 706t, 714, 717ff, 763r
 - characteristics, 718ff
 - choosing, 719, 794, 875r
 - chronology, 790–794
 - circuits, 791
 - CMOS, 790–794
 - DTL, 790
 - ECL, 790
 - input, 718, 795, 797g, 875r
 - input current, 795, 795g
 - interconnecting, 799, 798–802, 875r
 - life cycle, 715g
 - logic levels, 706 (box), 718
 - output, 718, 796, 797, 798g, 875r
 - RTL, 790
 - speed and power, 719
 - speed vs power, 719g, 792g
 - speed vs voltage, 719g, 794g
 - supply voltage, 718
 - threshold voltage, 796, 797g
 - transfer characteristics, 796g
 - TTL, 790–793
- fan-out, 711, 720, 794ff, 795n
- none in transmission gate, 725, 726
- FIFO, 747
- flip-flop, 196, 728ff, 762r
- clocked, 730, 732
 - debouncer, 802, 802s
 - edge-triggered, 731
 - hold time, 732
 - master-slave, 732
 - metastability, 732, 733g, 733s
 - multiple inputs, 730
 - propagation time, 732
 - RS, 729
 - setup time, 732
 - setup time violation, 733g, 733s
 - toggling, 731, 732
- type-*D*, 731, 732
- type-*JK*, 731
- type-*T*, 731
- floating input, *see* logic, unused input
- FPGA, *see* FPGA
- gate, *see also* buffer, logic, *see also*
- mini-logic, 708–724, 762r
 - 2-input select, 724, 725
 - AND, 709, 709
 - circuits, discrete, 711
 - example, 712, 714
 - exclusive-OR, *see* logic, gate, XOR
 - interchangeability, 713
 - inverter, 709, 710
 - NAND, *see also* memory, nonvolatile, 186, 710, 710, 1024
 - NOR, *see also* memory, nonvolatile, 710, 710, 1024
 - NOT, 709, 710
 - OR, 709, 709
 - standard, 709
 - transmission, 172, 725, 725
 - universal, 715, 717, 800
 - XOR, 710, 710, 737, 753, 771, 782, 957, 975, 982
 - XOR realization, 722
- glitch, 738, 739, 743s
- in one-shot, 759
- glue, 793
- GTL, 857
- hardware description language, *see also*
- programmable logic device, *see* logic, HDL, 711
- HDL, *see also* programmable logic device, 711
- HIGH and LOW, 704
- hold time, 732
- IC packages, 715p
- identities, 722t
- input characteristics, 795
- input overdrive, 806
- input protection, 804, 804
- inputs, 795
- current, 795, 795g
 - driving, 802
 - overcurrent, 806
 - pulldown, 805
 - pullup, 805
 - unused, 806
 - voltage, 797g
- interfacing, 790–874
- between logic families, 799, 798–802
- isolator, 823
- Karnaugh map, 723
- keeper circuit, 802, 803
- latch, 740
- level translator, 800, 802
- levels, 17, 706 (box), 762r
- CAN bus, 1044

- symmetrizing, 978
 life cycle, 715g
 lockup, 755
 LVDS, *see also* LVDS, 794
 LVPECL, *see* LVPECL
 magnitude comparator, 728, 728
 metastability, **732**, 733g, 733s, 756
 Mickey-Mouse, 468
 micropower design, 753
 mini, 712n, 715n, 793
 minimization, 723
 MOSFET, 184
 multiplexed display, 751, 751ff
 multiplexer, 724
 - expansion, 726, 726
 - race condition in, 756, 756
 - Verilog code for, 726
 multiplier-accumulator, 728
 NECL, 718, 718n
 negative-true, 704n, 714
 nMOS, 712
 - driving LED, 827g, 828
 - driving loads, 828
 - input characteristics, 828
 - interfacing, 826ff
 - output characteristics, 827
 - output circuit, 827
 open-collector, 721, 800, 807, 811, 817, 993
 - as level translator, 721
 open-drain, 721, 721, 800, 807, 811
 output characteristics, **796**
 - voltage vs current, 798g
 parity generator, 728
 pathology, **755–760**, 763r
 - unspecified rules, 757
 PECL, *see also* PECL, 718, 718n
 positive-true, 704n, 714
 power
 - dynamic, 754
 - minimizing, 754
 preload
 - asynchronous, 748, 752
 - synchronous, 748
 priority encoder, 727
 probing, 808, 809s, 810p
 programmable, *see* programmable logic
 - device
 propagation time, 710s, 732
 pulse generator
 - design example, 739
 - with flip-flops and counters, 739
 quiet, 759, 793
 race, *see also* runt pulse, 724n, 738, 748, 756
 register, *see also* computer, 740, 762r, 990
 - power, 819, 819t
 - shift, **744**, **744**
 removal time, 758
 reset
 - asynchronous, 743
 synchronous, 743
 reset/supervisor, 756t
 ringback, 759n
 robust link, 1120
 RTL, 711n, 712, 790
 runt pulse, *see* runt pulse
 SCR latchup, 759
 sequential, **728–745**, 762r
 - miscellaneous, 746
 - timing example, 748
 setup time, 732
 - violation, 733g, 733s, 756n
 shift register, 762r, 1081
 - feedback PRBS, 975
 - linear feedback, *see* LFSR
 - noise source, *see also* LFSR, 558
 - RAM as, 745, 745, 746g
 - timing, 746g
 speed, 710s
 - vs power, 792g
 - vs voltage, 794g
 standard, 763r, 793
 - combinational ICs, 724
 - gates, 715, 716t
 - sequential ICs, 740
 - when to use, 782
 startup reset, 755, 755
 state machine, 734, **734**
 - Mealy, Moore, 736
 - states, 704, 797g
 - strobe, 725
 SUHL, 790
 switch, **725**, 917t
 - switch input as pulldown, 729n
 - synchronizer, 737, 738
 - synchronous, **734**, 743s, 777
 - syntax, 711t
 - three-state, 720, 720, 993
 - through cables, **856ff**, 877r, **1117**
 - comparison, 874
 - timing skew, 737n
 - toggling, 196
 - toggling flip-flop, 731
 - Verilog code for, 732
 transmission gate, 172, 725, **725**, 917t, 1016
 - bidirectional, 725, 727
 truth table, 708
 TTL, 714, 790–793
 - characteristics, **718ff**
 - noise in, 758
 - output characteristics, 827
 unspecified rules, 757
 unused input, 718, 738, 754, 759, 760, 806
 - LVDS trick, 800
 wired-AND, 722, 1082
 - wired-OR, 721, 722
 lookup table, 735
 loop
 - second-order, *see* PLL
 loop gain, 111, **117**, 118–120
 loss
 - switching, 662
 loudspeaker
 - as microphone, 486
 low dropout, *see* voltage regulator, low-dropout
 low-voltage differential signaling, *see* LVDS
 LSB, *see also* number, 705, 711, 734, 737, 751, 882, 903, 909
 LVDS, 705n, 794, 864, 869, 869s, **868–870**, 870, 871s, 878r, 1030
 - levels, 873
 - power, 874g
 - rates, 873g
 - signal conditioning, 870, 871s
 - torture test, 869, 869s
 LVPECL, 794, 874
 macrocell, *see* programmable logic device (PLD)
 magazines, 1153
 magnet controller, 365
 man
 - transistor, 75
 Manchester code, **1041**
 Manchester coding, **1039ff**
 mantissa, 1048
 MARK and SPACE, 771n
 Mark (RS-232), 871
 math review, **1097–1100**
 maximal length shift register, *see* LFSR
 MDAC, *see* DAC, multiplying
 mecca, *see* ground
 memory, *see also* computer, *see also* logic, *see also* microcontroller, 745, 990, 991, **1014–1027**, 1051r
 - 1T1C cell, **1019**
 - 6T cell, **1016**
 - access time, *see also* memory, dynamic, *see also* memory, static, 746g
 - burst mode, 1021
 - cache, 990, 991
 - computer, 991
 - configuration, for FPGA, 769
 - double data rate, *see* DDRn
 - dynamic, 991, 1019, **1018–1021**, 1051r
 - asynchronous, 1018, 1020, 1021
 - latency, 1021
 - synchronous, 1021, 1022
 - timing, 1021, 1022
 - endurance, 769
 - EPROM, 769
 - flash, 769, 991, 1082, 1094, 1096r
 - HDD, 991
 - multilevel cell (MLC), 1025
 - non-volatile, 764, 769, 770, 772, 779, 787r, 1051r
 - nonvolatile, **1021–1027**, 1067

- EEPROM, 1023, 1051r, 1053, 1064, 1082, 1084, 1094, 1096r
 EPROM, 1023
 ferroelectric, 1022, 1025
 flash, 1022, **1024ff**, 1051r, 1053, 1089, 1094
 floating gate, 1022, *1023*
 JTAG programming, 1036
 magnetoresistive, 1022, 1026
 mask ROM, 1023
 NAND flash, 1024, *1025*
 NOR flash, 1024, *1024*
 phase change, 1022, 1026
 PROM, 1023
 page mode, 1019n
 pseudo-static, 1017, *1017*
 RAM
 as shift register, 745, 745, 746g
 read cycle, *1017*, 1019, 1021, 1022, 1049r
 retention, 769
 ROM
 in state machine, 735, 736n
 SSD, 992
 static, 769, 991, *1016*, **1016–1018**, 1051r, 1061, 1094, 1095, 1096r
 asynchronous, 1016, *1016*, *1017*
 synchronous, 1018, *1019*
 timing, 1016, *1017*, *1019*
 static vs dynamic, 1015
 volatile, 991
 volatile/nonvolatile, 1014
 wrapup, **1026**
 write cycle, *1017*, 1019, 1021, 1022, 1049r
 MEMS, 446n
 metastability, *see* logic
 meter, 61
 mho, 6
 microcomputer
 terminology, 989, 1049r
 microcontroller, 747, 749, 763r, 797, 887, **1053–1094**, 1095r
 8051, 1060, *1067*, 1087, 1090p, 1091–1093
 ac power control (design example), *1063*, **1062–1065**
 pseudocode, 1064, *1065*
 ADC timing example, 1088, 1088g
 pseudocode, 1089
 ARM, 1036, 1060, 1087, 1090, 1090p, 1091–1093, 1094n, 1095r
 as debouncer, 803, 804
 as timer, 469
 assembly code
 for PRBS generator, 783
 PRBS generator, 779
 assembly language, 779
 AVR, 1036, 1055, 1059, 1060, 1087, 1089–1093, 1095r
 Blackfin, 1061
 block diagram, *1054*
- bypassing, 1056
 C-language code
 for PRBS generator, 784
 PRBS generator, 782
 code download, 1059
 Coldfire, 1061, 1090p, 1093
 constraints, 1086
 debugger, 779, 1095r
 development environment, **1086–1092**, 1095r
 cost, 1092
 development kit, 1090, 1090p
 firmware, 1056
 frequency synthesizer (design example), 1067p, **1065–1069**
 block diagram, *1066*
 pseudocode, 1067, *1068*
 how to select, 1094
 IDE, 779
 implementing delta-sigma ADC, 932, 933
 in-circuit debugging, 1092, 1096r
 in-circuit programming, 1053
 instrumentation amplifier frontend, *1071*
 JTAG programming, 1036, 1053
 loading code on, **1089–1092**
 JTAG bootloader, 1091
 parallel bootloader, 1091
 proprietary bootloader, 1091
 SPI bootloader, 1091
 UART bootloader, 1090
 USB bootloader, 1091
 logic inputs, 1081, 1084
 MIPS, 1061
 MSP430, 1061
 object code, 779, 1096r
 output characteristics, 798g
 output current, 798g
 peripheral ICs, **1078–1086**
 direct connection, *1080*, **1079–1082**
 I²C connection, *1085*, **1084–1086**
 SPI connection, *1083*, **1082–1084**
 peripherals
 on-chip, 1061ff
 PIC, 1060
 popular families, **1059–1061**
 PowerPC, 1061
 PRBS generator, **777ff**, 782
 precision ADC in, 1071
 Propeller, 1061
 PSoC, 1061
 Rabbit, 1060
 realtime constraints, 1088
 SH-4, 1061
 simulator, 779, 1095, 1096r
 software, **1086ff**
 assembly code, 1087
 assembly language, 1095r
 BASIC, 1087
 C/C++, 1087
- Java, 1088
 Python, 1088
 special-function register, 779
 ST6/7, 1061
 stabilized platform (design example), **1077**, 1077p, 1079p
 block diagram, *1078*
 pseudocode, 1078
 suntan monitor (design example), **1054–1059**
 C-language code, *1058*
 circuit, *1054*, *1055*
 pseudocode, 1056, *1057*
 terminology, 989
 thermal controller (design example), *1071*, **1069–1077**
 block diagram, *1069*
 control loop, 1074, *1075*
 pseudocode, 1075, *1075*
 when to use, 785, 1093, 1096r
 wrapup, **1092–1094**
 XMOS, 1061
 microconverter, 1070
 microphone
 capacitor as, 682
 loudspeaker as, 486
 ribbon preamp, 505
 micropower, *see also* ADC, *see also* logic, *see also* op-amp, *see also* oscillator, crystal digital design, 753
 microstrip, *see also* stripline, 858, 1117, 1119
 Miller effect, *see also* capacitor, 105, **113ff**, 130r, 153, 164, 197, 197g, 198s, 511
 and differential amplifier, 114
 configurations that avoid, 115, 148, 152n
 Millman's theorem, 6, 1108
 mini-logic, 715n, 715p, 772n, 800n
 MiniGate, *see* mini-logic
 mixer, 395, 562, 563, 1139
 M²L, *see* logic, Mickey-Mouse
 modem, 873
 modified sinewave, 673s
 modulation
 8-VSB, 1138n
 8PSK, 1139
 amplitude (AM), 55, 56s, 970, 1134
 heterodyne, 970
 synchronous, 970
 BPSK, 970
 delta, 910
 frequency (FM), 969, 1134
 demodulation with PLL, 969
 Foster-Seeley detector, 970
 quadrature demodulation, 969
 quieting in, *see* AoE 2nd ed., p 898
 ratio detector, 970
 slope detector, 970
 pulse-code (PCM), 703, 971
 QAM, 970

- QPSK, 970, 1139
quadrature amplitude (QAM), 1138n
synchronous detection, 575, 576
video, 1133
- modulator
delta-sigma, 924, 925
magic in, 927
- monostable multivibrator, *see* one-shot
- monotonicity
converter, 880
- Monticelli output circuit, 318, 330
- Moore's law, xxix, 748, 989n, 990p, 1018n
- MOSFET, *see also* FET, 134
as pullup, 828
avalanche rated, 819n, 1073, 1073
capacitance, 164, 165, 187, 188–191t, 197g, 197ff, 205
construction, 134
depletion-mode, 209, 210t, 222r, 698
as current source, 622
as input protection, 210, 949
current source, 211
extending regulator V_{IN} , 211, 693
HV discharge, 211
- dynamic gate current, *see also* MOSFET, gate driver, 164
- floating-gate reference, *see* voltage reference
- gate capacitance, 197g, 197ff
- gate charge, *see also* MOSFET, power, 164n
- gate driver, 194, 194, 218t, 222, 222, 753, 797, 798g, 823, 828, 833, 861, 1073, 1095r
optocoupler, 206
- gate leakage, 163, 1059
- gate threshold, 137
- handling precautions, 200
gate damage, 201p
- high-voltage
creepage barrier, 665p
isolated power switch, 203, 205
- lateral, 213
- logic switch, 184
- maximum current, 221r
- maximum ratings, 221r
- noise, 519, 520g
- on-resistance, *see* MOSFET, R_{ON} and $R_{DS(ON)}$
polarity, 134
- power, 187ff, 188–191t
applications, 202ff
ballast, *see also* ballast, 213
body diode, 199
drain capacitance, 198
floating switches, 205
gate breakdown, 199
gate capacitance, 197g
gate charge, 188–191t, 197g, 197, 198s, 202, 205, 221r
gate protection, 199
- high-side switching, 202ff, 204
high-voltage, 202, 662, 695
lateral, 214g
light-at-night, 206
linear applications, 208
logic-level, 192, 193
paralleling, 201, 212ff, 214, 222r
piezo amplifier, 208
piezo driver, 207
power rating, 199
protected switch, 204
push-pull follower, 214
source ballasting, 192, 212ff, 213, 214
switch, 206t, 221r, 1073
switch examples, 206
switching applications, 195, 196, 192–196
switching cautions, 196
thermal runaway in, 214
thermal stability, 187
vs BJT and IGBT, 201, 202t, 208t
 $R_{DS(ON)}$, 139, 188–191t, 199, 221r
 R_{ON} vs $V_{CE(sat)}$, 201, 202t
 R_{ON} vs temperature, 187, 199, 213g
 R_{ON} vs voltage, 202, 662
schematic symbols, 134
series connection of, 697
source ballasting, 192, 214
switch, 1081
floating, 203
high-side, 825, 826t, 1082
protected, 824, 825, 825t, 1082
protecting, 823ff
switching examples, 193, 204, 205, 820
transfer characteristics, 212g
vs BJT, 202t
vs BJT and IGBT, 201
vs JFET, 170
- motor driver, 1078, 1079p
motorboating, 287
mouse, 1064
- MOV, *see* varistor
- MP3, 1137n
- MPEG, 1093
- MPEG-2, 1137n
- MPEG-4, 1061, 1137n
- MSB, *see also* number, 705, 711, 734, 737, 751, 882, 903, 909
- MSP430, *see* microcontroller
- multichannel scaling, *see* bandwidth, narrowing
- multimeter, 2, 10 (box)
true rms, 631
- multiplex
video, 1138
- multiplexer, *see also* analog switch, *see also* logic, 724
- FET analog switch, 173
in DAQ, 946
- multiplier, *see also* Gilbert cell
analog, 162, 562, 575
capacitance, *see* capacitance
frequency, *see* frequency
logic, *see* logic, multiplier-accumulator
- multiply
how to, 761
- multiplying DAC, *see* DAC
- multislope conversion, *see* ADC
- Nakamura, Shuji, 62
- NAND, *see* logic, *see* memory, nonvolatile
- narrowcast, 1142
- negative-impedance converter, 397
- negative-true, *see* logic
- netlist, *see* programmable logic device (PLD)
- network
local-area (LAN), 1046
neutral, *see* powerline, wiring
- NEXT (near-end crosstalk), 581
- night light, 206
- NMR, 577
- node, 2
- noise, *see also* amplifier, *see also* avalanche, *see also* op-amp, 15, 326, 473–481, 636s, 637
1/f, 337, 476g, 476, 491, 520, 590r
cancellation of, 485n
corner frequency, 566
filtered bandwidth, 564t
forever?, 566, 567s
integrated, 566g
JFET, 510, 517g
op-amp, 324, 324g, 530
- analog
filtered PRBS, 975, 977–982
averaging time, 574
band-limited, 477
bandpass filters
response, 565g
bandwidth, 477, 561ff
multisection RC, 561
of LC, 561
of an average, 562
- bistable, 477s
- BJT, *see* BJT
test circuit, 557
burst, 477, 477s, 590r
capacitively coupled, 581
common-mode choke, 585
crest factor, 568, 981
- current
density, 483
measuring, 569ff
of bias-canceled op-amp, 327, 527
ultra-low measurement, 571, 572
- current source, of, 487ff
- density, 474, 479, 590r
voltage, 481ff

- differential amplifier, 520
 digital
 generation with PRBS, **974–982**
 emitter follower, **487ff**
 e_n -C, *see also* transimpedance amplifier, 532, 538, **538ff**, 540–542g, 542s, 543g
 equivalent power (NEP), 537n
 exceedance probability curve, 574g
 excess, 475ff, 590r
 figure, **479**, 480g, 493g, 519, 592r
 contour plot, 490g, 492, 493g
 conversion to SNR, 480
 example, 492
 filtered
 over decades, 567s
 filtering out-of-band, 911
 flicker, *see* noise, 1/f
 floor, 418
 Gaussian, 475g, 482, 590r, 979, 981
 generator, 559
 pink, 559
 pink, spectrum, 560s
 PRBS, 558
 immunity, 705, 754
 in inverting amplifier, 521
 in noninverting amplifier, 520
 instrumentation amplifier, 362
 integrals, 564t
 integrated
 calculating, 563
 of op-amps, 338g, 530, 531g, 531t
 interference as, 478
 JFET, *see* JFET
 Johnson, *see* Johnson noise
 low-frequency specification, 564
 magnetically coupled, 581
 maxima, 574
 measurement, **555ff**, 568, 592r
 hot-cold, 557
 RF, 558
 transistor test circuit, 557
 MOSFET, *see* MOSFET
 mosquito, 1137n
 Nyquist, *see* Johnson noise
 of switching power supplies, 649
 of voltage regulator, 618
 filtering, 619, 620
 op-amp, 522t, 523t, 524t, 528g, 529g, 532s, **520–533**
 autozero, **333ff**, 334s, 568g, 570g, 572s
 choosing, **525–533**
 spectrum, 568g, 568s, 570g, 572s
 vs C_{in} , 532g
 peak vs rms, 532, 564, 568, 935n
 phase, *see* phase
 pink, 477s, 559, 563ff, 566
 popcorn, 477s, 478g, 590r
 potpourri, 574
 power supply, **578ff**, 580g, 580t, 593r, 618, 913
 capacitance multiplier, 557, 578, 579g
 pseudorandom, *see* PRBS
 quantization, 927g
 quantization error, 574
 quick guide to, 473
 red, 477s, 563ff
 rejection in PLL, 974
 resistance, **494**, 501, 502t, 522t, 528, 569, 592r
 rms vs magnitude, 574
 shaping, *see also* delta-sigma, 927, **927ff**
 shot, 327, **475ff**, 476t, 482g, 511g, 590, 591r
 equivalent to Johnson noise, 482, 509, 525n
 suppression of, 476, **487ff**, 488
 source
 PRBS circuit, 980
 sources, **558ff**, 590r, 592r
 switchmode power supply, 636g, 636s, 637
 telegraph, 477s
 temperature, **480**, 519, 592r
 threshold-crossing rate, 574
 true random, 982, 988r
 circuit, 984
 types of, 474, 477s, 558, 590r
 units of, 474
 unspecified, 503, 504g, 507, 517, 517g, 519, 535
 voltage
 from filtered PRBS, **978**
 voltage reference, *see also* voltage reference, 677t, 682g, **682**
 white, 474ff, 477s, 563ff
 zener, 676n
 nonlinearity
 converter error, 880, 899
 nonmonotonicity
 converter error, 880
 NOR, *see* logic, *see* memory, nonvolatile
 Norton equivalent circuit, 66, 69r, 1108
 notch, *see* LC, *see* filter
 NRZ, 1041
 NRZI, 1041
 NTSC, 1062, 1132n, 1134, 1136
 number
 2's complement, 707, 1046
 arithmetic in, 708
 BCD, 706
 codes, **705–708**, 880, 1046–1048
 denormalized, 1048
 dynamic range, 1048
 floating-point, 708n, **1047**
 formats, 1047
 formats, 1047
 Gray-code, **708**, 709
 binary conversion, 711
 hex, 705
 integer
 formats, 1047
 justification, 1046
 signed, 707t, 1046
 unsigned, 1046
 MSB in, 707ff, 1046ff
 not a, 1048
 of the beast, the, 666
 offset binary, 707
 overflow, 708
 packed BCD, *see* AoE 2nd ed., pp 736, 741
 sign-magnitude, 707
 signed, 707
 storage in memory, 1048
 nybble, 990
 Nyquist, *see also* sampling, 395, 419
 noise, 474
 Nyquist criterion, *see* sampling
 Nyquist noise, *see also* Johnson noise
 Odroid, 1053n
 off-axis pole, *see* pole
 offline, *see* ac powered
 offset binary, *see* number, codes
 Ohm's law, 4
 generalized, 46
 not obeyed by diode, 31
 ON resistance, *see* analog switch, FET, *see* MOSFET
 one second per hour (design example), 467
 one-shot, 77, 242, 459, 460, 463t, **461–465**, 471r, 739, 762r
 555, 460, 460
 application examples, 465
 cautions, **462ff**
 circuit, 461
 problems with, **462ff**
 protecting pulsed power devices with, 465
 reset, 462
 retriggerability, 462
 timing coefficient, 464g
 op-amp, **223ff**, 224p
 1/f noise, *see* noise
 absolute-value circuit, 257
 ac amplifier, 226
 biasing, 261, 262
 accuracy vs linearity, 313
 active clamp, 257, 289r
 active peak detector, 254
 active rectifier, 238ff, 257, 289r
 effect of slew rate, 238
 as voltage regulator, 235
 autozero, 254, 272, 295, **333ff**, 334, 335t, 370, 388, 389r, 528g, 933
 common-mode input range, 340
 external, 341, 341
 input current, 339
 instrumentation amplifier, 342
 integrated noise, 338g

- noise, 336g, 336, 337s, 569t
 noise current, 339, 569, 570g, 572s
 noise voltage, 339, 568g
 offset voltage, 339
 overload recovery, 337
 selecting, 338ff
 self-calibrating, 341
 settling time, 340
 slew rate, 340
 supply voltage, 338
 bandwidth, 247, 249, 290r, 308, 328, 329g
 basic circuits, 225–231, 288r
 bias canceled, 125, 252, 266
 better than JFET, 303g
 current noise of, 327, 527
 BJT, 163, 244, 244n, 245t, 248n, 290, 522t, 524t, 525, 569
 bias canceled, 327
 input current, 244, 290, 303, 303g, 304, 304g
 noise, 337, 526g, 568g
 RFI, 366, 369n
 slew rate, 308g
 Bode plot, 290r
 capacitive load, 332
 driving, 264
 stability, 265g
 stabilizing, 263s, 264
 cautions, 231, 289r
 chopper-stabilized, *see also* op-amp,
 autozero, 340, 340, 1070
 clamping, 912
 CMOS, *see also* op-amp, autozero, *see also*
 op-amp, input current, 163g, 245t, 258,
 265, 290r, 296t, 389r, 523, 524t, 525
 input current, 225, 244, 259, 289r, 303,
 304g, 325, 325g, 339
 noise, 526g, 531, 531g, 568g
 CMRR, 305, 328
 CMRR and PSRR, 249
 common-mode input range, 245, 290r
 of autozero, 340
 of difference amplifier, 354
 compensation, *see also* op-amp,
 overcompensation, 247, 280ff, 283, 290r,
 308
 compensation pin, 320, 321t
 clamping, 912, 913
 current feedback, *see also* feedback, 270,
 271, 272t, 308, 310t, 331g, 375t, 378,
 384–386, 513, 514, 521, 524t, 548
 peaking vs gain-setting R, 379g
 current source, 228–230, 242, 254, 344, 367,
 622, 623, 895
 Howland, 229, 230
 current-to-voltage converter, 233
 decompensated, 283, 283g, 308, 328, 515,
 542, 550, 553
 departure from ideal, 243–249, 289r
 detailed look, 242–253
 die (LT1028), 527p
 difference amplifier, 227, 288r, 347–387
 bandwidth, 355
 CMRR trim, 356, 357
 configurations, 356
 filter node, 355
 offset trim, 355, 357
 differential amplifier, 347–387
 differential input range, 232, 246, 535
 differentiator, 260, 288r
 distortion, 329ff, 331, 332g
 slew-rate, 248s
 vs frequency, 311g
 driving logic from, 808
 electrometer, 259, 289, 290r
 feedback at dc, 232
 follower, 227, 288r
 with bootstrap, 233
 frequency compensation, *see* op-amp,
 compensation
 gain, 249, 290r
 vs frequency, 281g, 281ff, 282–284g,
 311g, 328, 329g
 gain error, 312, 312g
 gain nonlinearity, 312ff, 313
 measuring, 313
 golden rules, 225, 288r
 high-power, 272t
 high-speed, 310t
 high-voltage, 272t
 hybrid amplifier with JFET, 151, 153g,
 155g, 343, 344, 534, 545
 ideal, 243, 288r
 input capacitance, 532
 input current, 163, 163g, 244, 252, 289r,
 295, 302, 325, 388r, 530, 535
 BJT better than JFET, 303g
 common-mode voltage, variation with,
 304, 304g, 306g
 effect on integrator, 257
 measuring, 325ff
 of autozero, 339
 temperature, variation with, 295, 303g,
 307, 325g, 530
 input impedance, 245, 250, 301, 306
 input offset current, 244, 252
 input protection, 258, 294, 362
 instrumentation, *see* instrumentation
 amplifier
 integrator, 230, 231s, 257–260, 288r, 933
 resistor stabilization, 259
 inverting amplifier, 225, 288r, 316n
 noise, 521
 JFET, 140, 155, 163, 163g, 226, 245t, 252,
 274, 296t, 389r, 492, 523, 524t, 525, 532g
 fast, 155t
 impact-ionization input current, 538
 input current, 225, 244, 303, 303g, 304,
 304g, 325, 325g, 339
 noise, 526g, 531, 531g, 568g
 RFI, 369n
 slew rate, 308g
 JFET hybrid, *see* op-amp, hybrid amplifier
 with JFET
 limitations, effect on circuits, 249–254
 linearity, 251
 low input-current, 303t
 low noise, 522–524t
 choosing, 525–533
 hybrid, 534
 micropower, 273
 Monticelli output circuit, 318, 330
 noise, 289r, 528g, 529g, 520–533, 592r
 0.001–10Hz, 1/f, $V_{n(pp)}$, 531g
 0.01–10Hz, 1/f, $V_{n(pp)}$, 564
 1/f, 528, 529g
 autozero, 333ff, 334s
 impedance, 326
 integrated, 338g, 530, 531g, 531t
 low-frequency, 530ff, 532s, 564
 measuring, 568
 vs C_{in} , 532g
 noise current, 326ff, 336g, 530, 570g, 572s
 measuring, 569ff
 of autozero, 339
 noise resistance, 528
 noise spectrum, 568g, 568s, 570g, 572s
 noise voltage, *see also* noise, 323, 324g,
 336g, 337, 535, 568g
 measuring, 567
 of autozero, 339
 noise voltage and current, 249, 526
 of bias-canceled, 327
 vs supply current, 525g
 noninverting amplifier, 226, 288r
 noise, 520
 nonlinear circuits, 236, 289r
 offset trim, 306, 534
 offset voltage, 244, 251, 289r, 304, 306, 323,
 388r
 effect on integrator, 257
 of autozero, 339
 test circuit, 323
 offset voltage drift, 244, 289r
 optional inverter, 232
 oscillator
 precision VCO, 267
 output current, 251, 272t, 290r
 output errors, 389r
 output impedance, 246, 250, 290r, 309
 effect on MFB filter, 414g
 effect on VCVS filter, 414g
 vs frequency, 250g, 311, 312g
 output range, 231
 output swing, 246, 290r
 vs frequency, 251g, 307g

vs load resistance, 246g
 output voltage
 vs load current, 247g
 overcompensation, 263, 285, 542, 571
 parameters, 245t
 unspecified, 295
 peak detector, 289r
 resetting, 255
 phase error, 314, 315g, 315t
 active compensation, 314, 315g, 315t
 phase reversal in, 275, 361n
 phase shift, 247, 290r
 vs frequency, 311g
 photodiode amplifier, 233
 photometer, 265
 pinch-off voltage tester, 240
 pinout, 225
 power, 588
 power and high-voltage, 272t
 power booster, 234
 precision, 292ff, 320, 321t, 388r
 choosing, 319
 representative, 302t
 vs speed, 329
 programmable pulse-width generator, 241
 PSRR, 306, 328, 533
 push-pull booster, 234
 rail-to-rail, 236, 246, 266, 277, 289, 290r, 315ff, 389r
 distortion, 317g, 318
 gain, 318g
 input circuit, 316
 input crossover, 316, 317g
 output circuit, 317
 output impedance, 316, 318g
 output saturation, 317
 output swing, 247g
 V_{OS} shift, 316g
 relaxation oscillator, *see also* oscillator, relaxation, 425
 representative, 271t
 sample-and-hold, 256, 289r
 schematic
 LF411, 243
 TLC271, 266
 self heating, 306
 sensitive millivoltmeter (design example), 253, 293, 296t
 series damping, 263, 263s
 settling time, 308ff, 311g, 320, 321t, 328
 of autozero, 340
 sign of feedback, 232
 single-supply, 245, 261, 265–270, 289r, 322
 slew rate, 248g, 251, 290r, 307, 328, 329
 distortion, 248s
 of autozero, 340
 vs f_T , 308
 vs input differential, 308g
 smorgasbord, 232

split feedback, 263, 264s, 265
 stuck-node tracer, 276g
 summing amplifier, 234
 summing junction, *see* summing junction
 supply rail splitter, 262
 stability, 263, 263s
 supply voltage, 248, 322
 of autozero, 338
 supply-rail bypass, 232
 tables of, 271–272t, 296t, 302, 303t, 310t, 320, 321t, 335t, 522–524t
 track-and-hold, 256
 transconductance, *see* OTA (operational transconductance amplifier)
 transimpedance amplifier, *see* transimpedance amplifier
 triangle oscillator, 239
 uncompensated, *see also* op-amp, decompensated, 283
 unity-gain frequency, 247, 247g, 281g, 281ff, 282–284g, 328, 329g
 voltage feedback, 385
 voltage gain, 247
 vs frequency, 247g
 zero-crossing detector, 269
 open collector, 173, 173, 721, 799, 807, 811, 817, 818
 open drain, 721, 799, 807, 811
 open frame, *see* power supply, modular
 optocoupler, 805, 837p, 844p, 845, 846, 847, 848, 850, 851, 843–851, 852, 877r, 915, 1062, 1064, 1081
 analog, 586, 847
 as variable resistor, 437, 438n
 current transfer ratio (CTR), 844ff, 845, 852
 for isolated feedback, 663
 gate drive, 206, 846
 linearizing, 849
 logic output, 844
 photoconductive
 linearity, 437
 phototransistor output, 844
 signal isolator, 586
 optoelectronics, 829–856, 876r
 16-segment display, 838
 5x7 matrix display, 839
 7-segment display, 838, 838
 angle encoder, 877r
 APD, 877
 coupler, *see* optocoupler
 detectors, 837p, 840, 841p, 876r
 display
 LED, multiplexed, 751, 751ff, 838
 multiplexed, 443, 751, 751
 display technology, 1142
 displays, 62, 830p, 836ff, 837p, 876r, 1081
 emitters, 830p, 829–840
 family tree, 829, 831 (box)
 fiber optics, *see* fiber optics
 image sensor, 841p, 1061
 interrupter, 844p, 851, 877r
 IrDA, 1061, 1081
 laser diode, *see* laser diode
 LCD, 836, 837p, 840, 1061, 1066, 1095, 1096r, 1142
 interface timing, 1028
 LED, *see* LED
 LED backlight, 1084
 LED stick, 839
 light-to-frequency, 1081
 miscellaneous, 837p
 multicharacter display, 839
 OLED, 836, 1082, 1143
 optocoupler, *see* optocoupler, 1081
 photo-Darlington, 842
 photoconductive, 437, 438n, 844p
 photoconductive mode, 842
 photodiode, *see also* avalanche, 841
 photomultiplier, 837p, 842, 842
 amplifier, 843
 phototransistor, 841
 photovoltaic mode, 842
 photovoltaic stack, 204, 849, 850
 PIN diode, 837p, 973
 plasma, 1143
 proximity detector, 851, 877r
 rotary encoder, 1066
 smart display, 839
 codes, 840
 synchronous detection, 578
 VFD, 836, 1066, 1067
 optointerrupter, *see* optoelectronics
 optoisolator, *see* optocoupler
 orthogonal
 adjustments, 515
 oscillation
 damped, 53g
 parasitic, 426, 427s, 442
 parasitic oscillations in, 427s
 slow logic transition, from, 801s
 oscillator, 289r, 425–457, 470r, 700r, 1081, 555, 429, 430t, 428–432
 50% duty-cycle, 429
 full-range duty-cycle, 430
 sawtooth, 430, 430
 triangle, 431, 432
 atomic standard, 451
 blocking, 656
 ceramic resonator, 450, 471r
 Clapp, 440, 441
 CMOS, 426
 Colpitts, 440, 440, 447
 crystal, 439, 443p, 443–450, 471r, 1063
 a caution, 449
 aging, 451, 471r
 circuits, 447, 447
 equivalent circuit, 444
 micropower, 448, 449g

- modules, 449
 “pulling”, 435
 series and parallel modes, 444, 444g
DDS, 451, 453, 455, 471r, 969, 1065, 1082, 1089
 emitter-coupled, 440
GPS-disciplined, 451, 471r
Gunn-diode, 434, 435
Hartley, 440, 440, 442
 inverter chain, 435, 973
JFET, 155
 - low-noise, 441
 - spectrum, 442g
 jitter, 457, 971
LC, 439, 470r
 - electrically tunable, 440
 local (LO), 395, 562, 971, 1139
 low-distortion, 437, 438, 1152
MEMS, 960, 971
 microwave, 1152
 not needed in μ C example, 1056
OCXO, 968
 op-amp
 - triangle wave, 239
 - parasitic oscillations in, 426**Peltz**, 440, 440
 phase noise, *see* phase, noise
 phase-shift, 438, 439
Pierce, 447, 447
PLL, 452, 471r
 precision, 1152
 precision VCO, 267
 programmable, 267
 quadrature, 454, 454s, **453–456**, 470r
quartz crystal, **443–450**
 ratiometric, 431
 relaxation, 267, 432, **425–435**, 470r
 - 555, 429
 CMOS logic, 426, 427, 559
 diac, 428
 high-voltage, 428
 neon, 428
 op-amp, 425, 426
 unijunction, 427, 428
 resistor-programmed, 433, 433g
 ring, 960
SAW, 450, 471r, 960, 971
 sawtooth, 430, 430, 917, 918
 silicon, 432, 433t
 sinewave, **435–443**, 470r
 - Wien bridge, **436ff**, 437, 438, 452t, 470r**TCXO**, **OCXO**, 450, 471r
 triangle, 239, 267, 431, 432
 tuning-fork, 441
 types, 452t
 varactor-tuned, 441
VCXO, 446, 471r, 960, 965, 969, 971
 voltage-controlled, 267, **434ff**, 470r, 959
 - in PLL, **959**
- Wien bridge**, *see* oscillator, sinewave, 847
 with integrated divider, 434
YIG, 434, 435
- oscilloscope**, 2, **1158ff**
 - analog, 1152, **1159**
 - digital, 1152, **1162ff**, 1163
 - aliasing, 1164
 - dead time, 1164
 - hints, 1160
 - probe, 67, 808, 809, 810s, 1160, **1161**
 - active, 809, 809s, 810p, 1161
 - current, 1161
 - skew, 1164
- OTA** (operational transconductance amplifier), 100
- output**
 - comparator stage, **811**
 - comparator swing, 810
 - creating differential, 372
 - current, comparator, 811, 811g
 - current, op-amp, 272t
- output current**
 - critical, in SMPS, *see* switchmode
- oven**, 450, 681
- overcompensation**, *see also* op-amp, 285, 285, 286
- overcurrent protection**, *see* current, limiting, *see* power supply, *see* voltage regulator
- oversampling**, *see* sampling
- overtemperature**
 - sensor, *see also* sensor, 13, 14, 203, 602, 604, 604 (box), 608, 671
 - absent, 695
- overvoltage**, *see also* switchmode, OVP, 691
 - shutdown, *see also* crowbar, *see also* power supply, 598, 658t, 672, 687, 691, 702r, 825
- OVP**, *see* overvoltage, *see* switchmode
- packet**, 1138
 - switching, 1141
- PAL**, *see* programmable logic device (PLD), 1062
- PALASM**, *see* programmable logic device (PLD)
- parallel**, 2
 - bootloader, 1091
 - capacitors, 21
 - conversion, *see* ADC
 - impedances, 46, 69r
 - JFETs to reduce noise, 509
 - MOSFETs, 201
 - port, 999–1002, 1063, 1066, 1067, 1069, 1081, 1084, 1095r
 - resistors, 5
 - resonant crystal mode, 444, 444g, 446g
- parameters**
 - unspecified, 295
- parasitic**
- coupling**, *see* capacitive coupling
- oscillation**, *see* oscillation
- SCR**, *see* SCR
- parity generator**, 728
- pass transistor**, *see* transistor, *see* voltage regulator, linear
- pattern sensitivity**, 857, 871s
- PC board design**, *see* AoE 2nd ed., pp 816–852, 954
- PC104**, *see* computer, data bus
- PCB**
 - ground plane, 759, 857
 - ground wiring, 758
- PCI**, *see* computer, data bus
- PCIe**, *see* computer, data bus
- PCM**, *see* modulation, pulse-code
- peak detector**, 156
 - active, 254, 255
 - passive, 254
- peak-to-peak**
 - amplitude, 14
 - full-power bandwidth, 251g
 - output swing, **246**
- PECL**, 874
- permeability**, 29
- perpetual motion**, 116
- PGA**, *see* amplifier, programmable gain
- phase**
 - control in DDS, 1068
 - detector, *see also* PLL, 575
 - equalizer, 415
 - error
 - of op-amp, 314, 315g, 315t
 - margin, 247, 263, 276, 282
 - noise, 966, 968, 971
 - sequence filter, 455, 456, 456g
 - shift, *see* phase shift
 - splitter, 105
 - with discrete BJTs, 88
- phase shift**
 - and feedback stability, *see also* Bode plot, **281–285**, 285
 - control in SMPS, 659
 - filter comparison, 404g
 - oscillator, 438
 - RC* lowpass, 50g
- phase shifter**
 - constant-amplitude, 89, 89
- phase-locked loop**, *see* PLL
- phase-sequence filter**, *see* filter, *see* phase phasor, 51, 52g, 89
- photoconductive mode**, 537n, 831 (box), 841n
- photocoupler**, *see* optocoupler
- photodiode**, **841**
- photometer**
 - single-supply, 265
- photomultiplier**, 842, **842**
 - amplifier, 843

- photon counting, *see* avalanche photodiode, *see also* optoelectronics, APD
 photoresistor, 206, 844p
 phototransistor, **841**
 photovoltaic mode, 537n, 831 (box), 841
 photovoltaic stack, 204, 849, 850
 PHY, 871
 pi network, 1109, 1124
 PIC, *see* microcontroller
 pickup, 59, 442
 - common-mode, 583
 PicoGate, *see* mini-logic
 PID loop, *see* feedback
 Pierce oscillator, *see* oscillator
 piezo, 24, **1054**, **1055**
 piezo amplifier, *see* amplifier
 piezo driver, 207, 333
 piezoelectric effect
 - capacitor, in, 682n
 - crystal, 443
 pink noise, *see* noise
 PLA, *see also* programmable logic device (PLD)
 platinum RTD, *see* sensor, temperature
 PLD, *see* programmable logic device (PLD)
 PLL, 435, 452, 972t, **955–974**, 987r, 1066, 1072
 - AM demodulation, 970
 - block diagram, 956
 - Bode plot, 961g, 963g
 - BPSK demodulation, 971
 - capture and lock, **964**
 - capture transient, 964, 965
 - clock generation, 972, 1072
 - “cut and try”, 963
 - design, **960–964**
 - first-order loop, 960
 - FM demodulation, 969
 - frequency multiplier (design example), **961–964**
 - circuit, 962
 frequency synthesis, 442, **966–969**
 - fractional-*n*, **966**, **966**
 - rational-approximation, 968, **968**
 laser offset locking, 973, 973
 loop
 - block diagram, 961
 - loop filter, 395, 960, 961, 988r
 - loop gain, 962, 962 (box)
 - loop stability, 960, 961
 - phase detector, 957, 957g, **957ff**, 957t, 958g, 958s, 959g, 987r
 - anti-backlash, 959
 - backlash, 958
 - dead zone, 958
 - pulse synchronization, 971
 - rejection of noise and jitter, 974
 - sampling clock, 907
 - second-order loop, 960
 signal regeneration, 971
 some realities, 964
 spur removal, 395
 VCO, **959**
 - 4046-type, 959, 959s
 - VCO variability, 964
 - with JFET oscillator, 394
 PMT, *see* photomultiplier
 pod, 745, 769, 1036, 1053, 1059, 1090, 1091, 1096
 polar coordinates, 1098
 pole, 52, 69r
 - off-axis, 393
 - splitting, 114
 pole-zero, *see* compensation
 POP, 995
 popcorn
 - noise, 477, 478g
 positive-true, *see* logic
 pot, *see* potentiometer
 pot core, 29, 581
 potential difference, *see* voltage
 potentiometer, 7, 8p, 63
 - digital, *see also* EEPOT, 63, 184, 412, 1082
 - taper, 739
 power, 2
 - ac detect, 1081
 - ac monitor, 1082
 - an hour of (design example), 466
 - density
 - battery vs capacitor, 690g
 - design, **623ff**
 - dynamic, *see* current, 754
 - entry module, 629, 630, 631, 699r
 - factor, 47
 - correction in offline SMPS, 668, 699r
 - in offline SMPS, 661, 699r
 - in unregulated supply, 635
 - five minutes of, 196
 - in ideal capacitor, none, 19, 47
 - in reactive circuits, 47
 - in resistor, 6
 - micro, *see* micropower
 - minimizing, in CMOS design, 754
 - one minute of, 23
 - phantom, 1046n
 - precision source, 285
 - quiescent
 - in CMOS, 185, 718, 719g, 790
 - in ECL, 719
 - in FPGAs, 769
 - in nMOS inverter, 185
 - in push-pull stage, 106ff, 107, 108, 215
 - in TTL, 718, 719, 758
 - semiconductor packages, 628, 629p
 - spectrum
 - from PRBS, 977, 979g
 - supervisor, 613, 691, 755, 755, 803, 1079
 - switching, 755
 - from logic levels, 192
 - with MOSFETs, 192–200
 - with outboard driver, 237
 too hot!, *see* heatsink, sizzle test
 tradeoffs
 - noise, 483g, 509g, 525g
 - speed, 792g
 train, *see* switchmode (SMPS)
 transfer, 11
 transistor, **624ff**
 - series connection, 697
 power dissipation
 - capacitance, 719, 719g
 power supply, *see also* voltage regulator, **594ff**, 595p
 - auxiliary, 668
 - clamp, 692
 - commercial modules, **684**, 685p
 - current limit, 597
 - foldback, 693, 694, 694g
 - of outboard pass transistor, 695
 - favorites, 1152
 - filtering, 32
 - flying capacitor
 - droop, 639g
 - ripple, 639g
 - high voltage, **695ff**, 696, 1152
 - kick-start, 669
 - laboratory, 608, 608, 611, 1152
 - linear
 - compared with switchmode, *see also* switchmode, 635ff
 - topology, compared with SMPS, 630
 - low noise, **578ff**, 580g, 913
 - low-noise, *see also* AoE 2nd ed., p 375
 - modular, **684**, 685p
 - noise, *see* noise
 - offline, *see* switchmode, offline
 - overvoltage protection, 598, **690ff**
 - pass transistor, *see* transistor, pass
 - power-factor correction, 661
 - programmable, *see* programmable rectifier, 634
 - damping spikes, 634
 - regulated, 123
 - regulator, 34
 - resonant charging, 40
 - ripple voltage, 33
 - sequencing, 912
 - spike, 635n
 - spikes, 633n, 634
 - split, 34, 630, 639
 - storage capacitor, *see also* capacitor, 633
 - ripple current in, 634
 - supervisor, *see* power
 - switchmode, **636ff**
 - ac-powered, *see also* power supply, *see also* switchmode, offline
 - compared with linear, 630, 635ff

- controller ICs, 658t
 current-mode ICs, 654t
 programmable, 1086
 voltage-mode ICs, 653t
 uninterruptible, 673, 673s
 unregulated, 630, 699r
 bench vs SPICE, 634, 635s
 from ac powerline, 628ff
 power factor in, 635
 voltage multiplier, 34
 power-on reset, *see* reset, logic startup
 powerline
 capacitor, 631, 668
 discharge resistor, 632, 668
 controller, 1063
 entry, 629
 filter, 631
 monitor, 1082
 monitor IC, 943, 943
 rejection in integrating ADC, 914, 934
 switch, 631
 transformer, 632
 leakage inductance in, 633
 rating, 632
 wiring, 628ff, 943
PRBS, 558ff, 762r, 770–782, 974–982, 988r
 8051 assembly code for, 783
 ABEL code for, 776
 analog noise from, 975, 977–982
 analog noise voltage, 978
 C-language code for, 784
 chipping sequence, 975
 digital
 filter, 979
 eye diagram, 871s
 feedback shift register, 975, 976, 979
 properties, 976
 taps, 976t
 noise generator, 559, 771
 spectrum, 560s
 noise source
 circuit, 980
 power spectrum, 977, 979g
 Verilog code for, 778
 VHDL code for, 780
 with cPLD, 772
 with discrete logic, 559, 771, 772
 with ECL logic, 981, 983p
 with microcontroller, 777ff, 782
 assembly code, 779, 783
 C-language code, 782, 784
 with PLDs, 981
 wrapup, 981
 pre-emphasis, 864, 870, 870, 871s, 873g
 precision
 vs dynamic range, 292, 388r
 prefixes, 4 (box)
 printed circuit
 SMT vs through-hole, 268, 269
 printer port (Centronics), *see* computer, data bus
 priority encoder, *see* logic
 probe
 active, 810p
 for logic signals, 808, 810p
 probing
 digital signals, 808, 809s, 810p
 program
 multiplex video, 1138
 programmable (with voltage)
 current source, 228–230, 367, 896
 oscillator, 267
 power supply, 605, 607, 610
 pulse generator, 918
 timer (one-shot), 242
 voltage source, 195
 programmable logic device (PLD), *see also*
 logic, 728, 737, 745, 763r, 765p, 787r,
764–789, 797, 1036
 ABEL, 764, 775, 776
 address decoder, 1000
 advice, 782ff, 788r
 applications, 787r
 cPLD, 764, 766, 789r
 PRBS bit generator, 772–777
 CUPL, 764
 FPGA, *see also* FPGA, 764, **768**, 787r, 1031
 configuration memory, 769
 logic element, 770
 GAL, 764
 HDL, 745, 764, 765, 787r
 behavioral coding, 777, 778
 structural coding, 777, 779
 HDL entry, 775ff, 787r
 advantages, 777, 787r
 in-circuit programming, 764, 769, 774
 macrocell, 764
 mixed-signal, 769
 netlist, 769, 787r
 noise generator, 981
 output characteristics, 798g
 packages, 765p
 PAL, 764, **765–768**
 circuit, 766, 767
 macrocell, 768
 PALASM, 764
 PLA, 768
 place and route, 769, 773, 787r
 pod, 745
 programmer, 769, 773, 1152
 programming, 787r
 schematic entry, 745, 773, **773ff**, 774, 787r
 advantages, 775, 787r
 software, 769
 Verilog, 775, 778
 VHDL, 745, 765, 775, 777, 780
 WebPACK, 770n
 when to use, 782ff
 programmable oscillator, 267
 programmable-gain amplifier (PGA), *see*
 amplifier
 propagation time, 710
 protection, input, *see* input protection
 proximity sensor, *see* sensor
 pseudo-differential, 275, 583
 pseudo-op, 996
 pseudo-random bit sequence, *see* PRBS
 pseudocode, 1056
 PSoC, *see* microcontroller
 PTAT, *see also* bandgap, 92n, 104, 431n, 604
 (box), 606, 621, 679, 680
 pullup
 active, 270, 717, 720, 721
 current-source, 85, 696
 passive, 185
 resistor, 5 (box), 185, 209, 237, 623, 712,
 720, 721
 pulse, 16
 code, *see* modulation, pulse-code
 duty-cycle
 limiting, 465
 forming network, 1126
 from step, 77, 458ff, 459s
 generator, 17
 high-voltage, 333, 917, 918
 long pulses, 740
 n-pulse, **752**, 753
 programmable pulse-width, 241
 single, 739
 single-pulse, 739
 triggerable (design example), 739, 740
 with discrete BJTs, 77–79
 with flip-flops and counters, 739
 height analysis, 914
 limiting width of, 465
 runt, *see also* logic, *see* runt pulse, 757
 spectrum of, 941g
 stretcher, 194
 synchronization
 with PLL, 971
 width modulation, *see* PWM
PUSH, 995
 push-pull
 BJT output stage, 81, 106–108, 129r
 biasing, 108
 crossover distortion, 107
 thermal stability of, 108, 214
 MOSFET output stage
 thermal stability of, 214
 op-amp power booster, 234
PWM, *see also* switchmode, 470r, 645, 699r,
 1061, 1062, 1072, 1077, 1094, 1095,
 1096r
 analog vs digital, 1072, 1072
 as digital-to-analog converter, 888, 888, 890,
 985r
 digital, 1072

- in class-D amplifier, 109s
 in switchmode converters, 642, 645ff, 656, 665
 in thermal control, 1070
 light dimming, 834
 rate multiplier as, 890
 thermal controller, **1069–1077**
 to DAC converter, 889
 torque-motor control, 890
 pyroelectric detector, 841p
- Q (quality factor), 53g, **53ff**, 54g
 of crystal, 443
 spoiling, 53
 QAM, 456
 quadrature, 395n
 detector, 969
 encoder, 844p, 852, 1066
 FM demodulation, 969
 oscillator, 454, 454s, **453–456**, 470r
 RF, 455
 square waves, 455
 quadrature-amplitude modulation, *see* QAM
 quantization
 noise, 927g
 quiescent, *see* current, *see also* power
 quieting
 in FM, *see* AoE 2nd ed., p 898
- R–2R*, *see* ladder
 Rabbit, *see* microcontroller
 radio
 AM, 55, 56s
 waveforms, 55g, 56s
 radiofrequency, *see* RF
 rail splitter, 262, 277
 rail-to-rail, *see* op-amp
 ramp, 15
 generator, 27
 random walk, 981
 RAS, 1019
 Raspberry Pi, 1053n
 raster, 1132
 rate multiplier
 as PWM, 890
 ratiometric, 123, 431, 739, 884, 1072
 r_{bb} , *see* BJT
 RC circuit, 21, 21g, **21ff**
 RC snubber, *see* snubber
 RCA, *see* connector
 reactance, **40ff**
 graph of, 49g
 reactive circuits, **40ff**
 power in, 47
 read cycle, *see* computer, programmed IO, *see also* memory
 reading and references, **1154ff**
 rectification, **31ff**
 rectifier, *see also* diode, 12, **31ff**, 32t, 634
- active, 238ff, 289r, 634, 634n
 bridge, 32, 33, **612**, 613, **630**, 662s, 699r, 805
 active, 634n
 dual-voltage input, 660
 fast-recovery, 670
 forward drop, 31
 full-wave, 32
 active, 257
 full-wave center-tapped, 33
 half-wave, 32
 inrush current in, 651
 power supply
 spikes, 633n, 634
 Schottky, *see* diode
 signal, 35
 soft-recovery, 670
 synchronous, 289r, 634
 reference
 design, 671
 reflection coefficient, 1117
 refresh, *see also* memory, dynamic display, 1001
 register, *see* logic
 regulation
 cross, 672
 line, 595n
 load, 595n
 secondary, in SMPS, 671
 regulator, *see* voltage regulator
 series pass, 598
 relay
 driver, 194
 driving from logic, 817ff
 electromechanical, 59, 818
 latching, 459, 515, 819
 low-level, 515
 optocoupled, **843ff**
 solid-state, *see* SSR
 reset
 logic startup, 691, 755, 755, 1079
 of core, in SMPS, 657
 resistance
 base-spreading, *see* BJT, r_{bb}
 dark, 206, 537n, 1059
 dynamic, *see also* BJT, emitter resistance, 12
 internal, 10
 leakage, 10
 negative, 7, 397, 646, 650n, 1113
 noise, *see* noise resistance
 of analog switch, 175, 948n
 ON, *see* analog switch, FET, *see also* MOSFET
 small-signal, 12
 source, 10
 thermal, *see* thermal resistance
 trimmer, *see* trimmer
 resistor, 3ff, 3p, 5 (box), 68r
 4-wire, 294n
 accuracy, 1106t
- active, *see also* AoE 2nd ed., p 257, 416, 416
 bleeder, 211, 634
 carbon, 5 (box), 300, 476, 591, 696, 1105
 nonlinearity, 697, 698g
 chip
 sizes, 4n
 color code, 1105t
 current-sensing, 754, 760
 digital, 1082
 discharge, for powerline capacitor, 632
 E96 series, 1104t
 emitter-ballasting, 113, 113, 138, 146, 192, 201, 214, 508
 excess noise in, 476
 high-voltage, 698, 1104, 1105
 nonlinearity, 697, 698g
 in parallel, 5
 in series, 5
 international notation, 5n
 Kelvin, 277, 294n, 350, 365, 898, 1070
 metal-film, 5 (box), 300, 476, 679, 696, 1105
 negative temperature coefficient, *see also* sensor, temperature, thermistor, 661
 noninductive, 696
 nonlinearity, 697, 698g, 1106t
 positive temperature coefficient, *see* AoE 2nd ed., p 216
 power in, 6
 power package, 3p
 precision, 293, 300, 345, 348–350, 696, 1105
 precision divider, 679
 properties of, 300, 388r
 pullup, 5 (box), 209, 237, 623, 720, 721
 logic input, 805
 MOSFET as, 828
 on demultiplexer, 727
 series damping, 263, 263s, 264, 264
 source-ballasting, 192
 standard values, 1104
 suppression, 573
 T-network, 259
 tempco, 300, 679, 1106t
 thick-film, 1105
 thin-film, 1105
 types, **1104ff**, 1106t
 variable, 63
 JFET, 161
 stability, 679
 voltage coefficient, 697, 1106t
 voltage rating, 697, 697n
 wirewound, 3p, 5 (box), 8p, 476, 591, 1070, 1105
 resonance, *see* LC, *see also* capacitor, bypass, *see also* oscillator, crystal; oscillator, LC, *see also* power supply, resonant charging
 resonant
 charging, 39, 40

- circuit, 52ff
reverse polarity protection, 616, 665, 671
RF
driving cable, 862
noise measurement, 558
RFI (radiofrequency interference), 582, 668
ribbon microphone, 505
ring buffer, *see* buffer
ring detection, *see* AoE 2nd ed., p 985
ringback, 759
ringing
capacitive loads, 263s, 264
in SMPS, 668, 668n
logic signals, 809s, 856ff, 877r
ripple, 635, 636s, 639g, 699r
current, 644
effect of capacitor ESR, 639n
effect of switchmode frequency, 641
filtering, 619
in unregulated supply, 599, 632
of filter, 399
switchmode power supply, 636s
rise time, 16
of RC , 22
of filter, 400
slow causes failure, 426, 757, 801
RLL, 1041
rms amplitude, *see* amplitude
Rogowski coil, 944, 944
rotary encoder, 1066
RS-232, *see also* computer, data bus, 771, 872s, 871–873, 1038, 1038ff, 1039s, 1061–1063, 1066, 1081, 1089, 1095r
and cable length, 873
driver ICs, 872
levels, 873
mark, 1038
power, 874g
pseudo-random byte generator, 770
rates, 873g
signals, 1039t
START bit, 1038
STOP bit, 1038
timing ambiguity in, 1038
to USB adapter, 871n, 1064
RS-422, 864, 865, 865ff, 865s
levels, 873
power, 874g
torture test, 866, 866s
RS-485, 865, 865ff, 865s, 1038ff, 1061
isolated, 867, 868
levels, 873
power, 874g
rates, 873g
RTC, 1084
RTD, *see* sensor, temperature
rubidium, *see* oscillator, atomic
runt pulse, *see also* logic race, 738, 743s, 748, 753n, 757
- s-plane, 52
S/H, *see* sample-and-hold
S/PDIF, 1061
safe operating area (SOA), 113n, 192g, 216, 603n, 604 (box), 627, 702r
Sallen and Key filter, 399, 409
sample
PLL clock, 907
sample-and-hold, *see also* op-amp, 156, 183, 183, 256, 256g, 301g, 342, 388r, 843, 849, 904, 950
sampling, 419, 900ff, 901, 907
bandpass, 907
depth
and dynamic range, 900
direct IF to digital, 907
images, 931g
Nyquist criterion, 900, 901
over, *see also* delta-sigma, 901, 901, 902n, 924, 928
ratio (OSR), 924
rate
and aliasing, 900, 901
and bandwidth, 900
rate and aliasing, 931g
under, 901, 907
band conversion, 907
window, *see* window
SAS, *see* computer, data bus
SATA, *see* computer, data bus
satellite
geostationary, 1139
saturation, *see also* antisaturation, *see also*
BJT, *see also* comparator, *see also* FET
current, 132, 165n
current (I_{DS}), *see also* FET, drain
characteristics
current (I_S), *see also* BJT
Darlington, *see* BJT
IGBT desaturation, *see* IGBT
in BJT, 73
Schottky clamp prevents, 717n
in oscillator, 437
of magnetic core, 657, 659
of output, *see* op-amp, rail-to-rail
voltage, 165n
sawtooth, *see* oscillator
scaling
of IC feature size, 793n
scary stuff, 1025
schematic
diagram
how to draw, 1101ff
entry
in SPICE, 1146
ugly, 1102
Schmitt trigger, 128r, 237, 237, 237g, 267, 269, 270, 279, 279, 289r, 459, 717, 754, 755, 801, 801s, 803s, 805, 807, 807, 808s
logic input, 801, 801s, 802
speedup capacitor, 808s
transfer function, 237g
with discrete BJTs, 79
Schottky, *see* diode, Schottky
SCPI, 1065n
SCR, 691, 1062
latchup, *see also* AoE 2nd ed., Fig. 14.41, 222, 759, 795
overvoltage crowbar, 598, 672, 690ff
SCSI, *see* computer, data bus
SD card, 1082
SDR, 1021
second breakdown, 113n, 187, 216, 627, 702r
second-order loop, *see* PLL
Seebeck effect, *see* thermal EMF
sensor
ac power, 943, 944
acceleration, 1077, 1079p, 1082, 1084, 1095r
atom, 553ff
charge, 933
current, 943, 944
force, 1077
grasp, 372
gyro, 1077
inductance, 1084
light, 498, 548, 578, 837p, 841p, 844p
lightning, 497
magnetic field, 1082
proximity, 1084
rotation, 1077, 1082, 1095r
sound, 486, 505ff
strain, 297ff, 347, 348, 588, 937
suntan, 278–280, 922, 1054–1059
temperature, *see also* PTAT, 13, 14, 671, 1070
absolute, 621, 680
RTC, 1071
RTD, 347n, 1070, 1070n
semiconductor, 621, 680, 1070
theristor, 123, 372, 661, 1070
thermocouple, *see also* AoE 2nd ed., pp 988–992, 337, 341t, 367, 675n, 937, 1070, 1084
SEPIC converter, *see* switchmode
SERDES, 855, 870, 870, 874
sensor, *see* computer, data bus, *see also* logic
series, 5
capacitors, 21
damping, 263, 263s, 264, 264
feedback, *see* feedback
impedances, 46, 69r
resistors, 5
resonant crystal mode, 444, 444g
series-feedback pair, 122, 286
with JFET, 150, 151g
servo, 1069, 1074
SETI, *see also* AoE 2nd ed., p 1038, 973

settling time, 309g
 of *RC* lowpass, 309g
 of filter, 400
 of op-amp, 308ff, 320, 321t
 setup time, *see* logic
 SH-4, *see* microcontroller
 Shannon sampling theorem, *see* Nyquist criterion
 shielded twisted-pair, *see* STP
 shielding, 579ff, 581, 593r
 magnetic, 581
 shift register, *see* logic
 shoot-through, *see* current
 shootout
 ADCs, SAR vs $\Delta\Sigma$, 939
 at the ADC corral, 939t
 JFET vs BJT, 517
 low-power ADC, 941
 shot noise, *see* noise
 shrinkage factor, 391n
 shunt, 294n
 current, 277
 feedback, *see* feedback
 shutdown, *see also* overcurrent, *see also*
 overvoltage, 272t, 524t, 600, 653t
 fault, 847, 847
 regulator failure during, 606, 619
 thermal, 235, 602, 604 (box), 671, 825
 siemens, 6, 90n, 147
 sign extend, *see* AOE 2nd ed., p 794
 sign-magnitude, *see* number
 signal
 amplitude, 68r
 averaging, 575, 576
 bandwidth reduction by, 562, 575
 differential, 347ff, 705n
 generator, 17
 guard, 358, 360, 587
 mixed
 PLD, 769
 protector, 175
 regeneration
 with PLL, 971
 sampling, 419
 single-ended, 347, 705n
 slew rate of, 362
 to-noise ratio, *see* SNR
 transformer, *see* transformer
 signals, 13ff
 signed number, *see* number
 significand, 1048
 Silicon Valley, law of, 750g
 silicon-controlled rectifier (SCR), *see* SCR
 SIM Card, 1061
 simulation, *see* SPICE
 SINAD, 985r
 sinewave, 14
 3-level, 673
 arbitrary phase, 456

digital generation, *see* DDS
 from square wave, 394s, 435, 436s
 inverter, 673s
 modified, 673, 673s
 oscillator, *see* oscillator, sinewave
 Single Gate, *see* mini-logic
 single pulse, 739
 single slope
 conversion, *see* ADC
 single-ended
 logic signal, 705n
 signal, 347
 sizzle test, 625
 skepticism
 of fourth fundamental element claim, 18n
 of parts-per-billion claim, 437
 skew
 clock, *see* logic
 probe, *see* oscilloscope
 threshold, *see* logic
 timing, *see* logic
 skin depth, 1122g
 slew rate, *see also* op-amp, 328
 and jitter, 457
 causes interference, 581, 587, 705
 filtered, 1073
 in oscillators, 426
 of composite amplifier, 920
 of current source, 367
 of differential amplifier, 385
 of op-amp, 248, 307, 328, 329, 515, 862
 of signal, 362
 reduced, 222, 607, 650, 759, 820, 865, 871
 too slow, 757, 808
 slope
 compensation, 650
 SMA, *see* connector
 small-signal, 12, 80, 147
 impedance, 81, 245
 symbol for, 80, 90, 1097
 transistor, 74t
 SMB, *see* connector
 SMBus, 1061
 Smith chart, 1121
 smoke, 672n
 smoothness
 silky, 505n
 SMU, 554, 1115
 favorites, 1152
 SNR, 478ff
 snubber, 39, 630, 634, 656, 659, 660, 669
 SOA, *see* safe operating area
 SoC, 1031
 soft start, 606n, 607, 645, 650
 solar cell, 2
 soldering iron
 favorite, 1152
 solenoid, 29
 sound pressure level (SPL), 505ff

source
 degeneration, 148, 159, 160, 169, 346, 367
 sinewave, 41
 source follower
 JFET, 156ff
 gain, 157
 input impedance, 157
 low distortion, 160, 161g
 output impedance, 157
 tutorial, 159
 with active load, 158
 operating point, 156
 output impedance
 vs BJT follower, 157
 push-pull power MOSFET, 214
 source-measure unit, *see* SMU
 source-measure unit (SMU), 897
 Space (RS-232), 871
 SparkFun, 1082, 1095r
 spectrum
 analyzer, 567, 1152
 spreading, 649, 975
 SPI, *see also* computer, data bus, 887, 1028,
 1030, 1032ff, 1061, 1066, 1081, 1086,
 1087, 1094
 ADC SAR example, 909
 bootloader, 1091
 bridge, 1084
 in ADC, 937, 943, 945
 in DAQ, 946, 947, 954
 isolation in DAQ, 950
 microcontroller peripherals, 1083,
 1082–1084
 SPICE
 amplifier analysis, 314, 315g, 1148
 comparison with bench, 459s, 635s
 crystal analysis, 444ff, 445, 446g
 filter analysis, 393g, 399g, 414g, 456g, 560g
 fun with, 93n
 MOSFET models, 168n
 power supply analysis, 633–635, 635s
 primer, 1146ff
 pulser analysis, 459s
 simulation
 comparison with bench, 1148s
 transistor model, 482n
 unregulated power supply
 bench comparison, 634
 spike, *see also* charge injection, 17
 differentiated edge, 26s
 from discharge, 200
 from flyback, 38, 193
 from hard switching, 668
 from leakage inductance, 669
 from snapoff, 199, 633n, 634
 ground-current, 856
 in frequency domain, 978
 in power supply rectifier, 633n, 634
 in SMPS driver, 669, 669

- logic driving capacitive load, 857, 857
spur, see frequency removal, 394
 square wave, 16
 converting to sinewave, 394s
 quadrature, 455
 SRAM, *see computer, see memory, static*
 SSR, *see also zero-crossing, see also zero-voltage switching*, 24, 59, 823, 848ff, 850, 851, 875r, 877r, 1062, 1063, 1081, 1095r
 leakage current, 1062
 stabilized platform
 microcontroller, 1077, 1077p, 1079p
 microcontroller (design example)
 block diagram, 1078
 standing-wave ratio, *see VSWR*
 star network, 1042
 START and STOP, 771
 state machine, *see logic*
 state-variable filter, 410ff
 status bit, *see computer, programmed IO*
 status register, *see computer, programmed IO*
 step, 17
 response
 filter comparison, 405g, 406t
 stepping motor, 1084
 STM (scanning tunneling microscope), 553ff
 image of Si crystal, 554p
 storage capacitor, *see capacitor*
 STP, 583, 1117
 strain gauge, *see sensor*
 stripline, *see also microstrip*, 456, 858, 871s, 1117, 1119n
 stuck node
 tracer, 276g
 subroutine, *see also computer, instruction set*, 996
 subthreshold region, *see FET, see JFET*
 successive approximation, *see ADC*
 summing amplifier, *see op-amp*
 summing junction, 225, 225, 230, 250ff, 270, 288r, 297, 298, 319, 369, 384, 497, 511, 547, 550
 bias current, 257ff
 capacitance of, 547
 impedance of, 251
 suntan monitor
 delta-sigma, 922ff
 microcontroller, 1054–1059
 op-amp, current divider, 279
 op-amp, integrating, 278
 op-amp, two-step, 279
 with ADC, 922
 with microcontroller, 1054–1059
 superbeta, *see BJT*
 supervisory, *see power, supervisor*
 surface acoustic wave, *see oscillator, SAW*
 surface-mount technology (SMT), 3p, 65, 66p, 268, 269, 432n, 601, 603, 627p, 789r, 793, 1104, 1152
 size compared, 3p, 20p, 29p, 65p, 269, 269
 sizes, 4n, 269n
 susceptibility, 90n
 sweep generator, 17
 switch, *see also analog switch*
 3-way, 59
 analog, *see analog switch*
 as digital input, 802, 802, 1081
 bounce, 729, 802, 802, 803s
 break-before-make, 179, 920
 cold-weld sticking, 573
 debouncer, 753, 802s
 built-in, 803
 clocked, 803, 803
 keeper circuit, 803
 latch as, 730, 802, 803
 slowdown plus Schmitt, 802, 803, 803s
 software, 803, 804
 SR flip-flop, 802, 802
 SR flip-flop as, 730
 supervisor as, 803
 debouncing, 729, 802
 DIP, 57p
 dry-switching, 58, 804, 817
 floating, 203
 form A, 58, 803
 form C, 58, 803
 high-side, 825, 826t
 matrix, 1068, 1069, 1081, 1095r
 mechanical, 56, 57p
 MOSFET, *see MOSFET, see switchmode*
 opto-interrupter, 851
 PCB-mounting, 57p
 powerline, 631
 protected, 175, 824, 825t
 protecting, 823ff
 pushbutton, 58
 reed, 573
 rotary, 58
 self-wiping, 804
 simple logic with, 58
 SPDT, 56, 58, 803
 SPST, 56, 58, 803
 T-switch, 179
 toggle, 57p
 toggling, 195
 switched-capacitor
 ADC, *see also ADC, charge redistribution*
 see also switchmode, inductorless filter, 415ff
 integrator, 416
 resonator, 454
 switching
 active, 32n, 643
 amplifier, 109, 109s, 673
 cold, 75, 725
 dry, *see switch*
 hard, 659, 671
 high-side, 77, 193, 195, 196, 820, 820ff, 821, 821, 823, 825, 826, 828
 loss, 662, 671, 1073
 soft, 671
 synchronous, 32n, 643
 switchmode (SMPS), *see also power supply, see also voltage regulator*, 609, 636ff, 699r
 basic topologies, 641ff, 642
 boost, 30, 647, 647, 700r
 bridge converter, 659, 700r
 buck, 30, 642ff, 700r
 intrinsically regulated, 643
 buck, examples, 644ff, 645, 646
 buck-boost, 649, 651, 700r
 burst mode, 643n
 compared with linear, 630, 635ff
 continuous-conduction mode, 644, 670n
 controller ICs, 658t
 core
 gapped, 656, 670
 core reset, 657
 critical conduction mode, 643
 critical output current, 643
 cross regulation, 672
 Ćuk, 649, 700r
 current discontinuity in, 649, 651
 current pulsation, 649–651
 current-mode, 642, 649, 651, 651ff, 701r
 pros and cons, 652, 701r
 current-mode ICs, 654t
 design equations, 644, 647, 648, 656, 657, 659
 discontinuous-conduction mode, 645, 666, 670
 duty cycle, 643
 efficiency, 636, 637, 646, 672
 feedback stability, 650, 669
 flux balance, 659
 flyback, 655, 657, 665, 700r
 power train, 671
 transformer in, 670
 forward converter, 656, 700r
 H-bridge, 655, 659
 hysteric, 644, 644, 700r
 inductorless, 638ff, 639g, 640t, 699r
 regulated, 641
 ripple, 639n, 641
 internally compensated, 645ff
 inverting, 648, 648, 700r
 isolated, 653ff, 700r
 flyback, 655
 topologies, 655
 LED driving, 832
 loss, 662
 low-noise, 649, 673n
 minimum output current, 643, 672
 negative input resistance, 646, 650n, 672

- noise, 636s, 637, 649, 672, 673n
 noise spectrum, 636g
 non-isolated, 641ff, 642
 boost, 647, 647
 buck, 642ff
 buck, examples, 644ff
 buck-boost, 651
 design equations, 644, 647, 648
 hysteretic, 644
 internally compensated, 645ff
 inverting, 648, 648
 waveforms, 643, 647, 648, 652
 wrapup, 649ff
- offline, 637, 656, 657, 660ff
 dual-voltage, 660
 feedback, 662
 input filter, 646, 650n, 660, 661, 665, 668, 672
 input transient, clamp, 669
 inrush current, 661, 668
 power-factor correction (PFC), 661, 661, 662s, 668
 real-world example, 665ff
 safety, 672
 when to use, 672
 wrapup, 672
- OVP, 654t
 phase-shift control, 659
 point-of-load, 637n, 685
 PWM, 659, 701r
 PWM modes, 651ff
 reference design, 671
 regulation, 630, 637, 637, 641, 642, 645, 646, 649–651, 656, 657, 659, 659, 662, 665, 671, 672, 700r
 ringing, 667s, 668
 ripple, 636s, 642, 645, 646, 649
 SEPIC, 649, 700r
 slope compensation, 650
 soft start, 650
 synchronous switching in, 643
 topologies, 638, 700r
 compared with linear, 630
 transformer in, 653
 voltage-mode, 642, 649, 651, 651ff, 701r
 pros and cons, 652
 voltage-mode ICs, 653t
 waveforms, 643, 647, 648, 652, 666, 667s
 wrapup, non-isolated, 649ff
 zero-current switching (ZCS), 650, 659
 zero-voltage switching (ZVS), 650, 659, 671
- synchronous, *see also* logic, *see also* memory
 counter, *see* logic, counter
 switching, *see* switching
 synchronous detection, *see* bandwidth, narrowing
 synthesizer, *see also* frequency, synthesizer, 17
 clock, 1084
 Sziklai, *see* BJT
- T network, 259, 1109, 1124
 tables, *see* Table of Contents
 take-back-half, 1075
 convergence, 1076g
 tank circuit, *see also* AoE 2nd ed., p 883, *see* LC
 tape
 electrical, 63p
 helical, 1135
 Kapton, 626
 taper, 739
 TCP/IP, 1094, 1140
 Teensy, 1053n
 Teflon, 299n, 301g, 326
 television
 analog
 broadcast, 1134
 recording, 1135
 spectrum, 1136s
 cable, 1134
 switched broadcast, 1142
 digital, 1136ff
 broadcast, 1138
 cable, 1138
 recording, 1142
 satellite, 1139
 spectrum, 1136s
 display technology, 1142
 HD, 1137
 satellite
 uplink, 1140p
 spectrum, 1137s
 tutorial, 1131ff
 temperature
 stabilized, 681
 oscillator, 450
 voltage reference, 676, 681
 temperature coefficient
 autozero amplifier, 335t, 339
 bandgap reference, 604 (box), 679
 BJT base voltage, 140
 collector current, 92
 crystal oscillator, 450
 FET drain current, 138, 138g, 547n
 FET gate current, 163
 FET gate voltage, 140
 IC reference, 677, 678t
 IC zeners, 676
 MOSFET R_{ON} , 187, 192, 202, 212, 213g, 215g
 MOSFET drain current, 212, 214, 215
 offset voltage, 244, 289r, 306, 388r
 resistor, 300, 388r, 679, 1105
 ways to specify, 683g
 zener diode, 674, 675
 temperature compensation
 bandgap reference, 604 (box), 679, 701r
 crystal oscillator, 446n, 450
 current source, 87, 431
- transistor, 87, 97, 102
 zener diode, 674
 temperature controller, *see* thermal controller
 temperature sensor, *see* sensor
 termination
 of transmission line, 739, 858ff, 1117
 texting, 707n
 Thévenin equivalent Circuit, 69r
 Thévenin equivalent circuit, 9ff, 69r
 examples, 1108
 Thévenin's theorem, 1107ff
 generalized, 55
 thermal controller, 123
 microcontroller, 1069–1077
 thermal EMF, *see also* op-amp, autozero, 339, 340, 675n
 thermal hysteresis, 683
 thermal resistance, 216, 603n, 624ff, 701r
 of heatsinks, 626g
 of PCB foil, 627g
 transient, 628, 702r, 1073
 thermal runaway, *see also* second breakdown, 108, 108ff, 112, 187, 212ff, 214, 215
 absent in MOSFET, 138
 thermal shutdown, *see* shutdown
 thermistor, *see* sensor
 thermocouple, *see* sensors, temperature
 three-state, *see* logic
 three-terminal regulator, *see* voltage regulator
 three-way switch, *see* switch
 threshold voltage, *see* FET, *see* JFET, *see* logic, *see* Schmitt trigger
 thyristor, 208, 581
 TIA, *see* transimpedance amplifier
 time
 delay, *see also* latency
 filter comparison, 404g
 in ADC, 903
 minimized with DMA, 1010
 delay circuit, 23
 hold, *see* logic
 latency, *see* latency
 propagation, *see* logic
 removal, *see* logic
 ripple-through, *see* logic, counter
 rise, *see* rise time
 settling, *see* settling time
 setup, *see* logic
 standard, 1152
 storage, *see* BJT
 time constant, *see also* rise time, 22
 time-interval measurement, *see* AoE 2nd ed., p 1022
 time-to-amplitude converter, *see* converter
 timer, 457–469, 470, 471r, 1096r
 555, 460, 460
 an hour of power, 466
 camera control (design example), 467
 ICs for, 468

- microcontroller as, 469
 one second per hour, 467
 programmable, 241
timing
 skew, 737n, 1027
TinyLogic, *see* mini-logic
 toggle, *see* logic, flip-flop, *see* switch
 tolerance, 6, 299, 388r
 effect on filter response, 402g
 tools
 favorites, 1152
 toroid, 581, 585
 common-mode choke, 584
 totem-pole, 697, 697
 touchscreen, 1082, 1084
 touchscreen digitizer, 944
 track-and-hold, *see also* op-amp, 256, 909
 tracking ADC, 909
 transconductance, *see also* BJT; FET; JFET, 89, 91
 amplifier, *see also* OTA, 90, 90ff
 enhancer, 148
 transconductor, 99
 transducer, *see* sensor
 transfer function, 7
 transform, *see* Fourier
 transformer, **30**
 balun, 379, 380
 bifilar winding, 656
 current, *see* current
 flyback, *see* inductor
 for wideband ADC input, 382
 gapped, 656, 670
 in feedback loop, 286, 536
 in switchmode converter, 653, 699r
 inductance, *see* inductance
 isolated SMPS, *see also* switchmode, **653ff**, **670**
 isolation, 672
 leakage inductance, *see* inductance
 powerline, 632, 699r
 leakage inductance in, 633
 rating, 632
 pulse
 for isolated feedback, 663
 signal, 497, **535–537**, 1124
 signal isolator, 586
 toroidal, *see also* toroid, 29, 29p, 537, 581
 variable, 64p
transient
 averaging, *see* bandwidth, narrowing
 capture, in PLL, 964
 suppressor, 632, 670, 699r
 thermal resistance, 628, 702r, 1073
transient response
 of voltage regulator, 617
transimpedance amplifier, 233, 288r, 537, **537ff**, **547–549**
 bandwidth, **537ff**
- bootstrapped cascode, 550, 550
 bootstrapping, 547
 capacitive feedback, 552, 571
 cascode input, **548ff**
 commercial, 570
 compensation, **539ff**, 540–542g
 composite, **543ff**, **544**
 noise, 544s
 current calibrator, 555
 JFET hybrid, **544**
 noise, 499, 511, 532, 593r
 $e_n C$, 538, **538ff**, 540–542g, 542s, 543g
 input, 538
 reduction by bootstrapping, 547
 noise calculation, 539
 noise model, 539
 patch clamp, 552
 regulated cascode (RGC), 551
 stability, 537, 570
 STM, 553
 wideband
 example, 540
 world's best, 545
transistor, *see also* BJT; FET; JFET; MOSFET
 bias-resistor, 712n, 827
 bipolar, *see* BJT
 BJT switch, 73–79, 91
 diamond, 100
 digital, 712n, 827
 field-effect, *see* FET
 man, 75
 packages, 73p
 pass, 594, 596, 597, 598, 695, 699, 700r
 protection, 695
 perfect, 99
 photo, **841**, 841p
 power, **624ff**
 pre-biased, 712n, 827
 series connection of, 697
 superbeta, *see* BJT
 switch, 127r
 thermal resistance of, *see also* thermal
 resistance, 624
 unijunction, 427, 428
transmission gate, *see* logic
transmission line, **1116ff**
 and sinewaves, **1120ff**
 characteristic impedance, 1116
 derivation of, 1127
 computer bus as, 1027
 delay line, 1128p
 differential, 878r
 LVDS, **868–870**
 rejection of common-mode signals, 866, 866s, 869, 869s
 digital signals on, **858ff**, 878r
 power dissipation, 874g
 impedance matching, 1122
 broadband lossless, 1124
- minimum loss, 1123
 narrowband lossless, 1125
 reactive, 1125
 transformer, 1124
 loss, 1121, 1122g
 matched
 capacitance disappears, 1116
 pre-emphasis, 864
 reflection, 1027, 1117, 1118, 1119s
 resistive attenuator, 1123, 1124t
 ringing, 1119s
 termination, **1117ff**
 back, **1118**
 series, **1118**
 twisted pair, 1117
 unterminated, 859, 859, 860s, 1119
transresistance amplifier, *see* transimpedance
 amplifier
tri-state, *see* logic, three-state
 triac, 581, 691, 1062
 quadrants, 692n
 triangle wave, 15
 triboelectric effect, 573
 trigonometric function generator, *see* AoE 2nd
 ed., p 293
trigonometry, **1097**
trimmer
 capacitance, 64
 CMRR, *see* CMRR
 distortion, 438
 frequency, 466
 notch frequency, 415
 offset, 244, 251, **304ff**, 305, 305g, 355, 515
 resistance, 8p, 63, 66p, 1128p
 time, 466
 voltage, 600, 603, 671
truth table, *see* logic
TTL, *see* logic
 tuned circuit, *see* LC, resonant circuit
 tunnel diode, *see* diode
 TVS, 39, 670
 twin-T filter, 414
 twisted pair, *see* cable
 wideband analog over, 352, 353
UART, *see also* computer, **1038ff**, 1061, 1063, 1064, 1067, 1071, 1089, 1090, 1095
 bootloader, 1090
ugly
 diagram, **1102**
UHF, *see* connector
 unblanking, 1000
 uncompensated, *see* op-amp
 undersampling, *see also* ADC, *see* sampling
 undersampling, deliberate, 907
 undervoltage, 691
 lockout, 701r
 unicast, 1142
 uninterruptible power supply (UPS), 673, 673s

unity-gain frequency, *see also* op-amp, gain, vs frequency
 universe
 age of, 771, 988
 unshielded twisted-pair, *see* UTP
 unsigned number, *see* number
 unused input, *see* logic
 up-down counter, *see* logic, counter
 UPS, *see* uninterruptible power supply
 USB, *see also* computer, data bus, 1042, 1042,
 1062–1064, 1081, 1089, 1095r
 bootloader, 1091
 isolated, 1081
 to RS-232 adapter, 871n, 1064
 UTP, 1117

V to f
 conversion, *see* ADC
 varactor, *see also* diode, 64, 435, 960, 969, 971
 tuned oscillator, 440, 470r
 Variac, 64p
 varistor, 39, 632
 aging, 632
 V_{BE} , *see* BJT
 $V_{CE(\text{sat})}$, *see* BJT, saturation
 $V_{CE(\text{sat})}$ vs FET R_{ON} , *see* MOSFET, R_{ON}
 VCO, *see* oscillator, voltage-controlled
 VCVS, *see* filter, types, *see* filter
 Verilog, *see also* logic, *see* programmable logic device (PLD), 711, 745, 765
 vertical retrace, *see* video, composite
 VGA, 1062, 1132n
 VHDL, *see* programmable logic device (PLD)
 Vicoreen, 3p, 698
 video
 amplifier, *see* amplifier
 analog, 1132
 back-terminated, 315, 352, 859n, 862
 coax, 1140
 composite, *see also* NTSC, 1133, 1133s
 connectors, 1143ff, 1144p
 DAC, *see* DAC
 digitizer, 1084
 encoder, 1030
 field, 1133n
 frame, 1132
 interlaced, 1133n
 modulation, 1133
 multiplex, 1138
 multiplexer, 178
 on demand, 1141
 over Internet, 1140
 phase compensation, 314, 381, 864
 progressive, 1133n
 switch, 178
 sync, 1133
 volt, 2
 voltage, 1, 68r
 amplifier, *see also* amplifier, 88, 117

as complex quantity, 44ff
 burden, 10
 common-mode, *see* amplifier
 comparator output swing, 810
 compliance, 8
 converter
 flying capacitor, 183
 defined, 1
 divider, 7, 7
 adjustable, 7
 equation, 7
 generalized, 48
 doubler, *see also* charge pump, 34, 34, 639,
 660, 872, 1063
 drop
 of diode, 31
 dropout, *see* voltage regulator
 Early, 93, 151n, 502
 electrostatic, 200t
 gain with RC , 71n
 high, *see* high voltage
 inverter, 639, 872, 1063
 Kirchhoff's voltage law, 2
 logic threshold, 796
 mode, *see* switchmode
 multiplier, 34
 noise, *see* noise
 offset, *see also* amplifier, *see also* op-amp,
 366
 cancelling V_{BE} , 85, 87
 comparator, 812
 correction with DAC, 949
 JFET, 139, 512, 515
 op-amp, 244
 offset in op-amp, *see* op-amp
 power-supply ripple, 33
 reference, *see* voltage reference
 regulator, *see* voltage regulator
 saturation, *see also* BJT, *see also* saturation,
 165n
 signal, 14, 21–27
 source, *see also* SMU, 8
 8-channel, 893, 895
 low-noise, 891, 892
 stiff, 37
 source, general laboratory, 891, 892
 spike, *see* spike
 thermal, kT/Q , 136n
 thermal, kT/q , 91
 thermoelectric, 341t
 threshold
 of digital logic, 797g
 trigger, *see also* Schmitt trigger, 428
 triboelectric, 573
 voltage controlled, *see* programmable (with
 voltage)
 voltage controlled oscillator, *see* oscillator
 voltage reference, 275, 674ff, 700, 701r
 2-terminal, 677t
 3-terminal, 678t
 accuracy, 683
 aging, 683
 bandgap, 104, 599, 602, 604 (box), 606,
 611, 677, 678t, 679, 701r
 as temperature sensor, 680
 noise in, 679n
 current source with, 896
 drift, 683
 humidity, 684
 in DAQ, 949, 950
 JFET pinchoff, 680, 680, 701r
 line and load regulation, 684
 low tempco, 676, 676, 681
 MOSFET floating gate, 681, 701r, 912
 noise, 677t, 682g, 682, 701r
 precision, 681
 PTAT, *see* PTAT
 self-heating, 684
 series, 674, 678t, 701r
 shunt, 674, 677t
 tempco, 683, 701r
 ways to specify, 683g
 temperature stabilized, 676, 677t, 681
 trim, 683
 V_{BE} , *see* voltage reference, bandgap
 x-ray exposure, 684
 zener, 674ff, 701r
 biasing, 675
 bootstrap biasing, 676
 compared with bandgap, 679
 compensated, 674
 drift, 675
 dynamic resistance, 675g
 IC, 676ff, 677t
 LTZ1000, the spectacular, 675
 noise, 674, 676n
 tempco, 675g
 voltage regulator, *see also* power supply, *see
 also* switchmode (SMPS), 34, 82
 3-terminal, 700r
 as current source, 620, 620, 621g
 floating HV, 698
 317-style, 604 (box), 605t, 700r
 adjustable to zero, 605, 607, 608
 as current source, 620, 620, 621g
 circuit, 606
 dual voltage, 612
 dual-tracking lab supply, 608
 high-voltage supply, 609
 hints, 604, 607
 proportional fan control, 608
 protection, 619
 schematic, 603, 606
 337-style
 schematic, 606
 7800-style, 602t
 723, 598ff
 in defense of, 600

- current limit, 619, 693
 foldback, 693
 current-reference, 611
 dropout, 599, 600, 700r
 emitter follower as, 82
 extending V_{IN} , 211, 693
 fault protection, 619
 filtering, 619, 620
 floating, 698
 fully integrated, 600ff
 high voltage, 609, 610, 695ff, 696
 linear, 699r
 3-terminal adjustable, *see also* 317-style, 602ff, 603
 3-terminal fixed, 601, 602, 602t
 adjustable to zero, 605, 607, 608, 611, 612
 bypassing, 616
 choosing, 613
 crowbar, 598
 current limit, 597
 dropout voltage, 606g
 error amplifier, 597
 feedback stability, 597
 ground-pin current, 616
 high-voltage, 693, 698
 idiosyncrasies, 613
 LDO stability, 617, 617g
 noise, 618
 pinouts, 613
 reverse polarity, 616
 taxonomy, 601
 transient response, 263g, 263s, 264, 617, 618s
 tutorial, 595ff, 596
 load dump, 618
 low-dropout, 561, 599, 700r
 low-dropout (LDO), 610, 610ff, 611, 612g, 614, 615t
 excess current near dropout, 616
 stability, 617, 617g, 700r
 LT3080-style, 611, 611
 as current source, 620, 620, 621g
 op-amp, 235
 point-of-load (POL), 685
 protection, 606, 607, 619
 ramp-up control, 606n
 schematic, LM317, 603, 606
 schematic, LM337, 606
 switching, 609
 taxonomy, 699r
 zener as, 595
 voltmeter, 2
 sensitive (design example), 253, 293
 true rms, 568
 VOM, 10
 von Neumann architecture, *see* computer, architecture
 VSWR, 1121
 wall plug
 blades and wires, 628n
 wall wart, 637n, 686
 wall-wart, 661
 watchdog, 755, 1059, 1061, 1064, 1067, 1079, 1096
 watt, 2
 wave
 standing, 1121
 waveform
 sampling, 419
 Wheeler's formula, 29
 white noise, *see* noise
 wideband
 analog link, 380
 Widlar, Bob, 97n, 101n, 102, 307, 598ff, 604 (box), 679
 Wien bridge, *see* bridge, *see* oscillator, sinewave
 WiFi, 1053, 1062
 Williams, Jim, 316n, 330, 438n, 1074, 1154
 Willison, John, 968
 Wilson mirror, *see also* current, mirror, 102, 102, 146
 window
 averaging, 562n, 941g
 comparator, *see* comparator
 quartz, 769, 1023
 sampling, 420
 tradeoffs, 421
 switch, 573
 wire
 in Verilog, 777
 long
 digital signals through, 856ff, 877r, 1117
 wired-AND, -OR, *see* logic
 wirewound resistor, *see* resistor, wirewound
 Words and Phrases, 714n
 world's best
 DMM, 918
 frequency-control algorithm, 1068
 low e_n amplifier, 505
 low-distortion oscillator, 437, 438
 low-memory capacitor (Teflon), 301g
 low-noise power supply, 578, 580g
 multichannel fast $\Delta\Sigma$ ADC, 956
 op-amp noise plot, 526g, 531g
 precision current source, 898
 precision resistor, 227n, 300, 1105, 1106t
 PWM DAC, 889
 transimpedance amplifier, 544, 545
 voltage reference, 675, 677t, 681, 684, 892n, 920n
 worst-case specifications
 violating, 296, 347, 388r
 write cycle, *see* computer, programmed IO, *see* memory
 X-capacitor, *see* capacitor, powerline rated
 XLR, *see* connector
 XOR, *see* logic, gates
 Y-capacitor, *see* capacitor, powerline rated
 yesterday, 273 (box)
 ZCS, 1062
 zener, *see also* diode
 active, 692, 692
 zero-crossing, 823
 detector, 269, 269
 solid-state relay, 823, 850, 851
 zero-current switching, 650, 823
 zero-voltage switching, 650, 823
 ZigBee, 1053, 1061
 ZVS, 850, 1062
 ZVS, ZCS, *see also* switchmode