



# INDEX

- A**
- Access time
  - defined, 788
  - ROM, 799
- Accumulator register, 318
- Acquisition time, sample-and-hold circuits, 762
- Active. (*See also* Asserted levels)
  - HIGH decoding, 390–391
  - logic levels, 88–89
  - LOW decoding, 391
- Actuator, 721
- Addend, 306, 318
- Adders
  - full, 319
  - parallel, 318–320
- Addition in
  - BCD, 312–314
  - binary, 298–299
  - hexadecimal, 314–315
  - OR, 58–62
  - 2's-complement system, 306–307, 328
    - addition
      - equal and opposite numbers, 307
      - positive number and larger negative number, 307
      - positive number and smaller negative number, 306
      - two negative numbers, 307
      - two positive numbers, 306
- Address, 788
  - bus, 794, 836
  - code, 254
  - decoders, ROM, 797–798
  - incomplete decoding, 841–843
  - inputs, 599, 790–791
  - multiplexing (in DRAM), 825–829
  - pointer registers, 845
  - setup time, 820
  - unidirectional, 794
- Advanced
  - CMOS, 74AC/ACT, 524
  - high speed CMOS, 74AHC, 525
  - low power Schottky TTL, 74ALS Series (ALS-TTL), 507
  - low voltage BiCMOS (74ALVT/ALB), 531–532
  - low voltage CMOS (74ALVC), 531
  - Schottky TTL, 74AS Series (AS-TTL), 507
  - ultra-low-power (74AUP), 531
  - ultra-low-voltage CMOS (74AUC), 531
  - very-low-voltage CMOS (AVC), 531
- Advantages of digital techniques, 6
- AHDL, 98–99, 409–410
  - adder, 342
  - adder/subtractor, 344–345
  - BCD-to-binary code converter, 654–655
  - BEGIN, 103
  - behavioral description of a counter in, 410
  - bit array declarations, 178–179
  - Boolean description using, 103
  - buried nodes, 105–106
  - cascading BCD counters, 421–423
  - CASE, 190, 417, 458–459, 639, 649
  - code converter, 654–655
  - comments, 105–106
  - comparator, 652
  - concurrent assignment statement, 103
  - CONSTANT, 344
  - converter, 654–655
  - counter, 277–278, 409–410, 459–461
  - decoder(s), 639–641
    - driver, 642–643
    - full-step sequence, 683
  - decoding the MOD-5 counter, 417–418
  - D latch, 271
  - DEFAULTS, 639, 650
  - demultiplexers, 649–650
  - design file, 182

- digital clock project (HDL), 693–710 (*see also* HDL)
- ELSE, 413
- ELSIF, 189, 413
- Encoder, 646–647
- END, 103
- essential elements in, 103
- flip-flops, 272–273
- four-bit adder, 342
- frequency counter project, 710–714 (*see also* HDL)
- full-featured counter, 412–414
- function prototype, 338
- IF/THEN/ELSE, 186, 646–647, 702
- INCLUDE, 707
- INPUT, 103
- intermediate variables in, 107
- JK flip-flop, 273
- keypad encoder project, 687–693 (*see also* HDL)
  - simulation, 693
  - solution, 689–691
- literals, 181
- MACHINE, 426–427
- magnitude comparator, 652
- multiplexers, 649–650
- MOD-5 counter, 406–407, 418
- MOD-6 counter, 698–699, 707
- MOD-8 counter, 682
- MOD-10 counter, 421–422, 700, 707
  - graphic block symbols, 705
- MOD-12 counter, 702–703
- MOD-60 counter, 707
- MOD-100 BCD counter, 421–423
- module integration, 707–708
- NAND latch, 270
- NODE, AHDL, 106, 339
- nonretriggerable one-shot, 462
- one-shots, simple, 462
- OUTPUT, 103
- PISO register, 455–456
- primitive port identifiers, 272
- retriggerable, edge-triggered one-shot, 465
- ring counter, 460
- ripple-up counter (MOD-8), 277–278
- SISO register, 453–454
- state descriptions in, 406–407
- state machines, simple 426–427
- stepper driver, 684
  - simulation testing, 686
- stepper motor driver project, 679–686 (*see also* HDL)
- SUBDESIGN, 103, 105–106, 178, 273, 341, 406, 413, 417–418
- TABLE, 640, 642–643, 646
- traffic light controller, 430–432
- truth tables, 181–182
- VARIABLE, 105, 272, 339, 406, 689
- Aliasing, 747–748
- Alphanumeric codes, 39–41
- ALTERA
  - cyclone family, 894–895
  - EPM7128S CPLD, 885–889
  - FLEX10K family, 890–894
  - function prototype, 338
  - graphic description file of an 8-bit ALU, 338
  - hardware description language, 98–99
  - logic array blocks (LABs), 885
  - logic elements (LEs), 890
  - macrofunction, 337
  - MAX+PLUS II, 99
  - MAX7000S, 885–889
    - primitive port identifiers, 272
    - programmable interconnect array (PIA), 885
    - using TTL library functions with, 337–338
- Alternate logic-gate representation, 86–89
- ALU integrated circuits, 317–318, 331–335, 767
  - expanding the ALU, 334
  - Operations
    - add, 332
    - AND, 333
    - clear, 332
    - EX-OR, 333
    - OR, 333
    - PRESET, 333
    - subtract, 332
  - other ALUs, 335
- American Standard Code for Information Interchange (ASCII), 39–41
- Analyzing synchronous counters, 393–396
- Analog
  - quantity, 719
  - representation, 4
  - systems, 5–6
- Analog-to-digital (ADC)
  - accuracy, 742–744
  - conversion, 737, 739–740
  - conversion time, 744, 750–751
  - converter (ADC), 7, 720
  - data acquisition, 745–748
  - digital amplitude control, 737
  - digital-ramp, 740–745
  - dual-slope, 757–758
  - flash, 755–757
  - IC, 8-bit successive approximation (ADC0804), 751–755
    - an application, 754
    - Chip Select ( $\overline{CS}$ ), 752
    - Clk In, 753
    - Clk Out, 753
    - differential inputs, 751
    - Interrupt ( $\overline{INTR}$ ), 753
    - READ ( $\overline{RD}$ ), 753
    - $V_{ref}/2$ , 753
    - WRITE ( $\overline{WR}$ ), 753
  - multiplexing, 762–764
  - other conversion methods, 757–761
  - quantization error, 743
  - resolution, 742–744
  - sample-and-hold circuit, 761–762
  - sigma/delta modulation, 758–761
  - successive approximation, 749–755 (*see also* Digital to analog converter)
  - tracking, 757
  - up/down digital-ramp, 757
  - voltage-to-frequency, 758
- Analog voltage comparators, 554–556
- AND gate, 62–65 (*see also* Combinational logic circuits)
  - alternate logic-gate representation, 86–89
  - Boolean description, 62
  - Boolean theorems, 76–80
  - counter decoding, 389–393
  - defined, 63
  - implementing from Boolean expressions, 71–73
  - summary of operation, 63
  - symbol, 63
  - which representation to use, 89–95

- AND operation, 57, 62–65
    - summary, 63
  - Answers to selected problems, 911–918
  - Application-specific integrated circuits (ASICs), 870–871
  - ARCHITECTURE, 104, 179
  - Arithmetic circuits, 317–318
  - Arithmetic/logic unit (ALU), 20, 317–318, 331–335
    - functional parts of an, 318
  - Arithmetic overflow, 308–309
  - Array, register, 796–797
  - ASCII code, 39–41
  - ASICs, 870–871
  - Asserted levels, 94
  - Associative laws, 78
  - Astable multivibrators, 260–262
    - 555 timer used as, 261–263
  - Asynchronous active pulse width, 239
  - Asynchronous inputs, 233–236
    - designations for, 234–235
  - Asynchronous (ripple) counters, 362–365
    - MOD number, 363–364
    - propagation delay, 365–367
  - Asynchronous systems, 221
  - Asynchronous transfer, 245
  - Augend, 306, 318
  - Automatic circuit testing (using DACs), 736
  - Auxiliary memory, 786
  - Auxiliary storage, 814
- B**
- B register, 318
  - Back-lit LCDs, 587
  - Backplane, LCD, 587
  - Barrell shifter, 767
  - Base-10 system, 10
  - Basic characteristics of digital ICs, 153–160
  - Basic counters using HDL, 405–411
  - BCD
    - to decimal decoder, 581–582
    - to decimal decoder/driver, 582
    - to 7 segment decoder/driver, 584–587
    - subtraction, 314
  - BCD addition, 312–314
    - sum equals 9 or less, 312
    - sum greater than 9, 313–314
  - BCD (binary-coded-decimal) code, 33–35
    - advantage, 35
    - comparison with binary, 35
    - forbidden codes, 34
  - BCD counters, 375–376
    - decoding, 391–392
    - displaying two multidigit, 605
  - Behavioral
    - description, 409
    - level of abstraction, 409
  - BiCMOS 5-volt logic, 525, 531–532
  - Bidirectional
    - busing, 637–638
    - data lines, 637
  - Bilateral switch, 546–548
  - Binary
    - addition, 298–299
    - arithmetic and number circles, 309
    - BCD, 33–35
    - coded decimal (*see also* BCD code)
    - counter, 251
    - counting sequence, 13
    - digit, 12
    - division, 311–312
    - multiplication, 310–311
    - parity method for error detection, 41–44
    - point, 12
    - quantities, representation of, 13–15
  - Binarily weighted, 730
  - Binary system, 11–13
    - binary to decimal conversion, 26
    - binary to gray conversion, 36
    - binary to hex conversion, 31
    - conversions, summary, 33
    - decimal to binary conversion, 26–29
    - gray to binary conversion, 36
    - hex to binary conversion, 31
    - negation, 303
    - parallel and serial transmission, 17–18
    - representing quantities, 13–15
    - signed numbers, representing, 299–306
  - Bipolar DACs, 728
  - Bipolar digital ICs, 155–156
    - ECL, 543–546
  - Bistable multivibrators, 211, 260–263
    - (*see also* Flip-flops)
  - Bit, 12
    - arrays, 177–178, 344
    - carry, 319
    - vectors, 177–178
  - Block diagram (digital clock using HDL), 694
  - Boolean
    - algebra, 57
    - alternate logic-gate representation, 86–89
    - AND operation, 62–65
    - constants and variables, 57
    - DeMorgan's theorems, 80–83
    - description of logic circuits, 66–68
    - evaluation of logic-circuit outputs, 68–71
    - implementing circuits from expressions, 71–73
    - NAND gate, 73–76
    - NOR gate, 73–76
    - NOT operation, 57, 65–66
      - summary, 66
    - OR operation, 57–62
      - summary, 60
    - simplifying logic circuits, 121
    - theorems, 76–80
    - truth tables, 57–58
    - which representation to use, 89–95
  - Bootstrap
    - memory, 812
    - program, 812
  - Bubbles, 88–89
    - placement of, 91
  - Buffer(s)/
    - circular, 846
    - driver, 536–537
    - inverting, 539
    - linear, 846
    - noninverting, 539
    - open collector, 536–537
    - output, ROM, 796–797
    - tristate, 539–540

- Building the blocks from the bottom up  
(digital clock using HDL), 698
- Bulk erase, 809
- Bundle method, 637
- Buried nodes, AHDL, 105–106
- Bus
  - address, 794
  - clock cycles, 845
  - clock rate, 845
  - contention, 540
  - control, 794
  - data, 794
  - drivers, 635
  - expanding, 634–635
  - high speed interface logic, 541–542
  - representation, simplified, 635–637
  - signals, 633–634
  - termination techniques, 542
- Busing, bidirectional, 637–638, 794
- Byte, 37–39, 787
- C**
- Cache memory, 845
- Capacity, memory
  - defined, 787
  - expansion, 838–841
- Carry, 298, 318
  - bit, 319
  - look-ahead, 326
  - propagation, 325–326
  - ripple, 325
- Cascading parallel adders, 326–328
- CASE using
  - AHDL, 190–191
  - VHDL, 191–192
- CD player, block diagram, 174
- Central processing unit (CPU), 20 (*see also* Microprocessor)
- Checker, parity, 149–151
- Checksum, 852
- Chip, 153
- Chip select, 795, 816
- Circuit excitation table, 399
- Circuits, digital, 15–17 (*see also* Logic circuits)
  - clock generator, 263
  - enable/disable, 151–153
- Circular buffers, 846
- Circulating shift register, 445
- CLEAR, 234–235
- Cleared State, 213
- Clock
  - crystal-controlled, 263
  - defined, 221
  - edges, 222
  - frequency, 222
  - generator circuits, 260–263
  - period, 222
  - pulse HIGH  $t_w(H)$ , 239
  - pulse LOW  $t_w(L)$ , 239
  - signals, 221–224
  - skew, 266–268
  - transition times, 239
- Clocked flip-flops, 221–224
  - asynchronous inputs, 233–236
  - D, 230–231
  - D latch (transparent latch), 232–233, 271
  - J-K, 227–229
  - S-R, 224–227
- CML (current-mode logic), 543
- CMOS logic family, 16, 155–158, 521–530
  - 4000/14000 series, 156–157, 524
  - 74AC series, 156–157, 524
  - 74ACT series, 156, 524
  - 74AHC series, 525
  - 74AHCT series, 525
  - 74ALB, 532
  - 74ALVC series, 531
  - 74ALVT series, 531
  - 74AUP series, 531
  - 74AVC series, 531
  - 74C series, 156
  - 74HC series, 156, 524
  - 74HCT series, 156, 524
  - 74LV series, 531
  - 74LVC series, 530–531
  - 74LVT series, 531
  - 74VME series, 532
  - advanced low-voltage, 531
  - BiCMOS 5-Volt, 525
  - bilateral switch, 546–548
  - characteristics, 523–530
  - driving TTL, 551
    - in the HIGH state, 551
    - in the LOW state, 551–552
  - electrically compatible, 156, 524
  - electrostatic discharge (ESD), 529
  - fan-out, 527–528
  - flash memory (28F256A), 809–811
  - functionally equivalent, 524
  - ground, 157
  - input voltages, 526
  - INVERTER circuit, 155, 521–522
  - latch up, 529
  - logic level voltage ranges, 157
  - low voltage BiCMOS, 531
  - low voltage levels, 525–526
  - NAND gate, 522
  - noise margins, 526
  - NOR gate, 522–523
  - open-drain outputs, 533–538
  - output voltages, 526
  - outputs shorted together, 533
  - $P_D$  increases with frequency, 526–527
  - pin compatible, 524
  - power dissipation, 526
  - power supply voltage, 157, 525
  - series characteristics, 523–530
  - SET-RESET FF, 523
  - static sensitivity, 528–529
  - switching speed, 528
  - transmission gate, 546–548
  - tristate outputs, 538–541
  - TS switch, 531
  - unconnected inputs, 157–158
  - unused inputs, 528
  - voltage levels, 525–526
- Code
  - alphanumeric, 39–41
  - BCD, 33–35
  - defined, 33
  - gray, 35–36
  - putting it all together, 37

- Code converters, 624–627, 653–655
    - basic idea, 624–625
    - circuit implementation, 626–627
    - conversion process, 625–626
    - other implementations, 627
  - Column address strobe (CAS), 827
  - Combinational logic circuits, 118–207
    - algebraic simplification, 121–126
    - complete design procedure, 128–133
    - complete simplification process, 138–141
    - designing, 127–133
    - exclusive-NOR, 144–149
    - exclusive-OR, 144–149
    - Karnaugh map method, 133–144, 322
    - parity generator and checker, 149–151
    - product-of-sums, 120–121
    - simplifying, 121–126
    - sum of products form, 120–121
    - summary, 193
  - Combining DRAM chips, 843
  - Command register, 810
  - Common
    - control block, 237
    - input/output pins (in RAM), 816–817
  - Commutative laws, 78
  - Complementation, 65. (*see also* NOT operation)
  - Complete hierarchy of the project (digital clock using HDL), 697
  - Complex programmable logic devices (CPLDs), 872
  - Computer
    - data acquisition system, 746
    - decision process of a program, 100
    - dedicated, 21
    - digital, 19–21, 721
    - embedded controller, 21
    - functional diagram of, 19
    - major parts of, 19–21
    - microcomputer, 20
    - microcontroller, 21
    - programming languages, 99
    - types of, 20–21
  - Concatenating, 182–183, 453
  - Conditional signal assignment statement, 647
  - Constants, 344
  - Contact bounce, 215
  - Control
    - bus, 794
    - inputs, 223, 233
      - synchronous, 223
    - unit, 20
  - Controlled inverter, 147
  - Conversion time, ADC, 744, 750–751
  - Converter, data, 813
  - Counters, 360–486
    - and registers, 360–486
    - asynchronous (ripple), 362–365
      - propagation delay, 365–367
    - basic idea, 396
    - BCD, decoding, 391–392
    - cascading, 388–389
    - decade, 375–376
    - decoding, 381, 389–393, 448–449
    - design procedure, 397–400
    - displaying states, 372
    - feedback, with, 445
    - glitches, 367, 372
    - HDL, basic, 405–411
    - integrated circuit registers, 437
    - J-K excitation table, 397, 399
    - Johnson, 447–449
    - with MOD numbers  $<2^N$ , 370–377
    - multistage arrangement, 388–389
    - NEXT state, 393–404
    - parallel in/parallel out-the 74ALS174/74HC174, 437–439
    - parallel in/serial out-the 74ALS165/74HC165, 441–443
    - PRESENT state, 393–404
    - presetable, 379–380
    - recycle, 363
    - ring, 445–447, 594–596
    - ripple, 277–280, 362–365
    - self-correcting, 394
    - serial in/parallel out-The 74ALS164/74HC164, 443–445
    - serial in/serial out-The 74ALS166/74HC166, 439–441
    - the 74ALS160–163/74HC160–163 series, 380–384
    - the 74ALS190–191/74HC190–191 series, 384–388
    - shift register, 445–449
    - spike, 372
    - summary, 436–437, 468
    - synchronous, analyzing, 393–396
    - synchronous design, 396–404
    - synchronous design with D FFs, 402–404
    - synchronous (parallel), 367–370, 380–389
    - synchronous (parallel) down and up/down, 377–379
    - troubleshooting, 450–452
    - undesired states, 397
  - Count enable, 381
  - Counters and registers, 360–486
  - Counting
    - binary, 12–13
    - decimal, 10–11
    - hexadecimal, 31–32
    - operation, 251–252
  - CPU (central processing unit), 20
  - Cross Bar Technology (74CBT), 531
    - low voltage (74CBTLV), 531
  - Crystal controlled clock generators, 263
  - Current
    - mode logic, 543
    - parameters for digital ICs, 490–491
    - sinking action, TTL, 495, 500
    - sinking transistor, TTL, 500
    - sourcing action, 495, 500–501
    - sourcing transistor, TTL, 501
    - transients, TTL, 516–517
- D**
- D latch (*see also* Flip-flops)
  - DAC (*see also* Digital-to-analog converter)
  - Data
    - acquisition, 745–748
    - bus, 628, 794
      - bundle method, 637
      - defined, 628
      - floating, 629
      - operation, 632–638
    - converter, 813
    - distributors, 610–617
    - hold time, 820
    - lines, 255
    - rate buffer, 846

- routing, by MUXs, 604–606
- sampling, 745
- selectors, 599–604
- setup time, 820
- storage and transfer, 245–247
- tables, 812–813
- word, 635
- Data transfer, 245–247
  - asynchronous, 245
  - data busing, 628–629
  - demultiplexers, 610–617
  - hold time requirement, 248
  - operation, 633
  - parallel, 231, 246–247
  - parallel versus serial transfer, 250
    - economy and simplicity of, 250
    - speed, 250
  - and portability, 812
  - registers, between, 633
  - serial, 247–250
  - shift registers, 247–250
  - simultaneous, 247
  - and storage, 245–247
  - synchronous, 245
- Decade counters, 375–376
- Decimal
  - counting, 10–11
  - point, 10
- Decimal system, 10–11
  - binary-to-decimal conversion, 26
  - conversions, summary, 33
  - decimal to binary conversion, 22–29
    - counting range, 28
  - decimal to hex conversion, 30–31
  - hex to decimal conversion, 29–30
- Decimal-to-BCD priority encoder (74147), 592–593
- Decision control structures in HDL, 184–192
- Decoders, 577–584
  - 1-of-10, 581–582
  - 1-of-8, 578–580
  - 3-line-to-8-line, 578–580
  - 4-to-10, 581–582
  - address, 797–798
  - applications, 582–584
  - BCD to decimal, 581–582
  - BCD to 7 segment drivers, 584–587
  - binary to octal, 578–580
  - column, 796–797
  - demultiplexer, 610–617
  - ENABLE inputs, 578
  - liquid crystal displays (LCDs), 587–591
  - row, 796–797
  - simulation (HDL), 683
  - using HDL, 638–641
- Decoding
  - counters, 389–393
  - Johnson, counter, 448–449
- Decoupling, power-supply TTL, 517
- DeMorgan's theorems, 80–83
  - implications of, 81–83
- Demultiplexers (DEMUXs), 610–617, 648–651
  - 1-line-to-8-line, 610–612
  - security monitoring system, applications, 612–613
- Dependency notation, 95–96
  - &, 95–96, 631
  - C, 236–237
  - $\geq$ , 95–96
  - 1, 95–96
  - R, 236–237
  - S, 236–237
  - $\Sigma$  (Sigma), 334
  - $\diamond$ , 537
  - $\nabla$ , 541
  - $\triangle$ , 95
- Depletion MOSFET, 518–519
- Describing logic circuits, 54–117
- Description languages versus programming languages, 98–100
- Designing combinational logic circuits, 127–133
- Detecting an input sequence, 244–245
- Development
  - software (for PLDs), 172–174
  - system (for PLD programming), 172
- Diagrams
  - logic circuit connections, 158–160
  - simplified bus timing, 634
  - state transition, 252–253, 372–373, 394
  - timing, 394
- Differential inputs, 751
- Digital
  - amplitude control, 737
  - circuits, 15–17 (*see also* Logic circuits)
  - clock project (HDL), 693–710 (*see also* HDL)
  - computers, 19–21 (*see also* Microcomputer)
  - integrated circuits, 16
  - multiplexer, 599
  - number systems, 10–13
  - one-shots, HDL, 461–467
  - pulses, 220–221
  - quantity, 719
  - ramp ADC, 740–745
    - up/down, 757
  - representation, 4–5
  - storage oscilloscope (DSO), 767–765
    - related applications, 765
- Digital and analog systems, 5–9
- Digital arithmetic, 296–358
  - BCD addition, 312–314
  - binary addition, 298–299
  - binary division, 311–312
  - binary multiplication, 310–311
  - carry propagation, 325–326
  - circuits, 317–318
  - circuits and operations, 296–358
  - full adder, 319
  - hexadecimal addition, 314–315
  - hexadecimal representation of signed numbers, 316–317
  - hexadecimal subtraction, 315–316
  - integrated circuit parallel adder, 326–328
  - number circles and binary arithmetic, 309
  - operations and circuits, 296–358
  - parallel binary adder, 318–320
  - signed number representation, 299–306
  - summary, 349–350
  - 2's complement system, addition, 306–307, 328
  - 2's complement system, multiplication, 311
  - 2's complement system, subtraction, 307–310, 328–331
- Digital signal processing (DSP), 764–768
  - architecture, 767
  - arithmetic logic unit (ALU), 767

- Digital signal processing (DSP) (*continued*)
  - Barrell shifter, 767
  - filtering, 766
  - interpolation filtering, 767
  - multiply and accumulate section (MAC), 767
  - oversampling, 767
  - weighted average, 766
- Digital signals and timing diagrams, 15
- Digital system projects using HDL, 676–717
  - summary, 714
- Digital systems, 5–6
  - family tree, 870–875
  - introductory concepts, 2–23
    - summary, 21
  - input internally shorted to ground or supply, 162–163
  - malfunction in internal circuitry, 162
  - open signal lines, 166–167
  - open-circuited input or output, 163–165
  - output internally shorted to ground or supply, 163
  - output loading, 168
  - power supply, faulty, 167
  - short between two pins, 165–166
  - shorted signal lines, 167
  - troubleshooting, 160–162, 556–557, 597–599, 617–620
    - case study, 168–170
    - tree diagram, 620
  - typical signal, 15
  - typical voltage assignments, 15
- Digital techniques
  - advantages, 6
  - limitations, 6–9
- Digital-to-analog converter (DAC), 7, 720–721
  - accuracy, 734
  - analog output, 723
  - analog-to-digital conversion, used in, 740–745
  - applications, 736–738
  - bipolar, 728
  - circuitry, 728–733
  - control, used in, 736
  - conversion, 721–728
  - conversion accuracy, 730–731
  - current output, with, 731–732
  - digitizing a signal, 736
  - full-scale output, 721, 724
  - input weights, 723
  - integrated circuit (AD7524), 735–736
  - monotonicity, 735
  - offset error, 734–735
  - output waveform, 724
  - percentage resolution, 725–726
  - R/2R ladder, 732–733
  - resolution, 724
    - what does it mean, 726
  - serial, 737–738
  - settling time, 735
  - signal reconstruction, 736–737
  - specifications, 733–735
  - staircase, 724
  - staircase test, 738
  - static accuracy test, 738
  - step size, 724
  - troubleshooting, 738–739
- Digital vs. analog, review, 719–721
- Digitize
  - reconstructing a signal, 746–748
  - signal, 736–737, 745–748
- Digits, 4, 10
- DIMM (dual-in-line memory module), 834
- Diode, Schottky barrier (SBD), 506
- DIP (dual-in-line package), 153
- Direct Rambus DRAM (DRDRAM), 835
- Discrete steps, 4
- Displaying counter states, 372
- Displays
  - LCD, 587–591
    - back-lit, 587
    - passive matrix panel, 590
    - reflective, 587
    - Super Twisted Nematic (STN), 590
    - TFT (Thin Film Transistor), 590
    - Twisted Nematic (TN), 590
  - LED, 586–587
    - common-anode, 586
    - common-cathode, 586
- D latch (transparent latch), 232–233, 271
- Distributive law, 78
- Divide and conquer, troubleshooting process, 597
- Dividend, 311
- Division, binary, 311–312
- Divisor, 311
- Don't care conditions, 142–143
- Double Data Rate SDRAM (DDRSDRAM), 835
- Driver, decoder, 582
- DSP (Digital Signal Processing), 765–768
- Dual
  - in-line package (DIP), 153, 497
  - slope ADC, 757–758
- Dynamic RAM (DRAM), 823–824
  - address multiplexing, 825–829
  - combining chips, 843
  - controller, 832
  - DDRSDRAM, 835
  - DIMM, 834
  - DRDRAM, 835
  - EDO, 835
  - FPM (Fast Page Mode), 834–835
  - memory modules, 834
  - Read/Write cycles, DRAM, 829–831
    - Read cycle, 829–830
    - Write cycle, 830
  - refresh counter, 831
  - refreshing, 823, 831–833
    - methods,
      - burst, 831
      - CAS-before-RAS refresh, 832, 835
      - distributed, 831
      - RAS-only refresh, 831
  - SDRAM (Synchronous DRAM), 835
  - SIMM, 834
  - SLDRAM, 835
  - SODIMM, 834
  - structure and operation, 824–829
  - technology, 834–835
- E**
- ECL integrated circuit family, 16, 543–546 (*see also* Emitter coupled logic)
- Edge triggered devices, 272–277
  - event, 272
  - logic primitive, 272

- Edge-detector circuit, 226–227
- Edges, of a clock signal, 221–222
- EDO (Extended Data Output) DRAM, 835
- EEPROMs (electrically erasable PROMs), 805–807
- Eight input multiplexers, 601–602
- Electrical noise, 41
- Electrically Erasable PROMs (EEPROMs), 805–807
- Electrostatic discharge (ESD), 529
- ELSIF, 187–189
  - using AHDL, 189
  - using VHDL, 189
- Embedded
  - controller, 21
  - microcontroller program memory, 812
- Emitter coupled logic (ECL), 16, 543–546
  - basic circuit, 543–544
  - characteristics, 543–546
  - OR/NOR gate, 543, 545
- ENABLE inputs, decoders, 578
- Enable/Disable circuits, 151–153
- Encoders, 591–597
  - decimal to BCD priority, 592–593
  - 8-line-to-3-line, 591
  - octal to binary, 591
  - priority, 592–593
  - switch, 593–596
- Encoding, 591
- Enhancement MOSFET, 518–519
- EPROMs (erasable programmable ROMs), 803–805
- Erasable Programmable ROMs (EPROMs), 803–805
- Erase
  - command, 811
  - verify command, 811
- Error detection, parity method for, 41–44
- Etching, incomplete, 167
- Even-parity method, 42
- Event, 272
- Excitation table, J-K, 397
- Exclusive
  - NOR circuit, 145–147
  - OR circuit, 144–145
- Expanding the bit capacity of a circuit, 343–348
- Extension, sign, 302
- External faults, 166–168
- F**
- Fan-out, 491
  - CMOS, 527–528
  - determining, 510–513
  - TTL, 509–514
- Fast page mode (FPM) DRAM, 834–835
- Fast TTL (74F), 508
- Feedback multiplexer (FMUX), 884
- Field programmable gate arrays (FPGA), 872,
- Filling K map from output expression, 141
- First-in, first-out memory (FIFO), 845–846
- Flash
  - ADC, 755–757
  - conversion time of, 756–757
  - memory, 808–811
- Flip-flops, 19, 2208–295
  - actual ICs, 240
  - ambiguous output, 227
  - applications, 243
  - asynchronous inputs, 233–236
  - bistable multivibrator, 211
  - clearing, 211
  - clock signals, 221–224
  - clocked, 221–224
  - clocked D, 230–231
    - implementation of, 231
  - clocked J-K, 227–229
  - clocked S-R, 224–227
  - D (data), 230–231
    - implementation of, 231
  - D latch (transparent latch), 232–233, 271
  - defined, 210–211
  - edge triggered, 222
  - frequency division and counting, 250–254
  - input sequence detection, 244–245
  - latches, 19
  - memory characteristics, 211
  - NAND gate latch, 211–216, 226
    - alternate representations, 214
    - summary of, 213
    - troubleshooting case study, 219–220
    - using AHDL, 270
  - NOR gate latch, 216–218
  - override inputs, 234
  - propagation delays, 238–239
  - related devices, 208–295
  - resetting, 211
  - setup and hold times, 223–224
  - shift registers, 247–250
  - state on power-up, 218
  - summary, 280–281
  - synchronization, 243–244
  - terminology, 214–215
  - timing considerations, 238–241
  - timing problems, 241–242
  - troubleshooting circuits, 264–268
- Floating
  - bus, 629
  - gate, EPROMs, 804
  - inputs (*see also* Unconnected inputs), 157–158, 514
- Four-input multiplexers, 601
- Free-running multivibrator, 260–263
- Frequency, 222
  - counter project (HDL), 710–714 (*see also* HDL)
    - division, 250–254, 364–365
    - and counting, 250–254
- Full adder, 319
  - design of, 320–323
  - K-map simplification, 322
- Full-custom ASICs, 872
- Full-featured counters in HDL, 412–417
- Full-scale error (of a DAC), 734
- Full-scale output (of a DAC), 721, 724
- Full-step sequence (HDL stepper-motor), 679
- Function generator, 813–814
- Function prototype, ALTERA, 338
- Fusible-link, PROMs, 803
- Future, digital, 8
- G**
- GAL16V8 (Generic Array Logic), 881–885
  - complex mode, 895
  - feedback multiplexer (FMUX), 884
  - output logic macro cells (OLMCs), 883–885
  - output multiplexer (OMUX), 884



- GAL16V8 (*continued*)
  - product term multiplexer (PTMUX), 884
  - registered mode, 885
  - simple mode, 885
- GAL22V10 (Generic Array Logic), 885
- Gate(s)
  - AND, 63
  - arrays, 871
  - NAND, 73–76
  - NOR, 73–76
  - OR, 58–62
  - which representation to use, 89–95
- Generator
  - function, 813–814
  - parity, 149–151
- Giga-scale integration (GSI), 154–155
- Glitches, 367, 372
- Glossary, 898–910
- Gray Code, 35–36
- Gunning Transceivers Logic Plus, 542
  - Plus (74GTLP1394), 531
- H**
- Half adder (HA), 322–323
- Half-step sequence (HDL stepper-motor), 680
- Hardware description language (HDL), 98, 173
- HDL, 98, 173
  - adders, 340–343
  - basic counters using, 405–411
  - behavioral description, 409
  - behavioral level of abstraction, 409
  - bit arrays, 177–178
  - bit vectors, 177–178
  - CASE, 459, 639, 683, 701
  - circuits with multiple components, 277–280
  - code converters, 653–655
  - combining blocks using only, 706–707
  - comparator, 652–653
  - concatenation, 453
  - decision control structures, 184–192
    - concurrent, 184
    - sequential, 184
  - decoder/driver, 7-segment, 642–645
  - decoders, using, 638–641
  - demultiplexers, 648–651
  - designing number systems, 177
  - digital clock project, 693–710
    - block diagram, 694
    - building the blocks from the bottom up, 698
    - combining blocks graphically, 705–706
    - complete hierarchy of the project, 697
    - hours section circuit, 695
    - MOD-6 counter simulation, 700
    - MOD-60 section, 697
    - prescaler, 697
    - top-down hierarchical design, 696–698
  - encoders, 645–648
  - format, 102–104
  - frequency counter project, 710–714
    - block diagram, 711
    - sampling interval, 710
    - timing and control block, 713
    - timing diagram, 712
  - full-featured counters in, 412–417
  - function prototype, 338
  - hierarchical design, 417
  - IF/ELSE, 184–185, 460
  - IF/ELSIF, 701
  - IF/THEN, 185
  - index, 178
  - keypad encoder project, 687–693
    - block diagram, 687
    - problem analysis, 687
    - simulation, 693
    - strategic planning, 689
  - literals, 177
  - magnitude comparator, 652–653
  - MOD 12 design, 701–702
  - MOD 60 graphic block symbol, 706
  - mode, 102
  - multiplexers, 648–651
  - nesting, 686
  - NEXT, 459
  - one-shots, 461–467
  - PRESENT, 459
  - projects using, 676–717
  - registers, 452–459
  - representing data, 177–181
  - retriggerable, edge-triggered one-shots in, 464–465
  - ring counters, 459–461
  - scalars, 177
  - schematic diagram, 102
  - sequential circuits using, 268–271
    - D latch, 271
    - NAND latch, 270
  - simulation of basic counter, 411
  - simulation of full-featured counter, 416
  - small-project management, 678–679
    - definition, 678
    - strategic planning, 678
    - synthesis and testing, 678–679
    - system integration and testing, 679
  - state transition description methods, 405
  - stepper motor driver project, 679–686
    - full-step sequence, 679
    - half-step sequence, 680
    - problem statement, 680–681
    - strategic planning, 681
    - synthesis and testing, 681
    - wave-drive sequence, 680
  - structural level of abstraction, 280
  - syntax, 102–104
  - TABLE, 639
  - timing simulation, 175
  - truth tables, 181–184
  - type, 102
  - wiring modules together, 417
- Hertz, 222
- Hexadecimal
  - addition, 314–315
  - arithmetic, 314–317
  - number system, 29–33
  - representation of signed numbers, 316–317
  - subtraction, 315–316
- Hierarchical design, 173
- Hierarchy, 696
- High capacity programmable logic devices (HCPLDs), 872
- High speed
  - bus interface logic, 541–542
  - CMOS, 74HC/HCT, 524
  - logic comparison, 546

High-state noise margin ( $V_{NH}$ ), 493  
 Hold time ( $t_H$ ), 223–224, 238, 248  
 Hours section circuit (digital clock using HDL), 695  
 Hybrid systems, 8

- I**
- IC synchronous counters, 380–389  
 IEEE/ANSI standard logic symbols, 95–96, 236–237, 537, 541  
 AND, 95  
 common control block, 237  
 D Flip-flop, 237  
 definition, 95–96  
 dependency notation (*see also* dependency notation)  
 exclusive-NOR, 145–147  
 exclusive-OR, 144–145  
 flip-flops, 236–238  
 for logic-gate ICs, 95  
 inverter, 95  
 J-K flip-flop, 237  
 monostable multivibrator, 256–260  
 NAND, 95  
 NOR, 95  
 one-shot, 256–260  
 open-collector output, 537  
 open-drain output, 537  
 OR, 95  
 traditional, 95–96  
 tristate outputs, 541  
 IF/ELSE, 184–185  
 IF/THEN, 185  
 IF/THEN/ELSE using AHDL, 186  
 Implementing logic circuits with PLDs, 100–101  
 Implications of DeMorgan's theorems, 81–83  
 Improved flash memory, 811  
 Incomplete address decoding, 841–843  
 Indeterminate  
 logic level, 161  
 voltages, 157  
 Inhibit circuits, 64  
 Input  
 currents for standard devices, 550  
 sequence detection, 244–245  
 unit, 20  
 Integrated-circuit logic families, 488–574  
 ALU(s), 331–335  
 add operation, 332  
 AND operation, 333  
 clear operation, 332  
 EX-OR operation, 333  
 expanding, 334  
 OR operation, 333  
 other, 335  
 PRESET operation, 333  
 subtract operation, 332  
 basic characteristics, 153–160  
 bipolar, 155–156, 543–546  
 defined, 489–490  
 ECL, 543–546  
 interfacing, 548–552  
 MOS (*see also* MOS logic family)  
 summary, 558  
 terminology, 490–497  
 unipolar, 155–156  
 Integrated-circuit packages, 495–497  
 common, 496  
 dual-in-line (DIP), 495–496, 497  
 gull-wing, 497  
 J-shaped leads, 497  
 lead pitch, 496  
 low-profile five-pitch ball grid array (LFBGA), 497  
 plastic leaded chip carrier (PLCC), 497  
 quad flat pack (QFP), 497  
 shrink small outline package (SSOP), 497  
 small outline IC (SOIC), 497  
 surface-mount technology, 496  
 thin quad flat pack (TQFP), 497  
 thin shrink small outline package (TSSOP), 497  
 thin very small outline package (TVSOP), 497  
 Integrated circuit parallel adder, 326–328  
 Integrated circuit registers, 437  
 parallel in/parallel out-the 74ALS174/74HC174, 437–439  
 parallel in/serial out-the 74ALS165/74HC165, 441–443  
 serial in/parallel out-the 74ALS164/74HC164, 443–445  
 serial in/serial out-the 74ALS166/74HC166, 439–441  
 Integrated circuit shift-register counters, 449  
 Interfacing  
 5-V TTL and CMOS, 550  
 high-voltage outputs driving low-voltage loads, 554  
 integrated circuit, 548–552  
 logic ICs, 549  
 low-voltage outputs driving high-voltage loads, 553  
 mixed-voltage, 553–554  
 not needed, 549  
 required, 549  
 with the analog world, 718–782  
 summary, 769–770  
 Intermediate signals, 105–108  
 Interpolation filtering, 767  
 Invalid voltage levels, 494–495  
 Inversion (*see also* NOT operation), 57, 65–66  
 Inverter, 65–66  
 circuits containing, 67–68  
 controlled inverter, 147  
 response to slow noisy inverter, 257  
 Inverted flip-flop output, 210  
 Inverting tristate buffer, 539
- J**
- Jam transfer, 246, 380  
 JEDEC  
 standard, 172  
 standard memory packaging (JEDEC), 822  
 J-K excitation table, 397, 399  
 Johnson counter, 447–449  
 decoding, 448–449
- K**
- Karnaugh map  
 complete simplification process, 138–141  
 don't-care conditions, 142–143  
 filling from output expression, 141  
 format, 134–135  
 looping, 135–138  
 method, 133–144  
 simplification, 322  
 summary, 143–144  
 Keypad encoder project (HDL), 687–693 (*see also* HDL)

- L**
- Labeling
    - active-LOW signals, 94
    - bistate signals, 94
  - Ladder, R/2R, 732–733
  - Large scale integration (LSI), 154–155, 489
  - Latches, 18, 2111–218, 232–233, 268–271
    - (*see also* Flip-flops)
    - resetting, 212
    - setting, 212
  - Latch-up, 529
  - Latency, 827
  - Least significant bit (LSB), 12
  - Least significant digit (LSD), 10
  - Libraries of parameterized modules, 347–348
  - Light-emitting diodes (LEDs), 586–587
    - common-anode vs. common-cathode, 586
  - Limitations of digital techniques, 6–9
  - Linear buffers, 846
  - Linearity error (of a DAC), 734
  - Liquid crystal displays (LCDs), 587–591
    - backplane, 587
    - driving an, 588–589
    - types, 589–590
  - Loading
    - factor, 491
    - TTL, 509–514
  - Local signals, 105
  - Logic
    - diagram using schematic capture, 160
    - function generation, 607–609
    - level, 57
    - primitive, 272
    - probe, how to use, 161, 556–557
    - product life cycle, 532
    - pulser, how to use, 161, 556–557
    - standard, 871
  - Logic circuits
    - analysis using a table, 69–71
    - analyzing, 92–94
    - arithmetic, 317–318
    - combinational (*see also* Combinational logic circuits)
    - connection diagrams, 158–160
    - defined, 16
    - describing, 54–117
    - describing algebraically, 66–68
    - disabled, 151–153
    - enabled, 151–153
    - evaluation of outputs, 68–71
    - implementing from Boolean expressions, 71–73
    - implementing with PLDs, 100–101
    - interface, 548–552
    - pulse-shaping circuit, 365
    - pulse-steering, 153
  - Logic gates, 57–117
    - alternate representation, 86–89
    - AND, 63
    - Boolean theorems, 76–80
    - DeMorgan's theorems, 80–83
    - evaluation of outputs, 68–71
    - IEEE/ANSI representations, 95–96
    - NAND, 73–76
    - NOR, 73–76
    - NOT circuit (INVERTER), 65–66
    - OR, 58–62
      - summary of methods to describe, 96–98
      - truth tables, 57–58
      - which representation to use, 89–95
  - Logic operations, 57
    - on bit arrays, 338–340
  - Logic signals
    - labeling active-LOW, 94
    - labeling bistate, 94
  - Logic symbol interpretation, 88–89
    - summary, 89
  - Logical complementation or inversion (NOT operation), 65–66
  - Look ahead carry, 326
  - Look up table (LUT), 873
  - Looping, 135–138
    - octets, 137–138
    - pairs, 135–136
    - quads, 136–137
  - Low-power Schottky TTL, 74LS Series (LS-TTL), 506–507
  - Low-state noise margin ( $V_{NL}$ ), 493
  - Low voltage (74LV), 531
    - BiCMOS technology (74LVT), 531
    - CMOS (74LVC), 530–531
    - series characteristics, 532
    - voltage technology, 530–532
  - LPMS (library of parameterized modules), 348
  - LSI. *See* Large-scale integration
  - LUT (look up table), 873
    - functional block diagram, 891
  - LVDS (Low Voltage Differential Signaling), 542
- M**
- Machines, state, 425–437
    - Mealy model, 426
    - Moore model, 426
    - traffic light controller, 429–435
  - Macrofunction, 337
  - Magnitude comparator, 621–624, 652–653
    - applications, 623
    - cascading inputs, 622–623
    - data inputs, 621
    - outputs, 622
  - Magnitude of binary numbers, 299
  - Major parts of a computer, 19–21
  - Mask-programmed
    - gate arrays (MPGAs), 871
    - ROM (MROM), 800–802
    - storage devices, 786
  - Maximum clocking frequency ( $f_{MAX}$ ), 239
  - Mealy model, 426
  - Medium-scale integration (MSI), 154–155, 489
  - Megafunctions, 348
  - Memory, 18–19, 784–866
    - auxiliary, 786, 789
    - bipolar static RAM cell, 818
    - bootstrap, 812
    - capacity, 787
    - CD ROM, 807–808
    - cell, 787
    - compact disk, 786
    - connections, CPU, 793–794
    - density, 788
    - devices, 784–866
    - dynamic, devices, 789
    - embedded microcontroller program, 812
    - enable, 791–792

- expanding
  - capacity, 838–841
  - word size, 836–838
- fetch operation, 788
- first-in, first-out (FIFO), 845–846
- flash, 808–811
  - bulk erase, 808
  - command register, 810
  - erase command, 811
  - erase verify command, 811
  - IC (28F256A), 809–811
  - improved, 811
  - program command, 811
  - program-verify command, 811
  - Read command, 810
  - sector erase, 808
  - set-erase, 811
  - set-up program, 811
  - tradeoffs, 809
- fold-back, 842
- general operation, 790–793
- main, 786, 789
- map, 842
- mass, 789
- modules, 834, 837
- NMOS static RAM cell, 818
- nonvolatile, 788–789, 795
- random-access, 788–789
- read-only, 789
- Read/Write, 789
- sequential-access, 789
- special functions, 844–846
  - cache memory, 845
  - first-in, first-out, 845–846
  - power-down storage, 844–845
- static, devices, 789
- store operation, 788
- summary, 853–854
- terminology, 786–789
- unit, 20
- volatile, 788
- word, 787
- working, 786, 789
- Microcomputer
  - application, 254–255
  - defined, 20
  - input unit, 20
  - memory unit, 20
  - output unit, 20
- Microcontroller, 21
- Microprocessor, 20
  - digital signal processing (DSP), 871
  - READ operation, 794
  - WRITE operation, 794
- Minuend, 308
- Mixed-voltage interfacing, 553–554
  - high-voltage outputs driving low-voltage loads, 554
  - low-voltage outputs driving high-voltage loads, 553
  - voltage-level translator, 553
- MOD number, 253, 363–364
  - changing, 374
  - general procedure, 374–375
  - Johnson counter, 447–449
  - ring counter, 445–447
- Monostable multivibrator, 256–260. *See also* One-shot
- Monotonicity (of a DAC), 735
- Moore model, 426
- MOS
  - electrostatic discharge (ESD), 529
  - FETs, 518–521
  - logic family, 518–521
  - NMOS, 519–520
  - static sensitivity, 528–529
  - technology, 518–521
- MOSFET, 16, 518–521
  - basic switch, 519–521
  - CMOS, 521–523
  - digital circuits, 519–520
  - N-MOS, 519
  - P-MOS, 520
- Most significant bit (MSB), 12
- Most significant digit (MSD), 10
- MSI. *See* Medium-scale integration
- MSI logic circuits, 576–673
  - BCD to decimal decoder, 581–582
  - BCD to 7 segment decoder/drivers, 584–587
  - data busing, 628–629
  - decoders, 577–584
  - demultiplexers (DEMUXs), 610–617
  - encoders, 591–597
  - liquid crystal displays (LCDs), 587–591
  - multiplexers (MUX), 599–604
  - summary, 656–657
  - tristate registers, 629–631
- Multiple-emitter input transistor, 498
- Multiplexers (MUX), 599–604, 648–651
  - applications, 604–609, 612–617, 828
  - control sequence, seven-step, 608
  - eight-input, 601–602
  - four-input, 601
  - operation sequencing, using, 607
  - quad two-input, 603–604
  - two-input, basic, 600–601
- Multiplexing, 599
  - ADC, 762–764
  - address (in DRAM), 825–829
- Multiplication
  - AND, 62
  - of binary numbers, 310–311
  - in the 2's-complement system, 311
- N**
- NAND gate, 73–76
  - alternate representation, 86–89
  - CMOS, 522
  - counter decoding, 389–393
  - defined, 75
  - internal circuitry of the edge-triggered J-K FF, 229
  - internal circuitry of the edge-triggered S-R FF, 226–227
  - latch flip-flop, 211–216
    - summary of, 213
  - TTL, 498
  - universality of, 83–86
    - which representation to use, 89–95
- Negation, 303
- Negative-going threshold voltage ( $V_T$ ), 256
- Negative-going transition (NGT), 222
- NEXT state, 393–404
- Nibble, 37–39
- NMOS logic family, 16
  - logic circuits, 519
- NMOS static RAM cell, 818

- Noise, 6, 264
    - immunity, 493
  - Noise margin, 493
    - CMOS, 526
    - DC, 493
  - Nonretriggerable one-shot, 258
  - Nonvolatile memory, 788–789, 795, 803
  - NOR gate, 73–76
    - alternate representation, 86–89
    - CMOS, 522–523
    - defined, 73
    - ECL, 543, 545
    - latch, 216–218
    - universality of, 83–86
    - which gate representation to use, 89–95
  - Normal flip-flop output, 210
  - NOT circuit (INVERTER), 65–66
    - alternate representation, 86–89
    - circuits containing, 67–68
    - controlled inverter, 147
    - defined, 66
    - DeMorgan's theorems, 80–83
    - implementing from Boolean expressions, 71–73
    - NMOS, 519
    - symbol, 65
    - which representation to use, 89–95
  - NOT operation, 57, 65–66
  - Number circles and binary arithmetic, 309
  - Number systems, 10–13
    - and codes, 24–52
    - applications, 44–46
    - binary, 11–12 (*see also* Binary system)
    - decimal, 10 (*see also* Decimal system)
    - digital, 10–13
    - hexadecimal, 29–33
    - putting it all together, 37
    - summary, 46
  - Numerical representations, 4–5
- O**
- Observation/analysis, troubleshooting process, 597
  - Octal to-binary encoders, 591
  - Octets, looping, 137–139
  - Odd-parity method, 42
  - Offset error, 734–735
  - One-shot (monostable multivibrator), 256–260
    - actual devices, 259
    - AHDL, 462, 465
    - HDL, 461–467
    - retriggerable, edge-triggered in HDL, 464–465
    - VHDL, 462–464, 466–467
  - 1's complement form, 300
  - One-time programmable ROM (OTP), 803, 873
  - Open-collector buffer/drivers, 536–537
  - Open-collector outputs, 533–538
  - Open-drain buffer/drivers, 536–537
  - Open-drain outputs, 533–538
  - Operation
    - fetch, 788
    - refresh, 789
  - Operational amplifier (in a DAC), 728
  - OR gate, 58–62
    - alternate logic-gate representation, 86–89
    - Boolean theorems, 76–80
    - defined, 59
    - ECL, 543, 545
    - implementing from Boolean expressions, 71–73
    - symbol, 59
  - OR operation, 57–62
    - summary, 60
    - which representation to use, 89–95
  - Organizational hierarchical chart, 175
  - Oscillator, Schmitt-trigger, 260–261
  - OTP (One-Time Programmable ROM), 803, 873
  - Output
    - buffers, ROM, 798
    - currents for standard devices, 550
    - enable time ( $t_{OE}$ ), 799
    - loading, 168
    - unit, 20
  - Overflow bit, 323
  - Override inputs, 234
- P**
- Pairs, looping, 135–136
  - Parallel
    - in/parallel out-the 74ALS174/74HC174, 437–439
    - parallel in/serial out-the 74ALS165/74HC165, 441–443
    - loading, 379
    - transmission, 17–18
    - parallel-to-serial conversion, 606–607
  - Parallel and serial transmission, 17–18
    - trade-offs between, 18
  - Parallel binary adder, 318–320
    - carry propagation, 325–326
    - complete, with registers, 323–325
    - integrated circuits, 326–328
    - troubleshooting case study, 335–337
    - 2's-complement system, 328–331
  - Parallel data transfer, 231, 246–247
    - vs. serial transfer, 250
  - Parasitic, 529
  - Parity
    - bit, 42–44
    - checker, 149–151
    - checking, 150
    - checking the, 43
    - errors
      - single-bit, 43
      - two-bit, 43
    - generator, 149–151
    - method for error detection, 41–44
  - Percentage resolution, 725–726
  - Period, 222
  - PIPO (parallel in/parallel out), 437
  - PISO (parallel in/serial out), 437
  - PISO register, AHDL, 455–456
  - PISO register, VHDL, 456
  - Pixels, 589
  - Plastic leaded chip carrier (PLCC), 497
  - Positional-value system, 10
  - Positive-going
    - threshold voltage ( $V_{T+}$ ), 256
    - transition (PGT), 222
  - Power
    - down (in MROM), 802
    - down storage, 844–845
    - requirements for digital ICs, 492–493
    - supply decoupling, TTL, 517
    - up self-test, RAM, 852

- Precision reference supply, 731
  - Prescaler (digital clock using HDL), 697
  - PRESENT state, 393–404
  - PRESET, 234
  - Presetable counters, 379–380
  - Priority encoders, 592–593, 756
  - Product-of-sums, 120–121
  - Program
    - command, 811
    - defined, 6, 19
    - verify command, 811
  - Programmable Logic Device/s (PLDs), 99, 170–176, 871
    - Architecture/s, 868–918, 877–881
      - FPGA (field programmable gate array), 874
      - FPLA (field programmable logic array), 881
      - programmable array logic (PAL), 873, 879–881
      - PROMs, 877–879
      - summary, 895–896
    - CPLD, 872
    - design and development process, 174–175
      - test vectors, 175
      - top-down, 174
    - development cycle flowchart, 176
    - development software, 173–174
      - AHDL, 173
      - compilers, 101
      - timing simulation, 175
      - VHDL, 173
    - FPGA, 872
    - fundamentals of PLD circuitry, 875–877
    - generic array logic (GAL16V8), 881–885
    - hardware, 170–171
    - HCPLD, 872
    - hierarchical design, 173
    - look up table (LUT), 873
    - macrocell, 873
    - mask programmed gate arrays (MPGAs), 871
    - more on, 872–875
    - one-time programmable (OTP), 873
    - organizational hierarchical chart, 175
    - programmable array logic (PAL), 873
    - programmer, 172
      - universal, 172
    - programming, 171–172
      - development system, 172
      - JEDEC standard 172
      - JTAG, 172
      - zero insertion force (ZIF) socket, 172
    - SPLD, 872
    - standard JEDEC memory packaging, 822
    - symbology, 876–877
  - Programmable ROMs (PROMs), 803
  - Programmer, 172
  - Programming languages, 99
  - Projects, using HDL, 676–717
    - digital clock, 693–710
    - frequency counter, 710–714
    - keypad encoder, 687–693
    - management, 678–679
    - stepper motor driver, 679–686
  - PROMs (programmable ROMs), 803
  - Propagation delays ( $t_{PLH}/t_{PHL}$ ),
    - in asynchronous counters, 365–367
    - flip-flop, 238–241
    - integrated circuits, 491
    - TTL NAND gate, 505
  - Pull-down transistor, TTL, 500
  - Pull-up transistor, TTL, 501
  - Pulse(s), 220
    - leading edge, 221
    - negative, 220–221
    - positive, 220–221
    - shaping circuit, 365
    - steering circuit, 153, 226
    - trailing edge, 221
- ## Q
- Quad
    - flat pack (QFP), 497
    - looping, 136–137
    - two-input multiplexers, 603–604
  - Quantization error, 743
  - Quartz
    - crystal, 263
    - watch, 251
  - Quasi-stable state, 256
- ## R
- R/2R ladder digital-to-analog converters, 732–733
  - RAMs (random-access memories),
    - architecture, 815–817
    - capacity expansion, 838–841
    - defined, 788–789
    - dynamic devices, 789
    - power-up self-test, 852
    - semiconductor, 814–815
    - static (SRAM), 818–822
    - troubleshooting, 847–852
      - know the operation, 847–850
      - testing the complete system, 851–852
      - testing the decoding logic, 850–851
    - word size expansion, 836–838
  - Read command, 810
  - Read operation
    - CPU, 794
    - defined, 788
    - RAM, 816
  - Read/write
    - input ( $R/\bar{W}$ ), 791
    - memory (RWM), 789
  - Reconstructing a digitized signal, 746–748
  - Reflective LCDs, 587
  - Refresh counter, 831
  - Refreshing, DRAM, 789, 818, 823, 831–833
  - Register array, 797
  - Registers, 245, 360–486
    - accumulator, 318
    - address pointer, 845
    - and counters, 360–486
    - B, 318
    - complete parallel adder with, 323–325
    - HDL, 452–459
    - notation, 323–325
    - sequence of operations, 325
    - shift left operation, 250
    - tristate (74ALS173/HC173), 629–631
  - Repeated division method, 27–29
  - Representing
    - binary quantities, 13–15
    - data in HDL, 177–181
    - signed numbers, 299–306
    - using 2's complement, 300–306

- RESET, 235
- Resetting a flip-flop,
  - and setting simultaneously, 213
  - defined, 212
  - latch, 212
- Resolution
  - ADC, 742–744
  - DAC, 724, 733–734
  - what does it mean, 726
- Resolution, percentage, 725–726
- Retriggerable one-shot, 258–259
- Ring counter, 445–447, 594–596
  - in circuit, 595
  - starting a, 447
  - state diagram, of, 446, 689
- ROM (read-only memory), 795–796
  - applications, 811–814
  - architecture, 796–798
    - output buffers, 798
  - block diagram, 795
  - burning-in, 795
  - CD, 807–808
  - column decoder, 796–797
  - defined, 789
  - erased, 795
  - mask-programmed, 800–802
  - one-time programmable (OTP), 803
  - output buffer, 796–797
  - programming, 795
  - READ operation, the, 795–796
  - row decoder, 796–797
  - testing, 852–853
  - timing, 799–800
  - types of, 800–808
- Row address strobe ( $\overline{\text{RAS}}$ ), 827
- S**
- 74 TTL series, 156, 506, 508
- 74AC series, 156–157, 524
- 74ACT series, 156–157, 524
- 74AHC series, 525
- 74AHCT series, 525
- 74ALB series, 532
- 74ALS TTL series, 507–508
- 74ALVC series, 531
- 74ALVT series, 531
- 74AS TTL series, 507–508
- 74AUC series, 531
- 74AVC series, 531
- 74C series, 156–157
- 74CBT series, 531
- 74CBTLV series, 531
- 74F-Fast TTL series, 508
- 74GTLP series, 531
- 74HC series, 156–157, 524
- 74HCT series, 156–157, 524
- 74LV series, 531
- 74LVC series, 530–531
- 74LVT series, 531
- 74LS TTL series, 156, 506–508
- 74S TTL series, 506, 508
- 74SSTV series, 531
- 74TVC series, 531
- S, 236–237
- SAM (sequential-access memory), 789
- Sample-and-hold circuits, 761–762
- Sampling, 745
  - frequency, 748
- SBD (Schottky Barrier Diode), 506
- Schmitt-trigger
  - devices, 256
  - oscillator, 260–261
  - response to slow noisy input, 257
- Schottky
  - barrier diode (SBD), 506
  - TTL, 74S Series, 506
- SDRA (synchronous DRAM), 835
- Sector erase, 808
- Security monitoring system, 612–613
- Select inputs, (in MUXs), 599–600
- Sense amplifier (in DRAM), 825
- Sequential-access memory (SAM), 789
- Sequential circuits, 243
  - design, 396–404
  - using HDL, 268–271
- Sequential logic systems, troubleshooting, 450
- Serial
  - in/serial out—the 74ALS166/74HC166, 439–441
  - transmission, 17–18
- Serial data transfer, 247–250
  - between registers, 248–249
- Set up program/program control, 811
- Set-erase, 811
- Sets, 339
- Setting the flip-flop
  - latch, 212
  - and resetting simultaneously, 213
- Settling time, of a DAC, 735
- Setup time ( $t_s$ ), 223–224, 238
- Shift register counters, 445–449
- Shift registers, 247–250
  - bidirectional universal, 444
  - left, 250
  - octal (8-bit), 444
  - parallel in/parallel out—the 74ALS174/74HC174, 437–439
  - serial in/serial out—the 74ALS166/74HC166, 439–441
- Shrink small outline package (SSOP), 497
- Sigma ( $\Sigma$ ), 326
  - delta modulation (ADC) 758–761
- Sign
  - bit, 299
  - extension, 302
  - magnitude system, 299
- Signal
  - alias, 748
  - contention, 165
  - flow, 363
- Signed numbers
  - representing, 299–306
  - In sign-magnitude form, 299
- SIMM (single-line memory module), 834
- Simple programmable logic devices (SPLDs), 872
- SIPO (serial in/parallel out register), 437
- SISO register, AHDL, 453–454
- SISO register, VHDL, 454–455
- SISO (serial in/serial out register), 437
- Skew, clock, 266–268
- Sloppy wiring, 167
- Small outline integrated circuit (SOIC), 497
- Small scale integration (SSI), 154–155, 489

- Small-project management (using HDL), 678–679
    - definition, 678
    - strategic planning, 678
    - synthesis and testing, 681
    - system integration and testing, 679
  - SODIMM (small-outline, dual-in-line memory module), 834
  - Solder bridges, 167
  - Special memory functions, 844–846
  - Spike, 372
  - SPLDs (simple programmable logic devices), 872
  - Staircase
    - test, of a DAC, 738
    - waveform, of a DAC, 724
  - Standard
    - cell ASICs, 871–872
    - logic, 871
  - State
    - descriptions in AHDL, 406–407
    - descriptions in VHDL, 407–408
    - machines, 425–437
      - traffic light controller, 429–435
    - table, 252
    - transition description methods, 405
    - transition diagram, 252–253, 372–373
      - Mod-6 counter, 373
      - synchronous counter, 398
  - Static accuracy test, of a DAC, 738
  - Static RAM (SRAM), 818–822
    - actual chip (MCM6264C), 821–822
    - read cycle, 820
    - timing, 818–819
    - write cycle, 820–821
  - Stepper motor
    - control, 401–402
    - driver project (HDL), 679–686 (*see also* HDL)
    - universal, interface circuit, 682
  - Step-size, 724
  - Storage, auxiliary, 814
  - Straight binary coding, 33
  - Strategic planning (using HDL), 678, 681
  - Strobe inputs (in DRAM), 827
  - Stub Series Terminated Logic (74SSTV), 531
  - SUBDESIGN, 103, 178
  - Subpixels, 589
  - Subtraction
    - BCD, 315–316
    - hexadecimal, 315–316
    - 2's-complement system, 307–310, 328–331
  - Substrate, 153
  - Subtrahend, 308
  - Successive-approximation ADC, 749–755
  - Sum bit, 319
  - Sum-of-products form, 120–121
  - Switch
    - bilateral, 546–548
    - debouncing, 215
    - encoders, 593–596
  - Synchronization, flip-flop, 243–244
  - Synchronous
    - control inputs, 223, 233
    - counter design with D FF, 403
    - Link DRAM (SLDRAM), 835
    - presetting, 380
    - systems, 221
    - transfer, 245
  - Synchronous data transmission system, 613–617
    - receiver operation, 614–615
    - system timing, 615–616
    - transmitter operation, 614
  - Synchronous (parallel) counters, 367–370
    - actual ICs, 369–370
    - advantages over asynchronous, 369
    - design, 396–404
      - stepper motor control, 402
    - down and up/down, 377–379
    - operation, 369
    - presetable, 379–380
  - Synthesis and testing (using HDL), 681, 681
  - System integration and testing (using HDL), 679
- T**
- Table
    - analysis using, 69
    - circuit excitation, 397, 399
    - J-K excitation, 397, 399
    - look up (LUT), 873
    - state, 252
  - Temporary storage, RAM, 815
  - Test vectors, 175
  - Theorems
    - Boolean, 76–80
    - DeMorgan's, 80–83
    - multivariable, 77–78
  - Thin Film Transistor (TFT) LCD, 590
  - Thin quad flat pack (TQFP), 497
  - Thin shrink small outline package (TSSOP), 497
  - Thin very small outline package (TVSOP), 497
  - 3 line to 8 line decoder, 578–580
  - TI signal switch (TS switch), 531
  - Tied-together inputs, TTL, 515
  - Timer, 555 used as an astable multivibrator, 261–263. (*see also* Astable multivibrator)
  - Timing diagrams, 15, 394
    - simplified bus, 634
  - Timing problems in Flip-flop circuits, 241–242
  - Toggle mode, 227
  - Toggles, 12
  - Top-down hierarchical design (digital clock using HDL), 696–698
  - Totem-pole output circuit, 501
  - Tracking ADC, 757
  - Tradeoffs (for nonvolatile memories), 809
  - Traditional or IEEE/ANSI, 96
  - Transducer, 720
  - Transfer operation, data, 245
  - Transition diagram, state, 252–253
  - Translation Voltage Clamp (74TVC), 531
  - Transmission gate, CMOS, 546–548
  - Transparent latch (D latch) 232–233. (*see also* Flip-flops)
  - Trigger input, 225
  - Tristate
    - buffers, 539–540
    - data bus, 540
    - ICs, 540
    - outputs, 538–541
    - registers (74ALS173/HC173), 629–631
      - connected to data bus, 632
  - Tristate TTL, 538–541
    - advantages of, 538–539
    - buffers, 539–540
    - ICs, 540



- Troubleshooting
    - basic steps, 160–162
    - case study
      - gates, 168–170
      - parallel binary adder/subtractor, 335–337
    - counters, 450–452
    - decoders, circuit with, 597–599
    - digital systems, 160–162, 556–557 (*see also* Digital systems)
    - digital-to-analog converters, 738–739
    - divide-and-conquer, 597
    - fault
      - external IC, 166–168
        - correction, 160
        - detection, 160
        - isolation, 160
    - finding shorted nodes, 557
    - flip-flop circuits, 264–268
      - open inputs, 264–265
      - shorted outputs, 265–266
    - internal IC faults, 162–166
    - observation/analysis, 597
    - parallel binary adder/subtractor, 335–337
    - RAM systems, 847–852
      - know the operation, 847–850
      - testing the complete system, 851–852
      - testing the decoding logic, 850–851
    - security monitoring system, 612–613
    - sequential logic systems, 450
    - synchronous data transmission system, 613–617
    - tools used in, 161, 556–557
    - tree diagram, 620
  - Truth tables, 57–58
    - using AHDL, 181–182
    - using HDL, 181–184
    - using VHDL, 182–183
  - TTL logic family, 155–156, 498–502
    - active pull-up action, 501
    - ALS series, 156
    - AS series, 156
    - biasing inputs LOW, 516
    - characteristics, 506–509
    - circuit operation-HIGH state, 500
    - circuit operation-LOW state, 498–500
    - comparison of series characteristics, 508
    - current ratings, 512
    - current transients, TTL, 516–517
    - current-sinking action, TTL, 500
    - data sheets, 502–506
    - defined, 16
    - fan-out, 509–514
    - fast series (74F), 508
    - ground, 157
    - input voltages, 526
    - interfacing w/CMOS, 550
    - INVERTER circuit, 155
    - loading, 509–514
    - logic-level voltage ranges, 157
    - low-power Schottky, 74LS series (LS-TTL), 506–507
    - LS series, 156
    - maximum voltage ratings, 504–505
    - NAND gate, basic, 499
    - NOR gate, basic, 502
    - open-collector outputs, 533–538
    - other characteristics, 514–518
    - output voltages, 526
    - power, 157
    - power dissipation, 505
    - propagation delays, 505
    - S series, 156
    - Schottky, 74S series, 506
    - series characteristics, 506–509
    - standard, 74 series, 506
    - subfamilies, 156, 506–509
    - summary, 502
    - supply (power) voltage, 157, 503
    - temperature range, 503
    - tied-together inputs, 515
    - totem-pole output circuit, 498, 501
    - tristate, 538–541
    - unconnected inputs (floating), 157–158, 514
    - unused inputs, 514–515
    - voltage levels, 503–505
  - Twisted-ring counters, 447
  - Two-input multiplexer, basic, 600–601
  - 2's complement
    - addition, 306–307
    - form, 300
    - special case representation, 304–305
    - subtraction, 307–310
    - system, 299, 328–331
      - addition and subtraction, combined, 330–331
      - addition, 328
      - multiplication, 310–311
      - subtraction, 328–331
  - Types of computers, 20–21
    - dedicated, 21
    - embedded controller, 21
    - microcomputer, 20
    - microcontroller, 21
    - microprocessor, 20
  - Types of LCDs, 589–590
- U**
- Ultralarge-scale integration (ULSI), 154–155
  - Unasserted levels, 94
  - Unconnected inputs
    - TTL, 157–158, 514
    - CMOS, 157–158, 528
  - Undersampling, 748
  - Unipolar digital ICs, 155–156. *See also* CMOS logic family
  - Universal programmers, 172
  - Universality of NAND gates and NOR gates, 83–86
  - Unused inputs
    - TTL, 157–158, 514–515
    - CMOS, 157–159, 528
  - Up/down digital-ramp ADC, 757
  - Usefulness of hex and octal, 32
  - Using TTL library functions with ALTERA, 337–338
  - UV light, EPROMs, 804
- V**
- VERSA Module Eurocard (74VME), 532
  - VHDL (very high-speed integrated circuit hardware description language), 98–99, 410–411
    - Adder, 343, 347
    - Adder/subtractor, 345–346
    - AND, 342
    - ARCHITECTURE, 104, 179, 420, 424
    - BCD-to-binary code converter, 655
    - BEGIN, 104, 408, 411
    - behavioral description of a counter in, 410

- BIT, 104, 180, 274
- BIT\_VECTOR declarations, 179–181, 184, 339, 411, 420
- Boolean description using, 104
- BUFFER, 420
- Cascading BCD counters, 423–425
- CASE, 190–192, 407–408, 419, 428, 432, 435, 458–459, 691
- code converter, 655
- comments, 106–107
- comparator, 653
- complete clock, 709
- COMPONENT(s), 273–274, 420, 425, 432, 708–709
  - declaration, 274
  - graphic representation using, 274
  - HDL circuits with multiple, 277–280
  - library, 273–275
- concurrent assignment statement, 104
- conditional signal assignment statement, 647
- CONSTANT, 345
- converter, 655
- D latch, 271
- Decoder(s), 641
  - driver, 643–644
  - full-step sequence, 683
- decoding the MOD-5 counter, 419
- data types, common, 180
- demultiplexers, 650–651
- design file, 183
- digital clock project, 693–710 (*see also* HDL)
- DOWNT0, 339, 342, 691
- ELSIF, 187–190
- encoder, 647–648
- END, 104, 408
- ENTITY, 104, 179, 183, 278, 341, 407–408, 419–420, 423–424
- enumerated type, 428
- essential elements in, 104
- EVENT, 276, 278, 408
- flip-flops, 275–277
  - JK flip-flop, 274–275
  - MOD-8 ripple counter, 278–279
  - simulation, 276
- FOR loop, 347
- four-bit adder, 342–343
- frequency counter project, 710–714 (*see also* HDL)
- full adder, single-bit, 347
- full-featured counter, 414–415
- GENERATE statement, 346–348
- IF/THEN/ELSE, 187, 428, 435, 644, 653
- IN, 179
- INTEGER, 180, 187, 411, 415, 643–644
- intermediate signals in, 117
- iterative loop, 347
- JK flip-flop, 275
  - simulation, 276
- keypad encoder project (HDL), 687–693
  - (*see also* HDL)
  - simulation, 693
  - solution, 691–693
- LIBRARY, 647–648
  - components, 273–275
- libraries, 180
- libraries of parameterized modules, 347–348
- local signals, 106–107
- LPMs, 348
- macrofunctions, 180
- magnitude comparator, 653
- megafunctions, 348
- multiplexers, 650–651
- MOD-5 counter, 408
- MOD-6 counter, 699, 708
  - graphic block symbols, 705
  - simulation, 700
- MOD-8 counter, 682
  - simulation, 682
- MOD-10 counter, 700–701, 708
- MOD-12 counter, 703–705
  - graphic block symbols, 705
  - simulation, 705
- MOD-60 counter, 708
- MOD-100 BCD counter, 424
- module integration, 708–710
- NAND latch, 271
- nonretriggerable one-shot, 463
- objects, 180
- one-shots, 462–464
  - simulation, 464, 467
- OR, 342
- PACKAGE, 345
- PISO register, 456
- PORT, 104
  - MAP, 275, 280, 420, 425, 432, 710
- PROCESS, 187, 275–276, 278, 407–408, 411, 414–415, 419, 435, 459, 466, 643–644, 653, 691, 703–704
- RANGE, 187, 411
- retriggerable, edge-triggered one-shot, 466–467
- ring counter, 460–461
- ripple-up counter (MOD-8), 278–279
- SELECT, 182
- sensitivity list, 187
- SIGNAL, 106, 184, 276, 279, 339, 407–408, 643–644, 704
- simulation of full-featured counter, 415
- single-bit full adder, 347
- SISO register, 454–455
- stepper driver, 685
  - simulation testing, 686
- stepper motor driver project, 679–686 (*see also* HDL)
- state descriptions in, 407–408
- state machine, simple, 428–429
- STD\_LOGIC, 180, 274
  - values, 181
- STD\_LOGIC\_VECTOR, 180
- traffic light controller, 432–435
- truth tables, 182–184
  - concatenating, 182–183
  - selected signal assignments, 182–184
- TYPE, 428
- VARIABLE, 275–276, 407–408, 466, 643–644, 703–704
- WHEN, 641, 647–648
- WITH, 182
- VLSI (very large scale integration), 154–155, 489
- Volatile memory, 788
- Voltage
  - comparators, 554–556
  - controlled oscillator, linear (VCO), 758
  - to frequency ADC, 758
  - level translator, 553
  - levels, invalid, 494–495
  - parameters for digital ICs, 490–491

**W**

Wave-drive sequence (HDL stepper-motor), 680  
Wired-AND connection, 535–536  
Word, 37–39  
    size, 39  
Write cycle, 255  
    address setup time, 820  
    data hold time, 820  
    data setup time, 820  
    time, 820

## Write operation

CPU, 794  
defined, 788  
RAM, 816

**Z**

Zero  
    count, 12  
    insertion force socket (ZIF), 172

---