

## Name Index

- Abbott, C., 195, 198–202, 277, 319, 367, 370, 372, 489  
Abelson, R., 432  
Abrahamson, A., 653  
Abramowitz, M., 66  
Ackroff, J. M., 674  
Aho, A., 495, 510  
Alles, H., 192–193, 195, 200, 211, 244, 257, 261, 468, 641  
Allouis, J., 195, 201  
Alonso, S., 192, 206, 209, 212, 641  
Appleton, J., 192, 206, 209, 212, 641  
Arfib, D., 3, 83, 89–90, 93, 219, 461, 642  
Asti, V., 262  
Atal, B., 116
- Bach, J. S., 379, 381–383, 394, 396, 398, 422, 427, 668, 678, 693  
Backus, J., 99, 289  
Baecker, R., 199, 221–222, 376, 379, 386, 393, 427, 436  
Balaban, M., 425  
Barlow, C., 2  
Baroni, M., 403, 408, 422, 423  
Bartlett, M., 194, 369  
Bartók, B., 446  
Bastiaans, M., 145  
Bates, R., 376, 454  
Baumgart, B., 631  
Baur, F., 365  
Beauchamp, J., 3, 42, 83, 93, 97, 103, 112, 386, 642, 643  
Behrman, D., 540  
Beistad, R., 355  
Bell, A., 125  
Bell, G., 494  
Benade, A., 39, 102–103  
Beranek, L., 613, 619, 622  
Berg, P., 4, 162, 179, 201, 369  
Bergland, G., 371  
Berio, L., 279  
Bernoulli, B., 89  
Bernstein, L., 404–405, 407, 423  
Bischoff, J., 196, 540, 588–591, 596, 600  
Bismarck, G. von, 681  
Blacking, J., 408  
Blood, W., 349, 351, 354  
Blum, T., 200  
Boretz, B., 404, 429  
Borning, A., 435  
Brahms, J., 420  
Bregman, A., 651, 658–664, 667, 674–675, 685–688, 694  
Bright, W., 404  
Bunt, A., 644
- Burt, W., 538  
Busby, T., 403  
Buxton, W., 192, 199, 206, 221–222, 318, 368, 376–377, 379, 386, 393, 395, 427, 436, 449
- Cage, J., 596, 598  
Campbell, J., 651, 660, 663, 694  
Cann, R., 4, 335  
Carlson, B., 293  
Carroll, J., 654  
Chadabe, J., 368, 523, 553  
Chafe, C., 408  
Chamberlin, H., 1, 194, 196, 541  
Chang, J., 654  
Chauveau, A., 195, 200–201, 261–262, 279, 489  
Chen, P., 425  
Chomsky, N., 403, 405, 411–414, 419, 421–422, 424  
Chowning, J., 3, 31, 45–47, 54, 68, 70, 193, 214, 290, 296, 642  
Ciamaga, G., 376  
Clark, M., 32  
Cleaveland, J., 416  
Cockerell, D., 485  
Commoner, F., 511  
Cochiere, R., 516  
Crosby, M., 50
- Dannenbring, G., 660, 663, 667, 674–675, 686  
Dashow, J., 3  
Date, H., 610  
Debussy, C., 419  
DeMarinis, P., 540, 600  
Deutsch, D., 432, 555, 669  
diGiugno, P., 195, 211, 261–262, 269, 279, 468, 489, 641, 643, 655  
Dodge, C., 4, 692  
Doucet, L., 343  
Dowland, J., 582  
Dowling, W., 663–664, 692
- Earle, N., 200  
Eastty, P., 195, 200–201, 489  
Ehresman, D., 648, 651  
Eisler, H., 584  
Ellis, A., 289  
Erickson, R., 640  
Escher, M., 661
- Fant, G., 128  
Fedorkow, G., 192, 206, 221, 318, 376–377, 449

- Flanagan, J., 125  
 Fogels, E., 192, 318, 377, 449  
 Forte, A., 420, 424, 431  
 Foster, S., 408  
 Frankish, C., 651  
 Freedman, M., 32  
 Frykberg, S., 376, 454  
 Fu, K., 417, 426
- Gabor, D., 145  
 Gabura, K., 422, 429  
 Gardner, M., 544  
 Gibbs, J., 146  
 Gilbert, B., 355  
 Gips, J., 417  
 Gold, B., 146, 192, 326  
 Gold, R., 196, 540, 588–592, 594, 596  
 Goldberg, A., 368  
 Gordon, J., 645, 648–649, 681, 685  
 Gottlob, D., 631  
 Goude, G., 648  
 Grauer, V., 583  
 Gray, A., 144  
 Green, D., 150, 630  
 Green, M., 436  
 Greimas, A., 403  
 Grey, J., 42, 44, 212, 640, 643, 645–646,  
     648–649, 654–655, 681, 685, 687  
 Gross, D., 200  
 Grossman, M., 357  
 Grossman, S., 357  
 Guilford, J., 688
- Haflich, S., 427  
 Halliday, M., 414  
 Halpern, L., 669, 679, 681  
 Hanauer, S., 116  
 Hansen, F., 445  
 Harmonic, P., 590, 594, 600  
 Harris, C., 613  
 Harris, L., 355  
 Hastings, C., 202  
 Hearn, W., 539  
 Heise, G., 665, 668  
 Helmholtz, H. von, 145, 289, 448  
 Hewitt, C., 371  
 Hill, A., 583  
 Hiller, L., 3, 365, 413, 582  
 Hoffman, D., 37  
 Hofstetter, F., 386  
 Hogg, J., 386  
 Hollander, L., 200  
 Holt, A., 511  
 Holtzman, S., 369, 371  
 Holtzman, S. R., 3, 436  
 Horton, J., 196, 540, 588–591, 596
- Houtgast, T., 658, 672, 674  
 Howarth, R., 376, 454  
 Howe, H., 144  
 Hundley, J., 99  
 Hutchins, B., 84
- Imberty, M., 407  
 Isaacson, L., 365, 413
- Jackendoff, R., 404–405, 423, 425, 431  
 Jacobini, C., 408, 422  
 Jacobson, R., 403, 420  
 Johnson, S., 513  
 Jones, C., 192, 206, 209, 212, 641  
 Jones, K., 404, 413, 417, 436
- Kaegi, W., 206, 209, 212–213, 318  
 Kahrs, M., 199, 655  
 Kaplan, J., 370  
 Kaplan, S., 193, 199, 370  
 Kartashev, S., 360  
 Kassler, M., 428  
 Kay, A., 368  
 Keiler, A., 405, 423  
 Kennedy, W., 376, 454  
 Kernighan, B., 395, 451  
 Kintner, P., 357  
 Knuth, D., 366, 425  
 Kobrin, E., 194, 199  
 Koenig, G., 572, 568–580  
 Kornfeld, W., 199, 371  
 Kott, J., 195, 262  
 Krasner, G., 371  
 Kraul, D., 541  
 Krueger, L., 355  
 Kruskal, J., 645  
 Kuttruff, H., 613, 622
- Lamb, M., 376, 454  
 Lansky, P., 4, 128  
 Laske, O., 369, 404, 407, 421, 433, 554, 566  
 Lathi, B., 47  
 Lawler, E., 511  
 Lawson, J., 195, 200–201, 489  
 LeBrun, M., 3, 49, 54–56, 68, 83, 85, 90,  
     92, 192, 219, 241, 267, 307, 318, 449, 461,  
     642  
 Leibig, B., 149  
 Leibniz, C., 146  
 Lerdahl, F., 404–405, 425, 431  
 Levelt, W., 644  
 Levitt, D., 435  
 Levy, M., 428  
 Licklider, J., 676  
 Lidov, D., 407, 422, 428–429  
 Lieberman, H., 371

- Lindblom, B., 427  
Loitz, G., 386  
Loy, D., 193, 198, 372, 603  
Luce, D., 32  
Luce, R., 644
- McAdams, S., 651, 676–677, 681, 683  
McNabb, M., 198  
McNamara, J., 494  
McPherson, G., 343, 361  
Makhoul, J., 144, 516  
Mann, F., 600  
Manthey, M., 199–200, 445  
Marcus, S., 651  
Markel, J., 144  
Marquardt, D., 616  
Martirano, S., 194, 199, 523  
Mathews, M., 6, 17, 22, 31, 45, 83, 149,  
194, 199, 212, 292, 326, 370, 376, 404, 457,  
523, 535, 643  
Meehan, J., 433  
Messiaen, O., 583  
Meyer, L., 407  
Meyer, M., 593–595  
Meyers, R., 368  
Mezei, L., 376, 386, 427, 436  
Miller, G., 665, 668, 676  
Minsky, M., 368, 407, 431, 433  
Misunas, D., 511  
Moles, A., 147–148  
Molino, J., 403  
Mont-Reynaud, B., 408  
Moon, D., 373  
Moore, F., 89, 192, 194–195, 299–300, 319,  
523  
Moorer, J., 1–3, 76, 191, 193, 195–196,  
198–202, 262, 289–290, 318, 370, 408, 413,  
449, 489, 512, 603, 642–643, 646  
Morrill, D., 3  
Morton, J., 651  
Mudge, J., 494  
Murray, D., 386  
Myhill, J., 581
- Narmour, E., 404–405, 431, 433  
Nattiez, J.-J., 403–405, 407, 419–420  
Nelson, H., 688  
Newell, A., 557  
Newman, W., 368, 376  
Newton, I., 146
- Obusek, C., 674  
O'Dell, T., 393  
Oppenheim, A., 621  
Oppenheim, D., 369, 539
- Patel, S., 199, 393  
Payne, M., 600  
Pellegrino, R., 194  
Perkis, T., 596  
Petersen, T., 4  
Pike, R., 222, 379  
Pinker, S., 661, 685–686, 688  
Planck, M., 146  
Poole, D., 31  
Portnoff, M., 642  
Potard, Y., 425  
Pousseur, H., 582  
Powers, H., 403–405, 407  
Prevot, P., 467  
Pulfer, J., 377, 386  
Purcell, S., 50  
Pythagoras, 605
- Quillian, M., 425
- Rabiner, L., 146, 192, 202, 326, 516  
Rader, G., 427  
Rakowski, A., 296–297  
Rameau, J.-P., 419  
Randall, J., 144  
Ravel, M., 676  
Reeves, W., 199, 221–222, 376, 379, 386  
393, 427, 436  
Regener, E., 79  
Riemersma, J., 644  
Riley, T., 193  
Risset, J.-C., 2, 6, 22, 31, 37, 83, 158, 212,  
643  
Ritchie, D., 377, 451, 513  
Ritsma, R., 681  
Roads, C., 3–4, 191, 213, 219, 241, 368,  
372, 416, 426, 432–433, 436, 461  
Rockmore, A., 408  
Roederer, J., 332  
Rolnick, N. 2, 198, 200, 261, 370  
Rosenfeld, A., 417  
Rossum, D., 194  
Rothenberg, D., 428, 582  
Rousseau, J.-J., 423  
Rudnick, S., 660–661  
Ruiz, P., 3  
Rumelhart, D., 653  
Rush, L., 408  
Russell, R., 347  
Ruwet, N., 404, 419, 431
- Sabine, W., 638  
Salomaa, A., 416  
Samson, P., 195, 369, 641  
Sasaki, L., 192, 324, 377, 449

- Saunders, S., 3, 192  
 Saussure, F. de, 408  
 Schaefer, R., 83  
 Schaeffer, P., 408, 448  
 Schafer, R. M., 551  
 Schafer, R. W., 202, 621  
 Schank, R., 432  
 Scharf, B., 648  
 Schenker, H., 420, 422, 424, 428, 583  
 Scherpenisse, J., 173  
 Schillinger, J., 583  
 Schloss, W., 408  
 Schönberg, A., 603, 678  
 Schottstaedt, B., 3, 67, 214, 307  
 Schouten, J., 668  
 Schroeder, M., 603, 605–606, 608, 610, 628, 631  
 Sebek, T., 405  
 Shepard, R., 646–647  
 Siebrasse, K., 631  
 Simon, H., 552  
 Smith, B., 647–648  
 Smith, J., 3  
 Smith, K. C., 192, 206, 221, 318, 376–377, 449  
 Smith, L., 31, 37, 300, 376, 386, 427, 200  
 Smolian, S., 372, 421–422  
 Snell, J., 427  
 Snell, J. M., 192, 195, 202, 368  
 Sniderman, R., 199, 386  
 Spiegel, M., 65  
 Sproull, R., 368, 376  
 Steele, G., 435  
 Steels, L., 435  
 Stegun, I., 66  
 Steiger, H., 686  
 Steiglitz, K., 127, 144, 151  
 Stevens, S., 644  
 Stockham, T., 156, 568, 632  
 Stockhausen, K., 1  
 Strachey, C., 365  
 Stravinsky, I., 420  
 Strawn, J., 192–194, 200–201, 203, 417, 426  
 Strong, W., 32  
 Suen, C., 83, 91, 96  
 Sundberg, J., 427  
 Sussman, G., 435  
 Sutherland, I., 447
- Tanner, P., 377  
 Tempelaars, S., 206, 209, 212–213, 318  
 Tempest, W., 613  
 Thompson, K., 377, 513  
 Thurlow, W., 674, 692  
 Tovar, 376
- Tozuka, Y., 610  
 Truax, B., 3, 70, 82, 371, 444  
 Tucker, W., 376, 454  
 Tyranny, "Blue" Jean, 600
- Ullman, J., 495, 510  
 Ulrich, W., 427  
 Uzgalis, R., 416
- Valette, D., 281  
 Van der Pol, B., 47  
 van Noorden, L., 651, 658, 660, 665, 668, 670–672, 674, 691–692  
 Varèse, E., 156, 678, 420  
 Vasarely, V., 661  
 Vaughan, R., 376, 454  
 Vercoe, B., 377, 444  
 Verschuur, J., 658, 672, 674, 676
- Wallraff, D., 195, 201, 367, 370  
 Warren, R., 674  
 Wedin, L., 648  
 Weierstrass, K., 89  
 Weinreb, D., 373  
 Weinstein, C., 621  
 Wessel, D., 44, 158, 197, 603, 647–649, 651, 654, 678, 685  
 Whitfield, J., 146  
 Wiener, N., 146–147  
 Wilks, Y., 432  
 Williams, J., 583  
 Winham, G., 151  
 Winningstad, N., 350  
 Winograd, T., 373, 405, 415, 431–432  
 Winston, P., 368  
 Wood, D., 511  
 Woods, W., 417, 419, 425  
 Worman, E., 102
- Xenakis, I., 148, 413, 444, 581–582, 584
- Young, R., 59  
 Zingheim, J., 31  
 Zwicker, E., 648

# Subject Index

Italic page numbers indicate illustrations.

- Acoustics, 605, 622–628. *See also* Reverberation  
ADC. *See* Analog-digital converter  
Additive synthesis, 2, 31–32, 289, 461, 677  
  data reduction in, 426, 642  
  hardware implementation of, 212, 641  
Advanced Micro Devices, 361  
*Aerial* (Truax), 82  
Aerovox, 346  
*Air* (Bartlett), 547  
Aliasing, 90  
*Allilia* (Cann), 116, 129  
Alphabet, 409  
AM. *See* Amplitude modulation  
Amplitude envelope. *See* Envelope  
Amplitude modulation (AM), 3, 92  
Amplitude, no-multiply scaling, 50–52, 192  
Analog-digital converter (ADC), 263  
Analog recording, distortion in, 192  
Analog synthesis. *See* Hardware  
Analysis/synthesis, 114–144  
  all-pole model, 127  
  all-zero model, 127  
  inverse filtering, 126–133, 139–143  
  residual, 127, 130–132, 140–141, 143  
  squared error, 140  
*Androgyny* (Truax), 81  
*Antony* (Wessel), 197  
Apogee Motor, 550  
Architecture. *See* Hardware  
*Arras* (Truax), 3, 82  
Articulation, 64  
Articulator, 118, 121, 123  
Artificial intelligence, 368, 432  
Asp (hardware), 202, 372  
ASP (program), 161, 163  
*Atmosphères* (Ligeti), 290  
ATN. *See* Grammar  
Attack, 651, 655, 685–686. *See also* Envelope  
*Audio Wave* (Bischoff), 590  
Augat, 343–344, 346, 349, 352, 361  
AVS, 346  
AVX Ceramics, 362  
  
Backus Normal Form (BNF), 446, 562  
*Banjo Music* (Cann), 115  
BASIC, 513  
Bass, string, 619  
Bassoon, 24, 649  
Beckman, 362  
Bell Laboratories, 31, 191, 200, 244, 257, 370, 523, 641. *See also* Conductor program; Synthesizers  
Bell tones, 6, 25, 70  
Belongingness, 687  
Bessel function. *See* Frequency modulation  
Binary, 366  
·BNF. *See* Backus Normal Form  
*Bolero* (Ravel), 676  
Boundary  
  fission, 665–666, 671–672  
  temporal coherence, 665  
Bourns, Inc., 362  
Brass instruments, 22, 99, 102, 649. *See also* names of instruments  
  simulation of, 3, 21, 30–44, 95–113, 643  
Buchla synthesizer, 523  
  
C (language), 451, 513, 514, 517  
Cal Data, 100, 513  
Cascade FM. *See* Frequency modulation  
CCRMA. *See* Computer music studios  
CD. *See* Conceptual dependency  
Cello, 649  
Cent, 297  
Centre Engineering, 362  
Chebychev polynomials, 90–91. *See also* Waveshaping  
Chorales (Bach), 408, 422–423  
Clarinet, 649  
  simulated with frequency modulation, 42  
  simulated with waveshaping, 83  
CMI synthesizer, 199, 201  
CMN. *See* Common music notation  
Cmusic, 194, 366  
Cognition, musical, 421, 424, 551–552, 555, 563  
Coherence, 668–669  
  temporal, 660, 665, 691  
Common music notation (CMN), 379, 384  
Communications Satellite Systems, 336  
Compiling, 495, 497, 499  
Complex modulator. *See* Frequency modulation  
Composition, 553. *See also* Computer music composition  
  aleatoric, 581–582, 590  
  algorithmic, 417, 569–570, 578  
  grammar-based, 422–423  
  group, 588–600  
  serial, 1, 573, 569  
  stochastic, 444, 523–524, 531–532, 541, 544–545, 581–587, 594  
*Computer Cantata* (Hiller), 582

- Computer music composition, ix–x, 30, 160, 196, 199, 489, 573–574. *See also* Composition; *names of compositions* in studio, 539, 599  
 interactive, 551, 553–554, 560–561, 563, 576–577, 588–600  
 real-time, 45, 160, 537–538  
 using  $c:m$  ratios, 3, 68–82  
 with grains, 148–149, 151–152  
 with live instruments, 30–31  
 with microcomputer, 196, 597–600  
 with pre-recorded sounds, 247, 518
- Computer music studios. *See also* Bell Laboratories; Lucasfilm; McGill University; Michigan State University  
 Aarhus, 445, 568  
 Albany, 523, 526, 531, 534  
 CCRMA (Stanford), 31, 202, 301, 312, 603, 610, 641, 644, 655  
 CME (San Diego), 149, 199  
 Colgate University, 31  
 GRM, 281, 288  
 Institute of Sonology (Utrecht), 160, 173, 568, 572, 575–578  
 IRCAM, 2, 194–195, 256, 261, 279, 370, 449, 468, 485, 578, 610, 628, 644–645, 647, 655  
 Mills College, 540  
 MIT Artificial Intelligence Laboratory, 199  
 MIT Experimental Music Studio, 152  
 Oberlin, 200, 249  
 SSSP (Toronto), 199, 200, 206–225, 376–377, 443
- Computers  
 Burroughs B6700, 149, 152  
 CDC 6600, 511  
 Control Data, 352  
 CRAY-1, 347, 352, 354, 508  
 DEC PDP-1, 369, 377  
 DEC PDP-8, 352  
 DEC PDP-10, 17, 31, 632, 647  
 DEC PDP-11 (and LSI-11), 154, 200, 221, 238, 244, 246, 249–250, 254, 257–258, 262–263, 277, 279, 469–470, 476, 477, 481, 484–485, 488, 513, 517, 523, 568  
 DEC PDP-15, 160–161, 173, 568  
 DEC VAX-11/780, 191–192  
 IBM, 352, 597  
 KIM-1, 540–541, 548–549, 588–590, 592  
 Lisp Machine, 199, 367
- Conceptual dependency (CD), 432–433
- Concertgebouw, Amsterdam, 631
- Conductor program (Bell Laboratories), 523, 535
- Constraints, 435  
 Convolution, 632  
 Cornet, simulated, 3, 103–108.
- COTREE, 426–427
- Counterpoint, 691
- Critical band, 650
- Cross synthesis, 4, 143. *See also* Analysis/synthesis; Linear prediction
- Curtis synthesizer modules, 549
- Cymbal, granulated, 158
- DAC. *See* Digital-analog converter.
- DAG. *See* Directed acyclic graph
- Database, relational, 425
- DEC PDP-11 assembler 239, 536
- Decay, 685–686. *See also* Envelope
- Delay, entry, 445–446, 455
- Device driver, input/output, 366–367
- Dialectic* (Myhill), 583
- Digital-analog converter (DAC), 292 multiplying, 192, 200, 211–212, 222
- Digital audio. *See also* Computer music; Computer music studios; Hardware; Synthesizers recording, 515, 520 distortion in, 192
- Digital Equipment Corporation (DEC). *See* Computers; UNIX
- Digital Music Systems, 195, 201, 225–243, 367
- Directed acyclic graph (DAG), 495–499
- Discrete summation formulas, 3, 318, 642
- DMX-1000, 195, 201, 225–243, 367
- Drum, simulated, 26
- Duck, Donald, simulating voice of, 125
- E-mu, 194
- Earth's Magnetic Field* (Dodge), 692
- Eastty switching annex, 263
- ECL. *See* Emitter-coupled logic
- EGG synthesizer, 200
- Elco, 349, 362
- Electronic music, 1, 568–569, 571–573. *See also* Composition; Westdeutscher Rundfunk
- Ultra Spectra-Strip, 362
- Emitter-coupled logic (ECL), 202, 323, 355–364. *See also* Integrated circuits
- English horn, 649
- Envelope, 462–464, 472–477, 515–516, 526–529, 642–643, 655. *See also* Attack; Decay; Hardware amplitude, 115, 642. *See also* Music V amplitude scaling, no-multiply method,

- 50–52, 192  
frequency envelope, 533–534, 642  
line-segment approximation, 417, 426  
scaling, 200, 212, 261, 269, 271, 458, 469,  
474–479, 642–643, 655
- Envelope generators. *See* Envelope;  
Hardware
- ESQUISSE, 648
- Excel Products, 343, 361
- Fairchild, 347, 354, 358, 360
- Fairlight CMI, 199, 201
- Farey series, 79–81
- Fictional Travels in a Mythical Land*  
(Gold), 593
- Field* (Roads), 158
- File, register, 492
- Filters, analog, 312
- Filters, digital, 133–139. *See also*  
Reverberation; Reverberators  
all-pass, 605–607, 613  
fixed-point implementation in hardware,  
621  
one-pole, 509  
pole, 127, 134–135, 137  
transfer function, 136–137
- two-pole, 134–137
- two-zero, 138–139
- zero, 127, 139
- Fission, auditory, 650, 665, 670, 691
- Fission boundary, 665–666, 671–672
- Floating Point Systems, 350
- Flute, 43, 649
- FM. *See* Frequency modulation
- Foldover, 90
- Formant, 123, 125–126. *See also* Speech  
simulated, 27–28
- Forth, 549
- FORTRAN, 513
- 4CED Program, 277, 370
- Fourier transform, 145–146  
fast (FFT), 509, 632
- French horn, 649
- Frequency domain, 136
- Frequency modulation (FM), 2–3, 6–29,  
31, 33–43, 45–47, 68–72, 202, 459–460,  
516, 642, 667  
bandwidth, 10, 13–16, 17, 45, 73  
Bessel functions in, 7, 9–11, 15–17, 27,  
37, 55–56, 58, 65–67  
 $c:m$  ratio, 11, 13, 37, 68–82, 459  
chorus effect in, 64, 81  
carrier, 7  
cascade modulator, 58  
complex carrier, 47–50, 216
- complex modulator, 47–50, 54–59,  
65–67, 216, 307
- definition, 7–11
- deviation, 7, 21, 216
- double-carrier instrument, 27–28, 39–43
- double modulator, 54–59
- efficiency, 3
- fundamental of spectrum, 71–74, 79
- hardware implementation of, 52–53,  
214–217, 235–241, 266, 307–308,  
476–479
- index, 7, 13, 15–17, 20–22, 59, 62,  
237–238
- inharmonic spectra, 13, 15, 25, 69
- instrument definition, 18–22, 27–28,  
37–43
- microcomputer implementation, 52–53
- missing fundamental, 13, 69
- modulator, 7, 24, 59, 64
- Music V instruments for, 18–21, 27–28,  
496
- negative increment, 19, 296, 301
- no-multiply amplitude method for index,  
51–52
- normal form of  $c:m$  ratio, 79
- peak deviation, 7, 21, 216
- phase inversion in, 10–12, 56–58
- reflected sidebands, 11–12, 14–15, 42,  
57–58
- simulating articulation, 64
- simulating bassoon, 24
- simulating brass, 3, 21–23, 30–44
- simulating clarinet, 24
- simulating drum, 26
- simulating formants, 27–28
- simulating natural tones, 28–29
- simulating organ, 23
- simulating percussion, 24–27
- simulating piano, 59–61
- simulating strings, 62–64
- simulating woodwinds, 23–25
- sine, 47
- spectral harmonicity, 69
- spectrum produced by, 7–8, 10–14, 47,  
57–59, 68–69, 71, 74–82
- time-varying spectra, 6, 13, 15–17,  
23–25, 28, 36–38, 46
- triangle, 3, 47–51
- vibrato, 38, 62, 64
- zero-hertz wraparound, 42
- Frequency resolution, 193, 295–300, 332,  
333
- Fujitsu America, 361
- Functions, approximation of, 89
- Funktion Gelb* (Koenig), 568

- Funktion Grün* (Koenig), 568  
 Fundamental, missing, 679, 681–683, 685  
 Fusion, auditory, 676
- Gardner-Denver, 336, 362  
 Garry, 343, 361  
*Geisslerlieder*, 419  
*Gemisch*, 445  
 Grain, 150. *See also* Granular synthesis  
 Grammar, 403–442. *See also* Language; Rules  
     ambiguous, 428, 430  
     applied to music, 403–404, 408–409, 419–442  
     array, 417  
     attribute, 425  
     augmented-transition-network (ATN), 417–419  
     formal, 409  
     deep structure, 406, 424–425  
     generative, 410, 414  
     graph, 417  
     multidimensional, 416–417  
     pattern, 417  
     phrase-structure, 414  
     plex, 417  
     regulated, 416  
     shape, 417  
     space, 417  
     systemic, 414–415  
     transformational, 414, 417  
     tree, 417  
     Type 0 (free), 411–412  
     Type 1 (context-sensitive), 412, 429, 431  
     Type 2 (context-free), 411–413, 416, 446  
     Type 3 (finite-state), 411, 413
- Granular synthesis, 4, 145–159. *See also* Quanta  
 Graphemes, 409  
 GRM, 281, 288  
 GROOVE, 194, 200, 523  
 Grosser Musikvereinsaal, Vienna, 605, 631  
 GS Program. *See* Granular synthesis  
 GUIDO, 386
- Hardware, analog synthesis, 199, 539–540, 542, 549  
 Hardware, digital. *See also* Emitter-coupled logic; Integrated circuit; Miami Number Cruncher  
     arithmetic logic unit (ALU), 492  
     cooling of, 315  
     VLSI, 203
- Hardware, digital sound synthesis, xii. *See also* Amplitude; Envelope; Integrated circuits; Synthesizers  
 ADC, 263  
 additive synthesis, implementation of, 212  
 architecture, 194–196  
 block processing, 507–509  
 branching, 285, 321  
 commercial constraints on, 370  
 control information in host address space, 246, 250, 253, 275  
 DAC, 192, 200, 211–212, 222, 292  
 diagnostics, 193–194  
 direct sound synthesis by mainframe, 196, 369  
 direct sound synthesis with mini- and microcomputers, 196, 202–203  
 envelope generation, 237, 253–254, 269–271, 309, 315, 318, 469, 643  
 evaluating expressions, 488  
 evaluation of, 1, 196–197, 476  
 fixed-point arithmetic, 621  
 frequency modulation, 52–53, 214–217, 235–241, 266, 307–308, 476–479  
 frequency resolution, 295–300, 332–333  
 graphic interface, 563  
 horizontal bus architecture, 195, 319–323  
 horizontal microcode machine, 494  
 host computer, 234  
 increment, 292–293  
 instruction prefetch, 228  
 interconnection of units (“patching”), 247, 273, 275–276, 494, 529–534  
 interrupt handling, 52, 246, 254, 271–273, 276, 285, 370, 481, 484–485, 524, 528, 541, 549, 590  
 I/O bandwidth, 198–199  
 keyboard-controlled synthesizer, 2, 193–194, 203  
 memory addressing, 206, 266–267, 275–276, 286  
 microprogrammed, 195, 225, 228–230, 233–238, 241–242, 281, 283, 321–322, 491–511. *See also* Microcode, Microprogramming  
 mixed sample rates, 201–202, 209, 235, 253, 261, 277, 285, 508  
 modular, 195  
 multiplier, 231, 265–266, 303, 306–307, 314–315  
 multiprocessor networks, 196  
 non-real-time vs. real-time, 370–371  
 Orr ADC, 263  
 phase angle increment register length, 296–297  
 pipelined, 195–196, 230–231, 274, 277, 306, 312, 314–318, 493–494

- precision of, 242, 244, 250  
program update, 228  
real-time, 52, 250, 370–371, 524, 536  
reliability, 193  
sample and hold, 292  
sample period jitter, 295  
sample period subdivided, 228–229, 265, 273–275, 283, 321, 493  
sample rate, 200–201, 206, 209, 229, 283  
scaling functions, 200, 212, 261, 269, 271, 469, 474–476, 642–643, 655  
smoothing filter, 202, 292, 294–295, 312  
software access to low-level hardware, 370  
software simulation of, 372  
stream processing, 507–509  
time-multiplexed, 250, 304–306  
track or ground, 292, 309  
T. T. Electronics J77C smoothing filter, 312  
T. T. Electronics J87C smoothing filter, 312  
updating control parameters, 254, 370, 642  
user input, ix, 199–200, 244, 246–247, 257–260, 386, 485–489, 540, 544, 547, 647  
vertical microcode machine, 493  
VOSIM, implementation of, 212–215, 318  
vs. software, 200, 220  
wavetable lookup, 209–212, 250–251, 266–268, 290–293, 300–303, 326–334  
Hardware, hybrid synthesis, 199–200, 540–541. *See also* Synthesizers  
Harmonic, 289  
Heterodyne filter, 642  
Heuristic, 500  
Hybrid synthesis, 369. *See also* Hardware; Synthesizers  
ICMC, 540, 693. *See also* UNESCO  
Icon, 405  
ILC Data Device Corporation, 362  
Improvisation, 247  
Increment, 326  
Indian music, 540  
*I Never Knew You Cared* (Berg), 173–179  
Information content, acoustical, 147–148  
Information unit, acoustical, 146  
Instantiation, 456  
Institute of Sonology (Utrecht). *See* Computer music studios  
Integrated circuits (ICs), 230, 277, 281, 285, 302, 306, 307, 312, 314–317, 319, 338, 340, 342, 347–349, 351, 352, 354–357, 541, 549, 594  
Interdyne, 343, 346, 361  
International Computer Music Conference, 540, 568, 693  
*Internationale*, 172  
Interpreter, 517  
INV, 367, 512–522  
IRCAM. *See* Computer music studios  
Jazz, 427, 435  
Keyboard, piano-style, 387–388, 392, 484–485  
mapping between keys and events, 199  
touch-sensitive, 257–259  
KEYS, 467  
*Klangfarbenmelodie*, 603  
Kleffman Electronics, 342, 345–346  
Knowledge, representation of, 553  
*Kontakte* (Stockhausen), 568  
Koto, 582  
KYST, 645, 648–649  
Language, formal, 409. *See also* Grammar as model for music, 404–405  
phrase-structured, 413  
Language, natural, 403, 409, 432  
Language, programming, 366, 371. *See also* BASIC; C; DEC PDP-11 assembler; Forth; FORTRAN; Lisp; Macro-15; 6502  
machine language  
League of Automatic Music Composers, 600  
Linear prediction, 4, 140, 143. *See also* Analysis/synthesis  
Linear response, 85  
Line-segment approximation, 417, 426  
Linguistics, and music, 404–405. *See also* Grammar; Language  
Lisp, 418, 426  
Location, sound spatial, 539, 660–662, 669.  
*See also* Reverberation  
*Locks and Dams* (Berg), 168, 172  
Logic, emitter-coupled. *See* Emitter-coupled logic  
Logic, formal, 428  
Loop, phase-locked, 540  
*Love Songs* (Truax), 81, 82  
Lucasfilm, 195, 202. *See also* Synthesizers  
ludwig, 377, 379–384, 397–398, 400  
McGill University, 694  
Macro, 366  
Macro-15, 161, 173

- Macrostructure, phantom, 412  
*Maentwrog, Music for Soleil* (Cann), 116, 124, 129  
 Markov chain, 413  
 Masking, 674–675  
 Melody, perception of, 664, 667–668, 677–678, 689, 691–692  
 Memory, human, 551–567  
 Menu. *See* Software  
 Message, 371  
 Mevent, 452–456  
 Miami Number Cruncher, 337–338, 355  
 Michigan State University, 644  
 Microcode, 233–234, 319, 367, 372, 491–511. *See also* Hardware  
 Microcomputers, 281–288, 369. *See also* Hardware  
     composing with, 196, 597–600  
     in direct synthesis, 196, 202–203  
     implementation of FM, 52–53  
     S-100 bus, 202  
 Microprogramming, 491–494, 497  
     branch and bound, 505–507  
     critical-path scheduling, 501–502  
     critical resource counting, 500–502  
     enumeration, 502–504  
     reduce and conquer, 502  
     stepwise refinement, 502  
     verticalizing, 493  
 MIT. *See* Computer music studios  
 Motorola, 354–356, 358, 360  
 Mozart, W. A., piano sonatas, 427  
 Mupac, 343, 345, 361  
 Mus10, 31–33, 376, 480–482  
     LINEN, 33–34, 36  
     MAG, 33  
     OUTA, 33  
     RANDI, 33–34  
     unit generator in, 32  
     ZOSCIL, 33–34, 36  
 Music 11, 154  
 Music 1000, 238–241, 370. *See also* DMX-1000  
 Music 4BF, 114, 134  
 Music IV, 370  
 Music V, 17–21, 27–28, 37, 134, 149, 151–153, 194, 336, 369–370, 376, 404, 447, 457, 480, 482, 495, 496, 581  
 Musique concrète, 2  
 MUZACS, 199  
 National Advanced Systems, 336  
 National Semiconductor, 361  
 NEC America, 360  
 Necker cube, 661  
 Nekyia (Loy), 663  
 Networks  
     basic transition (BTN), 417–418  
     constraint, 435  
     semantic, 425  
*Network Piece* (Bischoff, Gold, Horton), 588–600  
 Networks Orchestra, 547  
 New England Digital, 201, 206, 209, 212, 536–537, 641  
 NIHR, 97–98. *See also* Waveshaping  
 Noise, 1/f, 544. *See also* Composition, stochastic  
 Nonlinear distortion. *See* Waveshaping  
 Nonlinear interharmonic relationship (NIHR), 97–98. *See also* Waveshaping  
 Nonlinear processing. *See* Waveshaping  
 Non-real-time systems, 369  
 Nonstandard synthesis, 4, 160–187, 201, 369, 572–573  
 Nonterminals, 409  
 Note, musical (sound object), 542, 547, 604  
 NP-completeness, 504  
*nscor* (Roads), 158  
 Nyquist theorem, 293–294  
 Object, 443, 448, 450, 457–462  
 Object-oriented language, 371  
*Objet* (Roads), 158  
 Oboe, 649  
 Occlusion  
     auditory, 676  
     visual, 672–674  
 OK Machine and Tool Corporation, 336, 362  
 Operating system, 367  
 Orchestra, talking, 4. *See also* Cross synthesis  
 Orchestration, 414, 443, 456–457  
 Organ, simulated with frequency modulation, 23  
 Oscillator. *See* Hardware; Music V  
 Overtones, 289  
 Parse tree, 406–407, 409, 436, 495  
 Partial, 289  
 Patch, 540  
 Pattern recognition, 417, 426, 445  
 Pattern, sound, 445  
 Perception  
     auditors, 146–147, 296  
     musical, 658, 666, 689–691  
 Perceptual dissimilarity judgment, 644–645  
 Percussion instruments, 646–647. *See also* names of instruments simulated, 24–27

- Performance, live, ix–x, 539, 547  
Performer, musical, 658  
Petri net, 510–511  
Phase vocoder, 642  
Philharmonic Hall (old), New York, 631–632  
*Phōnē* (Chowning), 3  
Phonology, 404  
Phrase, musical, 547  
Piano, 59–61, 115, 571. *See also* Keyboard simulated, 59–61  
*Piano Music* (Cann), 115  
Piano-roll notation, 379  
PILE, 160–187  
Pipeline. *See* Hardware  
PLACOMP 386–387, 390  
PLAY, 368, 523–537  
PLAY1, 523–537  
PLAY2, 536–537  
Plessey, 354, 356, 360  
POD, 444  
POD6, 70, 74  
Poisson distribution, 584–585  
Pole, 127, 134–135, 137. *See also* Filter  
Polyphony, 691  
Procedural model of music, 433, 552, 564  
PROJECT 1, 569–572  
PROJECT 2, 569–572  
*prototype* (Roads), 157–158  
Pseudo-Tape, 200  
  
Quanta, acoustical, 145–149. *See also* Granular synthesis  
Quantization, frequency, 193  
  
Racal-Milgo, 335, 337, 352  
Random number generator. *See* Composition, stochastic  
Real-time systems, 369  
Register, 492  
Residual, 127, 130–132, 140–141, 143. *See also* Analysis/synthesis  
Resolution, frequency, 193  
Reverberation, 613–614, 616–619, 622–632, 634, 636. *See also* Acoustics digital, 603–639  
Reverberators, digital. *See also* Filters; Reverberation  
all-all-pass, 607, 611–612  
all-pass, 603  
all-pass with filter, 610, 613–615, 620  
comb-all-pass, 607, 611–612, 619–621, 630  
comb with filter, 610, 613–616, 619  
oscillatory all-pass, 608–609, 611–612  
oscillatory comb, 608–609, 611–612  
series-all-pass, 607, 611–612  
Rhetoric, 403  
Rotron, 315  
Rules. *See also* Grammar  
morphophonetic, 414  
production, 410  
rewrite, 410  
self-embedding, 413  
transformation, 414  
  
SAE. *See* Stanford Applied Engineering  
Sal-Mar Construction, 194, 199, 523  
Sampling theorem, 293–294  
Samson box, 195, 641, 643  
Saxophone, 431, 649  
granulated, 158  
Scaling multidimensional, 645–647  
simultaneous linear equation, 654  
scd, 377, 393–395, 399  
Schmitt trigger, 349  
scored, 377, 384–386  
Score, hierarchical representation of, 444–445  
SCORE program (CCRMA), 37, 386, 427  
score program (SSSP), 443–445, 452–457  
scriva, 377, 395–397, 399  
Segregation, auditory stream, 650, 665, 670, 691  
Semantics, musical, 407, 415, 423, 434–435, 555, 558–561, 564–566  
Semiotics, 403, 405–406  
Semistochastic Music Language (SSML), 581  
Semitone, equal-tempered, 297  
Sentence, 409  
Sequencer, 199–200, 540  
Siemens, 361  
Sign, 405  
Signal processing, digital, 192. *See also* Filter; Fourier transform; Reverberation; Reverberator  
Signetics, 358, 360  
Sine waveform, 289–290, 301, 333–334  
Sinusoid, 2, 289  
*Six Dark Questions* (Morrill), 3  
6502 machine language, 540  
SKETCHPAD, 447  
Snare drum, granulated 158  
Software, computer music xii, 376–402, 443–466, 512–538. *See also* names of programs and languages  
complexity, 373  
directory window, 380, 384  
grammar-based, 368

- Software (cont.)**
- graphic input, 537
  - hierarchical data structure to represent music, 368
  - menu-driven, 199, 380–383, 385–386, 389, 392–393
  - orchestration, 384
  - parallel processes model, 372
  - piano-roll notation, 379
  - process-model based, 368
  - scope, 393, 395, 397–398
  - score-editing, 376–402
  - score format, 480–485
  - use of high-level languages in, 371
  - user interface, 368–369, 372, 376–380, 384, 387, 390–391, 397
- Software, sound synthesis, 467–511.** *See also* Hardware; Microcode; Microprogramming
- access to low-level hardware, 274
  - combined with real-time inputs, 484
  - expression evaluation, 370
  - incorporating real-time control information, 370
  - instrument definition, 238, 483
  - interconnection, 486
  - I-time code, 238
  - note list, 30, 483
  - orchestra, 238
  - structured programming in note list, 485
  - unit generator, defined, 370
  - vs. hardware synthesis, 200
- Sone, 644
- S-100 bus, 202
- Sonic Landscape No. 4* (Truax), 81
- Sonology, 421
- Sound synthesis.** *See also* Hardware; Software
- analog, 577–578
  - circumventing multiplication in, 192
  - digital, 577–578
  - hardware vs. software, 200
  - hybrid, 194, 577
  - of natural sound, 1, 6, 27, 28, 30
  - off-line, 194
  - on mainframes, 191–192
  - real-time, 160
  - subtractive, 4
- Spectra-Strip, 349
- Spectrum evolution matching, 95–98.** *See also* Waveshaping
- Spectrum, sound, 2.** *See also* Timbre
- analysis of, 2, 136. *See also* Fourier transform
  - center of gravity, 650, 682
- envelope of, 123–124, 126, 645–646, 649, 655, 676
- related to tuning system, 193
- time-varying, 6, 426, 642–643, 651
- Speech, 116–124**
- formant, 123, 125–126
  - mixed voiced, 119
  - noise driving function, 121
  - pulse train driving function, 121–122
  - synthesis of, 3, 125–133, 571, 604
  - unvoiced, 119, 121
  - vocal tract; 116–124
  - voiced, 119, 121
  - vowels, 119–120
  - whispering, 118
  - whistling, 118
- Sprechstimme*, synthesis of, 114
- SSML, 581
- SSP, 573
- SSSP.** *See* Computer music studios
- Stanford Applied Engineering (SAE), 361
- Stochastic Music Language (SML), 581
- Stria* (Chowning), 193
- Streaming, auditory, 659–664**
- coherence, 660, 665, 668–669, 691–692
  - continuity effect, 671–672, 674–675
  - frequency and tempo effects, 662, 667–669
  - loudness effects, 670–676
  - pulsation threshold, 672, 675–676
  - roll effect, 671–672
  - timbre effects, 676–689
- String, 409
- String instruments, simulated 62–64.** *See also* names of instruments
- String Quartet No. 4* (Bartók), 446
- Studie II* (Stockhausen), 156
- Studies for Trumpet & Computer* (Morrill), 31
- Summation formulas, 3, 318, 642
- sview, 400
- Symbol, 406**
- Symbol table, 495**
- Symphony Hall, Boston, 614, 631
- Synclavier, 201, 206, 209, 212, 536–537, 641
- SYN4B, 449, 467–490
- Syntax, musical, 406–407, 423, 431, 558–561, 564–566, 650**
- Synthesis.** *See* Sound synthesis
- Synthesis by instruction, 4, 160–187, 201, 369, 572–573**
- Synthesis technique (digital), xii, 1, 161.** *See also* names of techniques
- Synthesizers.** *See also* Hardware; Keyboard

- Asp (Lucasfilm), 202, 372  
Black Box, 539–550  
Bell Laboratories, 244–249, 257–260, 641, 643  
Buchla, 523  
DMX-1000, 195, 201, 225–243, 367  
EGG, 200  
E-mu, 194  
Fairlight CMI, 199, 201  
FRMBox, 195, 319  
GROOVE, 194, 200, 523  
Hybrid IV, 199  
IRCAM 4A, 197  
IRCAM 4B, 200–201, 250–256, 261, 370, 467–469, 471–480. *See also* SYN4B  
IRCAM 4C, 195, 200–201, 261–280, 489  
*See also* 4CED  
IRCAM 4U, 195  
IRCAM 4X, 195  
Sal-Mar, 194, 199, 523  
Samson box, 195, 641, 643  
SSSP, 192, 195, 197, 199–200, 206–225  
Synclavier, 201, 206, 209, 212, 536–537, 641  
SYTER, 281–288  
System, formal, 414  
System utility, 367  
Terminal, 409  
*Terminus* (Koenig), 568  
Terrain Reader, 592–593  
Thevenin network, 340  
3M cable, 349, 362  
Timbre, ix, 6, 31, 448, 555, 603–604, 640–658, 676–689. *See also* Spectrum analogy, 651–654  
electronic-sounding, 6, 43, 46  
interpolation of, 143, 647, 651–655  
subjective scale for, 644–645  
use in composition, 443, 685  
use in orchestration, 384, 397  
Time domain, 136  
Time, perception of. *See also* Perception audio, 554, 566  
conscious, 554, 556  
interpretive, 554–556  
Token, 406, 409. *See also* Grammar  
Tom-tom, granulated, 158  
Transfer function. *See* Filter  
TREE, 426–427  
Tri function, 47  
Trombone, simulated, 100–102  
Trumpet, 30–32, 649  
formants in, 37  
simulated with frequency modulation, 3 time-varying frequency, 38  
time-varying spectrum, 42–43  
variations in spectrum, 37, 39, 42, 43  
vibrato, 38  
T. T. Electronics, 312  
Tuba, simulated, 43  
Tuning system  
microtonal, 547  
non-tempered, 193  
related to spectrum, 193  
tempered, 193  
*Turenas* (Chowning), 3  
*Two-part Inventions* (Bach), 379, 381–383, 394, 396, 398  
*Übung für Klavier* (Koenig), 568  
UNESCO Workshop on Computer Music, 568  
Unit generator, 17–18. *See also* Music V  
Universals, in music, 423  
UNIX, 377, 395, 513, 515  
Venda music, 408  
Vibrato, 193, 277. *See also* Frequency modulation; Trumpet  
Vocabulary, 409  
VOSACS, 571  
VOSIM, 460–461, 570–571  
hardware implementation, 209, 212–215, 318  
Waveshaping, 3, 83–94, 95–113, 461–462, 642  
amplitude normalization, 92  
analog implementation, 83  
Chebychev polynomials, 90–91  
controlling phase, 92  
definition, 84–85, 95–96  
formants, 93  
hardware implementation, 219–221, 318  
modulation product, 85  
nonlinear interharmonic relationship (NIHR), 97–98  
shaping function, 85–91  
simulating brass instruments, 3, 95–113  
simulating clarinet, 83  
spectrum produced by, 89, 91–93, 96  
time-varying spectrum, 89, 91–92  
transfer function, 85–91  
with filter, 95–113. *See also* Spectrum evolution matching  
Wavetable lookup synthesis, 1–2, 191–192, 201, 206, 326–334, 464, 497, 516, 549–460  
addressing schemes (truncate, interpolate), 300–302

- Wavetable lookup synthesis (*cont.*)  
increment, 326  
interpolation, 319, 328, 330–333  
noise, 192  
phase angle width, 301–302  
phase jitter, 327  
quarter-wave symmetry of sine, 301,  
  333–334  
rounding, 328, 330  
table size, 328–333  
truncation, 326, 329–330
- Webern triad, 582
- Well-Tempered Clavier* (Bach), 427, 678
- Westdeutscher Rundfunk, 568–569
- Wild Horse Ride* (Pousseur), 582
- Woodwind instruments, 23. *See also names  
of instruments*  
simulated, 23–25
- Word, 409
- Worman's Law, 102
- XPL, 536
- Zero, 127, 139. *See also Filters, digital*
- Zero-hertz wraparound, 42. *See also  
Frequency modulation*
- Z transform, 136