

# APPENDIX

## BIBLIOGRAPHY

The references listed here have appeared in the form of books, manuals, brochures, and articles in technical publications. Individual items have been selected because of their general or specific interest, or because they "fan out" through additional references not included here.

The list is representative rather than comprehensive and is heavily weighted in favor of recently-published material ('70's). In most cases, the practical has been preferred to the theoretical. Within each subject grouping, the titles are listed alphabetically.

The interested reader should, in any event, seek to obtain catalogs and application notes (often voluminous) from manufacturers of the nonlinear devices of interest. Lists of current manufacturers, their products, and their addresses, will be found in such industry guides as *EEM* and the *Electronics Buyer's Guide*. Since the technology is rapidly expanding (and changing), one should also seek to be placed on manufacturers' mailing lists, and to subscribe to at least one of the major semimonthly electronics industry technical periodicals to keep up with new products, new techniques, and new literature.

Readers of this book are invited to subscribe to *Analog Dialogue*, which appears (approximately) quarterly, and is available at no charge from Analog Devices, Inc. Other publications available are the most recent edition of the *Analog Devices Product Guide*, data sheets on individual products, and occasional "Application Notes" on topics of interest.

Copies of certain publications mentioned in this Bibliography, designated by an asterisk (\*), are also available upon request (free, except for the *A-D Conversion Handbook*) as of the time this book has gone to press. They will be available as long as the supply lasts. Except for these items, *no other publications mentioned here are available from Analog Devices.*

## LINEAR AND NONLINEAR CIRCUITS, GENERAL INFORMATION

\**Analog-Digital Conversion Handbook*, Edited by D. Sheingold, Analog Devices, Inc., Norwood, Mass., 1972, \$3.95.

*Applications Manual for Operational Amplifiers*, Philbrick-Nexus Research, Dedham, Mass., 1965.

"Designer's Guide: Nonlinear Function Modules," T. Cate and others, *EEE*, September 1969.

*Linear Applications*, National Semiconductor, Santa Clara, California, February, 1973.

*Modern Operational Circuit Design*, J. I. Smith, Wiley-Interscience, New York, 1971.

*Operational Amplifiers*, G. Clayton, Butterworth & Co. (Publishers), Ltd., London, U.K., 1971.

*Operational Amplifiers, Design and Applications*, G. Tobey, J. Graeme, L. Huelsman, McGraw-Hill Book Co., New York, 1971.

*A Palimpsest on the Electronic Analog Art*, H. Paynter, George A. Philbrick Researches, Inc., 1955, *Out of Print*.

*\*Product Guide*, Analog Devices, Inc., Annual.

"Some Aspects of the Theory of Nonlinear Networks," A. Wilson, *Proceedings of the IEEE*, 61-8, August 1973.

## FUNCTION FITTING

"Approximate Analog Functions with a Low-Cost Multiplier-Divider," D. Sheingold, *EDN*, February 5, 1973.

"Design of Nonlinear Networks with a Prescribed Small-Signal Behavior," B. Peikari, *IEEE Transactions on Circuit Theory*, CT-19-4, July 1972.

"Feedback Linearizes Resistance Bridge," R. Guyton, *Electronics*, October 23, 1972.

*Fitting Equations to Data*, C. Daniel, F. Wood, J. Gorman, Wiley-Interscience, New York, 1971.

"Get Perfect (*sic*) Linearity in CRT's," A. Popodi, *Electronic Design*, 1, January 4, 1973.

"Linearize Analog Signals Continuously," M. Weiner, D. Schneider, *Electronic Design*, 24, November 23, 1972.

"Trig. Function Generators (Applications Brief), National Semiconductor, MOS Brief 10, 1970.

## TIME-FUNCTION GENERATION

"Adjustable Sinewave Audio Oscillator Employs Improved AGC for Wide Frequency Range," C. Schwerdt, *Electronic Design*, 4, February 15, 1973.

"Analog-to-Pulse-Width Converter Yields 0.1% Accuracy," N. Robin, *EDN*, November 1, 1970.

"The Basics of Using FET's for Analog Signal Switching," A. Evans, *EDN*, May 20, 1973.

"Current-Controlled Triangular/Square-Wave Generator," S. Franco, *EDN*, September 5, 1973.

\*Data Sheets, Models 350, AD351 Comparators, Analog Devices.

\*"Digital Sweep Generator," R. Craven, *Analog Dialogue*, 5-4, 1971.

"Function Generators, a Family of Versatile Wave Makers," L. Hunter, *Electronic Products*, November 19, 1972.

"Generate Low-Distortion Sine Waves," J. Vanderkooy, C. Koch, *Electronic Design*, 14, July 5, 1973.

"MOS Analog Function Generator," J. Kubinec, National Semiconductor, MOS Brief 3, 1968.

"Precise Tri-Wave Generator," R. Dobkin, *Electronic Engineering Times*, 1973.

"Triangle-Wave Generator Keeps Slopes Constant as Amplitude Changes," D. Larsen, *Electronic Design*, 20, September 28, 1972.

"Triangular and Square-Wave Generator has Wide Range," R. Burwen, *EDN*, December 1, 1972.

"Using IC's to Generate Waveforms," A. Grebene, *Electronic Products*, March 20, 1972.

"Wide-Range Ramp Generator has Programmable Outputs," C. Wojslaw, W. Buschmann, *EDN*, October 15, 1972.

"Zener Diode" Controls Wien-Bridge Oscillator," W. Crittenden, E. Owings, *EDN*, August 1, 1972.

## INSTRUMENTATION AND MEASUREMENT

"The dB-Anything," K. Simons, *Proceedings of the IEEE* (Letters), 61-4, April 1973, pp. 495-496.

"Don't Eyeball Noise," G. Franklin, T. Hatley, *Electronic Design*, 24, November 22, 1973.

"An Electronic Wattmeter for Non-Sinusoidal Low Power Factor Measurements," D. Hamburg, L. Unnewehr, *IEEE Transactions on Magnetics*, September 1971.

"High-Performance Flame Ionization System for Gas Chromatography," D. Smith, *Hewlett-Packard Journal*, March 1973.

"Integrate and Hold Circuit Gives Electrochemical Measurements," R. Warsinski, *Electronic Design*, 1, January 4, 1973.

"JFET Circuit Linearizes Transducer Output," F. Trofimenkoff, R. Smallwood, *IEEE Transactions on Instrumentation and Measurement*, IM-22-2, January 1973.

"Linearizing Thermocouple Amplifiers," L. Garelick, E. Hauptmann, *Advances in Instrumentation (ISA)*, Volume 26, Part 4, Paper 852.

"Logarithmic Quantities and Units," C. Page, *Proceedings of the IEEE (Letters)*, 61-10, October 1973, pp. 1516-1518, in re "dB".

"Logarithmic Readout Attachment for Double-Beam Spectrometers," J. Shepherd, H. Hedgpeth, *Review of Scientific Instruments*, 44-3, March 1973.

"Low-Current Ammeter," R. Dobkin, *Electronic Engineering Times*, 1973.

\*"Measuring Airflow Using a Self-Balancing Bridge," J. Miyara, *Analog Dialogue*, 5-1, 1971.

\*"Measuring Sine-Wave Amplitudes Without Filtering," D. Jolley, *Analog Dialogue*, 5-2, Spring 1971.

"Narrow Peaks Caught by Better Detector," R. Klatt, *EDN/EEE*, August 15, 1971.

*Omega Temperature Measurement Handbook*, Omega Engineering, Inc., Stamford, Conn., 1973.

"Referencing Thermocouple Junctions," B. Hollander, *Instruments and Control Systems*, March 1973.

"RMS Voltage Measurements—Which Method Works Best?" R. Chapel, *Electronic Products*, January 15, 1973.

"Some Effects of Waveform on VTVM Readings," B. Oliver, *Hewlett-Packard Journal*, 6-8, April 1955, continued in 6-9, May 1955, and 6-10, June 1955.

\*"True-RMS Measurement," L. Counts, *Analog Dialogue*, 7-1, 1973.

"A Wideband Wattmeter for the Measurement and Analysis of Power Dissipation in Semiconductor Switching Devices," F. Schwarz, N. Voulgaris, *IEEE Transactions on Electron Devices*, ED-17-9, September 1970.

## SIGNAL PROCESSING

\*"Adjustable Low-Pass Filter," R. Burwen, *Analog Dialogue*, 4-2, December, 1970.

"Analog Multipliers Offer Solutions to Video Modulation Problems," G. Shapiro, *EDN*, September 1, 1972.

"Applications of a Monolithic Analog Multiplier," A. Bilotti, *IEEE Journal of Solid State Circuits*, SC-3-4, December 1968.

- "A Comparison of Analog and Digital Techniques for Pattern Recognition," K. Preston, *Proceedings of the IEEE*, 60-10, October 1972.
- "Demodulate DPSK Signals Coherently Using a Costas Phase-Lock Loop," R. Hennick, *EDN*, July 1, 1972.
- "Design of a Noise-Eliminator System," R. Burwen, Audio Engineering Society Preprint 838(B-8), 1971.
- "Design Your Own Dynamic Phase Shifter," G. Strauss, *Electronic Design*, 12, June 8, 1972.
- "Dual Comparator and R-C Filter Estimate Probability Density Function," J. Sparacio, R. Pierro, *Electronic Design*, 4, February 15, 1973.
- Electronic Music Synthesizers: Product Information Sheets and Users' Manuals, ARP Instruments, Inc., Newton Highlands, Mass.
- "Fast Amplitude Control of a Harmonic Oscillator," D. Meyer-Ebrecht, *Proceedings of the IEEE*, 60-6, June 1972.
- "FET's in R-C Network Tune Active Filter," A. Delagrange, *Electronics*, December 7, 1970.
- \*"Frequency Modulator," R. Burwen, *Analog Dialogue*, 5-5, 1971.
- "A General Analysis of the Phase-Locked Loop," J. Connelly, Harris Semiconductor Application Note 602/A, October 1972.
- "Generate Noise-Free Timing Pulses with an IC Peak Sampler," G. Oshiro, *Electronic Design*, 10, May 11, 1972.
- "Introduction to the Phase-Locked Loop," D. Jones, Harris Semiconductor Application Note 601, October 1972.
- "Making Systems Fail-Operational by Using Multiple Channels with Automatic Voters to Select the Best Signal," P. Rostek, *Electronic Design*, 17, August 16, 1969.
- "A Method of Measuring the Peak Value of a Narrow Impulse by the Use of a Voltage-Forced Pulse-Lengthener Circuit," M. Uno, *IEEE Transactions on Instrumentation and Measurement*, IM-22-2, June 1973.
- "Modems," J. Davey, *Proceedings of the IEEE*, 60-11, November 1972.
- "A New Generation of Integrated Avionic Synthesizers," R. Brubaker, G. Nash, Motorola Semiconductor Application Note, AN553, 1971.
- "Op Amps Replace Transformer in Phase-Detector Circuit," A. Gangi, *Electronics*, May 12, 1969.
- "Phase-Locked Loop Helps Generate Waveforms with Variable Duty Cycle and Phase Shift," N. Calvin, *Electronic Design*, 19, September 13, 1973.

- "Phase-Locked Loop IC's are Ready and Stable," A. Grebene, *Electronic Products*, February 19, 1973.
- "Programmable Active Filters," R. Sparkes, A. Sedra, *IEEE Journal of Solid-State Circuits*, Correspondence, February 1973.
- "Separate the Signals from the Noise with . . . Voltage Correlator Circuit," T. Cate, *Electronic Design*, 25, December 6, 1970.
- "Signal Recovery Using a Phase-Sensitive Detector," P. Danby, *Electronic Engineering* (U.K.), January 1970.
- "Simple Linear PLL Demodulator Uses Discrete Components," T. Mollinga, *EDN/EEE*, April 15, 1972.
- "60Hz Frequency Discriminator," R. Burwen, *EEE*, February 1971.
- "A Synchronized Phase-Lock Loop," R. Bohlken, *EDN*, March 20, 1973.
- "Systems Applications for Voltage-Controlled Active Filters," P. Harvey, *EEE*, October 1969.
- "Take the Guesswork Out of Phase-Locked Loop Design," D. Kesner, *EDN*, January 5, 1973.
- \*"30dB Automatic Gain Control," L. Counts, *Analog Dialogue*, 7-1, 1973 (and erratum, 7-2, 1973).
- "Try the Monolithic Multiplier as a Versatile AC Design Tool," E. Renschler, D. Weiss, *Electronics*, June 8, 1970.
- "Use This Tan-Lock Demodulator," R. Hennick, *Electronic Design*, 25, December 6, 1970.
- "Voltage-Controlled Phase Shift of Triangular Waves," K. Kuijk, H. Hagenbeuk, *IEEE Transactions on Instrumentation and Measurement*, IM-22-2, June 1973.

## COMPUTING AND CONTROL

- "Analog Arithmetic Unit Offers Good Accuracy," C. Wojslaw, *EDN*, July 1, 1972.
- "Analog Modules Multiply User's Options," G. Tobey, *Electronic Products*, February 19, 1973.
- "Analyzing Low-Frequency Random Phenomena with an Analog Computer," P. Kommineni, G. Smith, *Instruments & Control Systems*, April 1973.
- "Analyzing Signals for Information," I. Langenthal, *Instruments and Control Systems*, December 1970, and January 1971

"Applications for Trigonometric Computing Modules," N. Sussman, *EEE*, September 1969.

"Automatic Brightness Control and Linearity Correction Circuits for Large-Screen Color Oscilloscopes," I. Lamoth, *IEEE Transactions on Instrumentation and Measurement*, IM-22-2, June 1973.

"A Computer for the Calibration of Skeletal Muscle Vascular Resistance," R. Zambuto, R. Reder, C. Sanders, W. Powell, *IEEE Transactions on Bio-medical Engineering*, BME-19-6, November 1972.

"Detection and Measurement of Three-Phase Power, Reactive Power, and Power Factor, with Minimum Time Delay," I. R. Smith, L. A. Snider, *Proceedings of the IEEE*, Letters, November 1970.

"Distortion Correction in Precision Cathode-Ray Tube Display Systems," Intronics, Inc., 1970.

*Electronic Analog and Hybrid Computers*, G. Korn, T. Korn, McGraw-Hill Book Co., New York, 1964.

"IC Op Amps Straighten Out CRT Graphic Displays," J. Divilbiss, S. Franco, *Electronics*, January 4, 1971.

"Linearize Your CRT Displays," K. Peterson, *Electronic Design*, 17, August 16, 1970.

"Low-Cost, Logarithmic Mass Flow Computer," NASA Tech Brief 71-10407, Lewis Research Center, Cleveland, Ohio, November 1971, J. Watson, D. Noga, J. Dolce, J. Gaby, digested in *Instrumentation Technology*, August 1972.

\*"Measuring Sine Wave Amplitudes Without Filtering," D. Jolley, *Analog Dialogue*, 5-2, 1971.

"Phase-Locked Loops for Motor Speed Control," A. Moore, *IEEE Spectrum*, April 1973.

"Phase-Locked Loops Provide Accurate Efficient dc Motor Speed Control," L. Milligan, E. Carnicelli, *EDN*, August 1, 1972.

"Real-Time Signal Analysis," R. Rothchild, *Medical Electronics and Data*, March-April 1971.

"Relaxation Time Measurements by an Electronic Method," R. Brousseau, J. Vanier, *IEEE Transactions on Instrumentation and Measurement*, IM-22-1, March 1973.

"Resistance Network Converts Limit Detector to Movable Window Operation," B. Pearl, *Electronic Design*, 6, March 15, 1973.

"Special Report on Signal Averagers," G. Flynn, *Electronic Products*, February 1969.

"Using Analog Function Modules for Measurement and Control," J. Huffman, T. Gibson, S. Rose, *Instruments and Control Systems*, December 1972.

"Variable Sweep-Rate Frequency Response and Vibration Testing," C. Lorenzo, *Instruments and Control Systems*, September 1971.

\*"Vector Difference Circuit," L. Counts, *Analog Dialogue*, 7-1, 1973.

## LOG, LOG RATIO, AND ANTILOG CIRCUITS

"Bipolar Operation of Paired Log Transistors," D. Sheingold, *Proceedings of the IEEE* (Letters), Vol. 58, pp. 1855-56, November 1970.

"A Circuit with Logarithmic Transfer Response over 9 Decades," J. Gibbons, H. Horn, *IEEE Transactions of the Circuit Theory Group*, CT-11-3 September 1964.

\*"Design of Temperature-Compensated Log Circuits Employing Transistors and Operational Amplifiers," W. Borlase, E. David, Analog Devices' Application Note, September 1969.

"Get Wider Dynamic Range in a Log Amp," G. Niu, *Electronic Design*, 4, February 15, 1973.

"How to Specify Parameters of Nonlinear Circuits," G. Osgood, J. Knitter, *EEE*, September 1969.

"Large-Signal Behavior of Junction Transistors," I. Ebers, J. Moll, *Proceedings of the IRE*, December 1954, pp. 1761-1772.

"Logarithmic Analog-to-Digital Converters: A Survey," S. Cantarano, G. Pallotino, *IEEE Transactions on Instrumentation and Measurement*, IM-22-3, September 1973.

"Logarithmic and Exponential Amplifiers," D. Spicer, R. Mann, Texas Instruments Application Report, Bulletin CA-149, March 1970.

"A Logarithmic Transcoder," D. Degryse, B. Guerin, *IEEE Transactions on Computers*, C-21-11, November 1972.

"Multiplication and Logarithmic Conversion by Operational Amplifier-Transistor Circuits," W. Paterson, *Review of Scientific Instruments*, 34-12, December 1963.

"Transient Response of an Operational Amplifier with Logarithmic Feedback," H. Musal, *Proceedings of the IEEE* (Letters), Volume 57, pp. 206-208, February 1969.



## MULTIPLIERS AND DIVIDERS

\*"AD555 Monolithic Quad Switches Make 4-Quadrant Multiplying DAC's with 12-Bit Linearity," H. Krabbe, A. Molinari, *Analog Dialogue*, 5-2, 1971.

"Analog Multiplication at High Frequencies with a High Dynamic Range," G. Papadopoulos, *IEEE Journal of Solid-State Circuits*, SC-8-6, December 1973.

"Analog Multiplier Applications," J. Pepper, *Instruments and Control Systems*, June 1972.

"Characteristics and Applications of Modular Analog Multipliers," E. Zuch, *Electronic Instrumentation Digest*, April 1969.

\*"A Complete Monolithic Multiplier-Divider on a Single Chip," R. Burwen, *Analog Dialogue*, 5-1, 1971.

"Distortion in Bipolar Transistor Variable-Gain Amplifiers," W. Sansen, R. Meyer, *IEEE Journal of Solid-State Circuits*, SC-8-4, August 1973.

"Don't be Fooled by Multiplier Specs," R. Stata, *Electronic Design*, 6, March 15, 1971.

"Electronic Multiplier-Divider Uses One or 2 IC's," Z. Peled, *Electronic Design*, 21, October 10, 1968.

"An Electronic Multiplier for Accurate Power Measurement," M. Tomota, T. Sugiyama, K. Yamaguchi, *IEEE Transactions on Instrumentation and Measurement*, IM-17-4, December 1968.

"An Error-Stabilized Analog Divider," G. Fitton, *EEE*, February 1971.

"Evaluating and Using Multiplier Circuit Modules for Signal Manipulation and Function Generation," Analog Devices' Applications Brochure, 1970, *Out of Print*.

"Feedback Stabilized 4-Quadrant Analog Multiplier," H. Brüggemann, *IEEE Journal of Solid-State Circuits*, SC-5-4, August 1970.

"FET Conductance Multipliers," F. Crawford, W. Adams, *Instruments and Control Systems*, September 1970.

"In IC Form, Hall-Effect Devices Can Take on Many New Applications," M. Oppenheimer, *Electronics*, August 2, 1971.

"Linearizing Almost Anything With Multipliers," R. Burwen, *Electronic Design*, 8, April 15, 1971.

\*"Multiplier Memories and Meanderings," D. Sheingold, *Analog Dialogue*, 5-1, 1971.

"The Multiplying D/A Converter," C. Brown, *Electronic Products*, June 21, 1971.

"New Planar Distributed Devices Based on a Domain Principle," B. Gilbert, *Proceedings of the IEEE Solid State Circuits Conference*, February 19, 1971, pp. 166-7.

"A Precise Four-Quadrant Multiplier with Subnanosecond Response," B. Gilbert, *IEEE Journal of Solid-State Circuits*, December 1968.

"A Precision Current Multiplier/Divider," G. Bredekamp, *Proceedings of the IEEE (Letters)*, November 1972.

"Save Money With Analog Multipliers," R. Burwen, *Electronic Design*, 7, April 1, 1971.

"Top Performance from Analog Multipliers?" T. Cate, *Electronics*, April 13, 1970.

\*"Two-Quadrant Multiplier," R. Burwen, *Analog Dialogue*, 4-2, December 1970.

"A Two-Quadrant Multiplier Integrated Circuit," J. Holt, *IEEE Journal of Solid-State Circuits*, SC-8-6, December 1973.

## PIECEWISE-LINEAR APPROXIMATIONS, POWERS & ROOTS, MISCELLANEOUS

"AC-to-DC Converters for Low-Level Input Signals," R. Kreeger, *EDN*, April 5, 1973.

"Add FET to Threshold Detector to Improve Hysteresis," G. Oshiro, *Electronic Design*, 12, June 8, 1972.

"Analog Sorting Network," D. Morgan, *Electronic Design*, 2, January 18, 1973, and sequel (Letters), 17, August 16, 1973.

"Analog Switches Replace Reed Relays," D. Fullagar, *Electronic Design*, 13, June 21, 1973.

"Automotive and Industrial Electronic Building Blocks," R. Russell, T. Frederiksen, *IEEE Journal of Solid-State Circuits*, SC-7-6, December 1972.

"Design Features of a Precision ac-dc Converter," L. Marzetta, *Journal of Research of the National Bureau of Standards*, 73C-3, 4, July-December, 1969.

"Extraction of Square Roots . . . a Useful Analog Instrumentation Technique," T. Cate, *Electronic Instrumentation Digest*, January 1971.

"A Hybrid-Circuit RMS Converter," H. Handler, *Proceedings of the IEEE Solid-State Circuits Conference*, 1971, February 19, 1971, pp. 190, 191.

"Ideal Rectifier Uses Equal-Value Resistors," A. Lloyd, *Electronic Design*, June 21, 1967.

"Midvalue Selector Doubles as Precise Voltage Limiter," A. Moses, *The Electronic Engineer*, December 1970.

"Nonselective Frequency Tripler Uses Transistor Saturation Characteristics," R. Lockhart, *Electronic Design*, 17, August 16, 1973.

"Op Amp Art" (Absolute-Value Circuits), S. Rudnick, *EEE (Letters)*, June 1968.

"Op Amps Form Self-Buffered Rectifier," J. Graeme, *Electronics*, October 12, 1970.

\*SERDEX Serial Data Exchange Modules, Analog Devices, Inc., 1973.

"Simple Control for Sign of Op Amp Gain," S. Franco, *Electronic Design*, 23, November 8, 1970.

"Triodes as  $n$ th Power Elements," G. Philbrick, *The Lightning Empiricist*, Vol. 1, No. 1, 1952, *Out of Print*.

\*"Versatile New Module:  $Y(Z/X)^m$  at Low Cost," F. Pouliot, L. Counts, *Analog Dialogue*, 6-2, 1972.



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