Index

A
AAD (assembly activity detector), 401–402
Abrasive cleaning, 312
Absolute encoders, 755
AC (aerobic capacity), 428
Acceleration error coefficient ($c_2$), 753
Accelerometers, 754
Access, convenience of, 662–663
AC circuits, see Alternating current circuits
Accuracy, 566, 601
Achieved availability, 280
ACIS (American Committee for Interoperable Systems), 43
Across variables (term), 445, 670
Actions, SFC, 810
Action blocks, 811–812
Action-dependent HDP (ADHDP), 862
Active circuits, 473
Active devices, 473
Active noncontact scanners, 26
Active steps, 810
Actuators, 756–762
electromechanical, 756–758
hydraulic, 758–760
pneumatic, 760–762
Actuator compensation, 856–860
Adams–Bashforth corrector methods, 721
Adams–Moulton corrector methods, 721
Adaptive control, 803, 850
integral reinforcement learning for, 863–866
for nonlinear systems with hysteresis, 858–859
for nonlinear systems with input constraints, 859
Adaptive critics, 861
A/D converters, see Analog-to-digital converters
Adders, 769, 770
Adder circuits, 485, 486
Addition, binary, 918
Additives, in plastics, 334–335
Additive manufacturing (AM), 46–48
Additive property of phasors, 513–514
Additive property of sinusoids, 501
Additivity, 462
Additivity property, 463–464
Address, memory, 926
ADHDP (action-dependent HDP), 862
Adhesive bonding, of plastic parts, 337–338
Adjustable load, 468
Adjustment, 646
Admissible policies, 863, 867
Admittance, 518–519. See also Impedance(s)
transfer, 544
ADP, see Approximate dynamic programming
Advance operator, 742
Adversaries (Design for Six Sigma), 346
Advocates (Design for Six Sigma), 346
Aerobic capacity (AC), 428
Affinity diagram, 137
AHAM (Association of Home Appliance Manufacturers), 81
Air Defense Command and Control System, 4
AISI (American Iron and Steel Institute), 197
Aliasing, 588
Alterables (term), 636
Alternating current (AC) circuits, 495–531
energy storage devices in, 504–512
phasor analysis of, 512–525
power in sinusoidal steady state operation of,
525–531
signals in, 495–504
AM (additive manufacturing), 46–48
AMD 990FX, 14
AMD Athlon dual-core processor, 17
American Committee for Interoperable Systems (ACIS), 43
American Electronics Association, 208
American Iron and Steel Institute (AISI), 197
American Society for Nondestructive Testing (ASNT), 309
American Standard Code for Information Interchange (ASCII) code, 927
Ammeters, 904
Ampere, 442
AMPL (A Mathematical Programming Language), 120
Amplification, signal, 473, 552
Amplifiers, 675
differential, 756
function of, 750
Amplitude, of waveforms, 496, 500, 502–503
Index

Analogs (term), 680–681
Analog Devices (company), 950
Analog electronics, 896–908
circuit analysis in, 901–902
definitions used in, 896–897
electrical elements in, 897–901
examples of, 907–908
RL/RC transient response in, 904–906
sources/meters in, 903–904
Analog filters, 581–587
Butterworth, 582–583
eccentric, 585, 586
inverse Chebyshev, 584–585
least squares method of designing, 585, 586
prototype circuit for, 586–587
Chebyshev, 584–585
Analog instruments, 567
Analog quantization size, 930
Analog simulation, 717
Analog-to-digital (A/D) converters, 519, 599, 787, 930–931
Analysis, signal processing, 440
Analysis and optimization stage (design process), 6, 7
Analysis problems, 543
Analysis software, 39–43
Anchoring, 646
Angular frequency, of sinusoid, 501
ANSYS, 39, 947
Anthropometry, 420–422
data and use, 420–421
in design, 421–422
measurements in, 420
A percent linearity or nonlinearity, 567–568
Aperiodic signals, 502
Apparent power, 528
Application of DfE approach metric, 84
Approximate dynamic programming (ADP), 847, 859–866
for discrete-time systems, 860–862
and integral reinforcement learning for
continuous-time systems, 863–866
and reinforcement learning, 886–888
APT (Automatically Programmed Tools) language, 823, 831–835
Aqueous cleaning, 311
AR, see Augmented reality
Arbitrary frequency response curve fitting, 585, 586
Architecting phase (system design), 656–657
Area under the impulse, 497
Armature-controlled dc motors, 756, 757
Array function, 36
Arts and Crafts movement, 208
ASCH (American Standard Code for Information
Interchange) code, 927
Ashby, Mick, 88
“Asking approach” to requirements identification, 635–636
ASNT (American Society for Nondestructive
Testing), 309
Assembly, virtual reality for, 399–404
Assembly activity detector (AAD), 401–402
Assembly errors, 168
Association of Home Appliance Manufacturers
(AHAM), 81
Associative laws of Boolean algebra, 921
Asynchronous serial data transfer, 929, 930
AT&T, 120
Attenuation, signal, 552
Attributes of objectives, 637
A-type element, 671, 672, 674, 679
Auditory display, VR, 379, 380
Augmented reality (AR), 373, 377, 378, 401–402, 407–408
Authoring tools, VR, 380
AutoCAD™, 397
AutoCAD LT 2013 32-bit, 16
AutoCAD software, 43
AutoCAD WS, 16
Autocorrelation function, 727
AutoDesk, Inc., 43
Autodesk Inventor, 46
Automated drafting, 13
Automatically Programmed Tools language,
see APT language
Automation, of remanufacturing, 314
Automotive industry, sustainability in, 179–180
Automotive Parts Rebuilder’s Association, 306
Availability:
definition of, 279
of information, 646
modeling of, 291–295
Averages, in data summaries, 606
Average power, reactive and, 525–527
Average value (waveform), 502, 503

B
Back emf, 747
Backlash, 857–858
Backlash nonlinearity, 735
Backpropagation of signals, 857
Backstepping neurocontrollers, 853–854
Balanced subcircuits, 451
Bandpass filters, 590, 592–593
Bandpass gain, 550, 551, 561
Bandpass responses, 556–559
Band reject filters, 593–594
Bandstop gain, 550, 551
Band-stop responses, 556–559
Bandwidth, 550, 706
Bang-bang control problem, 804
Bar bending stress, 107
Bar buckling load, 107
Bar deflection, 107
Bartlett window, 589, 590
Base rate, 647
Basic oxygen furnace (BOF), 102–105
Batt input device, 381, 382
Battery Directive (European Union), 81
Battery-free remote control, 91
BCD (binary-coded decimal), 927
Bearings, failure rate estimation for, 171
Bearing failure, 160
BEES (Building for Environmental and Economic Sustainability), 185
Behavior:
  defining, 693
  describing, 693, 694
  specifying, 694
Behavioral evaluation, 661
Behind the Tape Reader (BTR), 824
Bellows, 760
Benchmarking, 69, 71, 133
Bending failure, 159
Bill of material (BOM), 60
Binary addition, 918
Binary-coded decimal (BCD), 927
Binary numbers, 916–919, 927
  addition of, 918
  of different size, 916–917
  and hexadecimal numbers, 917–918
  two’s complement of, 918–919
Binary-weighted summer DAC, 490
Binomial distributions, 258–259
Biodesign products, 184, 185
Biological cleaning, 311–312
Biomechanics (ergonomics), 424–428
  joint movements, 424–426
  muscle forces, 426–427
  tissue tolerances, 427–428
Bipolar junction transistors (BJTs), 911
Bipolar terms, 526
Bits, 916
BJTs (bipolar junction transistors), 911
BL (burdened assembly labor cost), 56
Black belts, 344
Black & Decker, 308
Blackman window, 589, 590
Blake, William, 208
Blocks, programming, 828, 830, 831
Block diagrams, 693–695, 748–750
BMW, 386
Board members, 79
Bode diagrams/plots, 704–707, 709, 711, 713, 781, 782, 784
Body trackers, 374
Boiler-generators, 802
BOM (bill of material), 60
Boolean algebra identities, 921–922
Boundaries of system, defining, 98
Boundary representation (B-rep) method, 10, 34, 35
Boxcar algorithm, 607, 608
Brainstorming, 70–71, 637
Brainwriting, 637
Brake systems, failure rate estimation for, 169–170
Branches, 679
Braungart Design Consultants, 236, 237
Bridge circuit:
  node voltage analysis of, 455–456
  proportionality constant of, 463
Bridge network, 158–159
Brundtland, Gro Harlem, 77
Brundtland Commission, 187
Brundtland Report, 77
BTR (Behind the Tape Reader), 824
Buckling, 42
Buffers, 484, 921
Building block approach:
  to op-amp circuit analysis, 482
  to op-amp design, 488–489
Building for Environmental and Economic Sustainability (BEES), 185
Bulk micromachining, 946
BUND, 208
Burdened assembly labor cost, 56
Bus, 14–15
Butterworth filter, 582–583
Bytes, 916

C
C2, 386, 398
CAD, see Computer-aided design
CADENCE, 947
CAESAR (Civilian American and European Surface Anthropometry Resource) project, 420
Calibration, instrument, 566
California Institute of Technology, 5
CAM (computer-aided manufacturing), 835–836
Capabilities, physical effort and, 418
Capacitance: defined, 504 equivalent, 507–508
Capacitive reactance, 517
Capacitive storage elements, 671, 674
Capacitors, 504–505, 898–900 constraints in phasor form on, 514, 515 impedance of, 516
Capacitor energy, 505
Car crash simulation, 386–387
Carnegie Mellon University, 229
Carothers equation, 334
Carson, Rachel, 208
Cascade connections: and bandpass responses, 556, 557 and frequency response, 547–549 of op-amp circuits, 492, 493
Cascade control, 779, 780
Caterpillar, 82, 304, 307, 313, 314
Cathode ray tube (CRT) screen, 4, 27–28
Cauchy’s gradient method, 116
Causal base rate, 647
Causal loop diagrams, 638–640
Causal signals, 502
CAVE™, 372, 406, 408
CAVELIB software, 397
CAVEvis, 389–390
Cavities, reducing number of, 323
CCCs (current-controlled current source), 474
Cebon, David, 88
Celsius, degrees, 566
Center of mass, 420
Central processing unit (CPU), 9, 14, 925
Cerebellar model articulation controller (CMAC), 847
Certified Green e Power, 179
Certified Organic products labeling, 179
Cesium clock, 566
Cesium fountain atomic clock, 566
CES Material Selector, 88
CFD, see Computational Fluid Dynamics
CFD Research Corporation, 947
Chain rule, 547, 548
Chamfering function, 36
Characteristic equation, 539
Characteristic equations, 715
Characteristic polynomial, 692
Charette, 637
Charge: in capacitors, 504 in electric circuits, 440, 441
Chemical engineering, virtual reality applied to, 409–411
Chip storage capacity, 15
Circuits, 439, 444, 446. See also Electric circuits
Circuit analysis, 482–484, 901–902
Circular resonators, 950, 951
Civil engineering, virtual reality applications in, 402–408
DIVERCITY, 402, 404, 405
VIRCON, 402, 404
Clariant Chemical Corporation, 237
Classical control theory, 687
Classical linear systems analysis, 681. See also Transform methods
Classic designs, 315
Cleaner and Greener Certification, 179
Cleaner Technologies Substitutes Assessment (CTSA), 229
Cleaning: ease of, 320 in remanufacturing, 310–312, 322–323
Clean Vehicles program, 179
Climatex Life-cycle fabric, 236, 237
CL (cutter location) level, 823
Closed-loop control systems, 748
Closed-loop gain, 483
Closed rule, 721
Cloud storage, 16
Clutches, failure rate estimation for, 171–172
CM, see Corrective maintenance
CMAC (cerebellar model articulation controller), 847
CMM (coordinate measuring machine), 25
CMOS (complementary metal–oxide–semiconductor), 948
CNC (computer numerical control), 823, 824
Co-contraction, 427
Cognitive illusions, 649
CoinEasy, 121
COIN-OR (Computational Infrastructure for OR), 121
Collaborative product design (CPD), 48–49
Collaborative Research Institute for Sustainable Products (CRISP), 187
Collective-inquiry methods, 637–638
Collocated teams, 67, 69
Combinatorial logic operators, 920–921
Combined constraints, 447–448
Command transfer function, 752
Communications, data, 617–620
Communication accomplishments, in efficacy evaluation, 661–662
Communications processors, 808
Community, stakeholders in, 79
Commutative laws of Boolean algebra, 921
Companion matrix, 687
Compatibility, 680
<table>
<thead>
<tr>
<th>Title</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Compensation, 777–781</td>
<td></td>
</tr>
<tr>
<td>feedback, 778–780</td>
<td></td>
</tr>
<tr>
<td>feedforward, 778, 780</td>
<td></td>
</tr>
<tr>
<td>parallel, 778</td>
<td></td>
</tr>
<tr>
<td>series, 778–779</td>
<td></td>
</tr>
<tr>
<td>Compensators, 777</td>
<td></td>
</tr>
<tr>
<td>Competitive benchmarking, 69, 71</td>
<td></td>
</tr>
<tr>
<td>Competitors, 79</td>
<td></td>
</tr>
<tr>
<td>Complementary metal–oxide–semiconductor (CMOS), 948</td>
<td></td>
</tr>
<tr>
<td>Complete response of system, 694</td>
<td></td>
</tr>
<tr>
<td>Completing the square, 691</td>
<td></td>
</tr>
<tr>
<td>Complex-frequency domain, 688</td>
<td></td>
</tr>
<tr>
<td>Complex method, 117</td>
<td></td>
</tr>
<tr>
<td>Complex poles, 691</td>
<td></td>
</tr>
<tr>
<td>Complex power, 527–529</td>
<td></td>
</tr>
<tr>
<td>Complex s-plane, 699, 701</td>
<td></td>
</tr>
<tr>
<td>Compliance, 569, 571</td>
<td></td>
</tr>
<tr>
<td>Components:</td>
<td></td>
</tr>
<tr>
<td>reusable, 320</td>
<td></td>
</tr>
<tr>
<td>standardization of, 318</td>
<td></td>
</tr>
<tr>
<td>Compound filters, for frequency response, 562–563</td>
<td></td>
</tr>
<tr>
<td>Compression techniques, 605–609</td>
<td></td>
</tr>
<tr>
<td>compressive failure, 159</td>
<td></td>
</tr>
<tr>
<td>Compressor systems, failure rate estimation for, 170</td>
<td></td>
</tr>
<tr>
<td>Computational Fluid Dynamics (CFD), 388–391</td>
<td></td>
</tr>
<tr>
<td>CAVEvis, 389, 390</td>
<td></td>
</tr>
<tr>
<td>NASA Virtual Wind Tunnel, 388–390</td>
<td></td>
</tr>
<tr>
<td>ViSTA FlowLib, 391</td>
<td></td>
</tr>
<tr>
<td>VR-CFD, 389</td>
<td></td>
</tr>
<tr>
<td>Computed torque method, 790</td>
<td></td>
</tr>
<tr>
<td>Computers:</td>
<td></td>
</tr>
<tr>
<td>classes of, 16–17</td>
<td></td>
</tr>
<tr>
<td>in design process, 8–13</td>
<td></td>
</tr>
<tr>
<td>engineering PCs, 17</td>
<td></td>
</tr>
<tr>
<td>hardware for CAD, 13–18</td>
<td></td>
</tr>
<tr>
<td>input devices, 18–27</td>
<td></td>
</tr>
<tr>
<td>output devices, 27–29</td>
<td></td>
</tr>
<tr>
<td>Computer-aided design (CAD), 3–18, 29–51, 835–836, 947</td>
<td></td>
</tr>
<tr>
<td>applications of, 44–51</td>
<td></td>
</tr>
<tr>
<td>design applications for, 8–13 have</td>
<td></td>
</tr>
<tr>
<td>and design process, 5–8</td>
<td></td>
</tr>
<tr>
<td>hardware used in, 13–18</td>
<td></td>
</tr>
<tr>
<td>historical perspective on, 4–5</td>
<td></td>
</tr>
<tr>
<td>software for, 29–43</td>
<td></td>
</tr>
<tr>
<td>standards for and translators of, 43</td>
<td></td>
</tr>
<tr>
<td>virtual reality techniques for, 381</td>
<td></td>
</tr>
<tr>
<td>Computer-aided manufacturing (CAM), 835–836</td>
<td></td>
</tr>
<tr>
<td>Computer-assisted programming, 831–835</td>
<td></td>
</tr>
<tr>
<td>Computer numerical control (CNC), 823, 824</td>
<td></td>
</tr>
<tr>
<td>Concatenation, 37–38</td>
<td></td>
</tr>
<tr>
<td>Concentration diagrams, 142–143</td>
<td></td>
</tr>
<tr>
<td>Concept development (Design for Six Sigma), 351–357</td>
<td></td>
</tr>
<tr>
<td>Concept phase (new product development), 59</td>
<td></td>
</tr>
<tr>
<td>Conceptual design, and design for the life cycle, 222</td>
<td></td>
</tr>
<tr>
<td>Conceptual design and virtual reality, 380–386</td>
<td></td>
</tr>
<tr>
<td>3DM, 381</td>
<td></td>
</tr>
<tr>
<td>3-Draw, 381</td>
<td></td>
</tr>
<tr>
<td>COVIRDS, 382, 383</td>
<td></td>
</tr>
<tr>
<td>freeform sketching system, 384, 385</td>
<td></td>
</tr>
<tr>
<td>HoloSketch, 381, 382</td>
<td></td>
</tr>
<tr>
<td>JDCAD, 381, 382</td>
<td></td>
</tr>
<tr>
<td>virtual sculpting, 382, 383</td>
<td></td>
</tr>
<tr>
<td>VR techniques for evaluating, 384–386</td>
<td></td>
</tr>
<tr>
<td>Conceptual VIRtual Design System (COVIRDS), 382, 383</td>
<td></td>
</tr>
<tr>
<td>Condensation polymers, 330</td>
<td></td>
</tr>
<tr>
<td>Conductance, 444, 518</td>
<td></td>
</tr>
<tr>
<td>Conjoint analysis, 224</td>
<td></td>
</tr>
<tr>
<td>Conjugate matching, 523</td>
<td></td>
</tr>
<tr>
<td>Connection constraints:</td>
<td></td>
</tr>
<tr>
<td>for electric circuits, 445, 446</td>
<td></td>
</tr>
<tr>
<td>phasor form of, 514</td>
<td></td>
</tr>
<tr>
<td>Conservatism, 647</td>
<td></td>
</tr>
<tr>
<td>Constant-k filters, 563</td>
<td></td>
</tr>
<tr>
<td>Constitutive relationship, 671</td>
<td></td>
</tr>
<tr>
<td>Constrained optimization methods, 116–120</td>
<td></td>
</tr>
<tr>
<td>direct search, 116–117</td>
<td></td>
</tr>
<tr>
<td>linearization, 118–119</td>
<td></td>
</tr>
<tr>
<td>SQP, 119–120</td>
<td></td>
</tr>
<tr>
<td>transformation, 117–118</td>
<td></td>
</tr>
<tr>
<td>Constrained optimization problem, 112</td>
<td></td>
</tr>
<tr>
<td>Constraints (electric circuit):</td>
<td></td>
</tr>
<tr>
<td>combined, 447–448</td>
<td></td>
</tr>
<tr>
<td>connection, 445, 446</td>
<td></td>
</tr>
<tr>
<td>element, 444</td>
<td></td>
</tr>
<tr>
<td>Constraints (term), 636</td>
<td></td>
</tr>
<tr>
<td>Construction, virtual reality applications in, 402–408</td>
<td></td>
</tr>
<tr>
<td>and AR tools, 407–408</td>
<td></td>
</tr>
<tr>
<td>with CAVE™, 406</td>
<td></td>
</tr>
<tr>
<td>DIVERCITY, 402, 404, 405</td>
<td></td>
</tr>
<tr>
<td>VIRCON, 402, 405</td>
<td></td>
</tr>
<tr>
<td>Constructive solid geometry (CSG) method, 10, 34, 35</td>
<td></td>
</tr>
<tr>
<td>Consumer demand, for remanufactured products, 304</td>
<td></td>
</tr>
<tr>
<td>Contact scanners, 25</td>
<td></td>
</tr>
<tr>
<td>Contents, memory, 926</td>
<td></td>
</tr>
<tr>
<td>Contingent valuation, 224</td>
<td></td>
</tr>
<tr>
<td>Continuity, 679–680</td>
<td></td>
</tr>
</tbody>
</table>
### Index

Continuous distributions, 263–266  
exponential distribution, 264–265  
lognormal distribution, 264  
normal distribution, 263–264  
Weibull distribution, 265–266  
Continuous-path machines, 827–828  
Continuous-time dynamic simulation, 644  
Continuous-time Hamilton–Jacobi–Bellman equation, 867–872  
Continuous-time systems, 863–866  
Contouring controllers, 827–828  
Control:  
  - illusion of, 647  
  - objectives of, 762  
Control action, 762  
Control algorithm, 762  
Control charts, 139–140  
Control law(s), 762–768  
  - derivative, 767–768  
  - integral, 765–766  
  - proportional, 763–765  
  - proportional-integral-derivative, 768  
  - proportional-plus-integral, 766–767  
Controller hardware, 769–773  
  - digital, 796–798  
  - electronic, 769–772  
  - feedback compensation and design of, 769  
    - hydraulic, 772–773  
    - pneumatic, 772  
  - Controllers, robot, 836–840  
  - Control processors, 808  
  - Control program, robot, 838–841  
Control systems:  
  - classifications of, 751–752  
  - elements of, 751  
  - functions of, 750  
  - future trends in, 801–804  
  - purpose of, 748  
  - system-type number/error coefficients of, 752–753  
  - transfer functions of, 752  
Control system design, 747–804  
  - actuator, 756–762  
  - block diagrams in, 748–750  
  - compensation/alternative control structures, 777–781  
  - and control laws, 762–768  
    - digital, 787–800  
    - gain selection criteria, 773–777  
    - graphical methods of, 781–787  
    - hardware, 769–773  
  - software support for, 800–801  
  - structure of control system, 750–753  
  - transducer/error-detector, 753–756  
    - in the z-plane, 791–794  
Control systems simulation software, 800–801  
Control voltage, 478  
Convex programming, 114  
Coordinate measuring machine (CMM), 25  
Coordinate systems, NC, 825–827  
Core charges, 306  
Corner frequency, 553  
Corrective maintenance (CM), 251, 252, 286  
Correlation(s):  
  - in data summaries, 607  
  - illusion of, 648  
  - Correlation coefficient, 726  
Corrosion coating, 322, 323  
Cost accounting tools, environmental, 233–234  
Coulombs, 440  
Coupled Hamilton–Jacobi equations, 877–884  
Covariance, 726  
Covector, 947  
COVIRDS (Conceptual VIRtual Design System), 382, 383  
COVISE, 391  
CPD (collaborative product design), 48–49  
CPU, see Central processing unit  
Cradle-to-cradle design, 210  
Cramer’s rule, 478  
Creep failure, 159  
Creo 2.0, 15  
CRISP (Collaborative Research Institute for Sustainable Products), 187  
Critically damped response, 540, 541, 699  
Critical step size, 723  
Critics, adaptive, 861  
Cross-correlation function, 727  
CRT (cathode ray tube) screen, 4, 27–28  
CrystalEye stereo glasses, 397  
CSG method, see Constructive solid geometry method  
CTSA (Cleaner Technologies Substitutes Assessment), 229  
Current:  
  - defined, 441–442  
  - from dependent sources, 475  
  - input, 454, 484, 485  
  - interface, 468, 471–472, 523  
  - at interface, 468  
  - in inverting amplifiers, 485  
  - Kirchhoff’s law of, 446, 447, 459, 514, 532, 902, 907  
  - magnetizing, 525  
  - mesh, 458, 459, 478  
  - in node analysis with dependent source, 476  
  - output, 475
phasor, 514, 520–522
reference marks for, 442–443
rotor, 525
short-circuit, 465, 466
stator, 525
as term, 897
in transformers, 511
Current-controlled current source (CCCS), 474
Current division, 452–453, 518–519, 545
Current division rule, 453
Current source(s), 897, 903
dependent, 473–479
equivalent, 450
ideal, 444, 445, 897
Current transfer function, 544
Current-value inspection, 613–614
Customers:
environmental concerns of, 78, 81
as stakeholders, 79
Customer input, in Design for Six Sigma, 349
Customer needs mapping, 139
Customer returns, 308
Cutoff frequencies, 549, 550, 552, 553, 556, 557, 706
Cutter location (CL) level, 823
Cutting depth, 827
Cutting speed, 827
Cutting tools, 823–824
CyberForce, 375, 376, 378, 400
CyberGlove, 375, 376, 378, 399
CyberGlove Systems LLC, 376, 377, 394
CyberGrasp, 378, 379, 400
Cybersickness, 372
CyberTouch, 378, 379
Cyclic frequency, of sinusoid, 501

D
D/A converters, see Digital-to-analog converters
Dahlin’s algorithm, 795
DaimlerChrysler, 179
D’Alembert forces, 680
Damage-resistant designs, 315–316
Damped natural frequency, 699
Damping, 699
Damping ratio, 540, 541, 560, 699
DARPA (Defense Advanced Research Projects Agency), 949
Data, transfer of digital, 928–930
Data acquisition, 598–602
accuracy/precision, 601
configuration vs. implementation of, 621, 623
linking storage and, 623
sampling interval, 599–600
time-based vs. event-driven, 602
with Web programs/interfaces, 621
Data analysis, 616–617
Database management systems, 611–612
Database storage, 611–612
Data chain, 620–622
Data communications, 617–620
benefits of standard, 620
considerations for, 623
network, 618
OPC standard for, 619–620
OSI standard for, 619
parallel, 617
serial, 617, 618
Data conditioning, 602–609
compression techniques, 605–609
filtering, 604–605
nonlinear relationships, 603–604
simple linear fit, 602–603
Data display and reporting, 613–616
current-value inspection, 613–614
of historical data, 614–616
of individual points, 614
Data flip-flops, 924
Data presentation context, 647
Data reduction, optimization for, 110–112
Data saturation, 647
Data storage, 609–613
database, 611–612
file, 610–611
in-memory, 609–610
linking acquisition and, 613
and third-party acquisition systems, 612–613
triggers for, 609–610
Data visualization (virtual reality), 386–391
computational fluid dynamics, 388–391
finite-element analysis, 386–391
DC circuits, see Direct-current circuits
DC component (of a waveform), 503
DC signals, 495
Dead-time elements, systems with, 783, 800–801
Dead zones, 856–857
Decade, 552
Decibels, 552
Decimal prefixes, 441
Decision analysis, 649
Decision making, 646–649
in new product development, 77
in systems engineering, 631
Decision situation models, 653–654
Decision support tools (design for remanufacturing), 325–326
Deckard, Carl, 47

Index 961
Decrement property of exponential waveforms, 499
Deep reactive ion etching (DRIE), 946
Defense Advanced Research Projects Agency (DARPA), 949
Delay operator, 742
Deletion function, 36
Delft University of Technology, 91
Dell, 308
Delphi, 637–638
$\Delta$-connected impedances, 519–521
$\Delta$-connected resistors, 450, 451
Demands, physical effort and, 418
Deming wheel, 137
Density function, 726
Department of Energy (DoE), 178, 179
Dependent sources:
analysis with, 474–476
mesh current analysis with, 477–478
node voltage analysis with, 476–477
Thévenin equivalent circuits with, 478–479
Derivative control, 767–768
Derivative gain, 767
Derivative property:
of phasors, 514
of sinusoids, 502
Derivative time, 767
Describing function, 782
Describing-function analysis, 731–737
Descriptive identification of requirements, 635, 636
Descriptive methods, 639
Descriptive modeling, 642
Design:
anthropometry in, 421–422
circuit, 469–473
control system, see Control system design
interface, 469–473
MEMS, 947
operational amplifier, 488–489
with plastics, see Plastics
for product sustainability, see Product sustainability, design for
signal processing, 440
system, see System design
value system, 631, 637
Design decisions, 77
Design errors, 168
Design for adjustability approach, 422
Design for assembly (DFA), 7–8, 57, 76, 324–325
in new product development, 70
principles for, 70–71
Design for average approach, 422
Design for disassembly (DfD), 324–325
Design for environment (DfE), 209–210, 249
Design-for-environment (DfE) programs, 75–93
creating, 79–86
and decision making in new product
development, 77
and design for X activities, 76
design process with, 84–85
environmental objectives in, 77–83
identifying/understanding stakeholders in,
79–80
innovative products from, 91–92
integration of, 85–86
metric selection for, 83–84
Design for Environment Software, 185
Design-for-environment (DfE) tools, 86–91
CES Material Selector and Eco-Audit Tool, 88
environmental effect analysis, 88–90
ENVRIZ, 90–91
guideline/checklist documents, 86–87
life-cycle assessments, 90
product design matrix, 87
Design for extremes approach, 421–422
Design for maintainability, 249–297. See also
Repairable systems design
continuous distributions in, 263–266
corrective maintenance, 252
and defining failure, 253
discrete distributions in, 258–263
and estimation of $R(t), v(t), f(t)$ using empirical
data, 274
failure process modeling in, 274–278
and intensity functions for commonly used
distributions, 271–272
and modeling of maintainability, 282–285
opportunistic maintenance, 252
Pareto analysis for data segregation in, 266–267
preventive maintenance, 251–252
and preventive maintenance, 254–257
random variables in, 257–258
reliability models in, 268–271
and steady- vs. transient-state systems, 253–254
systems vs. component approach to, 252–253
terminology related to, 251
three-parameter Weibull probability distribution
used in, 273–274
Design for manufacturing (DFM), 7–8, 57, 71, 76
Design for Manufacturing and Assembly
(DFM&A), 55–73
defined, 56
design for assembly, 57
design for manufacturing, 57
goal of, 57–58
ideal process for applying, 59–61
methodology for, 68–71
metrics for, 71–73
motor drive assembly case study, 61–66
upper management support for, 65, 67–68
Design for product assurance (DfPA), 250
Design for reassembly, 322
Design for remanufacturing, 314–326
cleaning guidelines, 322–323
decision support tools, 325–326
design for assembly and, 324–325
and design for reassembly, 322
and design for reverse logistics, 317
disassembly guidelines, 321–322
hardware guidelines, 319–324
hazardous materials and substances of concern in, 318
inspection and testing guidelines, 324
product architecture design guidelines, 315–316
product maintenance and repair guidelines, 316–317
proliferation vs. standardization of parts, 317–318
and remanufacturing of products vs. components, 314
replacement, reconditioning, and repair guidelines, 323–324
sorting guidelines, 320–321
uncertainties in, 319
and use of proprietary technology, 318–319
Design for reverse logistics, 317
Design for Six Sigma (DFSS), 341–369
about, 341
defining requirements phase of, 349–351
developing the concept phase of, 351–357
IDDOV process, 347–367
identifying the project phase of, 348
management of, 344–346
myths about, 342
optimizing the design phase of, 357–367
phases of, 347–349
and TQM, 135
understanding customer requirements phase of, 349
verifying/launching phase of, 367
Design for the Environment program, 178
Design for the life cycle (DILC), 207–243
conceptual phase, 222
corporate motivators, 213, 215
and cradle-to-cradle design, 210
and design for environment, 209–210
distribution design, 218–219
and ecodesign, 210
embodiment and detail design, 222, 224
and environmentally conscious design, 210
and expanded robust design, 239–240
future of, 239–243
and going beyond design, 220–222
and green engineering/design, 210
historical influences on development of, 208
implementation of, 234–239
and industrial ecology, 210
manufacturing design, 218
material design, 217
methods, design, 222–224
motivations for, 211–213
product definition, 222
and product design process, 216
product end-of-life design, 220
and product packaging, 216, 217
product service design, 219
product use design, 219
and regulation, 213, 214
tools for, 224–234. See also Design tools
uncertainty of, 240
Design for X (DFX), 76, 208, 250
Design optimization, 357–367. See also Optimization
Design phase (new product development), 59, 60
Design phase (TQM), 131–136
acquisition/process control, plans for, 134
benchmarking in, 133
control, design, 131
and Design for Six Sigma, 135
process design review, 133–134
quality design characteristics, 131
quality function deployment (QFD), 132
quality improvement guidelines, 135
quality loss function, 132–133
review, product design, 132
for software development, 136
and Taguchi’s approach, 134–135
Design problems, 543
Design process:
applying computers to, 8–13
with D/E programs, 84–85
ergonomics in, 419
optimal, 101
steps in, 5–8
Design reliability, 161–169
about, 161–162
failure rate allocation method, 162–163
FMEA (failure modes and effect analysis), 167
FTA (fault tree analysis), 167–168
and human error, 168–169
hybrid reliability allocation method, 163–164
safety factor/safety margin, 164–165
stress–strength interference theory method, 165–167
Design review, 13
Index

Design tools, 224–234
and design indicators, 229, 231–233
in product definition stage, 224–230
Desired values, 847
Desktop computers, 17
Desktop VR, 373
Desktop VR displays, 377
Detail design variables, for optimization, 99–100
Detailed design phase (system design), 657–658
Development phase (new product development), 59
Device constraints, phasor form of, 514
DfA, see Design for assembly
DfD (design for disassembly), 324–325
DfE, see Design for environment
DFI (duty, freight, and insurance), 56
DfLC, see Design for the life cycle
DFM, see Design for manufacturing
DFM&A, see Design for Manufacturing and Assembly
DfPA (design for product assurance), 250
DFSS, see Design for Six Sigma
DfX, see Design for X
DHP (dual heuristic programming), 862
Diagonized canonical variables, 716
Diaphragms, 756
Difference amplifiers, 915
Difference equations, 740, 788
Differential amplifiers, 480, 486–488, 756
Differential equations, 788
Differential voltage, 494
Differentiator, 915
Digital algorithms, 789–795
computed-torque, 790
direct design of, 794–795
feedforward compensation, 790–791
z-plane control design, 791–794
Digital circuits, 920–925
and Boolean algebra identities, 921–922
combinatorial logic operators for, 920–921
and flip-flops, 922–924
Schmitt trigger in, 924–925
in sequential logic devices, 922
timing diagrams for, 921
Digital computers, 925–928
Digital control/controllers, 787–800
algorithms for, 789–795
hardware/software for, 796–800
PID, 788–789
principles of, 787–789
structure of, 787–788
Digital data transfer, 928–930
Digital feedforward compensation, 790–791
Digital filters, 587–594, 775
FIR, 588–590
frequency-domain, 594
IIR, 590–592
from low-pass prototypes, 592–594
z-transforms, 587–588
Digital instruments, 567
Digital Mirror Device, 948
Digital optical encoders, 932
Digital signal processors (DSPs), 796
Digital simulation, 717–723
continuous-system simulation languages, 723
Euler method, 719–720
multistep method, 721
numerical integration errors, 722
predictor–corrector method, 722
Runge–Kutta methods, 720–721
selecting integration method, 723
time constants/time steps, 722–723
Digital-to-analog (D/A) converters, 490–491, 519, 599, 787, 931
Digitizers, 23–24
Dimension-driven design, 31, 32
Diodes:
ideal, 901, 908–909
light-emitting, 910–911
photodiodes, 911
real, 909
Zener, 910
Diode circuits, analysis of, 909
Direct-current (DC) circuits, 454–473
interface design for, 469–473
linearity properties of, 462–464
maximum signal transfer in, 468–469
mesh current analysis of, 458–461
node voltage analysis of, 454–458
Thévenin and Norton equivalent circuits, 465–467
Direct-design method, 794–795
Direct NN control, 848
Direct-search optimization methods, 115–117
Dirt protection, 322, 323
Disassembly, 319, 324–325
Disassembly guidelines, 321–322
Disassembly time, 84
Discrete distributions, 258–263
binomial, 258–259
geometric distribution, 260
hypergeometric distribution, 260–261
negative binomial, 259–260
Poisson distribution, 261–263
Discrete-event digital simulation models, 644
Discrete-time systems, 737, 740–745
  approximate dynamic programming for, 860–862
difference equations, 740
  neural network control for, 852
  pulse transfer functions, 742–744
  uniform sampling, 740–741
  zero-order hold, 743–745
  z-transform, 741–743
Discrete transfer functions, 742, 743
Displacement transducers, 753–754
Distinct poles, 689, 690
Distributed numerical control (DNC), 823, 824
Distributed-parameter models, 728–729
Distributed systems, 616–617
Distributed Virtual Workspace for Enhancing Communication (DIVERCITY), 402, 404, 405
Distributed VR systems, 373
Distribution(s):
  and design for the life cycle, 218–219
  discrete, 258–263. See also Discrete distributions
Distribution function, 726
Distributive laws of Boolean algebra, 922
Disturbance input, 751
Disturbance rejection, 748
Disturbance transfer function, 752
DIVERCITY, see Distributed Virtual Workspace for Enhancing Communication
Divergence, 810
DJSI North America (North American Dow Jones Sustainability Index), 79
DNC (distributed numerical control), 823, 824
Documentation, in efficacy evaluation, 662
DoE (Department of Energy), 178, 179
Dominant poles, 701, 702
Double word (dword), 916
Dow Chemical Company, 229
Drafting, automated, 13
Drawing Exchange Format (DXF), 43
DRIE (deep reactive ion etching), 946
Driving force, 539
Driving-point impedance, 543
Driving simulation, 391–395
Drunk Driving Simulator, 394
DSPs (digital signal processors), 796
D-Type element, 673, 674
Duals (term), 681
Dual heuristic programming (DHP), 862
Dualogs, 681
Duplication function, 36
Dutch Promise Manual, 229
Duty, freight, and insurance (DFI), 56
Dword (double word), 916
DXF (Drawing Exchange Format), 43
Dynamical complications, additional, 852
Dynamical systems, 884
Dynamic analysis, 12
Dynamic games:
  neural network algorithms for, 872–884
  nonlinear two-player zero-sum, 872–877
  non zero-sum, 877–884
Dynamic inversion neurocontroller, 857–858
Dynamic response, 42–43
Dynamic response of sensors, 756

E
EBay, 82
ECCs (execution control charts), 809
Eco-Audit Tool, 88
Eco-Compass, 229
Ecodesign, 210
Eco-efficient products, 184, 185
Eco-It, 208
Eco-Kettle, 92
Ecolabeling programs, 78
Econometrics, 644
Economic dependency, 253
Economic Input Output Analysis Life-Cycle Assessment (EIO-LCA), 229
Economic machining problem, 108–110
EcoScan, 208
Eco-Toaster, 92
Edge-triggered RS flip-flops, 922, 923
Editing features (CAD), 36
Educational accomplishments, in efficacy evaluation, 662
EEA (environmental effect analysis), 88–90
Effective value, of waveform, 504
Efficacy evaluation, 661–662
Effort variable, 568
Eigenstructure, 715–717
Eigenvalues, 715–717
Eigenvectors, 715–717
EIO-LCA (Economic Input Output Analysis Life-Cycle Assessment), 229
Electrical devices, 444
Electric circuits, 459–563
 Alternating current, 495–531
 Assigning reference marks in, 448
 Combined constraints for, 447–448
 Connection constraints for, 445–446
 Design of, 469–473
 Direct-current, 454–473
 Division of voltage and current in, 451–453
Electric circuits (continued)
element constraints for, 444
  equivalent, 448–450
  equivalent current and voltage sources for,
  450
  first-order, 531–538
  frequency response of, 543–563
  ground for, 443
  ideal current and voltage sources for, 444–445
  in linear active devices, 473–495
  reduction process for, 453–454
  second-order, 538–543
  signal references in, 442–443
  symbols and units for, 440
  transformations of Y-Δ connections, 450–451
  transient response of, 531–543
  variables in, 440–442
Electric field, between capacitor plates, 504
Electrohydraulic systems, 759, 760
Electromechanical actuators, 756–758
Electromotive force (emf), 757
Electromyography (EMG), 425, 426
Electronic controllers, 769–772
Electronic displays, 27–28
Element constraints (electric circuits), 444, 532
Element laws, 671–674
Element-structuring aids, 638–639
Elkington, John, 79
Elliptical filters, 585, 586
ELV’s (end-of-life vehicles), 181
ELV (End of Life Vehicle) Directive, 302, 319
Embedded control systems, 800
Embodiment and detail design (design for the life
  cycle), 222, 224
Emf (electromotive force), 757
EMG (electromyography), 425, 426
Employee skills, for remanufacturing, 313–314
Encoders, 755, 825
End-of-block code, 828
End-of-life design, 220
End-of-life options, 184
End-of-life strategies for products, 82–83
End of Life Vehicle (ELV) Directive, 302, 319
End-of-life vehicles (ELVs), 181
End-of-pipe legislation, 312
End users, 807
Energy:
  capacitor, 505
  in electric circuits, 440
  inductor, 506
  manufacturing and consumption of, 191,
    193–195
  sources of, 671
Energy consumption, 84
Energy storage devices, 504–512
  capacitors, 504–505
  equivalent capacitance and inductance in,
    507–508
  ideal transformers, 509–512
  inductors, 505–506
  mutual inductance in, 508–509
  Engineering, applications of optimization in,
    100–112
  Engineering PCs, 17
  Engineering workstations, 18
  Environmental Defense, 208
  Environmental effect analysis (EEA), 88–90
  Environmental impact, 83, 192
  Environmentally conscious design, 210
  Environmental objectives:
    creating, 80–83
    in DfE programs, 77–83
  Environmental performance, reporting, 82
  Environmental performance indicators (EPIs), 184,
    185
  Environmental priority number (EPN), 88, 90
  Environmental Protection Agency, see U.S.
    Environmental Protection Agency (EPA)
  Environmental regulations, compliance with,
    80–81
  Environmental risks, mitigation of, 81
  Environmental stewardship, 80
  Environmental stress, 429–430
    heat stress, 429
    vibration, 429–430
  ENVRIZ, 90–91
  EON Studio, 407
  EPA, see U.S. Environmental Protection Agency
  EPIs (environmental performance indicators), 184,
    185
  EPN (environmental priority number), 88, 90
  Equality constraints, 112
  Equilibrium relations, 680
  Equivalent admittance, 519
  Equivalent capacitance, 507–508
  Equivalent circuits, 448–450
  Norton, 465–467, 523
  Equivalent current sources, 450
  Equivalent impedance, 516–518, 524, 543
  Equivalent inductance, 507–508
  Equivalent input resistance, 511–512
  Equivalent resistance, 448–450, 466
  Equivalent voltage sources, 450
  Ergonomics:
    biomechanics in, 424
    organizational, 418
    physical, see Physical ergonomics (PE)
ERR (expected replacement rate), 253
Error analysis, 572–577
external estimates, 574–577
internal estimates, 572–573
normal distribution used to calculate probable error in X, 573–574
Error detectors, 756
ESI Group, 397
Estimator algorithms, 775, 781
Etching, 946
Ethernet, 618
Ethical behavior, 78
Euler method, 719–720
Ensemble computer-aided design (CAD) system, 61
Euroindicator 99, 232
Europe, sustainability challenge in, 181
European Union (EU), 80, 181
European Union Information Society
Technologies, 402
Evaluation, signal processing, 440
Evaluation phase (system design), 631, 658–659
Evaluation problems, 543
Evaluation stage (design process), 6, 7
Evans, Dave, 4
Event-driven data acquisition, 602
Excitations, 681
Execution control charts (ECCs), 809
Exhaust hood, self-cleaning, 92
Expanded robust design, 239–240
Expectations, 647
Expected replacement rate (ERR), 253
Expected value, probability distribution, 726
Experimental analysis, 12–13, 717
Experimental discovery of requirements, 635, 636
Explicit-opinion methods, 643
Explicit grading (sustainability), 200
Explicit rule, 721
Exponential distribution, 151, 264–265, 271
Exponential signals, 498–499, 537
Exponential waveforms, 498–499
Extra robustifying part, 850

F
Fabrication foundries, 948–949
Factory models, 397–399
Factory refurbished products, 308
Fact–value confusion, 647
Failure:
definition of, 253
and reliability, 159–161
Failure mode and effect analysis (FMEA), 88, 133–134, 167
Failure process modeling, 274–278
Failure rate allocation method, 162–163
Failure rate estimation models, 169–172
bearing, 171
brake system, 169–170
clutch system, 171–172
compressor system, 170
filter, 170
pump, 170
Fakespace Boom3C, 397
Fakespace PinchGlove, 398
Families, product, 325
Faraday’s law, 505
Fashion obsolescence, 315
Fasteners:
remanufacturing guidelines for, 322
standardization of, 318
Fast Fourier transform (FFT), 580–581
Fatigue:
localized muscle, 428–429
whole-body, 428
Fatigue failure, 159
Fault tree analysis (FTA), 167–168
FBDs (function block diagrams), 817, 821
FCA (full cost accounting), 234
FEA, see Finite-element analysis
Feasible intermediate points, 119
Feature-based modeling, 34–36
Feedback, 748–750
Feedback compensation, 769, 778–780
diagram of, 778
pseudoderivative, 781
state-variable, 780–781
Feedback control/controllers, 884
history of NNs in, 885–886
linearization design of NN, 848–852
multiloop neural network, 852–856
neural networks in, see Neural networks
Feedback linearization loop, 849
Feedback linearization NN controllers, 850
Feedback loops, 748
Feedforward command compensation, 790, 791
Feedforward compensation, 778, 780, 790–791
Feedforward control structures, 856–860
Feed rate, 827
Feed-rate function, 828, 830
FFT (Fast Fourier transform), 580–581
Fiber-optic cabling, 623
Field-controlled dc motors, 757
File storage, 610–611
Fillers, polymer, 334–335
Filing function, 36
Filters, 706, 781
analogue, 581–587
compound, 562–563

Kutz-ECFE bindex.tex V1 - 12/19/2014 8:16am Page 967
Filters (continued)
constant-\(k\), 563
data, 604–605
failure rate estimation for, 170
first-order, 552–559
low-pass, 554
\(m\)-derived, 563
Filtering, optimal, 726
Final control elements, 751
Final design and specification stage (design process), 6, 7
Final-value theorem, 692
Financial liability, reduction of, 81–82
Finite-element analysis (FEA), 11–12, 39–41, 386–389
Finite impulse response (FIR) filters, 586
design of, 588–590
IIR vs., 595
phase analysis of, 595
Finite-settling-time algorithm, 795
Finite impulse response filters
Flow control valves, 761
Flowmeters, Venturi-type, 755, 756
Flow relations, 680
Flow transducers, 755–756
Flow variable, 568
Fluid analysis, 255–256
Flyball governor, 759
FMEA, see Failure mode and effect analysis
Follow-up systems, 752
Force, standard, 565
Force ball, 375
Force control with neural networks, 855–856
Forced response, 537, 694
Force field analysis, 138–139
Force sensors, 933–937
Forcing variables, 681
Ford Motor Company, 179, 384, 385, 392, 398
Forecasting methods, 643–644
Forest Stewardship Council Certified Wood Standards, 178, 179
Forever Flashlight, 91
Four-bit A/D converters, 930–931
Fourier series, 706, 713
Fourier transform, 579–581, 741
fast, 580–581
inverse, 594
Four-terminal element, 674
Freeform sketching system, 384, 385
Free response of system, 694
Frequency-domain analysis of linear systems, 579–581
Frequency-domain filtering, 594
Frequency response, 543–563, 704, 706
and cascade connections, 547–549
compound filters for, 562–563
descriptors for, 549–552
first-order, 552–559
and input impedance, 543, 544
second-order \(RLC\) filters for, 559–561
transfer functions for, 543–547
Frequency response plots, 704–706
Frontline Systems, 120
FTA (fault tree analysis), 167–168
Fuji-Xerox, 314
Full cost accounting (FCA), 234
Fuller, Buckminster, 208
Fully immersive VR, 372
Functional anthropometric measures, 420
Functional approximation properties, 848
Function block diagrams (FBDs), 817, 821
Fundamental attribution error, 647
Fundamental laws of Boolean algebra, 921
Fuzzy logic control, 802–803, 847

G
Gain:
characteristic types of, 550–551
of controlled sources, 474
Gain and shift amplifiers, 915
Gain function, 549, 552
Gain margin (GM), 782
Gain selection criteria, 773–777
    nonlinearities and control performance, 777
    optimal-control methods, 775
    performance indices, 773–774
    reset windup, 777
    Ziegler–Nichols rules, 775–776
Galil Motion Control, Inc., 797, 799, 800
Gamma distribution, intensity function for, 272
GAMS (General Algebraic Modeling System), 120
Gantt charts, 142
Gap analysis, 141
Gas sensors, 951, 952
Gating functions, 497–498
Gauge factor, 935
Gaussian distribution, 727
Gaussian frequency distribution, 572
GB (gigabyte), 926
G-codes (preparatory functions), 828
G-code level, 823
Gel permeation chromatography, 331
General Algebraic Modeling System (GAMS), 120
General distribution (hazard rate model), 152
General Electric, 303, 307
Generalized reduced gradient (GRG) method, 118–119
General Motors, 179
General-purpose control devices (GPCDs), 805–841
    characteristics of, 805–813
    device architecture of, 808–809
    hierarchical control of, 805–807
    numerical, 823–836
    path control of, 813
    programmability of, 807–808
    programmable, 813–822
    robot, 836–840
    sequential control of, 809–813
General sinusoid, 501
Genetic algorithms, 114
Geological engineering, virtual reality applied to, 409, 410
Geometric distributions, 260
Geometric elements, definition of, 30–31
Geometric features, contaminant trapping, 323
Geometric modeling, 9–11
Geometric programming problems, 114
Gigabyte (GB), 926
Glass transition temperature, 333–334
Global climate change, 182, 183
Global O2 Network, 208
Global Reporting Initiative (GRI), 179
Global Sullivan Principles, 178
Global truncation error, 722
GM (gain margin), 782
Goal constraints, 109
Goal programming, 99, 109–110
Government organizations, 79
GPCDs, see General-purpose control devices
GPU, see Graphics processing unit
Gradient-based methods, 115–116
GRAFCET specification language, 809
GRANTA, 88
Graphical design methods, 781–787
    dead-time elements, systems with, 783
    Nyquist stability theorem, 782–783
    open-loop for PID control, 783–784
    with root locus, 784–787
    software for, 800
Graphical representation of image data, 38–39
Graphics cards, 15
Graphics processing unit (GPU), 9, 15, 16
Green design, 210
Green Design Institute, 229
Green engineering, 210
Green seal product standards, 179
GRG (generalized reduced gradient) method, 118–119
GRI (Global Reporting Initiative), 179
Ground:
    definition of, 679
    for electric circuits, 443
Group meetings, 639–640
Guard filter, 741
Guideline/checklist documents, 86–87
Gyrating transducers, 675
Gyration resistance, 675
Gyration ratio, 675

H
Habit, 647
Half-power frequency, 550
Hamilton–Jacobi–Bellman equation, 867–872
Hamilton–Jacobi–Isaacs equation, 872–877
Hamming window, 589, 590
Hand-based visual displays, 377
Handling errors, 168
Hanning window, 589, 590
Haptic display, 378, 379
Haptic Workstation™, 394
Hard drives, 16
Hardware:
  CAD, 13–18
  controller, 769–773
  for remanufacturing, 319–324
  for virtual reality, 374–380
Hardware-in-the-loop testing, 800
Harmonic oscillation, 699
Hatching function, 36
Hazardous materials, 318
Hazardous Materials Transportation Act, 81
Hazard rate models, 151–152
HDP (heuristic dynamic programming), 861–862
Head-mounted displays (HMDs), 4, 372, 377, 378
Heat balance calculations, 429
Heat stress, 429
Heaviside expansion theorem, 690
Hemispherium™, 377
Hertz, 501
Heuristic dynamic programming (HDP), 861–862
Hexadecimal numbers, 917–918
Hidden-line removal, 11
Higher-order systems, transient response of, 700–702
High-pass filters, 589, 590, 592
High-pass gain, 550, 551, 561
Hindsight, 647
Historical data, 614–616
representation of, 615–616
selection of, 615
HMDs, see Head-mounted displays
Hold circuits, 789
Hollerith, Herman, 825
HoloSketch, 381, 382
Homeostasis, 884
Homogeneity, 462
Homogeneous Poisson process (HPP), 275
HoQ (house of quality), 349–351, 353
Hornbeck, Larry, 948
Hoshin planning method, 140–141
House of quality (HoQ), 349–351, 353
HPP (homogeneous Poisson process), 275
HRM/Ritline, 88
Human error, 168–169
Human factors evaluation, 661
Human inference and decision, 646–649
Hybrid optimal adaptive controllers, 865–866
Hybrid reliability allocation method, 163–164
Hybrid simulation, 717
Hybrid solid modeling, 10, 11
Hybrid systems, 737
Hydraulic actuators, 758–760
Hydraulic controllers, 772–773
Hydraulic motors, 759
Hydraulic transmission, 759
Hypergeometric distributions, 260–261
Hysteresis, 858–859

I
IAE (integral absolute-error) criterion, 774
ICG (interactive computer graphics), 4, 5, 14
IDDOV process, 347–367
defining requirements, 349–351
developing the concept, 351–357
identifying the project, 348
optimizing the design, 357–367
phases of, 347–349
understanding customer requirements, 349
verifying and launching, 367
IDE (Integrated Drive Electronics), 15
Ideal current source, 444, 445, 897
Ideal diodes, 901, 908–909
Ideal model of op amp, 482
Ideal transformers, 509–512
Ideal transistor switch model, 912
Ideal voltage source, 444, 445, 897, 898
IdeMat software, 208, 226
IEC, see International Electrotechnical Commission
IEC 60848 standard, 809
IEC 61131-3 standard, 809
IEC 61131 standard, 821–822
IEC 61499-1 standard, 809
IEC 61512-1 standard, 809
IEEMSs (integrated environmental management systems), 235
IFR (increasing failure rate), 252
IGES (Initial Graphics Exchange Specification), 35, 43
IGRIP™, 397
IIR filters, see Infinite impulse response filters
IL (instruction list), 817, 821
Illusion of control, 647
Illusion of correlation, 648
Imersdesk, 397
Impedance(s):
defined, 516
driving-point, 543
INDEX

In–out scope tool, 348
In phase (term), 514
Inputs:
  circuit, 462
  control system, 748
  in I/O form, 681
Input admittance, 569
Input commands, 9
Input constraints, 859
Input current:
  of inverting amplifiers, 485
  of ladder circuits, 454
  of voltage followers, 484
Input devices, computer, 18–27
  digitizer, 23–24
  keyboard, 19–20
  mouse, 20–21
  pointing stick, 11
  scanner, 25–27
  touch pad, 22–23
  touch screen, 23
  trackball, 22
for virtual reality, 374–377
Input impedance, 543, 544, 568, 569
Input–output (I/O) form, 681–684
  converting, to phase-variable form, 687
deriving the, 682–684
Input/output (I/O) processors, 809
Input–output (I/O) relationships:
  of differential amplifiers, 486–488
  of inverting amplifiers, 485
  of noninverting op amps, 482
  of noninverting summers, 488
  proportionality constant from, 463
  of summing amplifiers, 485, 486
Input resistance:
  equivalent, 511–512
  of inverting amplifiers, 485
Input transducers, 491
Inspection:
  ease of, 320
  in remanufacturing, 309–310, 324
Inspection errors, 168
Instability failure, 159
Installation errors, 168
Instantaneous power, 525–526
Instantaneous value, of waveforms, 502
Institute for Market Transformation to Sustainability (MTS), 178
Instruction list (IL), 817, 821
Instrumentation systems, operational amplifiers in, 491–495
Integer programming (IP), 114

and design for the life cycle, 210
implementation of, 240
Industrial Revolution, 208, 209
Inequality constraints, 112
Infinite impulse response (IIR) filters, 586
design of, 590–592
FIR vs., 595
phase analysis of, 595
Industrial Reality, 399
Information, central role of, 650–652
Information processing by humans and organizations, 646–649
Infrared thermography, 255
Inherent availability, 280
Initial and final conditions method, 534–536
Initial Graphics Exchange Specification (IGES), 35, 43
Initial step of sequence, 810
Initial-value theorem, 691–692
Inkjet printers, 28
In-memory storage, 609–610
Inner feedback loops, additional, 853, 854
Inner force control loops, additional, 855
Innovation-based sustainability, 180, 181
Innovation statements, 84
}

equivalent, 516–518, 524, 543
input, 543, 544
in measurements, 568–571
transfer, 544
Implementation phase (system design), 657–658
Implicit grading (sustainability), 200
Implicit rule, 721
Improper rational functions, 691
Impulse functions, 497–498
Impulse response, 693
Incidental base rate, 647
Increasing failure rate (IFR), 252
Incremental algorithm, 789
Incremental encoders, 755
Independent energy storage elements, 682
Independent remanufacturers, 306
Independent variables, in optimization problems, 99–100
Indirect NN control, 848
Inductance:
equivalent, 507–508
mutual, 508–509
Inductive reactance, 517
Inductive storage element, 671
Inductors, 505–506, 900, 901
  constraints in phasor form on, 514, 515
  impedance of, 516
Inductor energy, 506
Industrial ecology:
  and design for the life cycle, 210
  implementation of, 240
Industrial Revolution, 208, 209
Inequality constraints, 112
Infinite impulse response (IIR) filters, 586
design of, 590–592
FIR vs., 595
phase analysis of, 595
Infinite Reality, 399
Information, central role of, 650–652
Information processing by humans and organizations, 646–649
Infrared thermography, 255
Inherent availability, 280
Initial and final conditions method, 534–536
Initial Graphics Exchange Specification (IGES), 35, 43
Initial step of sequence, 810
Initial-value theorem, 691–692
Inkjet printers, 28
In-memory storage, 609–610
Inner feedback loops, additional, 853, 854
Inner force control loops, additional, 855
Innovation-based sustainability, 180, 181
Innovation statements, 84

Input admittance, 543, 544, 568, 569
Input commands, 9
Input current:
  of inverting amplifiers, 485
  of ladder circuits, 454
  of voltage followers, 484
Input devices, computer, 18–27
  digitizer, 23–24
  keyboard, 19–20
  mouse, 20–21
  pointing stick, 11
  scanner, 25–27
  touch pad, 22–23
  touch screen, 23
  trackball, 22
for virtual reality, 374–377
Input impedance, 543, 544, 568, 569
Input–output (I/O) form, 681–684
  converting, to phase-variable form, 687
deriving the, 682–684
Input/output (I/O) processors, 809
Input–output (I/O) relationships:
  of differential amplifiers, 486–488
  of inverting amplifiers, 485
  of noninverting op amps, 482
  of noninverting summers, 488
  proportionality constant from, 463
  of summing amplifiers, 485, 486
Input resistance:
  equivalent, 511–512
  of inverting amplifiers, 485
Input transducers, 491
Inspection:
  ease of, 320
  in remanufacturing, 309–310, 324
Inspection errors, 168
Instability failure, 159
Installation errors, 168
Instantaneous power, 525–526
Instantaneous value, of waveforms, 502
Institute for Market Transformation to Sustainability (MTS), 178
Instruction list (IL), 817, 821
Instrumentation systems, operational amplifiers in, 491–495
Integer programming (IP), 114
Index

Integral absolute-error (IAE) criterion, 774
Integral control, 765–766
Integral gain, 765
Integral-of-time-multiplied absolute-error (ITAE) criterion, 774
Integral-of-time-multiplied squared-error (ITSE) criterion, 774
Integral property, of sinusoids, 502
Integral reinforcement form, 864
Integral reinforcement learning (IRL): in continuous-time systems, 863–866
online implementation of, 865–866
with policy iteration, 864
with value iteration, 865
Integral squared-error (ISE) criterion, 774
Integrated across variables, 670
Integrated Drive Electronics (IDE), 15
Integrated environmental management systems (IEMSs), 235
Integrated Systems Engineering, 947
Integrated through variables, 670
Integration phase (system design), 657–658
Integrator buildup, 777
Integrator op amp, 915
Intel Core i7, 14
IntelliSense Corporation, 947
Interactive algorithm, 771, 772
Interactive computer graphics (ICG), 4, 5, 14
Interconnections, pattern of, 679
Interconnection laws, 679–680
Interface(s):
  DC circuit, 465, 469–473
design of, 469–473
  software development kit, 613
Web, 621
Interfaces, standardization of, 318
Interface current, 468, 471–472, 523
Interface power, 468
Interfaces, PLC, 815–817
Interface voltage, 468, 471
Interlaboratory standards, 565
Internal compensation, 781
International Committee on Weights and Measurement, 566
International Electrotechnical Commission (IEC), 809, 813, 815, 817, 820, 821
International Standards Organization (ISO), 430, 619
International System (SI) units, 440, 441
Interpretation, 649–650
Interpretive structural modeling, 641
Interrupts, 788
Intrinsic availability, 280
Inverse dynamics, 424–426
Inverse Fourier transform, 594
Inverse Tchebyshev (Type II) filters, 584–585
Inverse transform, 688
Inversion of partial-fraction expansion, 689, 690
Inverters, 769, 920
Inverting amplifiers, 484–486, 545–547, 913–914
Inverting input, 480
Investor Responsibility Research Center (IRRC), 82
I/O differential equations, 682
I/O form, see Input/output form
I/O processes, 15
I/O (input/output) processors, 809
I/O relationships, see Input/Output relationships
Iowa State University, 389
IP (integer programming), 114
IRIS Performer, 397
IRL, see Integral reinforcement learning
IRRC (Investor Responsibility Research Center), 82
ISE (integral squared-error) criterion, 774
ISO (International Standards Organization), 430, 619
Isoclines, method of, 737
ISO standards:
  ISO 14000 standards, 192, 235
  ISO 14001, 188
Issue analysis, 628, 640–646
Issue formulation, 628, 635–640
collective-inquiry methods for, 637–638
descriptive methods for, 639
element-structuring aids for, 638–639
Issue interpretation, 628–629
ITAE (integral-of-time-multiplied absolute-error) criterion, 774
ITSE (integral-of-time-multiplied squared-error) criterion, 774
i-v characteristics, 444, 445, 514–516

J

Jacobian elliptic function, 585
Jacobian matrices, 731
Japan, 181
Jastrzębowski, Wojciech, 417
JDCAD, 381, 382
Joint distribution, 726
Joint movements (ergonomics), 424–426
Jordan canonical form, 716–717
Joules, 442
K
Kaizen, 138
Kano model, 349
Kano technique, 224, 225
Karmarkar, Narendra, 114
Kb (kilobyte), 926
KCL, see Kirchhoff’s current law
Kelvin, 566
Kernel density estimate, nonparametric, 277–278
Keyboards, 19–20
Kilobyte (kb), 926
Kilogram, standard, 565
Kinect tracking device, 374, 376
Kinematic analysis and synthesis, 12
Kirchhoff’s current law (KCL), 445–447, 459, 514, 532, 902, 907
Kirchhoff’s voltage law (KVL), 445–447, 514, 531, 901–902, 907, 908, 936
Kookmin University, 394
K-out-of-n unit network, 156–157
KVL, see Kirchhoff’s voltage law

L
Labels, for sorting parts, 321
LabView, 799, 800
Ladder circuits, 453–454, 563
Ladder diagrams (LDs), 817, 821
Lag compensators, 778, 779, 786, 799
Lagging phasor, 516
Lagging power factor, 528
Laminated object manufacturing, 47
Lands (term), 758
Landfills, 208
Lanner Group, 398
Laplace transforms, 579–580, 688, 689
Laptops, 17
Large-screen stationary displays, 377
Laser plotters, 28–29
Laszlo, Chris, 180
Latches, 923–924
Laurentian University, 409
Layering, 13
LCA, see Life Cycle Assessment
LCC (life-cycle costing), 233, 234
LCD (liquid crystal display) screens, 28
LDs (ladder diagrams), 817, 821
Lead compensators, 778, 779, 786
Leadership:
  design requirements of, 659–660
  in efficacy evaluation, 661
Leading phasor, 516
Leading power factor, 528
Lead–lag compensators, 778, 799
Least significant bit (LSB), 490, 916
Least squares criterion, 110–111
Least-squares fit, 585, 586
LEDs (light-emitting diodes), 910–911
LEED Rating System, 179
Legislation compliance, 78
Length standard, 565
Lenzing, 237
Leopold, Aldo, 208
Liability:
  avoidance of, 78
  and design for the life cycle, 241
LiDAR Viewer, 409
Life Cycle Assessment (LCA), 78, 90, 179, 228, 229, 249–250
Life-cycle costing (LCC), 233, 234
Life-cycle design, see Design for the life cycle (DfLC)
Life cycle of systems engineering, 629–634
Light-emitting diodes (LEDs), 910–911
Light intensity detectors, 492–493
Limit cycles, 730
Limit of error, 573
LINDO Systems, 121
Linear active devices, 473–495
  dependent sources for, 473–479
  operational amplifiers, 479–495
Linear circuits, 440, 462. See also Electric circuits
Linear dimensions, 420
Linear fractional programming, 114
Linear in adjustable parameters (LIP), 847
Linearity, 567
  of DC circuits, 462–464
  in phasor domain, 521–522
Linearization optimization methods, 118–119
Linearizing approximations, 731
Linear models, standard forms for, 681–687
  converting I/O to phase-variable form, 687
  I/O form, 681–684
  state-variable form, 681, 684–686
Linear programming, 112
Linear-quadratic problem, 775
Linear-quadratic-regulator (LQR), 804
Linear static analysis, 41–42
Linear systems, nonlinear vs., 730–731
Linear systems analysis, 687–714
  response to periodic inputs using transform methods, 704–714
  transform methods, 687–714
  transient analysis using transform methods, 693–704
Linear transfer, 480
Linear variable differential transformer (LVDT), 753, 754, 933, 934
Line search, 115
Line voltages, 530
Linked segment models, 424, 425
LIP (linear in adjustable parameters), 847
Liquid crystal display (LCD) screens, 28
LMF (localized muscle fatigue), 428–429
Loading, 544, 548, 549, 568
Load line, 467
Localized muscle fatigue (LMF), 428–429
Local truncation errors, 722
Logarithmic plot (Bode plots), 704–707, 709, 711, 713
Lognormal distribution, 264, 272
Look-back method, 478
Loops, 446
Loop method, 684
Low-pass filters, 581–585
Low-pass gain, 550, 551, 560
Low-pass prototypes, 592–594
LQG (linear-quadratic-regulator), 804
LSB (least significant bit), 490, 916
L sections, 562, 563
Lumped-parameter (lumped-element) models, 674, 728, 729
LVDT, see Linear variable differential transformer
Lyapunov’s stability theory, 803

M
Machining operations sustainability, 193–201
assessments of, 193–196, 200–201
optimized operating parameters for, 198–200
performance measures contributing to, 196–198
Mac® OS X®, 14
Magic-three code, 830
Magnetic flux, for inductors, 505, 506
Magnetic tape, 825
Magnetizing current, 525
Mainframes, 17
Maintainability:
and classes of maintenance policies, 251–252
definition of, 251, 279
design for, see Design for maintainability
efficacy evaluation, 662
modeling of, 282–285
terminology related to, 251
Maintenance:
corrective, 251, 252, 286
definition of, 251
necessity of, 250
opportunistic, 252
preventive, 251–252, 254–257, 286
Maintenance downtime, 251
Maintenance errors, 168
Maintenance guidelines, 316–317
Management:
and new product development, 77
support for DFM&A by, 65, 67–68
Manipulated variables, 751
Manipulators, robot, 837, 838
Manual material-handling systems, 430–432
Manual programming, 828–831
Manual programming codes, 829
Manufacturing, virtual reality in, 395–402
Matching problem, in physical ergonomics, 419
Material cost (MC), 56, 106
Material design, and design for the life cycle, 218
Manufacturing costs:
in design phase, 57
and sustainability, 191–192
Manufacturing design, and design for the life cycle, 218
Manufacturing operations sustainability measures, 189–193
Mass:
measures of, 420
standards of, 565
Massachusetts Institute of Technology (MIT), 381, 823
Massively parallel processing, 18, 19
Matched source and load, 469
Matching problem, in physical ergonomics, 419
Material cost (MC), 56, 106
Material design, and design for the life cycle, 217
Material flaw failure, 160
Material recycling, 302
Materials selection, for plastics, 329–335, 338–339
Mathematical models, 667–745
classifications of, 723–745
discrete/hybrid systems, 737, 740–745
distributed-parameter, 728–729
ideal elements of, 669–678
linear systems analysis approaches, 687–714
nonlinear systems, 730–739
rationale for, 667–669
simulation, 717–723
Index

standard forms for linear, 681–687
state-variable methods, 713–717
stochastic systems, 724, 726–727
system structure/interconnection laws, 677–681
time-varying systems, 729–730
Mathematical programming, 645
A Mathematical Programming Language (AMPL), 120
MATLAB, 121, 798–800
Matra Data, 61
Matsushita Alkaline Ion Water Purifier, 92
MAUT (multiattribute utility theory), 649–650
Maximum average power, 523
Maximum cutting speed possible constraint, 108
Maximum horsepower available constraint, 108
Maximum permissible speed constraint, 108
Maximum power transfer, 468, 469
Maximum voluntary exertion (MVE), 428
Mb (megabyte), 926
MC (material cost), 56, 106
M-codes (miscellaneous functions), 828
MCS (Motion Component Selector), 799
m-derived filters, 563
Mead, Carver, 5
Mean error, 573
Mean time between failure (MTBF), 276
Mean time between maintenance (MTBM), 251
Mean time to failure (MTTF), 251, 256, 270–271, 281
Mean time to repair (MTTR), 251, 256, 270–271, 281
Mean value, probability distribution, 726
Measurements, 565–577
accuracy/precision in, 566
anthropometric, 420
and error analysis, 572–577
impedance concepts in, 568–571
linearity, 567
sensitivity/resolution in, 566–567
standards for, 565–566
Measurement problem, in physical ergonomics, 418–419
Mechatronics, 895–940
and A/D conversion, 930–931
and basic analog electronics, see Analog electronics
binary numbers in, 916–919
and D/A conversion, 931
definition of, 895
and digital circuits, 920–925
and digital computers, 925–928
modeling example of, 937–940
op amps in, 912–915
sensors in, 931–937
and transfer of digital data, 928–930
Medians, in data summaries, 607
Megabyte (Mb), 926
Melt flow index (MFI), 331
Memory(ies), 15, 808, 925–928
MEMS, see Microelectromechanical systems
MEMSCAP, 947
MEMS-Exchange, 949
MEMS-PRO, 947
Mesh, 458
Mesh currents, 458, 459, 478
Mesh current analysis, 458–461
with dependent sources, 477–478
guidelines for, 461
in phasor domain, 523, 525
supermesh in, 460–461
Metalurgical failure, 160
Metal–oxide–semiconductor field effect transistor (MOSFET), 945
Metal removal rate, 827
Meter, standard, 565
Methodology (term), 630–631
Metrics:
for DfE programs, 83–84
for DFM&A, 71–73
MFI (melt flow index), 331
MGP (multigeneration plan) tool, 348
Microaccelerators, 950
Microcomputers, 928
Microeconomic models, 644
Microelectromechanical systems (MEMS), 943–954
books about, 953–954
design/simulations of, 947
elements of, 499–502
fabrication foundries for, 948–949
features of, 943–944
materials used in, 944
microfabrication procedures for, 944–947
Micro-hot-plate, 948
Micromirrors, 948, 949
Microsoft Excel, 120
Microsoft Office, 120
Microwave switches, 951
Milling cutters, 823–824
MINLP (mixed-integer nonlinear programming), 114
Min-max strategy, 422
Minnesota Office of Environmental Assistance, 87
Minnesota Technical Assistance Program (MnTAP), 87
Mirroring function, 36
Miscellaneous functions (M-codes), 828
Missouri University of Science and Technology, 402
Index

MIT (Massachusetts Institute of Technology), 381, 823
Mixed-integer nonlinear programming (MINLP), 114
MnTAP (Minnesota Technical Assistance Program), 87
Mobile animators, 377, 378
Mobile devices, 29
Modal matrix, 716
Models and modeling, 641–645
credibility of, 643
descriptive, 642
mathematical, see Mathematical models
optimization/refinement of, 644–645
parameter estimation in, 644
policy/planning, 642
predictive/forecasting, 642
usefulness of, 642–643
verification of, 644
Model behavior, experimental analysis of, 717
Model-free learning controllers, 845
Modern control theory, 687
Modern linear systems analysis, 681.
See also State-variable methods
Modern Plastics Encyclopedia, 338
Modification of actuating signal, 781
Modulators, 675
Molecular weight (polymers), 331
Moment of inertia, 420
MOSFET (metal–oxide–semiconductor field effect transistor), 945
Most probable error, 575–577
Most significant bit (MSB), 490, 916
Motion Component Selector (MCS), 799
Motion controllers, 796–797
Motion programming software, 799
Motivations, for design for the life cycle, 211–213
Motor drive assembly case study (DFM&A), 61–66
Mouse, 20–21, 375
Movement function, 36
Moving averages, 605
MSB (most significant bit), 490, 916
MSVT, 391
MTBF (mean time between failure), 276
MTBM (mean time between maintenance), 251
MTS (Institute for Market Transformation to Sustainability), 178
MTTF, see Mean time to failure
MTTR (mean time to repair), 256, 281–282
Muir, John, 208
Multipliers, 769
Multiattribute utility theory (MAUT), 649–650
Multifunctional teams, 68–69
Multigeneration plan (MGP) tool, 348
Multilayer neural network controllers, 848–850
Multi-life-cycle products, 185–187, 240
Multiloop controllers, 845
Multiloop neural network feedback control structures, 852–856
Multiloop NN feedback control structures:
backstepping neurocontroller for electrically driven robot, 853–854
flexible-mode compensation using, 854–855
high-frequency dynamics using, 854–855
Multiport elements, 674–678
Multistep methods (of numerical integration), 721
Multivariable unconstrained optimization methods, 115–116
Murrell, K. F. H., 417
Muscle forces (ergonomics), 426–427
Mutual inductance, 508–509
MVE (maximum voluntary exertion), 428

N

NADS (National Advanced Driving Simulator), 392, 393
NADS-1, 392, 393
NADS-2, 392, 393
NADS-MiniSim, 392, 393
NASA Virtual Wind Tunnel, 388–390
Nash equilibrium strategies, 878–879
NASTRAN, 39
National Advanced Driving Simulator (NADS), 392, 393
National Center for Supercomputing Applications, 389
National Defenses Research Council, 479
National Institute for Occupational Safety and Health (NIOSH), 192, 195
National Institute for Standards and Technology (NIST), 185, 397, 399, 406, 565, 566
National prototype meter, 565
National reference standards, 565
National Research Council (NRC), 180
National Research Council of Canada, 218, 219
Natural frequency, 540, 560, 699
Natural Resources Defense Council, 208
Natural response, 537
Natural state variables, 686
Natural Step System Conditions, 179
NCs, see Numerical controllers
NC interpolators, 827–828
NDT (nondestructive testing) methods, 309
Needs (term), 636
Need perception stage (design process), 6
Negative binomial distributions, 259–260
Index 977

NEi Software, 39
NEOS (Network Enabled Optimization System), 121
Nervous system cell, 845
Network communications, 618
Neural networks (NNs), 843–888
  actuators in, 856–860
  approximate dynamic programming, 859–866
  in control topologies, 847–848
  force control with, 855–856
  functional approximation properties of, 848
  historical development/future of, 884–888
  modeling, 845–847
  observers in, 859, 860
  preprocessing of inputs to, 852
  Neural network (NN) actuators, 856–860
  Neural network (NN) controllers:
    for discrete-time systems, 852
    feedback linearization design, 848–852
    multiloop feedback structures of, 852–856
    topologies of, 847–848
  Neural network functional approximation error, 846
  Neural network (NN) learning algorithms, 866–884
    continuous-time Hamilton–Jacobi–Bellman equation, 867–872
    coupled Hamilton–Jacobi equations, 877–884
    Hamilton–Jacobi–Isaacs equation, 872–877
    and optimal control for reinforcement learning, 866–867
  Neural network (NN) observers, 859, 860
  New product development:
    decision making in, 77
    DFM&A checklist for, 72–73
    goal of, 55
    phases of, 59
  Newton’s gradient method, 116
  Newton’s second law, 424
  NHPP (Nonhomogeneous Poisson process), 275–276
  Nibbles, 916
  Nichols charts/diagrams:
    for common transfer functions, 708, 710, 712, 714
    obtaining, 704
  NIOSH (National Institute for Occupational Safety and Health), 192, 195
  NIST, see National Institute for Standards and Technology
  NNs, see Neural networks
  NN (neural network) actuators, 856–860
  NN controllers, see Neural network controllers
  NN learning algorithms, see Neural network learning algorithms
  NN (neural network) observers, 859, 860
  NN weight tuning for stability theorem, 849–850
  Nodes, 446, 679
  Node analysis, fundamental property of, 456
  Node method, 684
  Node relations, 680
  Node voltages, 454–456
  Node voltage analysis, 454–458
    of bridge circuits, 455–456
    with dependent sources, 476–477
    guidelines for, 458
    in phasor domain, 523–524
    with supernodes, 456–457
  Noise, extracting signal from, 595–596
  Nominal group technique, 637
  Noncausal signals, 502
  Noncontact scanners, 26
  Nondestructive testing (NDT) methods, 309
  Nondistinct poles, 690–691
  Nongovernment organizations, 79
  Nonhomogeneous Poisson process (NHPP), 275–276
  Nonimmersive VR, 373
  Noninteractive algorithm, 771
  Noninverting amplifiers, 482–484, 545, 913–915
  Noninverting input, 480
  Noninverting summers, 488
  Nonlinear control, 803
  Nonlinear curve fitting, 111–112
  Nonlinear in parameters, 846, 847
  Nonlinear in tunable parameters, 848
  Nonlinear nodes, Thévenin and Norton equivalent circuits for, 467
  Nonlinear programming, 114
  Nonlinear static analysis, 42
  Nonlinear systems, 730–739
    adaptive neural control for, 858–859
    and controller performance, 777
    describing function method, 731–737
    with hysteresis, 858–859
    with input constraints, 859
    linearizing approximation method, 731
    linear vs., 730–731
    phase-plane method, 737–739
  Nonlinear two-player zero-sum games, 872–877
  Nonnegativity restrictions, 108
  Nonparametric kernel density estimate, 277–278
  Nonrepeated (distinct) poles, 689, 690
  Nonuniform rational basis spline (NURBS), 9–10
  Non zero-sum games, 877–884
  Nordic Swan Ecolabel, 179
Index

Normal distribution, 263–264, 272, 572, 573–574, 727
Normal-mode analysis, 42
Normative synthesis of requirements, 635, 636
North American Dow Jones Sustainability Index (DJSI North America), 79
Norton equivalent circuits, 465–467
general applications of, 465–467
for nonlinear loads, 467
in phasor domain, 523
Norton resistance, 466
Nozzle–flappers, 760, 772
NRC (National Research Council), 180
nth moment of distribution, 726
nth-order systems, 682
Number of parts and assemblies metric, 71
Number of separate assembly operations metric, 71
Numerator dynamics, 692
Numerical approximation errors, 722
Numerical controllers (NCs), 823–836
and CAD/CAM, 835–836
history/applications of, 823–824
input media for, 825
point-to-point/contouring, 827–828
principles of operation for, 824–827
programming of, 828–835
Numerical instability, 723
Numerical integration methods, 719–723
errors in, 722
Euler, 719–720
multistep, 721
predictor–corrector, 722
Runge–Kutta, 720–721
selecting, 723
NURBS (nonuniform rational basis spline), 9–10
NURBS curves, 26
NURBS surface patches, 26–27
Nylons, 330
Nyquist frequency, 741
Nyquist plot, 781, 782
Nyquist stability theorem, 782–783

O

Objective function, 112
Objectives measures (attributes of objectives), 637
Object systems, 641
Observer algorithms, 775, 781
Observers, neural network, 859, 860
Obsolescence, causes of, 315
Occupational Safety and Health Administration (OSHA), 81, 192, 195
Octave, 552
ODE (orientation-dependent etching), 946
OEMs, see Original equipment manufacturers
Off-line programming, 840, 841
Offset error, 764
Offsetting function, 36
Ohms, 444
Ohmmeters, 904
Ohm’s law, 444
Oil and gas industry, 408–409
OLED (Organic LED) screens, 28
OLE for prices control (OPC) standard, 619–620
OM (opportunistic maintenance), 252
One-port circuits, 543, 544
One-port element, 670, 671
One-port element laws, 671–674
Online programming, 841
Online solution:
for non zero-sum differential games, 880–882
for two-player zero-sum differential games, 875–876
Online synchronous policy iteration, 869–870
On–off controllers, 763
Op amps, see Operational amplifiers
OPC (OLE for prices control) standard, 619–620
Open-circuit voltage (Thévenin and Norton equivalent circuits), 465, 466
Open Graphics Library (OpenGL), 15–16
Open-loop gain, 474, 481
Open-loop systems, 748, 783–784
Open-loop voltage gain, 474
Open rule, 721
Open systems, technical obsolescence and, 315
Open Systems Interconnect (OSI) standard, 619
Operating point, 731
Operating system, 14
Operational amplifiers (op amps), 769–772, 912–915
circuit analysis for, 482–484
design of, 488–489
differential amplifiers, 486–488
digital-to-analog converters, 490–491
ideal model of, 481–482
in instrumentation systems, 491–495
inverting, 913–914
noninverting, 484–486
noninverting summers, 488
notation for, 479–480
schematics of, 915
summing amplifiers, 485, 486
transfer characteristics for, 480–481
tension followers, 484
Operational deployment phase (system design), 659
Operational environments, 653–654
Operational readiness (OR), 279
Operational safety, and sustainability, 192
Operator errors, 168
Opportunism, 252
Opportunistic maintenance (OM), 252
Opportunity analysis, 142
Optical encoders, 755, 932–933
Optical mouse, 21
Optimal control, 804
and continuous-time Hamilton–Jacobi–Bellman equation, 867–872
of continuous-time systems, 863–866
neural network algorithms for, 866–872
for reinforcement learning, 866–867
theory of, 775, 804
Optimal filtering, 726
Optimization, 97–122, 631
applications of, 100–112
with CAD, 44
constrained methods, 116–120
requirements for application of, 98–100
software, 120–121
structure of problems, 112–114
unconstrained methods, 115–116
Optimization applications, 100–112
analysis/data reduction applications, 110–112
design applications, 102–107
operations/planning applications, 108–111
Optimization theory, 97
Optimization Toolbox (MATLAB), 121
Optimum systems control, 645
OR (operational readiness), 279
Order effects, 648
Organic LED (OLED) screens, 28
Organizational ergonomics, 418
Orientation-dependent etching (ODE), 946
Original equipment manufacturers (OEMs), 305–308, 318–319, 807
OSHA, see Occupational Safety and Health Administration
OSI (Open Systems Interconnect) standard, 619
Our Common Future, 208
Outcome-irrelevant learning system, 648
Out of phase (term), 514
Output(s):
circuit, 462
definition of, 748
in I/O form, 681
Output current, 475
Output devices, computer, 27–29
electronic displays, 27–28
mobile devices, 29
plotters, 28–29
for virtual reality, 377–380
Output equations, 684–685
Output feedback control, 859, 860
Output impedance, 568–569
Output power, 475
Output transducers, 491, 492
Output voltage:
of circuit with dependent sources, 475
of digital-to-analog converters, 490, 491
of ladder circuit, 454
of operational amplifiers, 480, 482
Overdamped response, 540, 541, 699
Overdriven elements, 777
Overlapped valves, 758
P
Packaging Directive (European Union), 81
Papanek, Victor, 208
Parallel communications, 617
Parallel compensation, 778. See also Feedback compensation
Parallel connections:
in circuits, 446
of inductors and capacitors, 507
phasor analysis of circuits with, 518–519
Parallel data transfer, 928, 929
Parallel network, 154
Parallel processing, 18, 19
Parallel-series network, 155–156
Parameter estimation, 644
Parametric modeling, 32–34
Pareto analysis, 266–267
Pareto diagram, 138
Parsons, John T., 823
Part geometry, 833, 836
Partial descriptors (for waveforms), 502–504
Partial differential equations, 728
Partial-fraction expansion theorem, 689, 690
Partitioned neural networks, 851–852
Part programming language, 828
Part proliferation, 317–318
Passband, 549
Passive elements, 674
Passive neural networks, 850
Passive noncontact scanners, 26
Path control, 813
Pattern of interconnections, 679
PCs, engineering, 17
PCIe (Peripheral Component Interconnect Express), 15
PDCA (plan–do–check–act) circle, 348
PD (proportional-derivative) control, 767–768, 771
PDF (pseudoderivative feedback), 781
PDM (product data management), 13, 50–51
Index

PE, see Persistence of excitation; Physical ergonomics
Peak-to-peak value, 502
Peak value, 502
Pedigree of instrument, 566
Penalty function approach, 118
Perfect coupling, 510
Performance criterion, for optimization, 98–99
Performance indices, 773–774
Performance objectives achievement evaluation, 661
Performance requirements, additional, 853
Period (waveforms), 500
Periodic inputs, 704–714
Periodic signals, 502
Peripheral Component Interconnect Express (PCIe), 15
Perpetual-life products, 185–187
Persistence of excitation (PE), 870
Personnel health, 192–193
Per-step truncation errors, 722
PET, see Polyethylene terephthalate
Pet projects, 346
pf (power factor), 528
PHANToM™, 378, 379, 383
Phase analysis, 595
Phase angle, 501
Phase crossover frequency, 782
Phase function, 549, 552
Phase margin (PM), 782
Phase planes, 737
Phase-plane method, 737–739
Phase portrait, 737
Phase shift distortion (PSD), 595
Phase variables, 687, 737
Phase-variable form, converting I/O to, 687
Phase voltages, 530
Phasors:
  defined, 512
  leading and lagging, 516
  properties of, 513–514
  rotating, 513
Phasor analysis, 512–525
and circuit theorems in phasor domain, 521–522
node voltage and mesh analysis, 523–525
with parallel equivalence and current division, 518–519
and phasor representation of sinusoids, 512–513
properties of phasors, 513–514
with series equivalence and voltage division, 516–518
Thévenin and Norton equivalent circuits in, 522–523
with Y-Δ transformations, 519–521
Phasor current, 514, 520–522
Phasor domain, 543
Phasor representation of sinusoids, 512–513
Phasor voltage, 514
Philips Sound and Vision, 236
Photodiodes, 911
Physical ergonomics (PE), 417–434
  analysis of, 420–430
  basis of, 418–419
  defined, 417
  in design process, 419
  disciplines contributing to, 419
  example applications of, 430–434
  history of, 417–418
  manual material-handling systems, 430–432
  refuse collection, 432–434
Physical ergonomics analysis, 420–430
  anthropometry, 420–422
  biomechanics, 424–428
  environmental stress, 429–430
  localized muscle fatigue, 428–429
  range of motion, 422–423
  strength, 423
  whole-body fatigue, 428
Physical variables, 670
Physical work capacity (PWC), 428
PI, see Policy iteration; Proportional-integral control
PID control, see Proportional-integral-derivative control
π sections, 562, 563
PIT (product ideas tree), 225
Planar circuits, 458
Plan–do–check–act (PDCA) circle, 348
Planning for action (systems engineering), 631
Plant (term), 751, 847
Plant control hierarchy, 806
Plant equations, 684–685
Plastics, 329–340
  additives in, 334–335
  joining techniques, 335–338
  materials selection, 329–335
  part design, 338
  part material selection for, 338–339
  polymer selection for, 329–334
  reinforced, 335
Plasticizers, 335
PLCs, see Programmable logic controllers
PLM (product life-cycle management), 10, 49–50
Plotter, 28–29
PM, see Phase margin; Preventive maintenance
Pneumatic actuators, 760–762
Pneumatic controllers, 772
Point clouds, 26
Pointing stick, 22
Point-to-point numerical controllers, 827
Poisson distributions, 261–263
Poka-yoke method, 140
Polar plots, 704, 707, 709, 711, 713
Poles:
  complex, 691
  of \( F(s) \), 688, 689
  of multiplicity \( q \), 690
  nonrepeated, 689, 690
  repeated, 690–691
Pole–zero cancellation, 702, 704
Policy capture, 650
Policy evaluation step, 861, 864, 865
Policy improvement step, 861, 864, 865
Policy iteration (PI), 861, 864
  for non zero-sum differential games, 880
  online synchronous, 869–870
  for optimal control, 868–869
  for two-player zero-sum differential games, 874–875
Policy (planning) modeling, 642
Pollution Prevention Pays program, 208
Polyethylene terephthalate (PET), 237, 330, 339
Polygon mesh, 26
Polymers, 329–334
  amorphous vs. semicrystalline, 332–333
  defined, 330
  hydrophilic vs. hydrophobic, 330–331
  thermoplastic, 330
Polymerization reactions, 330
Polystyrene, 339–340
Popov’s method, 803
Ports, 469, 543
Position control systems, 750–751
Position error coefficient (\( c_0 \)), 753
Positioning controllers, 827
Position sensors, 931
Position tracks, 374
Positive charge, 442
Postprocessors, 831
Potential problem analysis (PPA), 143–144
Potentiometers, 452, 750, 753, 931
Pound, 565
Power, 671
  apparent, 528
  associated with resistors, 444
  average, 525–527
  complex, 527–529
  defined, 442
  from dependent sources, 475–476
  instantaneous, 525–526
  interface, 468
  at interface, 468
  maximum average, 523
  maximum transfer of, 468, 469
  reactive, 525–527
  in sinusoidal steady state operation of AC circuits, 525–531
  as term, 897
Power drain, 569
Power factor (pf), 528
Power gain, in circuit with a dependent source, 475–476
Power spectrum, 727, 741
Power triangles, 527–528
PPA (potential problem analysis), 143–144
Pratt & Whitney, 307
Precision, data, 566, 601
Predictive (forecasting) modeling, 642
Predictor–corrector methods, 722
Preliminary conceptual design phase (system design), 656–657
Preparatory functions (G-codes), 828
Preventive maintenance (PM), 251–252, 254–257, 286
  automation of, 256–257
  and comprehensive evaluation/analysis, 256–257
  and design maintainability/availability performance, 256
  and empirical performance history, 256
  and system operation monitoring, 254–256
Prewarping, 591
Primary physical variables, 670
Primary transfer function, 752
Primary winding, 509
Probability, 726
Probable error, 573
Problem definition, 6, 7, 631
Problem formulation, optimization and, 98
Problem oriented languages, 807
Process controllers, 797–798
Process control systems, 752
Process models, virtual reality for, 397–399
Process reaction method, 775
Process sheets, 831
Process signature, 775–776
Process simulation, virtual reality for, 395–397
Product architecture design guidelines, 315–316
Product concepts, 57
Product data management (PDM), 13, 50–51
Product definition, 222
Product design for manufacturing and assembly, 55–73
  defined, 56
  design for assembly, 57
  design for manufacturing, 57
Product design for manufacturing and assembly
(continued)
goal of, 57–58
ideal process for applying, 59–61
importance of, 73
methodology for, 68–71
metrics for, 71–73
motor drive assembly case study, 61–66
upper management support for, 65, 67–68
Product design matrix, 87
Product development process, 55–56
Product development team, 67–69
Product diversity, 317–318
Product ideas tree (PIT), 225
Production phase (new product development), 59
Product life-cycle management (PLM), 10, 49–50
Product packaging, and design for the life cycle, 216, 217
Product service design, and design for the life cycle, 219
Product Stewardship program, 178
Product sustainability, design for, 184–188
measurement of sustainability, 185
multi-life-cycle products, 185–187
perpetual-life products, 185–187
and product sustainability index, 187–188
Product use design, and design for the life cycle, 219
Product variety, reducing, 320, 321
Profitability, of environmentally responsible products, 78
Programmability, 807–808
Programmable logic controllers (PLCs), 796, 809, 813–822
data types for, 822
function blocks for, 821
functions for, 820
IEC 61131 standard, 821–822
interfaces in, 815–817
principles of operation for, 813–815
programming of, 817–821
Programming:
of NCs, 828–835
of PLCs, 817–821
Projected keyboards, 19, 20
Project identification (Design for Six Sigma), 348
Project launch (Design for Six Sigma), 367
Project selection (Design for Six Sigma), 345–346
Proliferation, part, 317–318
Proper rational functions, 688, 691
Proportional band, 763
Proportional control, 763–765
Proportional-derivative (PD) control, 767–768, 771
Proportional gain, 763
Proportional-integral (PI) control, 766–767
digital, 793
hydraulic implementation of, 772–773
op-amp implementation of, 769–770
Proportional-integral-derivative (PID) control, 767, 768
digital forms of, 788–789
op-amp implementation of, 771–772
open-loop design for, 783–784
Simulink model of, 800–801
Proportionality constant, 482
Proportionality property, 462–463, 521
Proprietary technology, 318–319
Prototypes, 636
Prototyping:
rapid, 45–46
virtual, 45, 394, 396–397
Pseudoderivative feedback (PDF), 781
PT98 vibration meter, 255
Pugh methods, 352–356
Pulse transfer functions, 742–744, 749
Pumps, failure rate estimation for, 170
Punched cards, 825
Punched tape, 825, 828
Pure dependent source, 675
Pure gyroators, 675
Pure transducers, 675
Pure transformers, 674–677
Pure transmitters, 675
PWC (physical work capacity), 428

Q
Q-learning, 862, 887–888
Q point, 467
Quadratic index, 775
Quadratic programming, 114
Quadratures, 755
Quadrature optical encoders, 932, 933
Quality assurance, traditional approach to, 127
Quality function deployment (QFD), 132, 422
Quality future deployment (QFD), 184, 185
Quarter-decay criterion, 775
Quasi-Newton gradient methods, 116
QUEST™, 397
Questionnaires, 637–638

R
R-2R ladder DAC, 491
Radial basis function (RBF), 847
Ragazzini, John R., 479
RAM (random access memory), 15, 926
Ramp function, 498
Random-access memory (RAM), 15, 926
Random processes, 724, 727
Random variables, 257–258, 726–727
Ranges, in data summaries, 607
Range of motion (ROM), 422–423
Rapid prototyping, 45–46
Rasterization, 28
Rate action, 767
Rate limiter, 801
Rate time, 767
Rational functions, 688, 691
Raw materials, for remanufacturing, 306
Raytheon, 951
RBF (radial basis function), 847
RBRC (Rechargeable Battery Recycling Corporation), 80
RC circuits, 904–906
constraints for, 531–532
responses to exponential/sinusoidal inputs by,
536–538
step response for, 533, 534
Reactance, 517
Reactive power, 525–527
Real algorithm, 771, 772
Real constraints, 109
Real diodes, 909
Real eigenvalue analysis, 42
Real variable \( t \), 688
Reassembly:
design for, 322
ease of, 320
Recall, ease of, 647
Receivers, 753
RECHARGE, 80
Rechargeable Battery Recycling Corporation (RBRC), 80
Recognition, part, 321
Reconditioning:
in remanufacturing, 323–324
remanufacturing vs., 302–303
Recopol, 237
Rectangular window, 589, 590
Recursion, 740
Recycling, 83, 302
Reduction process (electric circuits), 453–454
Reference marks, in electric circuits, 442–443, 448
Refinement, 631
Refrigerators, 91–92
Refurbishment:
in remanufacturing, 312–313
remanufacturing vs., 302–303
Refuse collection, 432–434
Registers, 925, 926
Registration, Evaluation, Authorisation and
Restriction of Chemicals regulation (European Union), 81
Regulations, and design for the life cycle, 213, 214
Regulator, 751
Reinforced plastics, 335
Reinforcement learning (RL), 860
and approximate dynamic programming,
886–888
integral, 863–866
optimal control for, 866–867
Reinforcement learning control, 857
Reliability, 149–173
design, 161–169. See also Design reliability in efficacy evaluation, 662
and failure data, 172–173
failure rate estimation models of, 169–172
and failure types, 159–161
hazard rate models of, 151–152
statistical distributions of, 150–151
Reliability models, 268–271
Reliability networks, 152–159
bridge network, 158–159
\( K \)-out-of-\( m \) unit network, 156–157
parallel network, 154
parallel–series network, 155–156
series network, 153–154
series–parallel network, 154–155
standby system, 157–158
Remanufactured components, 314
Remanufactured products:
consumer demand for, 304
and reconditioned, repaired, or refurbished parts, 302–303
remanufactured components vs., 314
Remanufacturing, 82–83, 301–314
and customer returns, 308
defined, 302
facility processes for, 308–314
by OEMs, 307–308
potential benefits of, 303
reconditioning, repair, and refurbishment vs.,
302–303
recycling vs., 302
by third parties, 306–307
Remanufacturing facility processes, 308–314
automation of, 314
cleaning, 310–312
Remanufacturing facility processes (continued)
employee skills required for, 313–314
inspection and testing, 309–310
refurbishing, 312–313
typical, 308–309
Remanufacturing industry:
business practices in, 304–308
part and product flows in, 305
raw materials in, 306
size of, 303–304
Remanufacturing Institute, 302
Remanufacturing Vision Statement—2020 and Roadmaps, 179
Remote control, battery-free, 91
Renewal process (RP), 275
Repair:
in remanufacturing, 316–317, 323–324
remanufacturing vs., 302–303
Reparable systems design, 278–297
effectiveness measures, definition of, 279–281
idealized maintenance, 286–290
imperfect maintenance, 289, 291, 292
and modeling availability, 291–295
and modeling of maintainability, 282–285
and preventive vs. corrective maintenance, 286
repair and failure rates, 281
and system availability, 295–297
Reparability (term), 279
Repeated (nondistinct) poles, 690–691
Repeating-value compression, 607, 608
Replacement:
of parts, 320
in remanufacturing, 323–324
Representation systems, 641
Representativeness, 648
Required gain (instrumentation systems), 492
Requirements specification phase (system design), 655–656
Reset action, 766
Reset steps, 810
Reset time, 766
Reset windup, 777
Residual, 111
Residues, 690
Resistance(s), 444, 517, 934, 935
equivalent, 448–450, 466
equivalent input, 511–512
Norton, 466
in op-amp circuit analysis, 483–484
of strain gauge, 494
Thévenin, 466
Resistive elements, 674
Resistors, 898, 899
canstraints in phasor form on, 514
impedance of, 516
i-v characteristics for, 444, 445
Resolution, 566–567, 930
Resolvent matrix, 715
Resolvers, 825
Resource Conservation and Recovery Act, 81
Response to periodic inputs using transform methods, 704–714
Response variables, 681
Returns, customer, 308
Reusable components, 320
Reuse, 83, 196–197
Reverse logistics, 308, 317
Riccati equation, 866
Ricoh Group, 229
RL, see Reinforcement learning
RL circuits:
in filters, 559–561
step response in, 541–543
transient response in, 538–543
zero-input response in, 539–540
RL circuits, 904, 905, 907–908
constraints for, 532
step response for, 533
Robot controllers, 836–840
backstepping neuro-, 853–854
composition of, 836–838
control program of, 838–841
Robustness, 748, 850
ROM (range of motion), 422–423
Root loci, for common transfer functions, 708, 710, 712, 714
Root-locus plot, 781, 782, 784–787
Root-mean-square value, 503–504
Rotating phasors, 513
Rotation function, 36
Rotation transformation, 37, 38
Rotor current, 525
Round-off errors, 722
RP (renewal process), 275
RPM, hard drive, 16
RS flip-flops, 922–923
Runge–Kutta methods, 720–721
Rupture failure, 159

S
SaaS model, 49
Safe Drinking Water and Toxic Enforcement Act of 1986, 81
Safety factor, 164–165
Safety margin, 164–165
Index 985

Safety review process, 85
SAGE (Semi-Automatic Ground Environment), 4
Sallen-Key configurations, 563
Salmon Friendly products, 179
Sampled-data systems, 737
Sampling, uniform, 740–741
Sampling interval, data-acquisition, 599–600
Sampling time, 788
Saturation nonlinearity, 736
Scaling function, 36
Scaling transformation, 37, 38
Scanners, 25–27
Scatter diagrams, 143
Scenario writing, 639
Schmitt triggers, 924–925
Schumacher, Fritz, 208
SCSI (Small Computer System Interface), 15
SDKs (software development kits), 380, 613
S-domain, 580
Second (time unit), 566
Secondary physical variables, 670
Secondary winding, 509
Second central moment, 726
Second-order circuits, transient response of, 538–543
Second-order RLC filters, for frequency response, 559–561
Second-order systems:
  integral control of, 766
  PD control of, 767–768
  PI control of, 767
  proportional control of, 765
Second-order transient response, 699, 700
Secrecy, 346
Selection, sequence, 810, 811
Selection of Strategic Environmental Challenges (STRETCH), 236
Selective laser sintering, 47
Selective perceptions, 648
Self-cleaning exhaust hood, 92
Self-fulfilling prophecies, desire for, 647
Self-grounded haptic devices, 378
Self-inductance, 508, 509
Self-starting methods, 721
Semi-Automatic Ground Environment (SAGE), 4
Semiconductor electronics, 908–912
  analysis of diode circuits, 909
  ideal and real diodes, 908–909
  light-emitting diodes, 910–911
  photodiodes, 911
  transistors, 911–912
  Zener diodes, 910
Semi-immersive VR, 372
Sense–plan–act cycle, 896
Sensitivity, 566–567
Sensors, 931–937
  dynamic response of, 756
  force, 933–937
  linear variable differential transformers, 933, 934
  optical encoders, 932–933
  position, 931
Sensorama Simulator, 371
Separability rating, 84
Sequences, SFC, 810
Sequencing devices, 748
Sequential control, 809–813
Sequential function charts (SFCs), 809–812, 817
Sequential logic devices, 922
Serial communications, 617
Serial data transfer, 929–930
Series compensation, 778–779, 796–794
Series connections:
  in circuits, 446
  inductors and capacitors, 507
  phasor analysis of circuits with, 516–518
Series network, 153–154
Series–parallel network, 154–155
Series RLC circuits:
  in filters, 559–561
  step response in, 541–543
  transient response in, 538–543
  zero-input response in, 539–540
Servers, 17
Serviceability (term), 279
Servomechanisms, 752
Servomotors, hydraulic, 758
Set point, 752
Setup cost, 105
SFCs, see Sequential function charts
Sharing, product, 241
Shear loading failure, 159
Shift operator, 742
Short circuits, 444, 465, 466
Shot retention, 312
Should-not-use lists, 86
Siemens, 10, 444
Sierra Club, 208
Signals:
  in AC circuits, 495–504
dc, 495
  defined, 439
  references for, 442–443
  amplification, 473, 552
  attenuation, 552
  inversion, 475
Index

Signal processing, 579–596
  analog filters, 581–587
digital filters, 587–594
  extracting signal from noise, 595–596
  and frequency-domain analysis of linear systems, 579–581
  stability/phase analysis, 594–595
Signal transfer, in DC circuits, 468–469
Silicon Graphics ONYX 2 computer, 397, 399
SimPro, 208, 226
Simple linear fit, 602–603
Simplex method, 112, 114
Simulated annealing, 114
Simulation(s), 717–723
digital, 717–723
  experimental analysis of model behavior, 717
  MEMS, 947
  of online learning for non zero-sum games, 882–884
of online learning for optimal control, 870–872
  of online learning for zero-sum games, 876–877
Simulation modeling, 641–645
Simulation run, 717
Simulation study, 717
Simulink model, 800–801
Single-layer NN controllers, 850
Single perturbation NN controllers, 854, 855
Single-step methods of numerical integration, 721
Single-variable unconstrained optimization methods, 115
Singularity functions, 498, 695, 696
Sinusoidal signals, RC circuit responses to, 537
Sinusoidal steady state operation, of AC circuits, 525–531
Sinusoidal waveforms (sinusoids), 499–502, 512–513
SI (International System) units, 440, 441
6DOF mouse, 375
6DOF Stewart platform, 394
Six Sigma, 341, 342. See also Design for Six Sigma (DFSS)
Six-terminal element, 675, 678
SKETCHPAD system, 4, 14
Slave valves, 759
Sliding-mode manifold, 848
Slope property of exponential waveforms, 499
Small numbers, law of, 648
Smell-o-vision, 380
Smoothing, data, 604–605
Social judgment theory, 650
Socially responsible investors, 79
Software:
  analysis, 39–43
  for computer-aided design, 29–43
for control system design, 800–801
for digital control, 798–800
for optimization, 120–121
  3D graphics, 31–39
  2D graphics, 29–31
for virtual reality, 380
Software development kits (SDKs), 380, 613
Software quality function development (SQFD), 136
  Solid commands, 9
  Solid ground curing, 47
  Solid modeling, 10
    hybrid, 10, 11
  software for, 31, 32
  Solid-state drives (SSDs), 16
  SolidView tool, 61
  Solidworks, 46
  Solvent-based chemical cleaning, 311
  Sorting, in remanufacturing, 320–321
Source elements, 674
SpaceBall, 375, 376
SpaceMouse Pro, 375, 376
Spatial Corp., 43
  Specification (quarter-decay criterion), 775
  Speed of response, 696
  Spinal compression, 427–428
  Spindle speeds, 830
  Standard deviations, 325, 326
  Spreadsheet-based remanufacturing assessments, 136
  SQL (software quality function development), 325
  SQL language, 612
  SQP (Successive Quadratic Programming), 119–120
  SSDs (solid-state drives), 16
  ST, see Structured text
  Stability, NN weight tuning for, 849–850
  Stability analysis, 594–595
  Stakeholders, in DfE program, 79–80
  Standards, measurement, 565–566
  Standard deviation, 607, 726
  Standard form of double-order linear differential equation, 540
  Standard for the Exchange of Products (STEP), 43
  Standardization, proliferation of parts vs., 317–318
  Standard errors, 317
  Standby system, 157–158
  Stanley Black & Decker, 79
  State equations, 684–685, 715
  State reconstructors, 775, 781
  State transition matrix, 715
  State University of New York at Buffalo, 394
  State-variable feedback (SVFB), 780–781
  State-variable form, 681, 684–686
<table>
<thead>
<tr>
<th>Term</th>
<th>Page(s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>State-variable methods</td>
<td>681, 687, 713–717</td>
</tr>
<tr>
<td>Static analysis</td>
<td>12</td>
</tr>
<tr>
<td>Static anthropometric measures</td>
<td>420</td>
</tr>
<tr>
<td>Static compliance</td>
<td>569</td>
</tr>
<tr>
<td>Static error coefficient (c_i)</td>
<td>752</td>
</tr>
<tr>
<td>Static optimization models</td>
<td>426–427</td>
</tr>
<tr>
<td>Static stiffness</td>
<td>569</td>
</tr>
<tr>
<td>Stationary displays</td>
<td>377</td>
</tr>
<tr>
<td>Stationary processes</td>
<td>727</td>
</tr>
<tr>
<td>Statistical process control (STC)</td>
<td>256</td>
</tr>
<tr>
<td>Static state, 253</td>
<td></td>
</tr>
<tr>
<td>Steady-state errors</td>
<td>752</td>
</tr>
<tr>
<td>Steady-state Laplace transform</td>
<td>759–760</td>
</tr>
<tr>
<td>Steady-state response of system</td>
<td>764–768</td>
</tr>
<tr>
<td>STEP (Standard for the Exchange of Products)</td>
<td>43</td>
</tr>
<tr>
<td>Step-down transformers</td>
<td>510</td>
</tr>
<tr>
<td>Step functions</td>
<td>464–467</td>
</tr>
<tr>
<td>Stepper motors</td>
<td>757–758</td>
</tr>
<tr>
<td>Step response: of first-order circuits</td>
<td>532–536</td>
</tr>
<tr>
<td>in second-order circuits</td>
<td>540–543</td>
</tr>
<tr>
<td>Step-up transformers</td>
<td>510</td>
</tr>
<tr>
<td>Step waveforms</td>
<td>496</td>
</tr>
<tr>
<td>Stereolithography</td>
<td>47</td>
</tr>
<tr>
<td>Stereo scanning</td>
<td>26</td>
</tr>
<tr>
<td>Stiffness</td>
<td>568, 569–571</td>
</tr>
<tr>
<td>Stiff systems</td>
<td>723</td>
</tr>
<tr>
<td>STM (sustainability target method)</td>
<td>185</td>
</tr>
<tr>
<td>Stochastic dependency</td>
<td>253</td>
</tr>
<tr>
<td>Stochastic systems</td>
<td>724–727</td>
</tr>
<tr>
<td>random processes</td>
<td>724, 727</td>
</tr>
<tr>
<td>random variables</td>
<td>726–727</td>
</tr>
<tr>
<td>state-variable formulation</td>
<td>724, 726</td>
</tr>
<tr>
<td>Subassemblies, remanufacturing of</td>
<td>314</td>
</tr>
<tr>
<td>Subdominant poles</td>
<td>701, 702</td>
</tr>
<tr>
<td>Substances for concern</td>
<td>318</td>
</tr>
<tr>
<td>Subtractors</td>
<td>486–488, 495</td>
</tr>
<tr>
<td>Successive Quadratic Programming (SQP)</td>
<td>119–120</td>
</tr>
<tr>
<td>Summer op amp</td>
<td>915</td>
</tr>
<tr>
<td>Surveys</td>
<td>637–638</td>
</tr>
<tr>
<td>Susceptance</td>
<td>518</td>
</tr>
<tr>
<td>Sustainable Design Program (DoE)</td>
<td>178, 179</td>
</tr>
<tr>
<td>Sustainable development</td>
<td>76–78</td>
</tr>
<tr>
<td>Sustainable Environmental Management Information System software</td>
<td>229</td>
</tr>
<tr>
<td>Sustainable Industries Partnership program</td>
<td>178</td>
</tr>
<tr>
<td>Sustainable manufacture</td>
<td>182, 183</td>
</tr>
<tr>
<td>Sustainable Mobility Project</td>
<td>181–182</td>
</tr>
<tr>
<td>Sustainable Textile Standards</td>
<td>178, 179</td>
</tr>
<tr>
<td>Sutherland, Ivan</td>
<td>4, 5, 14</td>
</tr>
<tr>
<td>Sutherland, Sproull, and Associates</td>
<td>5</td>
</tr>
<tr>
<td>SVFB (state-variable feedback)</td>
<td>780–781</td>
</tr>
<tr>
<td>Symmetric multiprocessing</td>
<td>18, 19</td>
</tr>
</tbody>
</table>

Structured modeling, 641
Structured neural networks, 851–852
Structured text (ST), 817, 819, 821
Subassemblies, remanufacturing of, 314
Subdominant poles, 701, 702
Substances for concern, 318
Subtractors, 486–488, 495
Successive Quadratic Programming (SQP), 119–120
Summer op amp, 915
Surveys, 637–638
Susceptance, 518
Sustainable Design Program (DoE), 178, 179
Sustainable development, 76–78
Sustainable Environmental Management Information System software, 229
Sustainable Industries Partnership program, 178
Sustainable manufacture, 182, 183
Sustainable Mobility Project, 181–182
Sustainable Textile Standards, 178, 179
Sutherland, Ivan, 4, 5, 14
Sutherland, Sproull, and Associates, 5
SVFB (state-variable feedback), 780–781
Symmetric multiprocessing, 18, 19
Synchro control transformers (synchros), 753–754
Synchronous serial data transfer, 929, 930
Synectics, 637
Synthesis stage (design process), 6, 7
System(s):
  defining boundaries of, 98
  models for optimizing, 100
System acquisition, 633
Systems analysis and modeling, 631
System buses, 809
System definition matrix, 639
System design, 652–664
  characteristics of effective, 653, 663–664
  detailed design/integration/testing/implementation phase of, 657–658
  development of aids for, 654–659
  evaluation phase of, 658–663
  operational deployment phase, 659
  operational environments/decision situation models, 653–654
  preliminary conceptual design/architecting phase of, 656–657
  purposes of, 652–653
  requirements specification phase of, 655–656
Systems engineering, 625–652
  central role of information in, 650–652
  conditions for use of, 626
  49-element two-dimensional framework for, 632–633
  functional definition of, 628–629
  and information processing by humans/organizations, 646–649
  interpretation, 649–650
  issue analysis, 640–646
  issue formulation, 635–640
  life cyclefunctional elements of, 628–634
  as management technology, 625–628
  methodology/methods of, 635–652
  objectives of, 634–635
  results attainable from, 626–627
  seven-step framework for, 631–632
System error analysis, 617
System evaluation:
  algorithmic effectiveness of, 661
  behavioral/human factors, 661
  as design phase, 658–659
  efficac, 661–662
  methodology/criteria for, 660–661
  test instruments for, 662–663
System graph, 679
System integrators, 807
System-level architecting, 633
“Systems on a chip,” 951
System operation monitoring, 254–256
  and fluid analysis/tribology, 255–256
  with infrared thermography, 255
  and vibration measurement/analysis, 254–255
System relations, 679–680
System synthesis, 632, 637

T
TA (tooling amortization cost), 56
Tablets, 17
Tachometers, 754, 768
TA (tooling amortization) cost, 56
Tanner Tools, 947
Targets:
  target cost establishment, 71
  unit manufacturing cost, 55–56
TCA (total cost accounting), 233, 234
Tchebyshev filters, 584–585
TCP/IP (Transmission Control Protocol/Internet Protocol), 618
Teaching points, 839
Teach pendant, 838–840
Teardown, competitive, 69–70
Technical obsolescence, 315
Technical University of Delft, 208
Technology, proprietary, 318–319
Teijin, 238
Telepresence, 373
Temperature standards, 566
Temperature transducers, 755
Temporal descriptors (for waveforms), 502
Tensile yield strength failure, 159
Testing:
  in remanufacturing, 309–310, 324
  in system design, 657–658
Test input signals, 695, 696
Texas Instruments, 948
Thermal cleaning, 310, 311
Thermal equilibrium, 566
Thermal spraying, 313
Thermistors, 755
Thermodynamics, first law of, 671
Thermography, infrared, 255
Thermoplastic polymers, 330
Thermosetting resins, 330
Thévenin equivalent circuits, 465–467
  with dependent sources, 478–479
  general applications of, 465–467
  for nonlinear loads, 467
  in phasor domain, 522–523
Thévenin resistance, 466
Thévenin’s theorem, 568
Thévenin voltage, 539
Third-party acquisition systems, 612–613
Third-party remanufacturers, 306–307
Thoreau, Henry David, 208
3-dB down frequency, 552
3Dconnexion Inc., 375
3D graphics software, 31–39
dimension-driven design with, 31, 32
editing features of, 36
for feature-based modeling, 34–36
and graphical representation of image data, 38–39
for parametric modeling, 32–34
for solid modeling, 31, 32
for surface modeling, 31
transformations in, 36–38
for variational modeling, 32, 33
for wire frame modeling, 31
3DM, 381
3D mouse, 21
3D printing, 45–46
3-Draw, 381
3D scanning, 25–37
3M, 208
Three-dimensional transformations, 38
Three-mode controllers, 767
Three-phase circuits, 529–531
Three-port element, 675, 678
Three-position on–off device with hysteresis, 736
Through variables, 445, 568, 670
Time-based data acquisition, 602
Time constant, 499
Time domain, 688
Time factors:
in efficacy evaluation, 661
in project selection, 346
Time-invariant systems, 682
Time-series forecasting, 643
Time standards, 566
Time-varying systems, 729–730
Timing diagrams (digital circuits), 921
Tissue tolerances (ergonomics), 427–428
TM101 transmitter monitor, 255
Toasters, 92
Toggle flip-flops, 924
Tokens, 810
Tools:
design, see Design tools
robot, 837
standardization of, 318
Toolboxes, 800
Tooling amortization cost (TA), 56
Tool motion statements, 834–836
Toshiba GR-NF415GX refrigerator, 91–92
Total assembly time metric, 71, 72
Total cost accounting (TCA), 233, 234
Total flux, for inductors, 505
Total material cost metric, 72
Total product/packaging mass, 84
Total quality management (TQM), 125–144
and acquisition/process control, 134
affinity diagram in, 137
barriers to success, 129
and benchmarking, 133
concentration diagrams in, 142–143
control charts in, 139–140
Crosby’s approach to, 130
customer needs mapping in, 139
definition of, 126
Deming’s approach to, 129–130
deming wheel in, 137
and design control, 131
and Design for Six Sigma, 135
in design phase, 131–136
elements of, 127, 128
fishbone diagram in, 137–138
force field analysis in, 138–139
Gantt charts in, 142
gap analysis in, 141
Hoshin planning method in, 140–141
Juran’s approach to, 130–131
Kaizen in, 138
methods of, 136–144
opportunity analysis in, 142
Pareto diagram in, 138
poka-yoke method in, 140
potential problem analysis in, 143–144
principles of, 128–129
and process design review, 133–134
and product design review, 132
and quality design characteristics, 131
and quality function deployment, 132
and quality improvement guidelines, 135
and quality loss function, 132–133
review, product design, 132
scatter diagrams in, 143
software design, 136
stratification method in, 141–142
and Taguchi’s approach, 134–135
traditional quality assurance program vs., 127
Totals:
in data summaries, 607
Total truncation error, 722
Touch pad, 22–23
Touch screen, 23
Toxic Release Inventory (TRI) reporting, 318
TQM, see Total quality management
Trackballs, 22
Index

Tracking devices, 374–375
Tracking feedback, 847
Training requirements, for efficacy evaluation, 661
Trajectory, 737
Transconductance, 474
Transducers, 753–755
  displacement/velocity, 753–755
  flow, 755–756
  gyration, 675
  input, 491
  output, 491, 492
  pure, 675
  temperature, 755
  transforming, 675, 677
Transfer admittance, 544
Transfer function(s), 692, 749
  determining, 544–547
  first-order high-pass, 554, 556
  first-order low-pass, 552, 554
  for frequency response, 543–547
Transfer impedance, 544
Transforms, 687–688
Transformations, 36–38, 687
  optimization methods, 117–118
  three-dimensional, 38
  two-dimensional, 36–38
  of Y-Δ connections, 450, 451, 519–521
Transformation commands, 9
Transformation ratio, 675
Transform domain, 688
Transformers:
  defined, 509
  ideal, 509–512
  pure, 674–677
Transforming transducers, 675, 677
Transform methods, 681, 687–714
  response to periodic inputs using, 704–714
  transient analysis using, 693–704
Transform properties, table of, 688, 690
Transform table, 688, 689
Transient analysis using transform methods, 693–704
  complex s-plane, 699, 701
  effect of zeros on transient response, 702, 704
  first-order transient response, 696–699
  higher-order systems, transient response of, 700–702
  parts of complete response, 694
  performance measures, transient, 702, 703
  second-order transient response, 699, 700
  test inputs/singularity functions, 695, 696
  transient response, 531–543
  effect of zeros on, 702, 704
  first-order, 696–699
of first-order circuits, 531–538
of higher-order systems, 700–702
  second-order, 699, 700
  of second-order circuits, 538–543
  of system, 694
Transient state, 254
Transistors, 911–912
Transistor–transistor logic (TTL), 755
Transition conditions, 810
Translation, 36–38
Translators, 43
Transmission Control Protocol/Internet Protocol (TCP/IP), 618
Transmitter, 753
Transport delay, 800, 801
Transresistance, 474
Trees, 638, 639
Trend extrapolation, 643
Tribology, 255–256
Trim function, 36
Triple bottom line (TBL) model, 79
TRIZ methods, 352, 355
TRIZ principle, 90–91
Truncation errors, 722
T sections, 562, 563
TTL (transistor–transistor logic), 755
T-type element, 671, 672
Tuning software, 799
Turning tools, 824
Turns ratio, 510
2D graphics software, 29–31
2D scanners, 25
Two-dimensional transformations, 36–38
  (2%) setting time, 699
Two-phase ac motors, 757
Two-port element, 674, 675
Two-port interface circuits, 471–473
Two-port networks, 469
Two-position control, 763
Two’s complement, 918–919, 927
Two-stage valves, 759
Two-terminal element, 670, 671

U
Ultimate-cycle method, 776
Ultimate gain, 776
Ultimate tensile strength failure, 159
UML (Unified Modeling Language), 809
Unconstrained methods for optimization, 115–116
  multivariable, 115–116
  single-variable, 115
Unconstrained optimization problem, 112
Uncontrollable systems, 775
Undamped natural frequency, 540, 560
Underdamped response, 540, 541, 699
Underlapped valves, 758
Undetermined coefficients, method of, 537
UNEP (United Nations Environment Programme), 229
Unified Modeling Language (UML), 809
Uniformly ultimately bounded (UUB) time signals, 870
Uniform sampling, 740–741
Unipolar terms, 526
United Nations, 208
United Nations Environment Programme (UNEP), 229
United Nations Rio de Janeiro Conference, 208
U.S. Code of Federal Regulations, 302
U.S. Department of Defense, 303, 304
U.S. Environmental Protection Agency (EPA), 178, 192, 195, 311
U.S. Green Building Council LEED Rating System, 179
United States Council for Automotive Research (USCAR), 179–180
Unit impulse, 497
Unit manufacturing cost (UMC) target, 55–56
Unit ramp, 498
Unit step function, 496
Universal serial bus (USB), 14
University of Alberta, 381
University of Bonn, 400
University of Colorado, 408
University of Erlangen, 386
University of Iowa, 392
University of Kalmar, Sweden, 88
University of Kentucky (Lexington), 187
University of Missouri-Rolla, 394
University of North Carolina, 381
University of Wisconsin at Madison, 121
UNIX, 14
Unobservable systems, 775
Upward remanufacturing, 303, 314
USB (universal serial bus), 14
USCAR (United States Council for Automotive Research), 179–180
UUB (uniformly ultimately bounded) time signals, 870

V

VADE (Virtual Assembly Design Environment), 399, 400
Valuation, contingent, 224
Value iteration (VI), 865
Value system design, 631, 637

Valve positioners, 761–762
Vapor-matt, 312
Variable time step methods, 722
Variance, 726
Variational modeling, 32, 33
VDI 2243 Standard, 302, 319
VDS (Virtual Design Studio), 382
VEs (virtual environments), 372
Vehicle recycling, 184
Velocity algorithm, 789
Velocity control systems, 763
Velocity error coefficient ($c_1$), 753
Velocity transducers, 754–755
Venturi flowmeters, 755, 756
Verilog-A model, 947
Vertex relations, 680
VI (value iteration), 865
Vibrations, adverse health outcomes from, 429–430
Vibration measurement and analysis, 254–255
Video cards, 15
Video memory, 15
VIRCON, 402, 405
ViRLE (Virtual Reality Interactive Learning Environment), 409
VIRTTEX (VIRtual Test Track EXperience), 392–394
VirtualANTHROPOS, 400
Virtual Assembly Design Environment (VADE), 399, 400
Virtual Design Studio (VDS), 382
Virtual environments (VEs), 372
Virtual prototyping, 45, 394, 396–397
Virtual reality (VR), 371–411
  in civil engineering/construction, 402–408
  in concept design, 380–386
  in data visualization, 386–391
  defined, 372
  in driving simulation, 391–395
  evaluating concept design with, 384–386
  in geology/chemical engineering, 409–411
  hardware for, 374–380
  in manufacturing, 395–402
  in oil and gas industry, 408–409
  software for, 380
  types of, 372–373
Virtual Reality Interactive Learning Environment (ViRLE), 409, 411
Virtual Reality Laboratory, 409
Virtual sculpting, 382, 383
VIRtual Test Track EXperience (VIRTTEX), 392–394
“Visionary Manufacturing Challenges for 2020” (NRC), 180
ViSTA FlowLib, 391
Visual displays, in virtual reality systems, 377–379
Voltage(s):
control, 478
defined, 442
from dependent sources, 475
differential, 494
interface, 468, 471
at inverting input, 482
Kirchhoff’s law of, 446, 447, 514, 531, 901–902, 907, 908, 936
line, 530
in mesh current analysis, 459
node, 454–456
open-circuit, 465, 466
output, 454, 475, 480, 482, 490, 491
phase, 530
phasor, 514
reference marks for, 442, 443
as term, 897
Thévenin, 539
Voltage division, 451–452, 516–518, 544, 545
Voltage division rule, 452
Voltage followers, 484, 548
Voltage sources, 897, 898, 903
dependent, 473–479
equivalent, 450
ideal, 444, 445
Voltage transfer function, 544
Voltmeters, 903, 904
Volvo, 88, 91, 232, 393
VR, see Virtual reality
VR-CFD, 389
VR-Fact!, 397, 398
VRFactory, 397–399
VRFEA, 391
VS101 solid-state vibration switch, 255

W
Wall displays, VR, 377
Washington State University, 399
Waste management, and sustainability, 193
Water purifiers, 92
Watt, James, 759
Waveforms, 495–504
exponential, 498–499
for ramp function, 498
sinusoidal, 499–502
step, 496–497
WBGT (wet-bulb–globe temperature), 429
WCED (World Commission on Environment and Economic Development), 77
Wear, contamination caused by, 323
Weber, Wilhelm, 505
Web programs and interfaces, 621
WEEE, see Waste Electrical and Electronic Equipment Directive
Weibull distribution, 152, 265–266, 272, 289
Weibull probability density function, 273–274
Weighing function, 693
Welding labor cost, 105
Weld stress, 106–107
Wet-bulb–globe temperature (WBGT), 429
Wharington International, 237
Wheatstone bridge, 494, 934, 937
Whirlwind computer, 823
Whole-body fatigue, 428
Windings, transformer, 509, 510
Windows, 14
Windowing, 589, 590
Wire frame modeling, 9–10, 31
Wireless access points, 623
Wireless mouse, 20
Wireless transmission, 623
WITNESS VR, 398, 399
Word (term), 916
Wordsworth, William, 208
Work (term), 897
Working standards, 454, 565
Work safety, 192
Workstations, engineering, 18
World Business Council for Sustainable Development (WBCSD), 181–182
World Commission on Environment and Economic Development (WCED), 77
World Commission on Environment and Development, 208
World Environment Center, 80
World-grounded haptic devices, 378
World Summit on Sustainable Development (Johannesburg), 208
WorldUp™, 398
World Wildlife Federation, 208

X
Xbox 360 with Kinect, 373
Xerox Corporation, 303, 307
Index 993

**Y**

Y-connected impedances, 519–521
Y-connected resistors, 450, 451
Y–Δ connections:
in three-phase circuits, 529–530
transformations of, 450, 451, 519–521

**Z**

Zener diodes, 910
Zeros, of $F(s)$, 688, 689

Zero-input response:
in second-order circuits, 539–540
of system, 692, 694
Zero-order data hold, 743–745
Zero-state response of system, 692,
694
Zero-sum games, nonlinear two-player,
872–877
Ziegler–Nichols rules, 775–776
$z$–plane, control design in the,
791–794
$z$-transforms, 587–588, 741–743