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A CAHNERS PUBLICATION

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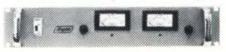

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CIRCLE NO. 1

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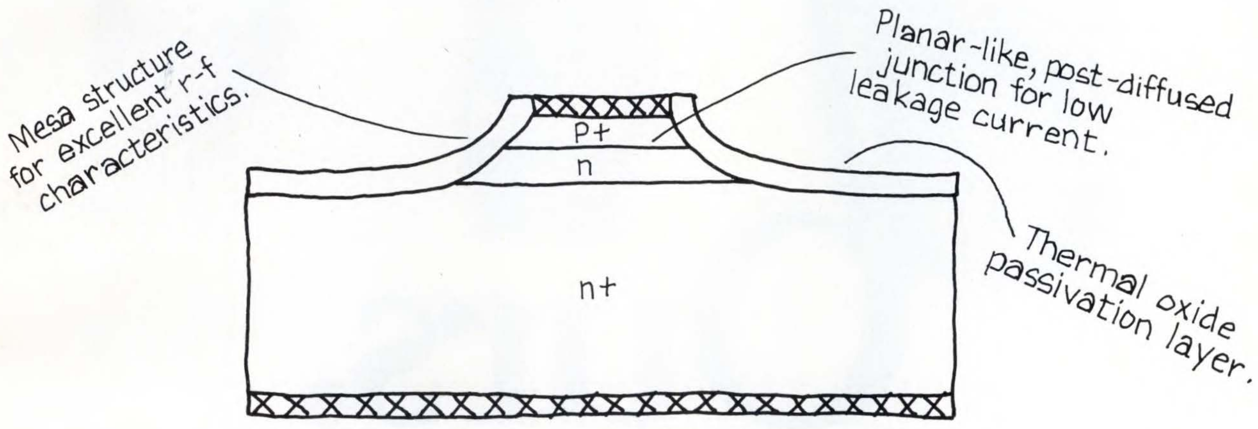

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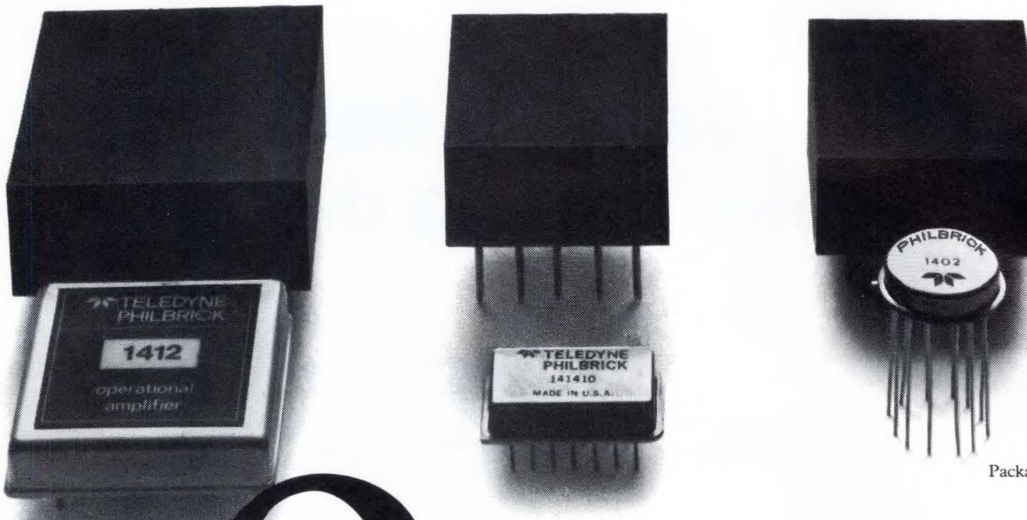

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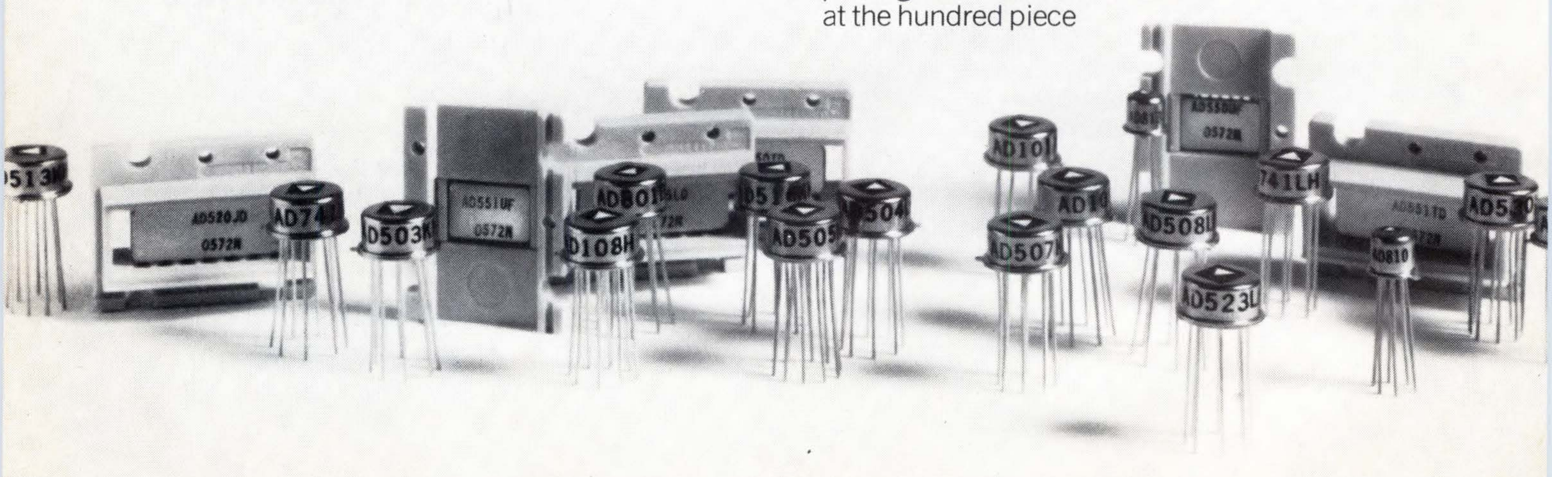

MARCH 1, 1972
VOLUME 17, NUMBER 2

EDN/EEE

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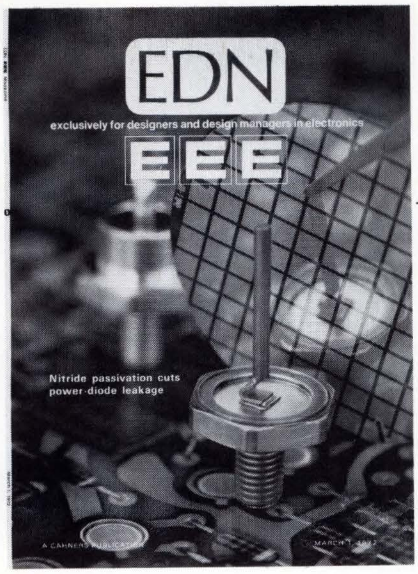

COVER

Cover photo, courtesy of International Rectifier Corp., El Segundo, Calif., shows the company's new 50A, 20V Schottky diode. For details on the device, see story on p. 54.

DESIGN NEWS

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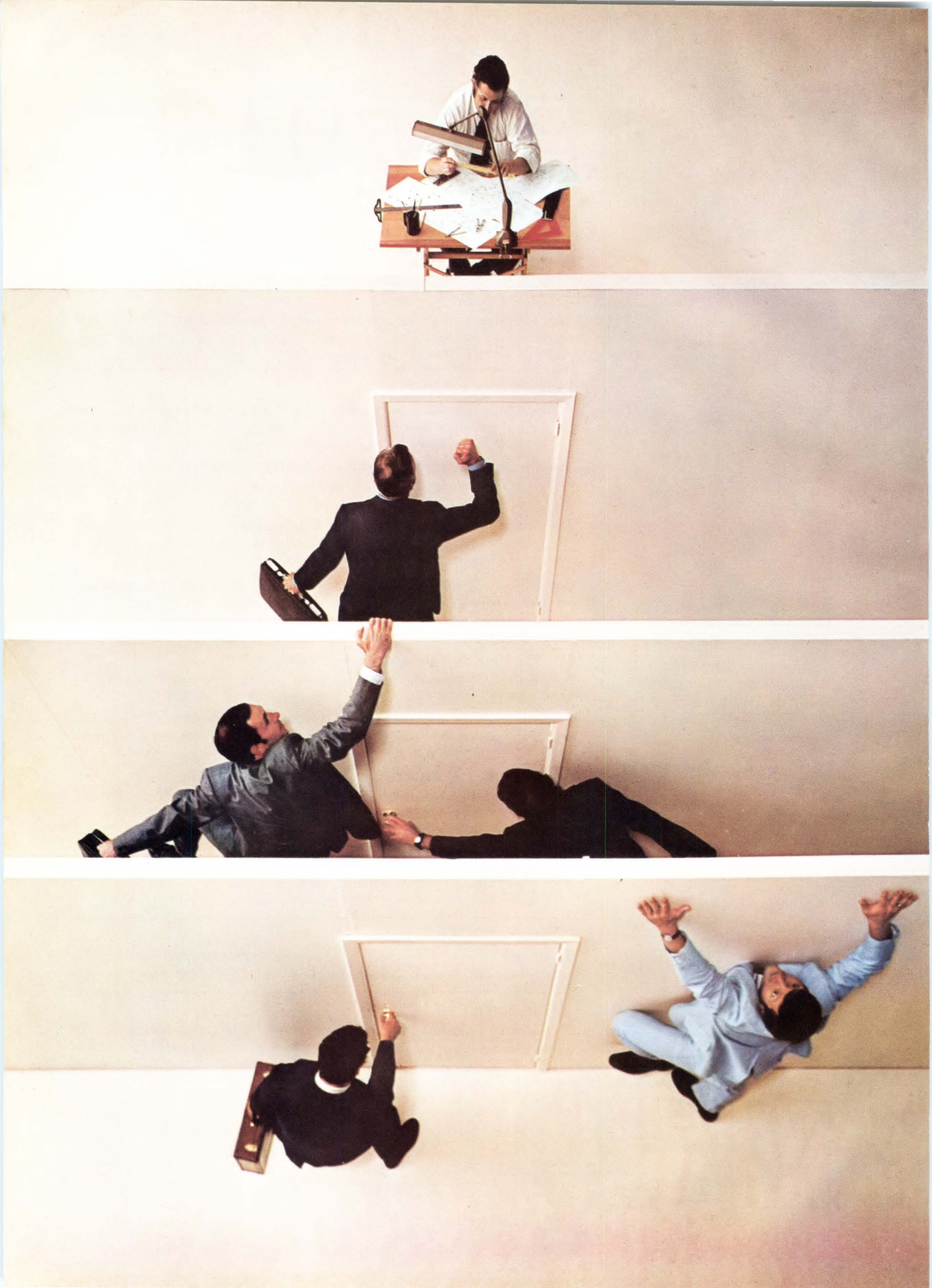

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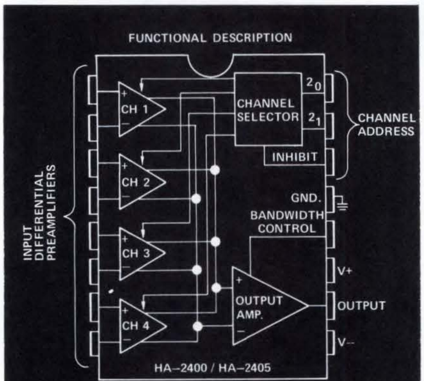
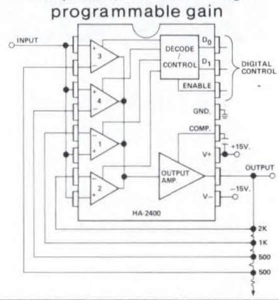
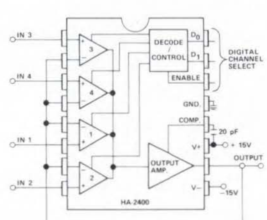
For more details on the PRAM contact your Harris representative or distributor.



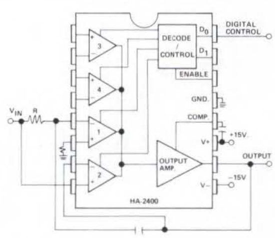
Amplifier, non-inverting programmable gain



Analog multiplexer with buffered input and output



Integrator/ramp generator with initial condition reset



More challenges:
The foregoing diagrams show just three of many applications we've designed using the PRAM. The following lists other possibilities we haven't had time yet to prove out. Why don't you try your hand at designing them or any other ideas you come up with, and send them to:
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CIRCLE NO. 9

Editorial

What kind of an engineer are you?

Engineers, like just about everything else, come in an almost endless variety. There are long ones, short ones, heavy ones, thin ones, black ones, white ones, and on and on. There are even, unfortunately, good ones and bad ones. And we say unfortunately because it would be nice if all engineers were good at their jobs.

What is it, though, that makes an engineer either a good one or bad one? We would be presumptuous if we tried to answer the question on an absolute basis, of course. But based on our observations over the years, we offer the following profile of a good engineer:

He's very competent technically, having a thorough grounding in engineering fundamentals and modern technology. But he's willing to keep learning, because he realizes the inexorable nature of technological change.

He's innovative in his approach to design problems, not being satisfied with the obvious or traditional tack. But he's not frivolous or wasteful in his efforts.

He's thorough, from the start to the finish of any project, paying careful attention to all facets of a design effort, not just those that he likes the best. But he doesn't get bogged down in details or lose perspective—he finishes projects on time.

He's cautious in specifying and using new devices and equipment. But he's not afraid to stick his neck out and apply state-of-the-art products where he feels they're appropriate.

He's dedicated to engineering and its goals, rewards and accomplishments. But he realizes there is more to life than just engineering, and as a result he has well-rounded interests.

And last, but not least, he realizes that engineering as a profession has problems and limitations, particularly in times like these. But he doesn't waste his time bad-mouthing the profession or bemoaning his fate.

There it is then: Our profile of a good engineer. How do you stack up?

Frank Egan

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805	X		+3 to +9		±0.1%	30
806		X	"		"	35
855	X		−3 to −9		"	30
856		X	"	Up to 0.5 amp	"	35
807		X	+30 to +60	0.150 amp	±0.05% at −20° to +125°C ±0.1% at −55° to −20°C	30
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CIRCLE NO. 11

NBS breakthrough yields frequency measurements at 88 THz

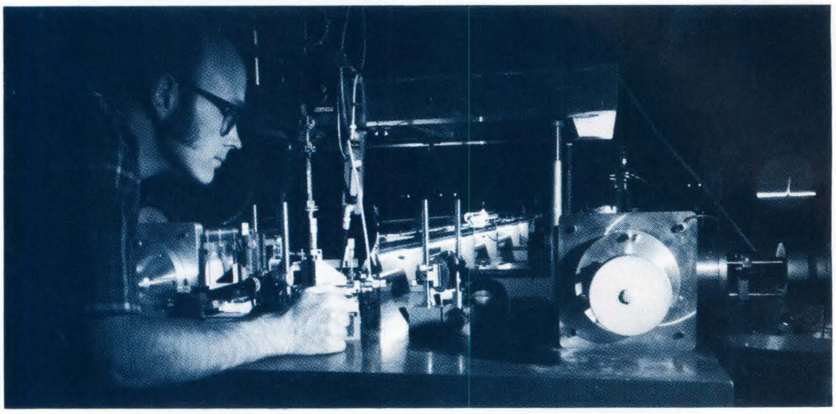
Scientists at the Boulder, Colo. facility of the National Bureau of Standards have successfully measured the absolute frequency of a helium-neon (infrared) laser. This, according to Dr. Lewis M. Branscomb, the Director of NBS, will have far-reaching effects for space scientists, astronomers and physicists.

The measured frequency was found to be 88,376,245,000,000 Hz, which is only a factor of five lower in frequency than visible light. How significant this achievement really is was explained by Dr. Branscomb: "Ever since Albert Einstein showed that time can be considered the fourth dimension of the space in which we live, scientists have looked forward to the possibility of using one gage—one 'yardstick' so to speak—not only for the three dimensions of space but for the fourth dimension of time as well. To interchange clocks and rulers scientists must know the speed with which light travels, which is equal to its wavelength times its frequency. With this demonstration that both the space (wavelength) and time (frequency) dimensions of a single light source can be measured with prodigious accuracy, this goal is now within our grasp.

Major benefits forecast

"A 30-fold more accurate determination of the speed of light should be possible," Branscomb said, "suggesting that this universal constant of nature might some day be assigned an arbitrary number, with only one standard used for both length and time measurement."

"Many . . . groups will benefit directly from this breakthrough," Dr. Branscomb continued, "and all of us will benefit indirectly. Manufacturers should achieve finer accuracy in their instruments and other precision equipment. Environmental scientists will find that improved control of precisely tuned lasers will permit new progress in the study of minute quantities of pollutants."

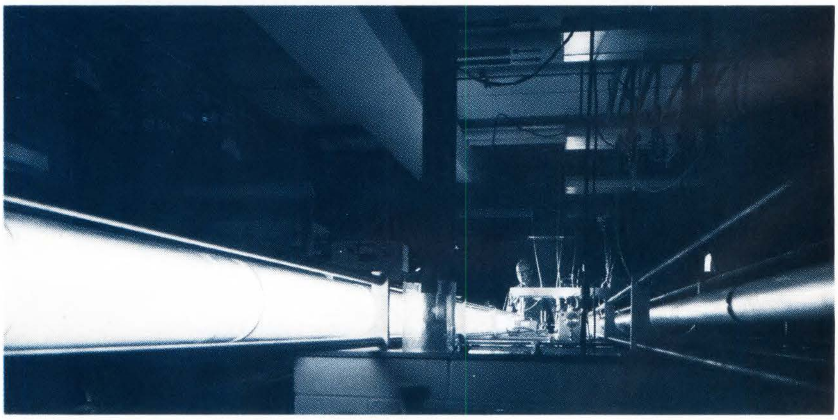


Three other lasers—hydrogen cyanide (R), water vapor (under Dr. K. M. Evenson's chin) and CO_2 (not shown)—formed the chain used to link the NBS frequency standard to the He-Ne laser whose frequency was measured.

This highest frequency measurement yet made by man represents a 100-fold increase in the span of frequency measurements over the last 4 years. Prior to this measurement, frequencies this high had to be calculated by dividing the speed of light by the measured wavelength. However, frequency-measuring techniques are more than 10,000 times more accurate than wavelength-measuring techniques.

Development and accurate measurement of superstable laser oscillators at frequencies approaching those of visible light—about one million times higher than the frequencies now used in FM radio and TV—opens up possibilities for a whole new frequency range for telecommunications, an increase of 200-fold over currently-employed frequency bands.

In the past, the most accurate speed-of-light measurement was made by measuring the wavelength and frequency of relatively low-frequency radio waves. The measurement of wavelength, an essential step in the procedure, was limited at these low frequencies to an accuracy of some 300 parts per billion. At high infrared frequencies, however, the measurement of wavelength will be limited



Large physical size of the lasers used for the measurement breakthrough is evident in this lengthwise view toward the end at which their output is focussed on the metal-contact detector.

only by the accuracy of the length standard itself (about 10 parts per billion). Thus, a 30-fold increase in the accuracy of the speed of light should be attainable.

The frequency measuring technique developed by NBS scientists K. M. Evenson, J. S. Wells, G. W. Day, and L. O. Mullen is quite similar to that used in the input stages of a common radio receiver. The He-Ne laser frequency (wavelength of 3.39 μm) is measured by using a specially constructed metal-contact "detector" as a harmonic generator and mixer. The detector multiplies accurately-known lower frequencies (from other lasers and microwave generators) to obtain a signal that is approximately equal to the unknown frequency being measured. The same detector then mixes in the unknown frequency, and produces a signal equal to the difference between the unknown and known frequencies. This low frequency difference (of a few million hertz) is then measured using well established methods.

The detection device that accomplishes this harmonic generation and mixing physically resembles a microscopic version of the catwhisker diode used in the early days of radio. Only one ten-thousandth of an inch in diameter, the sharpened tungsten-wire catwhisker touches a nickel surface to form the detector, and the whisker wire itself is the antenna for the radiation.

One of the team of scientists, Dr. K. M. Evenson, noted that while some of the lasers used for the breakthrough are large in physical size, their power output is in the 100 milliwatt region. Thus, working with them does not pose any great hazard to personnel.

Feedforward amplifier technique reduces noise and increases usable bandwidth

An old circuit design technique, feedforward correction, is the subject of renewed interest thanks to recent experiments conducted at Bell Telephone Laboratories.

The technique, originally advanced in 1924, may hold the key to reducing distortion and substantially increasing the message-carrying capacity of future microwave radio-relay and coaxial-cable communications systems. The recent experiments were carried out by Harold Seidel, working at different times with Henry R. Beurrier, Charles H. Bricker, and Allen N. Friedman of Bell Labs, Murray Hill, N. J.

Feedforward differs from the more conventional feedback technique in that an amplifier is not required to reprocess or recirculate a signal once it has passed through the system. It is this "loop-gain" of the reprocessed signal in the feedback amplifier that sets a limit on stability and requires very large device bandwidths.

The feedforward technique which permits engineers to design amplifiers in which the output signal and a sample of the input signal can be compared and corrected repeatedly to any desired degree of accuracy, is said to have three main advantages over conventional feedback:

1. It does not substantially reduce amplifier gain.

2. Gain-bandwidth is consumed entirely within the band of interest.

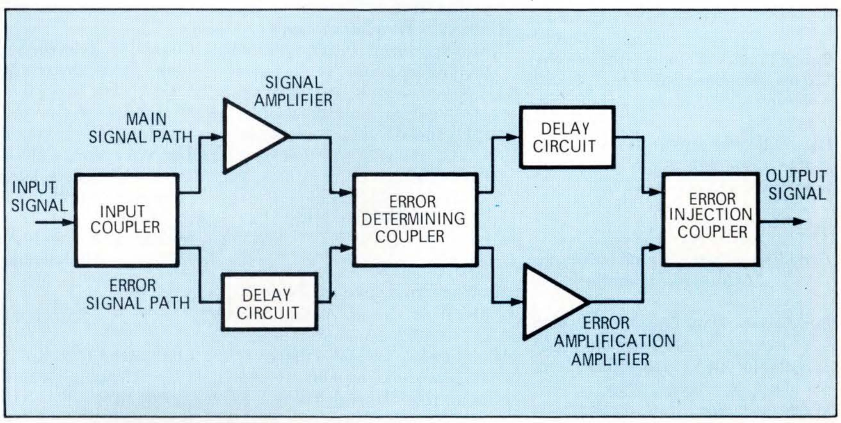
3. It is independent of the magnitude or shape of the amplifier delay.

The technique uses two parallel wavepaths—one for the main signal and one for the error signal. The main path includes one or more signal amplifiers and operates in the normal manner. The error-signal path accumulates the error components (noise and distortion) that develop in the signal traveling along the main path. Errors carried on the second path, synchronous with the first, can be injected into the main signal to cancel the error components in the main signal.

In the first experiment with a vhf amplifier in 1968, a 108-dB dynamic range was obtained. More recently, in a second experiment, feedforward control was applied to a high-performance, baseband, feedback amplifier used in carrier systems. With the addition of feedforward control, all intermodulation distortion products in this amplifier were reduced by about 40 dB over the entire range of 0.5 to 20 MHz.

In the third experiment, feedforward was applied to a traveling-wave tube, such as that used in the TD3 microwave radio system. The laboratory setup produced greater than a 40-dB intermodulation reduction over a 20-MHz channel at 4 GHz, using a single correction stage, and more than 50 dB using a second stage.

Circuit complexity in the latter two demonstrations was roughly double that of a conventional amplifier, but integration methods available at both vhf and microwave frequencies suggest that there will be no major difficulty in accommodating much of this increased hardware.



In the feedforward system, the input signal is divided into two paths by the input coupler. The error, or reference, signal is then delayed an amount of time roughly equal to the transit time through the signal amplifier. This delayed reference is compared to the output of the amplifier in the error-determining coupler to determine the error signal. The error is then removed from the main signal in the error injection coupler, after necessary amplitude, and time changes have been made.

IEEE-INTERCON technical sessions feature over 275 papers

Are you going to New York this month for IEEE's annual get-together—this year called IEEE-INTERCON? To help you decide, here is the technical program subdivided into technical specialities.

If you will be at the Show, be sure to stop in and see us at Booth 1532. There will be an editor there at all times. Stop by, get acquainted and maybe we can even talk you into writing a technical article for publication. Even if we can't, it's a good opportunity for editors and readers to get together and exchange ideas.

Technical papers are grouped under the following categories:

Communications	Displays	Microwaves
Components	Instrumentation	Optoelectronics
Computers	Microelectronics	Process Control

COMMUNICATIONS

Monday—2:00 PM to 4:30 PM

CATV Network via Satellite, J. V. Charyk, Comsat Corp.

CATV—Subscriber, Supply and Demand, H.J. Schlafly, Teleprompter Corp.

CATV and Regulation, D. Burch, FCC,

Video Conferencing, A.D. Williams, J. Duncanson, Bell Telephone Laboratory.

New Techniques in Connection with the Use of Cable and Home TV to Revolutionize Communications, W.F. Mason, Mitre Corp.

Transmission of a Holomicrogram Over a Limited Telemetry Channel, R.F. van Ligten, J.A. Levitt, J.T. Winthrop, American Optical Corp.

Monday—2:30 PM to 5:00 PM

Electronic Map Compilation, P. Rosenberg, Paul Rosenburg Associates.

Electronic Multiimage Analog Digital Processor and Color Display, R.K. Moore, P.N. Anderson, G.W. Dalke, R.M. Haralick, G.L. Kelly, University of Kansas.

Tuesday—9:30 AM to 12 Noon

Control and Communication Systems for Personal Rapid Transit Vehicles, T. Trexler, Bendix Systems Div.

Hybrid-Circuit Applications in Portable Communications Equipment, M.L. Topfer, Motorola Inc.

Tuesday—9:30 AM to 12 Noon

Control and Communication Systems for Personal Rapid Transit Vehicles, T. Trexler, Bendix Systems Div.

Hybrid-Circuit Applications in Portable Communications Equipment, M.L. Topfer, Motorola Inc.

Tuesday—2:00 PM to 4:30 PM

Canadian Data Communications, W. J. Inkster, Bell Northern Research.

Bell System Data Transmission Plans in the U.S., P. E. Muench, AT&T.

Serendipity of Digital Communications, C. R. Fisher, Datran.

Western Union Data Transmission Planning, J. E. Cox, Western Union Telegraph Co.

Plans for the Japanese Domestic Satellite System, F. Ikegami, S. Morimoto, Nippon T&T Public Corp.

Canadian Domestic Satellite Communication System, J. Almond, Telesat Canada.

Regional Communication Services via Intelsat Satellites, J. L. Dicks, Comsat Corp.

A Systems Approach to City Communications, R. P. Gifford, General Electric.

Community Reaction to Communications Technology, G. Heningburg, Newark Urban Coalition.

Tuesday—2:30 PM to 5:00 PM

Communications Applications of Minicomputers, T. C. Stockebrand, Digital Equipment Corp.

Wednesday—9:30 AM to 12 Noon

Mobile Communications for Urban and Interurban Use, J. Engel, BTL.

Wednesday—2:00 PM to 4:30 PM

900 MHz—A New Horizon in Land Mobile Communications, a Panel Discussion. Panelists: M. Cooper, Motorola Inc. H. A. Jones, RCA. G. R. Peterson, General Electric. R. E. Spence, FCC. J. B. Keane, AT&T.

Algorithmic Formulation of Communication Problems, M. Schwartz, Polytechnic Institute of Brooklyn.

Thursday—10:30 AM to 12 Noon

High-Power CW Gunn Oscillator for Communication Applications, A. L. Reynolds, ITT.

Microwave Technology in Gigabit PSK Modulation and Demodulation for Communication, C. L. Cuccia, Philco-Ford.

A 19-GHz Transmitter and Receiver for Experimental High-Speed Digital Transmission, W. J. Schwarz, R. W. Kordos, R. W. Judkins, BTL.

Technological Considerations for High-Speed Digital Radio Repeater, R. D. Silverthorn, Bell-Northern Research.

COMPONENTS

Monday—2:00 PM to 4:30 PM

Miniaturized Active RC Filters, G. S. Moschytz, Swiss Federal Institute of Technology, C. F. Kurth, BTL.

Miniaturized Crystal Filters, D. F. Sheahan, GTE Lenkurt Electric Co.

Miniaturized Digital Filters, S. A. White, North American Rockwell Microelectronics Co.

Tuesday—9:30 AM to 12 Noon

Precision Thick-Film Resistors for High-Voltage Dividers, J. E. Turnbaugh, Tektronix, Inc.

A High-Performance, Thick-Film Attenuator, T. Zanborelli, A. Antes, Hewlett-Packard.

Wednesday—2:00 PM to 4:30 PM

Latching Ferrite Technology, J. Pippin, Electromagnetic Sciences, Inc.

Recent Advances in Ferrite Limiters, R. Kalvaitis, H. S. Maddix, Varian Associates.

Tailoring Ferrites for Microwave Devices, R. G. West, A. C. Blankenship, Trans Tech Inc.

Thursday—9:30 AM to 12 Noon

Linear Wide-Band Amplifers Using Transferred Electron Devices, B. S. Perlman, C. L. Upadhyayula, RCA.

Transmission-Type ADAs, T. A. Midford, H. C. Bowers, Hughes.

Turnable Locked ADOs, S. F. Paik, C. W. Lee, Raytheon Co.

Thursday—10:30 AM to 1:00 PM

Solid Aluminum Capacitors, F. R. Kunnen, N. V. Philips.

COMPUTERS

Monday—9:30 AM to 12:00 Noon

Memory Hierarchies—Fact and Fiction, R. L. Mattson, IBM.

Applications of Program Modeling to Hierarchies, P. J. Denning, Princeton University.

Memory Hierarchies: Economic Considerations and Future Prospects, W. R. Beam, Consultant.

Hardware/Software Interfaces, J. Mekota, B. Rosenbaum, Honeywell.

Monday—2:00 PM to 4:30 PM

Computer Television—What Works and What Doesn't Work, P. Klein, Computer Television Corp.

Microprogram Control for Minicomputers, W. H. Roberts, Consultant.

The Wide Range of I/O Capabilities in a Microprogrammed Minicomputer, T. Mulder, D. Savitt, Microdata Corp.

Microprogramming—Real Applications in Minicomputers, D. Archdale, Interdata, Inc.

Monday—2:30 PM to 5:00 PM

Computer-Controlled Stereo Plotters for Mapping Purposes, U. V. Helava, Bendix Research Labs.

Geographical Information Retrieval System, J. L. Pfaltz, University of Virginia.

Tuesday—9:30 AM to 12 Noon

Computer Control of Urban Vehicular Traffic; A. Cimento, Sperry Rand.

User Requirements for Large-Capacity Memories, J. Jaffe, IBM.

Optical Mechanical Design Parameters for a Laser Recorder Mass Memory, B. French, Precision Instrument Co.

Holographic Optical Memory, R. D. Lohman, RCA Labs.

Design of an Optical Disk Memory, J. Aseltine, Oranic Memories, Inc.

Masstape—A Systems Approach to Mass Storage, D. G. Ronkin, J. Haines, Grumman Data Systems.

Tuesday—2:00 PM to 4:30 PM

The Cost of Developing Software, a Panel Discussion. Panelists: R. W. Wolverton, TRW; V. La Bolle, Dept. of Water and Power; T. E. Climis, IBM; R. E. Merwin, Safeguard Systems Office.

Tuesday—10:30 AM to 1:00 PM

The Minicomputer as a Subsystem Component, L. Seligman, Data General Corp.

Simple Processors: The Interface Link, S. Mintz, Hewlett-Packard.

Interfacing the Minicomputer in Dedicated Industrial Applications, P. Secoolish, D. E. W. Archdale, Interdata, Inc.

Tuesday—2:30 PM to 5:00 PM

Evaluation of Software for Industrial Minicomputer Applications, M. Mensh, Foxboro Co.

Applications of Minicomputers in Signal Processing, T. Storer, Time Data Corp.

Minicomputers Applied to Computer-Aided Design, G. D. Hornbuckle, Applicon Inc.

Wednesday—9:30 AM to 12:00 Noon

Core Memories in the '70s, A. L. Friedman, Electronic Memories and Magnetics.

MOS Storage—A Revolution in Main Memory, G. Moore, Intel Corp.

Bipolar Memory—The Technology for the Future, J. Ricci, Intersil Corp.

A Surface Acoustic-Wave Digital Recirculating Memory, H. Matthews, Sperry Rand.

Data Processing for Earth-Resource Sensors, P. Wintz, Purdue University.

Processing of Scientigraphic Biomedical Images, D. Chesler, Massachusetts General Hospital.

Trends for Small Systems, K. H. Olsen, Digital Equipment Corp.

Trends in Large Systems, J. Bertram, IBM.

Wednesday—2:00 PM to 4:30 PM

Effects of Computers and Automation, E. Katzenbach, Nova University.

Problem-Oriented Computer Languages, a Panel Discussion. Panelists: J. Sams, IBM; S. Fenves, J. Moline, University of Illinois, D. Roos, M.I.T.

Some Developments in the Digital Processing of Images and SOUND, T. G. Stockham, Jr., University of Utah.

Linear Programming Methods in the Design of Digital Filters, L. Rabiner, BTL.

Wednesday—10:30 AM to 1:00 PM

Economic Analysis of Computer-Controlled Test Systems, or Items the Supplier Failed to Mention, R. G. Rogers, General Radio Co.

Software Considerations in Automatic Test System Integration, R. E. Colgan, RCA Electromagnetic.

The Computer in the Environmental Test Lab, C. L. Heizman, Time/Data Corp.

Plug-in Measurements Come to the Computer, R. P. Anderson, General Radio Co.

Wednesday—2:30 PM to 5:00 PM

Building High-Performance Memory Systems with Dynamic MOS Memory Components, G. Larkin, Advanced Memory Systems, Inc.

Applications for OCS/MOS Memories, J. R. Oberman, RCA.

Static and Dynamic Control Memory in Microprogrammed Minicomputers, R. Genke, Interdata, Inc.

A Case for Intelligent Memories, W. Brunna, D. Duckman, Electronic Memories, Inc.

Thursday—9:30 AM to 12:00 Noon

Throughput Analysis in Serial Processing, G. Amdahl, Amdahl Associates.

Multiprocessors with Shared Resources, M. J. Flynn, Johns Hopkins University.

Second Thoughts on Parallel Processors, J. Shore, Naval Research Lab.

Multistream Processors—An Example and Some Further Thoughts, W. J. Watson, Texas Instruments Inc.

DISPLAYS

Tuesday—9:30 AM to 12:00 Noon

A Survey of 3D Displays, J. F. Butterfield, Stereotronics Television.

Three-Dimensional Displays Based upon the Sequential Excitation of Fluorescence, C. M. Verber, Battelle Columbus Labs.; J. D. Lewis, Battelle Development Corp.; R. B. McGhee, Ohio State University.

A Computer-Generated Holographic 3D Display, J. D. Lewis, Battelle Development Corp.; R. B. McGhee, Ohio State University; J. R. Shewell, Battelle Columbus Labs.

Tuesday—2:00 PM to 4:30 PM

Liquid Crystals—An Overview, G. H. Heilmeier, Office of the Director of Defense; A. Sussman, RCA Labs.

Display Applications of PLZT Ferroelectric Ceramics, J. R. Maldonado, BTL.

Light-Emitting Diodes, M. R. Lorenz, IBM.

Phosphors for Display Applications, J. D. Kingsley, General Electric.

Photochromics for Information Display, G. K. Megla, Corning Glass Research Labs.

Low-Loss Optical Glasses for Optical Fiber Waveguides, A. D. Pearson, BTL.

INSTRUMENTATION

Monday—2:00 PM to 4:30 PM

Portable Visual Performance Instrumentation, P. W. Davis, Dept. of Transportation.

Tuesday—10:30 AM to 1:00 PM

Building a Marketing Organization in the Systems Business, J. A. Prestridge, Teradyne, Inc.

Building a Marketing Organization in the Instruments Business, P. Macalka, General Radio.

Wednesday—10:30 AM to 1:00 PM

Plug-in Measurements Come to the Computer, R. P. Anderson, General Radio Co.

Measuring Transfer Functions Using Noise, P. Roth, Hewlett-Packard.

Computers in Instrumentation—Measuring the Unmeasurable, L. A. O'Neill, BTL.

Wednesday—2:30 PM to 5:00 PM

Digital Testers: What's Available? At What Cost? Who Needs Them? S. Sampson, BTL.

How to Talk to a Digital Tester: Is There a Universal Language?, S. D. Sadtler, Jr., Hewlett-Packard.

Automatic Test-Program Generation: What It Is; Where To Get It; How To Use It, R. McClure, C. Oualline, Telpar Corp.

Thursday—10:30 AM to 1:00 PM

Comparison of Techniques for Testing Hybrid Electronics Circuits, P. Jackson, Instrumentation Engineering.

Techniques for Single-and Multiple-Fault Analysis of MSI Digital Logic Arrays, R. Wooster, Western Electric.

MICROELECTRONICS

Monday—9:30 AM to 12:00 Noon

A Micropower Phase-Locked Loop, G. W. Steudel, RCA.

Triple-Diffused Vertical p-n-p Adds a New Dimension to Complementary Micropower Integrated Circuits, W. R. Harden, R. C. Gallagher, D. W. Williams, Westinghouse.

Computer-Aided Design of Digital Integrated Circuits, R. Rohrer, Sof Tech Inc.

Monday—2:30 PM to 5:00 PM

Microelectronics Environmental Control, L. C. Rogers, Motorola Semiconductor.

Tuesday—2:00 PM to 4:30 PM

Ion Implantation Equipment for Semiconductor Processing, S. Harrison, KEV Electronics Corp.

Ion Implantation and Radiation—Enhanced Diffusion in Semiconductors, J. F. Gibbons, Stanford University.

Applications of Ion Implantation to Semiconductor Manufacturing, R. J. Paluck, Mostek Corp.

Tuesday—2:30 PM to 5:00 PM

How to Jump into MOS Without Drowning, E. Berezin, Redactron.

A Test System for Detecting and Isolating Faults on Four-Phase MOS/LSI Printed-Circuit Boards, D. Parker, National Cash Register Co.

MOS IC Reliability Considerations, G. L. Schnable, RCA.

Monolithic Gating-Circuit Techniques for Power Control, A. P. Ferro, J. D. Harnden, J. R. Mullaly, D. L. Watrous, General Electric.

Power Hybrid Circuit Technology and Applications, S. W. Lefcourt, J. C. Pilecki, RCA.

High-Power Hybrid Control Circuits, B. J. Bixby, L. R. Carver, D. Cooper, International Rectifier Corp.

Wednesday—9:30 AM to 12:00 Noon

MOS Storage—A Revolution in Main Memory, G. Moore, Intel Corp.

Bipolar Memory—The Technology for the Future, J. Ricci, Intersil Corp.

Trends in Semiconductors, R. Noyce, Intel Corp.

Partitioning D/A Converter Circuits for Implementation in Monolithics, R. Stata, Analog Devices, Inc.

The Impact of Precision Large-Scale D/A ICs on A/D/A Converter Design, M. B. Rudin, Precision Monolithics, Inc.

Wednesday—10:30 AM to 1:00 PM

Microwave Integrated Circuits—An Overview, F. Sterzer, RCA.

A Perspective on Lumped vs. Distributed Microwave Integrated Circuits, O. Pitzalis, Jr., U.S. Army Electronics Command.

Application of Bulk Semiconductor Control Components to Microwave Integrated Circuits, A. Armstrong, P. E. Bakeman, W. C. Taft, R.P.I.

Packaging of Microwave Integrated Circuits for Systems Applications, R. J. Bauer, Westinghouse.

Wednesday—2:30 PM to 5:00 PM

Building High-Performance Memory Systems with Dynamic MOS Memory Components, G. Larkin, Advanced Memory Systems, Inc.

Applications for COS/MOS Memories, J. R. Oberman, RCA.

Thursday—9:30 AM to 12:00 Noon

Computer Aids in the Layout of Large-Scale Integrated Circuits, I. Schischa, B. Wilner, IBM.

Benefits and Problems of CAD in IC Layout, M. M. Goldman, Motorola Inc.

Interactively Aided IC Layout with a Minicomputer System, F. K. Richardson, Applicon, Inc.

MICROWAVES AND LASERS

Monday—2:30 PM to 5:00 PM

High-Speed Laser Trimming of Film Resistors, T. Chandler, Teradyne, Inc.; R. Lawler, Boeing.

Laserscribing—The Modern Way To Separate Semiconductor Die, H. P. Manley, Quantronix Corp.

Perforating Rubber with a CO_2 Laser, R. Scherer, Photon Sources.

Wednesday—2:00 PM to 4:30 PM

Latching Ferrite Technology, J. Pippin, Electromagnetic Sciences, Inc.

Recent Advances in Ferrite Limiters, R. Kalvaitis, H. S. Maddix, Varian Associates.

Tailoring Ferrites for Microwave Devices, R. G. West, A. C. Blankenship, Trans Tech Inc.

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Why Not Stripline?, H. Howe, Jr., Microwave Associates Inc.

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Wednesday—2:30 PM to 5:00 PM

The Application of Cylindrical Arrays to Microwave Landing Guidance Systems, R. Kalafus, U.S. Dept. of Transportation.

A New Cylindrical Electronic Scan Antenna for Air Traffic Control, P. W. Hannan, J. H. Gutman, R. J. Giannini, Hazeltine Corp.

Application of the Doppler Scanning Beam Concept to Microwave Landing Systems, H. W. Redlien, Hazeltine Corp.

Cost Effective Microwave Systems for Railroad and Automobile Safety Applications, J. B. Hopkins, F. R. Holmstrom, U.S. Dept. of Transportation.

A Millimeter-Wave Sensor and Detector for Clear-Air Turbulence, G. G. Haroules, W. E. Brown, G. W. Wagner, U.S. Dept. of Transportation.

Thursday—10:30 AM to 1:00 PM

Linear Wide-Band Amplifiers Using Transferred Electron Devices, B. S. Perlamn, C. L. Upadhyayula.

Transmission-Type ADAs, T. A. Midford, H. C. Bowers, Highes.

Tunable Locked ADOs, S. F. Paik, C. W. Lee, Raytheon Co.

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Technological Considerations for High-Speed Digital Radio Repeater, R. D. Silverthorn, Bell-Northern Research.

OPTOELECTRONICS

Monday—2:00 PM to 4:30 PM

Hybrid Optical Processing, A. Vander Lugt, Radiation, Inc.

Transmission of a Holomicrogram Over a Limited Telemetry Channel, R. F. van Ligten, J. A. Levitt, J. T. Winthrop, American Optical Corp.

Tuesday—10:30 AM to 1:00 PM

Characterization and Application of Photoconductors—A Practical View, J. G. Rabinowitz, Clairex Electronics.

New Light-Emitting Devices, K. Lawley, Monsanto Co.

Display Circuits That Reduce User Cost, L. Pond, Sperry Rand Corp.

Liquid Crystal Displays Can't Be THAT Good!, G. Leffer, Optel Corp.

Wednesday—9:30 AM to 12:00 Noon

Silicon Imaging Devices, R. W. Redington, General Electric.

Negative Electron Affinity Imaging Tubes, E. D. Savoye, F. R. Highes, R. E. Simon, RCA.

A Silicon-Diode-Array Camera Tube with Electronically Controllable Responsivity, E. H. Stupp, B. Singer, J. Kostelec, M. H. Crowell, North American Philips Corp.

Recent Advances in Charge-Coupled Imaging Devices, W. J. Bertram, D. A. Sealer, C. H. Sequin, M. F. Thompsett, BTL.

PROCESS CONTROL

Monday—2:00 PM to 4:30 PM

The Role of Cycloconverters in Solid-State Power Conditioning for AC Drives, W. S. Chow, J. D. Duckworth, G. Hausen, J. A. I. Young, Canadian General Electric.

EIA DRIVER HAS INTERNAL INHIBIT AND SLEW RATE CONTROL.

Our new 9616 EIA triple line driver provides simple, low-cost solutions to EIA applications. Our new 9617 EIA triple line receiver completes the set.

Our new 9616 Driver and 9617 Receiver meet all EIA-232-C/CCITT V.24 specs. And more. Together they provide the simplest low-cost solution to problems at the interface in data terminal equipment and data communications.

Unlike conventional EIA drivers, which are implemented by a positive NAND function, our 9616 is implemented by an And/Or/Invert function. With this logic configuration, you can perform the inhibit function without any external gating.

In addition, the 9616 incorporates internal slew rate control. No need for an external capacitor for each driver. Result: significant savings on board space, components, assembly.

In meeting RS-232-C recommendations our 9616/9617 feature:

9616 EIA Line Driver

- All inputs TTL compatible
- Each driver is output protected
- Symmetrical driver output voltage levels and current limits
- Supplies are +12V and −12V @ ±10% regulation

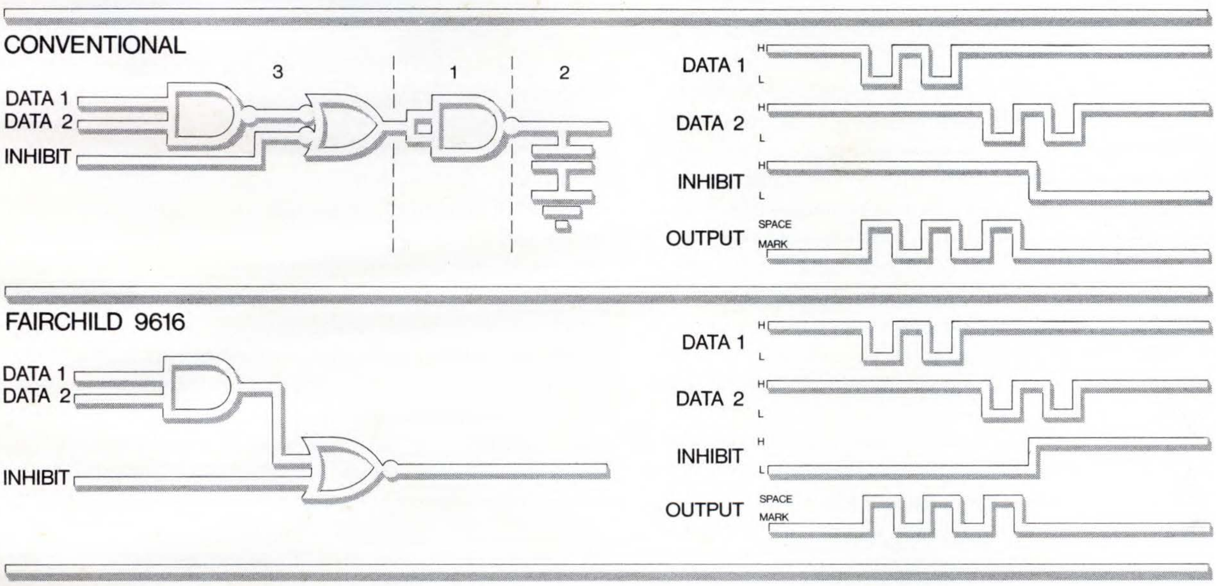
9617 EIA Line Receiver

- 3 to 7K Ω input resistance
- Inputs protected to ±25V
- Each Receiver operates in fail-safe mode
- Controllable slicing or hysteresis operation
- Individual response pins to increase AC noise immunity
- Outputs TTL/DTL compatible
- +5V supply operation, ±5% regulation

Both the 9616 Driver and the 9617 Receiver are available from distributor stock. Design-in quantities available now; production quantities in late March. The 9616 @ $4.50 and the 9617 @ $3.50 in quantities of 100-999.

Other Fairchild Drivers & Receivers

9614	Dual Differential Line Driver
9615	Dual Differential Line Receiver
9620	Dual Differential Line Receiver
9621	Dual Line Driver
9622	Dual Differential Line Receiver
SN75107-108	Dual Line Receivers
SN75109-110	Dual Line Drivers



COMPARISON OF CONVENTIONAL AND 9616 EIA DRIVERS
Conventional EIA Driver (1) requires external slew rate control capacitor (2) and external gating for inhibit function (3). Fairchild 9616 EIA Driver requires neither.

MADE IN FAIRCHILD

FAIRCHILD SEMICONDUCTOR, A Division of Fairchild Camera & Instrument Corp., 464 Ellis St., Mountain View, Ca. 94040. (415) 962-5011. TWX: 910-379-6435

CIRCLE NO. 12

Analog circuit modules offer advantages in industrial systems

By using modules, a designer can concentrate on improving his company's systems instead of diluting his efforts by extensive circuit design.

Tom Cate, Function Modules Inc.

If you design electronic equipment and systems for industrial use you have three alternatives open to you: design with discrete components and ICs, design with those plus analog circuit modules, or buy complete electronic systems. Today's economic conditions are a factor, too, for they practically force you to put economic and marketing considerations in the forefront.

Three design approaches and how they compare

Designing with discretes and ICs, the first approach, often leads to minimum material cost for any industrial circuit. For circuits of modest complexity and performance, you just can't beat the low material cost inherent in using a few discrete components and some monolithic or hybrid ICs. For example, assume that you need a single-ended amplifier circuit with 1 kΩ input impedance, a gain of -10, an output range of ± 10V, and accuracy of $\pm 1\%$. A single 741 IC op amp with two metal-film resistors will do an excellent job for the price of approximately $1.

When you get into high-performance circuits of greater complexity, though, —such as analog-to-digital converters, low-drift instrumentation amplifiers and accurate analog multipliers—the design ball game changes. Here the material cost still may be reasonable, but the cost of design time becomes high and the cost of labor for assembling and testing these circuits becomes very significant.

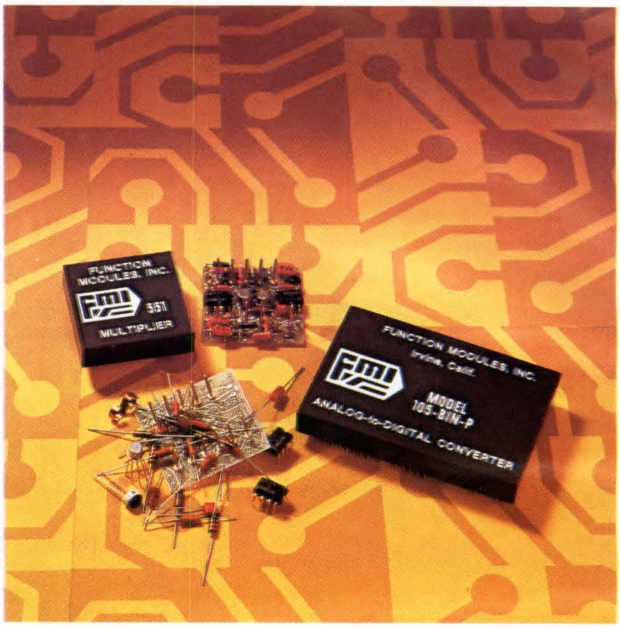
One danger inherent in designing complex industrial circuits from the discrete component level is that your company will sink too many dollars into reinventing old circuits.

The second design approach—incorporating discretes, ICs *and* analog circuit modules—has growing popularity among industrial/commercial companies.

Today, many industrial designers are making extensive use of such analog circuit modules as instrumentation amplifiers, multipliers, square-rooters, rms-to-dc converters, log amps, A/D converters, and D/A converters in order to reduce total system-design time. In addition, the increased market for analog circuit modules has led to significant breakthroughs in price and performance.

It is often true that the industrial system designer can buy state-of-the-art performance at very reasonable prices compared with in-house costs. And, as the companies making analog circuit modules have grown, their responsiveness to customized requirements has also improved. Standard modules are available today to implement a wide range of mathematical functions ($XY/10$, $X^2/10$, $\sqrt{10X}$, $10\sin X$, $A \log X$, etc.). Also, specialized combinations of these modules often can be developed for the industrial OEM designer.

Although a function module is generally committed to



performing a specific function, such as the *conversion of* a signal from one form to another or an *operation on* an analog signal, module circuits often can be adapted to related functions at surprisingly low cost.

The third approach—simply specifying a total electronics package—has been used successfully by some industrial systems companies, but it has two big dangers: First, your "value added" may not be significant, so your supplier may bypass you in the future and sell directly to your customer (for example, some companies making minicomputers are putting considerable effort into reaching such end-user markets as schools and hospitals). Of course, if your company's sales and service organization dominates the end-user market you may not have to worry about being bypassed.

The second danger is that you may not end up with a competitively priced system. You've got the cost of defining and specifying a complex electronic system, and your vendor has the expense of designing a customized system for you. Thus, the approach of buying a complete electronics system package is most viable where the electronics portion represents only a small fraction of the total system cost.

These three approaches to the electronic design of industrial/commercial systems and equipment are fundamentally different, but there is considerable interplay and overlap. Very often, a number of discrete parts are combined with analog circuit modules, digital IC circuits, and various pieces of mechanical hardware to be sold as a customized system to some industrial company. It, in turn, combines this with some special packaging and nonelectronic parts to make up a total system package. This total package is then marketed to the end-users, who may range from sophisticated researchers to recording studios searching for new effects in rock-music recordings.

As the needs increase for better control of our environment, for more efficient productivity, and for more entertainment, we will see expanded usage of electronics to meet them. But these needs will only be served by designing and marketing systems using electronics to satisfy the needs themselves, and not by continually developing electronic circuits to sell to other electronic companies. We must all concentrate on our own area of marketing expertise. There is no longer any economic justification for reinventing circuits where the same circuit function is readily available off-the-shelf in low-cost module form.

Members of the analog circuit module family

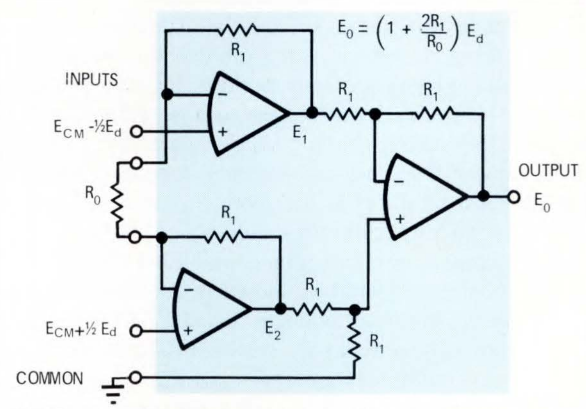
Analog circuit modules can, in general, be divided into three categories: instrumentation amplifiers, nonlinear function modules and converter modules.

Modular instrumentation amplifiers. Instrumentation amplifiers provide the function of accurately amplifying a low-level signal up to a high level, generally from the millivolt level up to a full-scale range of ±10V. They must have high input impedance, low drift, good linearity, and accurate gain. Most modular instrumentation amplifiers are differential-input, and are designed to reject common-mode inputs. Although they generally lack the built-in power supplies and high common-mode voltage range of their larger rack-mounted ancestors, the prices are now down into the $20 to $150 range, and the electrical performance is excellent.

Most of the commonly-used modular instrumentation amplifiers have several features in common. Among these: (1) They operate from ±15V supplies, and are designed for an input and output range of ±10V (the common of the +15V and −15V supplies must be connected to the amplifier common). (2) The gain is set by one external resistor. Performance as a function of gain setting is normally specified, and unlike with op amps, the linearity and stability of the gain is specified. (3) Provision is sometimes made for externally trimming input offset, output offset and CMR.

In the near future, we can expect to see on the market several modular instrumentation amplifiers with complete isolation between input and output. There may also be units with higher common-mode input-voltage ratings. One new, chopper-stabilized instrumentation amplifier with built-in track/hold capability has recently been introduced by Function Modules, Inc. Also, amplifiers with digitally-programmable gain have been developed for use with minicomputers.

As might be expected from the similarity in technology, the design and manufacturing of modular instrumentation amplifiers has been done best by people from the world of modular op amps. Of course, the designers of monolithic ICs would like to make a complete instrumentation amplifier on a single chip, but they are fighting the inherent problem of maintaining tight control of both voltage drift and gain stability. Some very-low-drift IC op amps, such as the 725, have been designed for instrumentation use, but their overall performance is very dependent on the external gain-setting network and the particular circuit configuration used. Also, some hybrid IC units have been designed, but these tend to either be less flexible in application than modular instrumentation amplifiers, or inherently lower in performance.



NOTE: E_{CM} is the common-mode input voltage, and E_d is the differential-input voltage. The external 15V power supply must be referenced to Common.

$$E_1 = E_{CM} + \tfrac{1}{2}\left(1 + \frac{2R_1}{R_0}\right) E_d$$

$$E_2 = E_{CM} - \tfrac{1}{2}\left(1 + \frac{2R_1}{R_0}\right) E_d$$

$$\text{Therefore, } E_0 = \left(1 + \frac{2R_1}{R_0}\right) E_d$$

Fig. 1 — Commonly-used (simplified) circuit for a modular instrumentation amplifier. Critical factors are the choice of ICs and of the gain-setting resistor networks.

A typical circuit used in modular instrumentation amplifiers is shown in simplified form in **Fig. 1**. Key factors in the design choice are the IC components, particularly for input sections, and the resistor networks for setting gain.

Many new modular instrumentation amplifiers with excellent performance are on the market today. Amplifiers with input voltage drifts of ±3 to ±1 μV/°C; over 100 dB CMR; and input noise levels of 10 μV rms to 3 μV rms are available in the $29 to $59 range.

Nonlinear function modules. The most important nonli-

ANALYSIS: $V_{\beta E1} + V_{\beta E2} - V_{\beta E4} - V_{\beta E3} = 0$

If Q_1, Q_2, Q_3 and Q_4 are matched and β s are large, then

$$\frac{mKT}{q} \log \frac{I_1 I_2}{I_3 I_4} = 0$$

But $\log 1 = 0$

so $I_1 I_2 = I_3 I_4$

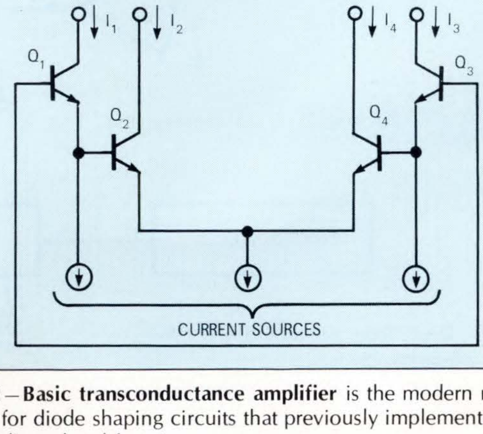


Fig. 2 — Basic transconductance amplifier is the modern replacement for diode shaping circuits that previously implemented most multiplier-related functions.

near function module of today is the multiplier; And it has many relatives—modules for squaring, square-rooting, dividing, and even for correcting pin-cushion distortion in CRT displays. There are also modules for converting the true-rms level of an input voltage to a dc output level. In the late 1960s, diode-shaping circuits were used to implement many of these multiplier-related functions, but now they can best be done by the more sophisticated circuits based on semiconductor transconductance effects.

A simplified transconductance multiplier circuit, with biasing problems ignored, is shown in **Fig. 2**. Techniques for converting the input voltages, usually referred to as X and Y, into currents will vary between designs. But transconductance multipliers generally use this basic configuration to create the product of the currents. The output current is then converted into voltage form, which is scaled to make the output voltage XY/10. Therefore, the output will be a maximum of ±10V as X and Y each vary between ±10V.

The following functions are easily implemented, either by changing pin connections on a multiplier or by modules using the transconductance effect that are committed to these functions.

$E_o = \sqrt{10X}$, where $0 < X \leq +10V$
$E_o = (1/10)X^2$
$E_o = 10\ Z/Y$, where $Z/Y \leq 1$
$E_o = \sqrt{1/2\ (X^2 + Y^2)}$
$E_o = A \log BX$, where A and B are externally-adjustable scale factors and $-10V \leq E_o \leq +10V$

Trigonometric functions are another type of nonlinear operation that's sometimes needed. These functions can be generated using diode or transistor shaping circuits that make segmented straight-line approximations, or by using multipliers to generate a power-series approximation. The specific application often determines the best combination of modules to obtain a particular trigonometric function, and the applications engineers of module companies can often give you some useful design guidelines. Also, customized versions of nonlinear function modules can often benefit both the customer *and* the supplier. The module designer can optimize the design for the specific nonlinear function needed, and in OEM quantities this can mean significant cost savings.

Converter modules. Modules that convert a signal from one form of representation to another can also be classified as function modules, or analog-circuit modules, if one of the signals is in analog form. In the late 1960s there was explosive growth of minicomputer usage in industrial systems. So it isn't surprising that there has also been a steep growth in the sales of modular analog-to-digital and digital-to-analog converters of all types. These converters are used to couple the digital world of the computer to the analog world of transducers, controls and displays.

Most of the measurable parameters of the physical world are analog. Temperature, flow, stress, pressure, pH, and the like are *inherently* analog variables. The conversion from analog to digital may take place inside the transducer, or back at the computer. Economics, reliability, current practice in industry, safety, and the nature of the process or system are some of the factors that determine where the conversion interface should take place. Although most of the modular A/D converters have single-ended analog inputs of ±10V range and parallel outputs of TTL logic, there are also some modular A/Ds with low-level, differential-input front ends. Also, some A/Ds feature serial output.

There are many different techniques of A/D conversion in common use. Two standard techniques for converting are successive approximation and integrating, or averaging. In successive-approximation converters, the input voltage is compared with an analog voltage that is derived from a DAC that monitors the digital output. A sequence of comparisons is made, one for each bit of resolution, and the digital output "successively approximates" the input. The converter first decides whether the input is greater or less than half of full-scale, then 1/4 of full-scale, and so on down to the least significant bit. Since an n-bit converter only needs n clock cycles to resolve n bits, successive-approximation converters can be very fast. Total conversion times of 10 to 20 μsec are common.

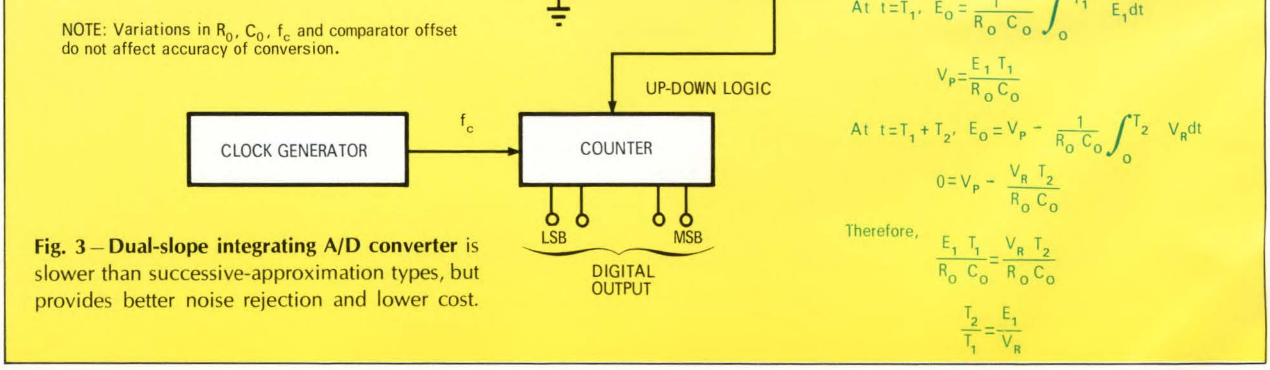


Fig. 3—Dual-slope integrating A/D converter is slower than successive-approximation types, but provides better noise rejection and lower cost.

Averaging-type converters integrate the input voltage over a fixed time interval. A digital count of the time necessary for the integrator to discharge to zero at a constant rate is proportional to the average value of the input voltage. This "dual-slope" technique of averaging, where the integrator input is switched between the input voltage and a reference voltage, is often used. A basic block diagram of a dual-slope converter is shown in **Fig. 3**. Integrating-type converters are inherently slower than successive-approximation types, but they have better noise rejection and are generally less expensive.

Modular D/A converters accept parallel TTL-level inputs, but the analog outputs may be in the form of voltage or current. A very wide range of codes is now available in modular D/As. The terminology isn't standardized, and some D/A converters can accept several different codes by varying external pin connections.

Some other types of modules used in data conversion are sample/hold modules, multiplexers, voltage-to-frequency converters, and special types of D/As, such as multiplying D/A converters (MDACs or ac DACs). The sample/hold modules have two modes of operation—they track an analog input voltage, then hold the voltage upon command of a logic input. This means that they can memorize an analog voltage at a selected point in time.

There is now a broad spectrum of D/A and A/D converter modules on the market that use a mix of monolithic- and hybrid-IC components with discrete parts to reach an optimum combination of price, performance and size.

No one manufacturing technology has yet dominated the scene. Monolithic D/As will certainly lead in the 6- to 8-bit category. For the 10- to 12-bit range, a mix of technologies is being used. DACs using hybrid and/or monolithic technology generally have the edge in minimizing size, while discrete techniques usually have the edge in price and performance. Most 10- to 12-bit modules use a mix of IC and discrete component technology. In the low-drift 12- to 14-bit range, the long-term stability of wire-wound resistors is generally required, and the reference diodes are carefully aged and selected.

There is constant pressure to optimize the cost, size, and performance of modular D/As and A/Ds. There are also constant changes in price and performance of the key components used in these modules. So it appears certain that there will continue to be price/performance breakthroughs in the early 1970s, and that converter modules will continue to use a mixture of technologies.

Using analog modules in industry

If these analog circuit modules are to be more than intellectual curiosities, they must offer economically attractive solutions in the design of industrial equipment and systems. To be sure, each system design problem has its own peculiar design contraints. But some examples that show how modules were used to solve typical system design problems may help trigger ideas as to how to use them in your next system design.

To simplify the circuit diagrams and explanations, ±15V power supply connections are generally not shown. Most of these modules require +15V and −15V power referenced to their own common, which also serves as the electrical common for both inputs and outputs. Many of the A/D and D/A modules also require +5V power. With these points in mind, let's take a look at some typical uses of analog modules in practical circuits.

Instrumentation and computation uses

Systems for instrumentation and computation probably make the most use of analog circuit modules. Instrumentation amplifiers are used to raise the signal levels, and the nonlinear function modules are used to perform operations on these signals. The data conversion modules convert the analog signals to digital form. Following are some typical applications of modules in instrumentation.

Measuring photometric absorption in analytical instruments. Many analytical instruments, such as UV detectors for liquid chromatography, require an output that is directly proportional to the absorbance. But the absorbance is proportional to the logarithm of the ratio of two currents.

To understand the problem, consider the basic principle in photometric absorption measurements: A beam of light is alternately caused to shine through a reference liquid that doesn't contain any of the absorbing substance, and a sample liquid. A vibrating shutter is normally used to alter-

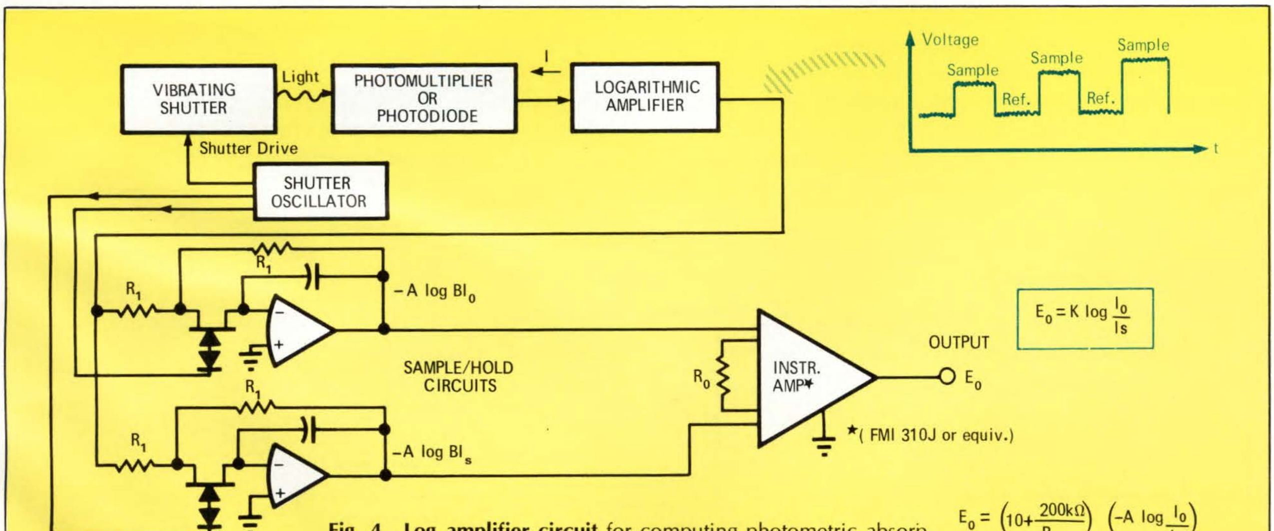


Fig. 4—**Log amplifier circuit** for computing photometric absorption in analytical instruments. Key feature is the cancellation of errors that results from alternate sampling of reference and sample.

$$E_0 = \left(10+\frac{200k\Omega}{R_0}\right)\left(-A \log\frac{I_0}{I_s}\right)$$

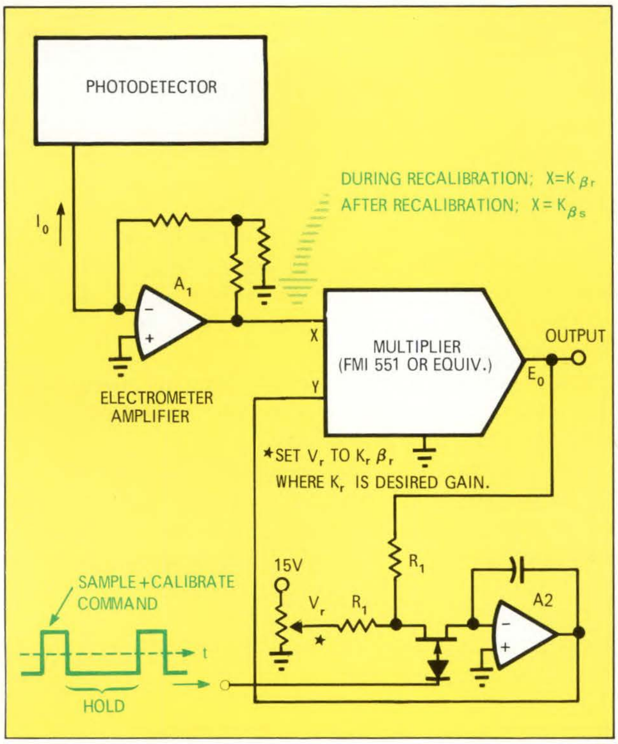


Fig. 5 – Automatic-gain-control circuit for photometers. Input to the photodetector is alternately from a reference lamp and the signal light source.

nate the light. The transmitted light is detected by a photomultiplier tube or solid-state photodiodes. If the photocurrent through the reference liquid is called I_o, and the photocurrent through the sample containing the absorbing substance is called I_s, then the absorbance is $\log_{10}(I_o/I_s)$.

When signal levels are high enough, the photocurrents can be fed directly into a log amp, but if they are too low it may be necessary to preamplify them. Also, if the dynamic range of both I_o and I_s is very wide, it may be desirable to normalize the output by dividing the absorbance by the sum of log I_o and log I_s. A block diagram of a circuit that computes absorbance is shown in **Fig.** 4.

A key feature of this design approach is that long-term variations in light and intensity, photodetector sensitivity, and log-amplifier drift are effectively cancelled out by the technique of alternately sampling between a reference and the sample being measured.

Linearizing temperature sensor outputs. Many sensors have nonlinear outputs that must be linearized and multipliers can be used for this. For example, multipliers can be used to compute the power series $AX + BX^2 + CX^3 + DX^4$.

Automatic-gain-control circuit for photometer use. In some photometric systems, a method of automatically calibrating the gain of a photodetector and amplifier combination is needed. Light input to the photodetector is switched mechanically between a reference lamp and the signal light source. When the photodetector is illuminated by the reference light, the output of a multiplier is compared with a reference voltage to develop a gain-error signal. The gain-error signal drives an integrator, and the integrator output is used to vary multiplier gain.

The circuit is shown in **Fig. 5**. The output of amplifier A1 is KB_r volts when the reference lamp is illuminating the photodetector, and KB_s volts for the signal. K is the overall gain through the photodetector and amplifier A1, and B is the light intensity. At recalibration time, the integrator is gated ON and the output of A2 will vary until

$$1/10\,(KB_rY - V_r) = 0, \text{ or } Y = 10V_r/KB_r$$

The integrator is then gated OFF, and the value of Y is held constant while the signal KB_s is transferred through the multiplier at a scale factor of V_r/KB_r. Reference voltage V_r is set equal to the desired value of gain, K_rB_r, so the actual scale factor will be K_r/K. The signal voltage KB_s is multiplied by K_r/K, so gain variations in the photodetector and amplifier A1 are eliminated and the output voltage E_o will be the desired K_rB_s.

The practical dynamic range of the circuit is limited by the linearity of the multiplier. For example, a range of 100:1 (Y varying from 10 to 0.1V) is feasible when using Function Modules Model 551 multiplier, which has maximum nonlinearity of ±0.1% of full scale.

A frequency discriminator. Combining a 90-degree phase-shifting circuit with a modular multiplier will form a low-cost frequency discriminator. With it, the frequency deviation of an ac input from a nominal center frequency is converted to a proportional dc output voltage. Such a device is very useful for speed control or for frequency monitoring. The circuit for it is shown in **Fig. 6**.

Nominal center frequency, ω_o, is set by the time constant R_oC_o. The phase-shifting circuit has unity gain and a phase shift angle, θ, of

$$\theta = -2 \text{ Arctan } \omega/\omega_o$$

The multiplier computes the product of 10 sin ωt and the phase-shifted signal 10 sin $(\omega t + \theta)$. Low-pass filtering of the product in order to extract the dc component proportional to cos θ can be performed by the output amplifier

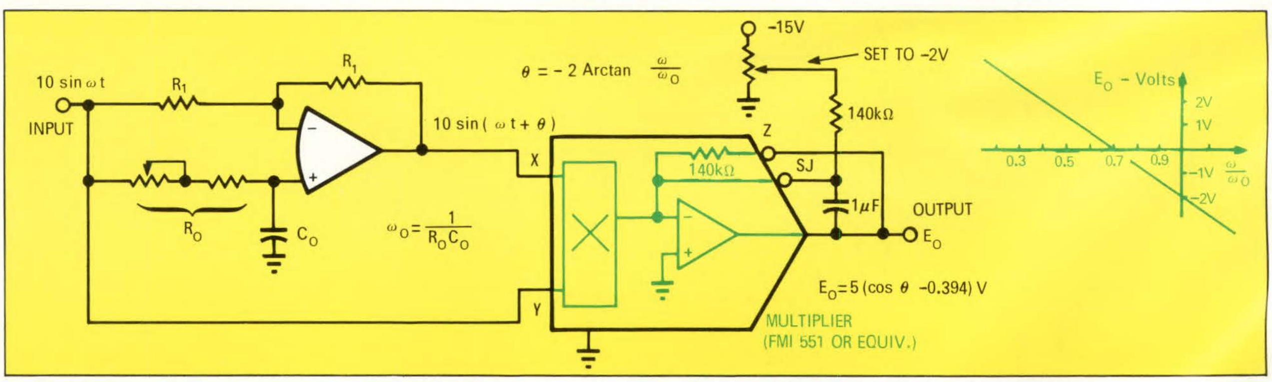


Fig. 6 – Frequency discriminator. Frequency deviation of an ac input from its nominal value is converted to a proportional dc output useful for speed control or for frequency monitoring.

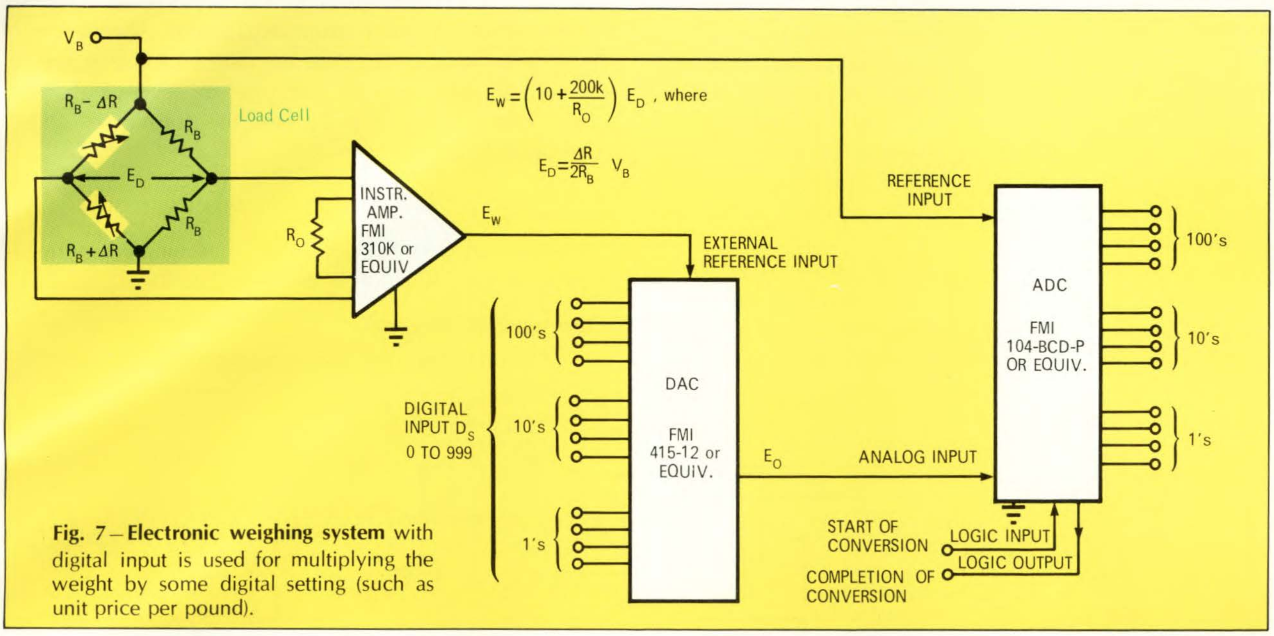


Fig. 7—Electronic weighing system with digital input is used for multiplying the weight by some digital setting (such as unit price per pound).

of the Model 551 multiplier. The cos θ term is related to frequency deviation ω/ω_o by:

$$\cos\theta = \frac{1 - (\omega/\omega_o)^2}{1 + (\omega/\omega_o)^2}$$

This is linear from an ω/ω_o of approximately 0.25 to 1.1—a 4:1 range. An output offset can easily be summed into the multiplier to make the output symmetrical about zero. With peak input of ± 10V and with an output offset of about -2V, the output will vary between ± 2.44V for ω/ω_o of 0.25 to 1.1.

Instrumentation circuit for weighing systems. Electronic weighing systems generally use bonded strain-gage load cells to develop a voltage proportional to the weight of some load. Modular instrumentation amplifiers are usually needed to amplify the load-cell signal, which may have a full-scale output of as little as 5 mV. The amplified signal is often converted into digital form for use in a digital computer or for displaying the weight digitally.

Sometimes there is an extra system requirement that the weight be multiplied by some digital setting. This digital input might be a unit price/pound of the item being weighed, or it might be some useful calibration factor. The capability of multiplying the weight by a digital number will probably be of most use where many different items or materials are being weighed under control of a digital computer.

The product of a digital setting D_s and the weight W_s can be computed by the circuit shown in **Fig. 7**. Here the load-cell bridge impedance is unbalanced by the weight of the load under test, such that $\Delta R/R_B$ is proportional to the weight. This generates a differential voltage E_s that is the product of the bridge unbalance $\Delta R/R_B$ and bridge excitation voltage V_B.

With the modular instrumentation amplifier shown, gain is set by an external resistor R_o. The amplified load-cell output is fed into the external reference input of a DAC that is designed to accommodate a reference variation of 0 to -10V. This DAC can be used as a one-quadrant multiplying-DAC. The DAC output, E_o, will be proportional to the product of the analog input E_w and the digital input D_s. In this application, the output will be positive for a negative reference input. A BCD-coded input (1-2-4-8 per digit)

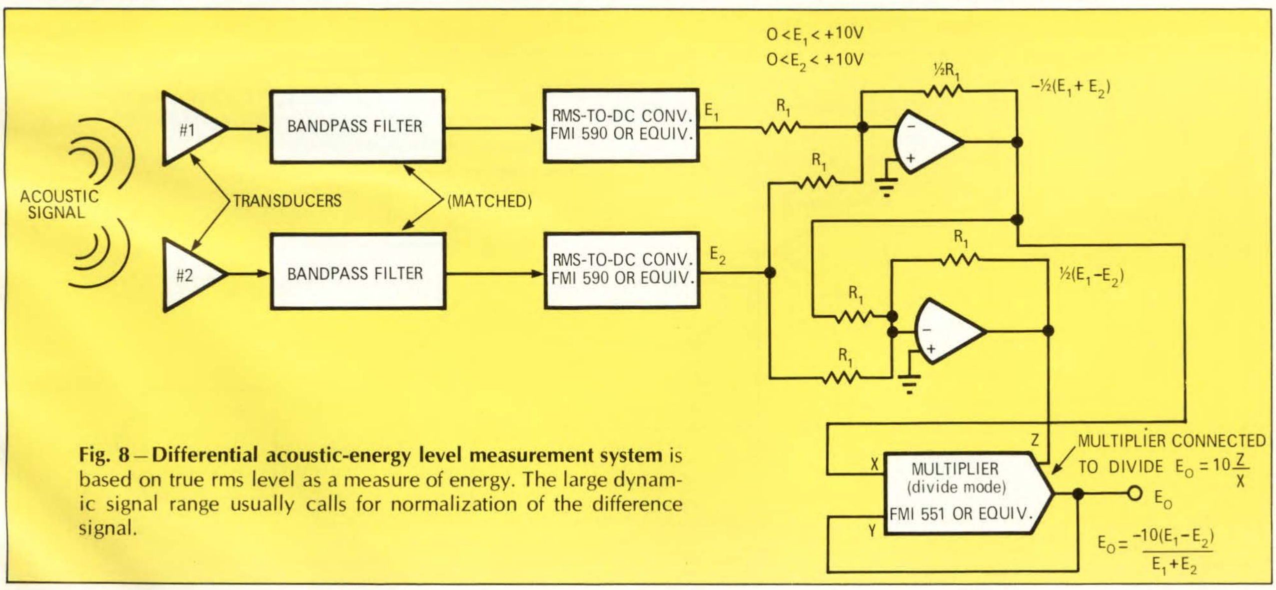


Fig. 8—Differential acoustic-energy level measurement system is based on true rms level as a measure of energy. The large dynamic signal range usually calls for normalization of the difference signal.

is shown, but the input could be binary coded if desired.

A dual-slope integrating A/D converter converts the analog product (out of the DAC) into a digital output. The particular A/D converter shown can be operated in a ratiometric mode by applying an external reference voltage. Then the digital output from the A/D converter is proportional to the ratio of the analog input voltage E_o to the reference input voltage V_B.

Using the load-cell bridge excitation voltage as an external reference to the A/D converter will save some dollars—for the bridge voltage no longer has to be accurate or stable. Because the amplifier output is directly proportional to V_B, and the A/D converter output is inversely proportional to V_B, the net effect of variations in V_B is zero. This means that we can now use a low-cost bridge excitation voltage and the A/D converter doesn't need an expensive internal reference circuit. Using the modules shown, an overall system accuracy of ±0.1% of full-scale is feasible.

Differential acoustic measurements. In acoustic measurements, the energy level of an echo is usually the parameter of interest. A computation of true-rms level will provide such a measure of energy. Also, in some systems, such as monopulse sonar receivers, the difference in rms level between the echos received by two transducers can be used to obtain vector information.

Differential rms measurements are also very useful in testing audio communications equipment. The dynamic signal range is often large, so the difference signal is usually normalized. If we designate the rms level of Channel 1 as E_1 and Channel 2 as E_2, then the normalized difference signal E_o will be

$$E_o = (E_1 - E_2)/(E_1 + E_2).$$

A simplified circuit diagram for computing this normalized differential function is shown in **Fig. 8**.

Information display uses

In addition to their use in instrumentation and computation devices, there also is need for analog circuit modules in many display systems. A/D converters are frequently used to convert analog signals into digital BCD format for driving digital displays. This is fine, but human operators may also want to *see* trend information, particularly for process control systems.

Even in direct digital control (DDC) systems, there is a need for DACs that convert computer outputs to records on a chart recorder, readings on an analog meter, or to a CRT display. In general, the more dynamic the variable of interest the more need there is for an analog display.

Nonlinear function modules, particularly multipliers, are very useful in CRT display systems. The resolving of coordinates, the rotation of a display, and the correction of geometric distortion in flat-faced, magnetically deflected

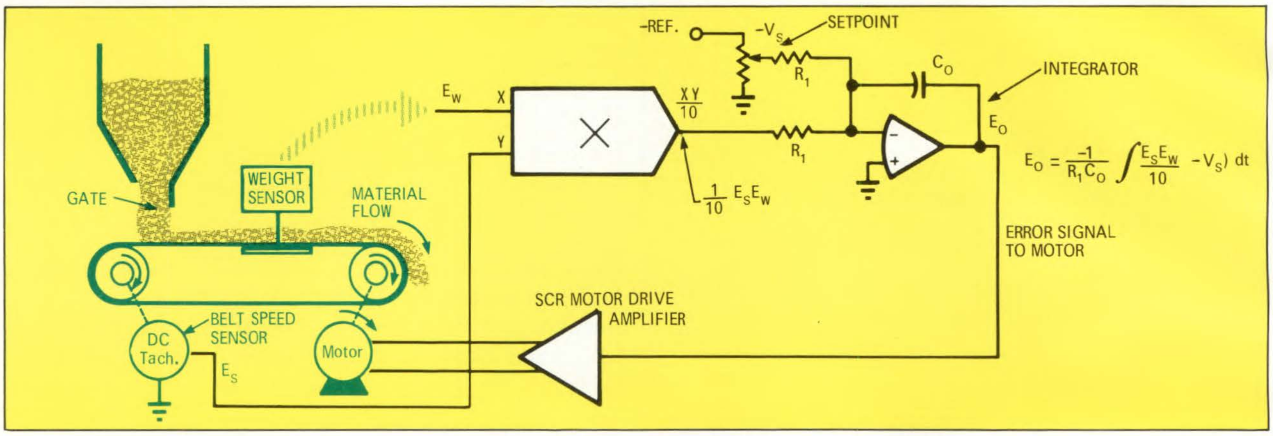


Fig. 9—Continuous proportioning system for automatic weighing applications. Belt speed is controlled to maintain a constant mass flow rate of the material.

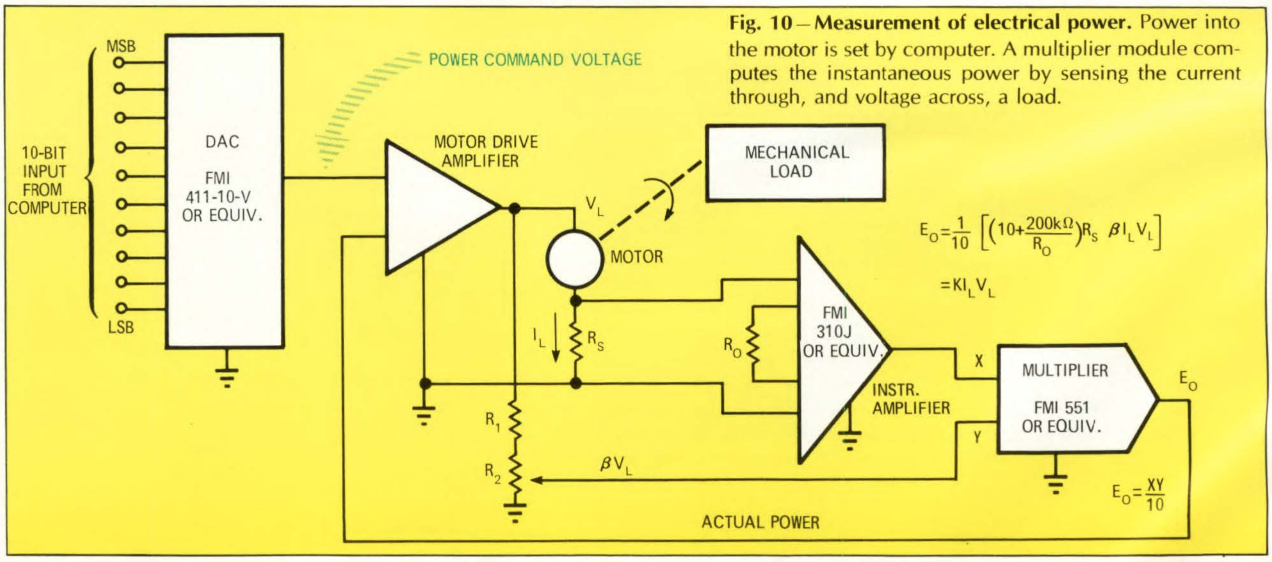


Fig. 10—Measurement of electrical power. Power into the motor is set by computer. A multiplier module computes the instantaneous power by sensing the current through, and voltage across, a load.

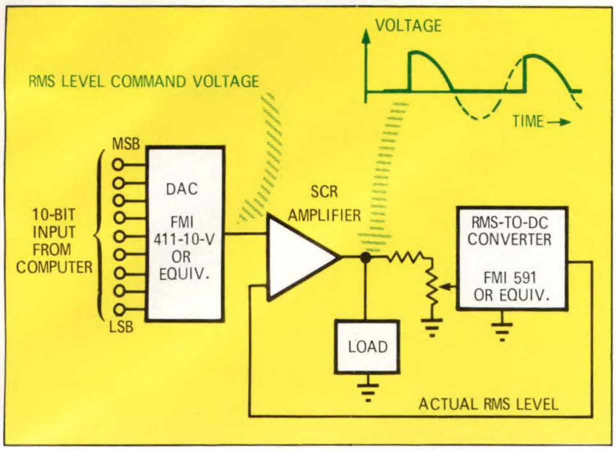


Fig. 11—Servo system for control of rms load takes its level commands from a computer and controls the rms voltage level from a SCR amplifier.

CRTs all require the use of multiplication circuitry. Squaring and square-rooting are commonly needed.

Control systems uses

Analog circuit modules also are extensively used in industrial control systems, where DACs and analog multipliers are particularly useful. Here are some control systems that put these modules to work.

Continuous proportioning system. Automatic continuous weighing is becoming more prevalent in many industries, and particularly so in food processing. Weigh feeder systems are used to proportion foods, primarily solids, that can be belt fed. The purpose of these systems is to continuously control the mass flow rate of a material into some process. To do this, the weight of material per lineal foot of feed belt is multiplied by the belt speed. The product is a weight per unit time. For example, 3 lbs/ft of material times a belt speed of 2 ft/sec is a flow of 6 lbs/sec.

Belt speed can be converted to an analog voltage by a dc tachometer on the pulley, and the weight can be sensed by a suspended platform with weighing bridge in contact with the belt. The electrical signals should be amplified up to a full-scale range of ±10V. The amplified signals, E_w and E_s, are then multiplied to compute their product. The actual mass flow (E_w times E_s) is summed with a setpoint voltage $-V_s$ and integrated to obtain an error signal E_o. The motor speed is made proportional to the error voltage E_o. If the weight of the material varies or the system is disturbed in any manner, the motor will change speed to make $E_sE_w/10$ equal to the setpoint V_s.

Such a system diagram is shown in **Fig. 9**.

Measurement of electrical power. Multipliers, and related circuits such as rms-to-dc converter modules, are very useful in computing power dissipation. The current through a load and the voltage across it are sensed and scaled up to a full-scale range of ±10V. To compute power, the voltage representing current is multiplied by the load voltage. The multiplier provides instantaneous power, so for average power you simply "low-pass filter" the multiplier output. A motor drive system that uses a multiplier for computing power is shown in **Fig. 10**. The power into the motor is set by the computer.

The true-rms value of a waveform is sometimes the desired parameter for control. A circuit for controlling the rms voltage from an SCR amplifier is shown in **Fig. 11**. The desired rms level is set by a digital computer, and a rms converter module senses the actual rms level.

Future developments

This sampling of typical applications demonstrates how valuable analog circuit modules are in systems and instruments for industrial use. While many of these applications may appear very specialized, the design approaches often can be applied to totally different problems.

Using analog circuit modules can help a designer to separate the circuit design problems from the system design problems. With them, he often can take a more sophisticated and effective design approach to his system problem. He may even find that the addition of circuits that compute and feed back information may *increase* the electronics portion of the system cost, but *reduce* total system cost.

Concepts developed during the late 1960s—particularly in adaptive control and optimization theory—can now, with low-cost analog circuit modules, be economically applied to industrial systems and instruments.

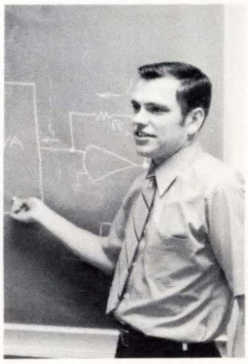
Who is FUNCTION MODULES, INC.?

Although the electronics industry was depressed in 1970, Tom Cate elected to found a new company, Function Modules, Inc., to manufacture analog circuit modules. Here is the reasoning that led to such an apparently risky commitment.

"Large module companies have excellent technical capability, but are spreading their resources over a broad spectrum of products and manufacturing technologies—everything from monolithic IC op amps to sophisticated instruments. This diffusion of resources makes it difficult for them to respond to the needs for their analog circuit module customers. On the other hand, several relatively small companies have specialized in serving narrow segments of the analog circuit module business. Some have chosen nonlinear function modules, and others have focused on A/D and D/A converter products."

Tom believes that neither the large companies with their diffusion of resources, nor the smaller specialists with their limited lines offer what is really needed by many users of analog circuit modules. The new company's aim is to develop a complete line of analog circuit modules, with emphasis on instrumentation amplifier modules, nonlinear function modules, and data conversion modules, such as ADCs, DACs, and MDACs. They will also be responsive to the needs for customized versions of these modules. ▭

Author's biography



Tom Cate, now V.P. of engineering and marketing at Function Modules, Inc. of Irvine, Calif., is well known to EDN readers. Before founding FMI he was product marketing engineer for Burr-Brown. Tom holds a B.S.E.E. from the Univ. of Oklahoma and an M.S.E.E. from Wichita State Univ. Currently he is national chairman of the ISA signal conditioners group.


PERT CPM

Test op amps the easy way with simple step-by-step methods

A few general-purpose circuits are all that are needed. Precautions are provided to avoid pitfalls commonly encountered when testing high-performance op amps.

E. R. Hnatek and **L. Goldstein,** National Semiconductor Corp.

Meaningful testing of op amps has become a controversial issue: test methods and usefulness have been questioned. Test circuits shown in MIL-STD-883 were originally developed for hand testing the first generation of op amps such as the 709. These circuits are not suited for automatic test equipment due to the large number of circuit changes required in a test sequence and because they are mostly for ac testers. Satisfactory testing of present-day op amps such as the 108, 108A and 725 for dc characteristics is not possible with MIL-STD-883 test circuits.

This article discusses the common pitfalls encountered when testing op amps and presents several general-purpose test circuits for measuring the performance of today's op amps that work both for bench testing as well as for automatic test equipment.

Why test an op amp?

There are two basic reasons for testing an op amp:

1. to verify that is is functional;
2. to find out if it meets its data sheet specification limits.

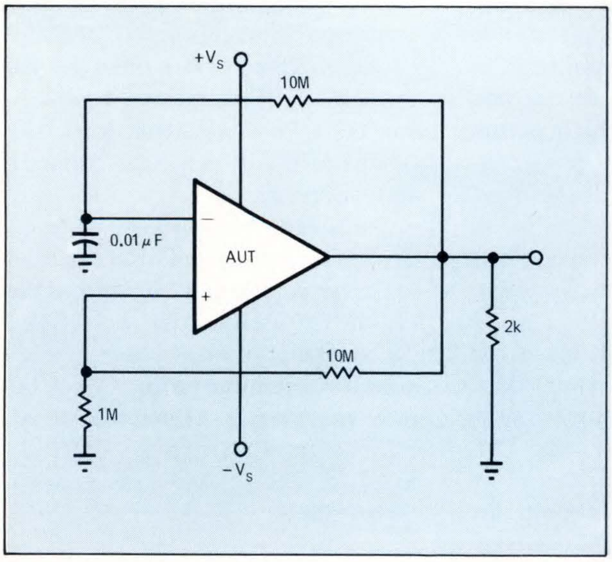


Fig. 1—**Simple functional testing of an op amp** is possible with this basic circuit. It ensures that the amplifier is operational.

If the dc characteristics are not critical, a simple circuit such as that shown in **Fig. 1** may be used. This circuit simply ensures that the device operates and that it will perform its required function. Complete dc testing however requires a more sophisticated test circuit than that of **Fig. 1**. Such a circuit is shown in **Fig. 2**. **Table 1** provides a detailed step-by-step "cook book" approach, using a 741 op amp as an example, to be used in measuring and calculating the data sheet electrical parameters using the circuit of **Fig. 2**.

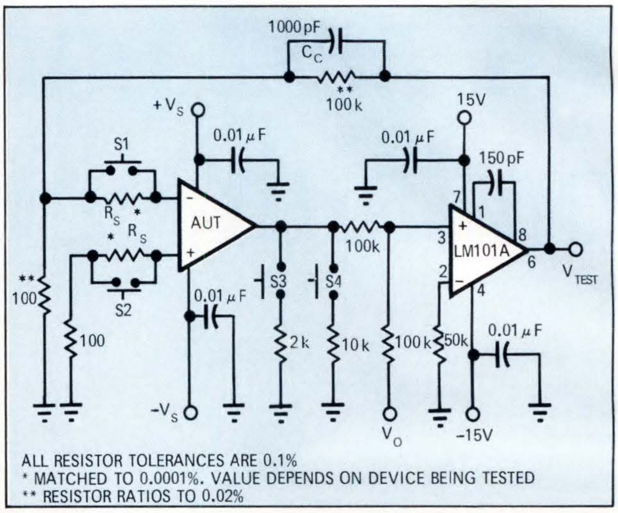


Fig. 2—**Complete op amp testing for dc characteristics** can be achieved with this test circuit. **Table 1** should be used in conjunction with this circuit.

The dc parameters listed in **Table 1** are by no means the only ones by which to judge an op amp's performance. Slew rate and noise are two important op amp characteristics that can be tested by **Fig. 3** and **Fig. 4**, respectively. **Fig. 3a** depicts a circuit suitable for measuring slew rate, small-signal reset time and overshoot. To minimize phase shifts that alter amplifier rise time and overshoot, a small capacitor is added across the feedback resistor. This capacitor compensates for the simulated inductance across the input. For example, the commonly used circuit shown in **Fig. 3b** has a faster rise time and more overshoot than the one in **Fig. 3A**. A 100-pF capacitor is added across the 10-k feedback resistor, in **Fig. 3B** for a more accurate measure of slew rate, rise time and overshoot.

Fig. 4 shows the schematic diagram for a general-purpose op amp noise-test circuit that can measure both noise currents and "popcorn" noise. Note that this circuit is only a slight modification of the one in **Fig. 2**.

To produce low-cost op amps, IC manufacturers keep device handling at a minimum through the use of automatic test equipment. Ac parameters such as gain and phase margins and input and output impedances can be bench tested in specially fabricated test fixtures. However, the added handling time and the special test fixtures required here escalate the device cost.

In some applications the input impedance is important. For dc applications, however the input bias current (I_{IB}) is the limiting factor and is easily measured. As a result, it makes more sense and costs less to measure an op amp's

Table 1. Measuring data sheet parameters

1. Input offset voltage at zero common-mode voltage[1]

a. *Measure:* $V_{test\,1}$ with $+V_S = +15V$, $-V_S = -15V$, $V_O = OV$ (GND), SI and S2 closed; $V_{test\,2}$ with $+V_S = +15V$, $-V_S = -15V$, $V_O = OV$ (GND), S1 and S2 open

b. *Calculate:* $V_{IO}\ (R_S = 100\Omega) = \frac{V_{test\,1}}{1000}$ V_{IO}, $(R_S = 10k\Omega) = \frac{V_{test\,2}}{1000}$

2. Input offset current at zero common-mode voltage[1]

a. *Measure:* $V_{test\,1}$ with $+V_S = +15V$, $-V_S = -15V$, $V_O = OV$ (GND), SI and S2 closed; $V_{test\,2}$ with $+V_S = +15V$, $-V_S = -15V$, $V_O = OV$ (GND), SI and S2 open

b. *Calculate:* $I_{IO} = \frac{V_{test\,1} - V_{test\,2}}{(1000)\ (10k\Omega)}$

3. Input bias current at zero common-mode voltage[1]

a. *Measure:* $V_{test\,1}$ with $+V_S = +15V$, $-V_S = -15V$, $V_O = OV$ (GND), S1 closed, S2 open; $V_{test\,2}$ with $+V_S = +15V$, $-V_S = -15V$, $V_O = OV$ (GND), S1 open, S2 closed

b. *Calculate:* $I_{IB} = \frac{V_{test\,2} - V_{test\,1}}{(2000)\ (10k\Omega)}$

4. Common-mode rejection ratio

a. *Measure:* $V_{test\,1}$ with $+V_S = +3V$, $-V_S = -27V$, $V_O = +12V$, S1 and S2 open; $V_{test\,2}$ with $+V_S = +27V$, $-V_S = -3V$, $V_O = -12V$, S1 and S2 open

b. *Calculate:* $\text{CMRR (dB)} = 20 \log_{IO} \frac{V_{test\,2} - V_{test\,1}}{(24V)\ (1000)}$

5. Supply-voltage rejection ration

a. *Measure:* $V_{test\,1}$ with $+V_S = +5V$, $-V_S = -5V$, $V_O = OV$ (GND), S1 and S2 open; $V_{test\,2}$ with $+V_S = +20V$, $-V_S = -20V$, $V_O = OV$ (GND), S1 and S2 open

b. *Calculate:* $\text{PSRR (dB)} = 20 \log_{IO} \frac{V_{test\,2} - V_{test\,1}}{(30V)\ (1000)}$

6. Positive-gain and positive-output swing

a. *Measure:* $V_{test\,1}$ with $+V_S = +15V$, $-V_S = -15V$, $V_O = OV$ (GND), S1, S2 and S3 closed and S4 open for $R_L = 2k\Omega$ (S3 open and S4 closed for $R_L = 10k\Omega$); $V_{test\,2}$ with $+V_S = +15V$, $-V_S = -15V$, S1 and S2 closed, $V_O = -10V$, S3 closed and S4 open for $R_L = 2k\Omega$
or $V_O = +12V$, S3 open and S4 closed for $R_L = 10k\Omega$

b. *Calculate:* positive gain $= \frac{(+12V)\ (1000)}{V_{test\,2} - V_{test\,1}}$ for $R_L = 10k\Omega$;

or positive gain $= \frac{(+10V)\ (1000)}{V_{test\,2} - V_{test\,1}}$ for $R_L = 2k\Omega$

7. Negative-gain and negative-output swing

a. *Measure:* $V_{test\,1}$ with $+V_S = +15V$, $-V_S = -15V$, $V_O = OV$ (GND), S1, S2 and S3 closed and S4 open for $R_L = 2k\Omega$ (S3 open and S4 closed for $R_L = 10k\Omega$); $V_{test\,2}$ with $+V_S = +15V$, $-V_S = -15V$, S1 and S2 closed, $V_O = +10V$, S3 closed and S4 open for $R_L = 2k\Omega$
or $V_O = -12V$, S3 open and S4 closed for $R_L = 10k\Omega$

b. *Calculate:* negative gain $= \frac{(-12V)\ (1000)}{V_{test\,1} - V_{test\,2}}$ for $R_L = 10k\Omega$;

or: negative gain $= \frac{(-10V)\ (1000)}{V_{test\,1} - V_{test\,2}}$ for $R_L = 2k\Omega$

Note 1: To measure V_{IO}, I_{IO} or I_{IB} at common-mode voltage (**Fig. 2**), the power supplies are manipulated as follows:
for +12 V common-mode voltage, $+V_S = +3V$, $-V_S = -27V$, $V_O = +12V$
for −12 V common-mode voltage, $+V_S = +27V$, $-V_S = -3V$, $V_O = -12V$
Calculate: V_{IO}, I_{IO} or I_{IB} as illustrated above in the examples given for zero common-mode voltage

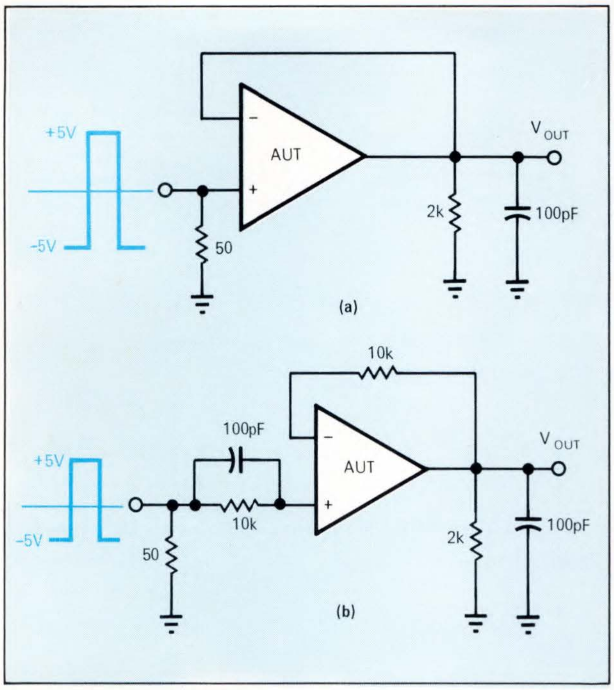


Fig. 3—**Slew rate, risetime and overshoot** can be measured with either of these circuits. Stray capacitance will have little influence on (a), resulting in better correlation between test fixtures than (b) for small-signal risetime and overshoot tests. To measure op amp slew rate accurately, use (b). It has faster risetime and more overshoot due to amplifier phase shift.

input bias current, input offset voltage (V_{IO}) and input offset current (I_{IO}) at common mode extremes than to measure dc input impedance.

Where input impedance coes become important is for frequencies above 1 kHz. Here it is more desirable to add a voltage follower such as the LM110 to the amplifier's input than to test its ac input impedance.

Output impedance depends on closed-loop gain. For most modern op amps, the low-frequency unity-gain closed-loop output impedance is less than 0.01Ω. For applications where the closed-loop gain is less than 40 dB, the output impedance can be neglected. Remember that most op amps incorporate output short-circuit protection, where the output decreases as the load current increases. For integrator applications, the maximum output current is normally limited by the short-circuit-current limit rather than by the output impedance.

Common test-circuit problems

All to often, op amps that show up as bad devices at a user's receiving inspection station or in actual use are in reality good devices because of the test circuits employed and the manner in which they were tested.

To prevent these test-circuit problems, use the test circuit **Fig. 2** and follow the precautions listed below:

1. Check for oscillation of the test loop. Incorrect compensation of the buffer amplifier will cause oscillations which show up as excessive offsets, low gain, high supply current, or as oscillations. A capacitor, C_C in **Fig. 2**, will normally stabilize the loop.

2. When checking input voltage, take care not to cause the inputs of the op amp to break down, as this will degrade input characteristics. This is particularly important when testing devices like the 709 and the 725 which have low input breakdown voltages of 6V.

There are two ways of measuring maximum input voltage. The first method makes use of a current which is forced through the inputs. The subsequent breakdown voltage is measured. This method however is not recommended since it causes reverse base—emitter breakdown of the input transistors and degrades input performance. With the second method, a voltage is applied to the inputs and the resultant current is measured. This method is a much safer one in that it does not degrade the op amp.

3. Check the tolerances of the circuit components. Incorrect tolerances of the circuit resistors can produce a

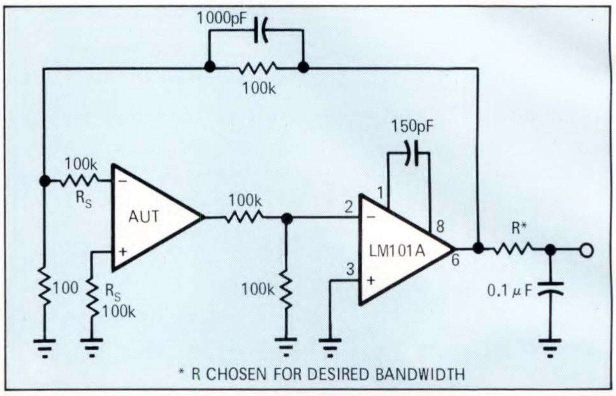


Fig. 4—**Measurement of op amp noise currents** and "popcorn" noise is easily achieved with small variations of **Fig. 2**.

significant measurement error. For example, if the common-mode rejection ratio (CMRR) is being tested by varying the input voltage as shown in **Fig. 5**, resistor matching must be such that the error (twice the resistor match) is small compared to the measured value. If CMRR is to be measured to 80 dB, the resistor match should be at least 100 dB or 1 part in 10^5—a 0.001% match.

When using source resistors (R_S), they must also be matched to minimize the error due to bias-current change with input voltage. This is also necessary when using the circuit in **Fig. 2**. During the era of the 709 op amp, a resistor match of 0.02% was sufficient. For modern op amps, such a match of 2 parts in 10^4 is twice the magnitude of the error that you're trying to measure. This will either add to or subtract from the CMR error of the op amp.

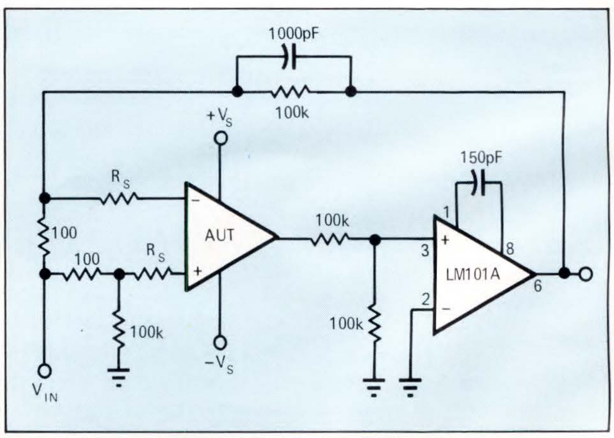


Fig. 5—**Resistor tolerances can produce significant errors** in the measurement of on op amp common-mode rejection ratio (CMMR). The value of the source resistors R_S depends upon the type of amplifier under test.

4. Minimize thermal effects when performing dc tests. Thermal effects are particularly noticeable when making gain measurements—especially where negative or infinite gains are often measured. Thermal effects can be minimized by pulse testing with a very short duty cycle of less than 5%. In this way the instantaneous and time-dependent effects can be observed. With these tests, and even with tests where the junction temperature of the device varies a small amount, the difference between the instantaneous and the final values is dependent on the loop response time. For relatively slow devices such as the 725, the loop response combined with thermal response may be greater than 30 seconds for certain tests.

5. Input and output voltages must not exceed either the supply voltages during usage or testing. Transients that occur when the power supply is turned ON and OFF often result in a higher input voltage than supply voltage. This condition can cause a catastrophic op amp failure. The negative supply voltage or ground should always be applied first or simultaneously with the positive supply to avoid "latch-up" or device destruction. Some op amps can be destroyed when an input voltage is applied to the op amp and both supplies are turned OFF. This turns ON the collector-base diode of the input transistors and grounds the positive power supply while it is OFF.

Device inputs can be degraded if a dc voltage is placed on the output of an integrator or on the input of a sample-and hold circuit and the positive supply is again OFF. If a large capacitor is used the inputs may be destroyed.

A high-voltage diode inserted in each power supply lead will prevent failures cuased by transients and power-supply reversals. Additionally, a resistor inserted in each input will limit the input current caused by high transient voltages. Both of these configurations are shown in **Fig. 6.**

What to expect from an op amp tester

An op amp tester should be capable of checking an op amp's performance over the entire guaranteed operating range. Common-mode rejection ratio (CMRR) must be checked over the entire input voltage range. CMRR degrades at the common-mode extremes. Testing CMRR over a 30V input range provides a large range of measurement accuracy particularly when testing op amps with greater than 100 dB of common-mode rejection.

For devices such as the LM101A and LM107 whose parameters are specified over the entire common-mode range, input off-set voltage, input offset current and input bias current must be tested at the input voltage extremes. The testing of input offset current at the common mode extremes is particularly important because it can detect channels in the input transistors as well as high-temperature failures.

At least one parameter should be tested at the minimum specified supply voltages—power-supply rejection ratio (PSRR). It should be measured by varying both power supplies simultaneously from minimum to maximum values. As with CMRR, a larger voltage excursion permits greater test accuracy.

Gain should be measured either at dc or at low-frequency ac (5 Hz or less) since the gain of most op amps begins to roll off at about 5 Hz (**Fig. 7**).

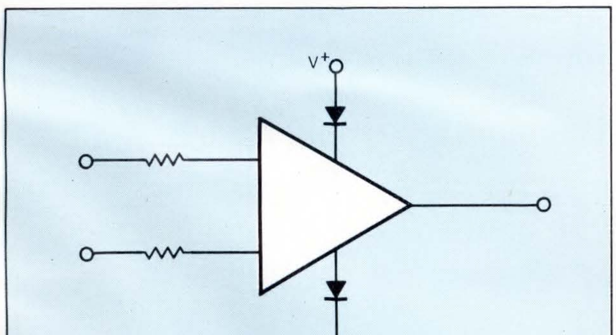


Fig. 6—**To protect an op amp** from power-supper transients and high input voltages, a pair of diodes and two resistors are used.

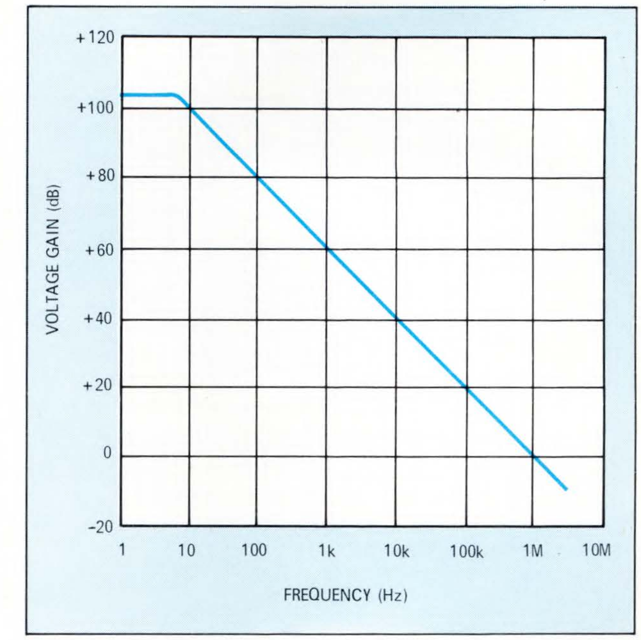


Fig. 7—**Op amp open-loop gain** should be measured at dc to 5 Hz, since the gain of most amplifiers begins to roll off beyond 5 Hz. Frequency response shown is typical for an amplifier with single-pole compensation.

Author's biographies

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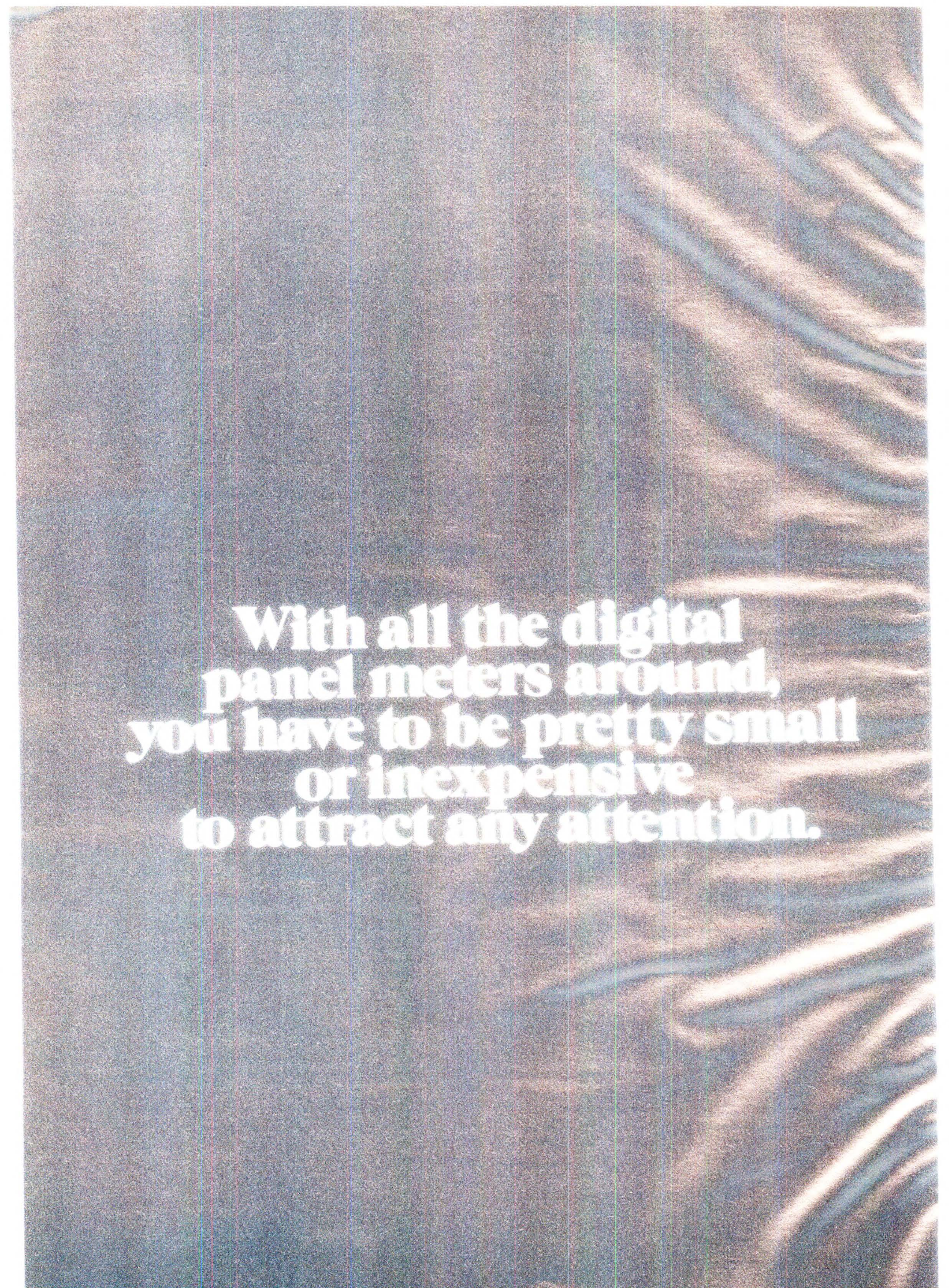
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CIRCLE NO. 14

Don't be confused by IC switching time specifications

A full understanding of such specs is necessary in order to properly design an MSI/LSI system. This step-by-step analysis will help to eliminate the confusion.

John Springer, Advanced Micro Devices

IC data sheets are supposed to help rather than hinder the designer, thus there is no reason why switching time specs should be confusing and misunderstood. These ac specs are obviously very important, but before they can be understood, clear, simple definitions of what they mean must be formulated. A good place to start is by looking at an ordinary TTL, J-K flip-flop. An analysis of this device should cover most ac specs. Once this is accomplished, the same techniques can be used with a simple MSI system. What this will yield is—(1) a set of consistent definitions for switching delays and (2) a method of analyzing ac delays in a large system.

Ground rules for the analysis

The J-K flip-flop used in **Fig. 1** assumes edge-triggered operation; therefore, the data on the input is transferred to the output when the clock goes from LOW to HIGH. The $\bar{C}_d$ input is an active LOW direct clear, which resets the flip-flop regardless of any other inputs. It will be further assumed that the flip-flop is an "ideal" (zero delay) flip-flop, and has delay lines on all the inputs and outputs. This allows us to analyze all the delays involved (**Fig. 1b**).

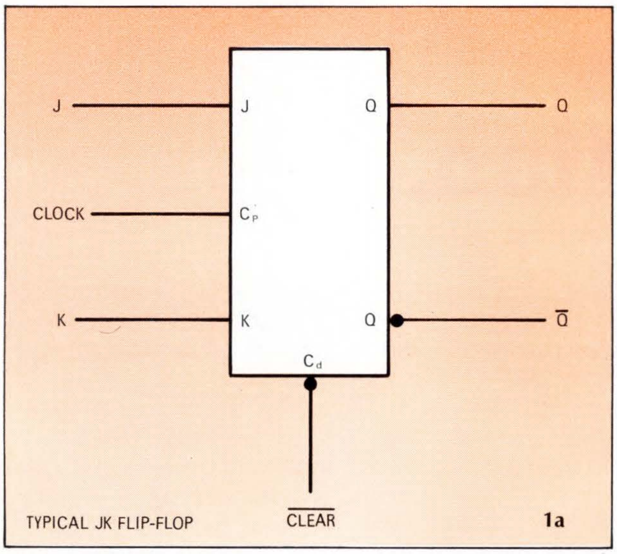
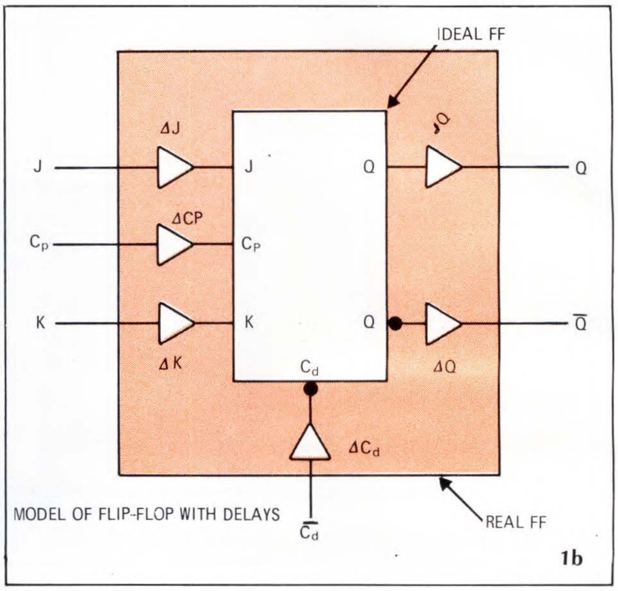
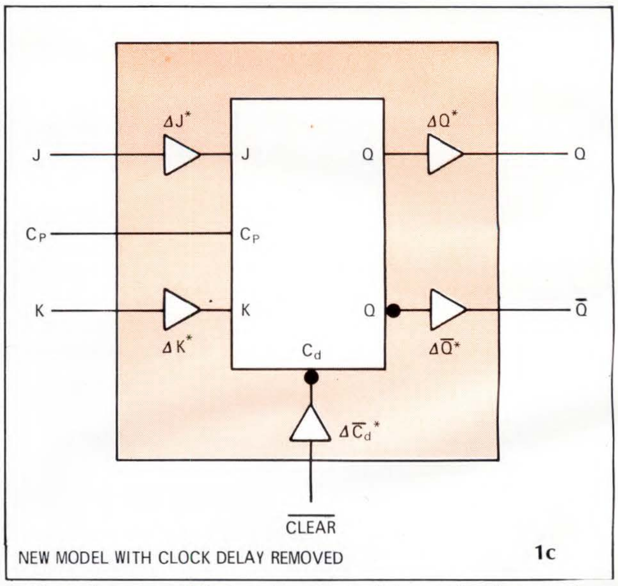


Fig. 1—A typical J-K flip-flop is used to analyze delays listed in IC data sheets.

Each delay element (ΔJ, ΔK, ΔC_p, etc.) has some specific delay for HIGH to LOW transitions and another delay for LOW to HIGH transitions. However, in a real flip-flop everything is usually referenced to the clock signal. Therefore, it is convenient to subtract the clock delay (ΔC_p) from all other input delays and then add it to the output delays, thus leaving no delay in the clock line. This new delay on the J input (ΔJ*) is then $\Delta J - \Delta C_p$; the delay on the output (ΔQ*) is $\Delta Q + \Delta C_p$; and so on (**Fig. 1c**).

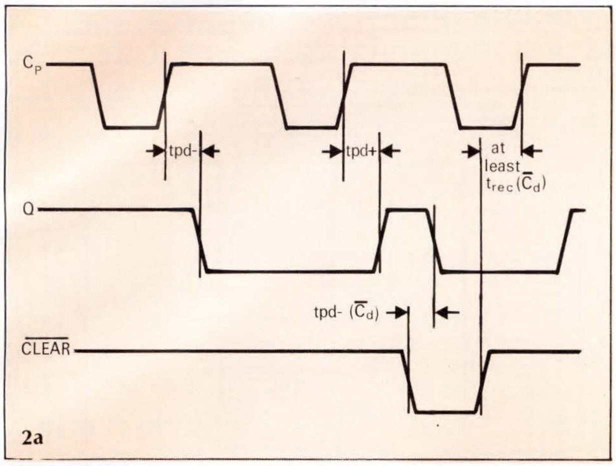




Since it is possible for the clock delay to be longer than an input delay, the new input delay can be either positive or negative. A negative delay simply means that the input can change after the clock changes, yet still get to the ideal flip-flop before the clock does.

Output delays are easiest

The simplest delays to analyze are the delays to the output, designated tpd+ and tpd−, as illustrated in **Fig. 2a**. This shows the behavior of one particular flip-flop. However, since every flip-flop will be slightly different, a large sample of devices will show the delays falling within some range (**Fig. 2b**). The colored areas indicate regions of uncertainty, or the spread in signal changes for a large sample of devices.



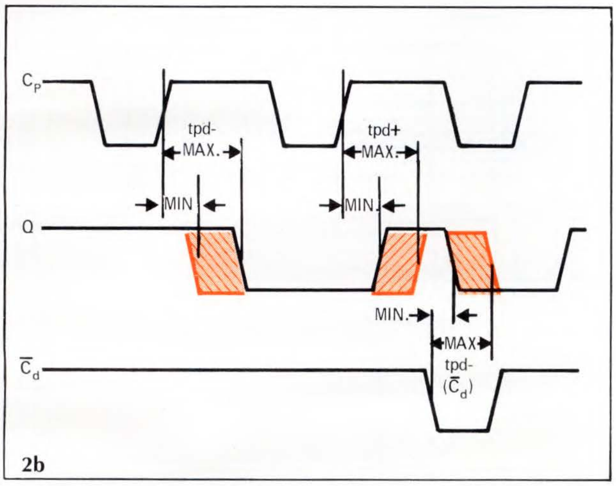


Fig. 2—Timing diagram (a) illustrates delays to the output of a J-K flip-flop. Assume that J-K is HIGH, so the flip-flop is toggling. At some time following the clock edge (tpd−), the Q output will go LOW. Following the next clock edge and after tpd+, the output will go HIGH. Also illustrated is the operation of the direct clear, $\overline{C}_d$. When this input goes LOW, then the output clears after delay tpd−($\overline{C}_d$). The first clock following the removal of the clear command will set the flip-flop, providing that at least t_{rec} ($\overline{C}_d$) (recovery time) has elapsed. This time is due to the ΔC_d + delay in the model. Output delays for a group of flip-flops is shown in (**b**).

A data sheet for this flip-flop should list both the typical and maximum values for the three tpd's shown. Although minimum tpd's are rarely specified, sometimes it is important to have them.

Input delays are a little less clear, and can lead to much confusion. One of the principle difficulties is that the specifications for input timing are often given as the requirements for an input forcing function rather than the device's response to a change at its input. Consider, for example, a set-up time specification. The set-up time can be thought of as the time required for the device to respond to data at its input, in which case it is maximum. Alternatively, set-up time may be thought of as a system requirement which must be met, and then it is a minimum time. Maximum delays in a device will therefore determine the minimum timing for a system, as will be shown later. In order to maintain consistency in the analysis, all delays expressed will be device delays rather than system requirements.

Input timing specifications are generally designated as "input set-up time" and "input release time." For a flip-flop to respond to input data, the ideal flip-flop must see the data before it sees the clock transition. In the model with no delay in the clock line, the input signal is delayed by ΔJ* (or ΔK*) from the clock, so for a given device an input applied after ΔJ* will not be sensed.

The delays ΔJ* and ΔK* are defined as the set-up times for the J and K inputs to the flip-flop; however, they may be different for LOW to HIGH changes than for HIGH to LOW changes. The delay for a change from LOW to HIGH on the J input is designated "t_sH(J)". The delay for a HIGH to LOW change on the K input is designated "t_sL(K)". (Ordinarily only a single set-up time is specified, the longer of t_sH and t_sL.

Fig. 3 shows a timing diagram, including set-up times, for a single flip-flop. No distinction is made between HIGH's and LOW's; however, t_s(J) is assumed to be different from t_s(K).

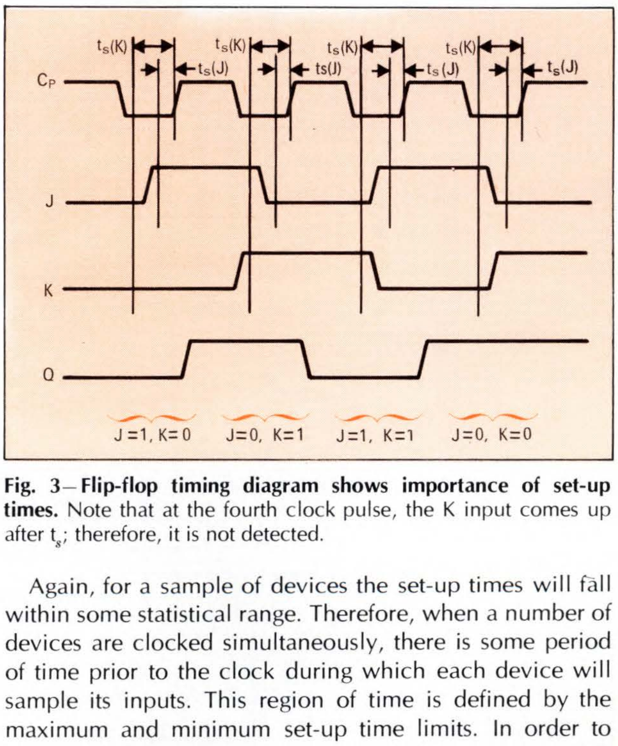


Fig. 3—Flip-flop timing diagram shows importance of set-up times. Note that at the fourth clock pulse, the K input comes up after t_s; therefore, it is not detected.

Again, for a sample of devices the set-up times will fall within some statistical range. Therefore, when a number of devices are clocked simultaneously, there is some period of time prior to the clock during which each device will sample its inputs. This region of time is defined by the maximum and minimum set-up time limits. In order to guarantee that a device will respond to an input signal, that input signal must be present before the clock by at least t_s max. Moreover, the signal must not change until after t_s min.

Some devices require as long as t_s max. to propagate a signal through ΔJ*, and some require only t_s min. The minimum set-up time is often called the "release time," as it is the time after which a signal change is guaranteed *not* to be detected. If t_s min. is negative, indicating that input changes may be detected even after the clock edge, then t_s min. is often called a "hold time."

Reliable operation of a sequential device requires that inputs be steady at all times between t_s max. and t_s min.

Note that if t_sH and t_sL are separately specified, then a HIGH must be maintained between t_sH max. (slowest response to a HIGH) and t_sL min. (fastest response to a LOW). Similarly, LOW's must be maintained between t_sL max. and t_sH min. For example, the switching limits in the table at the right tells us that to detect a HIGH on J or

Parameter	Definition	min.	max.	Units
$t_sH(J,K)$	HIGH data set-up time J and K inputs	0	15	ns
$t_sL(J,K)$	LOW data set-up time J and K inputs	−5	10	ns

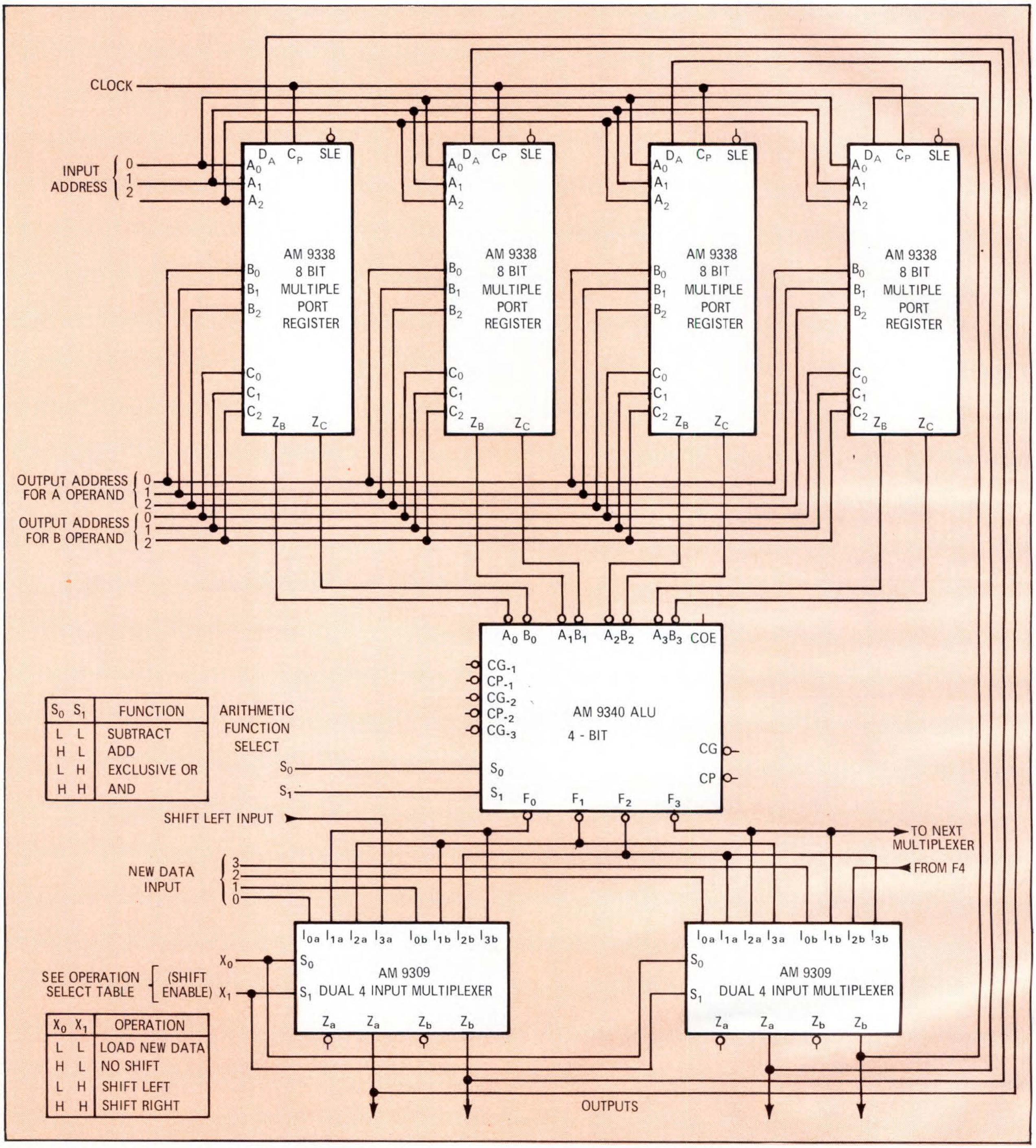
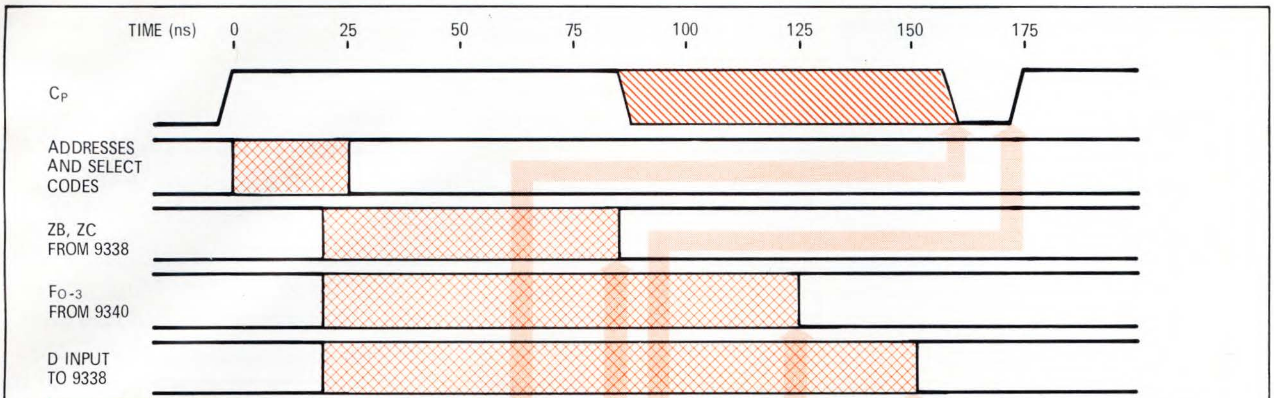


Fig. 5—MSI system is used to illustrate how speed calculations are applied. The Am 9340 arithmetic logic unit adds, subtracts, AND's, or EXCLUSIVE OR's two 4-bit operands, $A_{0\text{-}3}$ and $B_{0\text{-}3}$. The result, $F_{0\text{-}3}$ goes to a multiplexer and then to the inputs of Am 9338 multiple port registers, which are 8-bit synchronous memories. Because it is synchronously controlled by a clock input, its outputs can be fed in a loop back to its input without race conditions occurring. A cycle is initiated by a clock pulse on the Am 9338's, followed by three addresses, which define sources for the two operands, and the location for the stored result. Operation codes are applied to the select inputs of the Am 9340 arithmetic logic unit and to the select inputs of the Am 9309 multiplexers.

The two operands come out of the register following the two read addresses and a delay (tpd, address to output). The result appears at the $F_{0\text{-}3}$ (ALU) outputs after another delay through it and finally arrives at the multiple port register input, subsequent to the multiplexer delay. This result must be at the register input for a full set-up time before the register can be clocked to store the data and begin a new cycle. Minimum timing calculations would be quite difficult without the system in **Fig. 6.**



DEVICE	PARAMETER	DESCRIPTION	MIN.	MAX.	UNITS
Am9338	tpd (BC - Z)	Delay from B and C addresses to Z outputs	12	65	ns
	$t_S(D)$	Data set-up time	3	25	ns
	tpw CPL	Minimum clock LOW time	16	38	ns
Am9340	tpd (AB - F)	Delay from A or B inputs to F outputs	10	40	ns
Am9309	tpd (D - Z)	Delay from data inputs to outputs	8	25	ns

KEY TO TIMING DIAGRAM

Waveform	Inputs	Outputs
(solid line)	Must Be Steady	Will Be Steady
(H to L hatching)	May Change From H to L	Will Be Changing From H to L
(cross-hatching)	Don't Care Any Change Permitted	Changing State Unknown

Fig. 6—A timing diagram like this will determine minimum timing for the system shown in Fig. 5.

1. Assume a clock LOW to HIGH transition at T = 0 nsec initiating a cycle.
2. Also, assume that addresses and operation codes are derived from the same clock and arrive at the devices 20 nsec after the clock pulse. (For this system this is an arbitrary assumption, since it hasn't been indicated where these signals come from.)
3. After the B and C addresses are stable, delay tpd (BC-Z) max. is required before the register output is stable, bringing T to 85 nsec. Note that shortly after the B and C addresses appear, the outputs of all the circuits begin to change because the 9340 select code is also changing, as well as that to the multiplexer.
4. Following delay tpd (AB-F) max., the 9340 output is steady. This bring us to T = 125 nsec.
5. Multiplexer output is steady at T = 150 after tpd (D-Z), and good data finally reaches the multiple port register input. A 25 nsec set-up time is required, so a new clock LOW to HIGH transition can occur at T = 175 at the earliest.
6. Since the clock to the Am 9338 must be LOW at least 16 nsec, it must go LOW at T = 175 − 16 = 159 nsec. It may go LOW earlier, but it should not go LOW until the output of the register has reached a steady state (T = 85). This is because the 9338 is a master-slave type device, and when the clock goes LOW, the output latches up.

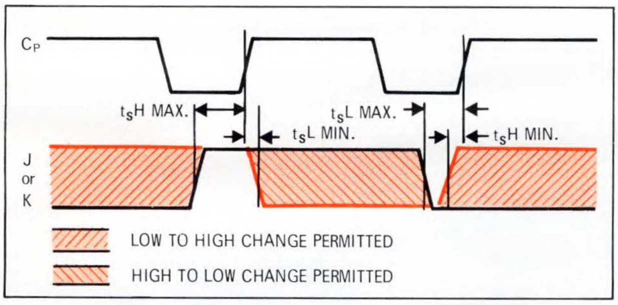


Fig. 4—Variations within a large number of devices require that close attention be paid to minimum and maximum set-up times. The colored areas show where input transitions will not effect system performance. Thus, differences in set-up times from device to device can fall only in the shaded areas.

K, the level must be applied 15 nsec before the clock and cannot be removed until 5 nsec after the clock. A LOW can be applied 10 nsec before the clock and can be removed coincident with the clock. The timing diagram in **Fig. 4** indicates the regions during which data can change.

An example demonstrates the technique

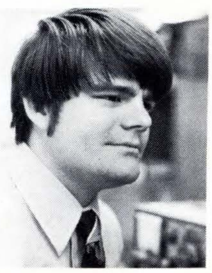
In order to better understand how these speed calculations and analysis are applied in an MSI system, consider the arithmetic processor illustrated in **Fig. 5**. Parameters required to define minimum timing for this system are listed in **Fig. 6**. By using these numbers, the system timing diagram can be constructed.

Such an analysis is quite simple and can be used to determine the maximum operating frequency of any system. The type of diagram developed in **Fig. 6** is absolutely essential to the design of a reliable memory system or of any system which is fed back upon itself. Semiconductor manufacturers are generally quite conservative when they specify maximum ac delays for their devices; therefore, a system designed around data sheet limits should operate reliably, with room to spare.

Minimum delays through devices, which are important in "pipelined" systems, can be assumed to be 50 percent of typical delays if they are not specified. The distribution of delays through IC's is not "normal Gaussian." It is "instead, log normal," with a steep slope on the low side of the peak and a long tail on the high side. Thus, most IC devices will have delays between 20 percent less and 50 percent more than the typical listed value. ▭

Author's biography

John Springer is an applications engineer for MOS and memory products at Advanced Micro Devices, Sunnyvale, CA. He was previously a member of Fairchild Semiconductor's applications department. John received his BSCh from College of Idaho and MSCh from Oregon State University.



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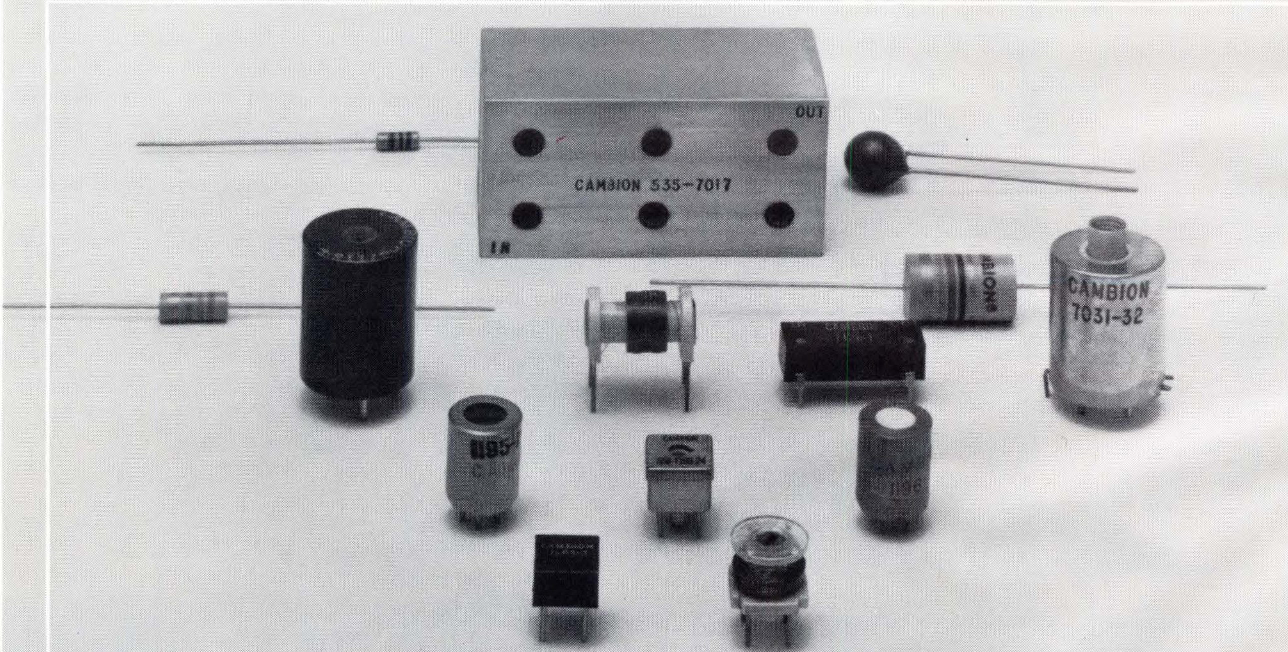

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ANOTHER MYTH DESTROYED.

Myth: National doesn't make FET op amps. And, even if they did, they probably wouldn't be as good as bipolar devices. And, besides, everybody knows that FET op amps have lousy offset voltage and drift specs. And, FET op amps are too expensive. And, anyway, why not just go to a module house in the first place...

Fact: National does make FET op amps. A "family" of five devices, to be exact. Including the super precise new LH0052 (with an offset voltage of 0.1mV, an offset voltage drift of just 5μV/°C, and bias current of less than 1pA); the LH0022 (high performance good general purpose FET op amp); the LH0042 (lowest cost FET op amp on the market with even better performance than cheap module designs); the LH0033 (at 1500V/μS, the fastest voltage follower available anywhere); the LH0032 (a 500V/μS device); and coming soon: The precise-and-speedy new LH0062 (slew rate, 80V/μS; bandwidth, 15MHz; settling rate, 800nS). Significantly, each of the above was designed and manufactured completely in-house using a special chip construction technique combining the best of J-FET and bipolar technologies. All of which goes to show that FET op amps are, indeed, alive and well at National Semiconductor Corporation, 2900 Semiconductor Drive, Santa Clara, California 95051. Phone (408) 732-5000. TWX: (910) 339-9240. Cable: NATSEMICON.

NATIONAL.

CIRCLE NO. 16

Bob Fillingham and Carlos Chong of Nemonic Data Systems

speak out on plated-wire memories

Cores, semiconductors, plated-wire . . . where is each best? How will they divide the huge memory market of the mid-70's? Here are some answers and predictions.

Plated-wire memories will soon account for a major portion of the random-access memory market. The independent (non-IBM) computer market for 1973 is projected at about $2.5 billion. Of that $2.5 billion, approximately $625 million will be spent on high-speed random-access memories. Plated-wire memories will account for over $170 million, or more than one-tenth of the 1973 market.

The weak markets of 1970 and '71, while slowing the growth of all memory makers, have actually put plated wire into a very sound position for growth.

All but one or two semiconductor-memory makers have lost vast sums of money. Some of them are no longer in the market place at all. The core-memory houses are not all in the same serious loss positions but have been forced into alarming price and profit-erosion situations. Plated-wire manufacturers have not escaped unscathed; no one has. But the plated-wire companies that survived have managed to show promising expansion and have not generally been forced into the cost cutting that has been so injurious to the semiconductor and core manufacturers. The reasons for plated wire's excellent position are the very reasons that the core and semiconductor manufacturers have been hurt. First, the slowdown or stoppage of large capital expenditures by many major users have given them time, and reason, to take another hard look at various random-access memory technologies.

Many large orders that would by default have gone to core memories 2 years ago, will go to plated wire next year.

Secondly, many users who would have purchased semiconductor memories have been forced into a "holding position" by the continuing evolvement of technology and price. This industry is literally boiling, and until some standardization and stability is established, many potential users will go elsewhere. Many of these customers will select plated-wire memories.

The semiconductor-memory manufacturers are still in for a few more hard years because main-frame manufacturers, who have typically gone out-of-house for about 60 percent of their memories, will change this policy as they shift to semiconductors. Most of them will, as IBM already has, bring their semiconductor capability in-house. All indicators seem to point to a reduction in the number of semiconductor-memory manufacturers in the next few years. Paradoxically, this will occur when the dollar volume of their industry is making a significant increase.

Make no mistake though; semiconductor memories are for real. They will, in time, account for a healthy portion of the high-speed random-access memory market.

Core memories have continued to dominate the market by sheer momentum. It's hard to believe that core memories could dominate the field as long as they have, but this cannot continue. The speeds already attained by semiconductor and plated-wire memories are totally beyond the capabilities of core. More important is the difficulty of automating core-memory fabrication. Both semiconductor and plated-wire technologies are readily automated, and eventually this will force core out of it's last stronghold—mass-storage memories. Plated-wire memories can already meet core prices head-on from about 16K words up. Half-million-bit plated-wire memories are now being delivered at a shade over 0.1 cent per bit.

Five-million-bit plated-wire memories in reasonable quantities (say 10 to 20 units) could be delivered today at around 0.7 cent per bit.

Core manufacturers are hard pressed to meet such prices, and the inherent speed advantage of plated wire will swing many users away from core memories.

"Most really big semiconductor manufacturers aren't pushing memory technology. They are just keeping up now, but once the industry stabilizes, they'll make a drive of their own, force most of today's technological and price leaders out of the market, and walk off with all the marbles."

"Fabrication techniques used in plated wire give us an enviable jump on semiconductor yields. We monitor the magnetic characteristics of the wire continuously as it comes from the plating tanks. When an anomaly occurs, we only lose a few inches of wire. We have practically a 99.99 percent yield from raw material, and better than 70 percent on a time-productivity basis."

If core memories have one feature that makes them attractive, it is nonvolatility. Loss of line power does not affect data stored in the memories. Plated wire shares this feature, but semiconductors do not. In general, power loss means data loss in a semiconductor memory. This, no doubt, is one of the areas that semiconductor makers are working on right now. They will probably solve this problem, but the solution will add greatly to their cost. For this reason, we feel that it will be a long time before semiconductor memories make any strong inroads into the bulk-storage market.

Plated-wire memories have only recently begun to penetrate the mainframe market in this country. The United States has lagged behind Japan and Europe in this respect. Japanese and European manufacturers couldn't sell a technology that was "just as good", and were looking at cost-effectiveness more objectively. They came to the same conclusions that are now being reached in this country; that plated wire is the next step in high-speed random-access memory technology.

One of the most difficult obstacles for any new technology to overcome is "old-thinking" on the part of engineers and managers.

For some reason, "old-thinking" can begin at any age. There are engineers today who are still designing new systems around core memories. They are doing this because they designed with cores when they were 21 years old and are very comfortable with core designs. It doesn't matter whether they are 25, 35 or 85 today. If cores work well for him, the "old-thinker" is unwilling to change until he is forced to. The "old-thinking" manager is a little easier to understand, especially if his background is nontechnical.

It is very had to convince someone who has no scientific bent that a millionth of a second is really much slower than a billionth of a second. They just can't relate.

Further, a large segment of management tends to put a heavy bias on the cost portion of a cost-effectiveness analysis. One legitimate factor which has helped the "old-thinkers" stick to cores is a nearly 20-year documented reliability history. Fortunately for the newer technologies, there are "new-thinkers" of all ages in both engineering and management who are willing to learn new techniques and who really understand cost-effectiveness. Plated wire, by now, has achieved a good history of reliability as have semiconductors—if not as components of IC memories, at least in other IC configurations. Finally, the outright price advantage of core is all but gone.

One area that will greatly aid the growth of plated-wire memories is the booming minicomputer market. As more and more minis are placed in the "hostile" environment of factories, in the process-control roles for which they are ideally suited, the demand for plated-wire memories will increase. Plated wire is uniquely qualified for such applications because of its speed and nonvolatility.

Several other technologies such as bubbles and opticals are on the horizon. Neither have shown their true potential yet, and it may be years before it is realized. One thing that seems apparent at this time is that the next generation of memory technologies will be much more specialized. They probably will not even have the capability to fulfill the entire spectrum of memory applications that today's technologies have. There are reasons why you wouldn't want to—but could—design an entire computer today with buffer, main store and bulk store memories using all plated wire, or all semiconductor, or all ferrite core. This ability very likely will not exist in the next generation. Bubbles seem destined only for massive bulk storage applications, competing with tapes and discs. Optical memories, thus far, have found their way into only a few read-only memories.

Evolution in the near future, for plated wire, seems to point to "mini-wire". Presently most plated wire is 5-mil

"Magnetic-core memories have been around too long already. Their share of the market will, within a few years, be divided among plated-wire and semiconductor memories, and perhaps one or two very specialized new technologies."

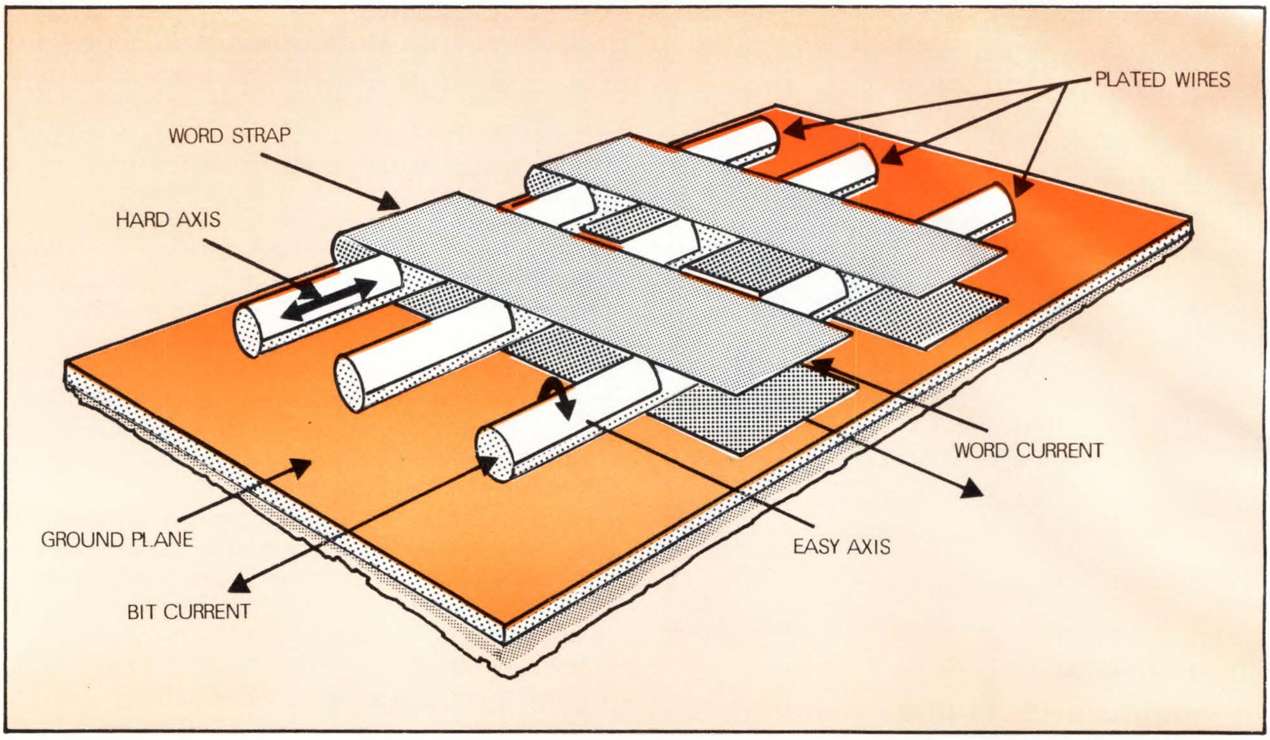

Fig. 1—Plated wire consists of a magnetic film electrodeposited around a cylindrical substrate. Presently, 0.005-inch diam beryllium-copper wire is the most commonly used base material. To eliminate surface defects, the wire is polished and plated with copper prior to the deposition of the memory element, which is a zero-magnetostrictive nickel-iron composition of approximately 81 percent nickel and 19 percent iron. Plated wire has a non-isotropic magnetic structure that has an easy axis in the circumferential direction resting in either clockwise or counter clockwise sense. This represents the binary form of the stored information. Each intersection of a plated wire and a word strap is a storage cell for a bit.

In writing, the plated wire serves as its own bit wire. At the same time that the magnetization vector is partially rotated by a word-current field, a small current is driven through the bit wire. This current generates a circumferential field that orients the magnetization in the proper direction. In other words, writing is a coincident-current operation in which the bit current must be large enough to switch the film under the word strap, but small enough not to disturb the film under the inactive word straps.

In reading, the plated wire serves as its own sense line. Word current creates a field that switches the film's magnetic vector 45 degrees at the intersection. This change causes a flux change to induce a positive or negative voltage, depending upon the information stored in the line. When the word current is removed, the vector returns to the original orientation.

diam but mini-wire systems now being introduced use 2-1/2-mil or smaller wire. 2-1/2-mil is about the limit of today's technology because the lack of rigidity in smaller sizes makes the wire very hard to handle in the assembly operations. The advantages of mini-wire are readily apparent. Packing density (bits per in^2) is more than doubled. Drive current is reduced to 40 percent, providing better compatibility with low-power IC drivers. The net result will be even lower initial prices, smaller packages, and lower power dissipation.

Today a designer has the choice of three technologies. If you can live with 750 nsec to 1 μsec or slower, and if price is very important, you may buy a core memory. There are so many standard core memories that you can probably find an off-the-shelf one that will suit your purpose. If you need much higher speeds, if volatility is not a problem, and if price is not of primary importance, you will want to take a hard look at semiconductors, especially for smaller size memories, say 50K-bit and under or for short production runs. If you need non-volatile information storage, if price is important, and if you can make use of the speed and savings in associated circuitry that accompany a non-destructive readout, you will find a plated-wire memory very attractive. Welcome to the club! ▭

Authors' Biographies

Bob Fillingham is President of Nemonic Data Systems. Before he came to Nemonic, Mr. Fillingham was the director of the memory products department of Stromberg-Carlson, and was responsible for the total activity pertaining to the manufacture and marketing of plated wire memories. Mr. Fillingham's engineering experience started with the Univac Division of Sperry Rand where he was assistant project engineer assigned to Ramo-Woolridge on the Univac 1103A computer.

Mr. Fillingham has attended the Univ of Denver and California State College while working toward a BS degree. He is affiliated with IEEE and ISA.

Carlos Chong is Vice-President of Nemonic Data Systems. Mr. Chong was formerly the chief engineer of the advanced engineering department of Ferroxcube Corporation and, in this capacity, was responsible for plated wire memory development for both commercial and military application. Mr. Chong has a B.S.E.E. with honors from the Univ of California—Berkeley and has taken graduate courses at the Univ of Washington and the Univ of Pennsylvania. Mr. Chong has been awarded five patents and has six others pending. He is a senior member of IEEE.

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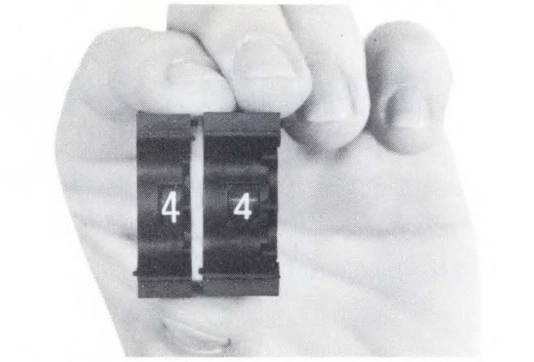

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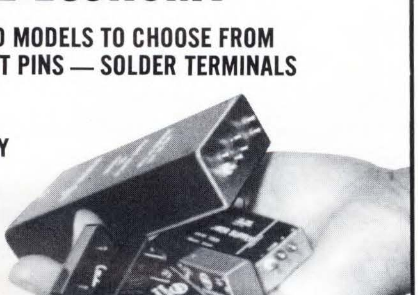

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CIRCLE NO. 35

Don't neglect the solid-state switch

Now that the driver is contained in the same package as the analog switch, this versatile component should be a standard item in the circuit designer's bag of tricks.

Dave Fullagar, Intersil, Inc.

The analog switch performs the same function as a reed relay. It is remotely controlled and has sets of contacts which can operate as single-throw or double-throw switches. A total comparison with reeds is misleading, however, since the solid-state analog switch is capable of usage in many applications where reeds cannot be considered. They are much faster, smaller, and more reliable than their mechanical counterparts. And prices are low. Most important, analog switches are easy to use.

Despite all the advantages of the analog switch, many

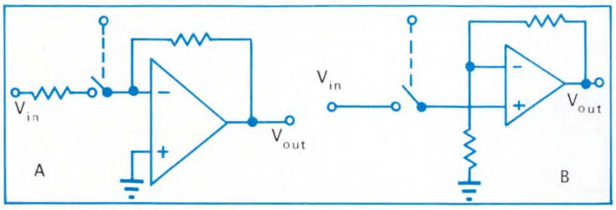

Fig. 1. Simple drivers can be used when the analog switch is placed at the summing point of an op amp (a). **When the switch FET sees the full analog signal swing,** more elaborate drivers are required (b).

designers appear reluctant to make full use of their potential. This is probably due in large part to bad experiences with do-it-yourself driver designs. As many designers found out, it is by no means simple to ensure that the FET switch stays off when it is supposed to be off, and remains on when it is supposed to be on. The problem is com-

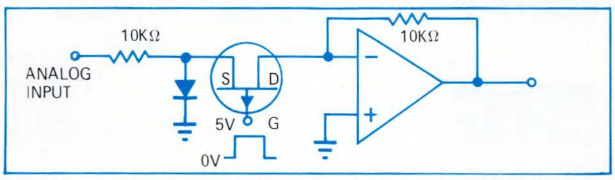

Fig. 2. For simple applications of the Fig. 1 type the analog switch circuit may be just an FET and a diode.

pounded when ±10 volt analog signals are being handled.

The introduction of complete switch/driver combinations in one package has eliminated these uncertainties. The control-signal logic levels are TTL compatible, and all the necessary circuitry to ensure correct operation of the

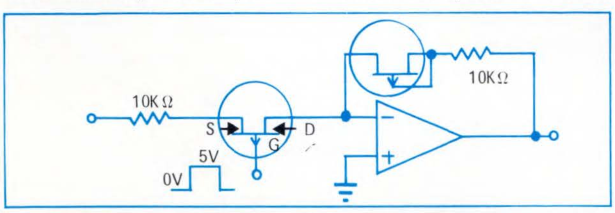

Fig. 3. The high on-resistance of P-channel FETs can be cancelled by using an identical FET in series with the op amp feedback resistor.

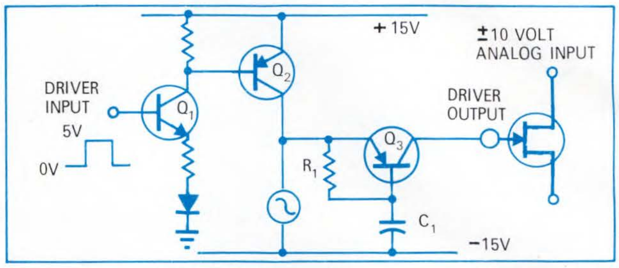

Fig. 4. The driver must hold the N-channel J-FET in the correct state for the ±10V input signals.

FET or MOSFET switches is contained within the integrated circuit.

It isn't necessary to understand the design details of the driver portion of an analog switch/driver combination to use the complete IC, but some appreciation of the circuit operation may help in quickly selecting the most appropriate part for a given application.

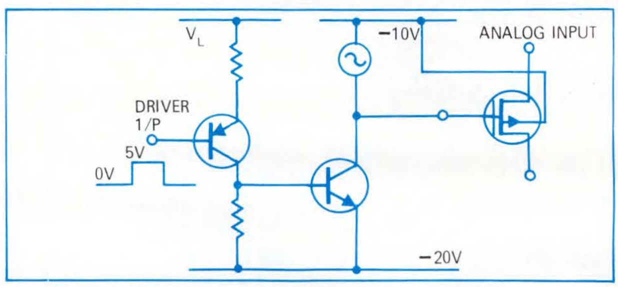

Fig. 5. For a MOSFET switch the driver switches the MOSFET between the +10V and −20V supply lines.

Two types of drivers are used

For J-FETs, two types of driver designs are in use. The simplest is suitable for all applications where the switches are placed at the summing junction (virtual ground point) of an operational amplifier (**Fig. 1a**). For applications where the FET sees the full analog signal swing, **Fig. 1b** for example, a more universal driver design is used.

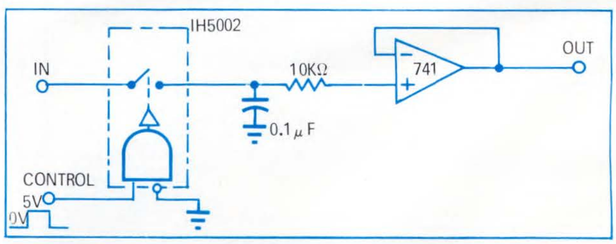

Fig. 6. Low-cost sample and hold circuit uses the IH5002, which is a 50Ω on resistance J-FET driver/switch combination packaged in an 8-lead plastic DIP. Switching time at 25°C is guaranteed to be <1μsec. The decay rate in the hold mode is dependent on the 741 input current, and is typically 800μV/msec.

The virtual ground concept is important since the signal amplitudes appearing at the switch are small, even though V_{in} and V_{out} (**Fig. 1**) may be large. This greatly simplifies the circuit design of the analog gate; each channel simply consists of a P- channel FET and a diode (**Fig. 2**). Costs as low as $1 per channel are realized with the Intersil IH5009/5010 family using this approach (**Ref. 1**). A recent market survey has shown that more than 70 percent of analog switching is performed at a virtual ground point.

The finite on-resistance of the P- channel FETs may be compensated for by using an additional FET in the feedback

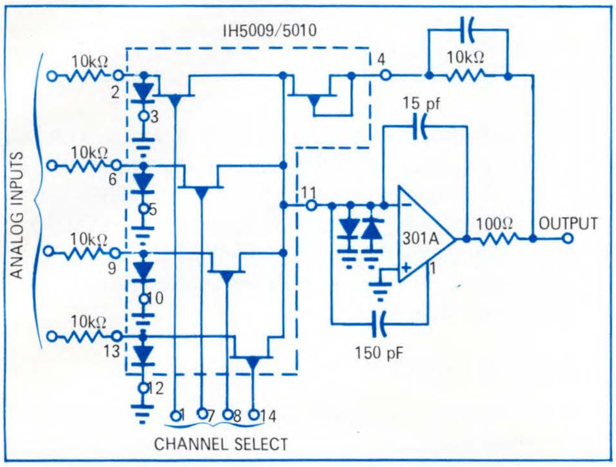

Fig. 7. Low cost 4-channel multiplexer makes use of the extra FET in series with the feedback resistor, effectively cancelling the switch resistance. The 301A hooked up as shown will slew at about 10V/μsec, and the overall multiplexer settles to 0.1% in about 1.5μsec.

loop (**Fig. 3**). As an example, an extra FET for this purpose is included in the IH5010 package. The $R_{DS\ (on)}$ of this FET is guaranteed to be within 50Ω of the other FETs in the package. Selections down to 5Ω match are available. By this means, the effective switch resistance can be reduced by a factor of 30, from 150Ω to 5Ω.

Typical J-FET and MOSFET drivers

In applications where the switch sees large analog signals, or where lower on-resistances are required, an N-channel J-FET is used. In these cases the driver must ensure that the FET remains in the correct state for ±10V

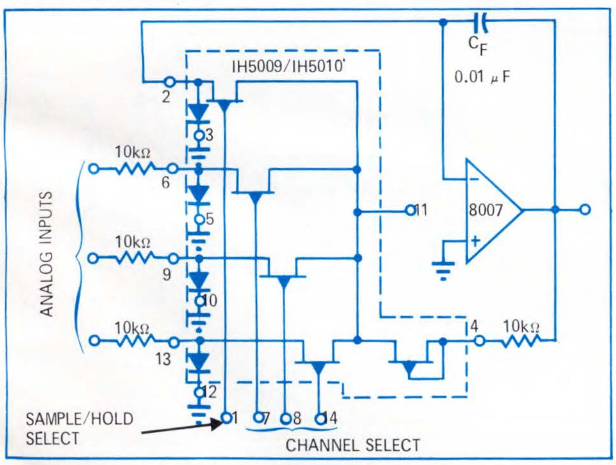

Fig. 8. In this 3-channel multiplexer with sample and hold, three out of the four switches are used to perform the multiplexing. The final switch controls the sample and hold. The signal decay rate in the hold mode is determined by C_F, and the worst-case leakage of the 1H5009 (200 pA).

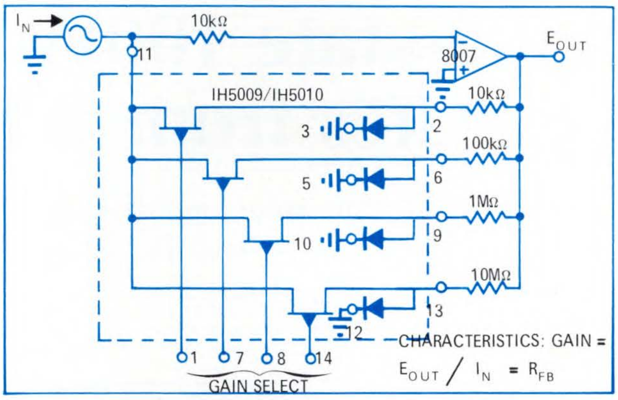

Fig. 9. A typical gain-programmable amplifier is shown. This one shows a current-to-voltage converter using J-FET switches and an 8007 FET input amplifier.

input signals. A simplified schematic of such a driver is shown in **Fig. 4**.

When Q_1 is off, Q_2 is off and the FET gate is held at -14.3V. For $V_p < 4$V, the FET will remain off for ±10 inputs. When Q_1 is turned on, Q_3 is turned on momentarily. The time is arranged to provide the optimum charge at the FET gate to switch it from the off to the on state. When

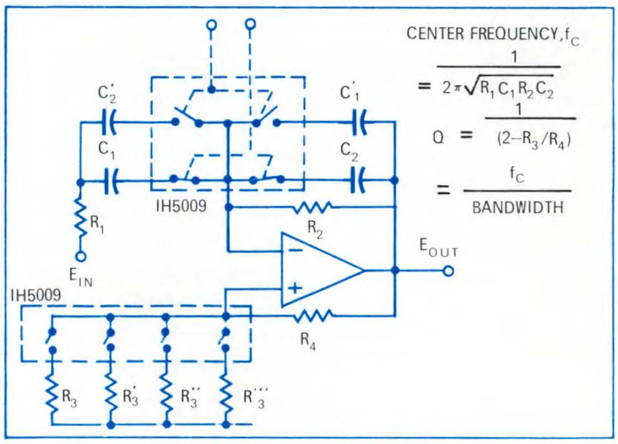

Fig. 10. Tunable bandpass active-filter features independent control of center frequency and Q. The analog switch in the negative feedback loop determines the value of f_c, while that in the positive feedback loop programs the Q.

a MOSFET is used, the driver simply derives -19V to $+10$V from the 0 to $+5$V TTL input. A circuit such as that shown in Fig. 5 does the trick.

Applications show advantages

A cross-section of the many possible circuit applications for solid-state analog switches is shown in **Figs. 6 through 11**. □

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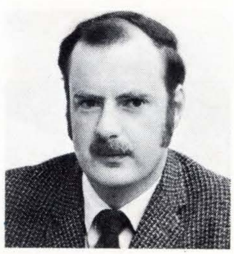
1. Intersil Application Note A004 "The IH5009 Series of low-cost, high-performance analog switches."

Author's biography



Dave Fullagar is manager of analog product development at Intersil, Inc. Prior to joining Intersil, he was with Fairchild Semiconductor, where he designed the μA741 operational amplifier. Dave holds a BS degree in physics and an MSEE, both from the University of Cambridge, England.

Solid-state 100W amplifier operates from a 12V source

This linear power amplifier for SSB applications uses only four transistors and spans 1.5 to 30 MHz with less then −30 dB of intermodulation distortion.

Don Schultz, TRW Semiconductors

A linear 100W power amplifier for SSB transmitter applications can be designed with only four transistors. The wideband amplifier operates from a 12V source and covers the frequency range of 1.5 to 30 MHz. It features intermodulation distortion of better than −30 dB and is capable of withstanding open and short-circuit load conditions at full output.

The all-solid-state design approach offers users and manufacturers of HF/SSB equipment several advantages over a vacuum-tube design. These include improved reliability, small size, high efficiency and an instantaneous bandwidth.

Amplifier design

Four TRW Semiconductor type PT5741 transistors are used in the amplifier (see **Fig. 3**). Each transistor exhibits a load impedance of 2.4Ω and an effective junction-to-case thermal resistance of 2.5° C/W. Each is rated for 30W of output power dissipation.

A push-pull configuration is used since the object is to design an untuned amplifier covering five octaves of bandwidth, and harmonics are of major importance. The Class B amplifier has harmonics in its output which are a function of the ratio f_{co}/f (cutoff frequency to operating frequency) and the selectivity of the output matching network. Even-order harmonics 40 dB down are easily achieved with this design, while off-order harmonics can be conveniently filtered.

The amplifier is shown schematically in **Fig. 1**. The two pairs of PT5741 transistors are operated in a push-pull configuration and then combined with zero-degree hybrid transformers T_1 and T_8 to convert the nominal 50Ω source and load impedance to two 100Ω ports which are in phase. Any amplitude or phase unbalance causes power to be dumped in resistors R_6 and R_7.

Impedance matching

Transformers T_2, T_3, T_6, and T_7 employ two ferrite-loaded brass tubes each, which form center-tapped, U-shaped windings. The high impedance winding is threaded, in continuous turns, through the brass tubing until the desired turns ratio is achieved and is determined for the collector as follows:

$$\frac{N_1}{N_2} = \sqrt{\frac{Z_L \cdot P_o}{2(V_{cc} - V_{sat})^2}} = 4 \qquad (1)$$

where:

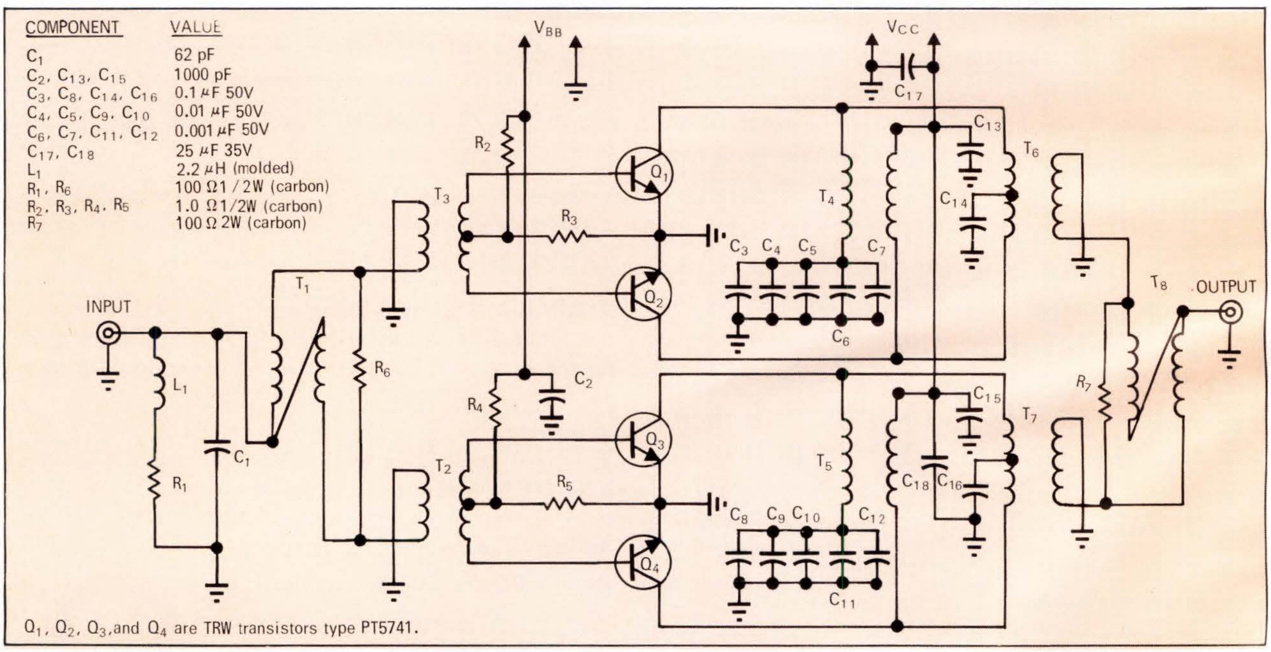


Fig. 1—This 100W linear power amplifier for SSB transmitter applications operates from a 12V source. It uses only four transistors in a push-pull output configuration to operate over a frequency range of 1.5 to 30 MHz. The amplifier tolerates a wide range of operating temperatures, bias, load VSWR and overdrive conditions with a minimum of control circuitry. Its intermodulation distortion is better than −30 dB and it can withstand both open and short-circuit load conditions.

$Z_{L'}$ = summing-port impedance (100Ω)
P_o = combined output power for the pair of transistors (55W)
V_{cc} = collector supply voltage (13.6V nominal)
V_{sat} = rf saturation voltage (1.5V)

The turns ratio of the input transformer is determined by:

$$\frac{N_1}{N_2} = \sqrt{\frac{Z_{in}}{2Z_{nom}}} = 4 \tag{2}$$

where:

Z_{in} = summing-port impedance (100Ω)

$$Z_{nom} = Z_{LF}Z_{HF} \tag{3}$$

The quantities Z_{LF} and Z_{HF} are the complex input impedance of the transistors at the low (1.5 MHz) and high-frequency (30 MHz) extremes, respectively. For the PT5741, these values are:

$$Z_{LF} = (6.3-j0.85)\Omega \approx 6.4\Omega \tag{4}$$

$$(5)\quad Z_{HF} = (0.95-j0.85)\Omega \approx 1.6\Omega$$

The calculated turns ratio for the output transformer agrees with that chosen for the finished amplifier. The input transformers, however, are found to be more optimum with a 5:1 turns ratio, which improved the match at the high end of the band.

Gain vs frequency response and the input match are tailored by the addition of L_1, R_1, and C_1 at the amplifier input. If should be noted that no extensive effort has been made to improve the input match and gain-frequency characteristics. A more complex network would certainly yield improved results. In the circuit, C_1 compensates, at high frequencies, for some of the leakage inductance present in T_2 and T_3. As the frequency decreases, the inductive reactance X_{L1} decreases and resistor R_1 is allowed to absorb a portion of the input driver power.

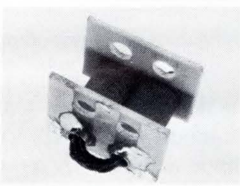
Collector feed network

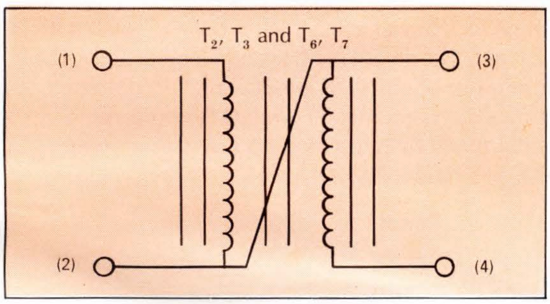
The collector feed transformers T_4 and T_5 combine with the output matching transformers to form a modified 180° hybrid combiner. The usual ballast resistor, which would normally be 1.2Ω, is replaced by a dc buss. Due to the modified combiner, differences in phase or amplitude that would otherwise exist at the collectors are now minimized by allowing the difference current to be by-passed to ground. The resulting output currents in T_6 and T_7 are highly balanced and provide exceptional second-harmonic rejection.

Details of the transformers' constructions are shown in **Fig. 2**. The ferrite material used has an initial permeability of 800 and remains about 200 at 30 MHz. Losses in the ferrite are quite low and the ferrite temperature rise is typically less than 20°C at cw output. The Curie temperature is 150°C minimum (165°C typical).

One of the most demanding aspects of linear power amplifier design is the bias network and associated temperature stability. Three major factors are important:

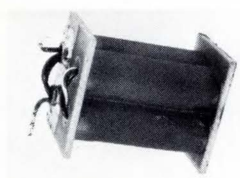
1. Large-signal rf amplifiers will generally rectify a portion of the input signal. If the base-emitter resistance is high, the amplifier will be biased Class AB for small signals, but will self-bias to Class C operation under large-signal conditions. The shift in operating point seriously increases intermodulation distortion. The bias source re-

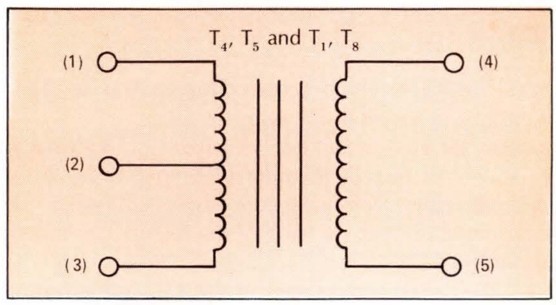




Winding Details
Twisted pair, #18 enameled copper wire, 5 twists per inch (not critical)

T_1 and T_8 are identical to T_4 and T_5 but are not mounted on PC frames.





Winding Details
1-3: One turn, consisting of 2 pieces of brass tubing, 0.190'' O.D.. T_2 and T_3 use 0.80'' long tubes. T_6 and T_7 use 1.375'' tubes.
4-5: T_2 and T_3 use 5 turns of #18 enameled copper wire. T_6 and T_7 use 4 turns of #18 enameled copper wire.

All ferrite beads are CN-20, type C-1-2 (Ceramic Magnetics, Inc., Fairfield, NJ. L = 0.190'', O.D. = 0.380'', I.D. = 0.190''.

Fig. 2—Assembly and winding details. The left photo is that of transformers T_4, T_5, T_6 and T_7, while the right one shows T_2 and T_3. Each transformer is constructed of columns of ferrite beads stacked atop one another (4 columns for T_4, T_5, T_6 and T_7 and 2 columns for T_2 and T_3). Single-sided G-10 epoxy-fiberglass PC boards are used on the ends.

sistance must therefore be kept very low, usually in the order of 0.5 to 1Ω.

2. Intermodulation distortion is usually minimum over a relatively narrow range of quiescent collector current. The boundaries are established by cross-over distortion and by the dc safe operating current. The transistors used in this design have safe operating currents of 6A at 13V and therefore have wide ranges of quiescent currents for which there are no measureable changes in intermodulation distortion.
3. Under small-signal conditions, the transistor dissipation is low, and the junction temperature will be quite close to the heat sink temperature. During periods of peak power dissipation, however, the junction temperature will rise. Recalling that we have essentially a constant-voltage bias source, and that the temperature coefficient of the emitter-base voltage is −2 mV/°C, we can easily foresee a potential for thermal destruction. Since the junction-to-case thermal time constant is in the order of microseconds, a dangerous situation can exist with changes in either peak power output, load VSWR, or ambient temperature.

Factor number 3 is most important. If thermal equilibrium cannot be maintained, destruction is rapid and complete. A criterion for thermal equilibrium can be derived as follows:

$$d(I_c) = g_m\, dV_B \tag{6}$$

$$d(I_c)V_{cc} = g_m\, V_{cc}\, dV_B \tag{7}$$

$$d(P_{diss}) = g_m\, V_{cc}\, dV_B \tag{7a}$$

$$d(P_{diss})\Theta_T = g_m\, V_{cc}\, \Theta_T\, dV_B \tag{8}$$

$$d(T_j) = g_m\, V_{cc}\, \Theta_T\, dV_B \tag{8a}$$

$$d(T_j) = g_m\, V_{cc}\, \Theta_T \tag{8b}$$

We know that the normal variation of V_B with temperature is −0.002V/°C. Thus:

$$\frac{dT_j}{dV_B}\ (\text{critical}) = 500°\ \text{C/V}$$

and any condition which causes dT_j/dV_B to exceed 500° C/V will induce thermal run-away.

Equation 8b gives quantitative insight into thermal stability and is an excellent guide to both the circuit and transistor designer. The transistors employed in the design embody improvements in each of the factors contained in **equation 8b**:

g_m The transconductance of the PT5741 is typically 2 mhos and is essentially constant at currents up to 5A. This is achieved by extensive use of emitter ballast resistors at each emitter site.

V_{cc} Since the transistor is designed to operate at 12V, there is a 2.3:1 improvement in thermal stability compared to 28V types.

Θ_T The transistor employs a single chip with a number of thermally isolated cells. Heat build-up due to thermal interaction is prevented and improved thermal impedance is achieved. The maximum $\Theta_{J\text{-}C}$ is 1.75° C/W. The thermal stability factor is:

$$\frac{dT_j}{dV_B} = 2 \times 12 \times 1.75 = 42$$

Furthermore, the amplifier is tolerant of both open and short-circuit load conditions at full-power output. It is particularly significant that the load mismatch is non-destructive even though there is no external temperature compensation and the total amplifier dissipation exceeds 200W under short-circuit conditions.

Amplifier performance

A number of linear power amplifiers have been constructed of the type shown in **Fig. 3**. They exhibit power transfer characteristics that are nearly linear under cw conditions at about 28MHz, with each amplifier terminated in a resistive 50Ω load. Sudden removal of the rf drive does not result in thermal hot-spotting.

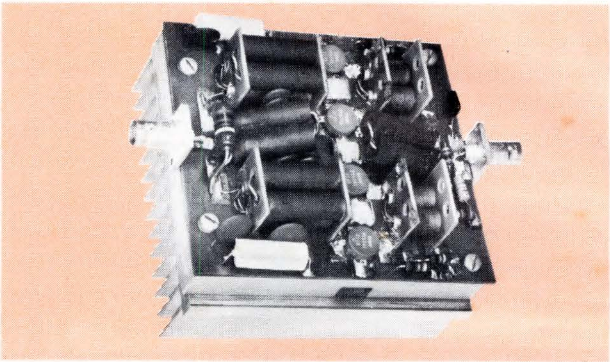


Fig. 3—In the layout of 100W linear power amplifier positioning of the four output transistors (located between the two rows of transformers) is critical. For example, at 30 MHz an extremely small value of 6 nH of inductance (which can be caused by an extra twist of wire) contributes about 1.2Ω of inductive reactance in the transistor's collector circuit. This would double the amount of resistance normally found in the collector output circuit to ground, and would contribute to output phase imbalance.

The uncompensated power gain is about 25 dB at 1.5 MHz and drops off almost linearly to 15 dB at 30 MHz. Uncompensated gain is achieved by removing L_1, R_1, and C_1, but is corrected for reflected power. With compensation, the amplifier's power gain smooths out to about 20 dB over 9 to 14 MHz (17 dB at 1.5 MHz and 15 dB at 30 MHz.)

Third-order products of intermodulation distortion characteristics are predominant while 11th order products are typically down by more than −55 dB (when referenced to one of two equal tones.) □

Author's Biography

Don Schultz is a senior applications engineer at TRW Semiconductors' Communications Group. He majored in mathematics at Northwestern University and the University of Southern California. A holder of numerous patents, Mr. Schultz has authored several technical articles and is currently in the process of developing a series of linear rf amplifiers.

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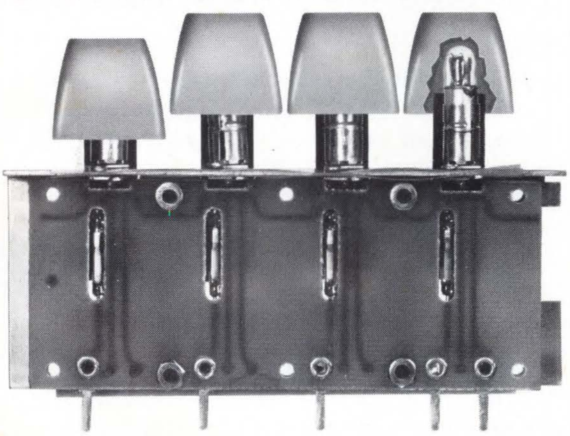

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CIRCLE NO. 21

Circuit Design Awards

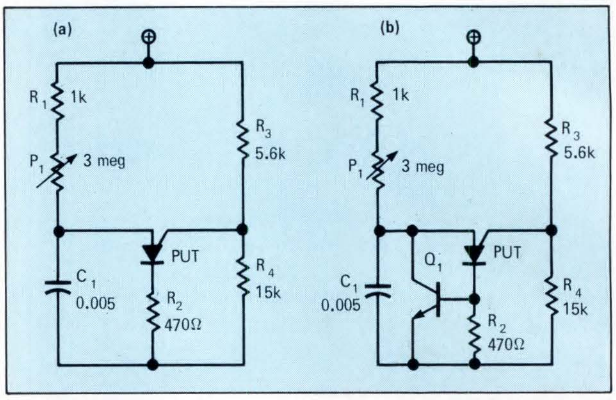
PUT oscillator has 4-decade frequency range

Herb Cohen
Electret Corp. New York N.Y. 10023

A simple PUT relaxation oscillator, as shown in (**a**), has a tendency to "latch up" when the current in P_1 exceeds the valley current of the PUT. This severely limits the component values and voltages for the design of wide range oscillators.

The addition of a single transistor, as shown in (**b**), will prevent latching. When the PUT fires, Q_1 goes into saturation, causing C_1 to be shorted out. Q_1 acts as a shunt path for the PUT and reverse biases the anode and cathode of the PUT momentarily, thereby assuring turn-off of the PUT.

An added benefit of C_1 discharging through Q_1 is that Q_1 has a lower saturation voltage than the PUT. The difference varies from a few millivolts for some transistors to 1.5 volts for many PUTs. When considering temperature stability, this difference allows much greater design flexibility. The frequency range of this circuit is 7 Hz to 23 kHz. ☐



The usual approach to PUT oscillator design (a) offers limited frequency range, and often suffers from "latch-up." **The addition of Q_1** across C_1 (b) prevents latch-up and permits an operating frequency range of 4 decades.

To Vote For This Circuit
Circle 150

Linear signal compressor has wide dynamic range

Richard Karwoski
Raytheon Co. Sudbury, Mass.

Here is an unusual and flexible way to compress or limit signals linearly and over a wide dynamic range.

Specific applications for this type of circuit occur in high-quality sound recording or other situations where small-amplitude audio signals must be compressed or limited to prevent overdrive. Most conventional limiting systems have drawbacks. Either they use nonlinear devices which distort the signals or they provide an inexact compression region which usually involves some sort of calibration procedure and always involves trial-and-error adjustments.

With the circuit shown in **Fig. 1**, amplifier A_4 produces a dc control voltage. The audio input signal is amplified by A_3 and rectified by CR_1 to provide the dc input for A_4.

The main signal path is from input to output via A_1. The local feedback around A_1 allows compression and gain adjustments. With R_f shorted, the control circuitry has no effect and the system becomes simply a linear voltage follower. The gain equation:

$$e_o = e_i\left[1 + R_f\left(\frac{R_s + R_n}{R_sR_n}\right)\right] \quad (1)$$

reduces to $e_o = e_i$

The system shown in **Fig. 1** is adjusted to provide unity gain with an input of 100 mV, regardless of the setting of R_f. No additional gain adjustments are needed even if the limiting is readjusted.

The limiting mechanism is based on the following equation for the configuration shown:

$$\frac{X}{1 + X} = Y \quad (2)$$

For small values of X, the equation degenerates to Y = X, which is equivalent to one-to-one compression. For large values of X, the output is asymptotically limiting.

Note the similarity between Eq. 2 and the well-know gain formula of Eq. 3.

$$\frac{Ae_i}{1 + A\beta} = e_o \quad (3)$$

In the limiter circuit, the feedback element β is an analog multiplier, the conductance of which depends on the control voltage from A_4, which in turn is proportional to the input amplitude.

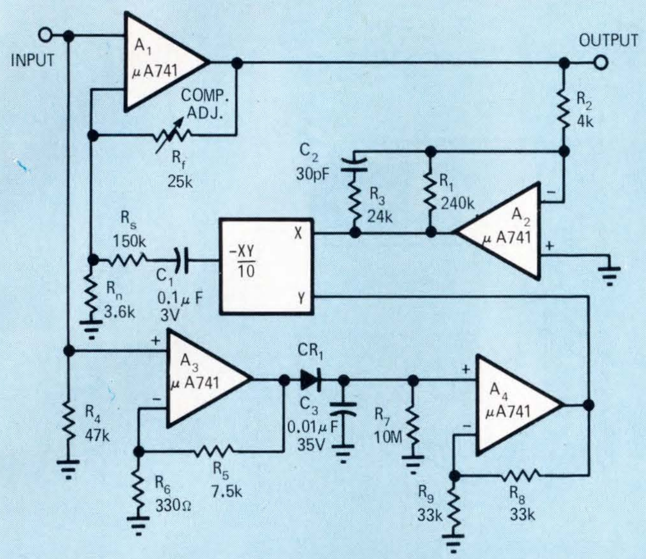


Fig. 1—Signal-compression circuit uses analog multiplier as gain-control element. Input signal is rectified and applied to multiplier which determines feedback to A_1.

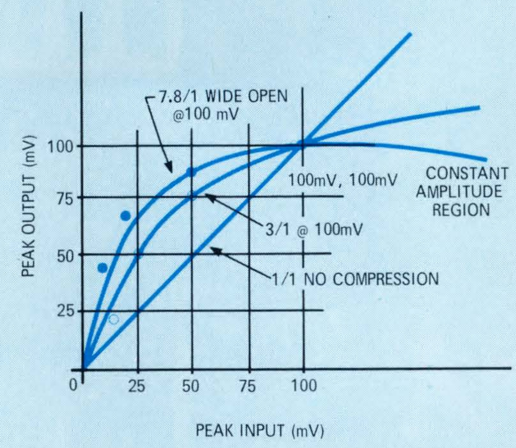


Fig. 2—Various input-output characteristics for different settings of R_f in the circuit of **Fig. 1.** Circuit is initially adjusted so that it provides unity gain with a peak input of 100 mV.

The transfer function for the complete circuit is as follows:

$$\frac{e_o}{e_i} = \frac{\left[1 + R_f\left(\frac{R_s + R_n}{R_s\,R_n}\right)\right]}{1 + 410\,(R_f/R_s)e_i\ \mathrm{pk}} \qquad (4)$$

A suitable value of R_n can be selected so that the 100-mV unity gain point remains the same for any setting of R_f. Then, with respect to this initial setting, one can adjust compression without affecting gain. **Fig. 2** shows various compression characteristics that can be obtained with the component values shown in **Fig. 1**.

Any suitable analog multiplier can be used in this circuit. A Teledyne Philbrick Type 4452 was used in the prototype version and it provided the required performance. ☐

To Vote For This Circuit
Circle 151

Simple op amp relaxation oscillator generates linear ramp output

Jerry Graeme,
Burr-Brown Research Corporation, Phoenix, Arizona

The common relaxation oscillator shown in **(a)** employs a unijunction transistor (UJT), and provides a timing pulse train and a crude ramp output. A fairly precise timing pulse rate can be achieved by appropriate bias of the UJT to remove temperature sensitivity. However, the zero temperature-coefficient bias varies widely between UJTs of the same type, making consistent low-drift bias impossible without trimming. In addition, the ramp generated by the relaxation oscillator generally has serious limitations.

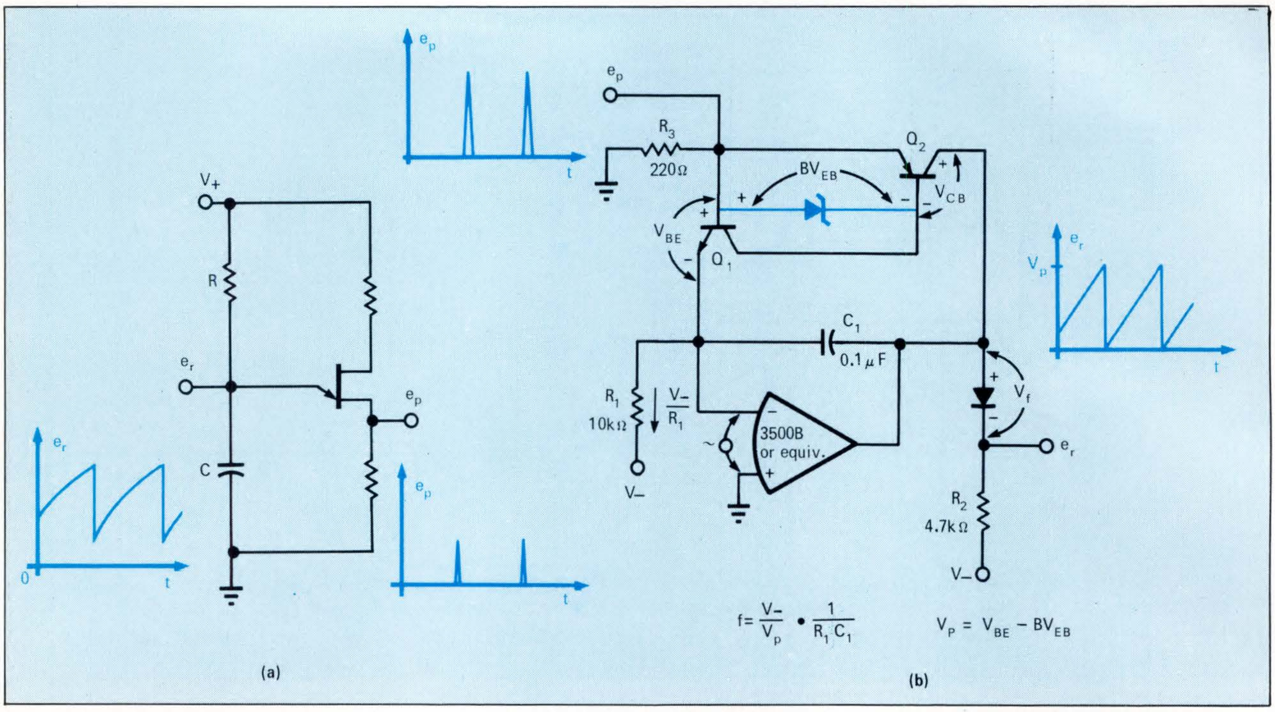
Poor ramp linearity and output offset are two of these limitations which can be overcome with the op amp circuit shown in **(b)**. The discharging action provided by the UJT is now provided by Q_1 and Q_2, and the capacitor charging current through R_1 is now controlled by the op amp. To insure a constant charging current to C_1, the op amp feedback holds one end of R_1 at ground level. The voltage on R_1 is then constant, and the charging current is independent of the capacitor voltage. This results in a linear rise in output voltage.

The output-voltage rise continues until Q_1 and Q_2 turn on, as initiated by the emitter-base breakdown of Q_2. Breakdown results from the inverted connection of Q_2 and provides a low output-voltage limit. Since the collector-base junction of inverted Q_2 is forward biased, its voltage drop is that of a forward biased junction.

This peak voltage is temperature stable because the typical 2.6 mV/C sensitivity of $-BV_{EB}$ is largely cancelled by the -2mV/C variation in V_{BE}. As a result, the temperature coefficient of the output peak V_p is around 0.01%/°C. Because the signal is a linear ramp, frequency drift is also 0.01%/°C Frequency, as set by the integration time, is:

$$f = \frac{V-}{V_p} \cdot \frac{1}{R_1\,C_1}$$

Once the emitter-base junction of Q_2 breaks down, a base current is supplied to Q_1. Then Q_1, in turn, supplies base current to Q_2 and discharging current to the capacitor. As the capacitor voltage drops below the breakdown point, Q_1 and Q_2 (because of their positive feedback) remain on, to continue discharging C_1. Discharging con-



Frequency drift and nonlinearity of conventional relaxation oscillator (a) are removed by compensating junctions and linearizing of the operational amplifier feedback (b).

tinues until the capacitor voltage will no longer sustain V_{BE}. At this point the capacitor voltage equals V_{BE} and the output er_{min} is zero. The cancelling voltage provided by V_f removes any output offset.

With this op amp circuit, the ramp-train frequency is limited only by the slewing rate of the op amp selected. Ramp linearity is limited by leakage from Q_1 and Q_2, the sensitivity of V_f to e_r, and the op amp input-overload-recovery following discharge. Leakage from Q_1 and Q_2 is limited by R_3, which also prevents this leakage from turning the transistors on. A stray turn-on current is also created by capacitance coupling from the output, which means that the selected value of R_3 is also frequency dependent.

Linearity errors from variations in V_f are a result of the change in the diode current as e_r changes the drop on diode bias resistor R_2. Nonlinearity from all of these effects is rarely more than 3%. □

To Vote For This Circuit
Circle 152

Single-digit BCD adder uses 3 ICs

Dennis W. Wood
The Boeing Co. Seattle, Wash.

A single-digit BCD adder can be implemented with only three dual in-line packaged ICs. If more digits are required, basic single-digit circuits can be cascaded, with the *carry out* from one stage connected to the *carry in* of the next stage.

As can be seen in the schematic, a single-digit BCD adder uses two 4-bit binary full adders and a multiple-input AND-OR gate.

The two BCD digits at the input are first added together in IC_1. If the sum of the two digits and the *carry in* is ≤9, there is no need for a carry to the next stage, and the binary output of IC_1 is simply the BCD sum.

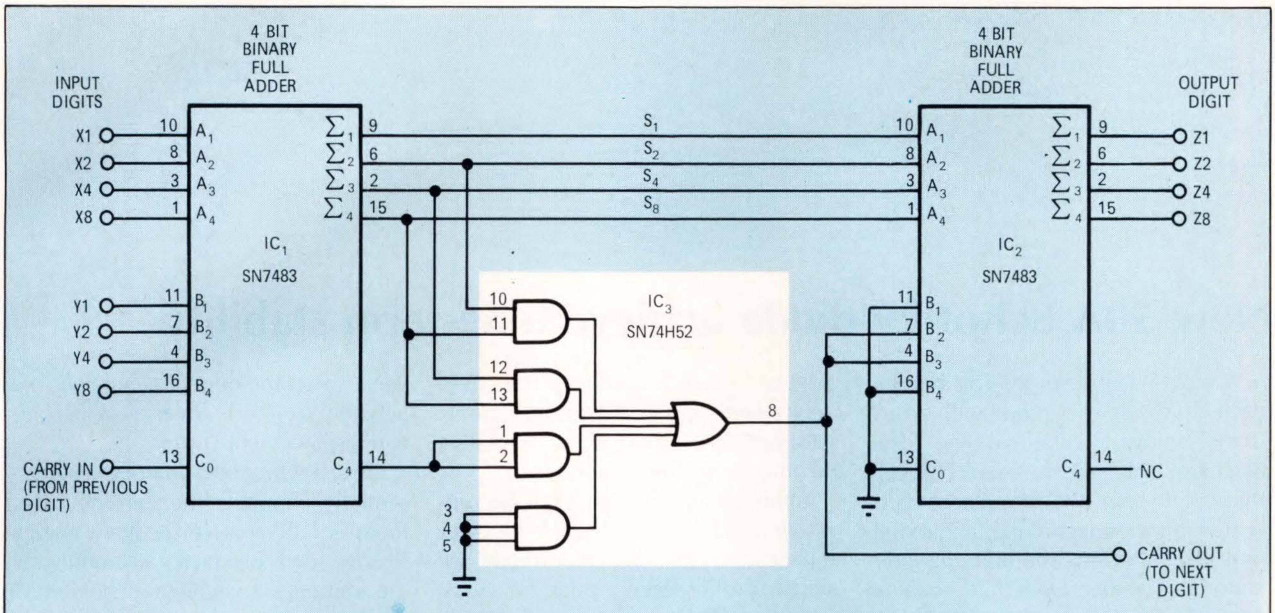
The B inputs to IC_2 are wired such that IC_2 adds a count of zero to IC_1's output if there is no carry, and adds a count of six if there is a carry.

If the sum of the two inputs and the *carry in* is ≥10, the circuit must generate a *carry out* to the next BCD-digit stage. The multiple AND-OR gate, IC_3, detects the specified input conditions and generates the required *carry out* signal.

The necessary input conditions for producing a *carry out* are satisfied whenever one of the following states occurs for IC_1: S_8 and S_2 are true, or S_8 and S_4 are true, or the *carry* C_4 is true.

Because the output of IC_1 is a binary sum instead of a BCD sum, a further correction is needed. This involves adding an extra count of six to the output of IC_1, thus forcing the binary counts of 10 through 19 to a count of 0 through 9. The procedure is summarized in the table.

Using similar techniques, it is possible to build a BCD-digit subtractor instead of an adder. Also, the radix of the adder can be changed to allow the addition of BCD minutes and seconds instead of straight digits. In this case, the



Simple BCD adder stage uses two 4-bit binary full adders and a multiple-input AND-OR gate for each stage. Further digits can be accommodated by cascading stages.

circuit should force a carry at a sum of six or greater and the output of IC_1 should be corrected by adding a count of ten to it. □

Generating a carry

SUM OF INPUTS AND "CARRY IN"	ADDER 1 OUTPUTS					ADDER 2 OUTPUTS				"CARRY OUT" TO NEXT DIGIT
	C_4	S_8	S_4	S_2	S_1	Z_8	Z_4	Z_2	Z_1	
0	0	0	0	0	0	0	0	0	0	0
1	0	0	0	0	1	0	0	0	1	0
2	0	0	0	1	0	0	0	1	0	0
3	0	0	0	1	1	0	0	1	1	0
4	0	0	1	0	0	0	1	0	0	0
5	0	0	1	0	1	0	1	0	1	0
6	0	0	1	1	0	0	1	1	0	0
7	0	0	1	1	1	0	1	1	1	0
8	0	1	0	0	0	1	0	0	0	0
9	0	1	0	0	1	1	0	0	1	0
10	0	1	0	1	0	0	0	0	0	1
11	0	1	0	1	1	0	0	0	1	1
12	0	1	1	0	0	0	0	1	0	1
13	0	1	1	0	1	0	0	1	1	1
14	0	1	1	1	0	0	1	0	0	1
15	0	1	1	1	1	0	1	0	1	1
16	1	0	0	0	0	0	1	1	0	1
17	1	0	0	0	1	0	1	1	1	1
18	1	0	0	1	0	1	0	0	0	1
19	1	0	0	1	1	1	0	0	1	1

To Vote For This Circuit
Circle 153

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Robert I. White winner of the November 1 Savings Bond Award. His winning circuit was called, "Gated 60 Hz clock avoids glitches." Mr. White is with the University of Wisconsin, Madison, Wis.

New 50A Schottky diode achieve long-term stability

A new 50-ampere, 20-volt hot-carrier Schottky barrier diode with an extremely low forward-voltage drop achieves excellent long-term stability through the use of a proprietary barrier-metallization technique, and oxide-nitride passivation. The unit, the International Rectifier 50HQ020, can be applied efficiently in the 20-40 Hz region.

Use of the oxide-nitride passivation technique is significant; without it, impurity ions such as ubiquitous sodium can migrate to the surface of the silicon near the edge of the barrier. This causes surface inversion and increased leakage.

Improved stability for Schottky devices is a sought after parameter since it affects equipment reliability and device utilization. For example, in low-voltage applications using less-stable power devices, leakage current can increase with time; this can cause a condition where the reverse power losses become significant compared with the forward power losses. The resultant increase in junction temperature will further increase the reverse power losses (due to an increase in leakage current, which is temperature dependent). This in turn can produce a positive feedback condition, causing a catastrophic device failure. Improved stability of the new IR Schottky markedly reduces the possibility of this type of failure.

An additional major feature of the new device is a reduction in the effects of temperature on leakage current—a change of only 2:1 is exhibited when the temperature moves from 25 degrees C to 100 degrees C. Previous devices on the market can change by as much as 5:1. The reduced sensitivity to temperature further improves overall device reliability with time and temperature.

The combined effect of improved stability and reduced temperature sensitivity means that designers can now achieve reliable performance over device lifetime and at close to full-rated specifications, without conservative derating to ensure reliability.

Although high-power Schottkys represent a major new concept in power rectification, the Schottky diode for signal use has been around for years.

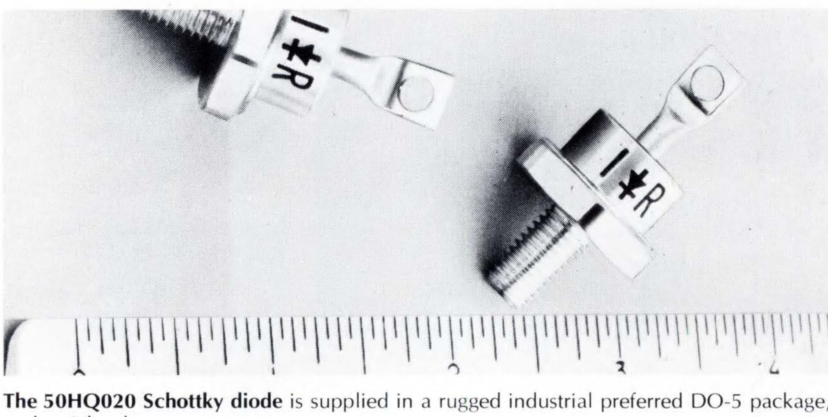
In the Schottky, which is essentially a metal-to-semiconductor surface barrier rectifier, the rectification takes place at the interface between the semiconductor material and the metal. It is a majority carrier device and does not have a PN junction like conventional alloyed or diffused silicon rectifier devices do.

The Schottky behaves somewhat analogously to the more familiar PN junction rectifier, but has a substantially lower voltage drop. Because it is a majority carrier device, it does not have the stored minority carrier charge found in the typical PN junction devices. This means that the Schottky switches more rapidly from forward to reverse—that is, it switches very rapidly into a blocking mode.

By contrast, in a PN junction device, minority carriers are stored in the base region. When the device is switched into the reverse mode, the store charge is swept out, resulting in a reverse current spike. The only reverse switching current generated in a Schottky device is a very low capacitive displacement current.

Since the Schottky barrier units essentially eliminate the current spike, there is little reverse recovery energy loss, which is one factor accounting for the improved switching efficiencies of the new units.

The lack of reverse recovery losses is also the reason for the Schottky's improved operation at higher frequencies. For example, at a frequency where a PN junction device has reverse recovery losses equal to or greater than the forward losses, the device can be operated at or less than half the rated forward power. But at the same frequency, the reverse losses in the Schottky are still low compared to the forward losses, so there is less need to derate the Schottky as a function of frequency.



The 50HQ020 Schottky diode is supplied in a rugged industrial preferred DO-5 package, and weighs about one ounce.

The lower forward voltage drop of the Schottky, 0.65V at 100A peak in the case of the IR device (versus 1 to 1.5V for a PN junction device), is obtained because the potential drop (or barrier voltage) at the metal-to-semiconductor barrier is roughly half that of a PN junction; as well as because of the use of a thin silicon epitaxial layer in conjunction with an extremely low resistance silicon substrate. The substrate acts as a series resistance in the forward direction.

Because of voltage capability limitations the new device is only suitable for low-voltage rectification. However, since its forward voltage drop is only about half that of a standard PN junction devices's drop, the Schottky can dramatically improve system efficiency. For example, consider the case of a 5V, 100A square-wave inverter power supply using a standard diode with a forward voltage drop of 1.15V, and requiring an input to the rectifier of 6.15V at 100A. This is 615 watts in and 500 watts out, or an efficiency of 81 percent. For the same system using a Schottky, the input to the rectifier would be 5.65V at 100A: 565 watts in for 500 watts out, or an efficiency of 88.5 percent.

The extremely low switching losses of the Schottky make it especially suitable for high-frequency rectification. In addition to reducing the size of transformers and filters by using high-frequency conversion, the new Schottkys can improve the efficiency of the rectifier section twofold—by reduced reverse-recovery losses and by low forward-voltage drop.

The 50HQ020 can typically be used in converter circuits at frequencies in excess of 20 Hz, compared with a general limit of 5 Hz for PN junction diodes.

Other characteristics of the 50HQ020 include:

- Max. peak one cycle, non-repetitive surge current 800A
- Max. I^2t (non-repetitive for 5 to 8.3 msec) . . . . 2650 A^2 sec
- Max. non-repetitive peak reverse voltage 24V
- Max. repetitive peak reverse voltage 20V
- Max. operating junction temperature range . . . . −65 to 100 deg. C.

Price in 100-lot quantities is $9.00, and delivery is four weeks.

Semiconductor Division, International Rectifier Corporation, 233 Kansas St., El Sequndo, CA 90245. Phone (213) 678-6281. **314**

Fully programmable synthesizer sets standards in sophistication

Frequency synthesizers fall into two categories: low-cost, moderate-performance types (about $2500) generally used in automatic-testing applications, and more expensive ones ($5000 or more) that offer greater sophistication and high-quality outputs needed in communication systems.

One of the most sophisticated synthesizers is one introduced by Hewlett-Packard. The automatic Model 3330B uses built-in ROMs that allow the instrument to be fully programmed (amplitude and frequency) from the front panel via an upward-tiltable keyboard, thus eliminating the need for a computer for sweep control.

The synthesizer uses seven digitally controlled phase-locked loops to provide a 0.1 Hz to 13-MHz range with a constant resolution of 0.1 Hz and a stability of $\pm 1 \times 10^{-8}$/day. A $\pm 1 \times 10^{-9}$/day option is also available. Additionally, the 3330B can be locked to any external source with a $\pm 1 \times 10^{-6}$/year optional reference.

While this completely programmable $6000 instrument offers fairly good harmonic distortion rejection down to −60 dB, its spurious response of −70 dB, is lower than that of other high-cost synthesizers.

However, it offers a host of features that put it in a class by itself. Its output of 0 to ±13.44 dBm (1.05V rms into 50Ω) is level to within ±0.5 dB. LED displays show both the frequency and amplitude (nine digits for frequency and four digits for amplitude).

As a sweeper, the instrument uses digital sweeping for linearity. Either single or continuous sweeps may be set up. Frequency parameters are entered from the keyboard or remotely. The size of the step can be as small as 0.1 Hz. Parameters such as center frequency, frequency step, time per step and the number of steps go into the memory, and are then executed by pressing a single button. The ROM operates the sweep until told to stop.

Many of the sweep parameters can be changed while the instrument is sweeping. The 3330B sweeps amplitude in steps as small as 0.01 dB, and the amplitude can be stepped at the end of each frequency sweep cycle to produce a family of curves.

All necessary status and control lines required for interfacing are standard. Each control has a specific 7-bit parallel ASCII code assigned to it. An addressing feature allows operation of several units in parallel. Only one programming device or interface card is needed to fully program multiple units. Hewlett-Packard's 3260A marked-card programmer is available as a programming accessory.

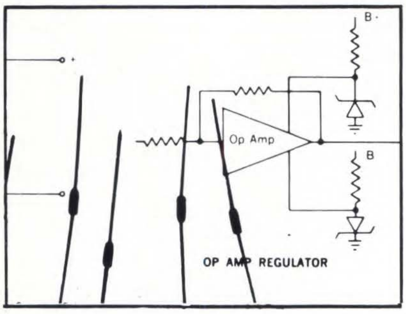
Model 3330B can also be amplitude modulated using an external signal of up to 100 kHz.

A less-expensive version (Model 3330A) is available at $5100. It does not contain the keyboard entry of amplitude parameters, cannot be amplitude swept and does not display amplitude values. It has a manual amplitude control and its output is level to ±0.5 dB. Otherwise it is identical to the Model 3330B.

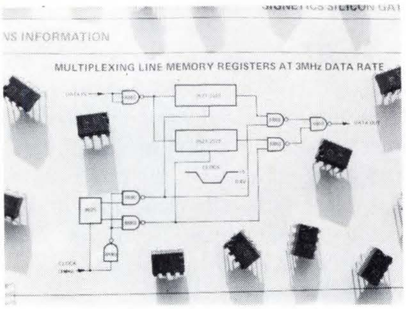
Delivery of both A and B versions is 60 days. Hewlett-Packard Co., 1501 Page Mill Rd., Palo Alto, CA 94304. Phone (415) 493-1501. **315**

Using built-in ROMs, Hewlett-Packard's Model 3330B synthesizer allows complete amplitude and frequency programming from an upward-tiltable keyboard on the front panel. The instrument ranges over 0.1 Hz to 13 MHz at a constant resolution of 0.1 Hz.

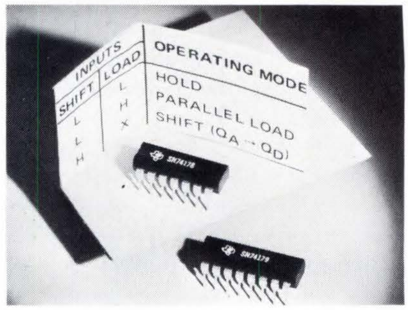
SEMICONDUCTORS



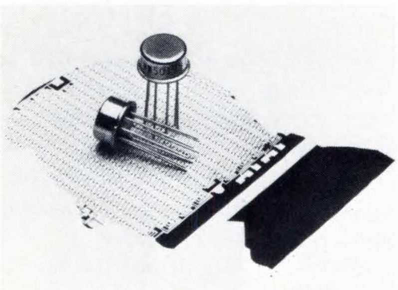
REFERENCE DIODES offer multi-current range. Operating current range is 1.0 to 3.0 mA for IN4611 family, 3.0 to 7.0 mA for IN4612 family and 7.0 to 15.0 mA for IN4613 family. All units are available in hermetically sealed DO-7 or micro strip package. Price: $2.65 (100 pieces). CODI Semiconductor Div., Computer Diode Corporation, Pollit Drive South, Fair Lawn, N J 07410. Phone (201) 797-3900. **170**



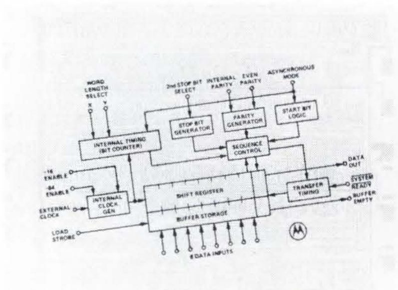
MOS STATIC SHIFT REGISTERS are bipolar-compatible. The dual 128-bit model 2521V register and the dual 132-bit model 2522V are P-channel enhancement mode, silicon-gate devices in 8-pin miniature dual-in-line packages. When ordered in a quantities between 250 and 999, the 2521V and 2522V sell for $5.00 each. Signetics, 811 East Arques Avenue, Sunnyvale, CA 94086. Phone (408) 739-7700. **173**



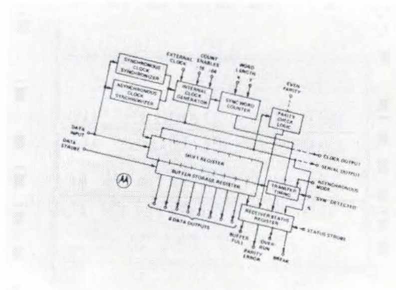
TTL SHIFT REGISTERS feature dc coupling. Designated the SN54/74178 and 179 the 4-bit shift registers are functional replacements for the 8270 and 8271 currently on the market. The 179 shift register has a direct clear input, the 178 does not. Prices begin at $2.00 each in orders of 100 pcs. Texas Instruments Inc., 13500 North Central Expressway, Dallas, TX. Phone (214) 238-3741. **176**



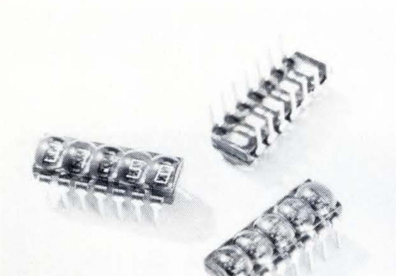
PROGRAMMABLE SHIFT REGISTERS fill the need for registers with odd lengths and tap locations. The MM4007/MM5007 mask-programmable dual 100-bit dynamic MOS register can be programmed from 20 to 100 bits long. The MM4019/MM5019 dual 256-bit register can be 40 to 256 bits. National Semiconductor Corporation, 2900 Semiconductor Drive, Santa Clara, CA 95051. Phone (408) 732-5000. **171**



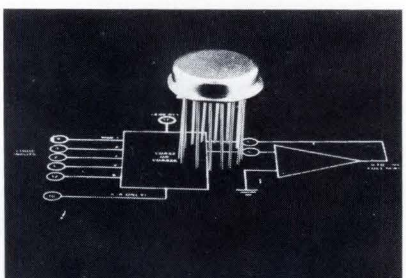
LIS TERMINAL TRANSMITTER, the MC2257L, provides versatile data transfer for communications data terminals. This LSI device replaces 30 TTL packages used in older transmitter design. Information is entered in parallel and stored until transmitted in serial form. Price is $20.40 in single quantities. Motorola Semiconductor Products Inc. P.O. Box 20912, Phoenix, AZ85036. Phone (602) 273-6900. **174**



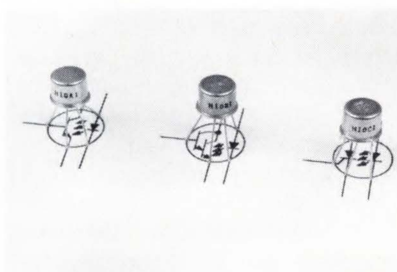
LSI DATA RECEIVER converts serial data to parallel form. The MC2259L receiver accepts digital data from a MODEM, and provides this data in parallel form. It operates over the range of dc to 10k bits per second in a divide-by-64 mode, or 200 k bits per second in a divide-by-1 mode. Price is $27.90 each in small quantities. Motorola Inc., Semiconductor Products Division, P.O. Box 20924, Phoenix, AZ 85036. Phone (602) 273-6900. **177**



LOW-POWER LED DISPLAY, requires only 7 milliwatts per digit. The HP 5082-7405 is a five-digit cluster, passivated monolithic seven-segment indicator. The self-magnifier enlarges each digit of the display cluster to a height of 0.112 inches. The five-digit cluster is 0.75 inches wide. Price is $17.50 each in orders of 100. Hewlett-Packard Company, 1601 California Avenue, Palo Alto, CA 94304. **172**



THE FET MULTIPLEXER CAM601 is a 6-channel device featuring a 60-ohm max. R_{on} and break-before-make action. Off-channel isolation is enhanced by ac grounding of the FET gates. Internal reference resistors assure tracking of ±10 volt ac signals without clipping or R_{on} modulation. Teledyne Crystalonics 147 Sherman Street, Cambridge, MA 02140. Phone (617) 526-7351. **175**



OPTOELECTRONIC COUPLERS use three different techniques. H10A1 LED-phototransistor coupler offers 3 μsec turn on. H101B1 LED-photo Darlington offers current transfer ratios of 500%. H10C1 LED-light activated SCR offers 1-amp output with 15 mA input. Prices start at $3.95 each in 1000 piece quantities. General Electric Company, Electronics Park, Syracuse, NY 13201. Phone (315) 456-2021. **178**

SEMICONDUCTORS

ULTRA LOW NOISE OP AMPS, 108LN and 308LN are pin-for-pin replacements for 101A/301A amplifiers. Both feature max. input referred voltage noise of 70 nV/Hz at 10 Hz and popcorn noise transition amplitude ($2R_s$ = 100K) of 25μV max. The 108LN is priced at $36.00 each and the 308LN at $5.95 each in orders of 100. Intersil Corp., 10900 N. Tantau Ave., Cupertino, CA 95014. Phone (408) 257-5450. **179**

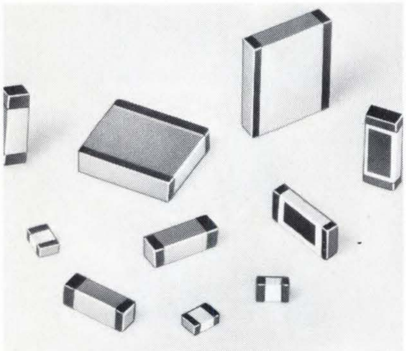
MOS 7 SEGMENT DECADE COUNTER, designated HCTRO177, drives LED or liquid crystal displays. This resettable up-down counter is a counter/latch/decoder/driver in one 16-pin package. Power dissipation is 350 mW, and the units may be cascaded. Hughes Microelectronic Products Div., 500 Superior Ave., Newport Beach, CA 92663. Phone (213) 670-1515. **180**

HIGH-VOLTAGE TRANSISTOR CHIPS for hybrid applications have V_{CEO} ratings from 175 to 225V and a minimum operating frequency of 50 MHz. The chips measure 19 mils square and 6 ±1 mils thick, and were designed specifically to drive plasma and gas-discharge display devices. In orders of 1000, prices range from 22 to 27¢ each. Dionics, Inc., 65 Rushmore St., Westbury, N.Y. 11590. Phone (516) 997-7474. **181**

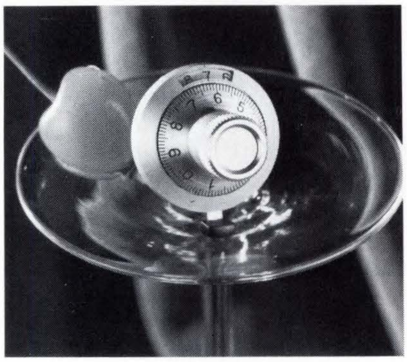
HIGH VOLTAGE TRANSISTORS feature V_{CEO} ratings from 400 to 800V. Available in both NPN and PNP versions, these transistors have hfe = 25 to 300 and $V_{CE(sat)}$ = 1.0V max. In quantities of 1000, the 400V units are priced at $3.00 each, the 500V units at $4.00 each, the 600V at $5.00, 700V at $6.00, and the 800V transistors are $7.00 each. Industro Transistor Corp., 35-10 36th Ave., Long Island City, N.Y. 11106. Phone (516) 466-6511. **182**

MICROPOWER OPERATIONAL AMPLIFIER, the CA3078AT, has a power supply range from ±0.75 to ±15V and requires only 12nA input bias current. Maximum input-offset voltage is 3.5V, input-offset current is 2.5nA, and open-loop voltage gain is 92dB. Price in 1000 unit orders is $4.95 each. RCA Solid State Div., Box 3200, Somerville, N. J. 08876. Phone (201) 722-3200. **183**

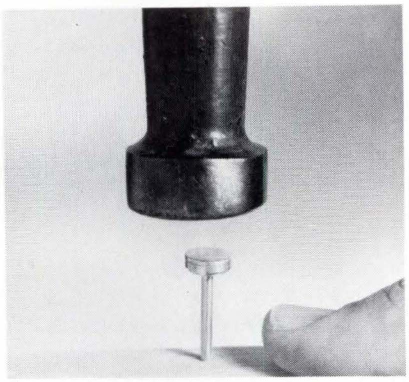
4-BIT MSI BINARY COUNTER, Type H156, is a high-level logic device featuring a minimum fan-out of 25. It is a synchronous preset and reset, and operates from supply voltages between 8 and 20V. The H156 is the 14th device to be introduced in the HLL MSI series. Società Generale Semiconduttori, Via C. Olivetti, 20041-Agrate Br., Milan, Italy. Phone (039) 63541. **184**



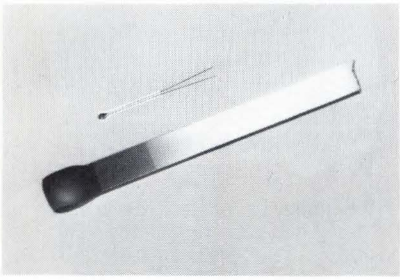
CHIP CAPACITORS employ multilayer monolithic construction. Type ULA chips with 25-, 50- and 100-volt ratings are now available in over 150 capacitance values per EIA-RS198 and MIL-C-55681 ranging from 1pF through 1μF, with tolerances from 1% to 20%. They are also available in chip arrays in 14- and 16-pin DIP packages. Aerovox Corporation, New Bedford, MA 02741. **185**



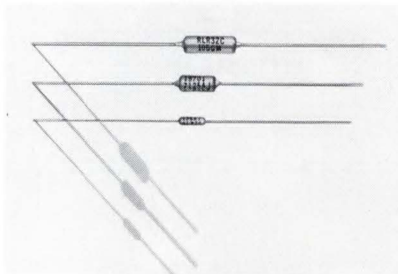
TURN COUNTING DIALS, series DFA, are designed to be small enough to conserve panel space, yet provide easy readability. The 1.1 inch dia. allows mounting densities of 99 units/ft^2. A graduated vernier dial integral with the knob indicates tenths and hundredths, providing setting accuracy of one part per 1000. Amphenol Controls Division, 120 South Main Street, Janesville, WI 53545 **188**



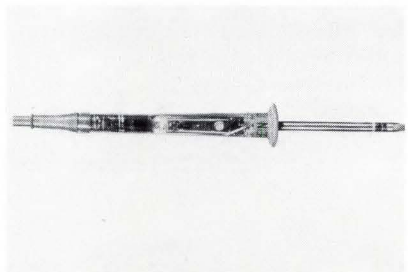
RUGGED MERCURY-WETTED SWITCH eliminates the dangers of mercury leakage and handling problems associated with glass switches. Logcell II switches are comparable to conventional mercury-wetted switches, providing bounce-free closures and up to a billion operations. Price ranges from \$1.00 to \$2.00, depending upon quantity. Fifth Dimension Inc., Box 483, Princeton, N J 08540 **191**



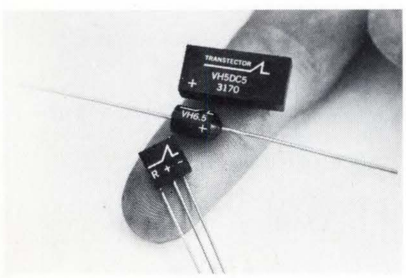
SUB-MINIATURE THERMISTOR PROBE features extremely fast time response and length slightly over 1/4". The "sub-mini-probe" consists of a thermistor bead sealed in a glass tube. Standard probes are available in nominal resistances of 500Ω to 300 kΩ, and can be used at temperatures up to 300°C. Fenwal Electronics, 63 Fountain St., Framingham, MA 01701. Phone (617) 872-8841. **186**



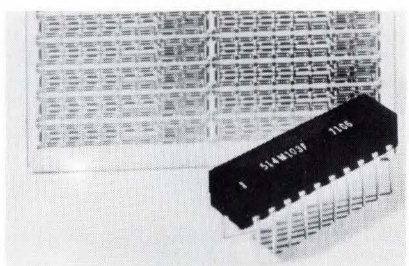
METAL FILM RESISTORS, the RLR 07, RLR 20 and RLR 32 styles, are fully qualified to MIL-R-39017. Power ratings are from 1/4 W to 1 W at 70C. Resistance range is 4.3Ω to 3.1 MEGΩ. Delivery is 6 weeks ARO. Samples are available. Mepco/Electra Inc., Columbia Road, Morristown, N J 07960. Phone (201) 685-5000. **189**



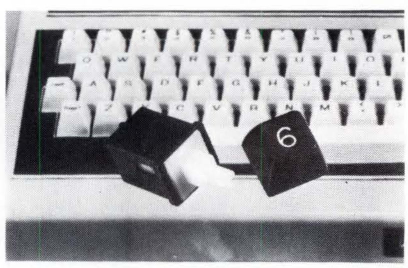
SOLDERING INSTRUMENT has internal temperature adjustment from 500 to 750°F. Temperature sensing, control amplifier and SCR power control circuit are all contained within the clear plastic handle of the *LONER* precision soldering tool. Price of the instrument with bench-rest and spare tips is \$35.00. EDSYN, Inc., 15954 Arminta St., Van Nuys, CA 91406. Phone (213) 989-2324. **192**



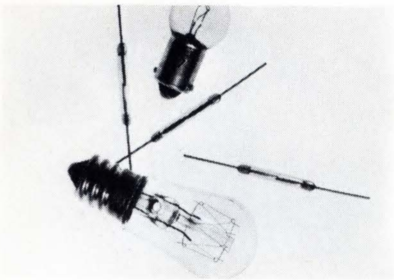
PROTECTIVE SCR CROWBARS provide a complete transient protection micro-circuit in a single package. Capable of handling overvoltage transients in 50 nsec and voltage surges of up to 40A for 10 msec. Standard trip points are from 5 to 50V dc. Pricing ranges from \$5.00 to \$12.00 in small quantities. Transtector Systems, 532 Monterey Pass Road, Monterey Park, CA 91754. **187**



THIN FILM LADDER NETWORKS are available in 8, 10, 12, and 14 bit R-2R versions. All four networks feature a tracking characteristic of less than 1 ppm/°C. Transfer linearity for the 8-bit network is 0.5%, 10-bit 0.03%, 12-bit 0.01% and 14-bit 0.005%. 8 and 10-bit networks are packaged in a standard 16 pin DIP, and the 12 and 14 bit networks are in a 20 pin DIP. Hybridyne, Inc., 3150 Pullman St., Costa Mesa, CA 92627. Phone (714) 540-5935. **190**



LOW-COST KEYBOARD SWITCH offers a life rating in excess of 10 million operations. Designated 601-M11A, the switch has an operating force of 2.5 ounces, ±0.50 ounces and mounts directly to printed circuit boards. Button pretravel is 0.100 in. minimum; stroke is 0.187 in. total. Amphenol Controls Division, Switch Operations, 419 South Arch Street, Janesville, WI 53545. **193**



SUB-MINIATURE REED SWITCH designated MAAC-2 switches lamps or other high-inrush loads. Maximum recommended lamp loads are 12V dc at 0.210A or 120V ac at 15 W. Physical dimensions: 1.775 in. length; 0.800 in glass length; 0.105 in. glass diameter. Hamlin, Inc., Lake Mills, WI 53551. Phone (414) 648-2361. **194**

ARGON LASER, Model 2000A, is the first 2-watt laser with automatic self-aligning optics. "Auto-tune" continuously aligns the mirrors so that their axes are always maintained coaxial with the plasma tube bore. This results in a constant power level and stabilized beam position. Optical Data Processing Inc., 38 Vitti St., New Canaan, CT. Phone (203) 966-8731. **195**

MINIATURE THUMBWHEEL SWITCHES snap together. The series 545 switches mount on 5/16 inch centers to provide any number of desired decades. Character height is 3/16 inches and switching functions include decimal—10 position, 1 or 2 pole binary with complements or binary without complements. Dialight Corp., 60 Stewart Ave., Brooklyn, NY 11237. **196**

PROTECTIVE COATING, "Anti-Heat," acts as a heat sink in welding, brazing and soldering operations. It is easily removed by wiping off the excess and washing the surface with plain water. Tempil° Division, Big Three Industries, Inc., Hamilton Blvd., South Plainfield, N J 07080. Phone (201) 757-8300. **197**

PHOTOCELLS FEATURE COLOR-CODING. The color-coded bases correspond with three peak spectral response areas—green, orange or red (515, 575 and 625 nm). "On" resistance typically is 500, 1500, and 3000 Ω when measured at 10 fc. "Dark" resistance values are typically above 10 MΩ. Price is $0.39 each in 2500 quantities. Allen-Bradley Co., 1201 S. Second St., Milwaukee, WI 53204. **198**

SERIES TUNABLE CAPACITORS, Models 7263 and 7283, are designed for critical "tweaking" of micro-stripline circuits. They are designed to mount across gaps in stripline circuitry. Capacitance ranges are 0.3 to 1.2, 0.4 to 2.5, and 0.5 to 4.5 pF. Prices are from $7.85 to $4.25 each. Johanson Manufacturing Corp., 400 Rockaway Valley Rd., Boonton, N J 07005. Phone (201) 334-2676. **199**

SUPER INSULATION minimizes thermal losses. Developed to provide maximum thermal efficiency for containment of such ultra-cold cryogenic fluids as liquid helium (−452°F) and liquid hydrogen (−423°F), "Super Insulation Systems" have demonstrated thermal conductivities from 10 to 200 times lower than conventional insulation. Insulation is contained in an annular space between inner and outer container shells under high vacuum. Union Carbide Corp., Linde Division, 270 Park Ave., New York, NY 10017. Phone (212) 551-4512. **200**

FREE SAMPLE—Plastic handles for printed circuit cards require no mounting hardware. Models 10035 and 10037 have molded clips which mate to pre-drilled holes in the PC board. The third series, Model 10036, mounts by means of two screws or rivets. Price for 1000 pieces is $0.21 each. Vero Electronics, Inc., 171 Bridge Road, Hauppauge, NY 11787. Phone (516) 234-0400. **201**

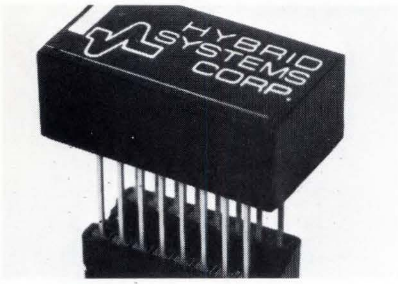
LOW TEMPERATURE-CURE COATING, in powder form, simplifies processing of components. The epoxy base powder, ECCOCOAT 721, overcomes one of the major objections of coating powders, which required the item to be coated to be pre-heated to a temperature of 350°F. It is now necessary to pre-heat the part to only 180°F. Price is $2 - $3 per pound. Emerson & Cuming, Inc., Canton, MA 02021. Phone (617) 828-3300. **202**

MOISTURE BARRIER SILICONE stabilizes semiconductor junctions and surfaces. MBS is a single component system especially processed from highly purified siloxane compounds, with self-catalyzing properties and cures to form a tough silastic protective coating impervious to moisture. It's operating temperature range is −65°C to +275°C. Material is available from inventory, priced from $12.00 per pound. Transene Company, Inc., Route 1, Rowley, MA 01969. Phone (617) 948-2501. **203**

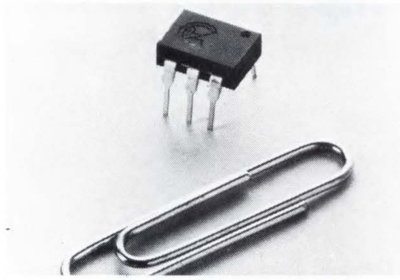
ELECTRICALLY CONDUCTIVE, copper based paint can be applied and cured at room temperature. Designated CBRC, it has a cured resistivity of about one ohm per square at 2-3 mils thickness and can be applied by brushing, spraying, or rolling. It can replace higher cost, precious metal paints in many applications. Available from stock at prices from $45.00 per gallon. Conshohocken Chemicals, Inc., 130 S. Easton Road, Glenside, PA 19038. Phone (215) 887-4471. **204**

MINIATURE FILTERED LAMPS are embedded in colored silicone rubber. The upper portion of the unbased T-3/4 or T-1 lamp is covered with a rubber filter and the base is potted to prevent light leakage. These assemblies are stocked in red, light blue, green, blue and yellow. For samples and additional data call or write: APM-Hexseal, 44 Honeck St., Englewood, N J 07631. Phone (201) 569-5700. **205**

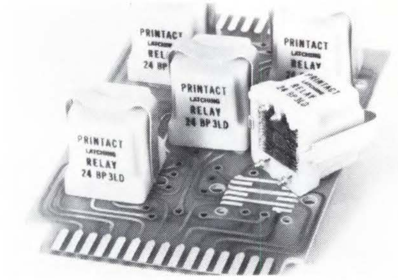
CIRCUITS



8-BIT D/A CONVERTER 371-8 features current-output performance for under $10 in single quantities. Reportedly the smallest discrete-component d/a converter on the market, it plugs into a single IC socket. Features include a built-in reference, DTL/TTL compatibility, 950-nsec settling, ±1/2-LSB linearity and temperature coefficient of 100 ppm/°C. Hybrid Systems Corp., 95 Terrace Hall Ave., Burlington, MA 01803. Phone (617) 272-1522 **207**

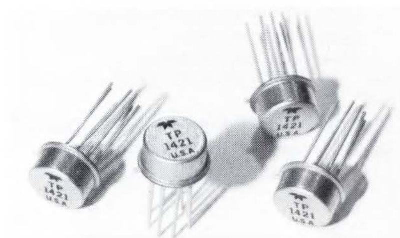


LED PHOTOTRANSISTOR ISOLATORS, 6-lead DIP 1500V types, feature minimum transfer ratios of 20% to 600%. Model CLI-2 has transfer ratio extremes of 30% and 100%, and rise and fall times into 100Ω of 5 μsec. Model CLI-3 has 20% at 1 mA and 100% at 10 mA. Rise and fall time is 5 μsec. Model CLI-5 has rise and fall times of 2 μsec. into 100Ω. Minimum transfer ratio is 20% at 20 mA. Clairex Corp., 560 S. Third Ave., Mount Vernon, NY 10550. Phone (914) 664-6602. **210**

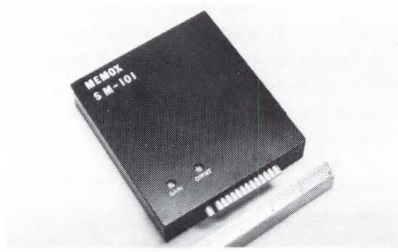


BINARY-TO-DECIMAL DECODERS contain built-in memory PC-board relays to perform a variety of switching functions. They use no relay sockets or soldering but plated conductors as the fixed contacts. Units convert any 6, 12, or 24V binary dc logic from a computer or any other instrument to decimal information. Price is $25 and delivery is 2 to 4 weeks. Printact Relay Div., Executone, Inc., Box 1430, Long Island City, NY 11101. Phone (212) EX2-4800. **213**

THERMOCOUPLE AMPLIFIER OMNI-AMP I is a self-powered portable microvolt unit that boosts thermocouple signals up to 100 times. It can be placed directly at a thermocouple output jack or between any standard thermocouple quick-disconnect. Gain is available in 7 fixed choices plus a variable gain, and frequency response is dc to 10 kHz. Amplifier, batteries, jacks and adapters cost $85. Omega Engineering, Inc., Box 4047, Stamford, CT 06907. Phone (203) 322-1666. **208**

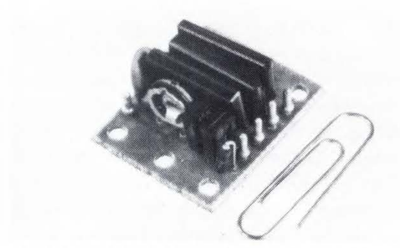


OP AMP Model 1421 packaged in a TO-99 case features 10-pA bias current, 10,000 CMRR, ±12V CMV and 10 mA of output current. The 1421 is directly interchangeable with the popular 741 and 740 op amps, is "latch up" proof, and incorporates output short-circuit and input fault protection. Its unity-gain bandwidth (f_t) is 1 MHz. Cost (100 to 249) is $8.50. Teledyne Philbrick, Allied Drive at Route 128, Dedham, MA 02026. Phone (617) 329-1600. **211**



SCANNING MEMORY for use with a conventional scope provides a steady, flickerless image of very-low-frequency signals. The SM-101 holds 5 sec of data in storage and updates and recirculates it 200 times/sec for scope presentation. A hold circuit prevents updating and permits observation of the stored data without degradation. Price is $485 and availability is within 60 days. Memox, Inc., 15904 Strathern St., Van Nuys, CA 91406. Phone (213) 994-9029. **214**

12-BIT D/A CONVERTER Model MN312 fits into a 16-pin hermetic DIP. The unit incorporates monolithic amplifiers and planar chips and a precision 12-bit nichrome ladder network. It provides an output range of 0 to ±1V and settles to 0.01% of its final value in less than 0.5 μsec. Price is $79 (1 to 24) and $45 (250). Micro Networks Corp., 5 Barbara Lane, Worcester, MA 01604. Phone (617) 756-4635. **209**



TONE ENCODER, thick-film hybrid Model ST-851, spans 20 Hz to 3 kHz with a frequency stability of ±0.5% over a temperature range of −30 to +100°C. Power requirements are 12.6V dc at less than 4 mA, nominal. The unit will function to specifications from 11 to 30V dc. The output is adjustable to 2.5V rms. Rise time is 10 msec. Alpha Electrical Services, Inc., 8431 Monroe Ave., Stanton, CA Phone (714) 821-4400. **212**

MULTIPLEXING A/D CONVERTER, multichannel system Series AN5800, provides up to 64 multiplexed 8 to 15-bit channels in the master control/display chassis, and expansion capability without limit in compatible expansion chassis. Price for an 8-channel multiplexer, sample and hold, 12-bit a/d converter with power supply, chassis and all interconnects is $1260. Delivery is 2 to 6 weeks. Analogic, Audubon Rd., Wakefield, MA 01880. Phone (617) 246-0300. **206**

CIRCUITS

DC-TO-DC CONVERTER Model PS-2402 is rated at +5V input and ±15V output at 150 mA and features dimensions of 2 by 2 in. and a low profile of only 0.375 in. It can be used on PC boards with 0.5-in. spacings and is rfi shielded. Its efficiency is 60%, isolation is $10^{12}\Omega$ and breakdown is 2500V rms. Cost is $69 and delivery is stock to 4 weeks. Stevens-Arnold, Inc., 7 Elkins St., S. Boston, MA 02127. Phone (617) 268-1170. **215**

OEM REGULATED POWER SUPPLIES provide 15 different output voltages from 4 to 28V dc with current ratings of 6 to 1.7A. Built-in features of the OLV-30 Series include: 0.1% line and load regulation, 0.1% ripple and noise, remote sensing and foldback current limiting as well as electrostatically shielded transformers. Prices start from $44. Elexon Power Systems, 18651 Von Karman, Irvine, CA 92664. Phone (714) 883-1717. **216**

CRYSTAL OSCILLATOR, voltage-controlled JKTO-85, features low power consumption of only 20 mW. Housed within a hermetically sealed container measuring only 0.75 cubic in., it is designed for any center frequency between 17.5 and 22.5 MHz with a frequency deviation of at least ±0.1% for a modulation input of ±2V (peak), dc to 20 kHz. Price in 100-unit quantities is $200 each. CTS Knights, Inc., Sandwich, IL 60548. Phone (815) 786-8411. **217**

FREQUENCY-TO-DC CONVERTERS, Series 200 Tach-Trol, are designed for measurement and control of rpm, linear flow or speed. They accurately convert frequencies into high-level output currents or voltages which are linearly proportional to the input signal. Standard current ranges of 1 to 5, 4 to 20 and 10 to 50 mA are field selectable. Airpax Electronics/Controls Div., Box 8488, Fort Lauderdale, FL 33310. Phone (305) 587-1100. **218**

VOLTAGE-TO-FREQUENCY CONVERTERS in a family of twelve models cover full-scale frequency ranges from 25 Hz to 100 kHz and feature 0.01% linearity. Input impedance exceeds 100 MΩ and zero and full-scale settings are adjustable by individual trimmers. The modules are designed to be powered from an external ±15V dc. Unit price for all models is $145 and delivery is stock to 30 days. North Hills Electronics, Inc., Glen Cove, NY 11542. Phone (516) 671-5700 **219**

POWER SUPPLY operates from either 98 to 132V ac or 196 to 264V ac at line frequencies of 47 to 63 Hz. Model SEI-5-6K-E provides an output voltage of 5V dc at 0 up to 6A continuous. The output voltage adjusts to ±0.5V. Line regulation is ±0.02% and load regulation is ±0.05%. Price is $64.50 (100 pieces) and includes a 5-year warrantee. Salient Electronics, Inc., Rexford, NY 12148. Phone (518) 393-4590. **220**

QUADRATURE SINEWAVE OSCILLATORS feature 0.04% distortion-buffered quadrature outputs (90° ±0.1°) which track to better than 100 ppm/°C, frequency drift to 100 ppm/°C and output amplitudes externally adjustable from 2 to 20V pk-pk with a resistor or voltage. They are available as fixed-frequency models (0.1 Hz to 20 kHz) or tuneable models which can be varied over a 1000:1 range. Frequency Devices, Inc., 25 Locust St., Haverhill, MA 01830. Phone (617) 372-6930. **221**

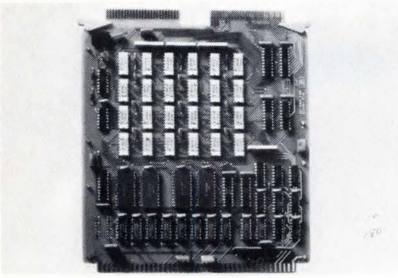
SAMPLE/HOLD AMPLIFIER ZD451 features sample accuracy of ±0.01% of full scale range, $10^{11}\Omega$ input impedance and a settling time of 7 μsec for a 0-to-10V input step. Other features include user selection of inverting or non-inverting operation, 50-nsec aperature time and user selectable gain of +1 to +100. It is priced at $39 (100 quantities). Zeltex, Inc., 1000 Chalmar Rd., Concord, CA. 94530. Phone (415) 686-6660. **222**

INSTRUMENTATION AMPLIFIER Type MSIA-1 uses three selected 741 op amps in a 14-lead flatpack that are connected in a classical three-amplifier, differential-input, single-ended output configuration. A built-in resistance network provides inherent closed-loop gain of unity in the 3/8 by 3/8 by 0.067-in. package. CMRR is 94 dB, drift is 5 μV/°C and noise is only 3.5 μV rms. Price is $35. Mini-Systems, Inc., David Rd., Box 429, N. Attleboro, MA 02761. Phone (617) 695-0206. **223**

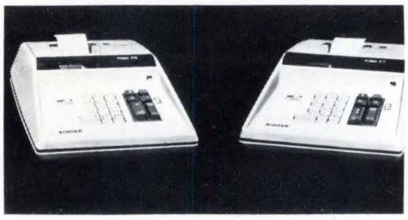
SOLID-STATE RELAY Type SLS-2500 features 1000V ac (pk-pk) I/O isolation, spst normally open contacts, 1A at 8 to 32V dc contact rating and drive-coil TTL compatibility. Coil operates from 2.4V dc at 1.6 mA maximum through −55 to +125°C and may be subjected to 32V dc continuously without damage. Contacts feature snap-action with hysteresis. Sterer Engineering and Mfg Co., 4690 Colorado Blvd., Los Angeles, CA 90039. Phone (213) 245-7161. **224**

TRUE ZERO-CROSSOVER ELECTRONIC SWITCH assures true zero-volt switching by forming an electrical cushion between the signal input and load power. Series 6500 module has a solid-state output switching circuit that is isolated from the input signal through a long-life reed relay. Guardian Electric Mfg Co., 1550 W. Carroll Ave., Chicago, IL 60607. Phone (312) 243-1100. **225**

DC POWER SUPPLY for powering linear ICs supplies ±15V at 200 mA from 2 by 3 by 1-in. module. Model BPM-15/200 with an input isolation transformer has output load regulation of ±0.1% and line regulation of ±0.05%. It can power up to sixty 741 op amps, features 65% efficiency and has 100-MΩ isolation. TC is ±50 pp/°C and output stability is ±0.05% over 0 to +71°C. Price is $69. Datel Systems, Inc., 1020 Turnpike St., Canton, MA 02021. Phone (617) 828-6395. **226**



FIRST WRITABLE CONTROL STORE and PROM writer for minicomputer users allows them to tailor the HP2100 instruction set to meet the unique needs of differing applications. Writable control store (WCS) has 256 24-bit words of RAM plus address and read/write circuitry on one card. The PROM writer converts microprograms developed with WCS to ROM. Hewlett Packard, 1501 Page Mill Rd., Palo Alto, CA 94304. Phone: (415) 493-1501. **227**



TWO NEW LOW COST CALCULATORS feature high speed printers. Model 215 is a printing multiplier and the Model 217 printing calculator has addition, subtraction, multiplication, division and squaring capabilities. Up to 10 digits can be entered, with answers up to 11 digits. Model 215 is priced at $249, and the Model 217 at $325. Business Machines Div., The Singer Co., 2350 Washington Ave., San Leandro, CA 94577. Phone: (415) 357-6800. **228**

CARD READER SYSTEM is a peripheral to 8- and 16-bit ALPHA and NAKED MINI computers. The system includes a Bridge 8000, 300 card/min card reader in a table configuration, and an interface controller which plugs into a standard prewired I/O slot in the computer's mother board. System cost is $3850. Computer Automation Inc., 895 West Sixteenth St., Newport Beach, CA 92660. Phone (714) 642-9630. **229**

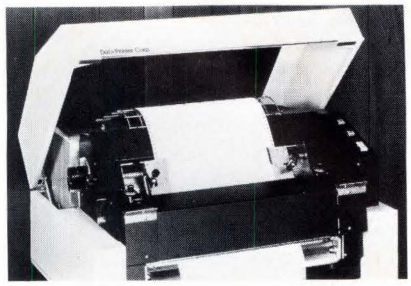
ELECTRONIC PRINTING CALCULATORS. Four models range from P-253, with four functions and one accumulating register, to P-256, with three accumulating registers, item counter, square root and percentage functions and sign control. All feature a 14-digit mosaic printer, floating input and fixed output decimals, and direct positive and negative accumulation registers. Philips Business Systems, Inc. 37 W. 57th St., New York, NY 10019. Phone (212) 751-6670. **230**

CASSETTE DIGITAL MEMORY SYSTEM. The 2-channel MT-5 stores two-million bits at a packing density of 800 bpi. Capstan drive system provides a tape speed of 7.5 ips with start and stop times of less than 25 msec. Two models are available: the MT-5W for "write only" and the MT-5R for "read only" applications. Price is $595. TEAC Corp. of America, 7733 Telegraph Rd., Montebello, CA 90640. Phone: (213) 726-0303. **231**

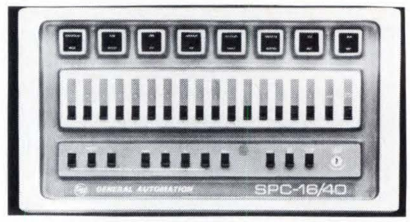
DISK STORAGE SYSTEM provides random access storage for any HP 2100 Series computer equipped with DMA (Direct Memory Access). It uses the IBM 2315 type disk cartridge in single or multiple disk drive configurations and provides 1.22m words of storage. Three operating systems are available: Real Time Executive, Disk Operating System, or Disk Based Auxiliary Memory System. Daconics Corp., 925 Thompson Pl., Sunnyvale, CA 94086. **232**

READ-AFTER-WRITE CASSETTE HEADS have precision-machined track locations that require no adjustment before mounting. The single-track Model A284A and two-track Model A-280A magnetic heads feature a crossfeed rejection of no less than 20 DB with a write rise time of 2μsec and can be used for virtually any digital application. Arvin Magnetics, 6950 Washington Ave., S. Eden Prairie, MN 55343. Phone (612) 941-6700. **233**

DIGITAL PRINTER, DM-500 series, prints 3 lines/sec and up to 21 columns. It can be supplied minus case and power supply, or without print mechanism. The latter includes one pc board with all drive electronics and power supply. An optional internal clock provides day of month, hours, and minutes. Price for 21 columns with case is $720 and $625 without case. Keltron Corp., 224 Crescent St., Waltham, MA 02154. Phone (617) 894-0525 **234**



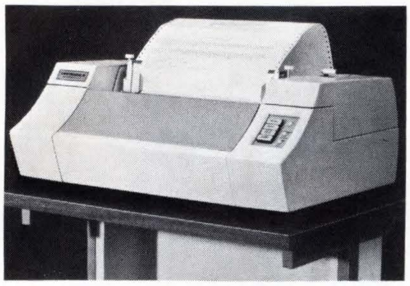
VARIABLE SPEED LINE PRINTER. Model 246 prints full 132 column lines at 200 lines/min, or speeds up to 400 and 600 lines/min utilizing 96 and 48 columns, respectively. Model 306 prints full 132 column lines at 300 lines/min or at 600 lines/min when utilizing 96 columns. Both models have 64 character drums and 8 channel VFU. Model 246 price is $5500 and Model 306 is $6100. Data Printer Corp., Msgr. O'Brien Highway Cambridge, MA 02141. Phone: (617) 492-7484. **235**



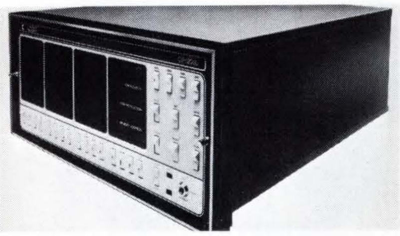
MINICOMPUTER FAMILY EXPANDS: The model SPC-16/40 shown and five other SPC-16 sisters (/45, /60, /65, /80 and /85) are priced from $3950 to $8550. They feature large four-layer pc boards with buried power and ground planes for low noise. The /80 and /85 models, use Schottky-clamped TTL to achieve 800 nsec cycle times. General Automation, Inc., 1055 S. East St., Anaheim, CA 92805. Phone: (714) 778-4800. **236**

FAN FOLD TAPE READER, TRF9300B, features LED light sources, self cleaning read heads and bipolar logic compatibility. It can stop on character at 300 char./sec and handle tapes having up to 60% light transmissivity without adjustment. Reader is 19 inch wide x 7 inch high and has fan fold bins with 150 ft. tape capacity. Electronic Engineering Co. of California, Electronic Products Div., 1441 E. Chestnut Ave., Santa Ana, CA 92701. Phone (714) 547-5501. **237**

PAPER TAPE SYSTEMS convert GRAF/Pen data input to punched paper tape. Systems 2012 and 2013 operate in either binary or BCD mode and include a GRAF/Pen stylus, 14 x 14 inch tablet, control units, and the paper tape punch. The latter punches up to 75 char./sec and is available in 5-to 8-track models. Prices for System 2012 start at $5995 and for System 2013 at $6295. Science Accessories Corp., 65 Station St., Southport, CT 06490. Phone: (203) 255-1526. **238**



9 x 7 DOT MATRIX LINE PRINTER. The 101A low cost impact printer prints at speeds of 165 characters/sec. Standard features are: paper runaway control, single line spacing, full 64-character set, hardware code selector, and 50 or 60 cycle multi-voltage operation. Price is $4130 for single units. Centronics Data Computer Corp., One Wall St., Hudson, NH 03051. Phone: (603) 883-0111. **239**



MICROPROGRAMMED MINICOMPUTER for general-purpose and business applications. Hardware features microprogrammed are: a serial I/O controller, a bootstrap loader, and a high speed Direct Memory Channel block I/O feature. The CIP/2200 includes memory addressing to 32K bytes, 1.1 microsecond full cycle memory speed, 8- or 9-bit memory bytes and 16 general-purpose 8-bit file registers. Process Controls Div., Cincinnati Milacron, Lebanon, OH 45036. Phone (513) 494-1200. **240**

DIGITAL MULTIPLEXERS, called MultiTerm 1, can utilize as many as 16 computer terminals on a single telephone or communications line. The terminals may be located up to 4000 ft from the MultiTerm 1 and are operational at speeds of up to 9600 baud. Provision for built-in modems has also been made. Pricing begins at $750. Delta Data Systems Corp., Woodhaven Industrial Park, Cornwells Heights, PA 19020. Phone (215) 639-9400. **241**

BRAIDED WIRE ALTERABLE ROM. The 1K x 16 ROM runs from a +5.0V supply, has system access times of 200 nsec and cycle times of 500 nsec, and is fully decoded including data registers. Up to eight memories may be paralleled. Dimensions are 5.2 x 8.5 x 1.25 inches. The ROM is plug compatible with the PDP-14 and PDP-16 and is priced at under 2¢/bit in OEM quantities. Datapac Inc., 18872 Redhill Ave., Santa Ana, CA 92707. Phone (714) 546-7781. **242**

DISC FILE SYSTEM. Model DC-16, interfaces IBM 2311 or single spindle 2314 compatible disc drives to non-IBM computers. It can handle up to nine disc drives (maximum of eight on-line), provides buffering and signal timing for the memory/disc data transmission, and monitors the status of the disc drive and the data transfers. Telefile Computer Products, 17785 Sky Park Circle, Box AO, Irvine, CA 92664. Phone (714) 549-3329. **243**

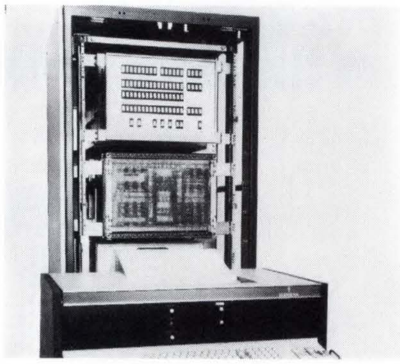
REPROGRAMMABLE ROM. Series 1002 capacitive field-alterable ROM (RE-PROM) has capacities from 256 to 26K bits per pc board and includes input buffering, timing and control, address decoding, output data registers and TTL/DTL interface. It is non-volatile, NDRO, and has an access and cycle times up to 50 nsec. Fully assembled and tested system price is less than 1¢/bit. Integrated Memories, 260 Fordham Rd., Wilmington, MA 01887. Phone (617) 658-5073. **244**

MODEMS. Series 12A line of modems, designed for application on the direct-distance dialing network, operate at 0-1200 bps. They are offered in half duplex with additional versions for 5 bps and 150 bps reverse channel, with or without automatic answer. Both custom-configured modem cards for OEMS and stand-alone modem packs are provided. Digital Communications Dept., Sanders Associates, Inc., Daniel Webster Highway Nashua, NH 03060. Phone (603) 885-2817. **245**

ADD-ON PLATED-WIRE MEMORIES. Model NM-8316 (16K x 16) and NM08332 (32K x 16) feature partitionable memory capability which provides software or program protection from accidental wipe-out. The amount of memory to be protected may be field programmed. Price is $9873 for NM-8316 and $13,202 for NM-8332. Nemonic Data Systems Inc., 1301 West Third Ave., Denver, CO 80223. Phone (303) 892-7012. **246**

KEY-TO-DISC SYSTEM, System 1302, offers a full-record CRT display at each key-station, and an 18,000-record disc capacity based on a record length of 125 characters. Other record lengths are available to improve data management. Monthly rentals are available. Purchase prices are: $31,500/Control Unit, $1200/keystation, and $4800 for the Expansion Adapter Unit. Inforex, 21 North Ave., Burlington, MA 01803. Phone (617) 272-6470. **247**

INFINITELY ALTERABLE MINI ROM, Model 816, is a non-volatile, NDRO, electrically alterable ROM. It utilizes a low-threshold, square-loop core, arrayed in a 2-core/bit mode and is available in a variety of configurations and storage capacities, with a maximum storage of 256 bits. Features include infinite alterability, full TTL compatbility, +5V-only operation, and 36-pin dual in-line packaging. Quadri Corp., 2950 West Fairmont, Phoenix, AZ 85017. Phone (602) 263-9555. **248**



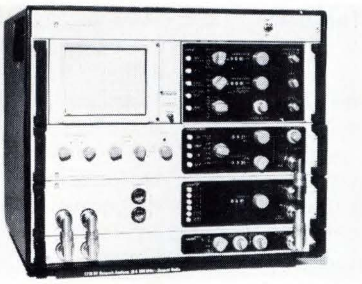
MINICOMPUTER FOR PROCESS CONTROL. Model 360, a 16-bit mini, can process 143 instructions consisting of 120 standard instructions, 8 executive instructions and 15 input/output instructions and features 3 interrupt levels. MOS or ferrite-core memories are used for the variable main memory with a maximum capacity of 60 K words (plus 1 K words of ROM). Siemens Corp., D-8520 Erlangen 2, Postfach 325, Federal Republic of Germany. Phone: (09131) 7-3394. **249**

32-BIT COMPUTER, systems 85, is an 850-nsec processor with core memory expandable from 8K to 131K words. Memory byte parity and page protection are standard. I/O facilities transfer data to and from peripherals at up to 1.17 million words/sec. As many as 16 device controller channels can be linked to the I/O bus. Prices range from under $150,000 to over $400,000. Systems Engineering Labs, Inc., 6901 W. Sunrise Blvd., Ft. Lauderdale, FL 33313. Phone (305) 587-2900. **250**

TAPE CLEANER, the Mark IV, uses a self-sharpening, rotating cylindrical blade to remove contaminants on the oxide side of a tape and a screen cleaner to clean the mylar backing. A vacuum removes contaminants from both sides. Cleaning at 180 inches/sec, a two-pass cleaning operation takes 5 min. Price is $2300. Data Devices, Inc., 6219 DeSoto Ave., Woodland Hills, CA 91364. Phone (213) 887-8246. **251**

REED RELAY MULTIPLEXER, the Reedscan Model 3000, is a systems oriented 3-wire or 6-wire multiplexer used for sequentially connecting from 2 up to 100 data sources. The scanning capacity can be expanded from the basic 10 channels up to 100 channels in ten channel increments. Channel identification is presented in 1248 BCD code. Basic 10-channel price is $995. Pivan Data Systems, 6955 North Hamlin Ave., Lincolnwood, IL 60645. Phone (312) 676-0790. **252**

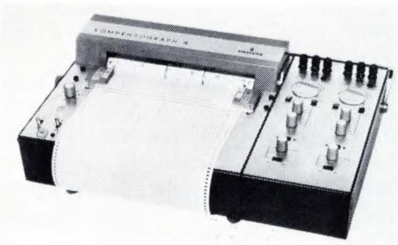
EQUIPMENT



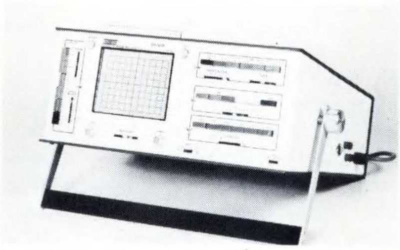
RF NETWORK ANALYZER Model 1710 provides precise measurements of transmission and reflection properties (including magnitude, phase, group delay, and S parameters) over 400 kHz to 500 MHz. It also features 115-dB dynamic range, 0.005-dB resolution and 50 or 75 Ω operation without performance degradation. Cost is $6850. General Radio, 300 Baker Ave., Concord, MA 01742. Phone (617) 369-4400. **253**

DATA ACQUISITION/CONTROL SYSTEM Series 9600 can be configured as a standalone or a distributed system to automate single processes or entire factories. Central to the system is an expandable minicomputer with a memory capacity of 8192 to 32,768 16-bit words. Systems start at $22,350 and deliveries are to begin April 1972. Hewlett-Packard Co., 1501 Page Mill Rd., Palo Alto, CA 94304. Phone (415) 493-1501. **256**

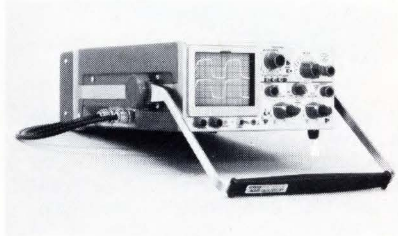
REAL-TIME ANALYZER for digital correlation and probability analysis, Model SAI-43A, features 400-point resolution at selectable sampling increments down to 0.2 μsec (5 MHz). It also provides 800-point precomputational delay. The unit operates in three modes—correlation (auto and cross), probability and signal enhancement. Signal Analysis Industries Corp., 595 Old Willets Path, Hauppauge, NY 11787. Phone (516) 234-5700. **259**



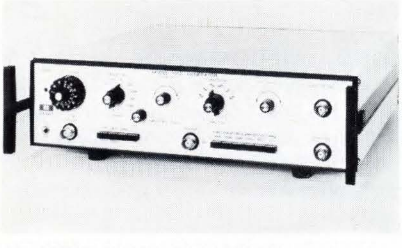
POTENTIOMETRIC RECORDER Kompensograph III has 0.25% accuracy, 0.1% linearity, 18 ranges of amplification and capability for forward and reverse recording. Available as a single or double-channel recorder, its short response times of 0.25 or 0.5 sec and interference voltage suppression allow its use in many applications. Kompensograph III has 11 selectable voltage ranges and 7 current ranges. Siemens Corp., 186 Wood Avenue South, Iselin, NJ 08830. Phone (201) 494-1000. **254**



10-MHZ SCOPES, single and dual-trace Models 310 ($425) and 320 ($495), respectively, feature calibrated attennuators on vertical and horizontal amplifiers and calibrated triggered sweep. Input impedance is 1MΩ, vertical sensitivity is 5 mV/div. to 50V/div. and sweep ranges from 100 msec/div. to 1 μsec/div. (plus 5X magnifier). Delivery is 60 days. Thorton Associates, Inc., 87 Beaver St., Waltham, MA 02154. Phone (617) 899-1400. **257**

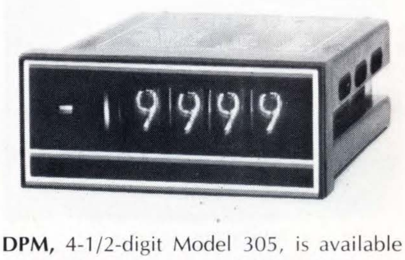


PORTABLE SCOPE Model 326 is the latest addition to the Sony/Tektronix series of scopes. Measuring 3.9 by 8.6 by 13.6 in. and weighing less than 12 lbs, the battery-operated dual-trace 326 offers bandwidth to 10 MHz at 10 mV/div., or 5 MHz at 1 mV/div. Sweep rates extend from 1 sec/div. to 1 μsec/div. (to 0.1 μsec/div. with X10 magnifier). Price is $1650. Tektronix, Inc., Box 500, Beaverton, OR 97005. Phone (503) 644-0161. **260**



VCF/TRIG FUNCTION GENERATOR Model 7050 has a 0.001-Hz-to-11-MHz range and trigger and gate capability for single-shot and burst waveforms. It produces sine, square, triangle, ramp, pulse and sync waveforms in continuous, single-shot or burst modes. Waveform symmetry can be continuously adjusted from a range of 19:1 through 1:1 to 1:19 for ramp and pulse operation. Exact Electronics, Inc., Box 160, Hillsboro, OR 97123. Phone (503) 648-6661. **255**

BIDIRECTIONAL COUNTER Series 7713 totalizes at 500 kHz. Its universal input circuit accepts sine and square waves or pulse signals. It can be used as a self-contained totalizer, or interfaced with the Veeder-Root Series 7700 family to form a complete data acquisition system. It comes with 4, 5, 6 or 7 illuminated decades and a ± indicator and operates from 105 to 125V ac, 50/60 Hz. Veeder-Root, Hartford, CT 06102. Phone (203)527-7201. **258**



DPM, 4-1/2-digit Model 305, is available with BCD for less than $250 in OEM quantities. Prices range from $195 to $375, depending on quantity. The 305 is interchangeable with Weston's DPMs and features a Nixie display. It can make 20 measurements/sec or be commanded to take a reading and hold it until it is re-triggered, and has programmable decimal points and polarity signs. Electro-Numerics Corp., 2961 Corvin Dr., Santa Clara, CA 95051. Phone (408)738-1840. **261**

EQUIPMENT

DIGITAL WATTMETER Model 235 offers true-rms power readings from 20 Hz to 20 kHz and allows comparative readings at reduced accuracy to 150 kHz. Full-scale power readings range from 2W (20V and 0.1A) to 20 kW (632V and 31.4A). The current input may float up to the full voltage (632V rms) above the low side of the voltage channel. Price is $2495. Clarke-Hess Communication Research Corp., 43 W. 16th St., New York, NY 10011. Phone (212) 255 2940. **262**

FREQUENCY METER/TACHOMETER Series 2700 features 20-MHz operation and LED displays. Features include automatic triggering with a sensitivity of 100 mV rms, a front-panel sensitivity control, stored display, buffered and latched BCD output and a 1-ppm crystal time base. Available in 4, 5 or 6-digit models, units are priced from $360 to $400. Electronic Research Co., 10,000 W. 75th St., Overland Park, KS 66204. (913) 631-6700. **263**

SIGNAL/NOISE GENERATOR Model 132 incorporates an oscillator, square-wave generator, sweep generator, FM modulator, wide-band noise generator, and pseudo-random sequence generator in one compact unit. Signal-to-noise or noise-to-signal mode allows selection of the amount of noise to be added to an analog or digital signal. Source is from 0.2 Hz to 2 MHz. Price is $795. Wavetek, Box 651, San Diego, CA 92112. Phone (714) 279-2200. **264**

CABLE TESTER known as Maze Master, has automatic search capability, and identifies wire loops in cable harnesses and simplifies production, test and troubleshooting. Each press of a button identifies on an LED digital display the source and successive termination points of wire loops in cable harnesses in less then one second.Cost is under $600. Addison, 1101 Bristol Rd., Mountainside, N. J. 07092. Phone (201)233-6010. **265**

VIDEO DIGITIZER for TV signal processing, testing and enhancement converts analog information into a 4-bit digital word at conversion rates of 20 MHz and an accuracy of $\pm 3\%$ of full scale (± 0.5 LSB). Designated the IAD-5104N, it offers display delay for use in on-line digital editing. Price is $950 and delivery is 3 to 4 weeks. Inter-Computer Electronics, Inc., Box 507, Lansdale, PA 19446. Phone (215) 822-2929. **266**

FUNCTION GENERATOR Model 1020 provides pulses, square-waves and ramp waveforms. Adjustable pulses, square-waves, AM and sawtooth FM are provided from 10 to 10,000 Hz. Pulse widths range from 0.2 to 20μsec. Price is $475. Polarad Electronic Instrument Div., 5 Delaware Dr., Lake Success, NY 11040. Phone (516) 328-1100. **267**

FREQUENCY COUNTER with digital offset has six-digit LED readout and operates from 20 Hz to 100 MHz and from 100-mV signals. The displayed frequency may be internally offset from the signal frequency by a constant value. This allows displaying receiver frequency by measuring its local oscillator. Model OFC-400 quantity price is $550. Micro-Tel Corp., 6310 Blair Hill Lane, Baltimore, MD 21209. Phone (301) 823-6227. **268**

RF SIGNAL GENERATOR, Model 947, provides a printer output of its frequency. The generator's output can also be fed directly to a computer without using an external counter to convert to BCD. Frequency can also be read directly on a 6-digit display. Model 947 has a range of 50 kHz to 80 MHz and stability of ± 10 Hz. The generator costs $3150. Logimetrics, 100 Forest Dr., Greenvale, NY 11548. Phone (516) 484-2222. **269**

25-MHZ COUNTER Type 460 has a six-decade, 7/8-in.-high seven-segment LED display with automatic decimal point. Sensitivity is 0.2V rms up to 10 MHz. A front-panel switch increases the sensitivity to 20 mV. It has 4 frequency ranges with gate times of 1 msec to 10 sec in decade steps. Cost is $375. Thornton Associates, Inc., 87 Beaver St., Waltham, MA 02154. Phone (617) 899-1400. **270**

TOTALIZING COUNTER Series 7443 features a precision-wound ac coil and avoids rectifier problems caused by voltage surges common to industrial installations. The counter operates at 600 counts per minute on 115 or 230V ac. It comes in base or panel-mounted 6-digit models with lock and key, thumbwheel or knob reset. Veeder-Root, Hartford, CT 06102. Phone (203) 527-7201. **271**

SOLID-STATE CONTROLLER Shawnee 336 is priced under $90. It is a plug-in, digital-set, solid-state impulse count controller with dpdt instantaneous and dpdt delayed contacts. The counter is available in a single range to count up to 9999 settable to the exact digit. It counts up to 4000/minute from switch closures or ac line voltages. Automatic Timing & Controls, Inc., King of Prussia, PA 19406. Phone (215) 265-0200. **272**

METER RELAY/CONTROLLERS, contactless Series 2600, average 25% less cost than comparable edgewise controllers. The 2600 Series feature all solid-state circuitry, a wide variety of standard ranges and are also available as indicators only. Manufacturer can also supply custom designs. Sigma Instruments, Inc., 170 Pearl St., Braintree, MA 02185. Phone (617) 843-5000. **273**

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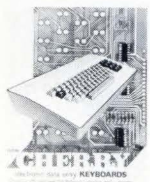
HONEYWELL COMPUTER JOURNAL presents a new look in editorial content along with "an enhanced international flavor". It contains what is believed to be a publishing first—a microfiche copy of the entire issue attached to the inside back cover. Subscriptions are available at $10 per year or $3 per copy by writing to A. H. Shriver, managing editor, Honeywell Computer Journal, Mail Drop B-106, Box 6000, Phoenix, AZ 85005. **275**

UPDATED BROCHURE of inductive components covers LC-filters, balun transformers and toroidal coils. Expanded to 20 pages, it includes useful design advice on the selection of filter types and a modern glossary of filter terms, in addition to detailed specifications of each component. The brochure is designated #11001 and free copies can be obtained by writing to: Cambridge Thermionic Corporation, 445 Concord Avenue, Cambridge, MA 02138. **278**

DIGITAL CASSETTE DRIVES. A new brochure describes operations and specifications of the Ampex Model TMC digital cassette drive. Specifically designed for data processing operations, the TMC is a high-performance recorder featuring single- or dual-track heads and ECMA-ANSI compatibility. Request brochure C-211 from Ampex Corp., Marketing Communications (MS-7-13), 401 Broadway, Redwood City, CA 94063. **281**



NEW KEYBOARD ELECTRONICS PRINCIPLE. A description of the scanning principle behind the Cherry keyboard encoding system is accompanied by a diagram showing interaction between an 8-bit counter, two multiplexers and a 4-to-16 line decoder. There is also a chart of basic electrical specifications. Cherry Electrical Products Corp., 3600 Sunset Ave., Waukegan, IL 60085. **276**

DIGITAL PANEL INSTRUMENTS selection is simplified with a pocket-size guide. This ten-page brochure lists specifications and prices for more than 75 Newport Laboratory meter models. Cross referencing of all instruments in tabular form permits rapid evaluation and comparison. Newport Laboratories, Inc., 630 E. Young St., Santa Ana, CA 92705. **279**

HIGH VOLTAGE CAPACITOR catalog provides detailed performance specifications on high-precision, wrap and fill, and hermetic-sealed film capacitors, including the new reconstituted mica and metallized polypropylene types. This reference book also includes high voltage units up to 200 KV. A complete section of engineering application notes are also featured. Del Electronics Corp., 250 E. Sanford Blvd., Mt. Vernon, NY 10550. **282**

NEW FREE CATALOG lists thousands of hard-to-find items for industry. Catalog 722 has 148 pages of over 4000 components: lenses, prisms, wedges, mirrors, mounts, and all types of accessories. Included in Edmund's new line of laser accessories are the following: 8X & 20X collimators, spatial filters, Brewster windows, photometers, universal connecting bases, and adjustable laser carriers. Edmund Scientific Co., 380 Edscorp Bldg., Barrington, N J 08007. **277**

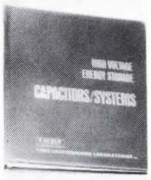
A DIGITAL INSTRUMENTS short-form catalog covers a line of miniature digital instruments for industrial controls. The four-page catalog includes a brief description of technical data, electrical and mechanical specifications, prices and options. It features a gate-fold page with template cut outs to exact size for determining panel-mounting requirements for all instruments shown. Electronic Research Co., 10,000 W. 75th St., Overland Park, KS 66204. **280**

ANALOG FUNCTION MODULES are shown in a 16-page catalog. Product lines covered include CRT display modules, analog multipliers-dividers, fast op amps, rms operator modules, sample-hold modules and modular power supplies. Intronics Inc., 57 Chapel Street, Newton, MA 02158. **283**

LITERATURE

MINICOMPUTER CATALOGUE. A revised 20-page catalog listing products and services, includes Data General's new Nova 1210, Nova 1220, and Nova 820 computers, and details new hardware options, including an 8K, 16-bit core memory and a turnkey operator's console. Separate sections deal with software, peripheral equipment, customer support, and the Nova instruction set. Write Data General Corp., Southboro, MA 01772. **284**

SEMICONDUCTOR PACKAGING Catalog provides details on packaging manufacturing, sealing, and finishing, as well as on the company's plating facility. Half the catalog is devoted to the more than 50 different types of semiconductor packages TI offers. A basic description that includes specifications, package measurements, and recommended applications is given for each package type. Texas Instruments Inc., 13500 North Central Expressway, Dallas, TX. **288**



ENERGY STORAGE CATALOG contains up-to-date product information, valuable to researchers and engineers who require capacitor discharge energy. The catalog, or any one of the five sections, are available free of charge on letterhead request. Tobe Deutschmann Laboratories, Inc., 550 Turnpike Street, Canton, MA 02021. **285**

A COMPLETE LINE OF PACKAGING SYSTEMS AND COMPONENTS are introduced in an 8-page short-form catalog. Products include card files, logic panels, DIP sockets, DIP packaging drawers and a complete software/wiring service. Scanbe Mfg. Corp., 3445 Fletcher Ave., El Monte, CA 91731. **289**

COMPUTER COMMUNICATION EQUIPMENT of many types are described in a 16-page brochure. Equipment includes message switching and communications processing computer systems and remote communications terminals. Systems and products discussed are accompanied by general descriptions together with pictures, diagrams and specifications. Computer Communications, Inc., 5933 W. Slauson Ave., Culver City, CA 90230. **286**

ANALOG X-Y RECORDER information is given in a four-page brochure. Gould Instruments's Brush 500 recorder for portable use or rack mounting is described. The instrument features pressurized-ink writing, a non-contact pen position feedback system that enforces 99.85% linearity and a writing speed of 40 in./sec in both axes. Gould, Inc., Instrument Systems Div., 3631 Perkins Ave., Cleveland, OH 44114. **290**

LED READOUT Bulletin RO5051 details series 745 solid-state readouts. The GaAsP device has a character height of 0.270 inch, and comes in a 14-pin DIP. Displays are available with either left or right decimal and have single-plane wide-angle visibility, and can be driven directly by most TTL and DTL circuits. Dialight Corp., 60 Stewart Ave., Brooklyn, NY 11237. **287**

BCD-TO-SEVEN-SEGMENT DECODER Type 704-1554 is described in a data sheet. The device drives Dialight's Series 745 single-digit solid-state numeric display and is capable of converting four lines of BCD code into the appropriate outputs, which in turn drive the single-digit solid-state readout. Dialight Corp., 60 Stewart Ave., Brooklyn, NY 11237. **291**

Application Notes

PHYSICAL MEASUREMENT INSTRUMENTATION. What type of physical measurement would you like to make: pressure? force? acceleration? vibration? displacement? strain? temperature? or maybe an engine analyzer is what you need? Tektronix, Inc. can show you how to make these measurements with an oscilloscope in a new 24-page booklet. Tektronix, Inc., Box 500-A, Beaverton, OR 97005. **301**

DIGITAL FREQUENCY SYNTHESIZERS are detailed in ICAN-6716, "Low-Power Digital Frequency Synthesizers Utilizing COS/MOS IC's." The App note briefly reviews digital phase-locked loop fundamentals and discusses practical digital loops including the use of hetrodyne down-conversion. Twenty-five figures include complete logic and circuit diagrams, as well as circuit and timing waveforms. RCA Solid State Div., Box 3200, Somerville, N J 08876. **299**

FET DESIGN BROCHURE, titled "FET Design Ideas," Bulletin CB-145, is 17 pages long and covers how to properly bias FETs, describes 26 different FET applications, and provides a listing of the most popular FETs in the industry. A complete listing of FET application reports currently available from TI is included along with ordering instructions. Texas Instruments Inc., Inquiry Answering Service, P.O. Box 5012, MS/308, Dallas, TX 75222. **302**

"TECH TIPS" 1-2 provides formulas for the calculation of average and RMS currents for a half-sine-wave form, and for phase control of a half-sine wave form at 60 Hz. Also included are charts which can be used to determine peak-to-RMS, average-to-RMS, peak-to-average, and reciprocals of the current relationships. Westinghouse Electric Corp., Semiconductor Div., Youngwood, PA 15697. **303**

METHODS OF MEASUREMENT for semiconductor materials process control, and devices—quarterly report April 1 to June 30, 1971—covers significant accomplishments of a program carried out by NBS on measurement of resistivity of semiconductor crystals, study of gold-doped silicon; measurement of transit time and related carrier transport properties in junction devices. U.S. Government Printing Office, SO Catalog No. C13.46:702, Washington, D. C. 20402. **304**

MANUFACTURER LIABILITY and related problems are discussed in a new leaflet published by the Hazard Evaluation and Liability Prevention Div. of Associated Testing Laboratories. The leaflet, "Here Is HELP," notes that product safety and minimizing the liability potential is of major concern to manufacturers, importers, repairers, retailers, advertising agencies, insurers and attorneys as well as those who are involved with industrial education and product standards. Hazard Evaluation and Liability Prevention Div., Associated Testing Laboratories, Inc., Box 408, Wayne, N J 07470. **300**

Reference copies of the following articles are available without charge:

R.S. NO.	TITLE	PAGE NO.
L61	Analog circuit modules offer advantages in industrial systems	18
L62	Test op amps the easy way with simple step-by-step methods	28
L63	Don't be confused by IC switching time specifications	34
L64	Bob Fillingham and Carlos Chong of Nemonic Data Systems speak out on plated-wire memories	40
L65	Don't neglect the solid-state analog switch	44
L66	Solid-state 100W amplifier operates from a 12V source	46

ADVERTISERS INDEX

Index to Ads, Products and Literature

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