Electronics®

Low-cost microcircuit modules: page 36
Special report on field-effect devices: page 45
Microwave solid-state delay lines: page 69

November 30, 1964
75 cents
A McGraw-Hill Publication

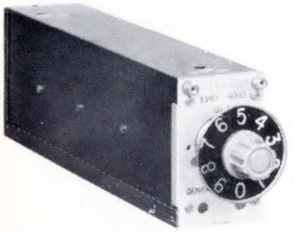
Below: the MOS transistor moves into spotlight, p 45

A Significant New Development

MODULAR
Decade Frequency Synthesizers

dc to 100 kc and dc to 1 Mc

Buy only the resolution you need — add more later if you wish



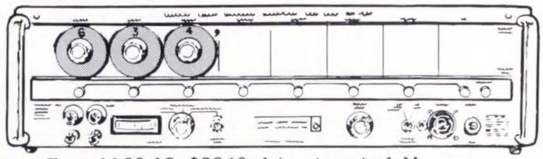
The heart of this new Synthesizer is a plug-in module called a Digit-Insertion Unit. Up to seven of these units can be assembled in a frame to produce a decade-frequency synthesizer with in-line readout. You can start with as few as three Digit-Insertion Units to form a complete working synthesizer — a 100-kc model adjustable in 100-cycle steps, or a 1-Mc model with 1-kc steps. Add another "D-I Unit", and the 100-kc model now has 10-cycle resolution; the 1-Mc model goes down to 100 cycles. Put in all seven D-I Units to get 0.01-cycle resolution all the way to 100 kc, or 0.1-cycle increments to 1 Mc.

That's not all A second module, a Continuously Adjustable Decade (CAD), can be included in any of the Synthesizers; it makes possible continuous adjustment of frequency, and provides at least three additional significant figures. The CAD can also functionally replace one or more of the D-I Units. For example, if you press the pushbutton at the 10-cps step position, the CAD replaces the decade directly above the actuated button and all decades to the right; the CAD automatically assumes a 0 to 100-cycle range. If the button at the 100-cps step position is pressed, the Continuously Adjustable Decade assumes a 0 to 1,000-cycle range. This process can be used to replace any number of decades, providing continuous frequency adjustment over a small or large range, as desired. Furthermore, by virtue of a self-calibrating feature of the CAD, frequency can be set to 3 or more significant figures in addition to that provided by the D-I Units.

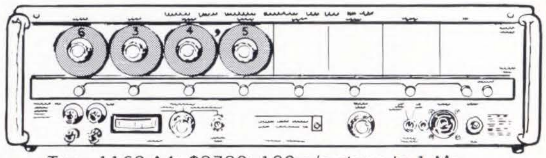
The CAD frequency may also be swept electronically by an external signal. The resulting sweep range may be made very small if a pushbutton to the right is actuated, or progressively larger as pushbuttons toward the left are used.

All signals produced by the Synthesizer are frequency-coherent with a single, built-in, room-temperature, primary-crystal oscillator. For extremely exacting requirements, this primary oscillator may be phase-locked to an external frequency standard. Remotely programmable digit units for these Synthesizers are soon to be available, as well.

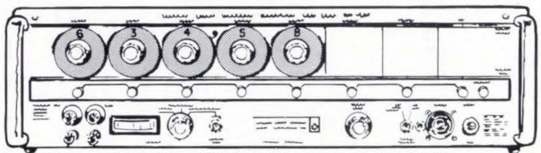
Level is adjustable up to 2 volts into 50 ohms when ac coupled, and a panel meter reads the output voltage. Output with dc coupling is up to 1 volt without metering.



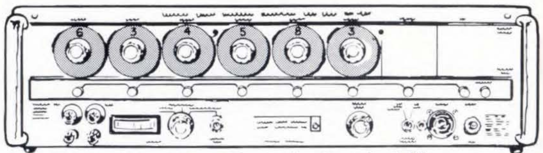
Type 1162-A3; $3340; 1-kc steps to 1 Mc



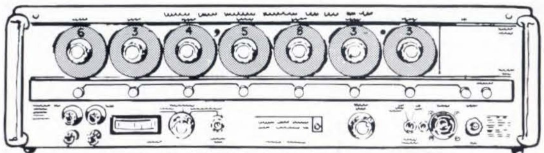
Type 1162-A4; $3780; 100-c/s steps to 1 Mc



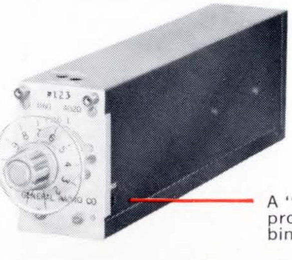
Type 1162-A5; $4220; 10-c/s steps to 1 Mc



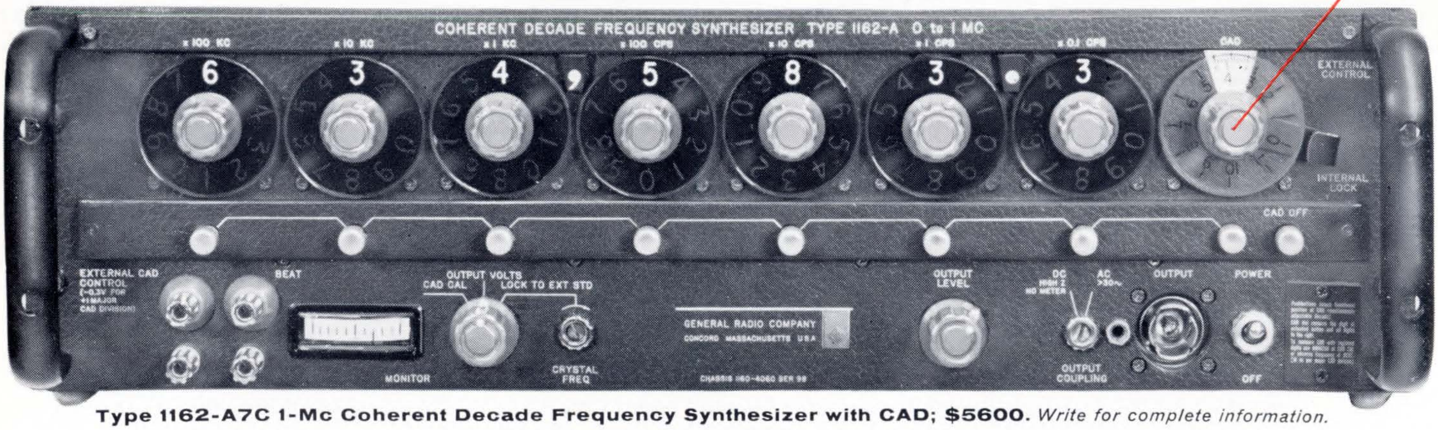
Type 1162-A6; $4660; 1-c/s steps to 1 Mc



Type 1162-A7; $5100; 0.1-c/s steps to 1 Mc



A "CAD" Unit, $510, may be added to any of the above to provide continuous frequency adjustment. Similar combinations available for Type 1161-A 100-kc/s Synthesizer.



Type 1162-A7C 1-Mc Coherent Decade Frequency Synthesizer with CAD; $5600. *Write for complete information.*

GENERAL RADIO COMPANY

WEST CONCORD, MASSACHUSETTS

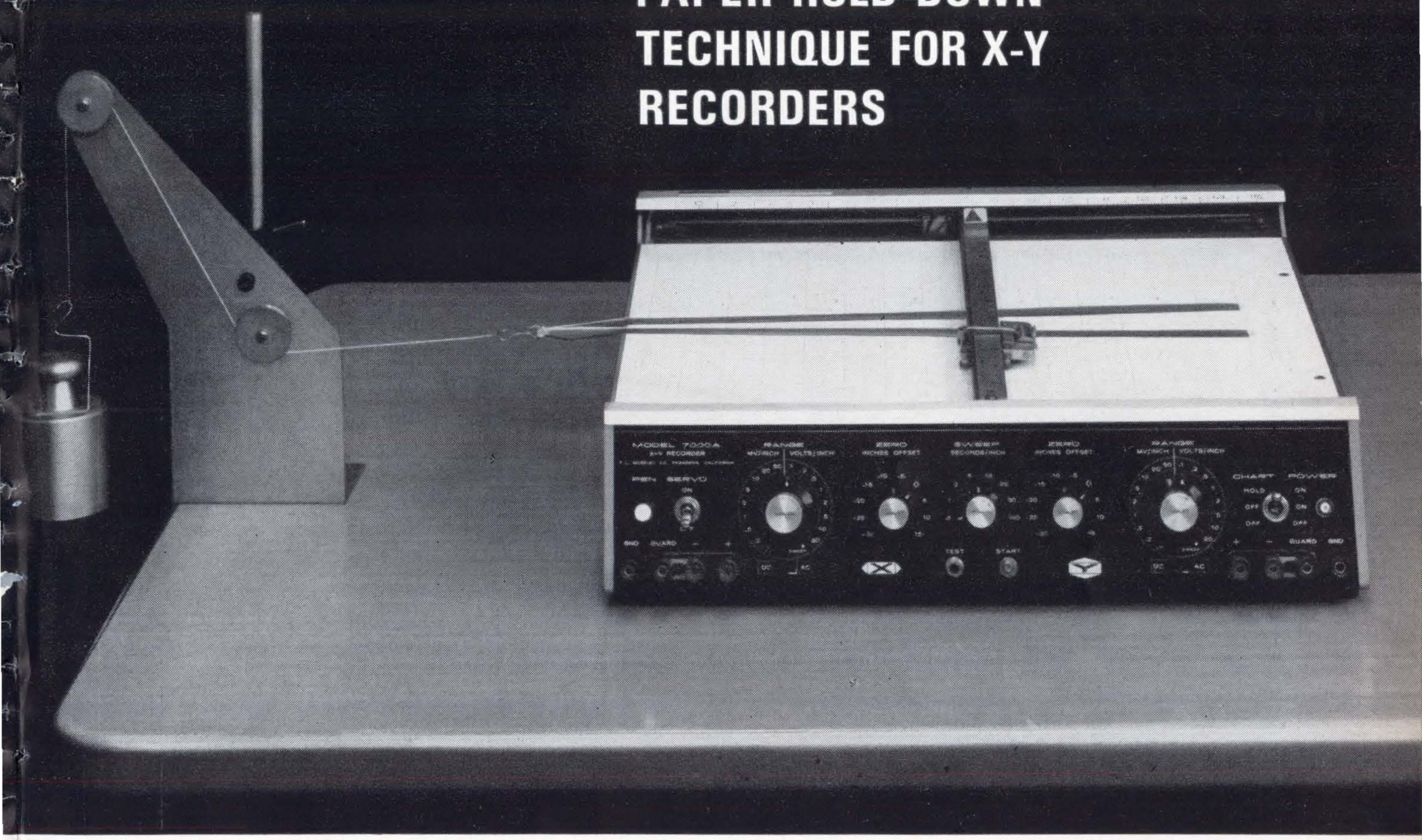
IN CANADA: **Toronto** 247-2171, **Montreal** (Mt. Royal) 737-3673
IN EUROPE: Zurich, Switzerland – London, England

NEW YORK, N. Y., 964-2722 (Ridgefield, N. J.) 943-3140	**CHICAGO** (Oak Park) 848-9400	**PHILADELPHIA** (Ft. Washington) 646-8030	**WASHINGTON, D.C.** (Rockville, Md.) 946-1600	**SYRACUSE** 454-9323	**DALLAS** FL 7-4031	**SAN FRANCISCO** (Los Altos) 948-8233	**LOS ANGELES** 469-6201	**ORLANDO, FLA.** 425-4671	**CLEVELAND** 886-0150

Circle 900 on reader service card

*Moseley introduces AUTOGRIP**

A REVOLUTIONARY PAPER HOLD-DOWN TECHNIQUE FOR X-Y RECORDERS



Test shows Moseley AUTOGRIP* in action. Paper is pulled by a 4 lb. weight without tearing, slipping or wrinkling.

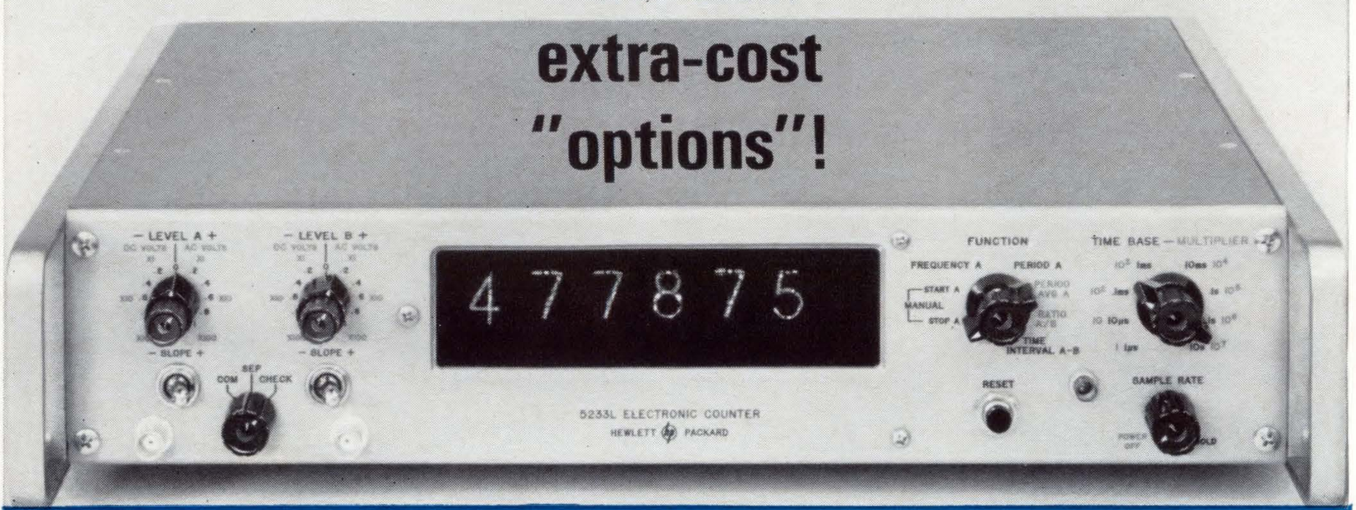
AUTOGRIP* is a significant breakthrough in chart paper hold-down systems. Eliminated are all moving or mechanical parts, no clips, no fans, no pumps, no motors. Uses an electrical principle with specially constructed platen. Quiet with full gripping efficiency even with paper smaller than platen.

Standard on the following Moseley recorders: Models 7000A, 7030A, 2D, 2DR, 2D-2, 2DR-2, 2D-2A, 2DR-2A, 2D-2M, 2DR-2M, 2D-2AM, 2DR-2AM, 2D-3, 2DR-3, 2D-3M, 2DR-3M, 2FRA, 2FRAM, 135, 135R, 135A, 135AR, 135M, 135MR, 135AM, 135AMR, 136A, 136AR. Available as an option at $95 additional on Models 7050A, 135C, 135CR, 135CM, 135CMR, 2D-4, 2DR-4, 2D-4M, 2DR-4M, 7590A, 7590AR. Call your Moseley/Hewlett-Packard field engineer or write: Moseley Division, Hewlett-Packard, 433 N. Fair Oaks Avenue, Pasadena, California 91102.

*Trade Mark Pat. pend.

HEWLETT PACKARD hp *MOSELEY DIVISION*

Solid-State Counters whose "extras" are not extra-cost "options"!



Value is the big benefit delivered to the user with every Hewlett-Packard solid-state counter . . . and in the "low-frequency" instrumentation area, no other company offers so much performance for so little money with such a wide variety of counters.

Seven counters to choose from, ranging in maximum counting rate from 300 kc to 2 mc, all with solid-state reliability, all offering display storage, all offering BCD output and a variety of other features you get only as extra-cost "options" with other counters.

Comparison is the key to your best counter buy. Compare specs on time base performance, temperature performance, input circuitry, maximum frequency range, display storage, BCD output, automatic decimal positioning, display of measurement units, convenient packaging, ease of operation, ease of reading, back-up service, built-in quality.

You'll see why your best buy is from Hewlett-Packard. Call your hp field engineer for a demonstration of the counter to serve your needs best. Or write for complete information, Hewlett-Packard, Palo Alto, California, 94304, Tel., (415) 326-7000; Europe: 54 Route des Acacias, Geneva; Canada: 8270 Mayrand St., Montreal.

Counter	Primary Uses	Frequency Range	Characteristics	Price
5211A Counter	Measure frequency, ratio, speed with proper transducers	300 kc maximum counting rate	4-digit resolution in neon columnar display; gate time 0.1 sec, 1 sec; power line time base (typically 0.1%)	$750
5211B Counter	Same as 5211A, except offers additional gate time of 10 sec			$825
5512A Counter	Measure frequency, period, multiple period average, ratio, multiple ratio	300 kc maximum counting rate	5-digit resolution in in-line display; time base stability $<2/10^6$/week	$1175
5212A Counter	Same as 5512A except offers neon columnar display			$975
5214L Preset Counter	Measures rate, time, totalizes; measures normalized rate, normalized time, counts N events	300 kc maximum counting rate	5-digit resolution in in-line display; preset N number, from 1 to 100,000; locally or program remotely	$1475
5223L Counter	Measure frequency, period, multiple period average, time interval, ratio, multiple ratio	300 kc	5-digit resolution in in-line display; time base stability $<2/10^6$/week	$1450
5532A Counter	Measure frequency, period, multiple period average, ratio, multiple ratio	1.2 mc maximum counting rate	6-digit resolution in in-line display; time base stability $<2/10^7$/month	$1550
5232A Counter	Same as 5532A except offers neon columnar display			$1300
5233L Counter	Measure frequency, period, multiple period average, time interval, ratio, multiple ratio	2 mc maximum counting rate	6-digit resolution in in-line display; time base stability $<2/10^7$/month	$1850

Data subject to change without notice. Prices f. o. b. factory.

HEWLETT PACKARD *An extra measure of quality*

9838

Electronics

November 30, 1964
Volume 37, Number 30

Electronics Review

Electronics Abroad

Probing the News

Technical Articles

Electronics

Editor: Lewis H. Young

Senior editors
Technical: Samuel Weber
News: Kemp Anderson, Jr.

Senior associate editors: John F. Mason, George Sideris

Department editors
Advanced technology: George V. Novotny
Avionics: W.J. Evanzia
Circuit design: Michael Elia
Communications: Alexander A. McKenzie
Components: Michael F. Tomaino
Computers: Stephen B. Gray
Industrial electronics: Louis S. Gomolak
Instrumentation: George J. Flynn
Manufacturing: George Sideris
Military electronics: John F. Mason
New products: William P. O'Brien
Solid state: Jerome Eimbinder, G.G. Tirellis
Space electronics: Joel A. Strasser
Staff writers: Leon H. Dulberger, Peggy Jackson

Regional editors
Boston: Thomas Maguire, editor; Robin Carlson
Chicago: Cletus M. Wiley, editor; Leslie Krimston
Los Angeles: June Long
San Francisco: Laurence D. Shergalis, editor; Mary Jo Jadin
London: Derek Barlow, editor

Copy editors
Howard Rausch, Sally Powell, Stanley Zarowin

Graphic design
Art director: Saul Sussman
Assistant art director: John C. Wright, Jr.
Editorial production: Ann Mella, Sandra A. Le Mond

Editorial secretaries: Claire Benell, Mary D'Angelo, Lynn Emery, Kay Fontana, Carolyn Michnowicz, Lorraine Rossi, Lorraine Werner

McGraw-Hill news service
Director: John Wilhelm; **Atlanta:** Fran Ridgeway; **Chicago:** Bruce Cross; **Cleveland:** Arthur Zimmerman; **Dallas:** Marvin Reid; **Detroit:** Donald MacDonald; **Los Angeles:** Michael Murphy, Ron Lovell; **San Francisco:** Margaret Ralston, Ed. Addeo; **Seattle:** Ray Bloomberg; **Washington:** George Bryant Jr., Glen Bayless, Charles Gardner

McGraw-Hill world news service
Bonn: Richard Mikton; **Brussels:** Arthur Erikson; **London:** John Shinn; **Mexico City:** Wesley Perry; **Milan:** Bruce Bendow; **Moscow:** Donald Winston; **Paris:** Dan Smith; **Rio de Janeiro:** Leslie Warren; **Tokyo:** Marvin Petal, Charles Cohen

Circulation manager: Hugh J. Quinn
Reprints: T.M. Egan

Publisher: C.C. Randolph

Electronics: November 30, 1964, Vol. 37, No. 30
Printed at 99 North Broadway, Albany, N.Y.
Second class postage paid at Albany, N.Y.

Subscriptions are solicited only from those actively engaged in the field of the publication. Position and company connection must be indicated on orders. Subscription prices: United States and Possessions and Canada, $6.00 one year, $9.00 two years, $12.00 three years. All other countries $20.00 one year. Single copies, United States and Possessions and Canada 75¢. Single copies all other countries $1.50.

Published every other Monday by McGraw-Hill Inc. 330 West 42nd Street, New York, N.Y.10036. Founder: James H. McGraw, 1860-1948.

Subscribers: The Publisher, upon written request to our New York office from any subscriber, agrees to refund that part of the subscription price applying to copies not yet mailed. Please send change of address notices, subscription orders or complaints to Fulfillment Manager, Electronics, at the address below. Change of address notices should provide old as well as new address, including postal zone number if any. If possible, attach address label from recent issue. Allow one month for change to become effective.

Postmaster: Please send Form 3579 to Fulfillment Manager, Electronics, P.O. Box 430, Hightstown New Jersey 08520

Readers Comment

Praise for Sarah

I read with interest your recent article regarding military electronics and the problem of guiding planes and supply dropping in South Vietnam, "Electronics in the Mekong Delta" [Sept. 7, p. 114].

I could not resist writing to tell you that we have had this problem here in Central Africa for some time, and we have very effectively solved this by the use of the British "Sarah" equipment.

As you probably know, the British Sarah equipment is a normal beacon with a voice capability, but it does unfortunately mean a special installation in the aircraft. This is not unlike the old Rebecca system, and we have in fact used existing Rebecca aerials.

The great advantage of the Sarah system is that it enables the crew of an aircraft not only to locate very accurately at great distance the dropping zone, at any time of day or night, and in adverse weather conditions, but it also enables them to locate possibly half-a-dozen other dropping zones at the same time. This is very useful where a number of platoons are operating over a wide area, and each requires separate drops.

Finally, I would like to mention that I was present at a number of tests, and we had, in fact, after very little practice, a dropping accuracy as good as 50 yards.

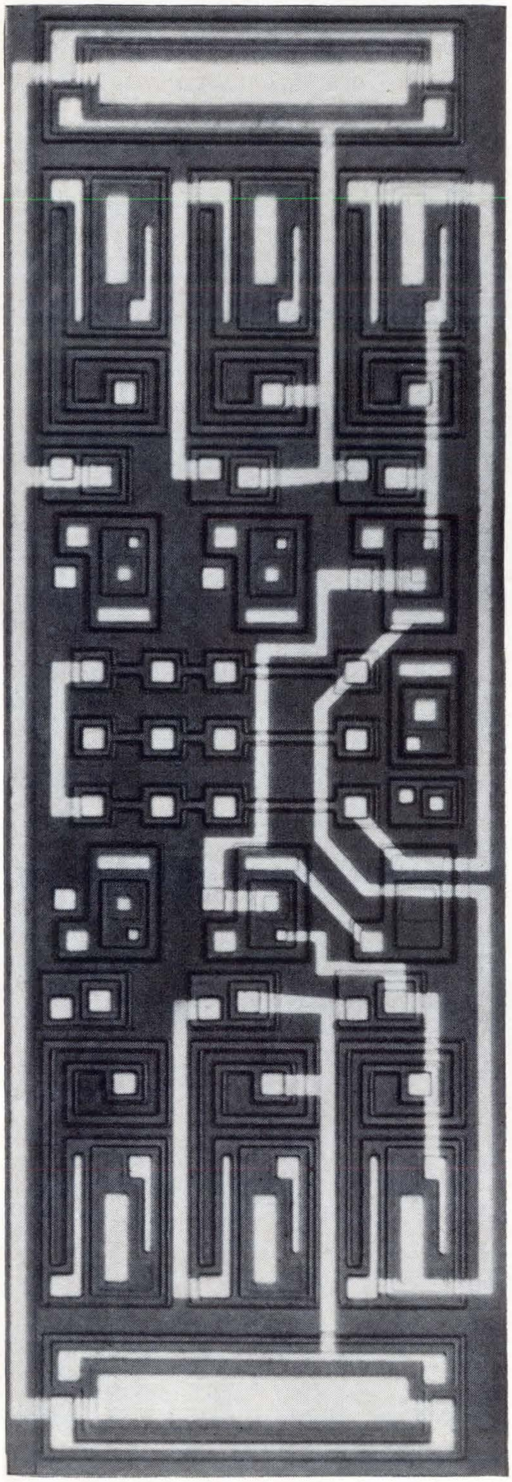
I would like to mention also that I believe the Sarah equipment is in use by NASA and was actually responsible for the quick location of Scott Carpenter when he landed downrange.

R.G. Whiteing
Associated Electronics (Pvt.) Ltd.
Salisbury, Rhodesia

▪ According to the Air Force, there are restrictions to the installation of new equipment; only "in-use" equipment is permitted. To be able to use Sarah, the Air Force would have to install additional antennas and receivers aboard its planes, but in AF tactical aircraft there is simply no room.

This does not mean that all Air

Now from Sprague!



UNICIRCUIT®
INTEGRATED CIRCUITS

actual size

This is a master-matrix UNICIRCUIT, interconnected to meet the requirements of a military systems manufacturer for an RS flip-flop. The photograph at the left, enlarged 38 diameters (1444 times area), speaks for itself as to the technical capability of the Sprague Electric Company to produce complex silicon monolithic integrated circuits.

If you would like to discuss your integrated circuit needs with an old-line established electronic components manufacturer who has a proven reputation for reliability, please write or telephone Mr. Albert B. Dall, Marketing Manager, Semiconductor Division, Sprague Electric Company, Concord, New Hampshire. *area code 603 Tel. 224-1961*

SPRAGUE COMPONENTS

INTEGRATED CIRCUITS
THIN-FILM MICROCIRCUITS
CAPACITORS
TRANSISTORS
RESISTORS
PULSE TRANSFORMERS
INTERFERENCE FILTERS
PULSE-FORMING NETWORKS
TOROIDAL INDUCTORS
ELECTRIC WAVE FILTERS
CERAMIC-BASE PRINTED NETWORKS
PACKAGED COMPONENT ASSEMBLIES
BOBBIN and TAPE WOUND MAGNETIC CORES
SILICON RECTIFIER GATE CONTROLS
FUNCTIONAL DIGITAL CIRCUITS

SPRAGUE®
THE MARK OF RELIABILITY

Force planes are forbidden to use Sarah. The Alaska Air Rescue Command has Sarah aboard. NASA did use the system to locate astronaut Carpenter. Sarah is installed aboard some Navy patrol craft.

The Air Force spokesman expressed surprise at the high accuracy reported by reader Whiteing, and said that the Air Force is looking for this kind of accuracy.

Silicon-transistor inverter

In his article on "Boosting d-c voltage with silicon transistors" [Nov. 16, p. 56] Harry T. Breece conveniently omits the important fact that the 2N3265 suggested for his example inverter costs $99 in 1-90 quantity. He would have done his readers a service by computing another lower-frequency design using the $4.95 2N3055 in multiple and comparing the two designs to show what is bought for the difference.

More basically, I wonder if this doesn't illustrate why defense costs are so high these days? More value engineering and attention to economics at the design level might help reduce our tax load.

R.W. Johnson
R.W. Johnson Co.
Anaheim, Calif.

▪ Although reader Johnson has a good argument, he has perhaps overlooked one significant point that the author was trying to make: there is a distinct saving in transformer weight when frequency is increased. This weight reduction may more than offset the cost of the devices.

Application note SMA-35, "12-volt audio amplifier and converter designs employing RCA silicon power transistors," includes the use of a 2N3055 in two converter circuits plus graphs of the efficiency and voltage output of both circuits, and is available from Commercial Engineering, RCA Electronic Components and Devices, Harrison, N.J.

Door openers

The Commission has noted the item in the Washington Newsletter section of Electronics regarding our proposed rules governing radio controls for door operators [Nov. 2, p. 36].

Your article gives the erroneous impression that our proposal would result in increased interference. On the contrary, our proposal is designed to reduce the radiation and thus reduce the likelihood of interference from these devices. This is accomplished by requiring that the radiation from both the transmitter and receiver be reduced 10 decibels from the levels presently permitted. The reduction in radiation from the continuously operating receiver and the infrequently operated transmitter will reduce the possibility of interference from radio-operated door controls more effectively than a duty cycle limitation on the transmitter alone.

The proposed rules would also eliminate a possible safety hazard by permitting the operation of the door to be reversed in the event a child or animal moves into the path of the closing door. The present duty cycle of one-second operation followed by a 30-second silent period did not permit such an operation during the period that the door is in motion.

The duty-cycle limitation would continue to apply to all other radio-control devices operated without a license under the provision of Part 15 of our rules.

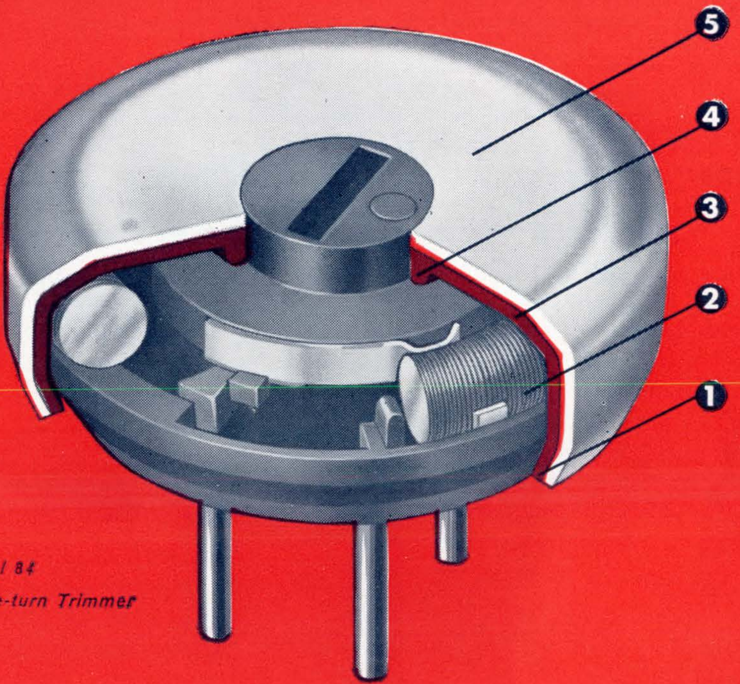
Ben F. Waple
Secretary
Federal Communications Commission
Washington

Decibel war

Your report that Radio Moscow shortwave broadcasts are 18 to 14 decibels stronger in Latin America than British radio signals [Nov. 16, p. 178] implies that little is known about even the type of transmitting sites of the Soviet and Chinese transmitters. Therefore, I assume the transmitter power is also unknown.

I suspect that the Soviets are merely running higher power. Their brute-force approach to satellite technology suggests that they recognize that powerful devices are one of the best proven ways to assure a successful effort.

Grady B. Fox, Jr.
Rochester, N.Y.



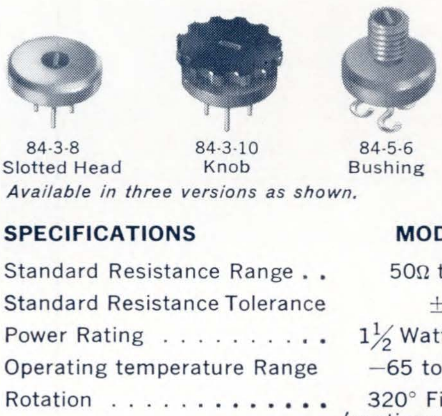
Model 84
Single-turn Trimmer

WHAT'S NEW IN TRIMMERS?

Unique silicone rubber lining providing
Military performance at industrial prices

No other trimmer gives you the superior performance of Spectrol's new model 84 at *any* price. Check these unique construction features which assure military reliability at industrial prices.

1. Silicone rubber lined cover is crimped to the base completely sealing the unit against dust and moisture. No adhesives are used in any of the assembly operations.
2. Largest resistance element available in any ½ inch trimmer is made possible by placing the element against the silicone-rubber lined metal cover. No thick-walled plastic cases or insulators are necessary. Larger element means larger wire and better resolution as well as higher maximum resistance value.
3. Silicone rubber lined cover provides a true voltage breakdown barrier.
4. Packing gland sealing of the shaft is provided by the unique molded rubber-lining permitting full potting or immersion.
5. Metal case provides greater heat dissipation, avoids hot spots and allows high power rating of 1½ watts at 50°C. For printed circuit applications, plastic base contacts PC board.



ACTUAL SIZE

84-3-8 Slotted Head | 84-3-10 Knob | 84-5-6 Bushing

Available in three versions as shown.

SPECIFICATIONS	MODEL 84
Standard Resistance Range . .	50Ω to 100K
Standard Resistance Tolerance	± 5%
Power Rating	$1\frac{1}{2}$ Watts at 50°C.
Operating temperature Range	−65 to +175°C.
Rotation	320° Fixed stops (continuous available)
Case Dimensions-inches	$\frac{5}{32}$ H x $\frac{1}{2}$ Dia.
Unit Prices (84-3-8)	
1-9	$3.95
500	$2.60

Call your nearest Spectrol distributor for immediate off-the-shelf delivery at factory prices. Samples of the model 84-3-8 available for industrial and military users. For your sample write on your company letterhead direct to Spectrol, San Gabriel.

SPECTROL ELECTRONICS CORPORATION

1704 South Del Mar Avenue
San Gabriel, California

Adams Court
Plainview, L. I., New York

P. O. Box 130
Brampton, Ontario

People

Ben H. Ciscel, new executive vice president of the International Electronic Research Corp., Burbank, Calif., says his new job involves unifying "four different companies which were brought together under the IERC name several years ago." He adds: "The trouble is these (companies) exist under one company only on paper. They put out separate ads, have different national reps and separate sales staffs." He will also be in charge of a projected expansion of product lines.

Despite his technically oriented background (he taught at the Massachusetts Institute of Technology and holds eight patents for automatic flight-control systems), Ciscel has shown an aptitude for management. As founder of the Gulf Aerospace Corp. in Houston, he started with a brochure and one employee and built up a $500,000 aerospace electronics business in 2½ years.

William Meng Duke, the new president of the Whittaker Corp. in Los Angeles, sees two ways to make the company less dependent on military hardware business. One is to expand and take in software services and systems contract work; the other is to make selective acquisitions or mergers to fill what he considers holes in the company's product area. "We won't buy a soap chips company, for example, just because it is making money."

Duke replaces William R. Whittaker, chairman, who used to be the president as well.

Before the 48-year-old Duke joined Whittaker, he was president of the Federal Laboratories of the International Telephone & Telegraph Corp.

from Solitron

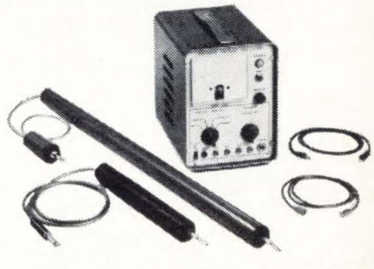
high voltage SOLIDPAK® rectifiers to 120 KV PIV

There Is No Substitute For Experience!

A great deal of experience in high voltage silicon rectifier applications has gone into the preparation of Solitron's 16-page Solidpak catalog. In it will be found helpful application notes, mechanical and electrical details, and application recommendations relative to current ratings and voltage safety factors. As complete as it is, the Solidpak catalog is not an end, but a beginning for Design Engineers who have difficult packaging or circuit reliability problems.

Custom Modification — The variety of units shown in the Solidpak catalog can be further modified to the particular requirements of a specific application with **short delivery time and at reasonable cost.**

Reliability — Solitron then goes still further, if you wish, by utilizing their exclusive Transient Voltage Indicator to check the specific transient-producing capability of **your** circuit and to insure complete reliability of the final design of each unit.



Model V-610 Transient Voltage Indicator — 60 KV Maximum
Also available for sale at $449.50

SEND FOR THE 16-PAGE SOLIDPAK CATALOG NOW!

Leader in Solid-State High Voltage Rectifiers, Temperature Compensated Zeners, Voltage Variable Capacitors, and Random/White Noise Components.

Solitron DEVICES, INC.

256 Oak Tree Road • Tappan, New York 10983
Or telephone: 914-359-5050 • TWX: 914-359-2325

Meetings

New Horizons in Solid State Electronics, Rochester Institute of Technology; Schraffts Motor Inn, Rochester, N.Y., **Nov. 30-Dec. 2.**

The Road to Commercial Electronics: A Conference on Converting Military Capabilities to Civilian Markets, Electronics Magazine, IIT Research Institute; Grover M. Hermann Hall, Chicago, **Dec. 1-2.**

Professional Technical Group on Vehicular Communications Annual Conference, IEEE; Sheraton Hotel, Cleveland, **Dec. 3-4.**

General Systems Knowledge Symposium, Society for General Systems Research, IEEE; American Association for the Advancement of Science, Montreal, **Dec. 26-31.**

Reliability and Quality Control National Symposium, ASQC, IEEE, IES, SNT; Hotel Fontainebleau, Miami Beach, **Jan. 12-14.**

Fundamental Phenomena in the Material Sciences Annual Symposium, Ilikon Corp.; Sheraton Plaza Hotel, Boston, **Jan. 25-26.**

Winter Power Meeting, PEEC/IEEE; Statler Hilton Hotel, New York, **Jan. 31-Feb. 5.**

On-Line Computing Systems Symposium, UCLA Extension Service, Informatics, Inc.; University of California Los Angeles, **Feb. 2-4.**

Winter Convention on Military Electronics, PTGMIL & L.A. Section of IEEE; Ambassador Hotel, Los Angeles, **Feb. 3-5.**

Electrical/Electronic Trade Show, Electrical Representatives Club, Electronic Representatives Assn.; Denver Auditorium Arena, Denver, **Feb. 15-17.**

Solid-State Circuits International Conference, University of Pennsylvania, IEEE; University of Pennsylvania and Sheraton Hotel, Philadelphia, **Feb. 17-19.**

Particle Accelerator Conference, AIP NSG/IEEE, NBS, USAEC; Shoreham Hotel, Washington, **Mar. 10-12.**

IEEE International Convention, IEEE; N.Y. Coliseum and New York Hilton Hotel, New York, **Mar. 22-25.**

Electron Beam Annual Symposium, Pennsylvania State University, Alloyd Corp.; Pennsylvania State University, University Park, Pa., **Mar. 31-Apr. 2.**

Electronic Parts Distributors Show, Electronic Industry Show Corp., New York Hilton and Americana Hotels, New York, **Mar. 31-Apr. 4.**

Cleveland Electronics Conference, Cleveland Electronics Conference, Inc., IEEE, ISA, CPS, Western Reserve University, Case Institute of Technology; Cleveland Public Auditorium, Cleveland, **Apr. 6-8.**

Conference on Impact of Batch-Fabrication on Future Computers, PGEC/IEEE; Thunderbird Hotel, Los Angeles, **Apr. 6-8.**

IEEE Region 3 Meeting, Region 3 of IEEE; Robert E. Lee Hotel, Winston-Salem, N.C., **Apr. 7-9.**

Electronic Components International Exhibition, FNIE, SDSA; Parc des Expositions (Fair Grounds), Paris, **Apr. 8-13.**

Telemetering National Conference, AIAA, IEEE, ISA; Shamrock-Hilton Hotel, Houston, Tex., **Apr. 13-15.**

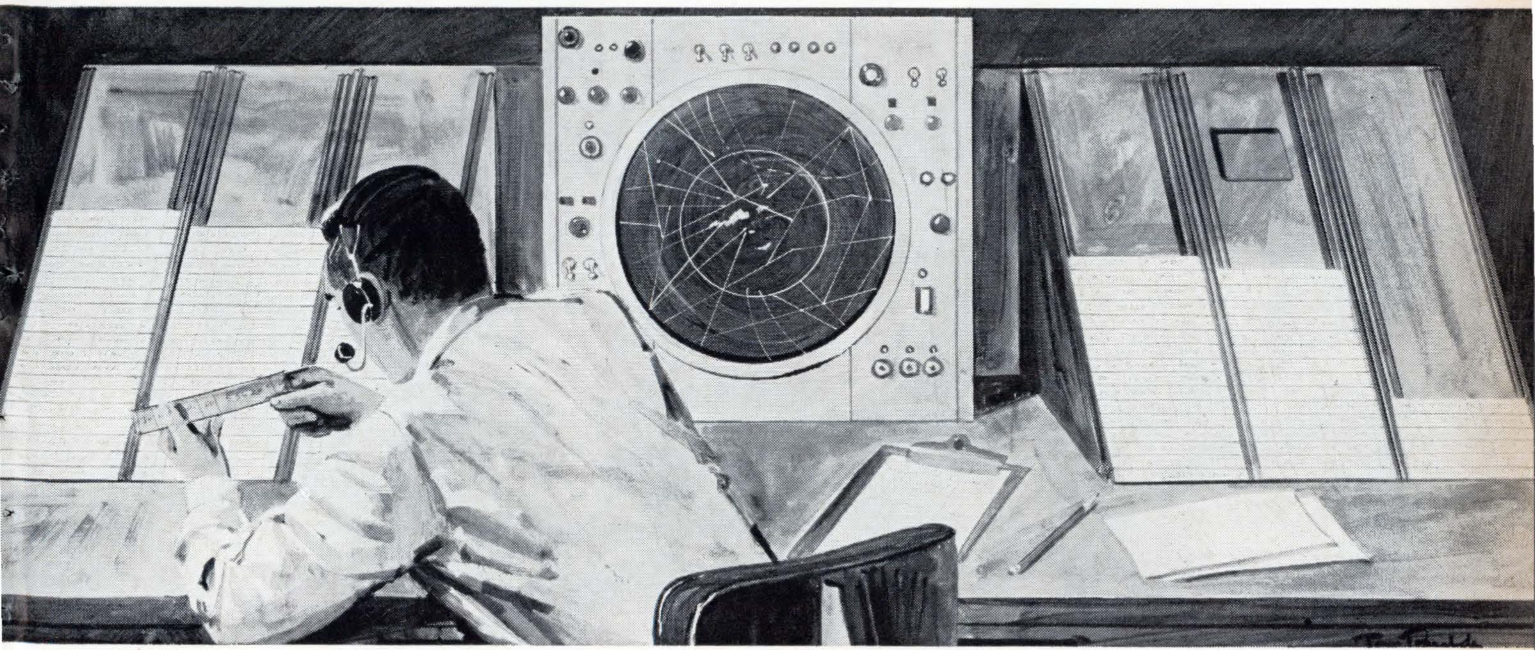
Electronics Instrumentation Conference and Exhibit, IEEE, ISA; Cincinnati Gardens, Cincinnati, Ohio, **Apr. 14-15.**

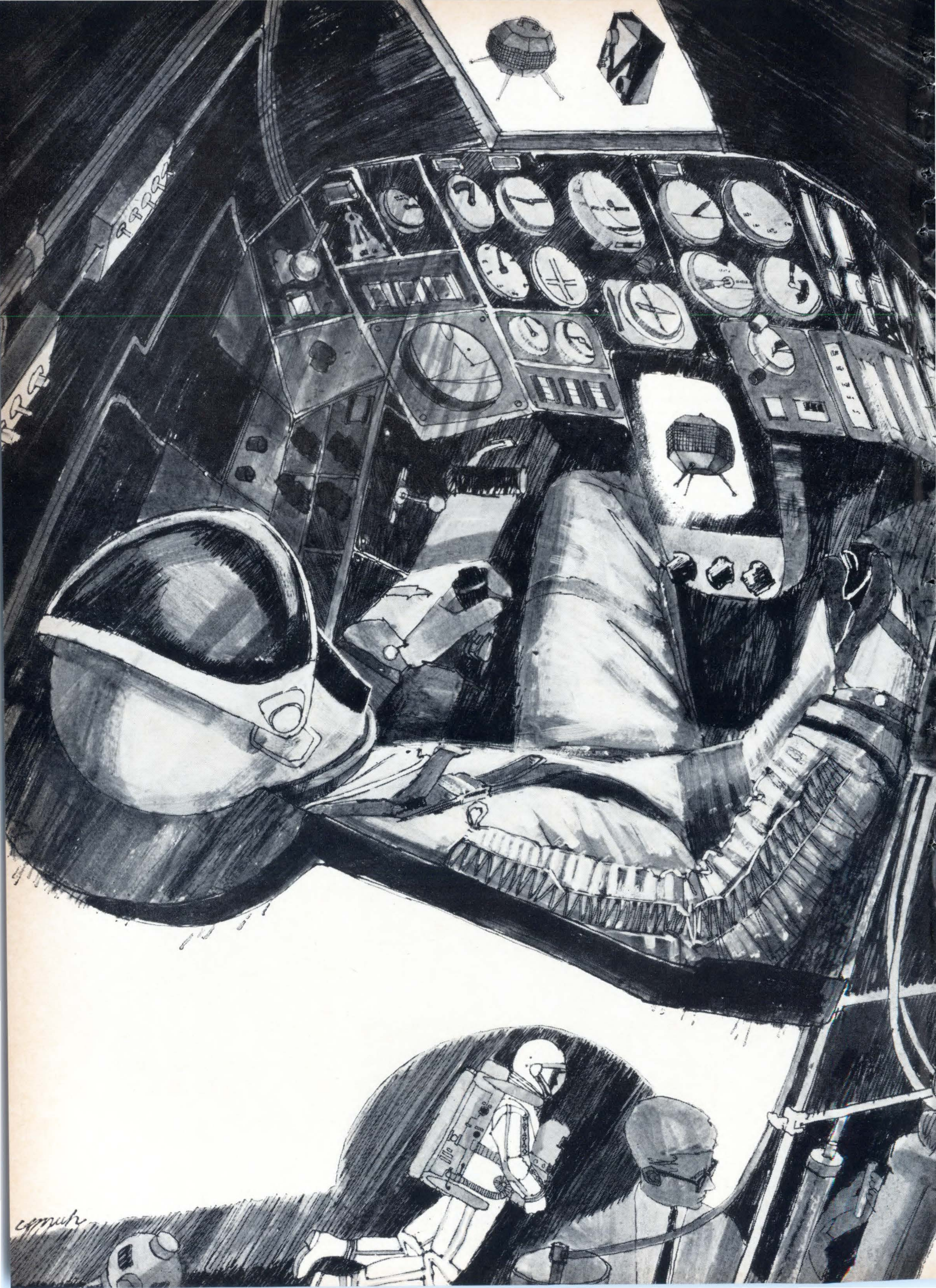
Frequency Control Annual Symposium, USAEL; Shelburne Hotel, Atlantic City, **Apr. 20-22.**

Call for papers

National Electronic Packaging and Production Conference (NEP/CON '65), EPP; Long Beach Arena, Long Beach Calif., June 8-10. Deadline is **Dec. 31** for submitting 300- to 500-word abstract in triplicate to Electronic Packaging and Production, 222 W. Adams St., Chicago, Ill. 60606, Att: NEP/CON Papers Committee.

Recent Advances in Optimization Techniques Symposium, IEEE, OSA; Carnegie Institute of Technology, Pittsburgh, Apr. 21-23. **Jan. 15** is deadline for submitting abstracts to A. Lavi, Dept. of Electrical Engineering, Carnegie Institute of Technology, Pittsburgh, Pa. 15213. Topics include engineering design by mathematical programing, comparison of various optimization techniques, methods of handling nonlinearities and constraints, optimization of discrete systems, performance optimization of dynamic systems.





LTV SCIENCE AND ENGINEERING

MAN DECLARES HIS INDEPENDENCE...IN SPACE

The astronaut will be more than a mere passenger who sits in his space capsule watching the world go by. Two projects in LTV Astronautics Division are helping to shape his destiny as a working spaceman.

Man's role "out there" will be enhanced by an unmanned space unit developed by LTV for the Air Force Systems Command. Called the Remote Maneuvering Unit (RMU), it is designed to be launched from a manned, orbiting spacecraft to examine other nearby craft. As the RMU is maneuvered, it televises the object's image to the crew of the mother craft. Radio-controlled by the spaceship crew, the RMU is guided by visual sighting and television.

A "declaration of independence" for man in space came when LTV contracted with Air Force Systems Command to develop a compact back pack that will enable an astronaut — for the first time in America's space program — to be detached from his orbiting mother craft and perform useful missions on his own. Scheduled for its first use with the two-man Gemini program as part of Air Force Experiment D-12, the pack will be used with a smaller chest unit being developed by NASA. Together, they are called a Modular Maneuvering Unit or MMU.

LTV Astronautics' contributions to the nation's space program — in addition to the maneuvering units — include launch vehicles such as NASA's versatile "workhorse" Scout, velocity packages, space defense systems and Saturn fuel and oxidizer tanks. LTV is building a Dynamic Crew Procedures Simulator for NASA Manned Spacecraft Center at Houston. It resembles the Manned Aerospace Flight Simulator that has been used to train astronauts at LTV's Dallas plant since 1961.

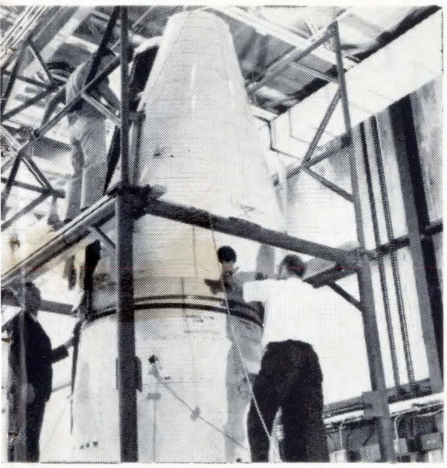
This broad space capability is another example of the versatile store of science and technology at LTV, leader in electronics, aircraft, missiles, space, mobile ground vehicles, ground and airborne communications, and range services. Ling-Temco-Vought, Inc., Dallas, Texas.

DIVISIONS AND SUBSIDIARIES: • LTV ALTEC • LTV ASTRONAUTICS • LTV CONTINENTAL ELECTRONICS • LTV LING ELECTRONICS • LTV MICHIGAN • LTV MILITARY ELECTRONICS • LTV RANGE SYSTEMS • LTV RESEARCH CENTER • LTV TEMCO AEROSYSTEMS • LTV UNIVERSITY • LTV VOUGHT AERONAUTICS • KENTRON HAWAII, LTD.

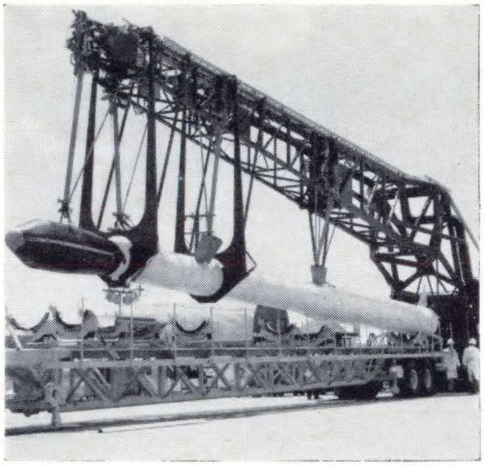
Circle 13 on reader service card

LTV
LING-TEMCO-VOUGHT, INC.

Velocity package for Project FIRE helped to pave way for Apollo high-speed reentry.

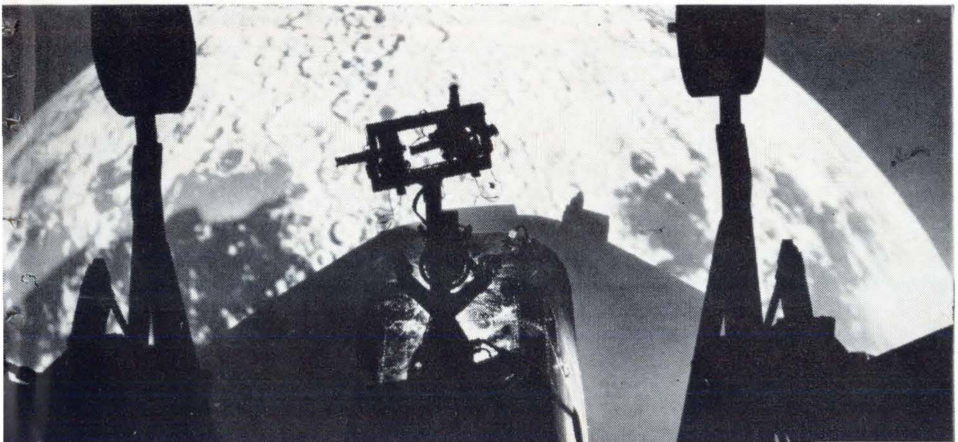


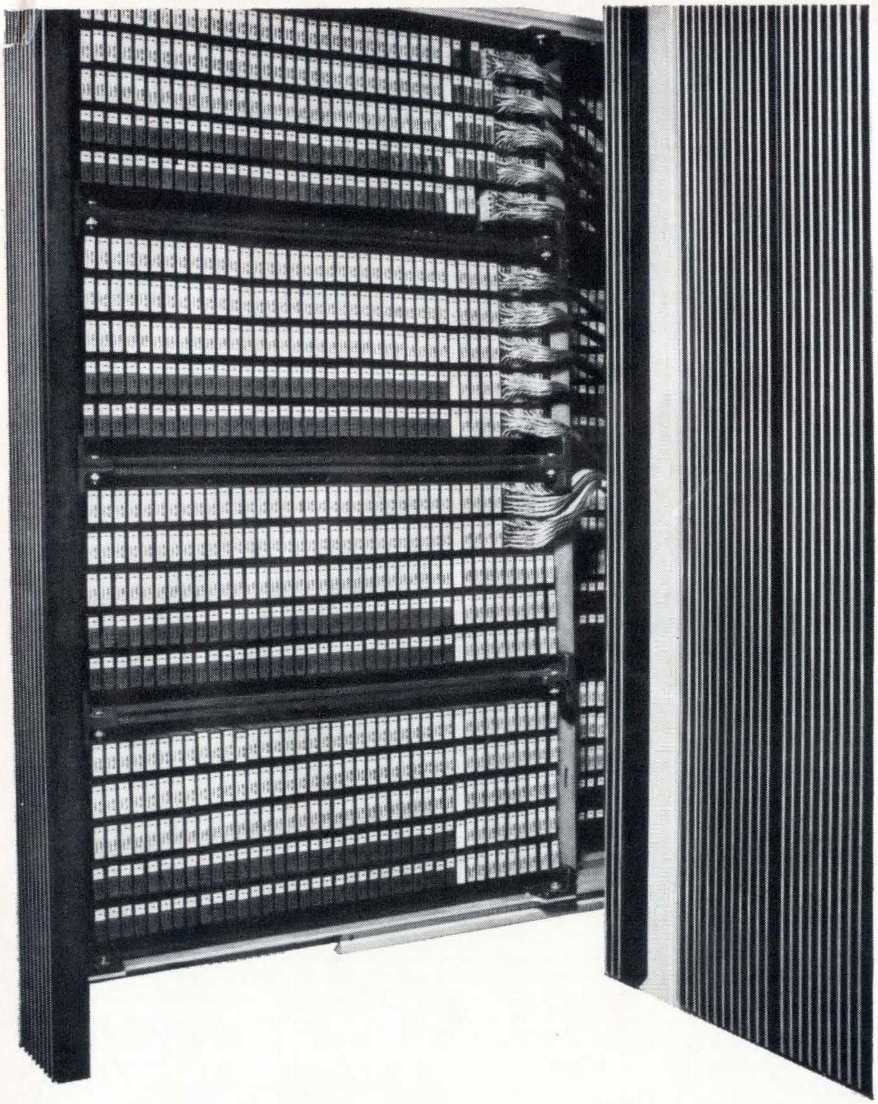
Scout is one of the most versatile and economical launch vehicles for both NASA and Air Force.



LTV "astronaut" wears a mock-up of Modular Maneuvering Unit for independent space flight.

America's astronauts have trained in LTV's realistic Manned Aerospace Flight Simulator.





DIGITAL MODULES are available from stock in two sets of fully compatible resistor-transistor logic circuitry—for bit rates up to 200 kc; for bit rates to 1 Mc. More than a dozen types include: 4-input NOR • Counter Shift Register • Power Inverter • Emitter Follower • Complementary Driver • Differential • Filter (Decoupler)

How's this for digital density!

Compact new logic modules combine flexibility, reliability and economy

Radiation Logic Modules can be used in any configuration, type or number compatible with your digital system requirements. They can be mounted in vertical or horizontal drawers, in standard 19" racks, or on breadboards . . . fixed or removable. Because of their compact modular construction, packaging densities up to 137 modules per inch of panel height can be achieved in standard racks. There's no need for design compromise.

RELIABILITY Superior engineering and rigid component selection assure highest reliability: based on extensive tests, MTBF for low-speed NOR Modules exceeds 2,940,000 hours! The units are also packaged for rugged use. Constructed of welded circuitry molded in epoxy and mounted with high-density module connectors on cast aluminum frames. The resulting positive-contact units measure only 0.4" x 1" x 1.1" with a 0.25" pin protrusion.

ECONOMY Each module represents a fraction of the entire digital system. Each is designed for easy interrogation. Change or replacement is as simple as plugging in another unit. Thus, expensive downtime is reduced, costly benchwork completely eliminated.

APPLICATIONS ASSISTANCE Radiation offers the services of its engineering staff in the application of digital logic modules, or in helping solve your unique data problems. Write or phone for technical data sheets. Radiation Incorporated, Products Division, Department EL-11, Melbourne, Florida. Telephone: (305) 723-1511.

RADIATION
INCORPORATED

PRICE LIST—DIGITAL MODULES

Part Number	Description	Unit Price
503815G1	NOR—Medium Speed	$ 10.38
503816G1	NOR—Low Speed	6.40
503818G1	Power Inverter—Low Speed	5.95
503818G2	Power Inverter—Medium Speed	10.69
503819G1	CSR—Low Speed	8.82
503819G2	CSR—Medium Speed	11.66
503819G3	CSR—Medium Speed	37.65
503820G1	MSMV "B" Side	7.74
503821G1	Diff (MSMV "A" Side)	9.68
503834G1	Filter (Decoupler)	7.55
503860G1	Compl. Driver—Low Speed	12.55
505694G1	Diode Gate	11.40
505703G1	D/A Converter	14.20
505704G1	Indicator Driver	14.15
506030G1	CSR-M1	21.20
507318G1	Emitter Follower—Low Speed	7.29
507318G2	Emitter Follower—Medium Speed	12.11
508334G1-G8	Octal Patch	4.20
508335G1-G2	Jumper Patch	4.84
508367G1	5 Volt Reference	196.20
508517G1	Module, Special Component	13.62
509050G1	Indicator Driver (Negative Coincident Input)	15.15

Specifications and prices subject to change without notice due to technological advances. Delivery, discount schedules and additional pricing information available upon request.

Editorial

Some false economy

The Johnson Administration never seems to tire of pointing with justified pride to cost-cutting in the Defense Department, achieved largely through competitive bidding. It's too bad the government doesn't pay as much attention to the way these lower costs are resulting in lower quality in some military components.

It has been charged repeatedly that the Pentagon's zeal for low bids is causing "junk" components to be used in some military electronics equipment, and that it is forcing some dependable suppliers out of business—at least out of government business.

These allegations come from responsible sources, both in industry and in the military. To protect these sources, we're not identifying them.

If many dependable companies do withdraw as government suppliers, the cost of military procurement will climb and the only reductions will have been in quality.

The military tube business is a good case in point. A few suppliers, faced with productive capacity that's hard to keep busy and with huge inventories of hard-to-sell tubes, have adopted a sell-'em-at-any-price policy. And the Pentagon has bought the tubes—in quantities of 200,000 to 400,000—far below the price asked from civilian buyers.

Here are some recent military purchases:

Tube no.	Book price to civilian customer, each	Military bid price, each
5814A	$1.39	$ .51
12AT7WA	1.50	.60
5726/6AL5W	.90	.26
5654/6AK5W	1.43	.569

Here is evidence that the Pentagon is cutting some costs. But what's happening to quality?

The sales manager of one tube supplier says his company was averaging about 5% below cost on military bids and was still missing more contracts than it was winning. Such a situation is understandable when you consider this example:

It costs $1.08 to make a 5751W1 twin diode—a ruggedized, reliable miniature model. Yet the military bought 50,000 of them early this year for 64 cents apiece.

Some military procurement officers suspect that they are not always receiving the reliable versions of these tubes at these bargain prices. They blame the unreliability of some communications gear on such components.

The suppliers can't afford to tighten their quality control. Some unreliable tubes, which statistically pass the tests for the more reliable versions, are shipped to the military. But these tubes are designed differently and don't perform in the field the way the reliable version is supposed to.

A similar price-vs.-quality problem has been faced more realistically by the auto industry, which buys all kinds of parts by the millions and hundreds of millions and is cost-conscious almost to a fault.

What Detroit calls back-alley shops sometimes win contracts on the basis of low bids, and the auto companies get their parts cheap but with problems. They receive as much junk as usable parts. The auto makers have devised a simple but practical answer: They hold a supplier financially responsible for every part delivered. If a part is found defective, the supplier not only doesn't get paid, but he gets the part back, shipped at his own expense.

Few motorists know it, but their car warranties are backed by the supplier of each part as well as by the company that made the auto.

The government would do well to adopt some of the auto makers' practices.

We strongly favor competitive bidding. But price should not be the sole criterion.

Electronics Newsletter

November 30, 1964

Court fights loom on planar rights

The gentlemen's agreement that has kept a major patent fight from erupting in the integrated-circuit business may be at an end.

The Fairchild Camera & Instrument Corp. notified the industry this month that it intends to license all companies using the silicon planar processes—basic techniques in the production of transistors and diodes and integrated circuits. Fairchild will seek a standard domestic royalty of 4% of gross circuit sales, which would greatly reduce its competitors' profits.

Two major producers of integrated circuits, the Raytheon Co. and Texas Instruments, Inc., have indicated they'll challenge the patents' validity.

Fairchild announced its decision after the Patent Office upheld two of Fairchild's basic patents (numbers 3,025,589 and 3,064,167, both issued in 1962). These had been challenged by the Hughes Aircraft Co. **The Patent Office upheld 16 of the 17 claims in the Fairchild patents, and Fairchild and Hughes settled the question on the remaining claim by making a cross-licensing agreement.**

Now Raytheon and its subsidiary, the Micro State Electronics Corp., have challenged the Fairchild patents. A suit contesting the validity of the patents has been filed in the State of Delaware, where Raytheon is incorporated.

And sources at TI indicate that company will provide further legal fireworks if the Fairchild patents are not overthrown by the Raytheon suit. TI, which has a few basic patents of its own [Electronics, July 13, p. 17], is expected to balk at paying the 4% royalty. Fairchild is now negotiating with TI and with Motorola, Inc., the other of the "big three" producers of integrated circuits.

Integrated circuits find new uses

The role of integrated circuits is widening.

Motorola Semiconductor Products, Inc., a subsidiary of Motorola, Inc., is rushing to the market with a monolithic integrated circuit for high-fidelity audio-amplifier use. Motorola had planned to unveil the one-watt amplifier integrated circuit at the 1965 Western Electronics Show and Convention, but the demonstration of a five-watt monolithic high-fidelity amplifier by the Westinghouse Electric Corp. at the Northeast Electronics Research and Engineering Meeting held earlier this month in Boston appears to have pressed Motorola to speed the introduction of its circuit.

The General Instrument Corp., still championing multichip integrated circuits [Electronics, Sept. 21, pp. 105-107], will announce a line of voltage-regulated integrated circuits next week. The multichip integrated circuits allow direct delivery of regulated voltages at each point of use instead of from a central power source. Each circuit contains three transistors, a zener diode, a temperature-compensating diode and five to nine resistors.

Report discloses circuit failures

Integrated-circuit manufacturers had better sharpen their quality control. This was the message in a report given this month by the Instrumentation

Laboratory of the Massachusetts Institute of Technology. The report was based on some 60 million hours of test data accumulated on circuits supplied by three vendors for the first series of Apollo spacecraft computers. **The circuits of two manufacturers showed a dismally poor record of quality control, the report said.**

A staff engineer at the lab, Mrs. Jayne Partridge, said part of the problem is people "putting their grubby hands on the circuits" before they are packaged. Some other causes of failure: purple plague caused by mechanical stress where leads were bonded to conductors on the circuits, poor conductor adhesion, thinning of conductors over oxide steps, scratched conductors and shorts caused by leads touching each other or the edges of circuit chips.

MIT refuses to identify the vendors, calling them A, B and C. The report said 5% of brand A circuits failed qualification tests and another 2% failed screening and initial operation tests. Circuits that passed these tests showed good reliability—estimated failure rate at a 90% confidence level is 0.005% per 1,000 hours of operational use. Brand B had about 30% test failures and an estimated failure rate of 0.3%. Brand C showed over 60% test failures and a rate of 1.8%.

All integrated-circuit manufacturers—including B and C—will get a chance to requalify for the next series of Apollo computers. The first computers used three-input NOR gates for all logic functions. The next computers will use a different circuit, a dual low-power gate. A single type of circuit improves computer reliability, since standardization makes it easier to test circuits in large volume and to determine the failure causes.

Brighter colors for tv tubes

A new rare-earth red phosphor that increases the brightness of color television screens by 40% is now being used in the production of tubes at Sylvania Electric Products, Inc., a subsidiary of the General Telephone & Electronics Corp.

Sylvania says that with picture tubes which use ordinary sulfide-based red phosphors manufacturers must attenuate the bright green and blue to achieve color balance," this lowers the over-all picture brilliance. The new phosphor, in addition to being brighter, is a purer spectral red than previous phosphors, which are more orange. The sharper red achieves more realistic skin tones and a whiter white.

The Westinghouse Electric Co., which does not make color picture tubes, has also announced synthesis of a new red phosphor that they say is 80% brighter than old phosphors; however, their compound, at $240 a pound, is twice as expensive as Sylvania's. Both have sold sample lots of the phosphor to picture tube manufacturers. The companies say that manufacturers can easily adapt production to include the new phosphors.

Radar spots periscopes

An airborne radar to detect submarine periscopes has been developed by the Missile Systems division of the Raytheon Co. The system is completely automatic. Except for one tube in the transmitter, all the equipment is solid state. Raytheon reports that it hasn't experienced operational failures since tests began on the radar, which the company developed on its own. The Navy has a contract with at least one electronics company for development of a periscope-detection radar.

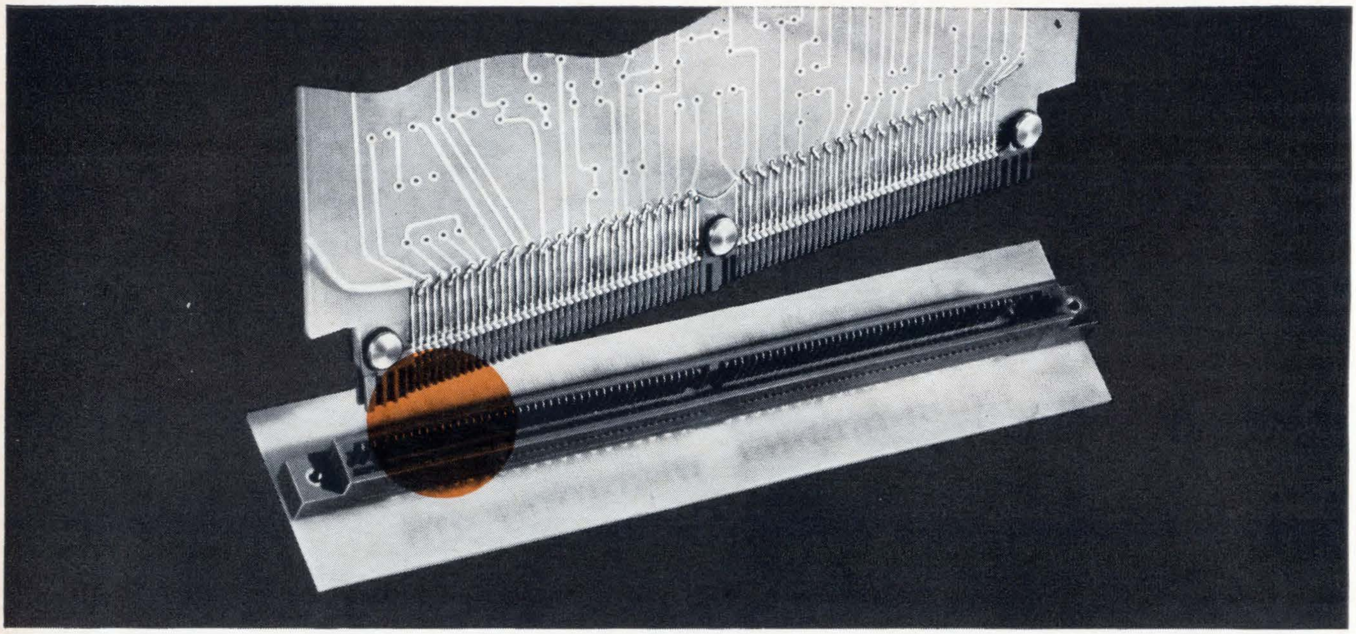
PNP SILICON POWER TRANSISTORS — 76 TYPES IN 9 PACKAGES

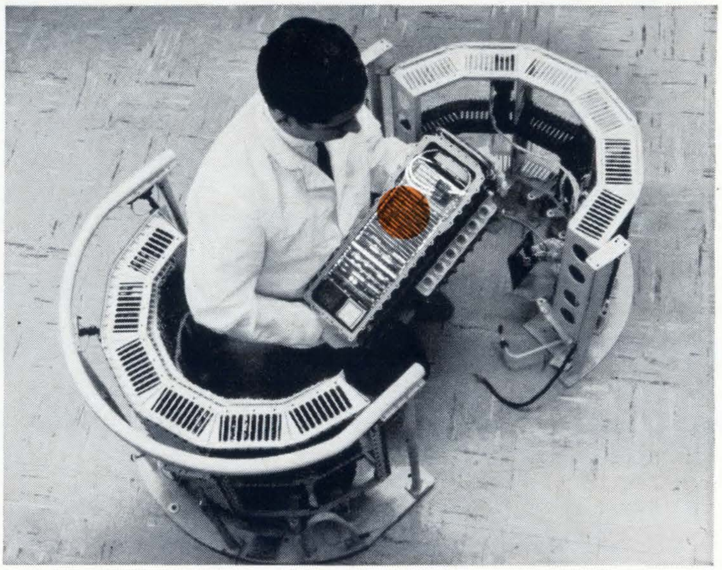
From Silicon Transistor Corporation comes PNP POWER POTENTIAL never achieved before with silicon transistors. For the first time, a broad line of PNP SILICON POWER transistors are available from 8.75 watts to 85 watts of power capability in a wide variety of package types. BV_{CEO} ratings range from 40 volts to 110 volts, with saturation resistances as low as 0.3 ohms @ $I_C = 1$ Amp, and minimum h_{FE} of 10 @ $I_C = 3$ Amps, and 20 @ $I_C = 1$ Amp. □ These PNP types can be used as complements to STC's existing NPN silicon power transistors, and are supplied in the 2N3163 through 2N3208 series and also other series customed to fit specific requirements. □ To satisfy almost any power circuit design, these characteristics are available in the following packages: TO-5, 7/16" D.E.S., TO-8, TO-37, TO-3, TO-53, 11/16" D.E.S., and the isolated collector versions of the TO-53 and 11/16" D.E.S. □ For more information, contact:

SILICON TRANSISTOR CORPORATION

CARLE PLACE, LONG ISLAND, NEW YORK. 516-Pioneer 2-4100. TWX 516-248-9085

DISTRICT OFFICES: **LOS ALTOS, CALIF.**, 201 CUESTA DRIVE (415) 941-0382. **DAYTON 19, OHIO,** 49 PARK AVE. (513) 298-9913. **TWX 513-944-0372**
HUNTSVILLE, ALA., 1000 AIRPORT RD., SUITE NO. 2. (205) 881-4793





How we made one printed circuit board do the work of 18

The men at Autonetics Division of North American Aviation licked the problem of boosting the capability of the Minuteman ICBM. They replaced conventional circuits with lightweight, compact *microcircuits* in the heart of the system—the Minuteman Guidance and Control Computer.

There was only one other problem. How to interconnect them?

The maze of wires in a wiring harness would have outweighed the very advantages microcircuitry had overcome! Clearly, the answer lay in a unique connector—one that would provide 160 positions on .050 inch spacing, yet meet the most stringent reliability and performance requirements.

To make a long story short, AMP engineers met the challenge by designing a special two-piece connector utilizing subminiature AMP-MECA★ contacts. This board-to-board connector not only did away with complicated harnesses, it provided the 160 contacts on a strip only 5½ inches long.

And it offered several other advanced features, such as bifurcated contacts and gold over nickel plating, which were in keeping with the Minuteman II concept.

Our story has a happy ending. The new AMP-MECA Subminiature Connector enabled one module board to replace 18 conventional boards in the system, helping double the capacity of the missile's computer.

Put this connector to work in your high density packaging . . . it will do the job for you, too. Contact us for full particulars today.

★Trademark of AMP INCORPORATED

AMP INCORPORATED
Harrisburg, Pennsylvania

INDUSTRIAL SALES DIVISION

A-MP★ products and engineering assistance are available through subsidiary companies in: Australia • Canada • England • France • Holland • Italy • Japan • Mexico • West Germany

Electronics Review

Volume 37
Number 30

Military

Defense budget

The Defense Department is expected to ask for about as much money for fiscal 1966 as was asked for 1965. New funds for research, development, test and evaluation will drop little if at all. Authority for future spending will decline, but by less than the $2-billion drop of this year.

This is the outlook as officials begin putting the finishing touches on the new defense budget that must be submitted to Congress in January.

The main reason for the continuing downturn in military procurement is that funding for expensive strategic weapons systems is nearly completed.

No new missile. No new intercontinental or air-to-surface missile is on the procurement horizon. Buying of strategic missiles is nearly over for the present except for additional Minuteman IIs and some Polaris missiles. The main effort will be on improving existing missiles—their accuracy and their ability to penetrate enemy defenses. Defense Secretary Robert S. McNamara still opposes development of a new strategic bomber.

In research and development, the new budget probably will accede to Air Force requests to at least begin developing a more powerful jet engine, a 60-mile air-to-surface missile and advanced avionics components to provide "building blocks" for a new bomber when and if a decision is made to proceed with one.

Defense officials have said that one of three planes—the F-111 (TFX) tactical attack bomber made by the General Dynamics Corp., the SR-71 strategic reconnaissance plane made by the Lockheed Aircraft Corp., or the experimental B-70 made by North American Aviation, Inc.—could be converted to a follow-on strategic bomber. The proposed engine, new missile and improved avionics could be used in any of these planes or in the B-52.

Reconnaissance plane. The only new strategic plane to be funded in the '66 budget is the SR-71, a reconnaissance design that has emerged from the Lockheed A-11, developed in secrecy as a follow-on U-2. The SR-71 will begin to go to Strategic Air Command units in fiscal 1966, which begins July 1, 1965.

Spending on tactical aircraft probably will rise. The new budget will include funds for continued development and some procurement of the F-111; for procurement of the VAL, a Navy fighter-bomber made by Ling-Temco-Vought, Inc., and for advanced Air Force and Navy models of the McDonnell F-4 Phantom, made by the McDonnell Aircraft Corp., with improved fire-control systems for greater air-to-air and air-to-ground missile capability.

Development of a heavy cargo plane with capacities greater than the new Lockheed jet-powered C-141 will probably be started. Studies are being conducted by Lockheed, the Boeing Co. and the Douglas Aircraft Co. Hardware contracts are expected late next summer. Initial funds will have to be provided in the budget if the work is to proceed.

In space activities, the new budget will provide for the first large-scale hardware for a manned orbital laboratory, a project to determine the extent of the military role for man in space, and for a start on a military communications satellite system.

The Navy budget provides about $2 billion for projects related to antisubmarine warfare—the same as this year.

Cutbacks. Recent cutbacks at 95 installations hit hardest at bomber bases of the Strategic Air Command and at radar facilities of the Air Defense Command. These two categories account for nearly half of the $477 million saving that McNamara claims for the cutbacks.

Sixteen radar stations in 13 states are being eliminated, at an annual payroll saving of $14 million.

Computers

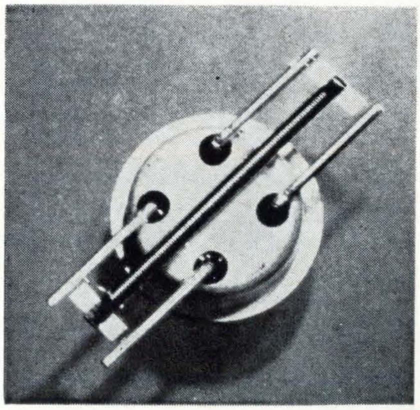
Scanistor

A dime-sized optical scanner read handwritten numbers and letters at a recent demonstration conducted by the International Business Machines Corp.

The solid-state device, called a Scanistor, was developed by IBM's Advanced Systems Development division and is still experimental. According to its developers it has been tested successfully in document and film scanning, in character recognition and in reading punched and mark-sense cards.

IBM says the scanner combines high resolution and fast response with other advantages of solid-state electronics—low power operation, small size and weight, long life and simple circuitry.

Single output wire. Earlier solid-state light-sensitive devices, such as the photocells used in electric-



Scanistor

Scanistor reads handwritten numbers and letters. The experimental machine punches characters into a card as co-inventor John W. Horton looks on.

eye cameras, can sense only the total amount of light falling on the surface to detect a pattern of the cells. As a result, many cells, arranged in-line or in a mosaic pattern, with a corresponding number of output amplifiers are needed.

The Scanistor provides, on a single output wire, an analog voltage that represents both the amount and position of light shining on its surface. It contains 100 light-sensitive diodes paired with 100 switching diodes. The diode pairs are spaced 0.005 inch apart to give a resolution of 200 image elements per inch. Scanistors, with a coarser resolution, have been built several inches long. In principle, a 10-to-20-inch Scanistor could be produced for scanning longer documents.

The Scanistor eliminates the mechanical methods, special vacuum tubes or matrices of photocells ordinarily used in optical scanners. Made of silicon, it is sensitive to both ordinary light and near-infrared radiation; other units could be made sensitive to far-infrared, a capability not possessed in vacuum-tube scanners such as orthicons and vidicons, or even by x-rays.

Operation. Two bars of silicon (germanium or other semiconductor materials could be used) form the top and bottom surfaces of the Scanistor. Dots of opposite-type semiconductor form diodes that are connected in pairs. One diode in each pair acts as a photodiode to measure the light intensity on that part of the Scanistor; the other is a switching diode that connects its photodiode to the output circuits at a particular value of scanning voltage.

In operation, a fixed bias voltage (typically 6 volts) is applied across two of the three Scanistor terminals. A variable scanning voltage is connected between the third terminal and one of the bias terminals; as this voltage increases from zero to the bias value, the Scanistor outputs a staircase current; the height of each step is proportional to the light falling on the corresponding part of the Scanistor's surface. This current is differentiated to obtain an output voltage whose shape corresponds to the light pattern.

Scanning ahead. Among the possible future uses suggested for the Scanistor are a hand-held reading device for entering a line of printed text into a computer; optical scanning in remote data-collection terminals; a position sensor to relay instrument readings to a central location; a read-out device for optical-storage mass memories, and infrared scanners for battlefield surveillance.

Cosmic computers

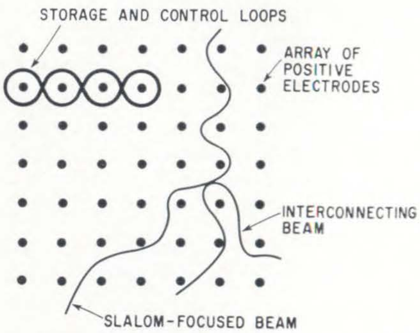
Computers with data rates of trillions or quadrillions of bits a second were envisioned at the microelectronics Symposium on Microelectronics and Large Systems in Washington.

Kenneth Shoulders of the Stanford Research Institute said such computers could some day be built with electron beams. He also describes a design for an electron-beam-operated computer using logic and storage cells only 0.2 micron in diameter. He has started work on a computer that uses electrons and ions as components.

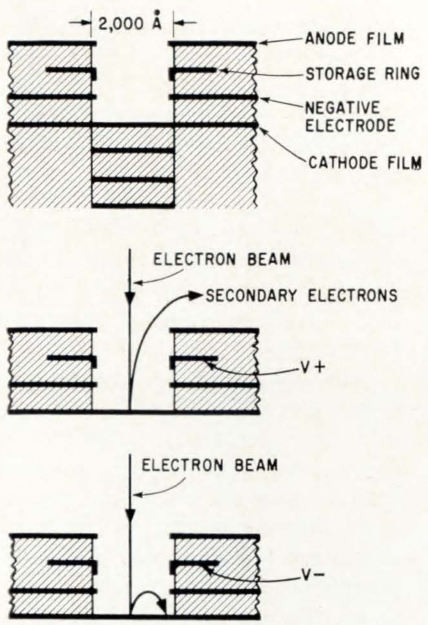
It was Shoulders' first public report in several years on his work in fabricating computer components of one micron or smaller.

Building with beams. Shoulders' basic goal is to develop for the Office of Naval Research the techniques needed to make a data-processing system that will pack 100 billion components into a cubic inch and have a data-retrieval rate of 10 billion bits a second.

To do this, he has built an electron-beam processing system that machines thin films of molybde-



Conceptual design of plasma computer. The electrodes, like the poles on a slalom course for skiers, control the path of the plasma particles.



Construction and operation of the thin-film cells proposed by Shoulders for use in electron-beam computer.

num and alumina into field-emission vacuum tubes and other components [Electronics, Nov. 16, p. 82].

Shoulders estimates that the computer's data rate, with one-watt input power, will be 10^{13} bits per second. The rate would rise in proportion to power input, but so would temperature—to 800° C at 10^{15} bits a second. The components, he said, could tolerate this temperature.

Reading with beams. The cell that Shoulders proposes for the electron-beam-operated computer [see diagram] is made by drilling a hole in a substrate, then depositing films of metal and insulator. As the layers forming the electrodes and storage-ring build up, the hole is filled. Then the bottom of the cell is shaped by an undisclosed method.

Shoulders has made cells, but not the arrays or fields of cells that a computer would require. He figures that a "couple of watts" input, a beam-scanning system consisting of perforated plates, and a field of 100 million cells, he can obtain a data rate of one trillion bits a second.

Each cell operates like a flip-flop with two gates in the input. In one state, the beam hits the bottom of the cell, the storage ring allows the secondary emission electrons to leave the cell, and they are detected by a photomultiplier. In the opposite state, the secondary electrons are trapped and cannot be read. The readout from one cell can be transferred to the next.

The electronic controls consist of: the electron-optical system; emission, lens and binary deflection-voltage regulators; a data-control system; and readout amplifiers. The deflection system is not accurate enough to read each cell in a field, and deflection rate is only one microsecond. However, Shoulders thinks groups of cells can be operated in parallel, to give the equivalent of one million little computers with 50-bit words. This arrangement could be used as an adaptive computer.

Circulating the beams. Shoulders disclosed that he has begun designing the plasma computer he suggested in 1960, but he doesn't expect to complete it in his lifetime. In fact, he warned any company interested in commercial survival against undertaking the research. The problems are so complex that as a commercial venture it would be a catastrophe, he said.

The motions of the ions and electrons that he would use as logic, memory, amplifying and connective elements are being simulated in the laboratory with tiny steel balls. The balls are propelled by electromagnetic fields, and guided by charged electrode pins [see the illustration on page 22].

Shoulders has made the balls orbit in persistent current loops, and has touched one steel ball with another so the first one bounds off. These experiments, he contends, demonstrate the three requirements of an operating system: storage, interconnection and gain. The use of electromagnetic fields to keep particles suspended in space and to contract clouds of particles has already been demonstrated by other researchers.

But Shoulders doesn't know whether he'll ever be able to make a gaseous plasma system stable. If one of the steel balls, for example, "stubs its toe" on a speck of dust, it goes out of control, and the balls have immense mass compared with plasma particles.

Supercomputer

A fantastic and mysterious computer system is being built by the Univac division of the Sperry Rand Corp. If it's ever completed, it will have the capacity of 4,000 or 5,000 ordinary computers.

The supercomputer is designed to handle one million instructions a second. If all the 25,000 computers now in existence were placed end to end, they could handle at most five or six million instructions a second.

Fantasy. Disbelief was expressed by many of the 400 people who heard the announcement in Washington on Nov. 17. The plan was disclosed by D.R. Lewis and G.E. Mellen of Univac at the Symposium on Microelectronics and Large Systems, sponsored by Univac and the Office of Naval Research.

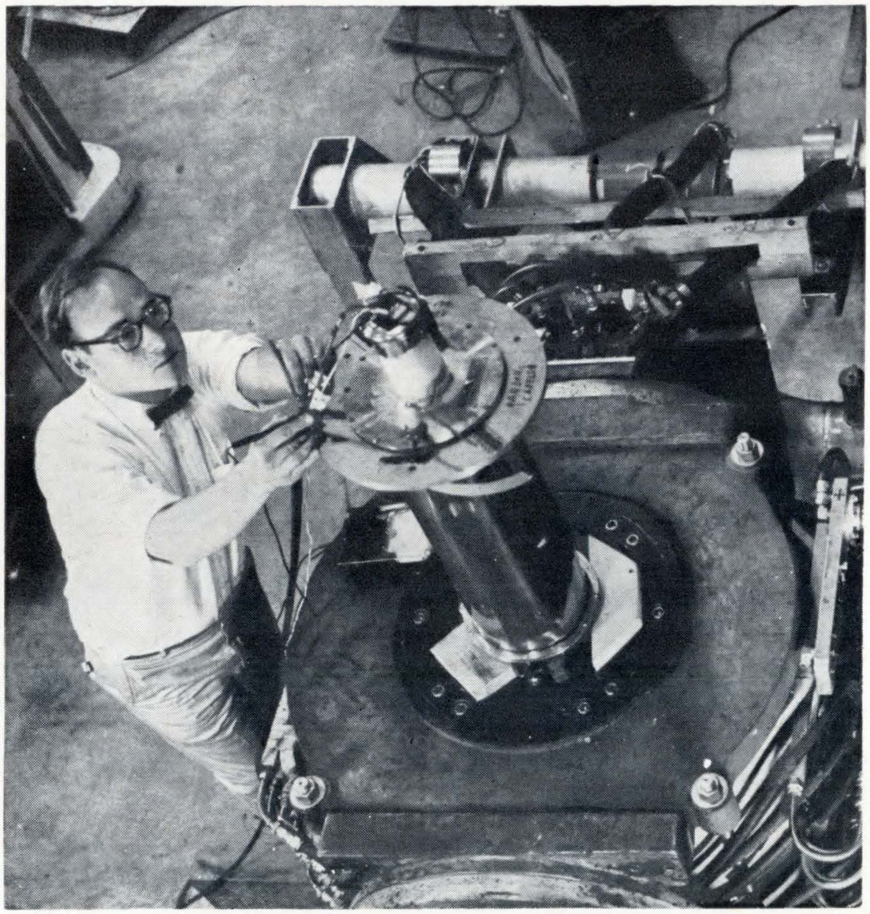
Lewis did not say when the new computer would be built, or how much it would cost, and even refused to disclose its name. He insisted, however, that it is not a "paper project," that parts of it have been built, and that Univac can deliver one of the giant systems if a customer wants one.

Some men at the meeting, and at a cocktail party later, named the system "fantasy."

Larc times 100. Only a small part of the total system needs to be built for it to operate as a computer. The system is a multiprocessor—a collection of independently operating modules—like the huge Larc computer that Univac built several years ago for the Atomic Energy Commission [Electronics, Apr. 28, 1961, p. 66]. But the new system would have 100 times the data-processing capacity of Larc and 33 times the capacity of Univac's big 1107 computers.

The system is to have more than 100 modular subsystems that will operate independently. It will be able to reorganize itself to solve many problems at once, or share the work on big problems.

There are four types of modules:


World's most powerful magnet is adjusted by its developer, D. Bruce Montgomery, at National Magnet Laboratory at MIT.

▪ **Processors.** There will be 25 of these, each able to handle 156 different types of instructions. Word length will be 32 bits, and add-subtract time 200 nanoseconds.

▪ **Memory modules.** The processors will get their programs from 64 of these. Each nondestructive-readout memory will have 4,096 words 68 bits long, on thin films. Each module will be capable of serving several processors, and any processor will have access to any memory.

▪ **Input-output systems.** Four of these, with 16 channels each, will provide 64 channels. Transfer rate between channels will be one megacycle. The number of channels can be expanded by multiplexing.

▪ **Operand memories.** Acting as intermediaries among all the processors and input-output systems will be thin-film destructive-readout memories.

Public utility. In all, there will be 2.5 million components in the system. Each processor requires 50,000 integrated-circuit logic nodes, compared with a total of only 12,000 in Univac's 1107. In 24 cubic feet the processor has a parts density 30 times the 1107's. Yet conventional plug-in card construction is used.

The system would be so large, Lewis said, that it could be operated as a public utility. Security locks will be built in, he said, to prevent unauthorized use of secret programs. About 10% to 15% of the circuitry is for checking errors.

Advanced technology

Big drawing power

In the late 1930's continuous magnetic fields of 100,000 gauss were generated by Francis Bitter in a cellar laboratory at the Massachusetts Institute of Technology. It has taken nearly 30 years to double that level. The strongest continuous field ever reported, 255,000 gauss, has been reached at the National Magnet Laboratory, adjacent to the MIT campus. The strongest field previously disclosed was 152,000 gauss, reported two years ago at the Naval Research Laboratory, Washington.

Used for study. The strong magnetic field will be used for research into the electronic properties of solids, the behavior of superconducting materials and the energy-level structures of potential materials for masers and lasers. The magnet could also produce an x-raser; this is a solid-state device that generates intense, well-collimated, coherent, monochromatic x-rays. It would be a significant tool for research in medicine, communications and crystal physics.

The National Magnet Laboratory is financed by the Air Force Office of Scientific Research and operated by MIT for research groups. When it was opened in the spring of 1963, the target field of 250,000 gauss was believed only months away [Electronics, May 17, 1963, p. 56], but engineering problems arose.

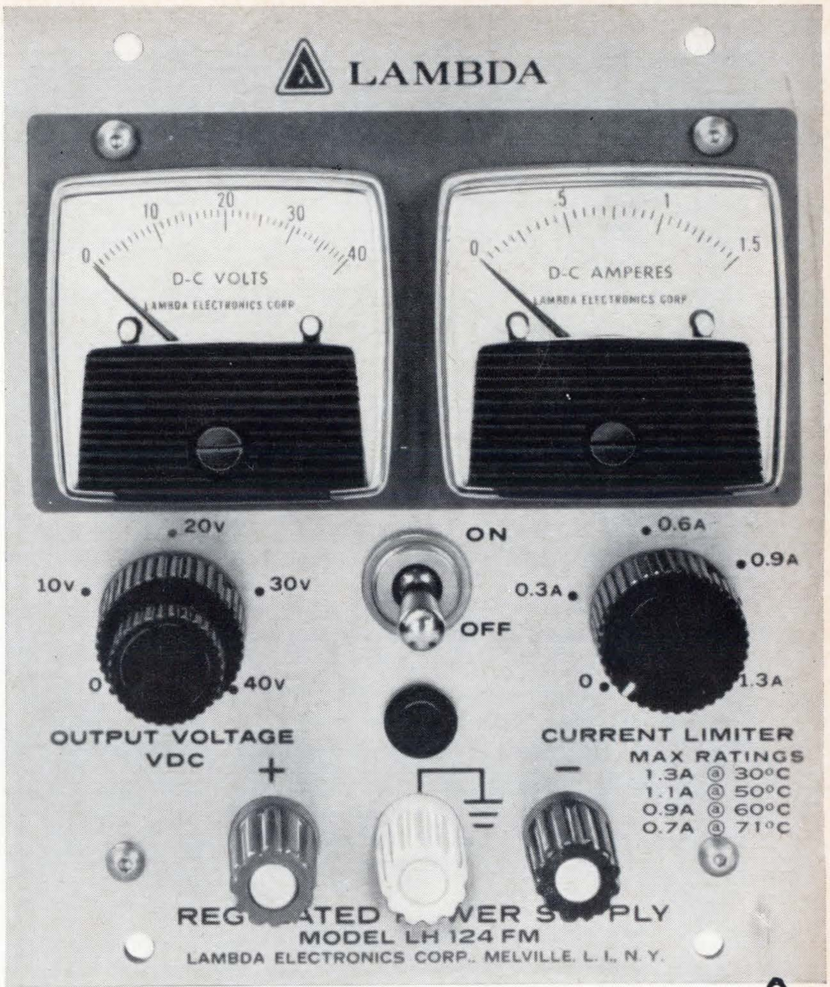
The 56,000 amperes used in the magnet create densities of 500,000 watts per cubic inch and pressures exceeding those at the deepest point in the ocean, 60,000 pounds per square inch.

The designer of the world's most powerful magnet, D. Bruce Montgomery, a researcher at the lab, says the 255,000-gauss level represents the current limit of safe operation, though the magnet has a peak design capability for continuous fields of up to about 300,000 gauss and pulsed fields above 400,000 gauss.

With added refinements—such as superconducting magnets—the lab hopes to push to continuous field strength, in steps, above a half-million gauss; but new engineering techniques will have to be found to contain and control this concentration of energy in such a small space.

Water for cooling. The maximum

ACTUAL SIZE FRONT PANEL ¼ RACK LH MODELS



PATENTS PENDING

5 Year Guarantee

Only Lambda offers ¼ rack power supplies with multiple current ratings

- Now LH Series is available in 0-10 VDC as well as 20, 40, 60 VDC ¼ and ½ rack models.
- Multi-Current-Rated™ up to 71°C.
- Modular-Subrack design for bench, chassis and rack use.
- Regulation—.015% or 1 MV (line or load)
- Ripple—250 microvolts rms, 1MV P-P
- AC Input — 105-135 VAC, 45-480 CPS.
- ¼ rack: LH 118, 121, 124, 127 – 5³⁄₁₆" x 4³⁄₁₆" x 15⁵⁄₁₆"
  ½ rack: LH 119, 122, 125, 128 – 5³⁄₁₆" x 8⅜" x 15⁷⁄₁₆"

Model	Voltage Range	CURRENT RANGE AT AMBIENT OF: (1)				Price (2)
		30°C	50°C	60°C	71°C	
LH 118	0-10VDC	0-4.0A	0-3.5A	0-2.9A	0-2.3A	$175.00
LH 119	0-10VDC	0-9.0A	0-8.0A	0-6.9A	0-5.8A	$289.00
LH 121	0-20VDC	0-2.4A	0-2.2A	0-1.8A	0-1.5A	$159.00
LH 122	0-20VDC	0-5.7A	0-4.7A	0-4.0A	0-3.3A	$260.00
LH 124	0-40-VDC	0-1.3A	0-1.1A	0-0.9A	0-0.7A	$154.00
LH 125	0-40-VDC	0-3.0A	0-2.7A	0-2.3A	0-1.9A	$269.00
LH 127	0-60VDC	0-0.9A	0-0.7A	0-0.6A	0-0.5A	$184.00
LH 128	0-60VDC	0-2.4A	0-2.1A	0-1.8A	0-1.5A	$315.00

(1) Current rating applies over entire voltage range. DC OUTPUT Voltage regulated for line and load.

(2) Prices are for non-metered models. For metered models and front panel controls, add suffix (FM) to model number and add $25.00 to the price. For non-metered chassis mounting models, add suffix (S) to model number and subtract $5.00 from the non-metered price.

SEND FOR LAMBDA CATALOG

LAMBDA ELECTRONICS CORP.

515 BROAD HOLLOW ROAD • MELVILLE, L. I., NEW YORK • 516 MYRTLE 4-4200

SALES OFFICES AND REPRESENTATIVES CONVENIENTLY LOCATED IN MAJOR CITIES

LA155

Circle 25 on reader service card

field strength of 255,000 gauss is maintained for about one minute. At full strength, the magnet draws more than 10 million watts, $\frac{1}{10}$ of the total load of the Cambridge Electric Light Co., and is cooled by 2,000 gallons of water per minute. The power comes from two d-c generators, each coupled to an 85-ton flywheel.

The lab more than doubles the nation's capability in magnetic-field generation.

Astronomy plan

The National Academy of Science has urged massive improvements in ground-based equipment for optical and radio astronomy. It proposes a 10-year, $224.1-million program of construction, instrumentation and automation. It also suggests studies to plan for using more sophisticated technology that is likely to be available 10 years hence.

Present antennas are too small to examine the wavelengths of high-energy radiation, and they give a fuzzy radio view of the sky.

Soviet plan. Large radio-telescope arrays are already under construction in Australia and at the Lebedev Physics Institute in Moscow. NAS believes that their use will put both countries ahead of the United States in radio astronomy.

Over the 10-year period, the NAS plan calls for the construction of 100 separate parabolic antennas, each 85 feet in diameter, operating in concert. It envisions a group of 300-foot dishes for exploration in the 21-centimeter wavelength of hydrogen, also for polarization studies, measurement of source spectra, monitoring of planets and cosmic radio sources, and radar experiments. Also included are a fully steerable radio telescope 600 feet across, and optical telescopes twice the size of the present 200-inch ones.

Bigger radio and optical telescopes are only one way to extend the frontiers of research. Increased efficiency of analyzing instruments on existing equipment is equally important.

Instrumentation whose development the academy favors for both radio and optical astronomy includes:

- Photoelectric cathodes with sensitive materials having improved efficiency in red and infrared.
- Image tubes with gain increases of 10 or 20 times.
- Infrared detectors, adapted to astronomical uses, that do not present problems due to ambient radiation.
- Parametric amplifiers and masers designed to eliminate both receiver and thermal noises.

Data-handling. NAS also recommends a few pilot programs to fully automate some observatories to help in data-handling. An automated observatory might include a medium-size digital computer; individual control console for each major instrument, with monitors and digital readouts showing data and instrument position; automatic measuring engines for fast and convenient readout of data; and remote control of slewing, guiding, focusing and switching of optical instruments.

Though this proposal is for ground-based facilities, NAS also stresses the necessity for costly orbiting observatories for special research projects.

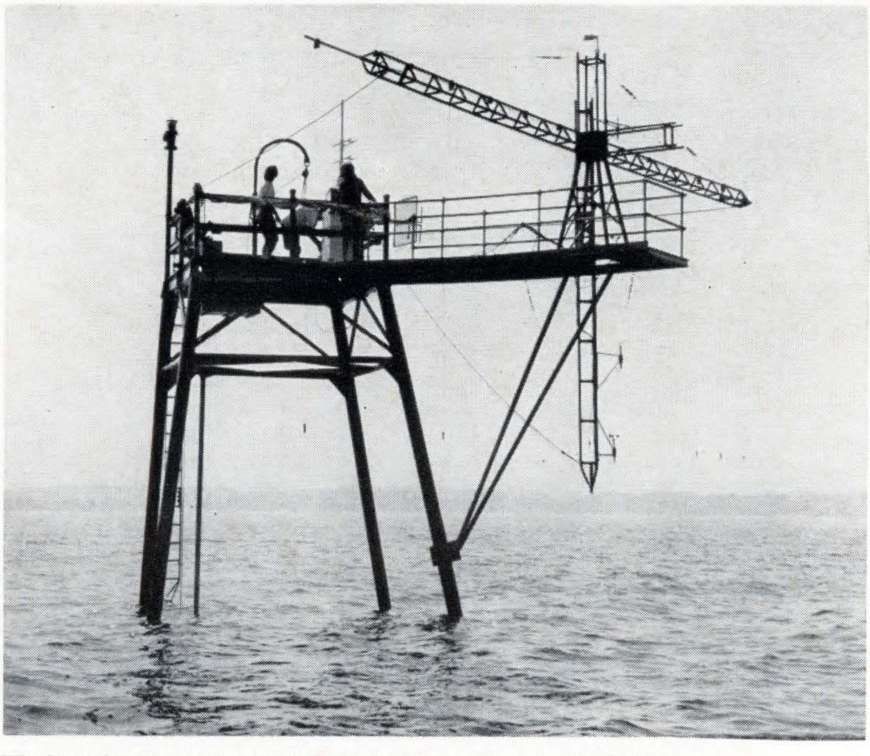
Oceanography

Winds and waves

In Buzzards Bay, where a southwest breeze sweeps toward Cape Cod from the Atlantic, a tower in 40 feet of water keeps track of the ups and downs of wind-generated waves.

The tower is a sensor site in a wave-measuring system developed by Raymond G. Stevens and Leonard F. Shodin of the Woods Hole Oceanographic Institution.

No theory exists to satisfactorily explain the growth of composite wave motion under wind action. There are many reasons for wanting to know more about the power spectrum in wave buildup—they range from getting early warning of destructive seismic waves, like the tsunami, to assessing the effect



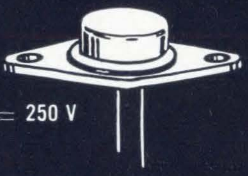
Winds and waves are measured by electronic sensors on this tower in Buzzards Bay. Vertical wires, barely discernible in photo, go down into the water where they are held taut by lead weights.

400V V_{CER}(sus)

5A I_C(peak)

10 Mc f_T(min)

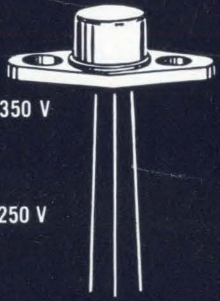
For the first time at Economy Prices



2N3583
V_{CER}(sus) min = 250 V

2N3584
V_{CER}(sus) min = 300 V

2N3585
V_{CER}(sus) min = 400 V



40255
V_{CEO}(sus) min = 350 V
I_C max = 1 amp
$\theta_{j\text{-}c}$ = 15° C/W

40256
V_{CEO}(sus) min = 250 V
I_C max = 1 amp
$\theta_{j\text{-}c}$ = 15° C/W

2N3439
V_{CEO}(sus) min = 350 V
I_C max = 1 amp
$\theta_{j\text{-}c}$ = 30° C/W

2N3440
V_{CEO}(sus) min = 250 V
I_C max = 1 amp
$\theta_{j\text{-}c}$ = 30° C/W

RCA ADDS THREE NEW "SMALL TO-3" (TO-66) HIGH-CURRENT TRANSISTORS TO THE LOW-COST, HIGH-VOLTAGE SILICON LINE

Here's high-voltage, high-current, high-frequency, silicon power with big performance built-in and high cost built-out. New RCA mass-production assembly techniques, new triple-diffused mesa process, and RCA's "small TO-3" (TO-66) diamond package put these three new transistors in a price class that's right for:

- High Voltage Inverters and Switching Regulators
- Line-Operated or High-Voltage Amplifiers
- Operational Amplifiers
- Electrostatic or Magnetic Deflection Circuits

Check RCA-2N3583, 2N3584, and 2N3585 for every socket, for every new design that requires big, high voltage performance and real economy. These three new types are conservatively rated for long-term field reliability.

		2N3583	2N3584	2N3585
h_{FE}	@ I_C = 100 ma, V_{CE} = 10 V	40 min	40 min	40 min
	@ I_C = 1 amp, V_{CE} = 10 V	10 min	25-100	25-100
h_{fe} @ 5 Mc	@ I_C = 200 ma, V_{CE} = 10 V	2 min	2 min	2 min
$I_{S/b}$	@ V_{CE} = 100 V	250 ma min	250 ma min	250 ma min
V_{CEO}(sus)	@ I_C = 200 ma	175 V min	250 V min	300 V min
V_{CE}(sat)	@ I_B = 125 ma, I_C = 1A		0.75 V max	0.75 V max
I_C		5 amp peak 2 A continuous	5 amp peak 2 A continuous	5 amp peak 2 A continuous

For price and delivery information, check your RCA Representative, or your RCA Distributor. And ask him about RCA's high voltage, small signal, TO-5 types 2N3435, 2N3550, and flange TO-5 types 40255 and 40256. For technical data, write: RCA Commercial Engineering, Section I-N-11-5, Harrison, N.J.

Also Available Through Your RCA Distributor
RCA ELECTRONIC COMPONENTS AND DEVICES, HARRISON, N.J.

RCA ® **The Most Trusted Name in Electronics**

Circle 27 on reader service card

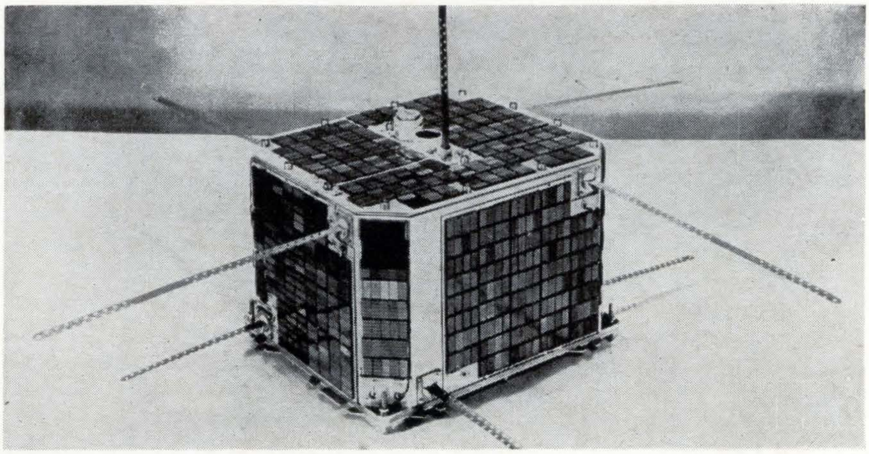
of sea conditions on missile launches and on antisubmarine warfare.

Six wave sensors hang from a horizontal boom of the observation tower. The resistance of these stainless steel wires varies with the elevation of the sea surface. The wires, which are kept taut by two-pound lead weights in the water, have a built-in resistance of two ohms per foot. In this adaptation of the step-resistance gage, the lineup of six parallel sensors on an adjustable boom can give directional information as well as amplitude. It is also possible to vary the phase relationship of the wires to give data on wind direction. For various analyses by oceanographers, a computer can be programed to correlate wave buildup and decline with wind velocity and direction.

Energy transfer. To help understand how energy is transferred from wind to waves, four anemometers are set at different heights on a vertical boom attached to the tower. Precision measurement of horizontal wind speed is needed, so the Woods Hole group designed a fast-response electronic version of the cup anemometer. In this virtually frictionless device a lamp is placed at the top of the vertical shaft and its light is chopped as the cups rotate.

A photo-actuated silicon controlled rectifier, the Photran, made by Solid State Products Inc., converts the chopped light into pulses. These pulses are integrated to produce analog voltages. The voltages, varying as functions of wind velocity, are converted to subcarrier f-m audio frequencies. Special circuits reject tidal effects, so that only the buildup and decline of wind-generated waves are measured.

Information from the six wave sensors, the four anemometers and a wind vane is sent on 12 channels to the oceanographic institution, two miles away. The data is put on 12 f-m subcarrier oscillators and transmitted simultaneously over a telemetering radio link; each channel has its own subcarrier frequency. The analog information is recorded on magnetic tape and later converted into digital form.



Range-measuring Secor, orbiting 600 miles above the earth, will pinpoint targets for intercontinental missiles.

Military electronics

On target

Intercontinental missiles, even though they seem to have been correctly sighted, launched and guided in flight, can miss their targets. That's because existing maps are inaccurate. With the help of a small satellite that can obtain exact latitude and longitude fixes on possible targets, map errors are being corrected.

The satellite, called Secor (for sequential collation of range), was launched last January aboard an Air Force Thor-Agena. Secor orbits at an altitude of 600 miles. It can measure distances of up to 1,000 miles with an error as small as 20 yards. Besides locating the precise position of possible missile targets, information from Secor will provide more accurate maps, improve navigation, and could pinpoint the position of ships, submarines, and aircraft.

Above the horizon. The satellite contains a transponder that receives and returns radio signals simultaneously from four ground stations. Three of the four stations are reference locations at known positions of longitude and latitude; the longitude and latitude of the fourth point is not precisely known.

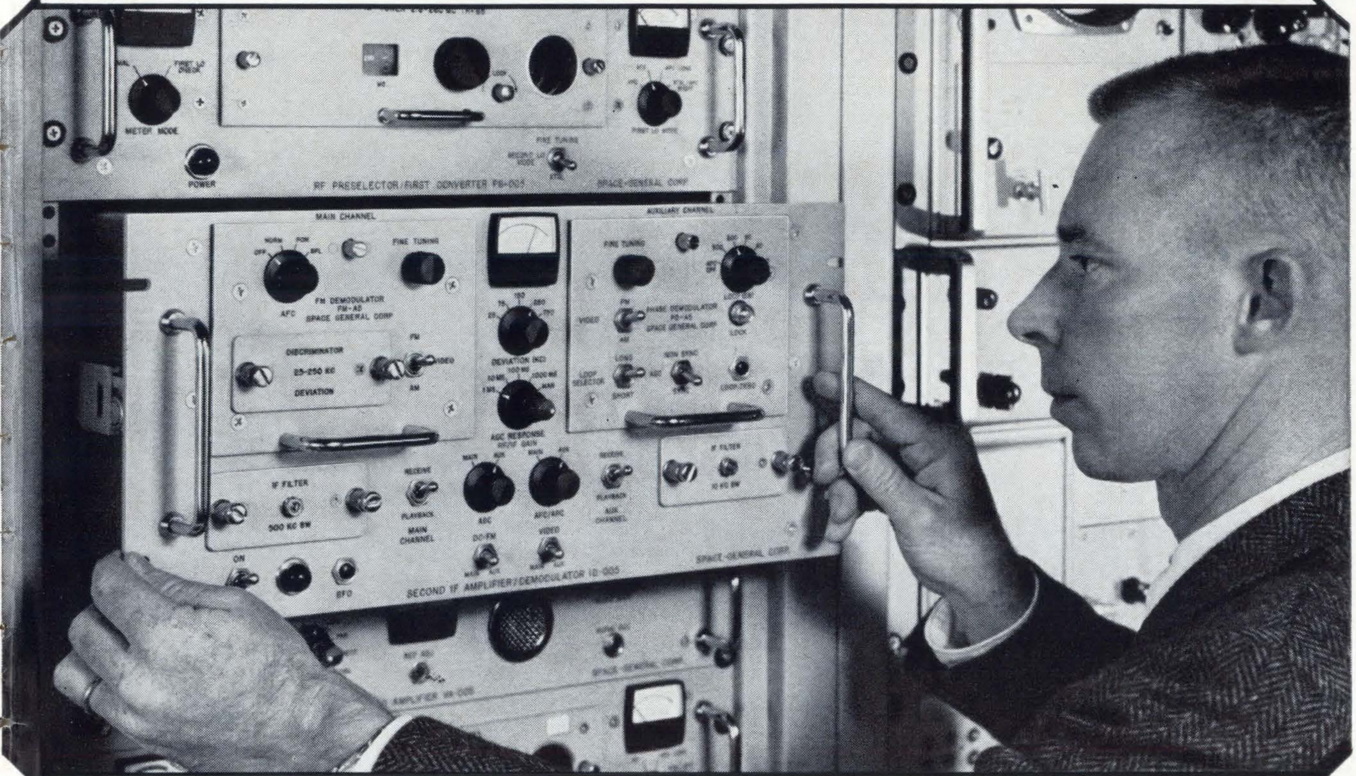
When the satellite appears above the radio horizon, each station computes its slant range (line-of-sight distance) to the satellite by interpreting the phase relationships between the signal transmitted from the station and the one returned by the satellite. This computation is made 20 times per second and is recorded on magnetic tape along with a timing signal from an electronic clock. This means that the distances measured from each station to the satellite can be correlated in time. The information, in digital form, is fed into a computer at the Army's Map Service Center in Washington.

Pyramid. The distances from the four ground stations to the satellite form the elements of a pyramid. With three of the base points at known positions, it is simple to establish the position of the fourth.

Secor is now being used to chart the position of Iwo Jima and other islands in the Pacific, with Japan and the Ryukus as reference points. Iwo Jima is not a target, but precisely locating this island will reduce errors in intercontinental distances between missiles and targets near Iwo Jima.

Other gear. Besides the transponder, Secor carries a telemetry system and a magnetic orientation device. It uses solar cells and batteries for power. The 40-pound satellite was built by the Cubic Corp. in San Diego, Calif., for the United States Army's Mapping Service.

Future mappers. The Army has no immediate plans for another Secor but an improved version, called Geos, will be launched next October. It will include Secor and other position-fixing systems.



This is an OVONIC* Threshold Switch

***A simple non-rectifying semiconductor device based upon an entirely new theory in solid state physics developed by Energy Conversion Devices.**

Oscilloscope trace showing E-I characteristic of the OVONIC threshold switch. Note instantaneous change from non-conductive state to the fully conductive state.

□ The two crossed wires shown greatly enlarged above are not a fully fabricated component. But they can be used just as is to demonstrate fundamental principles of a newly discovered phenomenon in the field of solid state physics. Ready?

First—if you examine the surfaces where the wires touch, you will notice a difference in color. This is actually an active thin film of a homogeneous semiconductor material. Unlike all other semiconductor switches, however, this active film element is not produced by precise doping of high purity material. Nor is its operation based upon conduction through P-N junctions. Nor is it asymmetrical with respect to forward and reverse current flow.

Instead, this unique OVONIC switch is of such a nature that it can be changed instantaneously from non-conductive to a conductive state, and vice versa, simply by increasing or decreasing the voltage or current in a circuit above or below a given threshold level. Or switching action can also be made to occur by changing the device's "firing" threshold relative to a constant supply voltage. Moreover, because the device responds identically to both positive and negative polarities, it is inherently capable of controlling either direct or alternating current.

This is the essence of OVONICS, a new field of control based upon an entirely new theory in solid state physics. And these are inherent capabilities of the many OVONIC threshold control devices now being developed by E. C. D. and its licensees throughout the world.

*New brochure describes basic OVONIC principles and many of the devices now being developed for various control circuits. A request on your letterhead will bring you a copy by return mail.

E C D

Career opportunities now open to qualified physicists, chemists, and electronic engineers. Send resume to:

Energy Conversion Devices, INC.

14121 West McNichols Road □ Detroit, Michigan □ 48235

Washington Newsletter

November 30, 1964

Electronic stakes in tariff bargaining

Tariff-cutting talks, which opened this month in Geneva, are being watched closely by United States electronics companies because the stakes are enormous.

In the first eight months of 1964, about $190 million of electronics goods were imported by the U.S.; of this, $113 million was in consumer goods. In the same period, **$905 million of electronics goods were exported;** 77% of that total was in military and industrial products.

Any major reduction in foreign barriers would open new markets for U.S. makers of industrial and commercial products. Simultaneous chopping of American trade levies would swell the imports of consumer products. **The question facing U.S. manufacturers: Would a gain in imports be offset by a rise in exports?**

The Electronic Industries Association wants reciprocal tariff cuts on commercial and industrial products. The U.S. Trade Expansion Act permits reductions of as much as 50% in U.S. tariffs. But on consumer items, the association has asked that the other countries cut tariffs while the U.S. maintains its barriers. Here's the argument: U.S. protection on consumer goods is about 30% lower than that imposed in Europe and Japan.

The talks are under the auspices of the General Agreement on Tariffs and Trade.

U.S. and Germany plan joint studies

The electronics industry is expected to benefit from closer defense cooperation agreed on by the United States and West Germany.

In the latest round of talks between Defense Secretary Robert S. McNamara and Kai-Uwe von Hassel, Bonn's defense minister, it was decided to jointly develop miniature inertial navigation systems for small ships. The development contract will be placed in the U.S., with the two governments sharing the costs.

Bonn and Washington will also work jointly on a light-weight craft for vertical short takeoff and landing (V/STOL) which Germany is developing for possible future use by the North Atlantic Treaty Organization. **Also being explored: possibilities for cooperation in antisubmarine warfare and for a heavier V/STOL plane.**

Germany plans to use the Bell Aerospace Corp.'s UH-1D to meet its utility helicopter requirements; some of the craft will be built in Germany. Three guided-missile destroyers will be constructed in this country for Germany, with a contract expected to be awarded about April 1.

Pentagon affirms reliability stress

Despite criticism, the Defense Department continues to favor reliability over sophistication in weapons development. Officials say new ideas will have to win acceptance in the research-and-development phase before being put into systems.

This policy was laid down again in speeches by Adam Yarmolinsky, special assistant to Defense Secretary Robert S. McNamara, and by Eugene G. Fubini, assistant secretary for research and engineering.

Yarmolinsky told a group of executives that components would be picked from established gear, not from "un-cost-conscious" possibilities that may merely seem to be feasible. **"Choices are being made at the less**

expensive end of the spectrum," he said.

Fubini spoke at the convention of the Association of the United States Army. If the very best must still be tested, he said, and if the second-best will cost too much, take too long or require too much logistic support, "Take the third best. It will work and keep working."

New urgency seen in industry studies

Congress and the White House will step up inquiries into the business effects of automation and of lessened defense production.

Congress is still recovering from the shock of Defense Secretary Robert S. McNamara's announcement that 95 military installations will be shut or curtailed. Leaders will put high priority on the work of the Senate Subcommittee on Labor and Public Welfare, headed by Sen. Joseph Clark (D., Pa.), which has spent more than a year studying conversion and dislocation problems. **Sen. George McGovern (D., S. D.) will reintroduce legislation that would require companies to prepare their plants and work forces for civilian production.**

The President's new 14-man Commission on Automation Technology and Change is organizing, and will report by Jan. 1, 1966. It will bring in specific proposals not only to promote technological change but to handle economic dislocation resulting from advanced technology and declining military spending.

Patrick E. Haggerty, president of Texas Instruments, Inc., is one industry representative on the commission. Joseph A. Beirne, president of the Communications Workers of America, will represent workers, including those in the electronics industry.

Avionics choices for Army, Navy

The Army is facing a decision on an armed air vehicle for the 1970's that will incorporate advanced integrated avionics. The choice is between rotary-wing and fixed-wing vertical-takeoff craft.

As many as three contractors will be selected early next year for program-definition studies. One or more contracts for prototypes should be let by mid-1965.

The Army also has two choices for the avionics system. It can take the integrated helicopter avionics system (IHAS), for which the Navy is about to let a development contract to the Teledyne Systems Corp., a subsidiary of Teledyne, Inc. [Electronics, Nov. 16, p. 37]. Or, as an interim selection, it can take the fully developed Navy system, called basic advanced integration system (BAIS).

With IHAS a craft can fly assault missions by instrument and can use terrain-avoidance radar, station-keeping equipment that maintains one plane's distance from another, and automatic navigation based on doppler navigation.

The Navy faces a similar avionics question with its CH-53-A Marine attack-transport helicopter. Delivery of this craft is expected by mid-1966, well before development of IHAS is expected. The Navy is considering using the BAIS system on an interim basis.

Navy lists electronic needs

The Office of Naval Materiel has issued a new list of research and development needs. Included are nearly 50 requirements in the electrical and electronics field. Copies may be obtained free from the Chief of Naval Materiel, Navy Department, Washington. 20360, Attn: Code Mat-44.

ULTRA-COMPARATOR* Dual Limit Controls keep a test rocket engine on its best behavior

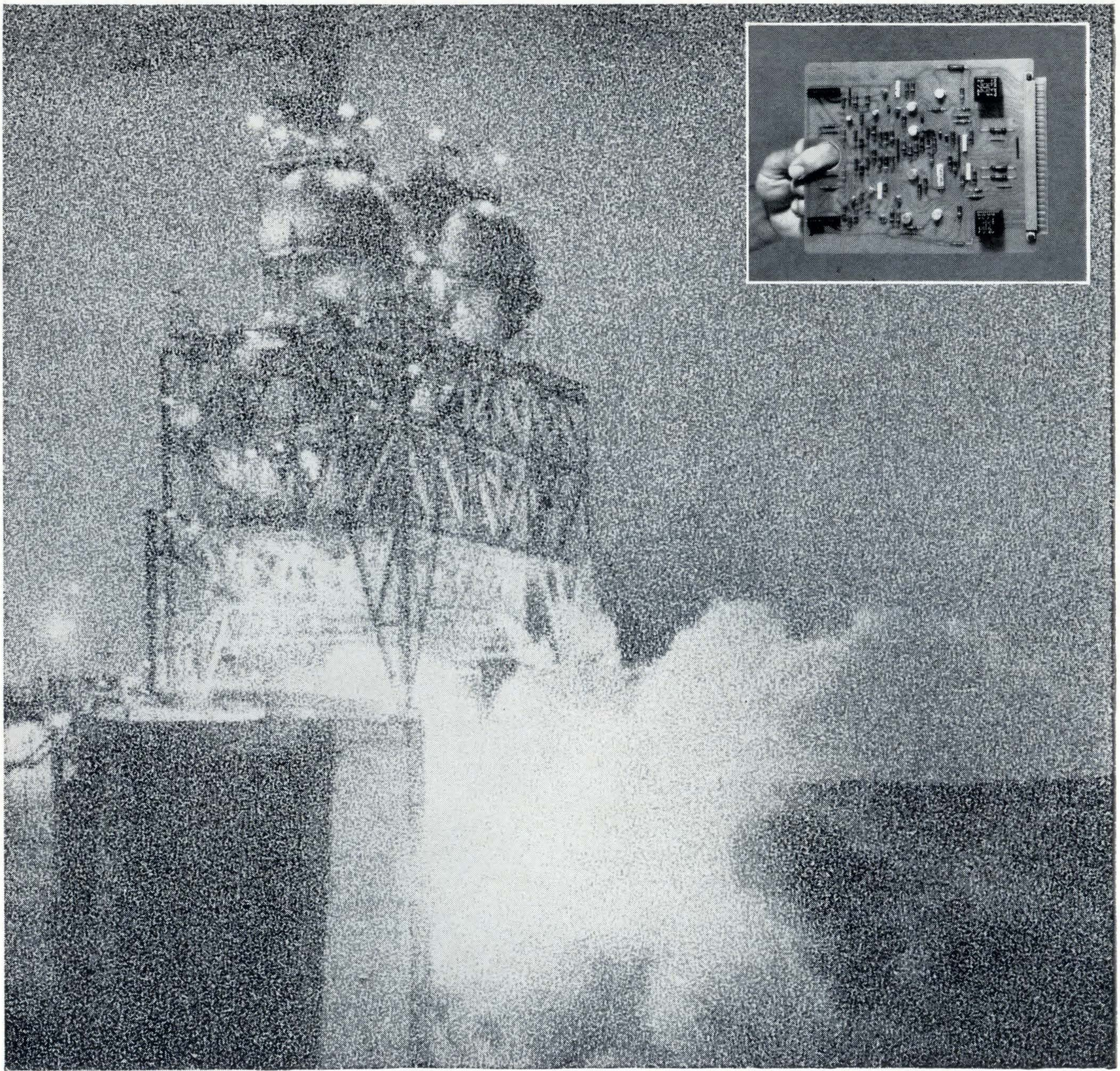
At the Rocketdyne Division of North American Aviation, scientists and engineers are continually checking out the most advanced rocket engines. Costly to build, these rocket engines may unexpectedly head for destruction when critical parameters go outside rated limits. To monitor or shut down rocket engines and prevent damage, fast, sensitive, reliable controls are needed. For this job, Rocketdyne is using Carter-Princeton Model 2020 ULTRA-COMPARATOR Dual Limit Controls at five critical points. The 2020 combines two 100K input impedance comparators on one small-size, computer-type, plug-in circuit card. Highly reliable, capable of evaluating low-level electronic signals without pre-amplification, it has the fastest power-relay output yet achieved—5 milliseconds from signal to full 2-ampere output. Here are Rocketdyne's applications:

1. Monitors at "Ignition Start" to pre-determine potential "stall condition," providing fast cut-off. **2.** Monitors an actuator-position signal from a linear feed-back transducer, causing an instant engine cut if engine is not following a pre-determined pattern. **3.** Monitors hydraulic pressure across the piston on gimbal actuators, permitting quick check to see that the load is below safe acceptable limits. **4.** Aids in bleeding air from the gimbal actuators by permitting a constant velocity actuator displacement. **5.** Monitors function generator output for level detection in order to set up logic circuits which give wave shapes for the determination of gimbal patterns.

The Model 2020 circuit is one of a series of new ULTRA-COMPARATOR units offering high sensitivity, compactness, reliability and adaptability at substantial savings. A limited number are available for free trial and evaluation.

For information, details, and specifications, contact Carter-Princeton, Electronics Division, Carter Products, Inc., 178F Alexander Street, Princeton, N.J. 08540. Phone (609) 921-2880.

CARTER-PRINCETON



* Trademark Pats. Applied For

Technical Articles

The field-effect transistor Part 1: page 45

The talk of the electronics world today is the field-effect transistor. It is superior to a conventional transistor as a low-noise amplifier, less sensitive to radiation, and can be operated in direct-coupled arrays.

I. A curiosity comes of age. Twice as many companies are making three times as many types of units.

II. Metal-oxide-semiconductor field-effect devices. A discussion of the unique characteristics of a type of FET that holds great promise for new circuitry.

III. How to measure noise in field-effect transistors. One advantage of the FET is its low-noise characteristic; however noise-level measurements are more difficult.

IV. Germanium in a MOS device. Economics has focused new attention on germanium as a FET material.

A new compact delay line: page 69

Research in microwave acoustics has produced a small solid-state device that can introduce time delays into a microwave signal line.

Myocoding helps paralytics: page 74

An electronic system picks up nerve signals at the skin surface and amplifies them to run a leg brace. It could be the basis for a family of electronically run artificial limbs.

Coming December 14

- Part II: Field-effect transistors—circuit applications
- A new look at digital television
- Synthesizing networks with negative reactance

Integrated-circuit system keeps costs down to earth

The same production equipment and personnel used to make printed-circuit assemblies will make these integrated-circuit modules. The new modules can also be taken apart and repaired, but they are 10 to 15 times smaller

By Fred A. Pendleton
Collins Radio Co., Dallas

A packaging design that is a practical approach to using integrated circuits in conventional and commercial equipment has been developed by the Collins Radio Co. The design bridges the gap between the high-density integrated-circuit modules with welded or soldered connections, that are used in missile and space systems, and the established approach of using modules made with replaceable printed-circuit-card assemblies.

Costs are kept competitive because the integrated-circuit modules are made with conventional printed-circuit-card production equipment. The reliability possible with present integrated-circuit systems is retained, and the maintainability is improved. The concept is suitable for present needs, yet flexible enough for future use.

And, although the development of the packaging system was not an exercise in high-density packaging, it does provide for component densities 10 to 15 times higher than the densities that can be attained with discrete components.

The module design illustrated is being used in a test set developed by Collins for military use. It had to be hand-portable and readily maintainable.

If the test set were made with discrete components, it would have been nearly as large as a telephone booth. The final size, using integrated circuits and some standard components mounted on printed-circuits, is 23⅛ by 13⅞ by 19¼ inches. This includes space for a power supply and storage area.

Further reductions in size could have been achieved with more complex packaging techniques, but cost would have increased and maintainability would have been restricted.

Compatible cards

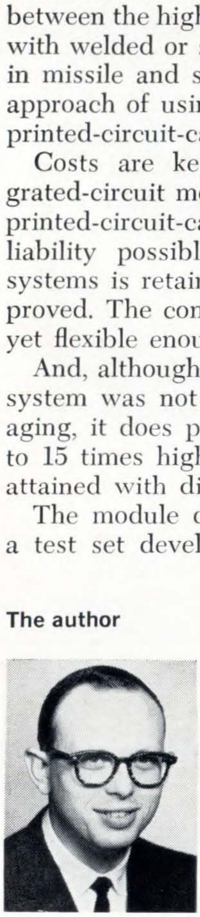
A typical integrated-circuit module is shown on page 38 in various stages of assembly. The 4½ by 6-inch card becomes a motherboard for retaining and interconnecting the integrated-circuit submodules. These submodules are small printed-circuit boards.

Each small board mounts up to four integrated-circuit packages and provides all interconnections between them. An assembled submodule with four integrated circuits meets the $100 maximum cost for expendable items designated by MIL-E-16400 as amended Jan. 10, 1964.

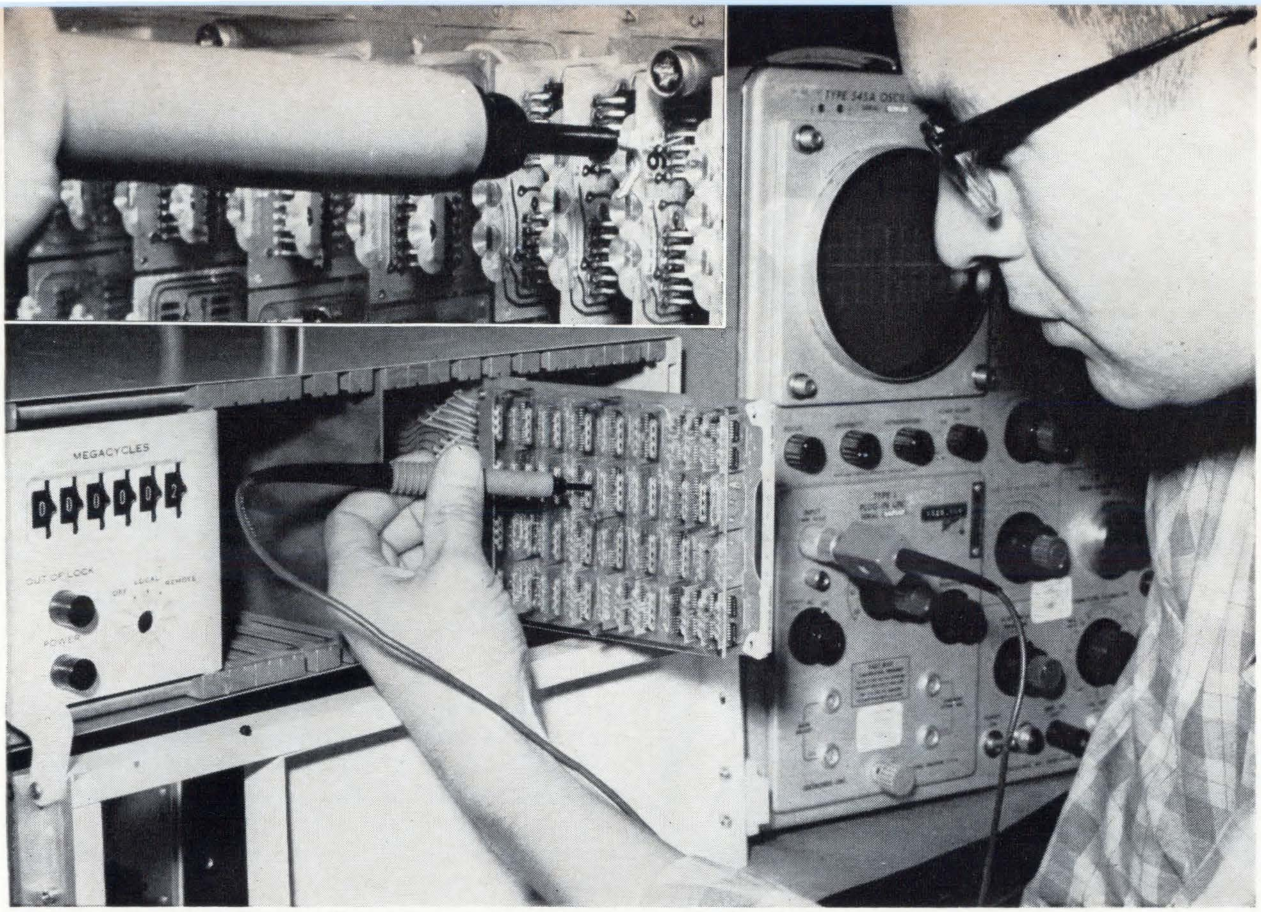
The integrated circuits can be welded or soldered to the submodule board. A plastic cover completes the module assembly.

The design is compatible with Collins' existing printed circuit and module standards. It is fully compatible with conventional modules, which can often be used in the integrated-circuit packaging system without change. Likewise, integrated-circuit modules can be substituted for conventional modules in already-designed equipment.

The author



Like many other designers of packaging systems for solid-state and microminiature electronic systems, Fred Pendleton is a mechanical engineer. He got his bachelor's degree from Texas A&M University, and is now working toward a master's degree in engineering administration at Southern Methodist University. He is employed in the Research and Development division of the Collins Co. facility in Dallas.



Slotted plastic cover does quadruple duty—as assembly fixture, structural member, submodule identifier and test fixture. Curved probe fits through slots, simplifying maintenance tests.

The conventional and integrated-circuit modules not only look the same, but existing tooling, processes and assembly practices can be used to produce both types.

The plastic cover, a unique feature of the packaging system, serves several functions. It is a fixture for retaining and supporting the submodules during assembly and machine soldering. It also serves as a protective cover for the individual components and submodules, a structural member for the overall module assembly, a surface for general symbols and test-point identification, and a locator or guide for test probes.

The cover is molded of clear plastic. One cover design and, consequently, one tooling charge, accommodates all modules. One silk-screen master is used to print identification for all submodule positions. Different module types are identified by markings on the module handle.

System packaging costs

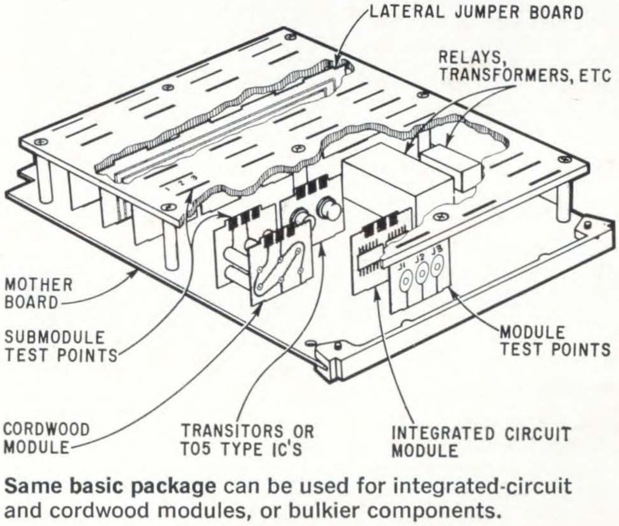
The cost history of integrated circuits will probably parallel that of transistors. Component prices will decrease as production processes are improved and demand increases. In comparison, the electronic packaging costs at the OEM level (original equipment manufacturer) have risen from about 5% of total system cost two years ago to 15% of total cost today. As integrated-circuit costs fall, this percentage will continue to rise.

Costs can readily be divided into three major areas: design costs (R&D), manufacturing costs and ownership costs.

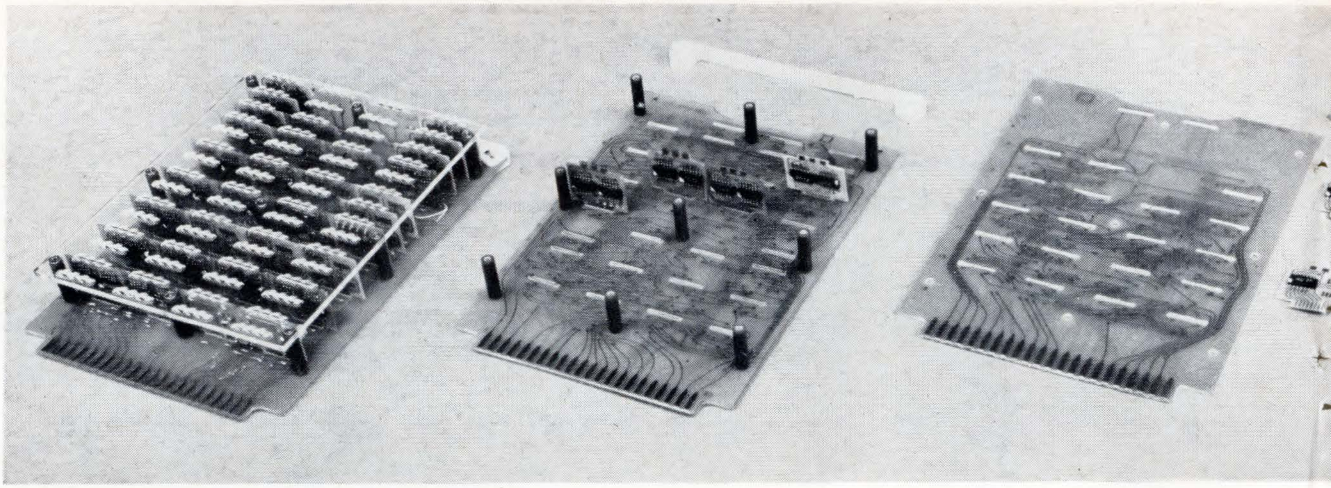
Design costs

The use of integrated circuits, rather than discrete components, will reduce design costs. One present design uses only seven different integrated circuits, repeated throughout the system at the submodule level. This repetition reduces the cost and quantity of documentation—formal drawings, schematics, component and test specifications.

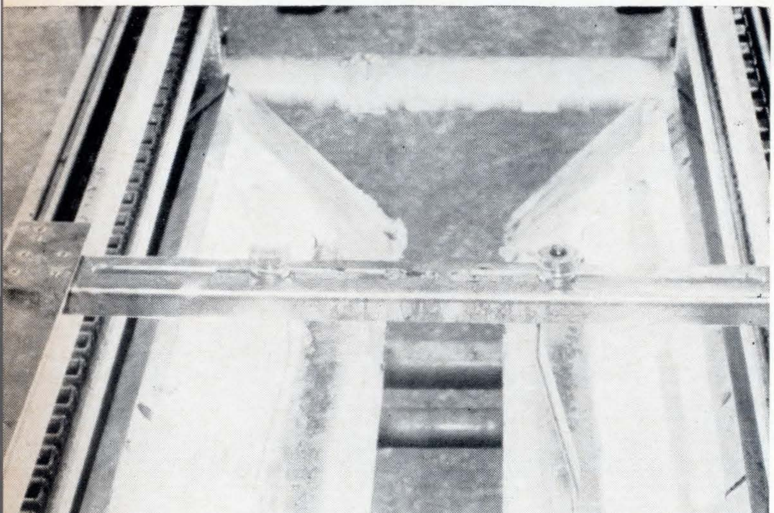
The wiring on the submodule reduces and controls wiring complexity on the motherboard. The motherboard is designed on a grid system so that all submodules are mounted on standard increments at predetermined positions. This grid system



Same basic package can be used for integrated-circuit and cordwood modules, or bulkier components.



Complete assembly (left) is built up by mounting the submodule printed-circuit cards on the printed-circuit motherboard after the integrated-circuit packages are soldered or welded to the cards.



Soldering the submodules to the motherboard is no problem. The assembly itself serves as the fixture. All submodule-to-motherboard joints are made during one pass through a wave-soldering machine.

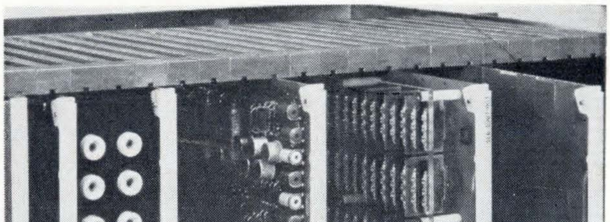
is illustrated on page 39. Every interface between a submodule and the motherboard is identical. Assigning numbers to each possible submodule location and each connection on a submodule develops a simple point-to-point interconnecting chart. An engineer, or technician, fills in the chart before drawings are prepared.

The tedious and costly process of making the motherboard master artwork (tape-up), which is required for etching the printed circuit, is greatly simplified by the chart. Many of the mechanical mistakes that may result when a complex schematic must be followed are also avoided by this method of point-to-point interconnection.

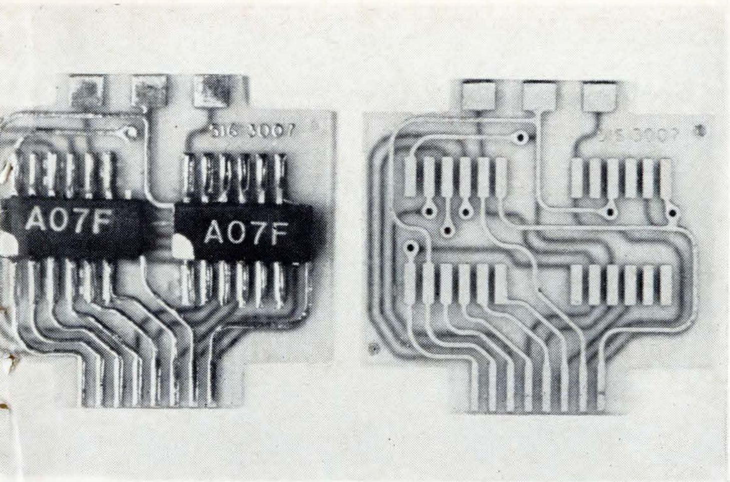
Manufacturing costs

While the development costs are important, the manufacturing costs are paramount in meeting competition. Particular emphasis has been placed on reducing and controlling production costs of this module.

High-density welded modules are not suited to conventional production techniques. Such modules are essentially handcrafted. Detailed and costly



Mockup shows how microcircuit modules and conventional modules can be assembled in the same system. The dimensions used for printed-circuit modules are used to make the microcircuit modules.



The submodule circuit board is shown on the right. Two integrated circuits are mounted on the board on the left.

inspection is required to guard against human error during manufacturing and assembly. The new packaging design minimizes such pitfalls. Existing processes and tooling are entirely suitable. The grid system that designates the slots and feed-through holes can be produced on the motherboard by tape controlled drills and punches.

A minimum of retraining is required of factory personnel. While they may be unfamiliar with integrated circuits, the assembly and inspection routines are quite similar to work already performed. This produces confidence, no mean factor in controlling production expenses.

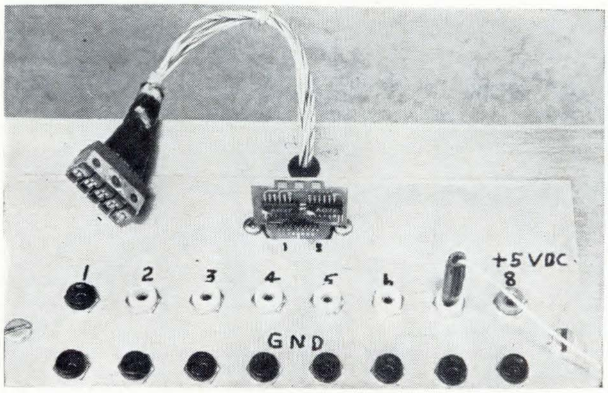
Repeatedly using a given submodule in a system provides further manufacturing economies. Quantity purchasing can be increased, scheduling is easier, setup time is reduced, production runs are longer and inventory is simplified.

The individual integrated circuits are generally welded to the submodule, but (to avoid a controversy over the relative merits of welding versus soldering) soldering can also be employed. Breadboard and engineering models are often soldered because soldered components are easy to replace during development. In production, welding will yield more submodule assemblies per operator hour.

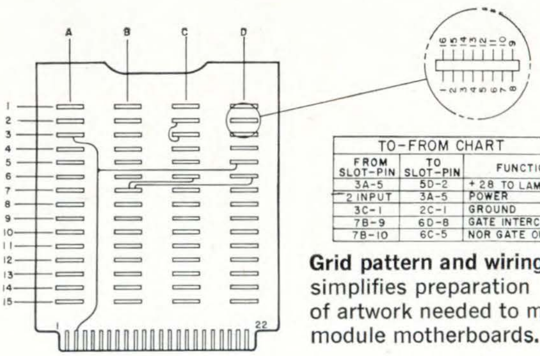
The weld schedule, which is established before the production run, considers the size and type of materials to be joined. The welding machine operator only positions the integrated circuit and initiates the weld sequence. Routine tests made during the run insure weld quality.

The completed submodule assemblies are individually tested. Defective and marginal units are eliminated at an early stage in the assembly of the module. This is accomplished through the use of electrical test fixtures. The solder tab on the submodule board mates with a standard connector on the tester, allowing easy and rapid checkout. The test fixture can often be built to test several electrically different submodules.

Completed submodules are inserted into the motherboard and the plastic cover is attached for the final assembly operation. The motherboards are moved on a conveyor through a wave soldering machine. This automated soldering operation makes hundreds of connections in several seconds and avoids hand soldering costs. The finished module is then tested, primarily for circuit continuity.



Submodule is tested by plugging it into electrical test fixture and slipping connector over the three test pads at the top of the printed-circuit card.



TO-FROM CHART		
FROM SLOT-PIN	TO SLOT-PIN	FUNCTION
3A-5	5D-2	+ 28 TO LAMP DRIVER
2 INPUT	3A-5	POWER
3C-1	2C-1	GROUND
7B-9	6D-8	GATE INTERCONNECT
7B-10	6C-5	NOR GATE OUTPUT

Grid pattern and wiring chart simplifies preparation of artwork needed to make module motherboards.

Ownership costs

The design and manufacturing savings will be reflected in the base price of the system. Other costs may be of equal or greater concern to the purchaser.

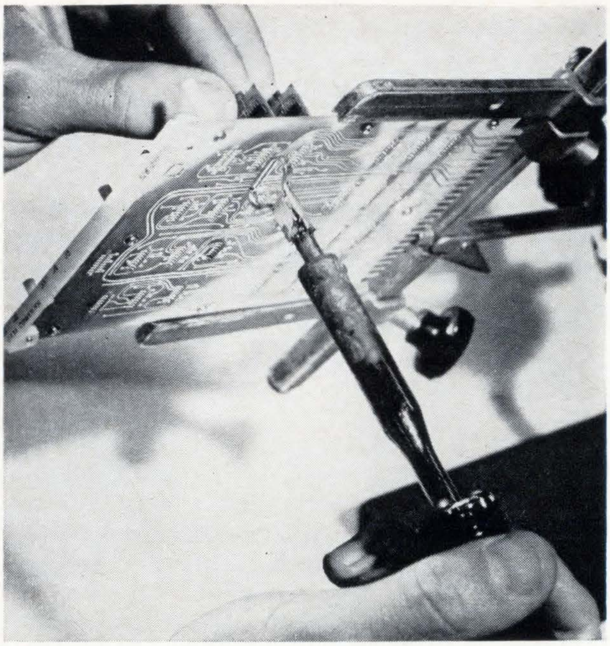
What about replacement costs? Is this system difficult to repair? At what level—submodule, module or system—can repairs be made? Would any advantage of owning an integrated-circuit system be offset by repair costs?

The answers depend upon how reliable and how maintainable the system is.

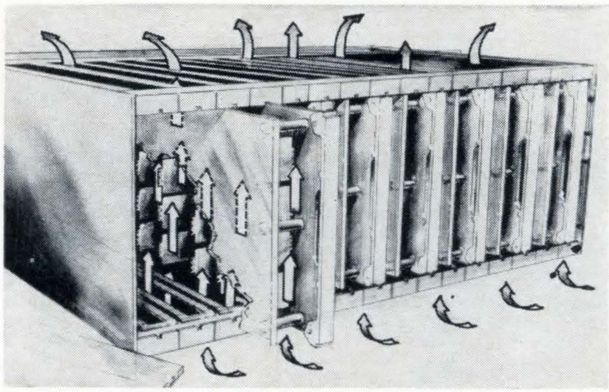
Reliability

Interconnecting modules and submodules by the use of connectors at each assembly level would simplify replacement and repair operation, but factors such as the reliability and cost of the interconnection must be considered. Therefore, a printed-circuit-board connector is used at the module level. This provides the desired compatibility with conventional modules and is a realistic compromise.

The submodules, however, are soldered to the



If submodule must be replaced, all the solder joints between the submodule and motherboard are melted by special tip on a soldering iron.



Air path and heat flow through an assembly of modules. Natural or forced-air cooling can be used.

motherboard for the following reasons: machine-soldered connections are reliable, the quantity of interconnections at this level is high, soldered connections are less costly than miniature connectors, connectors would cut down volumetric density, and inspection and testing of each submodule before soldering assures that it is electrically correct.

A single interconnection made with a connector has three to four times the failure rate of a machine-soldered connection. The high reliability of the integrated circuit itself must not be sacrificed solely for the convenience of replacement. As system reliability increases, more time to effect a repair can be justified.

Any physical environment of the system can affect its reliability. Humidity and salt spray tests show the module to be as reliable as any printed circuit board built to military specifications. Shock and vibration tests prove the module suitable for military requirements. The thermal environment of the module was also studied. The plate-fin configuration of the complete module assembly provides for the dissipation of heat through natural or forced air methods.

Maintainability

Maintainability and reliability really go hand-in-hand. Making a system reliable does not justify neglecting or even subordinating maintainability. This packaging method provides the following features to facilitate servicing and minimize downtime:

- Fault isolation at the major module level. Primary function test points on the module are accessible in the equipment. A spare module can be quickly substituted for a malfunctioning module to restore equipment operation status. Many systems include a self-test capability to locate malfunctions.
- Fault isolation at the submodule level. Test points on the submodule board are exposed at slots on the module's plastic cover. The photo on page 37 shows a technician troubleshooting a module assembly. The module is plugged into a point-to-point circuit extender to increase accessibility. A closeup of the test point and probe is also shown on page 39.
- A submodule can be removed with a soldering iron and replaced, as shown at the left. The soldering iron used to remove a submodule has a special tip that allows heat to be applied along the entire soldered interface of the submodule and the motherboard.
- Fault isolation at the circuit level. Any defective integrated circuit can be located through the test points of the submodule board. It can be removed and replaced by hand soldering or welding, but as integrated-circuit costs decrease, it will be more practical to put in a new submodule.

Hybrid system flexibility

The physical compatibility of the new module with existing conventional cards and modules is carried to the individual component level. Such flexibility is needed because circuit design may require the use of discrete components as well as integrated circuits.

Two adjacent submodule boards can be used in a cordwood module—a module in which components are stacked between two printed-circuit cards. Transformers, relays, filters and other larger components are mounted directly to the motherboard. The cutaway diagram on page 37 shows the integration of various component types in a single module. All can be machine soldered.

Should the amount of interconnection between submodules exceed the wiring densities available on the motherboard (made by etching conventional laminated-circuit boards), two alternatives are available. The amount of wiring on the motherboard can be extended by lateral jumper boards, utilizing the third dimension of the module. In highly complex modules, a multilayer motherboard can be employed.

Circuit design

Designer's casebook

Designer's casebook is a regular feature in Electronics. Readers are invited to submit novel circuit ideas, packaging schemes, or other unusual solutions to design problems. Descriptions should be short. We'll pay $50 for each item published.

High-current converter is small, quiet, low-cost

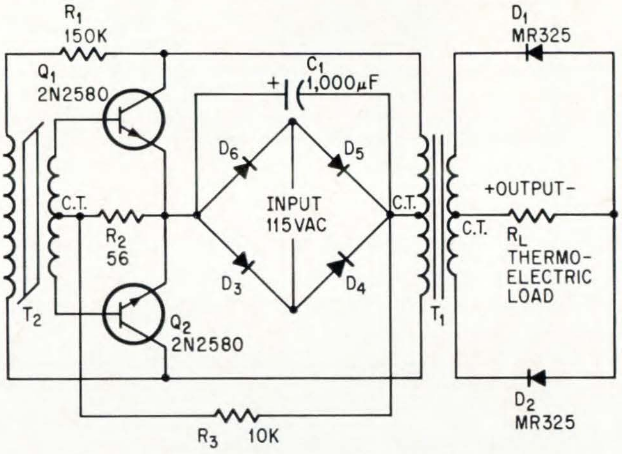
By Allan L. Wennerberg and F. H. Schroeder
Whirlpool Corp., St. Joseph, Mich.

A high-current, low-voltage d-c supply was needed to power thermoelectric heat-pump systems. The power supply had to be inexpensive, small, lightweight and quiet.

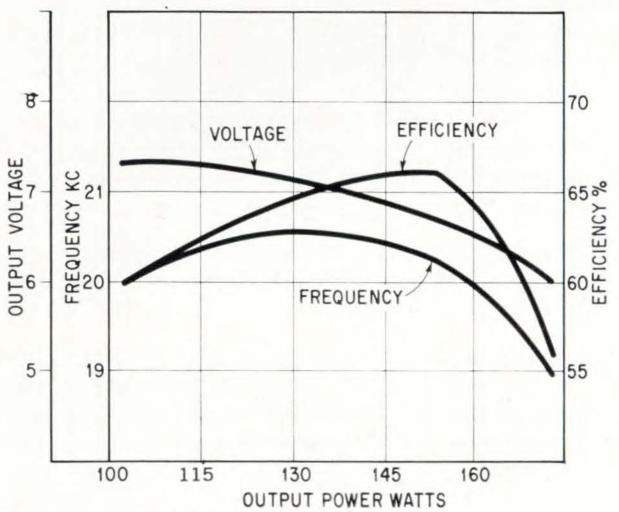
These needs were filled by directly rectifying the line voltage, inverting the rectified line voltage at some frequency above the audible range, stepping down the voltage as required by the load and finally rectifying again [circuit diagram, right].

Power transistors with an open-base collector-to-emitter hold-off voltage rating $V_{ceo} = 400$ volts currently are available. Therefore it was possible to construct a d-c to d-c converter in which the primary voltage was rectified directly from the line voltage. The stepdown power supply needed to power most d-c to d-c voltage converters was eliminated. To get rid of audible noise, the converter was designed to operate at frequencies above 18 kilocycles. With this high frequency it was also possible to reduce the size and weight of transformers and to eliminate the filter choke usually required in the output circuit.

Results of performance tests conducted in a 25°C ambient are shown in the graph, left. Test data show that maximum efficiency is obtained at an inverter frequency of 20.2 kilocycles and with a load current of 23 amperes. The power supply is packaged in a four-inch cube weighing six pounds.



The input voltage is rectified, inverted at a high frequency, stepped down to the load voltage, and rectified.

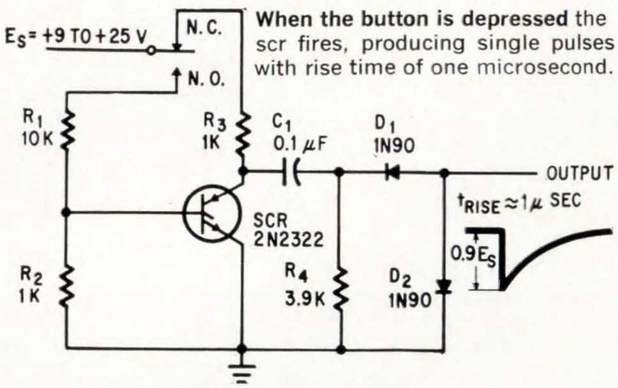


Maximum efficiency is obtained at 20-kc with a 23-amp load and a 6.75-volt output

Push button plus scr equals fast pulse

By Richard W. Bailey
Nuclear Reactor Laboratory,
Ohio State University, Columbus

Frequently a circuit is required to produce a single pulse with a fast rise time when a push button is depressed. In these cases, contact bounce of the push button is undesirable. The simple circuit shown (pg. 42) produces a single pulse with an am-



When the button is depressed the scr fires, producing single pulses with rise time of one microsecond.

plitude of about 90% of the supply voltage and a rise time of about one microsecond.

When the moving contact of the switch is in the normally closed position, the supply voltage is applied to the anode of the silicon controlled rectifier through R_3. But the resistance of R_3 is large enough to prevent the scr from firing with zero volts on its gate. Capacitor C_1 is charged to the supply voltage E_s through R_3 and R_4.

When the button is depressed, the anode remains at approximately E_s due to the charge on the capacitor. The instant the contact arm touches the normally open contactor, the positive gate voltage applied through the R_1 and R_2 resistor divider turns the scr on. The capacitor then discharges rapidly through the scr producing a negative transient output. Diodes D_1 and D_2 prevent a positive pulse from occurring at the output when the button is released. An operating voltage range from 9 volts to 25 volts can be realized with the component values shown.

Nomograph simplifies delay-line design

By Ronald Zane

University of California, Berkeley

The nomograph at right reduces the calculations necessary to design lumped-parameter, constant-k delay lines. A lumped-parameter delay line consists of a cascaded series of symmetrical π or T reactance networks. When $L/C = k$ is a constant, the network is referred to as a low-pass, constant-k prototype section. The characteristic impedance, Z, of a cascaded series of low-pass, constant-k sections is:

$$Z = (L/C)^{1/2} \quad (1)$$

Where L and C are the inductance and capacitance per section.

The attenuation of the reactance networks is zero for all frequencies up to cutoff frequency f_c. The cutoff frequency is given by:

$$f_c = 1/\pi\,[LC]^{1/2} \quad (2)$$

For input signals containing frequencies that are lower than f_c, a low-pass, constant-k section will produce the same signal at its output, but delayed by a time, T_s. The delay time per section is:

$$T_s = 1/\pi\, f_c = (LC)^{1/2} \quad (3)$$

The total delay time for a signal which passes through N cascaded sections is:

$$T_d = NT_s = N\,(LC)^{1/2} \quad (4)$$

Each network will affect the rise time of the input waveshape. When the input is a step function having frequency components which are lower than f_c, the rise time due to a section is:

$$T_{r1} = 1.1\,(LC)^{1/2} \quad (5)$$

The total rise time of an N section delay line is given by:

$$T_r = 1.1\,N^{1/3}\,(LC)^{1/2} \quad (6)$$

Dividing equations 4 and 6 and solving for N, the number of sections in the delay line is given by:

$$N = 1.2\,(T_d/T_r)^{3/2} \quad (7)$$

Given the total delay time, total rise time and characteristic impedance requirements, a delay line can be designed using this equation and the nomograph.

As an example, consider a delay line to be designed with the following requirements:

Total delay time, $T_d = 50$ microseconds
Total rise time, $T_r = 5$ microseconds
Characteristic impedance, $Z = 10{,}000$ ohms.

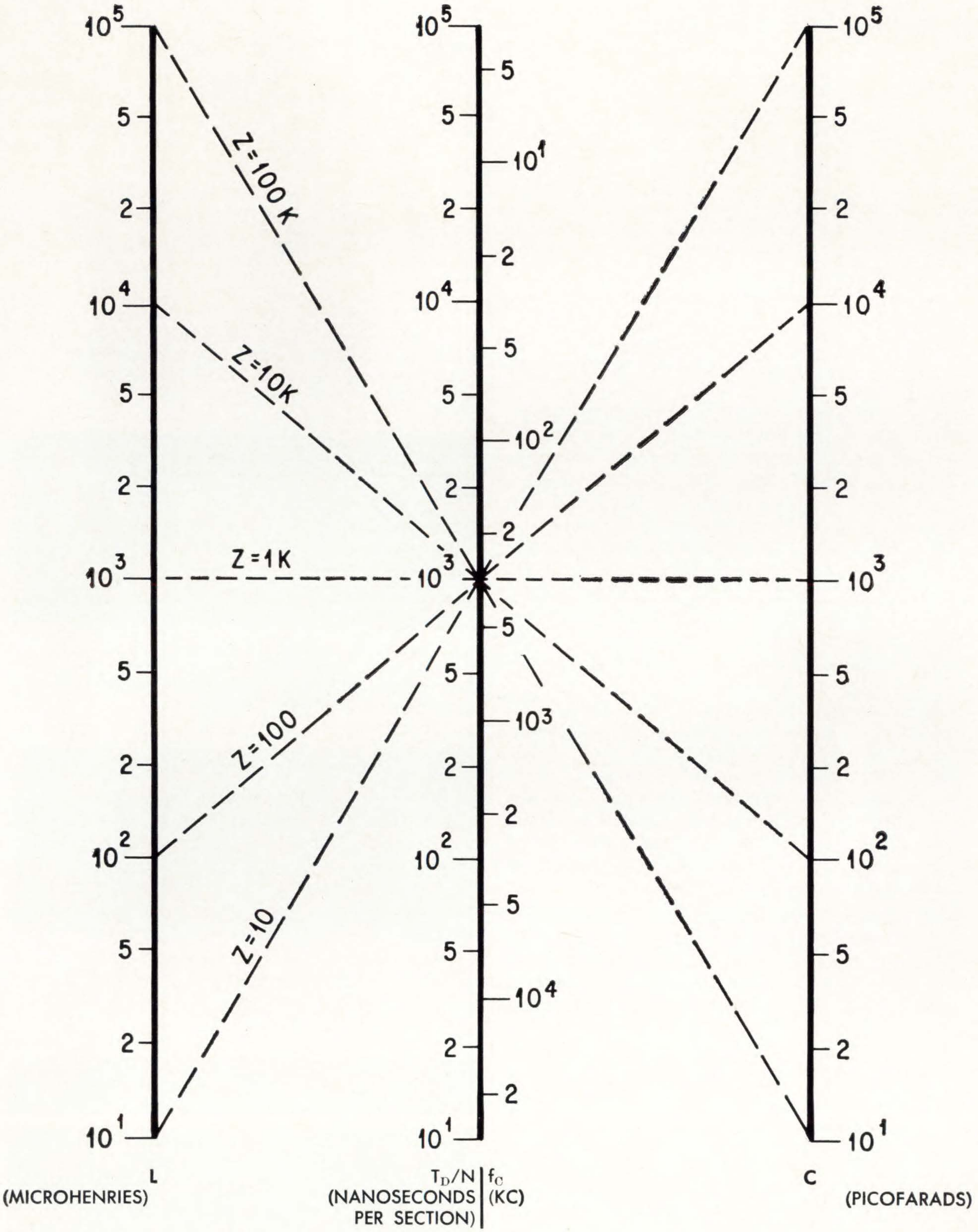
First calculate the number of sections required.

$N = 1.2\,(T_d/T_r)^{3/2} = 38$ sections

Next, determine the delay time per section.

$T_d/N = 50 \times 10^{-6}$ sec/38 sections $= 1.3 \times 10^3$ nanoseconds per section

On the nomograph, draw a straight line through T_d/N at 1.3×10^3 nanoseconds/section and parallel to the $Z = 10{,}000$ ohm line. This line will intersect at $L = 13$ millihenries and at $C = 130$ picofarads. Thus, the required delay line will consist of 38 sections with $L = 13$ mhy and $C = 130$ pf per section.



In the delay line nomograph, Z is the characteristic impedance of the line, L is the inductance and C the capacitance per section.

Germanium transistor as avalanche switch

By Byung Sung Ahn

Atomic Energy Research Institute, Seoul, Korea

Avalanche breakdown in silicon mesa transistors is one of the most useful methods for generating pulses with fast rise times. However, a less costly germanium transistor whose collector junction area is larger than its emitter area (as in a silicon mesa transistor) can be used as an avalanche switch.

Satisfactory test results were obtained with 20 type 2N388 germanium transistors used in an avalanche mode.

The circuit shown above was designed to provide narrow pulses with fast rise times. Transistor Q_2 is biased just below the emitter-open, collector-to-base breakdown voltage BV_{cbo}, so that an avalanche can be initiated, either by increasing the collector voltage, or by decreasing the base voltage. In this circuit, a negative input pulse reduces the impedance of Q_1 and the collector voltage of Q_2 approaches the supply voltage V_2 which exceeds the BV_{cbo} of Q_2. The magnitude of the collector supply voltage also determines the avalanche breakdown repetition rate, and can be adjusted to obtain the frequency required.

The input pulse shape must be rectangular. The number of avalanche breakdowns for each input pulse can be varied by adjusting the pulse width.

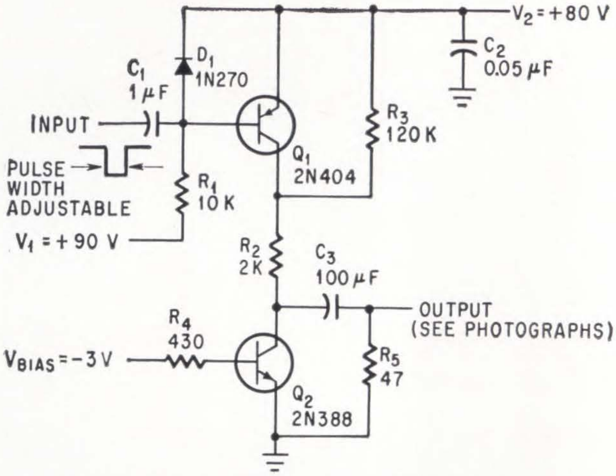
The 2N388 transistor was found to have a maximum avalanche repetition rate of four million pulses per second when one input pulse produced 10 avalanche pulses. In this case the input repetition rate should not exceed 100,000 pulses per second to avoid thermal damage to the 2N388.

The photo at top shows the output voltage waveform for a single avalanche discharge. The rise time is 4 nanoseconds, the pulse width at the 50% points (one-half the total pulse amplitude) is 8 nanoseconds, and the pulse height is 12 volts. These results were obtained at no load.

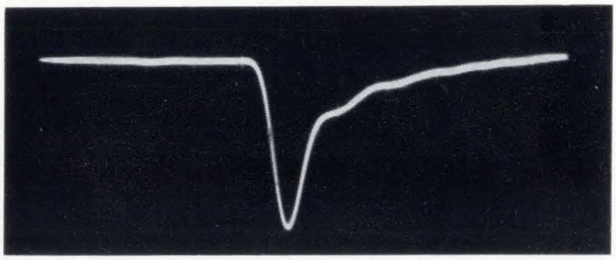
The center photo shows the output voltage for 10 avalanche discharges. The photo at bottom shows the voltage at the collector of the 2N388 for 10 avalanche discharges.

The data obtained is typical, but some deviations were observed because of variations in the characteristics of the same transistor type.

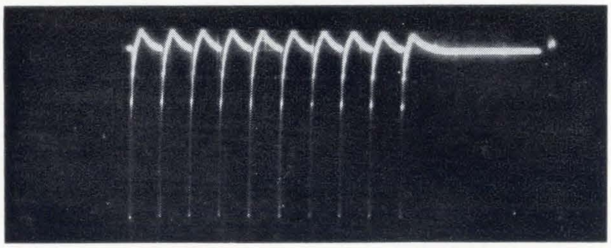
This simple circuit was designed for testing a counter, but it could also be used as a delayed pulse shaper, a keyed pulser, or a line-driving pulser, with remarkable economy.



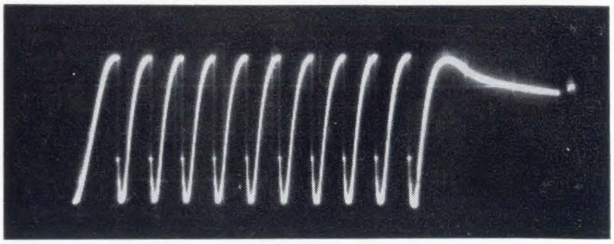
Q_2 is a germanium transistor used as an avalanche switch. The avalanche repetition rate is determined by the collector voltage of Q_2. The number of output pulses depends on the width of the input pulse.



Single avalanche discharge. Output pulse rise time is 4 nanoseconds, pulse width at 50% points is 8 nanoseconds, and pulse magnitude is 12 volts. (Time scale: 10 nanoseconds per division.)



Output pulses. Avalanche repetition rate is two million pulses per second. Input pulse width of five microseconds yields 10 output pulses for each input pulse. (Time scale: 0.5 microseconds per division.)



Collector voltage for 10 avalanche discharges. (Time scale: 0.5 microseconds per division.)

Part 1 Devices

The electronics industry's newest success story is the field-effect transistor. Beginning with this issue, Electronics presents a three-part report on FETs. The first part discusses silicon and germanium metal-oxide devices, their manufacture and low-noise properties. In coming issues we'll examine applications in communications and switching.

Field-effect transistors

The field-effect transistor: a 'curiosity' comes of age

Twice as many companies as in 1963 are making three times as many types of units. One big reason for the boom is the metal-oxide semiconductor version

By Jerome Eimbinder
Solid State Editor

The field-effect transistor, for years little more than a curiosity in the semiconductor industry, has suddenly caught the circuit designer's fancy.

Much of the new enthusiasm has been generated by the metal-oxide semiconductor (MOS) version of the field-effect transistor. But the junction field-effect device, older brother of the MOS transistor, is also enjoying renewed interest.

The prime reason for the popularity of field-effect transistors is that they permit operation at high-input impedances with very low noise levels. MOS field-effect transistors offer input impedances of 10^{15} ohms; with junction field-effect transistors, these impedances are about 10^{10} ohms. Noise figures under three decibels at 100 megacycles and higher are common with new MOS devices.

The field-effect transistor's low-noise performance [see comparison curves on p. 63] is certain to cause ripples in the market-place; already the number of manufacturers offering commercial field-effect transistors has grown to 14 from 6 a year ago.

Moreover, the field-effect transistor is considerably less sensitive to radiation than its conventional counterpart (reportedly one-tenth as sensitive), making it particularly attractive in military applications. MOS transistors have been made that can tolerate radiation levels of 3×10^{14} neutrons per square centimeter.

MOS field-effect transistors are especially useful in integrated circuits because they can be operated in directly coupled arrays [p. 51], thus eliminating external capacitive coupling. The operation of MOS transistors is relatively unaffected by changes in ambient temperature. This eliminates the need for temperature-compensating circuitry.

Many tube-oriented engineers also have an interest in the field-effect transistor that is more psychological than technical. Like the vacuum tube, the FET is a high input-impedance voltage-amplification device. Designing the FET into new circuits is much more natural for the circuit designer who is experienced with tubes and is converting to transistors.

One year ago, the six makers of field-effect transistors were Amelco Semiconductor, a division of Teledyne, Inc.; Crystalonics, Inc.; Ferranti, Ltd.; Sesco (Societé Européenne des Semiconducteurs); Siliconix, Inc.; and Texas Instruments, Inc. A total of 64 different field-effect transistors were commercially available.

Today 14 companies offer commercial lines with more than 200 types of FETs, at least five other firms are developing models, and two have entered the field and subsequently dropped out (Motorola Semiconductor Products, Inc., a division of Motorola, Inc.; and Tung-Sol Electric, Inc.). Motorola's exit was necessitated by heavy commitments in other areas and is believed to be only temporary. Tung-Sol made two FET types available early this year on a sampling basis after discontinuing its entire line of junction transistors. It dropped both types a short time later, and has stayed out of the transistor business. The total of field-effect transistor types available has more than tripled in 12 months.

New manufacturers

The eight newcomers to the field-effect ranks are the Dickson Electronics Corp.; the semiconductor division of the Fairchild Camera & In-

Manufacturers of field-effect transistor

Company	Insul. gate MOS Channel P	Insul. gate MOS Channel N	Junction Channel P	Junction Channel N
Amelco Semiconductor Division of Teledyne, Inc. Mountain View, Calif.	Dev.	Dev.		Com.
Crystalonics, Inc. Cambridge, Mass.				Com.
Dickson Electronics Corp. Scottsdale, Ariz.				Com.
Fairchild Semiconductor Division of Fairchild Camera and Instrument Corp. Mountain View, Calif.	Com.	Dev.	Com.	
Ferranti Ltd. Lancs, England		Com.		
General Micro-Electronics, Inc. Division of Victor Comptometer Corp. Santa Clara, Calif.	Com.			
Hughes Micro-Electronics Division of Hughes Aircraft Co. Newport Beach, Calif.			Dev.	
KMC Corp. Long Valley, N. J.	Dev.	Com.		Dev.
Philips Gloeilampenfabrieken, N. V. Eindover, Netherlands	Dev.	Dev.		
RCA Electronics Components and Devices Division Somerville, N. J.		Com.		
Raytheon Semiconductor Division Mountain View, Calif.	Com.	Dev.		
Societe Europeenne des Semiconducteurs Paris, France				Com.
Siliconix, Inc. Sunnyvale, Calif.		Com.	Com.	
Sylvania Semiconductor Division Woburn, Mass.		Dev.		
Texas Instruments, Inc., Semiconductor-Components Division Dallas, Texas	Com.	Com.	Com.	Com.
TRW Semiconductors, Inc., Division of Thompson Ramo Wooldridge, Inc. Lawndale, Calif.		Com.		
Union Carbide, Linde Division Mountain View, Calif.	Dev.	Dev.	Com.	Com.

Dev. = Developmental. Company in or near sampling stage.
Com. = Commercially available.

strument Corp.; General Micro-Electronics, Inc., a subsidiary of the Victor Comptometer Corp.; KMC Corp.; Radio Corporation of America; Raytheon Co.; TRW Semiconductors, Inc., a division of Thompson Ramo Wooldridge, Inc.; and the Linde division of the Union Carbide Corp.

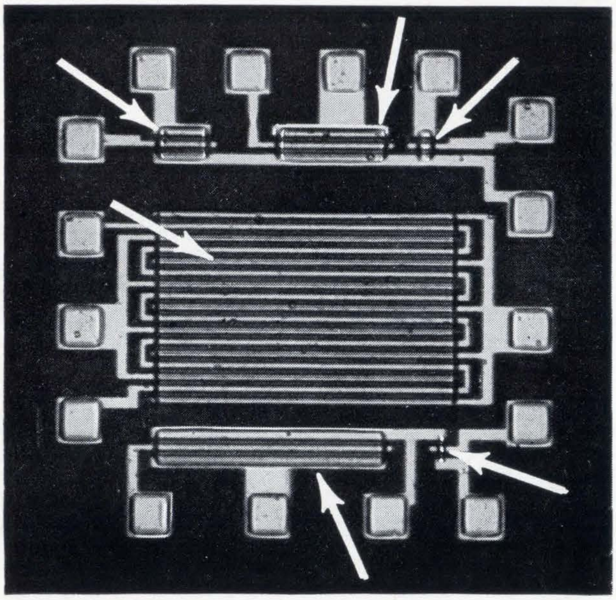
RCA, despite a long history in field-effect transistor research and an extensive sampling program that began in 1963, did not announce a commercial type until only two months ago. However, KMC's engineering staff consists almost entirely of former RCA people experienced with field-effect transistors. KMC was formed last April. General Micro-Electronics was heavily staffed with former Fairchild engineers, and Siliconix by former Texas Instruments people, when those companies opened for business. Dickson is also reported to have picked up some Motorola FET engineers, and the Stewart-Warner Corp. is said to have enticed a few from Siliconix.

The five companies expected to be supplying field-effect transistors shortly are Stewart-Warner; Atlantic Instruments and Electronics, Inc.; the microelectronics division of the Hughes Aircraft Co.; Philips Gloeilampenfabrieken, N.V., of the Netherlands; and the Sylvania Electric Products, Inc., a division of the General Telephone and Electronics Corp.

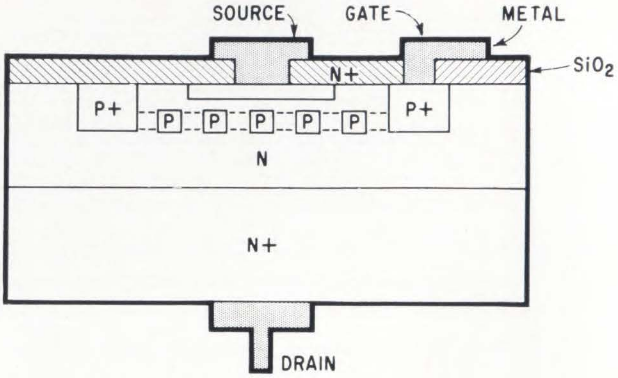
Atlantic Instruments is currently selling Sesco field-effect transistors in the United States but hopes to have a pilot line set up in a few months. Stewart-Warner says only that it has been considering entering field-effect transistor manufacturing [Electronics, Sept. 7, p. 18]. However, its new plant in Sunnyvale, Calif., has adequate facilities and the qualified personnel. Hughes is still very much in the semiconductor device business despite the recent change in the name of its semiconductor division to the Hughes Microelectronics division. It is expected to begin supplying samples soon of its multichannel field-effect types.

The field-effect transistors now being sold are competing directly with conventional transistors. However, the highest frequency at which a commercial FET can operate as an amplifier is 300 megacycles per second (KMC type K1001), whereas commercial conventional junction transistors as amplifiers can go to 1,000 megacycles per second with useful gain. Gain-bandwidth products as high as 2,800 megacycles have been attained for experimental npn transistors.

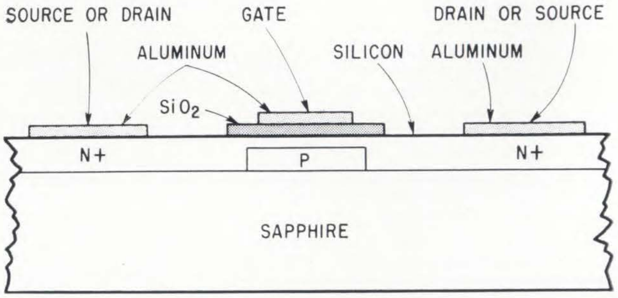
The highest continuous current rating specified for a FET is 10 amperes at 25°C (Sesco type 15P1). Conventional silicon power transistors recently became available with dissipation ratings of 300 watts and collector current ratings of 150 amperes at 100°C (Silicon Transistor Corp. types STC2500 and STC2501). Moreover, the only two companies (Crystalonics, Inc., and Hughes Aircraft) known to have power field-effect transistors in development are working on medium-power types with ratings considerably lower than the Sesco device. This leaves a wide market for field-effect manufacturers,



Thin-film circuit containing six field-effect transistors



Hughes multichannel field-effect transistor



Autonetics silicon-on-sapphire field-effect transistor ▶

and helps to explain why the rush into field-effect transistors resembles the westward movement in early America.

As in the semiconductor market, keen competition is expected among FET manufacturers. Earlier this month one company, Siliconix, Inc., in hopes of widening its share of the market, came out with a lifetime guarantee on eight of its field-effect transistors. This is the first guarantee of its kind for small-signal devices, although the Westinghouse Electric Co. has been offering a similar guarantee for eight months on its Jedec-registered power semiconductor devices. The guarantees by Westinghouse and Siliconix are effective for the lifetime of the equipment in which the semiconductor devices are originally installed.

Multichannel FETs

Multichannel field-effect transistors function similarly to single-channel devices. Appropriate voltages are applied to the gate to control the space-charge width in the channels; in this way they control the channel currents by area constriction. The use of several channels allows the handling of higher currents. These devices also avoid the reduction in frequency response that normally occur with increasing the size of a single-channel device to handle higher currents.

Multichannel germanium field-effect transistors, available commercially from Sesco, are the only power field-effect transistors on the market today. They can handle up to 10 amperes; germanium devices with 50-ampere ratings are under development. Sesco also is developing silicon power field-effect transistors that are expected to have 500-volt and 50-ampere ratings.

The high-power devices are called tecnetrons, an acronym for Stanislas Teszner, its inventor, and Centre National d'Études des Telecommunications, where Teszner developed his original field-effect devices.

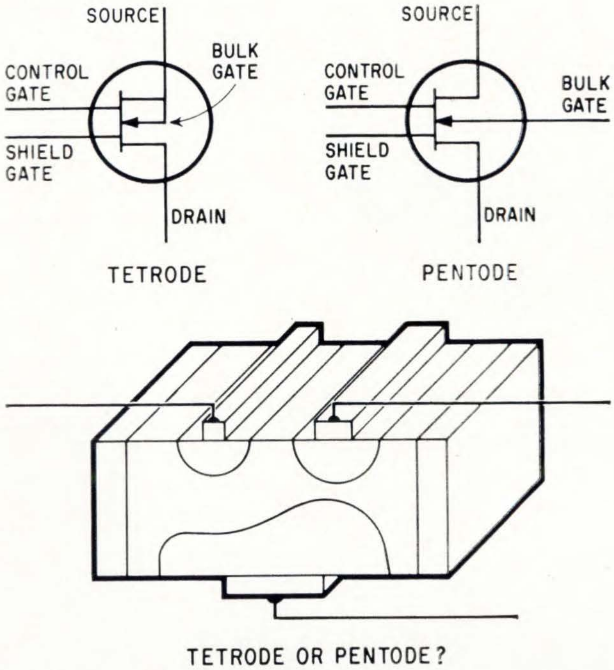
Hughes is developing silicon multichannel planar triode and tetrode field-effect transistors that it expects to handle up to two watts of steady-state dissipation. The Hughes devices have p-type channels for current to pass through the n-type material. Both round and square channels are being investigated.

One Hughes device has 100 parallel channels, and a breakdown voltage rating of 60 volts drain-to-source. It provides power gains of 14 decibels at 60 megacycles and 10 decibels at 100 megacycles per second. The transistor has a maximum frequency of operation (figure of merit) of 300 megacycles per second. The device, whose gate is completely embedded within the semiconductor material, is shown above.

Hughes expects to build multichannel field-effect transistors next year with maximum oscillation frequencies to 1,000 megacycles per second.

Thin-film field-effect transistors

Thin-film integrated circuits using epitaxial field-effect transistors are being made by producing the transistors separately and soldering them to passive thin-film circuits. However, the Autonetics division of North American Aviation, Inc., is developing a thin-film circuit designed to have both insulated-gate field-effect transistors and passive elements deposited on the same substrate. Autonetics will use the thin-film circuits in analog-to-digital converters to be used as voltage-level de-



Fairchild tetrode and pentode field-effect transistors. The pentode becomes a tetrode by connecting the bulk gate to the source.

tectors in new military computers.

The thin-film FET circuits are fabricated by growing silicon, the active element, on a passive sapphire base. The active areas are marked off and the remaining silicon is etched away. The thin-film passive components are then deposited on the bare sapphire base, and the active and passive components are interconnected by a second thin-film deposit.

Epitaxial geometry

The epitaxial geometry is a result of silicon substituting for aluminum and bonding with the oxygen atoms of the sapphire to form the first layer for subsequent growth.

Autonetics has fabricated both enhancement and depletion field-effect transistors using the single-crystal thin-film deposition technique. The thin-film transistors are n-channel devices.

Typical characteristics for the thin-film transistors are: transconductance (g_m), 2,000 micromhos; input capacitance (C_{in}), 2 picofarads; d-c input resistance (R_{in}), 10^{12} ohms; and amplification factor (μ), 20 to 30.

The Autonetics circuit pattern shown on p. 48 contains six thin-film field-effect transistors of various sizes. Each FET is indicated by an arrow.

The growth of silicon films on sapphire was first announced[1] in August, 1963, by two Autonetics scientists, Harold Manasevit and W. I. Simpson. The techniques used were described[2,3] by Manasevit, Simpson and others in 1964. A silicon-on-sapphire insulated-gate FET was reported in July, 1964 by RCA.

There is considerable activity now in growing sapphire crystals. Linde, Raytheon, the Lincoln Laboratory of the Massachusetts Institute of Technology, and others are investigating the Czochralski[4] method for sapphire growth. The cost of using sapphire in producing transistor thin-film circuitry is expected to be reduced sufficiently to make the use of sapphire practical.

A survey of potential applications for thin-film field-effect transistors, written by Charles Feldman of Melpar, Inc., was published earlier this year [Electronics, Jan. 24, pp. 23-26]. Applications with severe environmental conditions, particularly those with radiation fields present, headed the list.

Tetrode field-effect transistors

Several four-lead two-gate devices, such as the Texas Instruments TIXS11, the Siliconix 3N89, the RCA 3N98, and the General Micro-Electronics 1004 are currently available. These transistors do not have their gates tied to each other and may be operated as tetrodes if separate bias supplies are provided to each gate. However, the fourth lead of these devices is usually connected to ground for increased stability at high frequencies.

Fairchild Semiconductor is developing a device with three gates—a control gate, shield gate and bulk gate. The device can be operated as a tetrode if the bulk gate is tied to the source. By eliminating the bulk gate-source connection and by supplying independent bias to the bulk gate, the device can also be used as a pentode.

Hughes is preparing to announce availability for sampling of a multichannel tetrode family that will eventually have dissipation ratings from 0.5 to 2 watts.

A twin-triode was brought out by General Micro-Electronics in August. It consists of two p-channel MOS field-effect transistors diffused into a monolithic chip.

References

1. H.M. Manasevit and W.I. Simpson, **American Physical Society Meeting,** Edmonton, Alberta, Canada, August, 1963.
2. H.M. Manasevit and W.I. Simpson, **Journal of Applied Physics,** Vol. 35, 1964, pp. 1349-1351.
3. H.M. Manasevit, Arnold Miller, Fred Marritz, and Richard Nolder, **Technical Conference on Solid-State Interfaces,** Boston, Mass., August 31-September 2, 1964.
4. W.C. Dash, **Journal of Applied Physics,** Vol. 30, 1959, pp. 459-474.

The cover
Photographed with polarized light, this sculptured silicon pellet shows one structure for a metal-oxide-semiconductor FET. Its gate, the wide U-shaped channel, is offset from the source to reduce feedback capacitance and supply higher output resistance. The structure is a Radio Corp. of America design.

Metal-oxide-semiconductor field-effect transistors

Such devices hold great promise for new circuitry. Here is a discussion of their unique characteristics

By Frederic P. Heiman and Steven R. Hofstein
RCA Laboratories, Radio Corp. of America, Princeton, N.J.

The newest star on the device horizon is the insulated-gate metal-oxide-semiconductor field-effect transistor. It's a big name for a little device and a number of acronyms have been created, ranging from "igmosfet" to "most." But engineers who are using it call this newest member of a growing family the MOS field-effect transistor.

While MOS field-effect transistors have some characteristics of the vacuum tube, they differ significantly from the conventional junction transistor and the junction field-effect transistor. These differences are of interest to circuit designers who are seeking ways to use the device in new circuitry. In its most fundamental form, the field-effect transistor is a descendant of the electrical capacitor. However, modulation of the charge on the metal plate of a capacitor results in only a minute change in the sheet conductivity. The amount of charge moved before catastrophic breakdown of the dielectric occurs, even with the best of insulators, is the order of only one percent of a single atomic layer (approximately 10^{+13}atoms/cm^2, which corresponds to a field of $1 \times 10^{+7}$ v/cm).

In a useful electronic device, the amount of charge moved must represent a large fraction of the total charge available for conduction, and the mobility of the moved charge must be reasonably high. Neither of these two characteristics is readily obtained with metallic materials but both were observed in semiconductor materials by Julius Edgar Lilienfeld in 1928. By 1935, both Lilienfeld[1] and Heil[2] had patented insulated-gate field-effect devices made from semiconductor materials. Unfortunately, because of the limited knowledge of the physics of surfaces and thin films at that time, little advance in the perfection of these devices was made. Interest in them waned with the continued development of the vacuum tube.

In 1948, Shockley and Pearson[3] reexamined the modulation of surface charge in thin semiconductor films by means of a normal electric field. They found that roughly 90% of the charges moved by the external field resided on the surface in states that rendered them immobile for purposes of conduction. Investigation into the physics of surfaces continued, but the invention of the bipolar transistor overshadowed this work.

In 1952, Shockley[4] proposed a field-effect transistor structure which bypassed the problem of surface states, although it had other limitations.

F. P. Heiman

S. R. Hofstein

The authors

Steven R. Hofstein and Frederic P. Heiman have been working together at RCA Laboratories on insulated-gate field-effect transistors for the last four years. Both men received master's degrees and doctorates in electrical engineering from Princeton University. They were co-recipients of a 1963 RCA Laboratories Achievement Award for their contributions to the development of the metal-oxide-semiconductor transistor. Earlier this year they received RCA's David Sarnoff Outstanding Achievement Team Award in Science for their work in silicon-based integrated electronics. Hofstein joined RCA in 1959, one year before Heiman came to the company.

Shockley used a reverse-biased p-n junction to modulate the mobile charge in the relatively lightly doped n-type portion of the junction. The electric field was now almost completely immersed in the semiconductor, so that the surface played little part in the device operation and the problem of surface states was skillfully avoided. However, the use of the p-n junction had the disadvantage of allowing only depletion of charge in the n-type channel. Reversing the applied voltage forward biased the p-n diode and allowed heavy current flow from the control electrode. Enhancement of charge is also desirable since it makes possible large-signal operation with zero or positive bias and enables direct-coupled signal inversion without level shifting.

In 1960, Kahng and Atalla[5] proposed a silicon structure in which an insulated gate was used to induce conduction between two normally back-biased surface diodes, and, in 1961, Weimer[6,7] described the development of a thin-film insulated gate (control electrode) transistor utilizing cadmium sulfide as the semiconducting material. In 1962, Hofstein and Heiman[8,9] described the use of metal-oxide semiconductor material in a field-effect transistor with an insulated gate fabricated on single crystal silicon. Unlike the junction field-effect transistor, the new device allowed enhancement as well as depletion of the charge in the channel, and permitted operation with zero bias.

A cross-sectional view of this device is shown above right. The heavily doped regions are the source and drain electrodes; channel current flows from the drain through the channel to the source. The gate, or control electrode, is separated from the channel by an insulating layer. In one form of this silicon device the insulator is thermally grown silicon dioxide; hence the metal-oxide-semiconductor[10-14] field-effect transistor.

Operating modes

There are two modes of operation for insulated-gate field-effect transistors. In the depletion mode, charge carriers are present in the channel with zero gate bias and a reverse bias (negative gate potential for electron conduction units) depletes this charge, reducing the channel conductance. In the enhancement mode, the gate is forward biased (positive gate potential for electron conduction units); this enhances the channel charge and increases the channel conductance. Transistors which exhibit significant channel conductance at zero gate bias are called depletion-type transistors; transistors that show no channel conductance at zero bias are referred to as enhancement-type transistors. Since either electron conduction (n-type) or hole conduction (p-type) devices may be made, four types of MOS field-effect transistors are obtainable. The following discussion is based on n-types but also applies to p-type units if all polarities are reversed.

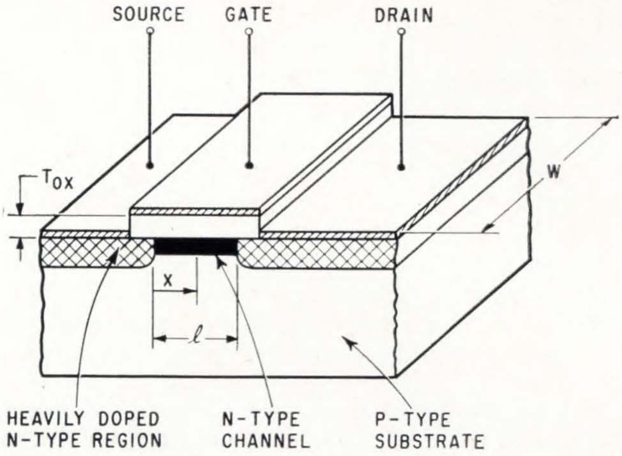
Enhancement-type transistors

In an enhancement-type transistor the gate electrode covers the entire channel, overlapping both source and drain regions. Any channel region which is left exposed contributes a very high series resistance to the device since there are few carriers in the channel at zero gate bias. The overlap results in a substantial capacitance from gate-to-source and gate-to-drain unless special provisions are made to increase the thickness of the oxide over the heavily doped regions.

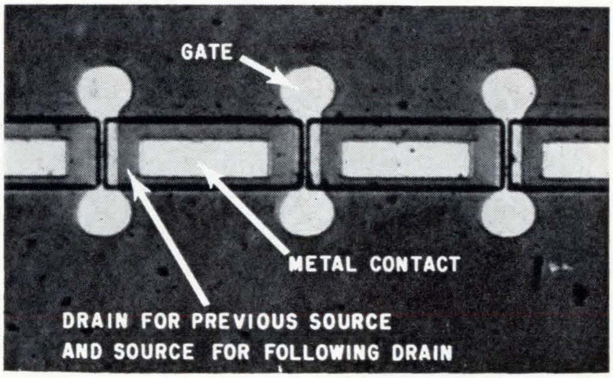
A ladder array of enhancement-type transistors is shown above. They are arranged in tandem; the drain of one unit is the source of the adjacent unit. This geometry simplifies the interconnection of many transistors in an integrated circuit and reduces the capacitance at each node. For a typical device the channel length is 15 microns, the channel width is 124 microns, the oxide thickness is 1200 angstroms and the maximum allowable drain voltage is +35 volts, being limited by the onset of avalanche multiplication in the channel region adjacent to the drain.

Depletion-type transistors

Transistors of the depletion type are fabricated with the source, drain and channel regions made of the same conductive material to yield substantial drain current at zero gate bias. The free-carrier concentration in the channel is much lower than the



Cross-sectional view of an insulated-gate MOS field-effect transistor.



Ladder array of enhancement field-effect transistors. Packing density is 2200 transistors per square inch.

source or drain-doping level so that complete pinch-off is obtained with a moderate oxide field. This type of transistor finds wide application as a small-signal amplifier, and the geometry chosen for it allows performance at ultrahigh and very high frequency levels with moderate power output.

Unlike the enhancement transistor, the depletion unit does not require that the gate electrode overlap both source and drain regions as illustrated by the offset gate geometry shown below for a high-frequency unit. The unmodulated portion of the channel near the drain electrode introduces a tolerable series resistance in the saturation region. The addition of a series drain resistance merely increases the drain voltage at which drain current saturates. As long as the small signal output resistance of the transistor is large, with respect to the unmodulated drain resistance, there will be little deterioration in circuit gain. However, any series source resistance introduces degeneration and is undesirable. Thus, if the gate electrode does overlap, it should overlap the source region.

The offset gate electrode significantly reduces the feedback capacitance since the active channel length is forced to coincide with the portion of the gate electrode which lies over the channel. The only inactive input capacitance results from the overlap of the source electrode. The exact distribution of active gate capacitance between source and drain is difficult to determine, but the depletion of majority carriers near the drain end of the active channel considerably reduces the feedback capacitance when the device is in saturation.

A close-up view of a depletion-type transistor that employs offset gate geometry is shown on page 53. The active channel length is 10 microns and the effective channel width is 0.125 cm. The output characteristics of a typical transistor of this type are shown at right on page 53. The interlectrode capacitances of a packaged device with a 5-milliampere drain current and 15 drain volts are:

Gate-to-source capacitance = 4.8 pF
Gate-to-drain capacitance = 0.3 pF
Drain-to-source capacitance = 1.12 pF

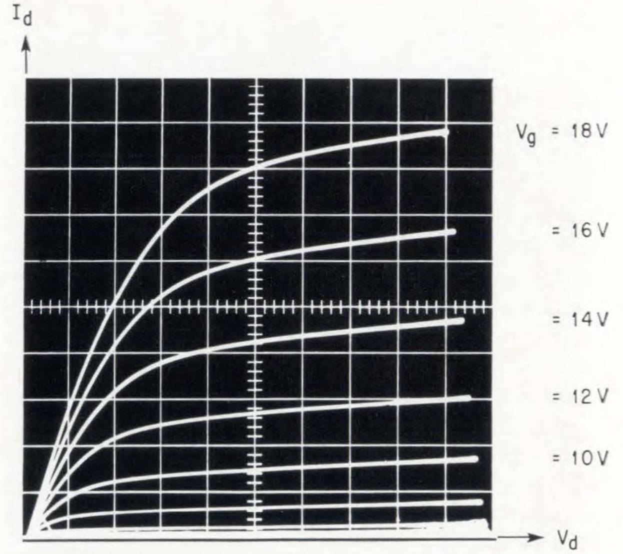
The unipolar transistor differs significantly from the bipolar transistor in that it is a majority-carrier rather than a minority-carrier device, and is a voltage rather than a current amplifying device. This latter characteristic brings the unipolar transistor much closer to the vacuum tube than to the bipolar transistor in behavior.

Pinchoff voltage

A fundamental parameter of the transistor is its pinchoff or threshold voltage (the voltage for which the channel is completely depleted and the source-to-drain current flow goes to zero). For n-type devices, a positive pinchoff voltage implies an enhancement-type unit; a negative pinchoff voltage, a depletion-type unit.

Transistor characteristic equation

The basic current-voltage equation for an MOS



Drain current vs. drain voltage for an enhancement field-effect transistor. Vertical scale: 1 milliampere per division. Horizontal scale: 2 volts per division.

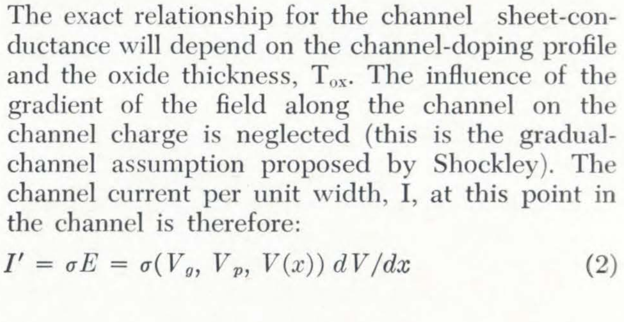
field-effect transistor may be derived by a procedure similar to that described by Shockley in his analysis of the junction-type unipolar transistor[4]. The channel sheet conductance σ, at a point, x, along the channel is considered as a function of the channel voltage at that point, V(x), the applied gate voltage, V_g, and the pinchoff voltage, V_p. Therefore:

$$\sigma(V_g, V_p, V(x)) \text{ when } (V - V(x)) > V_p \quad (1)$$

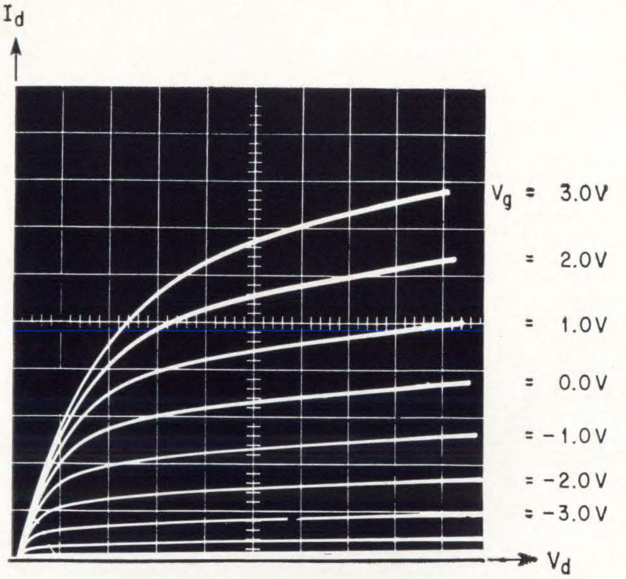
$$\sigma = 0 \text{ when } (V_g - V(x)) \leqq V_p$$

The exact relationship for the channel sheet-conductance will depend on the channel-doping profile and the oxide thickness, T_{ox}. The influence of the gradient of the field along the channel on the channel charge is neglected (this is the gradual-channel assumption proposed by Shockley). The channel current per unit width, I, at this point in the channel is therefore:

$$I' = \sigma E = \sigma(V_g, V_p, V(x))\, dV/dx \quad (2)$$



Depletion field-effect transistor doesn't need gate to overlap source and drain. Offset geometry reduces feedback capacitance from drain to gate when the device is operated in current saturation mode.



Drain current vs. drain voltage for a depletion field-effect transistor with offset gate geometry. Vertical scale: 2 ma per division. Horizontal scale: 5 volts per division.

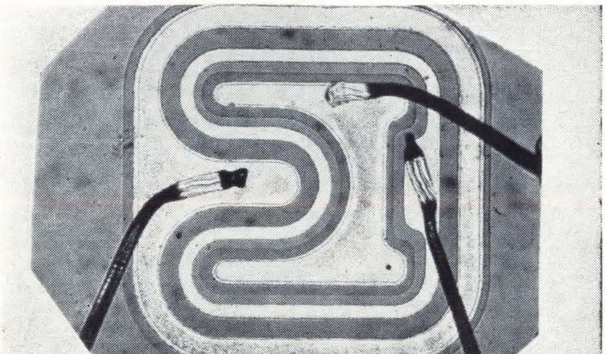
Since the current must be constant from source to drain, integration yields:

$$I'_d = {}^1/l \int_o^{V_d} \sigma(V_g, V_p, V(x))dV \quad \text{for} \quad V_d < V_g - V_p \qquad (3)$$

where l is the channel length, V_d is the applied drain voltage, and I'_d is the drain current per unit channel width.

As V_d is allowed to approach $V_g - V_p$, the channel conductivity at the drain goes to zero, and the drain current saturates. Visualizing how the drain current can continue to flow for $V_d > V_g - V_p$ with the channel supposedly completely pinched-off at the drain, is possible if it is remembered that this pinchoff is only a mathematical entity, a result of the oversimplified gradual-channel approximation for the channel conductance. In reality, as the channel conductance is reduced, the field gradient along the channel becomes substantial, and as V_d approaches $V_g - V_p$ space-charge dominated currents[15] are generated in the drain region. This type of current flow differs from ohmic type current flow in that the channel drift field now controls the distribution of mobile charge as well as the charge velocity. It is analogous, in this sense, to space-charge current flow in the conventional vacuum tube where the plate-to-cathode field gradient determines the space charge.

This space-charge region becomes dominant over the gate-controlled charge at the point in the channel where the voltage is essentially $V_g - V_p$. From that point it extends to the drain where the voltage is V_d. The drain current appears to saturate because the length of the space-charge region is generally much smaller than the over-all channel length. The source region of the channel, or that region from the source to the junction with the drain space-charge region, therefore predominates in determining the current. Since the region length is fairly constant and the voltage drop across it is fixed at $V_g - V_p$ (by definition), the current flow is essentially fixed. Further increases in drain voltage above $V_g - V_p$ are absorbed across this drain region with only a slight modulation of the source-region length. The saturation of drain current is therefore basically dependent on geometry. (An additional mechanism which can cause current saturation is the saturation of carrier velocity at high fields; this has been demonstrated to occur in n-type germanium,[16, 17] but has not been observed in silicon[18]).



Depletion field-effect transistor with offset gate geometry. The drain (inner region), gate (middle region) and source (outer region) leads are gold wires which are attached to the transistor by thermal compression bonding.

Shallow-channel approximation

Many MOS transistors are constructed with a shallow channel (the channel depth in the silicon is much less than the oxide thickness). The voltage drop from the surface through the channel into the semiconductor is small compared to the voltage drop across the oxide and may be neglected. The channel sheet charge density, ρ, is then given by:

$$\rho = C_{ox}[V_g - V_p - V(x)], \text{ for } V(x) \leqq (V_g - V_p) \qquad (4)$$

where x = distance along channel from source to drain. The channel sheet-conductance is given by:

$$\sigma = u_o\, p = C_{ox}\, u_o[V_g - V_p - V(x)] \qquad (5)$$

where C_{ox} is the oxide capacitance per unit area and μ_o is the carrier mobility. Combining equations 3 and 5 yields:

$$I'_d = \left[\frac{C_{ox}u_o}{2l}\right]\left[(V_g - V_p)^2 - (V_g - V_p - V_d)^2\right] \qquad (6)$$

For $V_d > (V_g - V_p)$, the saturated current I'_{ds} is

$$I'_{ds} = \frac{C_{ox}u_o}{2l}(V_g - V_p)^2 \qquad (7)$$

If the saturated current is differentiated with respect to gate voltage, the transconductance, g_m', is obtained:

$$g'_m = \frac{C_{ox}u_o}{l}(V_g - V_p) \qquad (8)$$

Equations 4 through 8 apply for a shallow-channel device. The transfer and gain characteristics for an actual device are shown on the next page.

Field-dependent mobility

Considering the carrier drift velocity directly proportional to the applied drift field (constant mobility) is, in general, valid only for a drift velocity much less than the average thermal velocity of carriers. Device sizes are often small enough so that applied fields and consequently drift velocities often exceed this limit (for example: $E = 10^{+4}$ v/cm, $V_{drift} \approx 10^{+7}$ cm/sec). The result is a mobility which usually varies with field, that is $u \propto E^{-n}$ where $1.0 > n > 0$. If an analysis similar to that for the constant mobility case is performed then:

$$I'_{ds} \; \alpha \; (V_g - V_p)^{2-n} \quad (9)$$

and:

$$g'_m \; \alpha \; (V_g - V_p)^{1-n} \quad (10)$$

Equivalent circuit

An approximate equivalent circuit for the MOS field-effect transistor operated in the saturation mode is shown at right. The pertinent circuit elements are defined below.

R_s and R_d are parasitic source and drain resistances and are usually caused by the metal-to-semiconductor contact on the source and drain regions. The only effect of R_d is to shift the value of the external drain voltage required to obtain drain current saturation. However, R_s appears as a common element to the input and output circuit and therefore causes degeneration. This, in turn, lowers the external terminal transconductance, g_m. This transconductance is expressed by:

$$g_m = \frac{g_{mo}}{1 + R_s g_{mo}} \quad (11)$$

where g_{mo} is the internal transconductance.

C_{db} is the drain-to-substrate (body) capacitance associated with the reverse biased drain-to-body n-p junction and is, in general, a function of the drain potential. For the step junction this capacitance will follow the inverse half-power law with a shunt minimum capacitance, C_{min}, associated with the junction periphery.

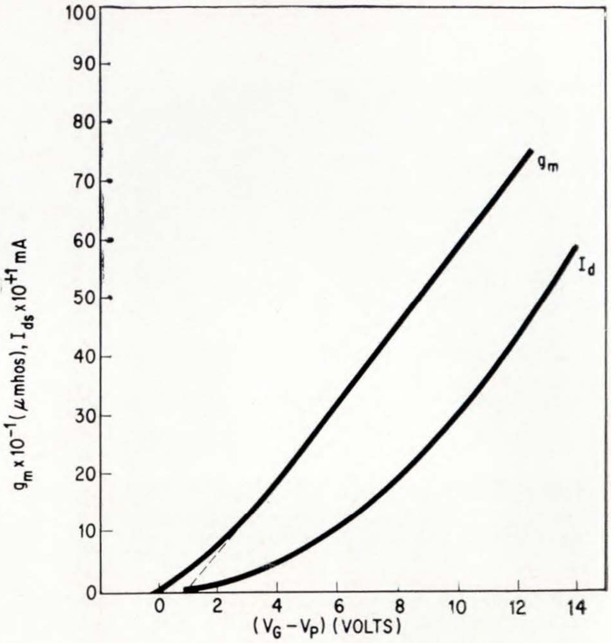
$$C_{db} = C_o(V_{db} + \phi)^{-1/2} + C_{min} \quad (12)$$

where C_o is not actually a capacitance but a constant equal to the dielectric constant of the semiconductor material divided by the junction-width constant, C_{min} is proportional to the junction perimeter, and ϕ is the contact potential. A typical C_{db} vs. V_{db} curve is shown on page 55.

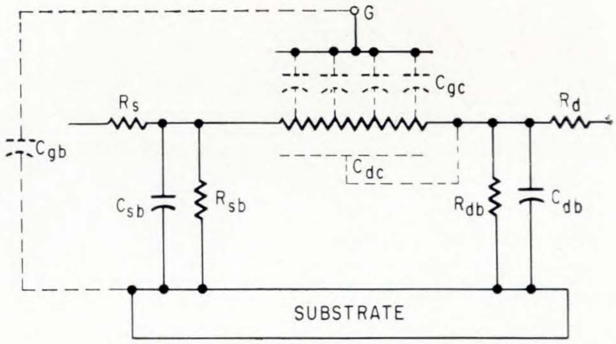
R_{db} is the reversed-bias leakage resistance of the p-n junction. For silicon this resistance is dominated by junction[19] and surface-generated currents[20] rather than bulk diffusion current from the body. At present, leakage current values in the low nanoampere range have been achieved for carefully fabricated back-biased silicon diodes.

C_{sb} and R_{sb} are the equivalent elements to C_{db} and R_{db} for the source-to-body junction.

C_{gs} is the gate-to-source capacitance. It is considered as an inactive portion of the gate capacitance since it does not modulate channel conductivity directly. It represents the portion of the metallic gate electrode overlaying the highly-doped source region.



Characteristics for a ladder-geometry shallow-channel field effect transistor.



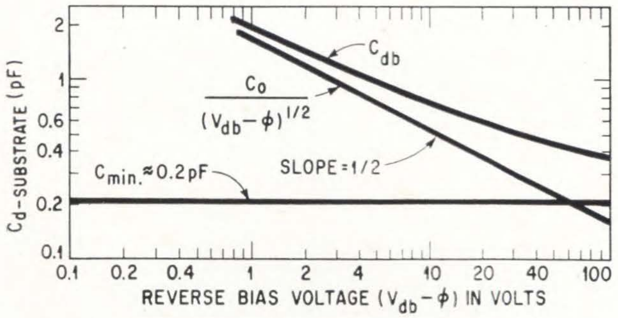
Approximate equivalent circuit for an MOS field-effect transistor operated in the saturation mode.

C_{gd} is the analogous drain-to-gate interelectrode capacitance. Since this capacitance is amplified by the Miller effect, its contribution to the input capacitance is a more serious problem than the gate-to-source capacitance, C_{gs}. As a result, some structures deliberately utilize a gate electrode asymetrically offset toward the source electrode to minimize C_{gd}.

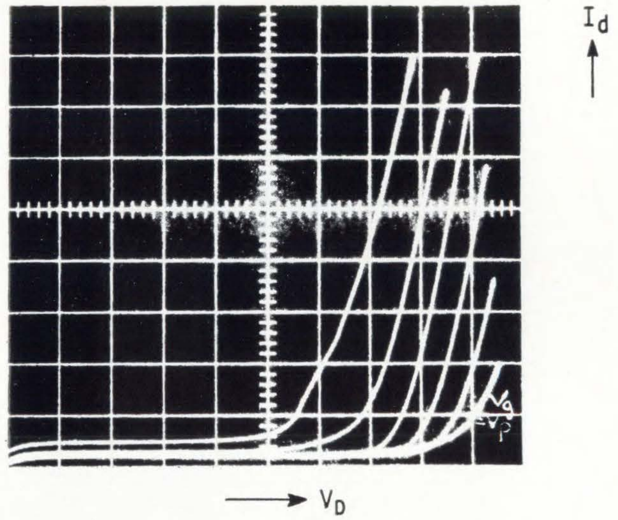
C_{gc} is the active gate-to-channel distributed capacitance and is expressed as follows:

$$C_{gc} = \frac{\partial Q_c}{\partial V_g} \quad (13)$$

where Q_c is the total channel charge. Therefore, C_{gc} will generally be a function of the applied gate and drain voltages. In saturation, this simplifies to:



Drain-to-substrate capacitance vs. reverse bias voltage for a ladder-geometry field-effect transistor



Drain breakdown voltage characteristic for operation in conduction mode (n-type unit Va > Vp)

$$C_{gc} = \frac{2}{3} A_{gc} C_{ox} \qquad (14)$$

where A_{gc} is the gate area overlying the active channel. Typically, oxide thickness $T_{ox} = 1000$ angstroms $= 10^{-5}$ cm, so that $C_{ox} = 10^{-8}$ Farads/cm^2. The gain-bandwidth product, $g_m/2\pi C_{gc}$, is directly related to the carrier transit time through the channel.

C_{gb} is the stray capacitance caused by the overlap of the metal gate electrode on the semiconductor body. Methods of reducing this capacitance include the use of small gate contact areas and thick oxide layers over the whole semiconductor surface except for the area directly over the active channel region. This latter technique also helps to reduce C_{gs} and C_{gd}.

C_{dc} is a composite feedback capacitance which may be expressed as follows:

$$C_{dc} = \frac{\partial Q_c}{\partial V_d} \qquad (15)$$

This capacitor is quite significant since it determines the degree to which drain current saturation is achieved.

Frequency response

The upper frequency limit of an MOS transistor is intimately related to τ_r, the transit time of a carrier from source to drain. As in any charge-control device, including the vacuum tube, at frequences approaching $1/\tau_r$, the real component of the input power to the control electrode increases substantially due to phase effects introduced by this transit time.

In any actual circuit, the maximum operating frequency is a function of the circuit as well as of the device. The gain-bandwidth product may be substantially lower than the upper limit of $1/\tau_r$. The intrinsic gain-bandwidth product is defined as

$$GBW = \frac{g_m}{2\pi C_{gc}}, \text{ this is equivalent to:}$$

$$GBW = \frac{1}{2\pi \tau_r} \qquad (16)$$

In actual practice, a MOS field-effect device of 10 microns channel length typically will have an upper frequency limit in the range of hundreds of megacycles per second.

Maximum drain voltage

The maximum allowable drain voltage, aside from power dissipation limitations, is limited by avalanche multiplication of channel current. This breakdown possesses two relatively distinct modes. The first is a gradual breakdown which becomes greater for increasing gate voltage and drain current. The soft (gradual) breakdown characteristic is caused by the generation of impactionized hole-electron pairs in the high field of the drain region. Since these holes and electrons act partially as a shielding plasma, the onset of severe avalanching is spread out over a wider voltage range. The asymptotic sharp breakdown of the drain represents the onset of direct breakdown to the substrate. It can also be seen that as channel pinchoff is approached the soft voltage component, as expected becomes almost negligible.

As the gate voltage is decreased beyond pinchoff for the same device, the breakdown voltage decreases as shown at left. This modulation and, in fact, the unexpected low breakdown voltage of the diode is caused by surface field-crowding present in shallow diffused junctions and direct gate-field modulation of the consequent surface-dominated breakdown. The effect of field crowding at the surface of a shallow junction is illustrated on page 56. A quantitative calculation of the breakdown voltage in this surface-dominated region, performed by J. Hilibrand,[21] has been consistent with the experimental observations.

The effect of the gate electrode is to directly enhance or counteract this surface field and, hence, to modulate the drain-to-substrate voltage required for breakdown. In the device as shown, the breakdown was almost completely dominated by the gate-to-drain field; variations in substrate resistivity of from 5 ohm-cm to 25 ohm-cm did not markedly change the breakdown voltage of 35 volts. The device possibilities of this gate modulated-breakdown phenomen have been considered by Atalla,[22] Hofstein and Warfield,[23] Nathanson, Szedon and Jordan,[24] and Shockley.[25] However it does not appear to offer any particular breakthrough in terms of device frequency performance.

Voltage-gain limitations

To obtain the approximate voltage gain in the region of saturation, it is necessary to consider possible feedback mechanisms.

It can be shown that for a large class of charge-control devices, the voltage gain, μ_A, is

$$\mu_A = \frac{C_{in}}{C_{fb}}, \qquad (17)$$

where C_{in} is the active input capacitance, and C_{fb} is a feedback capacitance. For a vacuum tube, this yields the well-known relation

$$\mu_A = \frac{C_{gk}}{C_{pk}}, \qquad (18)$$

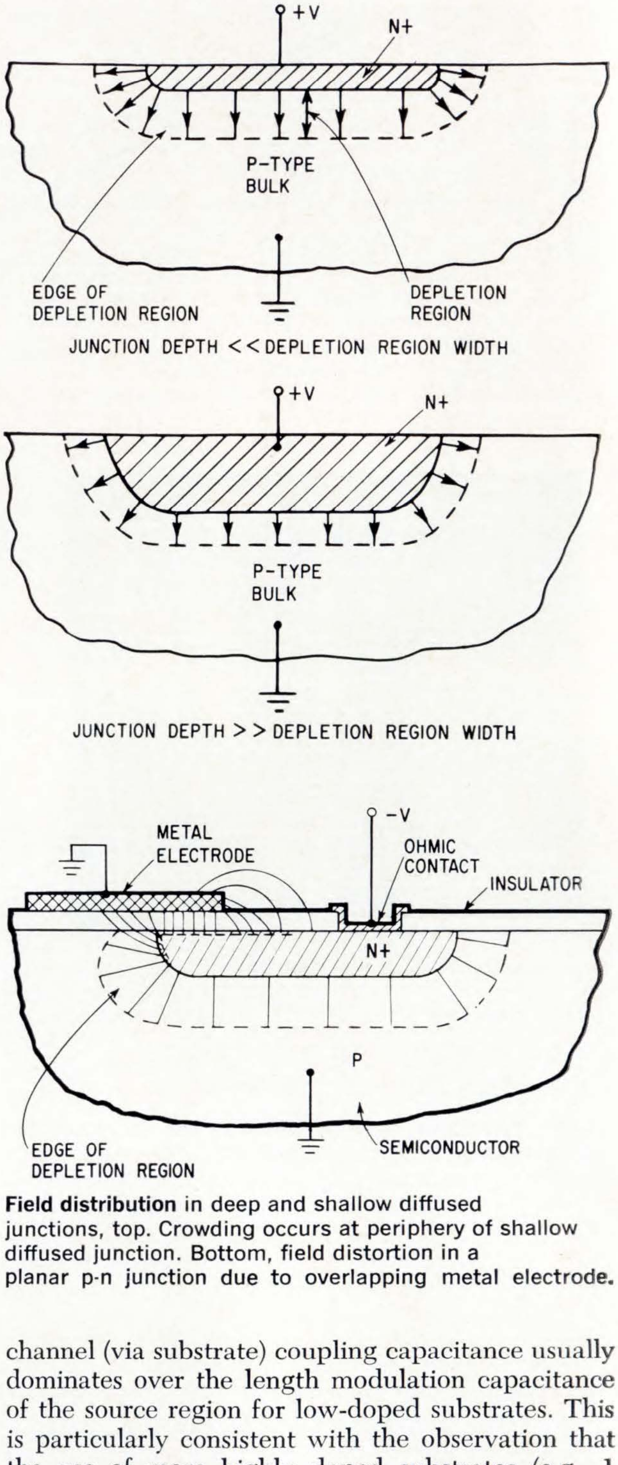
where C_{gk} is the grid-to-cathode capacitance and C_{pk} is the plate-to-cathode capacitance. The high voltage gain of the pentode is a direct result of the shielding effect of the screen grid which greatly reduces C_{pk} without affecting C_{gk}.

In the MOS field-effect transistor, C_{gk} is replaced by the active input capacitance C_{gc}. The problem is then to determine the sources of C_{fb}, the feedback capacitance. In this field-effect transistor, there are two dominating sources.

The first is the drain-to-channel (via the substrate) coupling capacitance. The penetration of the drain field into the channel-to-substrate depletion region will depend on the depth of this depletion region. For the high resistivity substrates commonly used (10 ohm-cm to 100 ohm-cm), this depth will be several microns. The drain then acts on the channel both as an inefficient gate as well as a collector of the channel carriers. Secondly, the space-charge dominated drain region of the channel, although small, is finite. As the drain voltage is increased, the juncture of the drain and source regions (approximately where $V(x) = V_g - V_p$ is pushed back further toward the source. Hence, the charge in the source region of the channel is modulated and is reflected as a drain-to-channel feedback capacitance.

An exact theoretical computation of these capacitances is almost impossible due to the necessity of solving a two-dimensional Poisson equation. If some simplifications are made, however, it can be shown that the predicted voltage gain will be of the order of $(l/T_{ox})^n$ where n varies from about ½ to unity, depending on the simplifications used in the model.

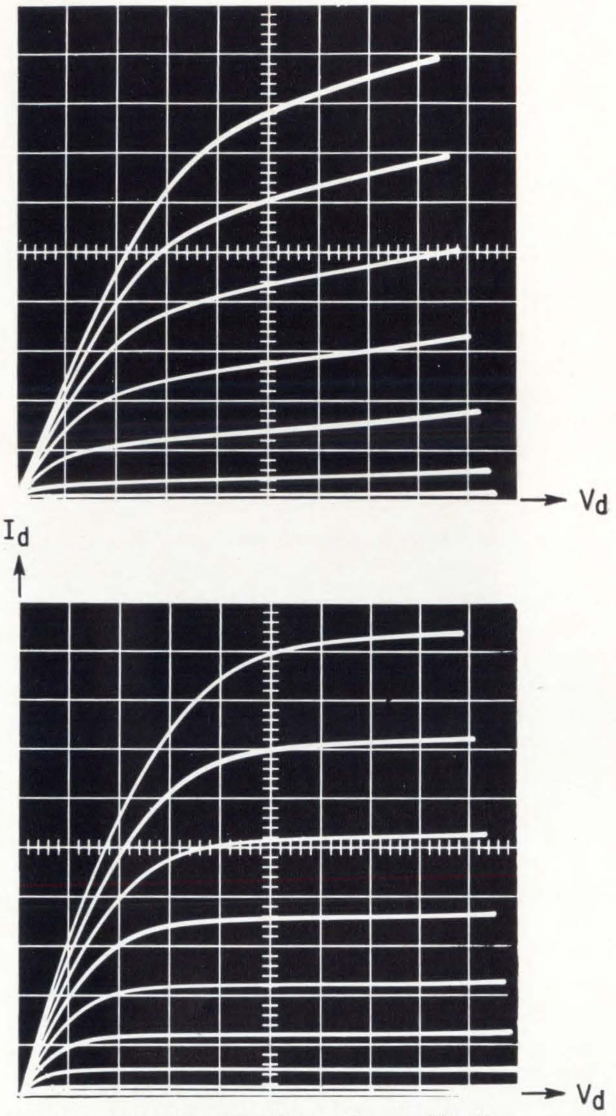
In practice, it has been found that the drain-to-channel (via substrate) coupling capacitance usually dominates over the length modulation capacitance of the source region for low-doped substrates. This is particularly consistent with the observation that the use of more highly doped substrates (e.g., 1 ohm-cm, which reduces the drain-to-substrate depleting region depth) does act to increase substantially the voltage gain, as shown on page 57. In a sense, the highly doped substrate acts as a screen grid in decoupling the drain-to-channel feedback capacitance.



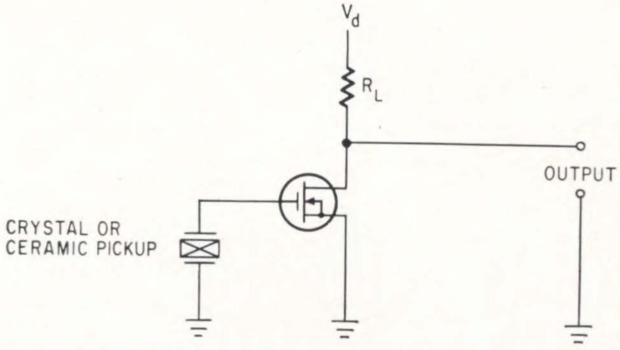
Field distribution in deep and shallow diffused junctions, top. Crowding occurs at periphery of shallow diffused junction. Bottom, field distortion in a planar p-n junction due to overlapping metal electrode.

High input impedance

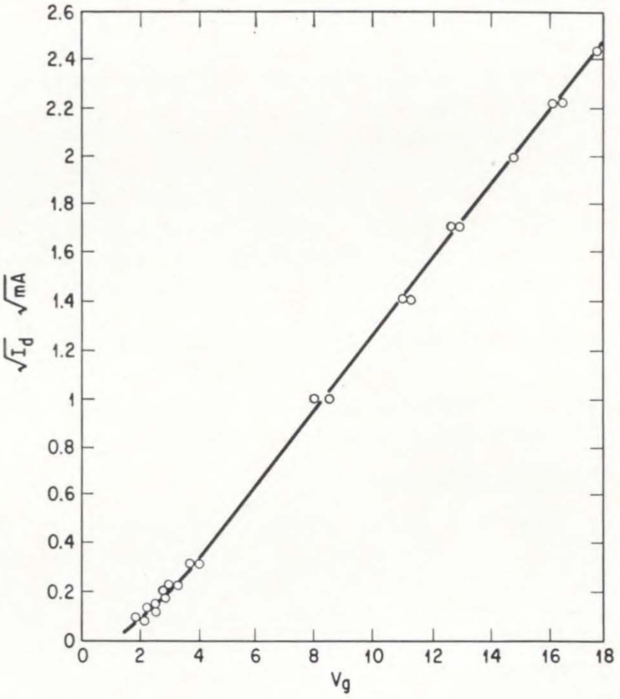
An input resistance of 10^{12} to 10^{14} ohms is regularly observed for packaged field-effect transistors and special mounting gometries have resulted in units with an input resistance of 10^{15} ohms. These numbers, coupled with the fact that the input cir-



Effect of substrate resistivity on the amplification factor of the transistor. Top: 1,000 ohm-per-centimeter substrate. Vertical scale: 1 milliampere per division Horizontal scale: 2 volts per division. l = 20 microns. W = 0.1 inch Bottom: 1 ohm-per-centimeter substrate. Vertical scale: 1 milliampere per division. Horizontal scale: 2 volts per division. l = 10 microns. w = 0.05 inch.



Simplified crystal input stage



Drain current vs. gate voltage

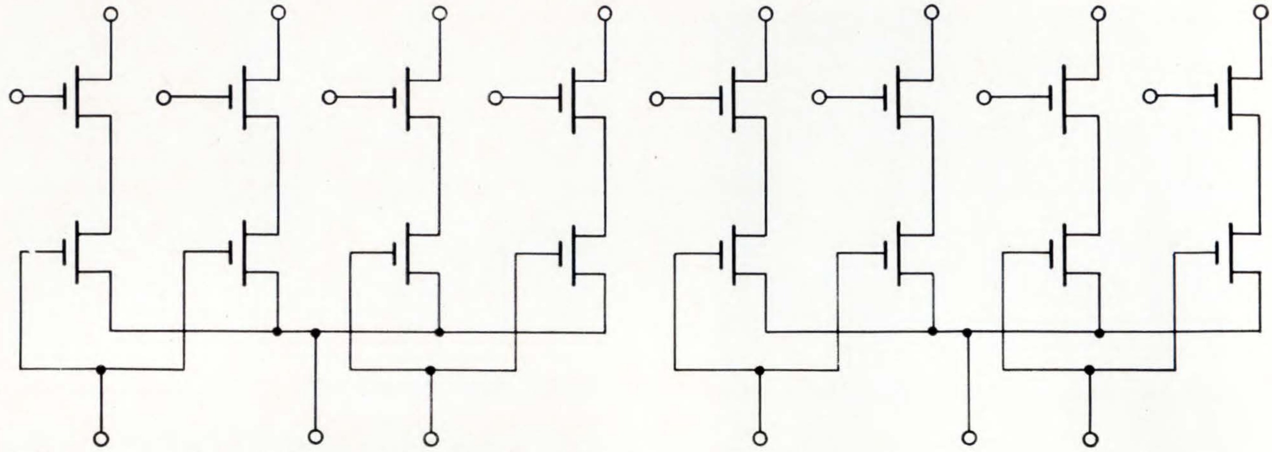
cuit is unaffected by the polarity of the gate voltage, immediately suggests electrometer-type applications. (The field-effect transistor is unique in this respect. Both the bipolar transistor and the vacuum tube exhibit unilateral control: The control electrode conducts significant current in these devices under forward bias). As a linear amplifier, the depletion-type transistor may be designed to operate at zero gate-bias. Since the input impedance is essentially capacitive, this device works well as the input stage to a crystal or ceramic pick-up device (see the circuit at right). While modifications are necessary if this circuit is to yield stable and high-quality performance, the simplicity of the circuit is worth noting.

Square-law transfer characteristic

The field-effect transistor exhibits a square-law transfer characteristic over a substantial current range. This enables low-distortion signal modulation. This is shown above where $\sqrt{I_d}$ is plotted as a function of gate voltage for a typical enhancement transistor. The deviation from a straight line at high current values is due to the degeneration produced by the parasitic source resistance. The "tail" which is apparent at low current values is due to the combined effects of surface states and the failure of the shallow-channel approximation.

Low noise

The field-effect transistor is a majority-carrier device and the shot noise usually associated with minority-carrier current flow in a bipolar transistor is absent. However, there is a shot-noise component present in the noise spectrum of experimental devices. The main source of noise at high



Sixteen-transistor logic gate for NAND or NOR circuitry

frequencies[26] in field-effect transistors is thermal noise due to random fluctuations in the channel free carrier concentration. Noise figures comparable to low-noise vacuum tubes are obtained at frequencies above 50 Mc.

The low-frequency noise spectrum,[27, 28, 29] which may extend up to tens of megacycles per second in some devices, is controlled by the fluctuation in the number of electrons occupying surface traps and resembles an f^{-n} distribution. The value of n is generally between 1 and 2, and the spectrum extends down to very low frequencies. At present, considerable research is being devoted towards a better understanding of the semiconductor surface, and an improvement in the low-frequency noise performance of these devices is likely.

Radiation resistance

Neutron radiation reduces the minority-carrier lifetime in semiconductors and therefore degrades the performance of bipolar transistors. Field-effect transistors generally can tolerate a higher dosage of radiation than bipolar transistors since mobility degradation or doping level changes require a higher level of radiation. Insulated-gate transistors have been fabricated to tolerate a neutron flux of 3×10^{14} neutron/cm^2 before the transconductance is reduced to 70% of its initial value.

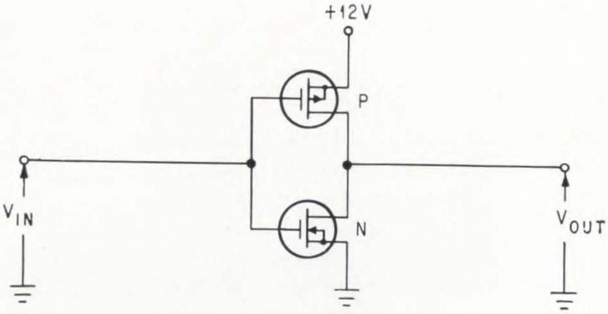
Switching circuits

The enhancement-type transistor is well suited for digital circuit applications because direct-coupled signal inversion is possible without the need for level shifting between stages. An early approach to integrated circuits with these devices[9] was to fabricate all the active devices on one silicon chip and place the load resistors and additional wiring on the supporting package. The 16-transistor logic gate shown above was fabricated with silicon insulated-gate field-effect transistors; a photograph of the finished wafer is shown on page 59. All wiring is insulated from the silicon by an additional layer of evaporated silicon dioxide with room left between circuits for dicing.

An attractive approach to integrated logic circuits involves the use of the complementary-pair inverter circuit[30, 31, 32] shown on page 59. Here, the p-type (hole conduction) enhancement transistor is used as an active load element and the need for passive elements is eliminated; entire circuits may be fabricated from n- and p-type transistors. This circuit has the further advantage that the standby power dissipation is on the order of several microwatts for either the high or low state. If V_{in} is +12 volts, the gate-to-source voltage of the p-type transistor is zero, and it is cut off. Negligible current (10^{-8} to 10^{-9} amperes) flows through the transistors, yet the output voltage is very close to zero because the n-type transistor is in its high-conductance state. If $V_{in} = 0$, the p-type transistor is on and the n-type unit is off, producing an output voltage of +12v. This circuit dissipates power during switching only and is capable of infinite d-c fan-out. However, a large fan-out slows the switching time and increases the average power dissipated during a-c operation.

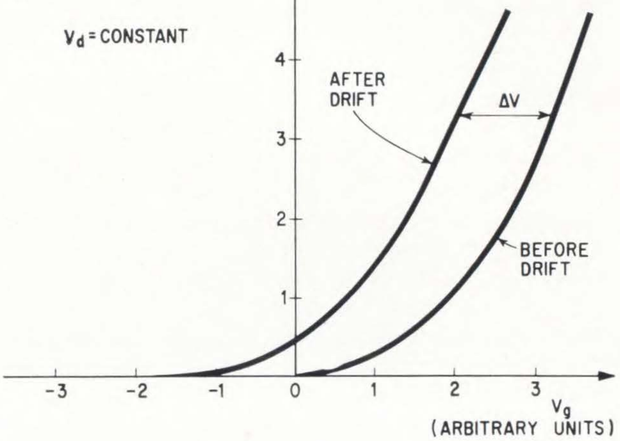
When comparing the power dissipation of a field-effect transistor circuit to that of a bipolar circuit, it should be pointed out that the bipolar output characteristics saturate at a low value of collector voltage and allow operation with a small collector supply voltage (typically 3 volts). The gradual saturation of the field-effect transistor in present devices produces a rounded knee in the output characteristics and a higher drain supply voltage (typically 12 volts) is required to separate the on and off voltages and improve the noise immunity of the circuit.

It should also be pointed out that the pinchoff voltage, V_p, is not an inherent property of the materials which comprise the transistor. It is determined by the surface state occupation (the number of trapped electrons) and device processing and cannot be controlled to the extent that doping densities can be controlled. This is in contrast to the bipolar transistor, where the threshold voltage is directly related to the semiconductor bandgap. Therefore, the transfer characteristic of a bipolar transistor can be held to a tolerance of several millivolts while the process variables obtained to-



A complementary-pair inverter circuit

Shift in the transfer characteristic of an n-type enhancement transistor caused by the extended application of positive bias.

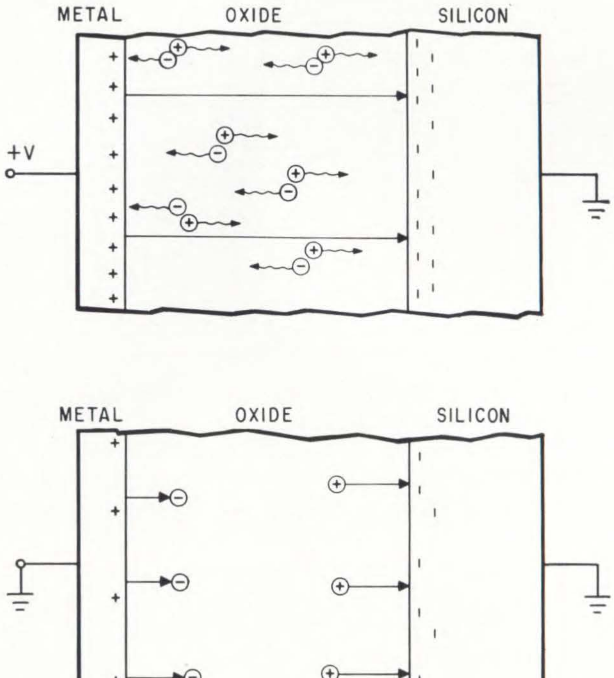


day yield field-affect transistors with an uncertainty in pinchoff voltage of at least 0.5 volts.

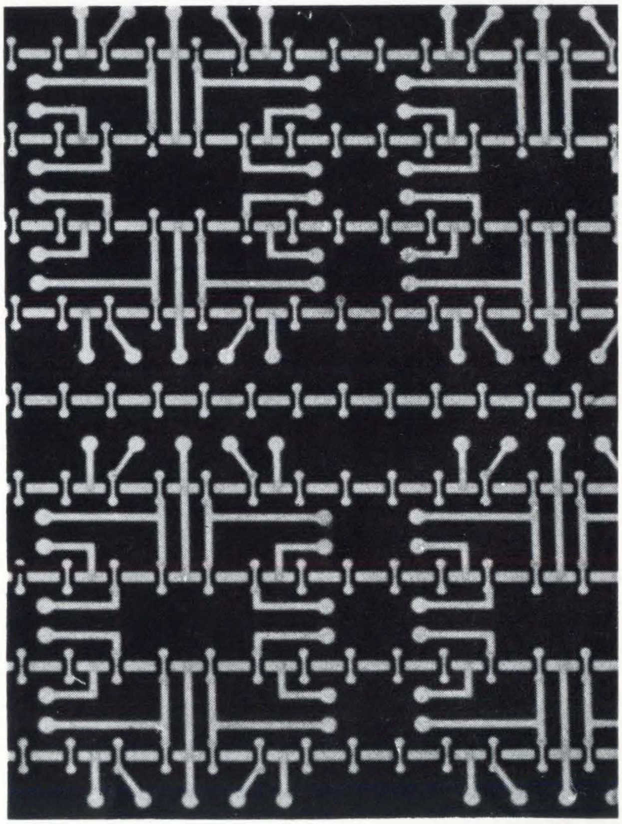
Stability

Semiconductor devices operating in the presence of high electric fields[33] such as the insulated-gate transistor have shown instability of characteristics related to the motion of ions and molecules in silicon dioxide[34] and other insulating films[35]. The enhancement transistor used in digital circuit applications generally operates at an oxide field greater than 10^6 volts/cm, which is close to the dielectric-breakdown strength of the silicon dioxide layer. On the other hand, the depletion transistor is usually operated near zero gate voltage in small signal amplifier applications, and the oxide field can be of the order of 10^5 volts/cm. Thus, instability due to migration of ions in the bulk of the oxide layer is more pronounced in the enhancement transistor.

Much research is presently underway to understand the details of the observed instabilities in field-effect transistors.[36, 37, 38] If it is assumed that the oxide layer is filled with mobile, polyatomic molecules that may be easily dissociated, then the application of a positive potential to the gate of an n-type transistor will tend to move the negative ions toward the gate electrode and the positive



Migration of ions in the bulk of the silicon dioxide layer can cause transistor characteristics to drift, top. Finite electric field which exists when the gate potential is reduced to zero, below.



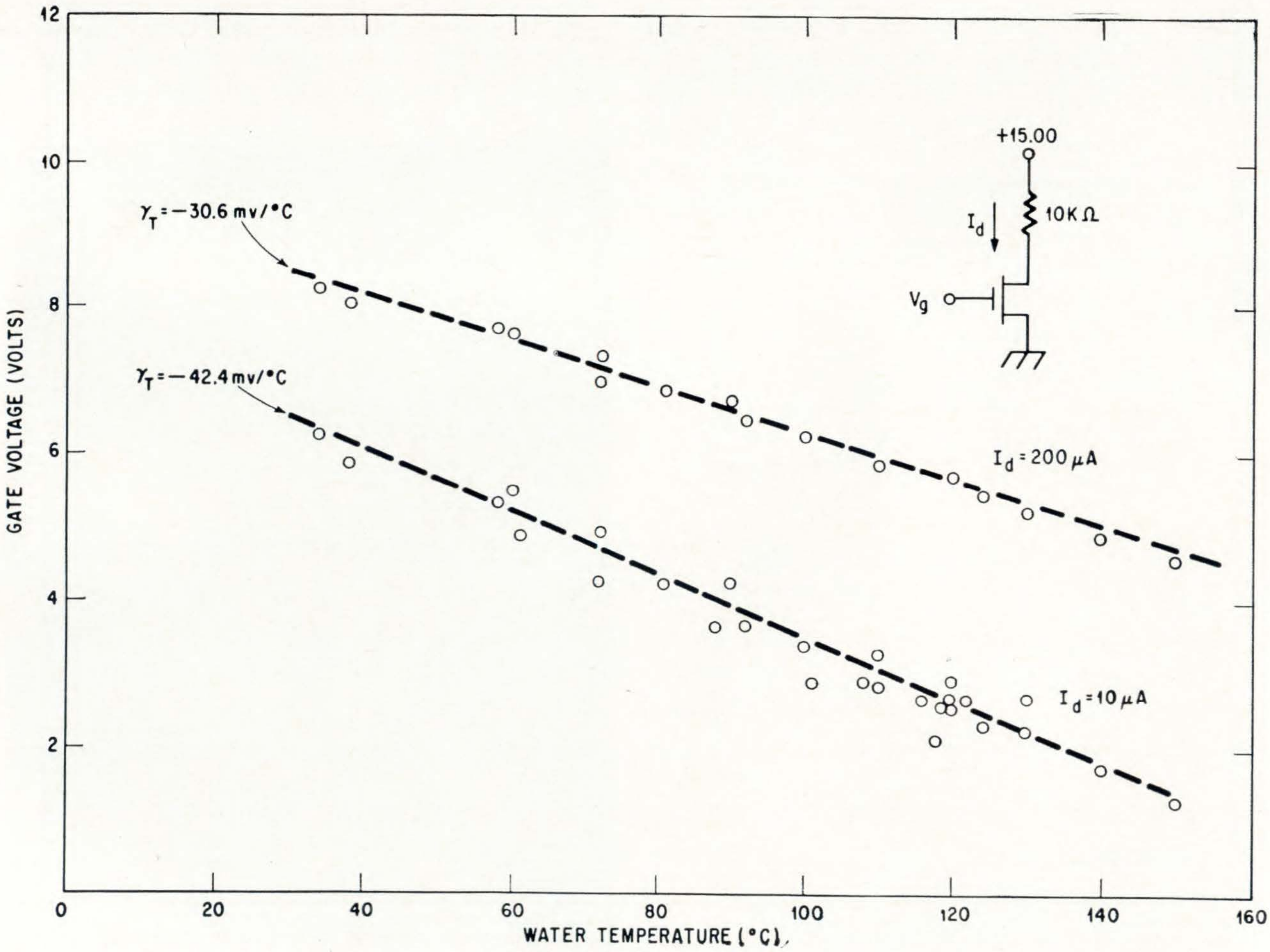
Ladder-geometry transistors in an integrated circuit

ions toward the silicon surface as shown on page 59. With the gate returned to zero potential, there remains an electric field pointing into the silicon which terminates on negative charge. Thus, when the gate bias is removed from an enhancement transistor that has been on for an extended period, the transistor does not turn off.

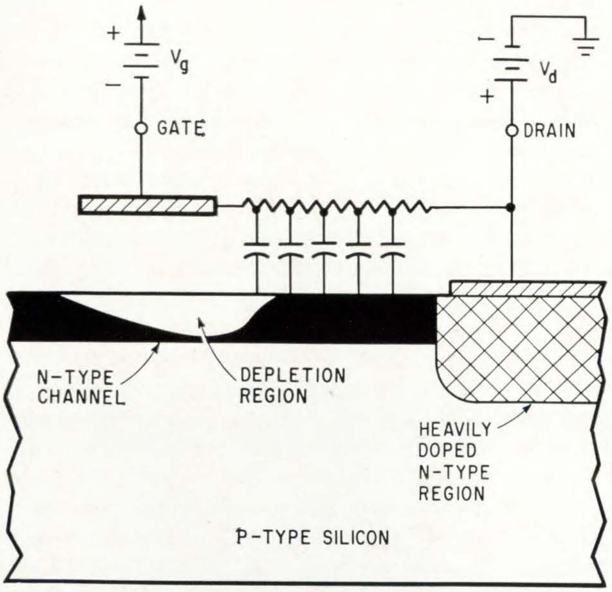
Whether the moving charges are positive, negative, or both, is still uncertain and their origin (i.e., injected from the gate contact or created in the bulk) has not yet been established. However, the external effect may be easily understood by examining the transfer characteristic of an n-type enhancement transistor before and after the application of a large positive gate bias for an extended period of time. Initially, the transfer characteristic appears as shown on page 59 (before drift). After the application of gate voltage, the curve drifts to the left and the instability may be quantitatively characterized by the voltage shift Δ V. This quantity increases with temperature, time of application and electric field strength. In some cases, drift has been observed until Δ V reached a maximum value. While in others Δ V seems to continually increase with time. When this type of instability was first observed, Δ V attained values as large as 5 to 6 volts; now it is possible to limit the drift to less than 0.5 volts by appropriate modification in forming the oxide layer.

Although the depletion transistor operates at a low-enough oxide field so that bulk charge migration is not a problem, the offset gate geometry which is often used for this type of transistor, exposes a portion of the channel oxide near the drain end of the channel. This introduces an additional problem because of the finite sheet resistivity of the oxide surface. Between gate and drain, the equivalent distributed R-C network,[39, 40] shown at right applies. With the gate negative and the drain positive, a potential gradient exists across the resistive surface and current starts to flow. This charges the distributed oxide capacitance in a time which may be from seconds to weeks depending on the value of surface resistance. The surface next to the gate electrode is negatively charged, causing depletion of channel charge beyond the gate geometry. When the gate potential is reduced to zero, this charge continues to exist, and a portion of the channel remains partially depleted, adding a series resistance to the channel. This lowers the zero-bias channel current when the gate potential is reduced to zero after long negative bias. Proper packaging and surface treatments can reduce this form of instability to an acceptable value.

Once a stable transistor is fabricated, it is found that the characteristics are a function of the instan-



Temperature characteristics for a ladder-geometry transistor



Equivalent circuit demonstrating drift characteristics of an offset-gate geometry transistor.

taneous value of temperature.[41] Since this is a majority-carrier device, mobility variations were first suspected. A useful relation in studying temperature effects on the field-effect transistor is:

$$\gamma_T = \left(\frac{\partial V_g}{\partial T}\right)_{I_d=\text{constant}} \tag{19}$$

. . . i.e., what change in gate voltage is necessary to maintain I_d when temperature is increased? If the mobility decreases with increasing temperature, the channel current would tend to decrease, and the gate voltage would have to be increased (for an n-type unit) to maintain I_d. Thus, mobility variations would produce a positive value of σ_T for an n-type transistor.

The presence of surface states, on the other hand, has an opposite effect. As the temperature is increased, trapped electrons tend to be ionized, increasing the channel conductivity. The gate voltage must be reduced to maintain I_d for an n-type unit. Transistors have been fabricated which possess positive, negative and zero values for σ_T over a limited operating range, and a typical set of curves for an enhancement-type device appears on page 60. The linear variation of gate voltage with temperature is to be expected from a simplified theory,[41] and values of σ_T ranging from —30mv/°C to —42mv/°C are indicated.

Promise of new circuitry

The development of a practical insulated-gate field-effect transistor came at a time when semiconductor device technology was well advanced. In fact, the technique developed for producing clean, passivated silicon surfaces made the MOS field-effect transistor possible. Techniques for the reduction of surface-state densities and the control of fine dimensions played a major role in this development.

The field-effect transistor possesses the desirable high-impedance voltage-controlled characteristics of a vacuum-tube pentode while it retains the many advantages characteristic of semiconductor devices. The concept of hybrid circuits, using both bipolar and field-effect transistors, will most likely introduce a new class of circuits possessing novel and improved performance.

References

1. J.E. Lilienfeld, U.S. Patent No. 1,900,018; filed March 28, 1928; issued March 7, 1935.
2. O. Heil, British Patent No. 439,457; filed March 4, 1935; issued Dec. 6, 1935.
3. W. Shockley and G.L. Pearson, Physical Review, Vol. 74, p 232, 1948.
4. W. Shockley, Proceedings of the IRE, Vol. 40, p 1365, 1952.
5. D. Kahng and M.M. Atalla, "Silicon—silicon dioxide field-induced devices," Solid-State Device Research Conference, Pittsburgh, Pa., 1960.
6. P.K. Weimer, "An evaporated thin-film triode," Solid-State Device Research Conference, Stanford University, Calif., 1961.
7. P.K. Weimer, Proceedings of the IRE, Vol. 50, p. 1462, 1962.
8. F.P. Heiman and S.R. Hofstein, "The silicon insulated-gate field-effect transistor," Electron Devices Meeting, Washington, D.C., 1962.
9. S.R. Hofstein and F.P. Heiman, Proceedings of the IEEE, Vol. 51, p 1190, 1963.
10. G.T. Wright, Solid State Electronics, Vol. 7, p 167, 1964.
11. C.D. Root and L. Vadasz, IEEE Transactions on Electron Devices, Vol. ED-11, p 294, 1964.
12. C.T. Sah, IEEE Transactions on Electron Devices, Vol. ED-11, p 324, 1964.
13. C.W. Mueller and P.H. Robinson, "Grow-film silicon transistors on sapphire," Solid-state Device Research Conference, Boulder Colo., 1964.
14. H.K.J. Ihantola and J. Moll, Solid State Electronics 1, p 423, 1964.
15. G.T. Wright, Proceedings of the IEEE, Vol. 51, p 1642, 1963.
16. J. Grosvalet, C. Motsch and R. Tribes, Solid State Electronics, Vol. 6, p 65, 1963.
17. E.J. Ryder, Physical Review, Vol. 97, p 641, 1955.
18. A.C. Prior, Journal of Physics and Chemistry of Solids, Vol. 12, p 175, 1959.
19. C.T. Sah, R.N. Noyce and W. Shockley, Proceedings of the IRE, Vol. 45, p 1228, 1957.
20. A.L. McWhorter and R.H. Kingston, Proceedings of the IRE, Vol. 42, p 1376, 1954.
21. J. Hilibrand, Private communication.
22. M.M. Atalla, U.S. Patent 3,045,139; issued July 17, 1962.
23. S.R. Hofstein and G. Warfield, to be published in IEEE Transactions on Electron Devices Feb., 1965.
24. H.C. Nathanson, R. Szedon, N.A. Jordon, Electron Devices Meeting, Wash., D.C. Oct. 31, 1963.
25. W. Shocley and W.W. Hooper, "The surface controlled avalanche transistor," Solid-State Device Research Conference, Boulder, Colo., 1964.
26. A. Van der Ziel, Proceedings of the IRE, Vol. 50, p 1808, 1962.
27. A.L. McWhorter, "I/f noise and related surface effects in germanium," Sc. D. Thesis, E.E. Dept. MIT, 1955.
28. A.G. Jordon and N.A. Jordon, "Noise in MOS devices," Solid-State Device Research Conference, Boulder, Colo., 1964.
29. C.T. Sah, "Theory and Experiments on the I/f surface noise of MOS insulated-gate field-effect transistors," Solid-State Device Research Conference, Boulder, Colo., 1964.
30. J.T. Wallmark, RCA Review, 24, p 641, 1963.
31. J.R. Burns, to be published in the RCA Review.
32. F.M. Wanlass and C.T. Sah, International Solid-State Circuits Conference, Phila., Pa., 1963.
33. See Transactions of Symposium on the Physics of Failure in Electronics, IIT Research Institute, Chicago, Ill., 1963.
34. W. Shockley, H.J. Queisser and W.W. Hooper, Physical Rev. Letters, Vol. 11, p 489, 1963.
35. M.H. Pilkuhn, Journal of Applied Physics, Vol. 34, p 3302, 1963.
36. D.R. Kerr, J.S. Logan, P.J. Burkhardt, and D.R. Young, "Stability of Silicon—silicon dioxide and silicon-glass interfaces," Solid-State Device Research Conference, Boulder, Colo., 1964.
37. J.E. Thomas, Jr., "Charge storage in insulator films and its effect on semiconductor surfaces," Solid-State Device Research Conference, Boulder, Colo., 1964.
38. M. Yamin, "Charge storage effects in silicon dioxide films," Solid-State Device Research Conference, Boulder, Colo., 1964.
39. S.R. Hofstein and G. Warfield to be published in Solid State Electronics.
40. E.H. Nicollian and A. Goetzberger, "Evaluation of channel properties by metal-insulator-semiconductor measurements," Solid-State Device Research Conference, Boulder, Colo., 1964.
41. F.P. Heiman and H.S. Miller, to be published in IEEE Transactions on Electron Devices.

How to measure FET noise

New method allows calculation of noise voltage at any source impedance

By Joel M. Cohen

Crystalonics, Inc., Cambridge, Mass.

An important consideration in the selection of components for oscillator or amplifier service is the amount of noise that a device contributes to the total circuit noise.

The widespread use of such low-noise devices as field-effect transistors has increased the difficulty of measuring noise and encouraged an overhaul of the standards of noise measurement.

The most widely used standard of noise measurement for semiconductor devices is noise figure—defined as the ratio of the signal-to-noise power ratio at the input to that at the output. However, this standard goes back to the days of the noisy vacuum tube when the absolute sensitivity of the amplifier was of paramont interest and comparisons of the relative merits of various amplifiers were significant. Now circuit designers need data that is meaningful and useful for circuit design as opposed to a noise figure that is useful simply as a method of comparison but has no meaning in itself when the conditions under which it is measured are not considered.

For example, a transistor with a three decibel noise figure measured at an input impedance of 100,000 ohms may put out 10 times more noise than a transistor with a noise figure of three decibels referenced to 1,000 ohms (see graph on page 63).

The author

Joel Cohen is director of engineering at Crystalonics, Inc. He heads the applications, device evaluation, and special test equipment departments.

There is justification for using a transistor with a noise figure specified at a higher input impedance only when a high source impedance is encountered. Thus a chart that converts noise figure at a specific impedance to a noise voltage at any impedance is needed. Another basic difficulty with the widely accepted noise figure is that it approaches unity asymptotically for devices such as low-noise FETs. Since this portion of the curve is very difficult to use, a better graphic representation of noise figure is necessary.

Noise figure to noise voltage

The set of curves on page 63 shows the noise voltages generated at various source resistances over a one-cycle bandwidth. To find the noise voltage corresponding to a given source resistance and transistor noise figure: first, find the source resistance; second, read up to the transistor noise figure (obtained from the transistor data sheet); third, read to the left to obtain the noise voltage. For example, suppose the source resistance is 10^7 ohms and the transistor noise figure is 1.0 db. Draw a line up from 10^7 ohms until it reaches the line representing a 1-db transistor noise figure. By drawing a horizontal line to the left, the noise voltage value of 0.2 microvolts is obtained. The same procedure may be used to obtain the noise voltage which corresponds to the total noise figure (transistor noise plus source noise).

Two transistors, a 2N3059 pnp junction device and a 2N3088A field-effect transistor, are used to illustrate how the noise figure diagram can aid the circuit designer. The maximum noise figures obtained from the data sheet are: 0.5 db at input impedance of 1 megohm for the FET and 3.0 db at 100,000 ohms for the pnp. For a source resistance of 10^5 ohms, the noise voltage for either type is about 0.01 microvolt. However for higher source resistances, the 2N3088A allows lower noise voltage levels. For operation with source resistances under 10^5 ohms, the 2N3059 is preferable.

This set of curves represents information the circuit designer actually needs in investigating the noise characteristics of a transistor. The total noise is referred to the input of the amplifier stage using that specific transistor at that specific source impedance. The noise-conversion curves are used only for conversion of noise figure to noise voltage referred to the input of the transistor with a specified source impedance.

Actually, to completely specify the noise conditions for the designer, the manufacturer should guarantee a maximum noise voltage and noise current referred to the transistor's input at a specific frequency.

Noise components

A more useful way of presenting transistor noise data is to separate the noise referred to the input of the transistor into noise voltage and noise current. It is assumed that in any active element, whether it be a transistor or complete amplifier,

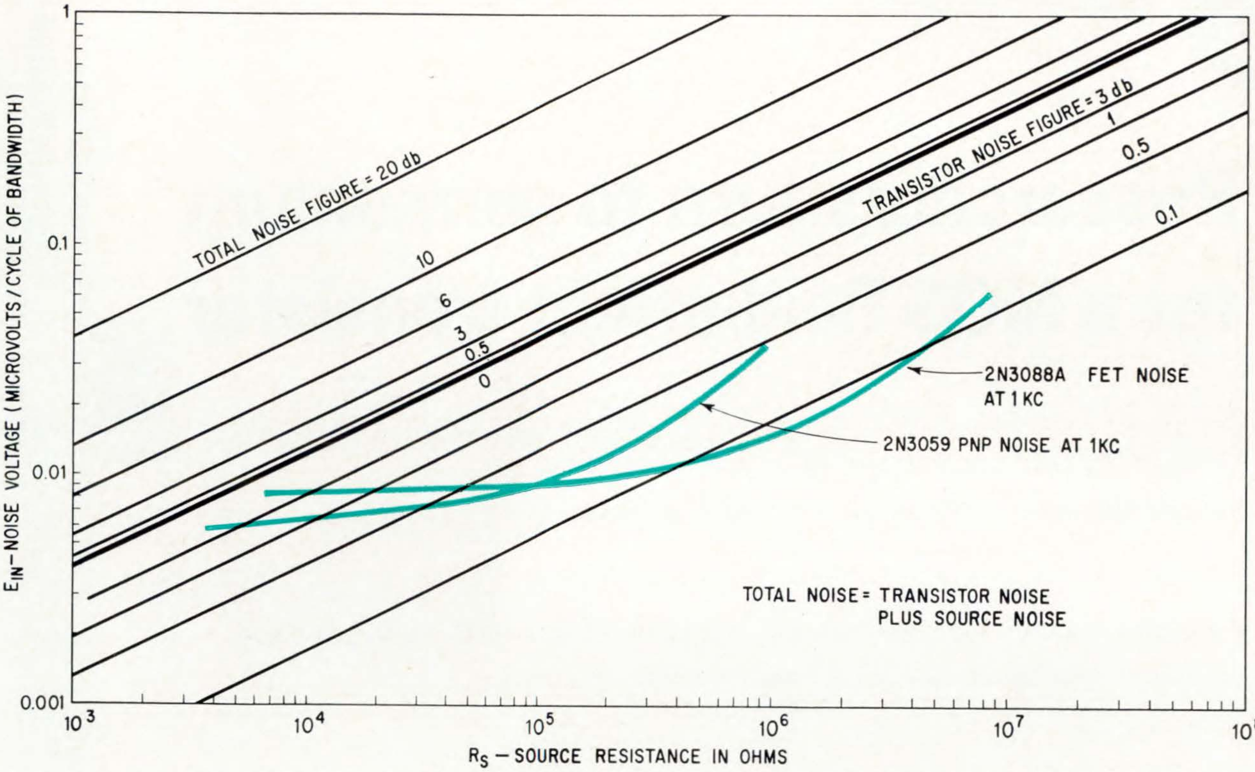
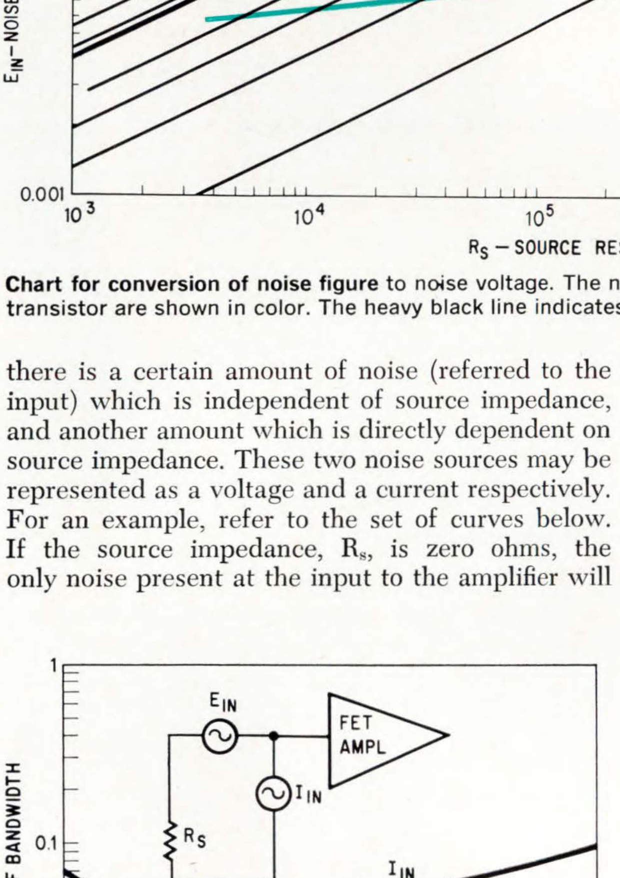


Chart for conversion of noise figure to noise voltage. The noise-figure levels for a pnp transistor and a field-effect transistor are shown in color. The heavy black line indicates the noise level of the source resistance.

there is a certain amount of noise (referred to the input) which is independent of source impedance, and another amount which is directly dependent on source impedance. These two noise sources may be represented as a voltage and a current respectively. For an example, refer to the set of curves below. If the source impedance, R_s, is zero ohms, the only noise present at the input to the amplifier will be the noise voltage, and a curve of noise voltage versus frequency may be plotted. If R_s is very large, then the voltage generated by the current generator across the source resistance becomes the most significant noise source, and a curve of I_{in} versus frequency may be generated. With these two single curves the total noise referred to the input of the transistor may be calculated easily for any source impedance and frequency, using the basic premise that the total noise voltage referred to the input is $E_{in} + I_{in}R_s$ plus the noise of the source itself. This total noise referred to the input usually is what the design engineer needs. The noise figure may be calculated using the basic equation:

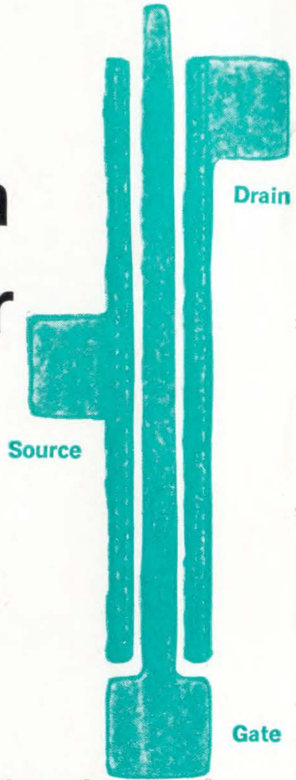


The two components of transistor noise for a 2N3088A FET are shown as a function of frequency; one is a voltage source, the other is a current source. I_{in} units are in picoamperes and are 0.1 times units at left.

$$N.F. = 20 \log_{10} \frac{N_T + N_R}{N_R}$$

where N_T is the transistor noise and N_R the source resistor noise. In place of N_T, substitute E_{in} plus $I_{in}R_s$, using the manufacturer's $E_{in}I_{in}$ curves.

The use of field-effect transistors operated at high impedances, increases the difficulty of measuring transistor noise and noise figure. For example, a 0.1 db noise figure, which is typical for some field-effect transistors, represents transistor noise that is only 1% of the source noise produced by an ideal resistor. In practice this means it is almost impossible to get an accurate noise figure measurement, since one cannot determine the noise of the source resistance within 1% regardless of the contribution of the transistor. For this reason, a reactive source impedance is used to determine the noise characteristics of the transistor. This impedance is usually provided by a capacitor.



Researchers turn to germanium for a MOS field-effect transistor

Work in the field has been limited to other crystals; striped geometry chosen for new class of devices

By Victor Harrap, George Pierson, Henry Kuehler and B. Keith Lovelace
Semiconductor-Components Division of Texas Instruments, Inc., Dallas

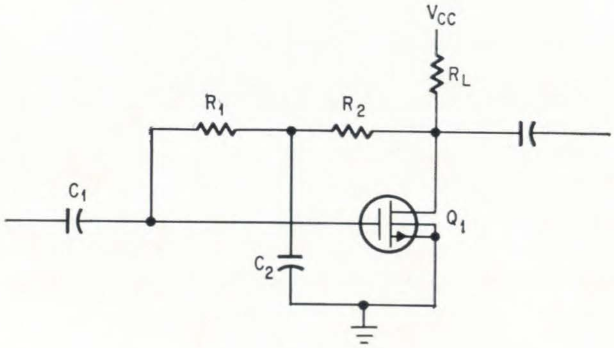
In 1963, when metal-oxide-semiconductor field-effect transistors (MOS FETs) were developed, engineers focused their attention on expensive crystals because they had great potential. Now scientists are examining the transistor workhorse, germanium.

Economics was the key factor. Thus research was directed in two areas—performance and economical fabrication—because engineers knew that the germanium FET would have to compete in the well-established germanium junction transistor market, which already is highly competitive.

Therefore, the aim was to fabricate the FET as cheaply as possibly while taking advantage of the fact that it has a lower noise characteristic than conventional transistors.

Recently, MOS FETs were made from silicon[1, 2, 3], cadmium sulfide[4, 5, 6, 7], cadmium selenide[8, 9, 10] and gallium arsenide[11]. However, despite the high-frequency capability offered by germanium's high electron mobility, the only use of germanium in field-effect transistors has been in the fabrication of conventional junction FETs.

After experimenting with a variety of configurations and processing techniques, the striped geometry was found to be among the most promising. This geometry was evaluated in conjunction with silicon dioxide coatings 1,500-angstroms thick.



$R_1 = 9.1\ M\Omega$ $R_2 = 9.1\ M\Omega$ $R_L = 10\ K\Omega$
$C_1 = 680\ pF$ $C_2 = 0.1$ $V_{CC} = 50\ V$

Biasing arrangement for n-channel device

Striped geometry

An n-channel germanium device was constructed using the striped geometry shown at the top of this page and biased to operate in the enhancement mode. Transconductance for this transistor reaches as high as 2,300 micromhos for a gate voltage of 5 volts and a drain voltage of 10 volts. With one volt supplied to the gate, the dynamic drain resistance at low frequencies is approximately 30,000 ohms and the voltage amplification factor (μ) is about 50.

The effect of various ambient temperatures on the drain characteristics of the germanium MOS striped-geometry transistor was studied. A series of tests was conducted at 25°C, 85°C and 125°C. After a number of runs, it was concluded that, as temperature rises, germanium MOS transistors exhibit gradual increases in drain current, zero-gate bias saturation current and slight increases in transconductance. However, this behavior is compatible with the design requirements for linear amplifiers over the entire operating range.

The mobility of the electrons in the n-channel is given by:

$\mu = 56.6\ (L)(d)S^2/Z$

where μ = mobility of electron in channel (square centimeter per volt-second)

L = channel length (in thousands of an inch)

d = insulation layer thickness (in angstroms)
S = slope of $\sqrt{I_{DS}}$ vs. V_G
(I_{DS} is in milliamperes and V_G is in volts)
Z = substrate width (in thousands of an inch)

By obtaining values from the drain current-voltage characteristics curve for $V_D = +5$ volts, using the slope relationship for I_{DS} and V_G shown on page 68 (approximately 0.53), L/Z equal to 0.032 and d equal to 1,500 angstroms, the electron mobility is calculated as 760 square centimeters per volt-second. This mobility figure is about one-fourth the mobility possessed by an electron moving through high-purity bulk material at room temperature. The lower mobility of the channel electrons is due to their tight confinement to the inversion layer. The turn-on voltage (V_T) is approximately one volt.

Device characteristics

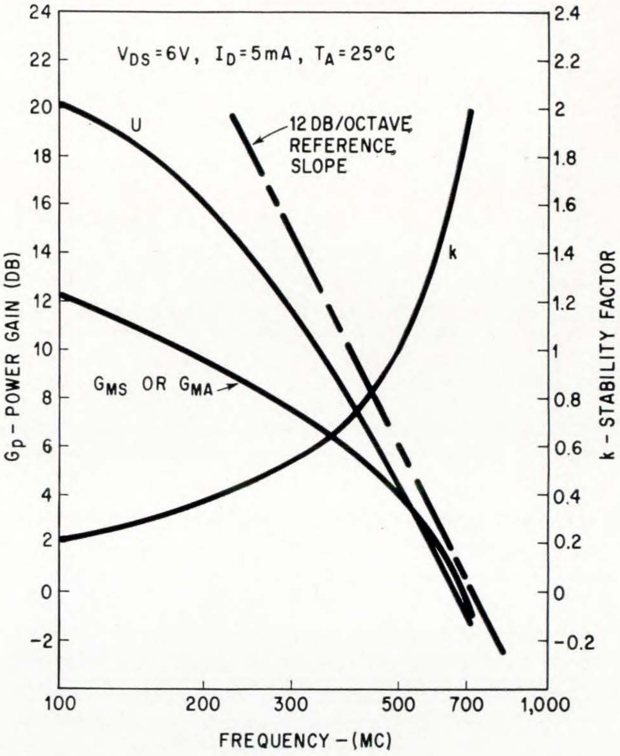
The gate-to-source insulation resistance for this germanium MOS transistor is about 3 x 10^{12} ohms with 20 volts across the oxide layer. The average breakdown voltage is about 150 volts, which corresponds to a dielectric strength of 1 x 10^7 volts per centimeter. Maximum drain voltages are about 15 to 20 volts. The drain leakage current with zero gate bias will vary according to the degree of inversion and the contact material. With $V_T = -1$ volt for the n-channel transistor, I_{DSS} is about 200 μa at a five-volt drain voltage. Representative capacitance values are as follows: gate-to-source capacitance = 2 pf, drain-to-source capacitance = 2 pf, drain-to-gate capacitance = 0.2-2.0 pf. Units with higher gate-to-drain capacitances are acceptable for low-frequency circuit applications. Units with the low feedback capacitance (C_{gd}) are desirable for high-frequency operation.

The high-frequency evaluation of germanium MOS transistors is conducted in terms of two-port parameter measurements. Common-source short-circuit admittances are measured over the frequency range of 100 megacycles to 1 gigacycle.

Two-port parameters

The frequency variation of the common-source admittance parameters for a single transistor is shown on page 67 (y_{is} is the common-source, input admittance; y_{os} is the common-source, output admittance; y_{fs} is the common-source, forward transadmittance; and y_{rs} is the common-source, reverse transadmittance). Of particular interest is the forward transadmittance, y_{fs}. As can be seen from the curve, the transconductance, Re (y_{fs}), at 1 gigacycle is only slightly less than at 100 megacycles, having passed through a broad peak between 200 and 500 Mc. Consequently, the magnitude of forward transadmittance $|y_{fs}|$, at 1 Gc is approximately two times its 100 Mc value because of the contribution of the imaginary component. The imaginary component is larger than the real component for frequencies above approximately 600 Mc.

The imaginary components of all four parameters are capacitive. These components increase ap-



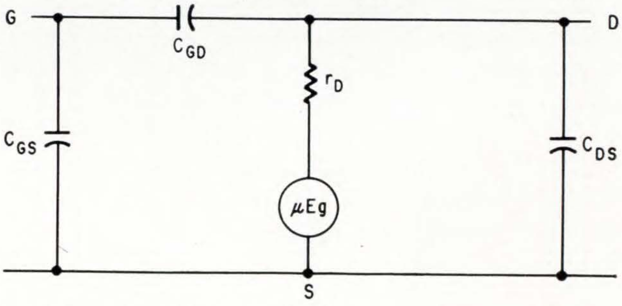
$$k = \frac{2R_e(y_{is})R_e(y_{os}) - R_e(y_{fs}y_{rs})}{|y_{fs}y_{rs}|}$$

$$G_{MS} = \left|\frac{y_{fs}}{y_{rs}}\right|$$

$$G_{MA} = G_{MS}\left[k - \sqrt{k^2-1}\right];\ k \geq 1$$

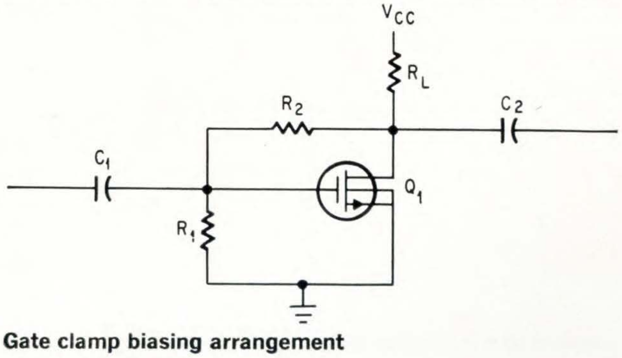
$$U = \frac{|y_{fs} - y_{rs}|^2}{4\left[R_e(y_{is})R_e(y_{os}) - R_e(y_{fs})R_e(y_{rs})\right]}$$

Power gain and stability versus frequency



C_{GS}= 2.7 pF C_{GD}= 2.2 pF C_{DS}= 2.5 pF r_D = 10 KΩ u = 9

Equivalent circuit of germanium MOS transistor



Gate clamp biasing arrangement

proximately in direct proportion with frequency except in the case of forward transadmittance. In this case, the increase is slightly more rapid. Equivalent input and output capacitances are each approximately 2 pf for this particular transistor. The equivalent reverse-transfer capacitance is approximately 0.2 pf.

The real components of reverse-transfer, input and output admittances increase rapidly with increasing frequency above 300 Mc. Over portions of this frequency range, the rate of increase is greater than that of a frequency-squared variation.

Gain and stability

Transistor gain and stability factors calculated from the measured admittance parameters are shown at right. Unilateralized gain, U, represents the maximum device gain attainable in a neutralized tuned amplifier that has no losses. For the germanium MOS transistor, U is approximately 20 decibles at 100 Mc and 16 decibels at 200 Mc. This indicates that in a properly designed neutralized circuit, single-stage circuit gains of about 16 db at 100 Mc and 12 db at 200 Mc may be obtained.

In the case of unneutralized tuned amplifiers, the amount of gain that can be realized depends upon circuit stability. Calculation of Rollett's stability factor,[12] k, shows that the transistor is only conditionally stable (i.e., $k<1$) for frequencies between 100 Mc and approximately 500 Mc. Hence the maximum stable gain, G_{MS}, defines the maximum realizable gain with a circuit stability factor of unity (i.e., operating at the boundary between unconditional and conditional stability). The value of G_{MS} for this transistor is approximately 12 db at 100 Mc and 10 db at 200 Mc. For a higher degree of circuit stability, the realizable gain will be less than G_{MS}. Above approximately 500 Mc, with $k>1$, the maximum attainable transistor gain is the maximum available gain, G_{MA}. This is obtained when input and output ports are conjugately matched. For this transistor, stable circuit gains of 10 db (per stage) at 100 Mc and 8 db at 200 Mc can be realized.

Above 300 Mc, the calculated gains decrease rapidly at a rate approaching 12 db per octave. The so-called maximum frequency of oscillation (frequency at which gain decreases to unity) is approximately 650 Mc for this transistor.

Circuit applications

The equivalent circuit is shown on page 65 for the germanium MOS transistor applied for the circuit[2] on page 64. The basic amplifying principles for the transistor may be treated the same as for a triode vacuum tube. Biasing the transistor by using resistors R_1 and R_2 between the drain and the gate tends to stabilize the bias point from one device to another. The capacitor C_2 bypasses the negative feedback voltage through R_2 to ground. However, this capacitor is not necessary if the driving source impedance is much less than R_1. The drain current for the device in the amplifier circuit is 4.2 ma, making the drain to source voltage (V_{DS}) equal to 8 volts. The drain current could be decreased and R_L increased by clamping the gate as shown in the circuit on page 65. This method increases the voltage gain (A_V) of the unit but lowers the input impedance of the circuit. Resistors R_1 and R_2 should not be greater than 20 megohms in order to maintain temperature stability. The lower limits on R_1 and R_2 depend on the input impedance level desired.

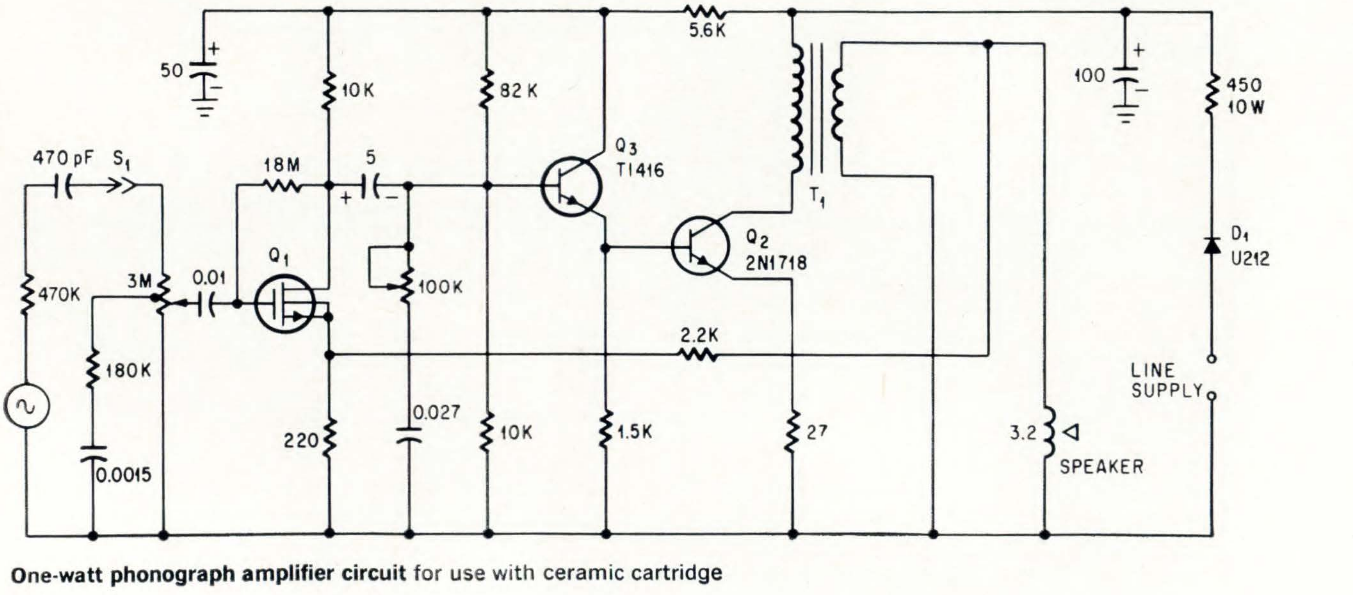
Frequency response of the transistor with various driving source impedances is shown at right. The input admittance C_1 results from the capacitance between gate and source of magnitude. This value is obtained from:

$$Ci = C_{GS} + (1 - A_V)\, C_{GD}$$

where

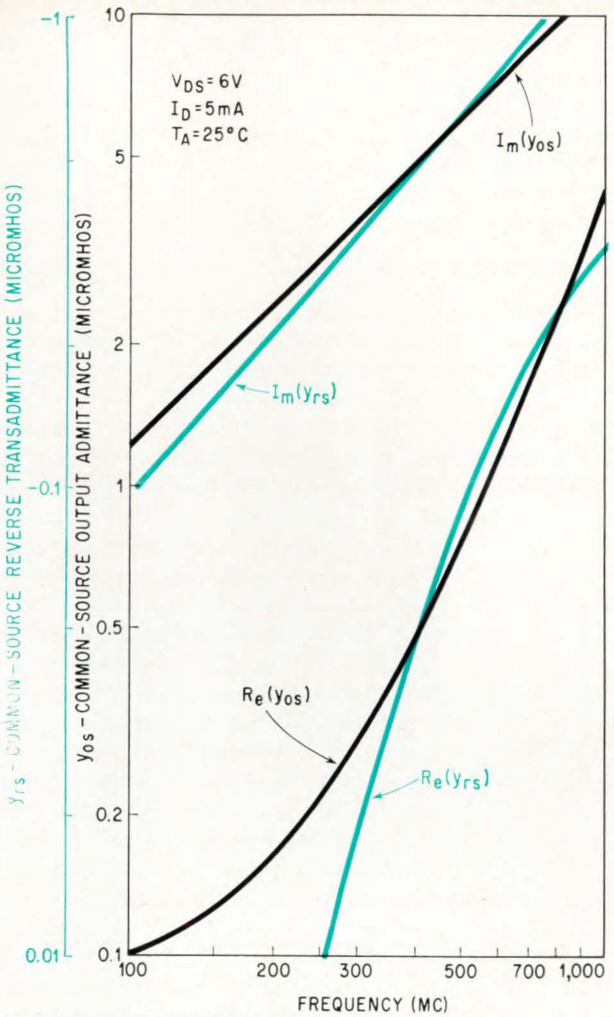
$$A_V = \frac{-u_{RL}}{R_L + r_D}$$

Using the component values given in the equivalent

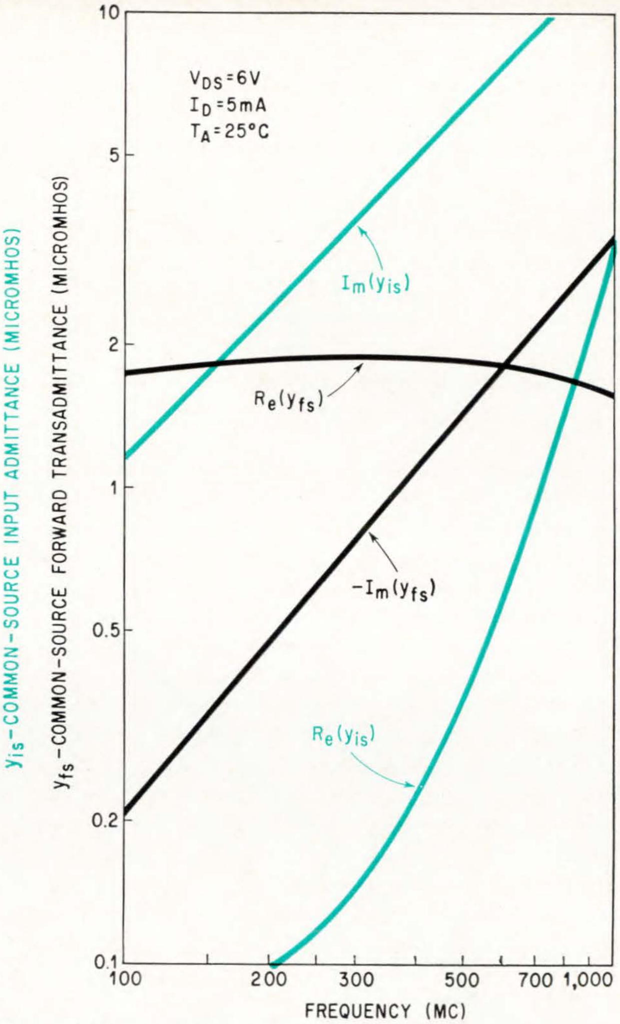


One-watt phonograph amplifier circuit for use with ceramic cartridge

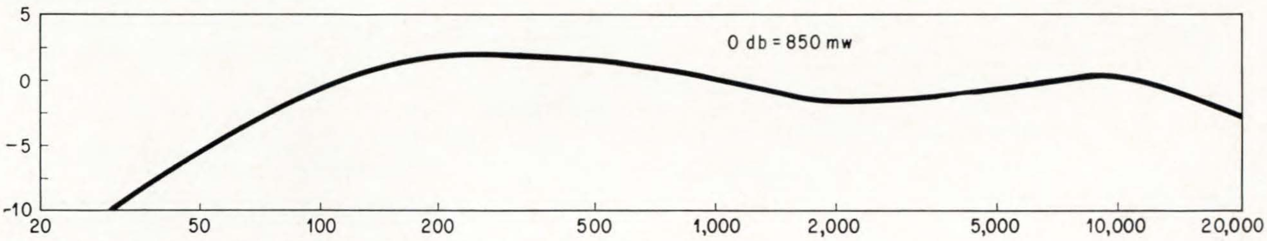
Characteristics of germanium MOS field-effect transistors



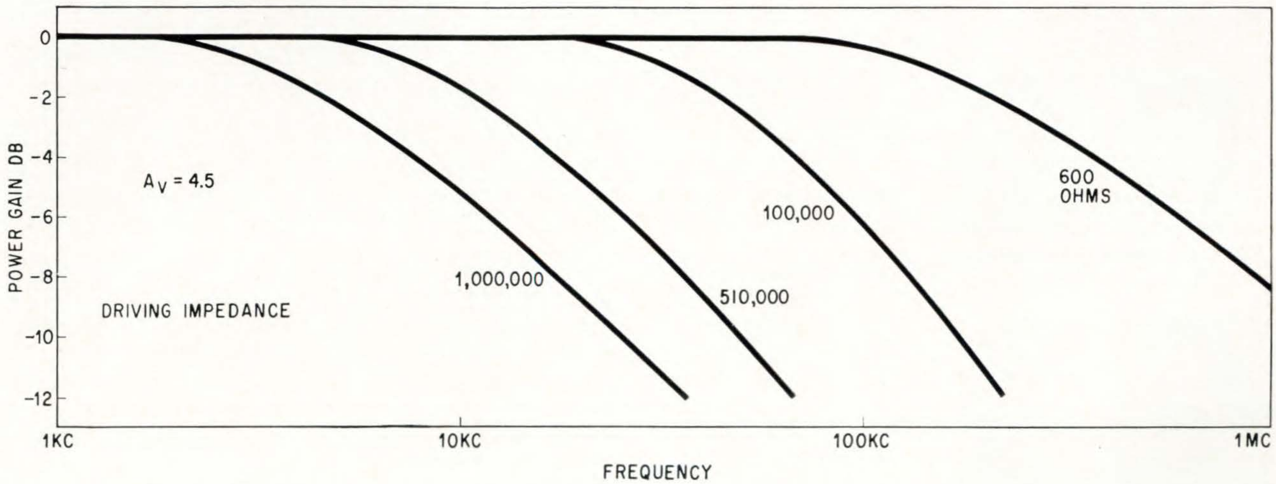
Output admittance and reverse transadmittance characteristics



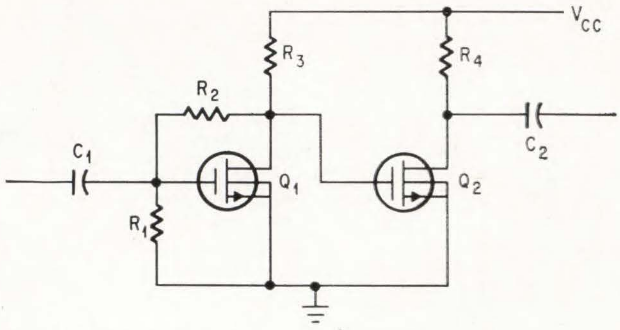
Forward transadmittance and input admittance characteristics



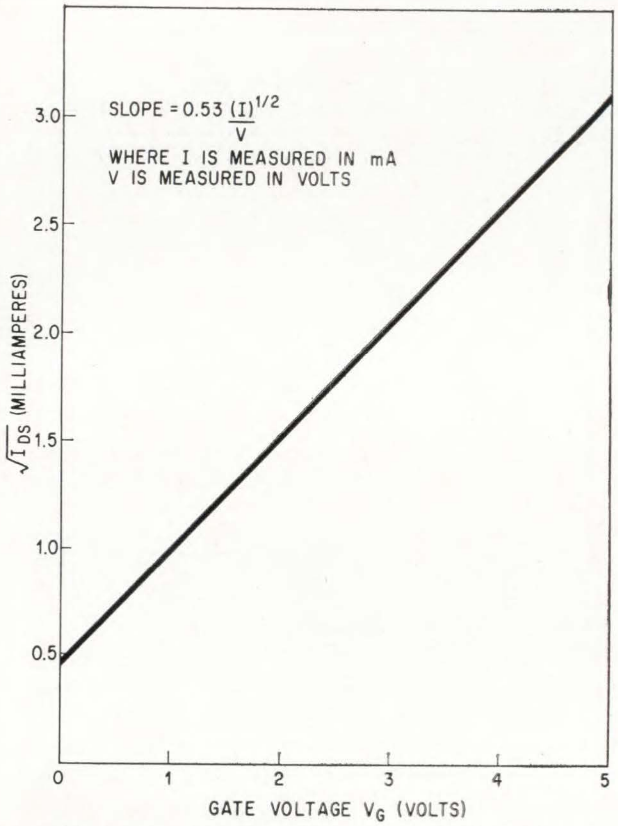
Power gain in db (y-axis) vs frequency in cps (x-axis) for the circuit shown on page 66.



Power gain versus frequency for various source impedances



Direct-coupled amplifier



Drain-to-source current versus gate voltage relationship helps determine electron mobility.

Amplifier performance data

Maximum power out......................	1.5 watts
Power output @ 10% THO................	1.0 watts
Frequency response (± 3 db).............	70CPS-20 KC
Sensitivity for 1 watt output...............	570 MV
Hum and noise below 1 watt..............	58 db
Total power dissipation....................	5.5 watts

circuit, A_V is 4.5 for an R_L of 10,000 ohms. Therefore, Ci is 14.8 pf.

Since this transistor is used in the enhancement mode, direct coupling becomes a simple procedure as shown at left. The operating point of Q_2 is set by V_{DS} for Q_1 which in turn is set by the choice of R_1 and R_2. The operating points of Q_1 and Q_2 should be chosen so that the V_{DS} for Q_1 is equal to or less than the V_{DS} for Q_2.

One practical application of this transistor is in an audio preamplifier used in a one-watt line-operated phonograph as shown on page 66. The high input impedance will not load a ceramic cartridge represented in the circuit as a 470,000-ohm resistor and a 470-pf capacitor in series with a voltage generator. Transistor Q_2 is used as an emitter-followed driver in order to transform the low input impedance of Q_3 up to a sufficiently high value to obtain voltage gain from the transistor. Performance data for the amplifier is given above.

As would be expected from the extremely high gate leakage resistance of the device at 25° C, and since it is operated in a feedback enhancement mode, the temperature stability of the circuit is excellent. It is plotted at right. No variation in circuit performance was observed over a temperature range of 25°C to 60°C. Input impedance decreased, however, from 4.55 megohms at 25°C to 4 megohms at 60°C. Although this is a 12% drop in impedance, the input impedance is still sufficiently high.

References

1. S.R. Hofstein and F.P. Heiman, "The silicon insulated-gate field-effect transistor," Proceedings of the IEEE, Vol. 51, p. 1190, Sept. 1963.
2. C.T. Sah, "Characteristics of the metal-oxide-semiconductor transistors," IEEE Transactions on Electron Devices, Vol. ED-11, p. 324, July, 1964.
3. F.M. Wanlass, "Novel field-effect device provides broadband gain," Electronics, Vol. 36, p. 30, Nov. 1, 1963.
4. H. Borkan, "Depositing active and passive thin-film elements on one chip," Electronics, Vol. 37, p. 53, April 20, 1964.
5. M.G. Miksic, E.S. Schlig and R.R. Haering, "Behavior of CdS thin film transistors," Solid-State Electronics, Vol. 7, p. 39, 1964.
6. P.K. Weiman, "The TFT—A new thin-film transistor," Proceedings of the IRE, Vol. 50, p. 1462, June, 1963.
7. R. Zuleeg, "Electrical Evaluation of thin film CdS diodes and transistors," Solid-State Electronics, Vol. 6, p. 645, 1963.
8. F.V. Shallcross, "Cadmium selenide thin-film transistors," Proceedings of the IEEE, Vol. 51, p. 851, May, 1963.
9. F.V. Shallcross, "Evaluation of cadmium selenide films for use in thin-film transistors," RCA Review, Vol. 24, p. 676, Dec., 1963.
10. H.L. Wilson and W.A. Gutierrez, "Cadmium selenide thin-film field effect transistors," Electrochemical Society Meeting, Pittsburgh, April, 1963.
11. "Development of a gallium arsenide metal-oxide semiconductor transistor," RCA Technical Documentary Report No. AL-TDR-64-146, Contract AF33(657)—11402, July, 1964.
12. J.M. Rollett, "Stability and power-gain invariants of linear twoports," IRE Trancactions on Circuit Theory, Vol. CT-9, No. 1, March, 1962, p. 29.

Reprints of this report are available. See the reader service card at the back of this issue.

The authors

V. Harrap

G. Pierson

H. Kuehler

B.K. Lovelace

Victor Harrap is the project manager for the germanium MOS FET group.

George Pierson is doing research in the area of high-frequency semiconductor devices.

Henry Kuehler is in charge of the audio applications section.

B. Keith Lovelace is currently engaged in studying methods for forming insulating and dielectric thin films.

Research in microwave acoustics spawns compact delay lines

Single-crystal devices are expected to be used in radar systems, radar displays and for electronic countermeasures

By G.P. Rodrigue

Sperry Microwave Electronics Co., Clearwater, Fla., a Sperry Rand Corp. division

Research in microwave acoustics has bred a generation of real-time delay devices for the microwave region. Now, a small solid-state passive device can introduce a controllable time delay into a microwave signal line. The components are smaller and more reliable than previous delay techniques.

Although technical problems remain, single-crystal delay lines are expected to be used in a variety of radar systems—including doppler radars—and in radar displays. Since a finite, measurable and constant time delay can be introduced with them, the devices can be used in systems to calibrate and test equipment for range and response. They can also be used for electronic countermeasures, in receiver protection and data comparison, in large array antenna synchronization and in generating reference signals.

Microwave acoustics refers to elastic vibrations in materials at a microwave frequency. Such vibrations are also called phonons. Recently it was discovered that coherent phonons can be generated, propagated and detected in crystals at frequencies well into the microwave region, at least through the X band[1,2]. Aside from the theoretical interest, there is also practical interest because elastic waves can be propagated in solids at a low velocity, which results in long real-time delays with small crystals.

The author

G. P. Rodrigue, a research staff consultant, received his Ph.D. in applied physics from Harvard University in 1958. His principal area of research is ferrite materials for microwave devices. He has a patent pending on a low-noise parametric amplifier.

Since the wavelength λ of a propagating elastic wave is related to the velocity of propagation v and frequency f by $\lambda = v/f$, it follows that the relatively low velocity of propagation is accompanied by a wavelength of the order of microns.

More recently it has been observed that pure magnetic modes, or spin waves, also can be excited and propagated in magnetic insulating crystals[3]. Many properties of these magnetic waves are similar to those of the elastic waves; in addition, the velocity of propagation of the magnetic waves can be varied and controlled by an applied d-c magnetic field. Propagation of these magnetic waves then makes it possible to control real-time delay in the crystal. Also, the velocity of propagating the magnetic waves can be an order of magnitude lower than the velocity of propagating pure elastic waves or phonons.

Two kinds of waves

The microwave acoustic field may be divided into two types of waves: elastic and magnetic. The pure elastic waves have an extremely stable velocity of propagation, within less than 1% over wide temperature and other environmental variations. The magnetic waves' velocity of propagation can be controlled by an external magnetic field. Since the frequency ω of a microwave signal is related to the applied magnetic field H by the gyromagnetic ratio γ as $\omega = \gamma$ H, it follows that those crystals which exhibit a field-controllable real-time delay also have a frequency-dispersive real-time delay.

Many varieties of magnetic waves can be propagated. Magnetostatic waves, which have wavelengths 0.01 centimeter or longer, are wave-like disturbances of the electronic spins within the magnetic structure of the material. In this region, the wavelengths are comparable to sample dimensions and boundary conditions are important. Spin waves are magnetic waves of much shorter wavelength, where surface effects are unimportant. For certain values of magnetic field and frequency, the elastic and magnetic waves have similar wavelengths and are strongly coupled. In this region of strong coupling, elastic and magnetic waves form admixtures that are called magnetoelastic waves. Since magnetoelastic waves also are field-dependent and frequency-dispersive, like magnetostatic waves, they will be grouped here with magnetic waves.

Material requirements

Microwave phonon propagation can be observed only in nearly perfect single crystals. Although any material can transmit elastic vibrations to some degree, the extremely small wavelength of the microwave phonon requires that, for any appreciable propagation, the material must be free of discontinuities larger than the elastic wavelength, that is, a few angstrom units. This restricts microwave phonon propagation essentially to single crystals, since polycrystalline substances with grain boundaries approaching the size of an acoustic wavelength would have prohibitively large reflections or scattering. The small wavelength of this radiation also requires that all end surfaces be polished to an optical quality to reduce scattering.

Suitable crystals of sapphire, ruby, rutile and quartz are readily available and have been investigated. Other materials, such as lithium fluoride, calcium fluoride, calcium tungstate, potassium bromide, magnesium oxide, titanium dioxide and nickel oxide, may also be useful for these applications. But their properties have not yet been fully investigated.

These materials are nonmagnetic and can be used in pure phonon propagation. Magnetic insulating materials like ferrites and garnets in single-crystal form also are capable of propagating microwave phonons. The garnet material, in particular yttrium iron garnet, was one of the first materials studied. In its best crystalline state, it is capable of extremely low-loss propagation. However, because it is hard to grow the crystals, it is extremely difficult to obtain reproducibly high-quality single crystals of yttrium iron garnet. The same problem applies to gallium and aluminum-doped yttrium aluminum iron garnet and to lithium ferrite. The pure yttrium gallium and yttrium aluminum garnets are also nonmagnetic and can be used only for pure phonon propagation, while in applications where field control or frequency dispersion are desired, the magnetic materials must be used.

Three kinds of problems

The problems in microwave acoustics resolve into three areas: generation, detection and propagation. It is also possible to obtain amplification of microwave phonons and magnetic waves[4,5]. While such amplification is feasible, however, it is still far from practical application. Only pulsed amplifier operation has been achieved at room temperature and its efficiency is extremely low moreover, the noise properties have yet to be established.

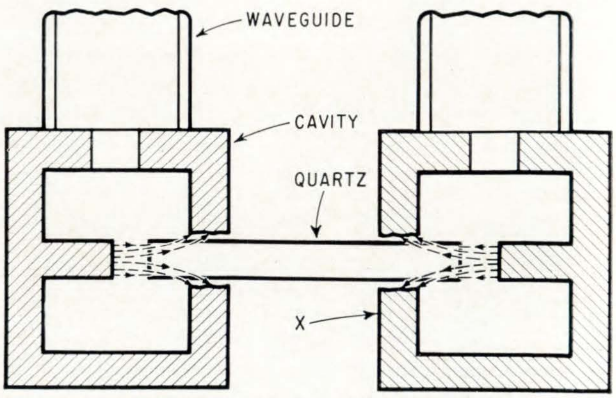
Since the generation and the detection of microwave acoustic signals involve the conversion of an electromagnetic signal to an acoustic vibration, or, in the case of magnetic waves, to a magnetic mode of oscillation, such conversion must occur in either a piezoelectric medium or a magnetic medium.

The propagation of elastic waves in solids has long been used to achieve time delay of electromagnetic signals. Until recently, however, its application was restricted to 100 megacycles and less. In 1958, Bommel and Dransfeld reported the excitation, propagation and detection of coherent acoustic waves at frequencies well in the microwave region.

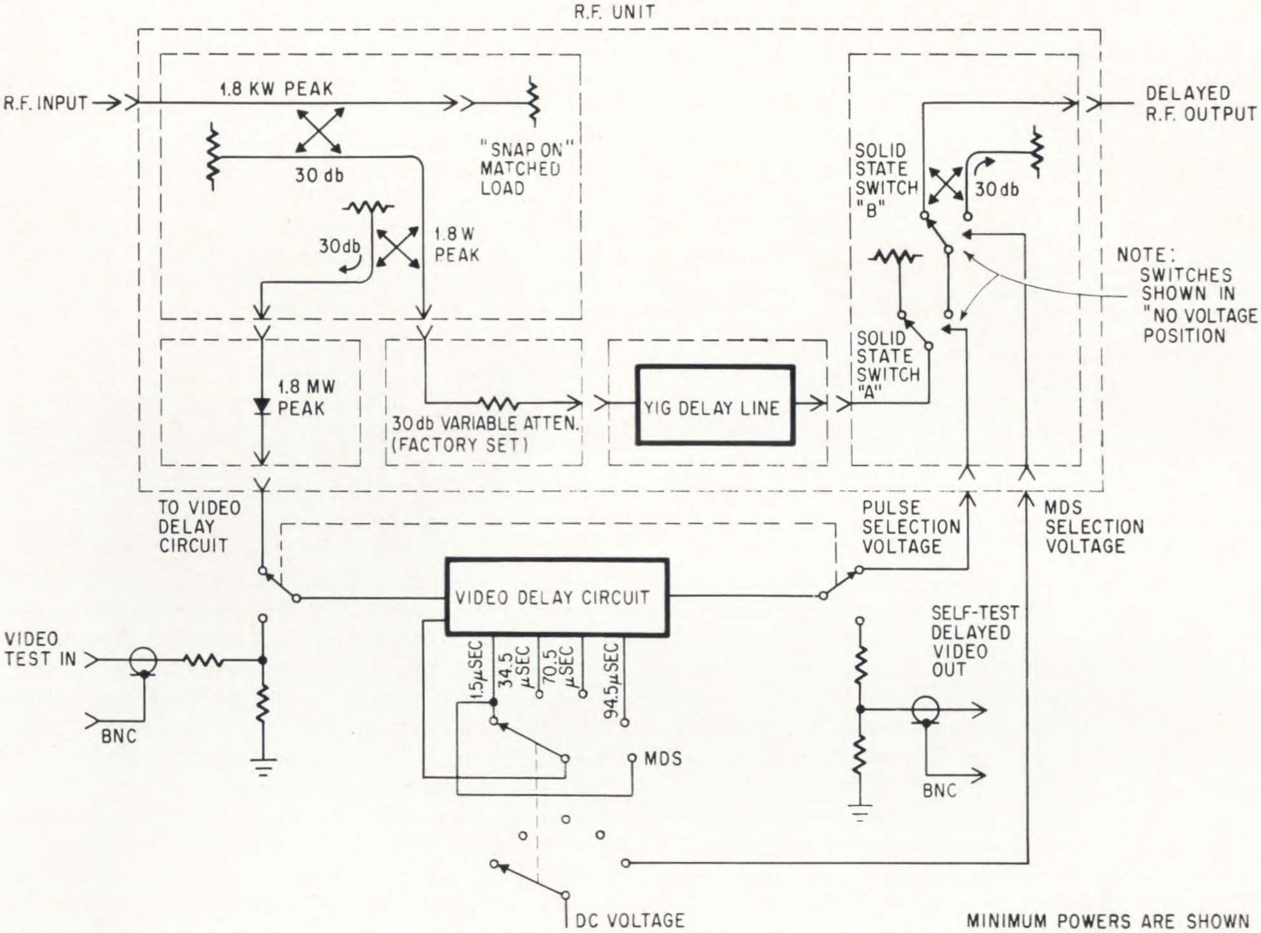
An arrangement similar to that shown below has been used extensively to study microwave phonons. The two reentrant cavities are coupled by a piezoelectric quartz rod. The transducer action, which converts the electromagnetic energy of the cavity to a vibrational wave in the quartz, occurs at the free ends of the quartz rod. The efficiency of this action is relatively low—about 10^{-3} to 10^{-4}. Most of the signal is thus reflected at the input to the quartz rod. Energy that is converted to a vibrational wave in the quartz propagates down the rod, but only a small portion is coupled out into the second cavity, and the majority of this energy is reflected from the right-hand face back down the rod toward the input cavity. As a result of such multiple reflections, it is possible to observe a succession of output pulses from the output cavity, separated by the time required for round-trip propagation of an elastic wave through the quartz.

If a delay medium other than a piezoelectric crystal is used, some form of transducer must be applied to the ends of the crystal. This transducer may be a thin quartz plate bonded to the end of the dielectric propagating medium. Since quartz transducers are fragile when cut to fundamental frequencies higher than 100 megacycles, it is usually necessary to operate on a harmonic of the fundamental frequency. Again such operation is relatively inefficient (about 10^{-3} to 10^{-4}) and the bandwidths are narrow.

A better transducer is a ferromagnetic film ap-

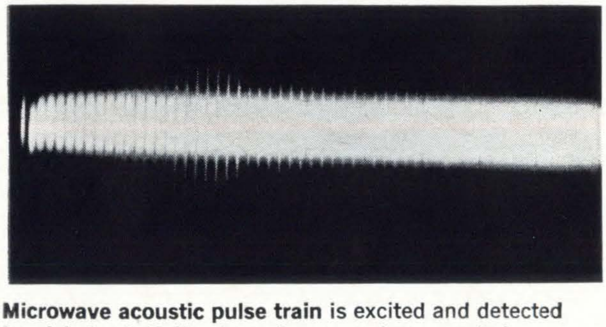


Reentrant cavities are used to study microwave acoustics. Input and output cavities are identical.



Electronic gating applied to a microwave circuit can select a single desired pulse out of the delay line output train.

plied to the end of the propagating medium. When a d-c magnetic field is applied to such a film, or when the film is magnetized, an r-f magnetic field can be used to excite precession of the magnetization (a slow rotation of the local magnetic axis) about its equilibrium direction. This precession will then excite either transverse or longitudinal waves in the propagating medium, depending on the orientation of the plane of precession with respect to the film. Such magnetic transducers may be thin films of ferromagnetic material, such as nickel or some magnetic alloy, evaporated onto the surface of a nonpiezoelectric, nonmagnetic crystal.



Microwave acoustic pulse train is excited and detected by nickel-cobalt film transducers and propagated through a single-crystal ruby rod. Time between pulses is 3.6 microseconds, and pulses are visible out to 200 microseconds.

Improved efficiency

The use of semiconductor depletion-layer transducers[6] offers some promise of improved efficiency in microwave transducer action. These transducers consist of thin, flat, high resistance depletion layers such as a p-n junction or rectifying metal-to-semiconductor contact in an extrinsic piezoelectric semiconductor. When an a-c voltage is applied across this junction, the thin depletion layer contracts or expands like the thin piezoelectric transducers discussed above. Because extremely thin depletion layers are easy to make, they can be made to have fundamental frequencies in the microwave range. As a result, they offer promise of vastly improved efficiencies and bandwidths over standard piezoelectric transducers. So far, however, the depletion-layer transducers have not achieved their theoretical efficiency, and the greatest need of the microwave acoustics field today is an efficient microwave acoustic transducer.

Excitation of magnetic waves

The electromagnetic fields also can be coupled by ferromagnetic resonance to the various normal modes of oscillation of the magnetization of a crystal. While such schemes are complex, it will suffice to say that no direct coupling to vibrational waves is required. The electromagnetic field is coupled, in this case directly to a mode of oscillation of the magnetization, which then propagates as a traveling wave through the ferromagnetic crystal. Energy can be coupled out into an electromagnetic field by a converse process, without conversion to an elastic wave. While conversion to an elastic wave is not required, it is allowed, and in some instances almost complete conversion of the magnetic wave to an elastic wave occurs as the disturbance propagates through the medium. With or without such conversion, however, it is possible to control the velocity of propagation of the magnetic or magneto-elastic wave by applying an external d-c magnetic field.

Applications of acoustic waves.

In most solids, acoustic waves propagate at 10^5 to 10^6 cm/sec. Magnetic waves propagate with similar speeds, or perhaps at 10^4 cm/sec. This low velocity leads to extremely short wavelengths. In fact, wavelengths of microwave acoustic signals are comparable to the wavelength of light—thousands of angstrom units. The velocity of propagation, which is independent of frequency for pure elastic waves, also results in a signal delay of approximately 1 to 10 μsec for each centimeter.

Until now, two methods were used for real-time delay of microwave signals. The first is the brute-force technique: using a long transmission line, usually a coiled coaxial line, strip line or waveguide. The second method involves active conversion of the microwave signal to a lower frequency signal, usually a 30-megacycle intermediate frequency. The time delay is then accomplished at the lower frequencies in solid-state lines, such as quartz, or in magnetostrictive lines using nickel or other magnetic metals. The new developments, however, have led to the possible realization of microwave delay lines with crystals only a fraction of an inch long capable of delays of 1 to 10 μsec, corresponding to radar ranges of 500 to 5,000 feet. While the insertion loss of such devices is still high, it compares favorably with that of standard microwave delay lines when delays of one microsecond and longer are sought.

Microwave delay lines using microwave acoustic phenomena are already feasible. Such lines can fall into two categories: those exhibiting fixed delay times, and those exhibiting dispersion, that is a delay time that varies with frequency or applied magnetic field. The fixed-time lines use pure phonon propagation, the variable type use magnetic wave propagation. At room temperature, the lowest phonon propagation losses are exhibited by near perfect crystals of yttrium iron garnet, while the losses in sapphire and ruby are only slightly greater.

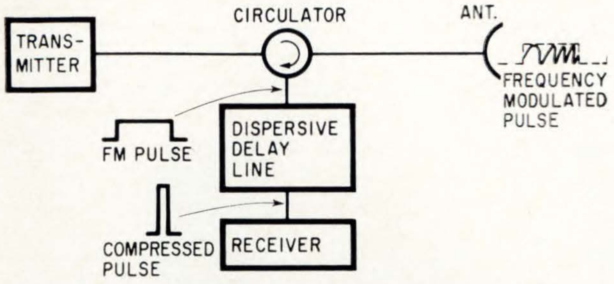
Test applications

The most immediate area of application of microwave delay lines is in test equipment. The delay device is used to simulate a target return and to provide either a calibrated return time or power level for radar or altimeter checkout, or both. The requirement here is for calibrated discrete delay times for range calibration at moderate delays of 1 to 150 μsec, corresponding to roughly 500 feet to 14 miles. Since a target return is simulated, attenuation is not important and can be 80 to 100 decibels or more. When such large attenuations are permitted, it is not necessary to employ high-Q cavities as coupling elements, and it is frequently desirable to forgo some coupling efficiency in favor of increased bandwidth. With the use of level-set attenuators, it is possible for the delay-line assembly to provide not only calibrated range points, but also calibrated signal levels for checking minimum detectable signal level.

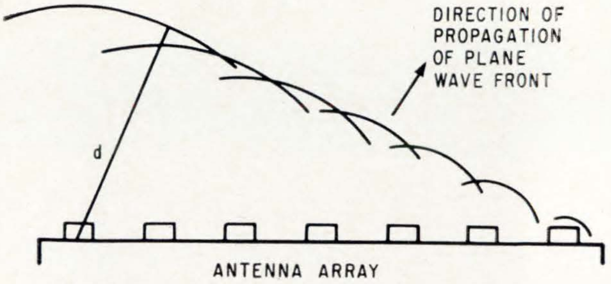
In some applications it is undesirable to have a train of output pulses such as shown on page 71. A single output pulse can be obtained by careful selection of materials or by careful design of the coupling structure. In cases where a variable discrete delay is desired, a simple electronic gating circuit can select any one pulse from the output train to provide a number of calibration points. The insertion loss of one of these pulses can be adjusted to correspond to the minimum detectable signal level of the system under test, thus providing not only a range check but also a minimum discernible signal (MDS) check. The circuit shown on page 71 accepts an input signal from the equipment under test, and provides any one of five selected output pulses. This output can be a pulse with any one of four selected delay times or simulated ranges, or it can be a pulse at the calibrated level to serve as a MDS check. The simple video delay circuit is triggered by sampling the input pulse; the circuit then actuates two solid-state switches (A and B) in the output of the r-f delay unit. Both switches are normally closed. In this position, switch A shunts output signals into the termination shown, and switch B is a direct connection to the output. On an impulse from the video delay circuit, switch A opens and allows the selected pulse from the pulse train to emerge as a simulated return at the r-f output connector. With the selector switch in the MDS position, switch A allows the first delayed pulse through, and switch B opens. This action reduces the first pulse by 30 decibels, and through factory adjustment of the variable attenuator of package number 2, this signal is made to correspond to the system MDS level.

Electronic countermeasures

In electronic countermeasures, delay lines could be used to produce false range and speed information. The circuit would receive a signal, delay it by some relatively long time, amplify it and reemit it. For applications in this type of device, the delay-line attenuation should be relatively low to reduce the required amplification, and a field-controlled variable delay could be used to provide false



Circuit using a delay line in pulse-compression radar



In an antenna array application, delay line can shape emitted beam. Distance d corresponds to the delay needed to deflect the wavefront by a selected angle.

velocity information to enemy radar.

Still another application of microwave delay lines is that of receiver protection and data comparison. In this application, delay time of the order of nanoseconds would be sufficient, but extremely low loss would be required. In such a circuit, any loss incurred in the delay unit would appear as a degradation in the noise figure of the receiving system. For this reason, low losses are important, and transducer loss, which at present is a major limitation in microwave delay lines, could not be overcome by any amount of subsequent amplification, however low the noise accompanying such amplification may be. It may be feasible, however, to precede the transducer by low-noise amplification. In operation, this protective circuit would serve as a limiter, and if the signal were above some threshold, the switch would be opened by the action of the power sensor, thus protecting the receiver from burning out.

Antenna applications

Another application of microwave delay lines, and again one involving very low-loss delay circuits, is in the area of large-plane, phased-array antennas. Real-time delays are designed between antenna elements at different parts of the array. For example, a real-time delay of approximately 10 nanoseconds would be needed between two antenna elements 20 feet apart if the transmitted pulse is to be sent out at an angle of 30 degrees from the line normal to the array. The geometry of such an array is sketched above. This application requires very low loss and very short, controllable real-time delays.

Delay lines with field-controllable delay times also exhibit a frequency-dispersive delay. Delays of this type could be used in pulse compression systems. Here the transmitted signal is a relatively long frequency-modulated pulse as shown at left. If the receiver contains a frequency-dispersive delay line, the frequency components are delayed by different times, and by proper control of this dispersion, all the energy of the return signal can be made to coincide, producing tremendous pulse compression and enhancement of the return signal. Frequency spreads of one to 20 megacycles are typical and, by all indications, losses will be low.

The field-controlled delay devices could also be used to provide reference signals in pulsed doppler radars and range gates in moving-target indication. All such applications, however, require that delay-line losses be kept to a minimum.

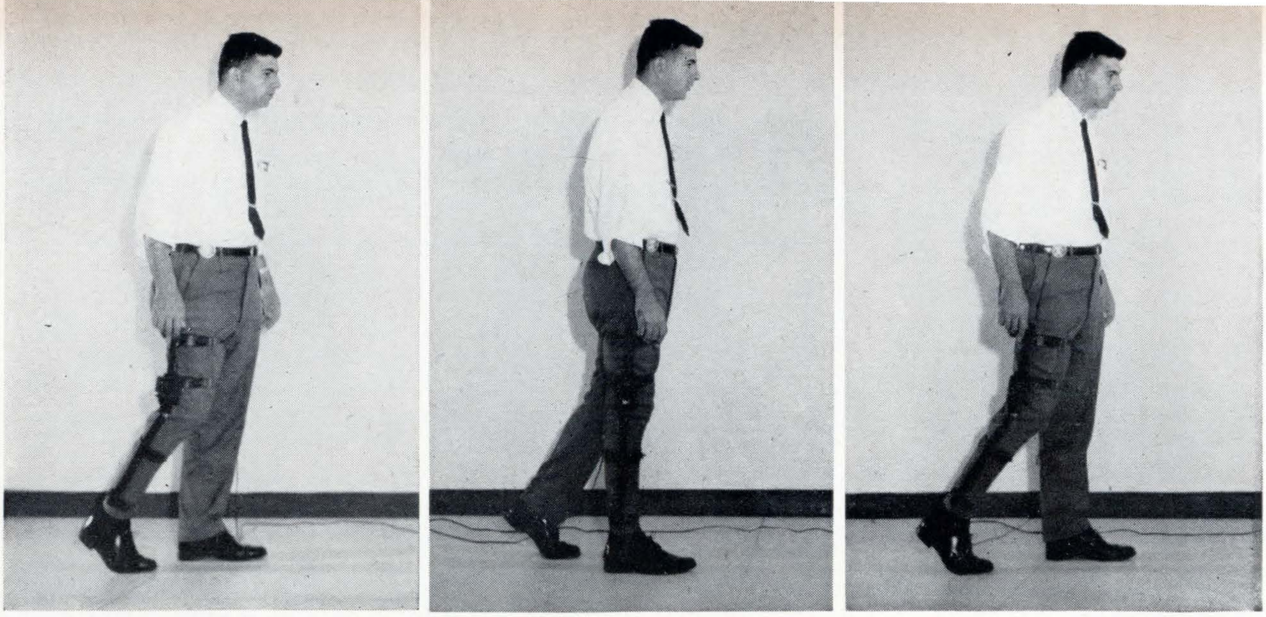
Several ideas have been proposed for reducing transducer loss; the chief one is the use of depletion-layer transducers, which have high fundamental frequencies, high theoretical efficiencies and large bandwidths. Nonlinear pumping of elastic waves in a ferromagnet might also be used to minimize transducer loss in delay lines or other magneto-elastic devices by applying in-phase acceleration only to the desired signal.

Other more exotic applications of microwave acoustics involve microwave mixing in acoustic parametric devices such as in amplifiers, harmonic generators, oscillators and limiters. These applications are remote at present because of the relatively high power necessary to achieve parametric action. Since the wavelength of microwave acoustic radiation in a solid is comparable to optical wavelengths, several devices have been proposed based on an optical-acoustic interaction. Acoustic waves propagating in a material such as quartz, rutile or sapphire will exhibit either a standing- or traveling-wave pattern, depending on the losses and terminations of the crystals. Since the wavelength of this microwave radiation is now comparable to optical wavelengths, the acoustic wave in the crystal forms a moving diffraction grating, and it is possible to obtain diffraction of light beams by the acoustic wave. This application has been demonstrated[7].

Microwave acoustic delay lines available now fall principally in the test-equipment area. They give delays of one microsecond to several hundred microseconds, depending on the operation. Insertion losses are 40 decibels and up, and bandwidths of several hundred megacycles are available.

References

1. H. Bommel and K. Dransfeld, Physics Review, Letters 1, p. 234 (1958); 2, p. 298 (1959); 3, p. 83 (1959).
2. E.H. Jacobsen, Physics Review Letters 2, p. 249 (1959).
3. J.R. Eshbach, Physics Review Letters 8, p. 357 (1962).
4. A.R. Hutson, J.H. McFee and D.L. White, Physics Review Letters 7, p. 237 (1961); K. Blotekjaer and C.F. Quate, "The Coupled Modes of Acoustic Waves and Drifting Carriers in Piezoelectric Crystals," Technical Report, July, 1963 Microwave Laboratory, Stanford University, Contract Nonr 225 (48) (NR 373-361).
5. H.S. Shiren, Application Physics Letters 4, p. 82 (1964); Physics Review Letters 11, p. 3 (1963).
6. D.L. White, IRE Trans UE-9, p. 21 (1962).
7. C.F. Quate, H.J. Shaw, C.D.W. Wilkinson and D.K. Winslow, "Diffraction of Light Waves by Hypersound," Microwave Laboratory Report No. 1141, Microwave Laboratory, Stanford University, Contract Nonr 225 (48) (NR 373-361) and Contract AF 33 (657)-11042.



Medical electronics

Paralytic's brain + Myocoder = Hope

Body signals are being used to control a leg brace.
Next step may be natural use of an artificial limb

By Lee Harrison

Bio-technology laboratory, Philco Corp., Blue Bell, Pa.

Electronics is holding out new hope for paralytics. A system has already been demonstrated that picks up nerve signals at the skin surface, amplifies them, and uses them to operate a leg brace.

So far only a laboratory prototype exists. But the maker—the bio-technology laboratory of the Philco Corp.—says that this could be the basis for a family of artificial limbs and electronically controlled braces to help damaged limbs operate naturally.

Philco used computer analysis to show that specific patterns of nerve signals can be isolated out of the tens of thousands that the brain generates to control body movement. These isolated patterns are directly related to specific movements and can be used to control artificial limbs.

The Philco study is financed partly by the Navy. Researchers say the system picks out specific nerve signals in the same way that the military identifies camouflaged missile sites in aerial photographs.

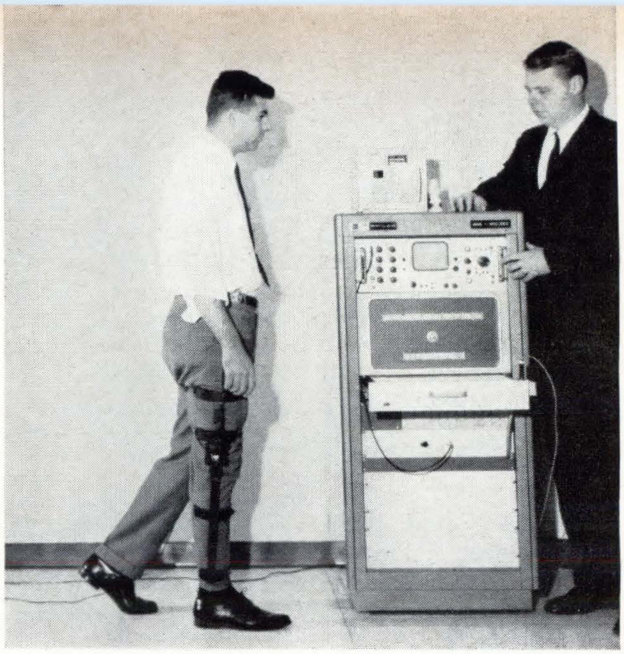
To use the computer program, Philco designed equipment to process and encode the nerve signals. Called a Myocoder, this device is believed to be the only one of its type.

To crook a finger

To move a muscle, the brain first generates small electrical signals, called electromyographic or EMG potentials. These travel from the brain through the central nervous system to motor points and then to the motor units that include junctions where a nerve ends and muscle fibers begin [top drawing, p. 75]. The central nervous system routes the signals to the required muscles. This action is automatic; a human isn't even conscious that it's happening. The motor units are fired, or energized, independently of each other.

The fibers of the various motor units needed to perform an action are intermingled throughout the muscle. The apparent asynchronous energizing of many fibers of many motor units generates an EMG signal that appears to be plain noise.

◀ **Leg brace** is operated by muscle-controlling nerve signals. Serge Minassian, a Philco design specialist, simulates a paralytic as Lee Harrison watches. ▶



Monitoring the EMG signal and making control sense out of it is the goal of Philco's tests.

The body's own control signals

For controlling prosthetics, or artificial limbs, orthotics such as a leg-brace, and similar devices, the EMG signal has three control features that can be exploited.

▪ Many control signals can be generated simultaneously simply by thinking. The central nervous system does the processing and routing job.

▪ EMG signals are reliable and unaffected by gravity, either constant or varying. Actuators receive control signals at the same time as the muscles affected. These actuators could be used, for example, to help astronauts or pilots control a craft under heavy buffeting. There would be no phase-lag problems.

▪ An EMG control system can be very small and simple, lending itself to microelectronics.

The prototype leg-brace shown above, operates through a transducer on the skin surface of the calf. With the help of a device to amplify and process the signal, the EMG energizes a solenoid's windings, which pull a plunger to unlock the brace at the knee.

Patterns give the answer

To get a useful signal from the voltages generated beneath the skin, the Philco technique detects patterns in the voltage fields on the skin surface rather than individual signals. There are three reasons for this approach.

▪ An individual muscle acts as a diffused signal source. Although there are points of maximum signal activity—motor points—no one point within the muscle appears to give a total measure of over-all muscle activity.

▪ By the time signals reach the transducer they are no longer individual; they have been attenuated and intermingled by intervening layers of muscle tissue, fat, and even the skin itself.

▪ Almost all body movements for which usable control signals must be found involve groups of muscles—there is no one area of signal activity.

A pattern-detection approach may also allow EMG signals to be put into a common range, or normalized, though varying from person to person.

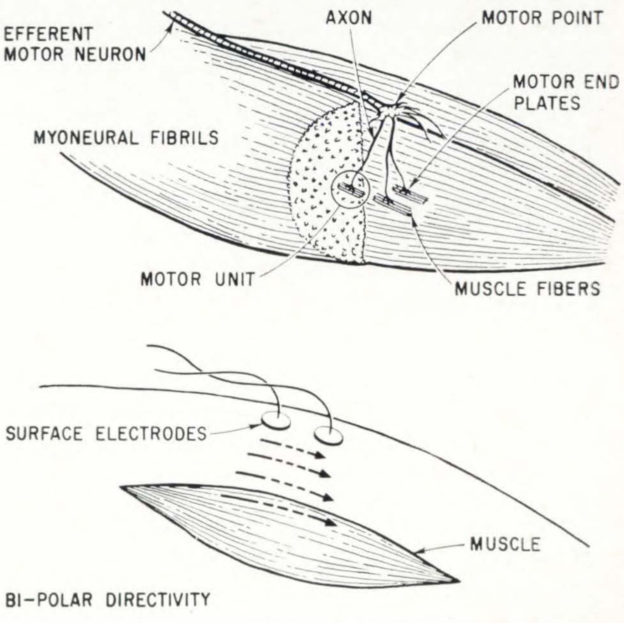
With the prototype leg-brace, Philco broke away from the "deterministic" approach that has been followed by other researchers. The orthodox method required a thorough understanding of the characteristics, patterns and changes of an enormous variety of nerve signals. This method's success has been limited by lack of information.

Philco's nondeterministic approach presumes only that all patterns fall into one of two statistical classes, and that any pattern contains many variables. The computer examines the patterns of both classes and finds the characteristics that distinguish one pattern from the other. These characteristics are used to form "discriminating masks" that classify future patterns.

Devising the program

The experimental program began with a preliminary data-gathering phase and a study of the literature already available on EMG. The preprocessing electronics equipment was designed on the basis of this study; instrumentation was planned for collecting, processing and analyzing data.

Before data-taking equipment could be designed, something had to be known about the EMG signal. The first task was to extract some meaningful parameter from the noise-like waveforms. This was



A signal to crook a finger comes through the central nervous system to the motor point and then to a motor unit—the junction where a nerve ends and muscle fibers begin. Two silver disk-electrodes are spotted on the muscle at the point of maximum nerve-signal amplitude.

accomplished in the preliminary signal analysis. Examination of EMG signals showed an increase in amplitude and frequency with increasing muscle force. However, measurements showed the root-mean-square value of the waveform to be more nearly linear with force than either amplitude or frequency.

In processing the signals for computer analysis, the rms value is extracted and quantized.

A biological data-collector

The preprocessing electronics consists of devices that amplify the raw EMG waveform after it is picked up by the electrodes, extract the rms value and quantize, or assign numerical values, for subsequent computer processing. This equipment was designed, built and packaged into a unit called the Myocoder, shown at the top of page 77.

In processing and quantizing the amplified signals are rectified, integrated, converted from analog form to digital, then from binary to decimal form, and printed out.

The Myocoder simultaneously samples six channels of EMG signals, using two electrodes connected to one myographic amplifier for each channel. Using six channels appears to give enough data to define patterns of nerve-signal activity.

EMG amplifier

The myographic amplifier [diagram, p. 77] is a high-gain differential unit with an input EMG signal range from 10 to 100 microvolts rms. Maximum calculated gain is about 400,000. Common-mode noise rejection is 45,000, with an equivalent noise input of about six microvolts. The amplifiers are differential types because the twin silver disk-electrodes are not referenced to any particular point in the system and extraneous signal interference such as powerline radiation (60 cycles per second) may be common to both electrodes.

In operation, the amplifiers increase the myographic signal by a factor of 180,000. The frequency response is from 20 to 5,000 cycles per second, with a notch filter at 60 cycles. For some monitoring tests it was necessary to attenuate the input signal to avoid clipping because of the high gain.

A cascade design

The basic myographic amplifier consists of two commercially available units in cascade. The first is a Burr-Brown Research Corp. model 9520, a general-purpose operational amplifier with differential input and output and a low-input noise rating.

The second unit is a Burr-Brown model 9462, an instrumentation amplifier with differential input, a 90-decibel common-mode noise-rejection rating and a gain of 1,000.

Redesigning the feedback loop

The high over-all gain of the 9462 unit during initial tests caused frequent re-adjustment of the d-c balance of the 9520 amplifier to maintain operation over the maximum linear range of the cascade system. This led to redesign of the feedback loop around the first amplifier as shown on page 77. Another was the fact that preliminary results showed that d-c, or very-low frequency, information was unreliable because of galvanic effects at the points where the electrodes meet the skin.

There is no d-c return in the feedback loop of Z_1 (R_1 in parallel with C_p) and Z_2 (R_2 in series with C_s). It is essential that capacitors C_s have low d-c leakage.

The gain of the amplifier system is equal to Z_1/Z_2 (assuming a generator of zero impedance in series with Z_1) so that at d-c Z_1 is infinite and the gain is zero. The mid-range gain is simply the ratio R_1/R_2, equaling 100. Actually R_1 is shunted by a finite impedance of 100,000 to 500,000 ohms, and the gain exceeds 100. The reactances of C_s and C_p set the lower (20 cps) and the upper (5 kc) cut-off frequencies, or 3 db points.

Because the input electrodes are shunted by $2R_2$, the input impedance is 20,000 ohms and the system's gain, from equivalent generator at the motor point to the output, is a function of the equivalent impedance of the source. This source impedance includes the effects of flesh, hair, bonding cream, electrode pressure and electrode orientation. Typical equivalent impedance averaged 20,000 ohms for the particular type of electrodes being used and for the method of attachment. Simulating this impedance in an experimental setup gave an over-all measured gain of 180,000. This was done by placing 10,000 ohms in series with each side of a low impedance generator.

The relatively low input impedance of the amplifier helped to increase its immunity to interference signals. Contact resistance effects were not noticeable.

Preprocessing, counting and print-out

The stage following the myographic amplifiers is the processing section of the Myocoder. Its dynamic range is 15 volts, peak-to-peak. Preprocessing involves converting the analog signal into a pulse-train of meaningful data. The number of pulses per unit of time represents the significant, or rms, portion of the EMG signal.

The counting section totals the pulses during a sample time that can be varied from 50 to 500 milliseconds.

The counter has two modes of operation—preset number of samples or free-running samples. Pressing a button on the Myocoder causes the counter to operate for preset number of sampling periods, print out the results and turn off. In free-running operation, samples are taken continuously and printed out. Both modes are helpful in watching muscle action simultaneously with data print-out.

Two kinds of body motion

Bipolar electrodes were attached to six spots on the muscles of the shoulder girdle [p. 77]. The exact locations were determined by having the subject perform certain motions. Two classes of nerve-activity motion were defined: class A, or motion involving raising the arm straight forward until it was perpendicular to the body, and class B for all other motion.

During this motion, myographic signals were monitored on the Myocoder's oscilloscope. When the electrodes were over an area of maximum signal amplitude, they were taped to the skin. A contact cream wetted the two electrodes spaced one inch apart.

Using the Myocoder, 10 to 12 lines of data were taken for each sample pattern. Each line consisted of six 2-digit numbers representing the output of each myographic amplifier, integrated over 100 milliseconds.

About 100 samples of class A patterns and of class B were recorded. Seven rows from each sample were then used to make a workable matrix of 42 numbers; these were converted into computer language, punched into cards and fed into a Philco S-2000 computer.

Processing the data

The tests resulted in a mass of samples in both classes. The computer program for classifying and separating patterns is called Multinorm. It classifies patterns according to their characteristics and separates them on the basis of the "universally optimum" likelihood ratio. This ratio is probability of picking a particular sample if one is unknowingly looking at "A" samples, compared with the probability of picking the sample if one is looking at "B" samples. If the likelihood ratio for a given sample is greater than one, that sample should be class A; if less than one, it should be class B.

This ratio, once established, is used to design a weighting function that is then used to separate new samples.

After the computer has calculated what the weighting function should be, on the basis of the first 50 samples of each class, the function is tested on all 200 samples, and scores for each sample are printed out together with the weighting function used. A score is the sum of the 42 variables and their weighting elements within one sample.

The weighting function is actually the detection mask for separating the patterns. Mathematically it is

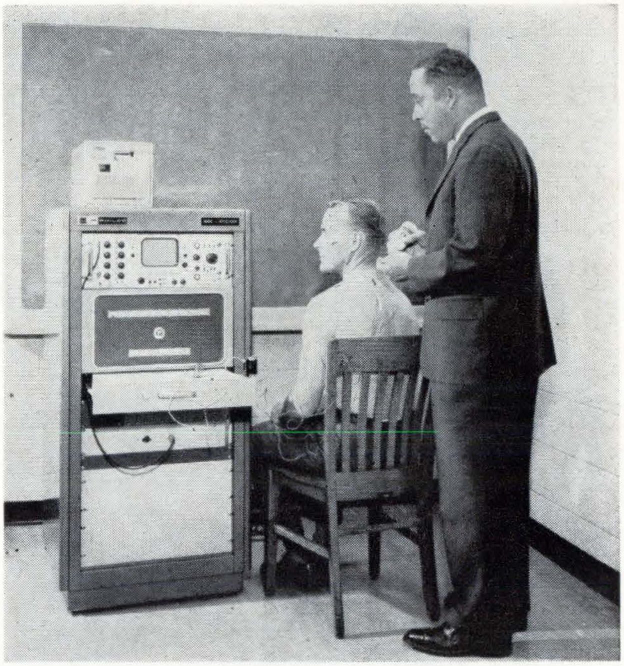
$$\Sigma a_i x_i + \Sigma b_i x_i x_j = C.$$

The first term is the linear term, the second the quadratic, and C is a constant that represents a signal threshold. The a_i's and b_i's are the weighting elements.

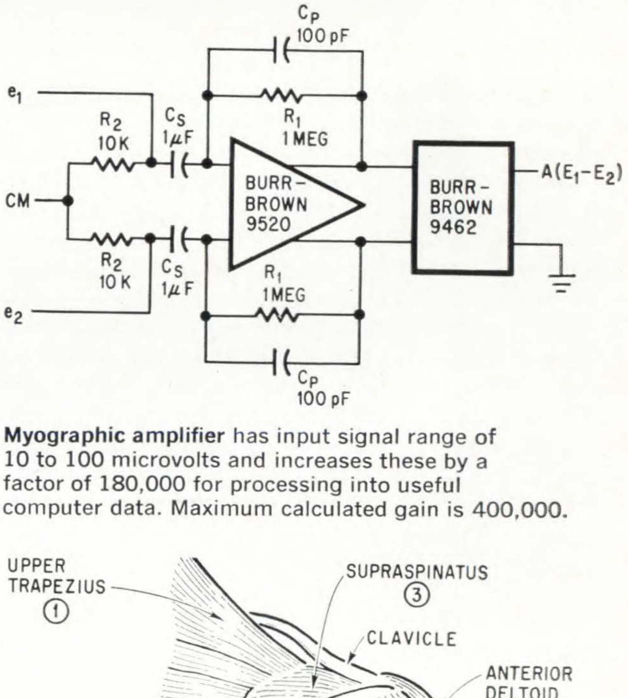
The first term represents a direct, linear weighting of each of the 42 numbers in the sample. The second term is the direct linear weighting of the product of each pair of numbers ($x_i x_j$) and of the squares of individual numbers ($i = j$).

The scores are then plotted for the best selection of C, the threshold.

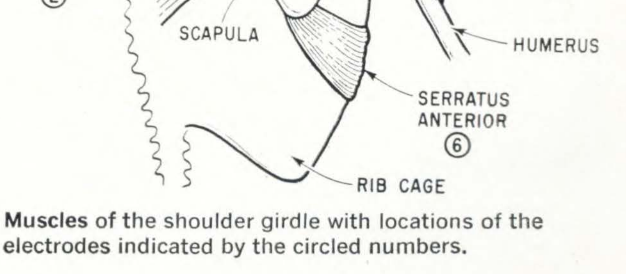
The first time the program was run, the score



Myocoder on the left collects six channels of EMG data from the transducer-pairs placed on the shoulder muscles of Roy Wirta, a senior engineering specialist. Philco's physiologist, F. Ray Finley, checks the setup.



Myographic amplifier has input signal range of 10 to 100 microvolts and increases these by a factor of 180,000 for processing into useful computer data. Maximum calculated gain is 400,000.



Muscles of the shoulder girdle with locations of the electrodes indicated by the circled numbers.

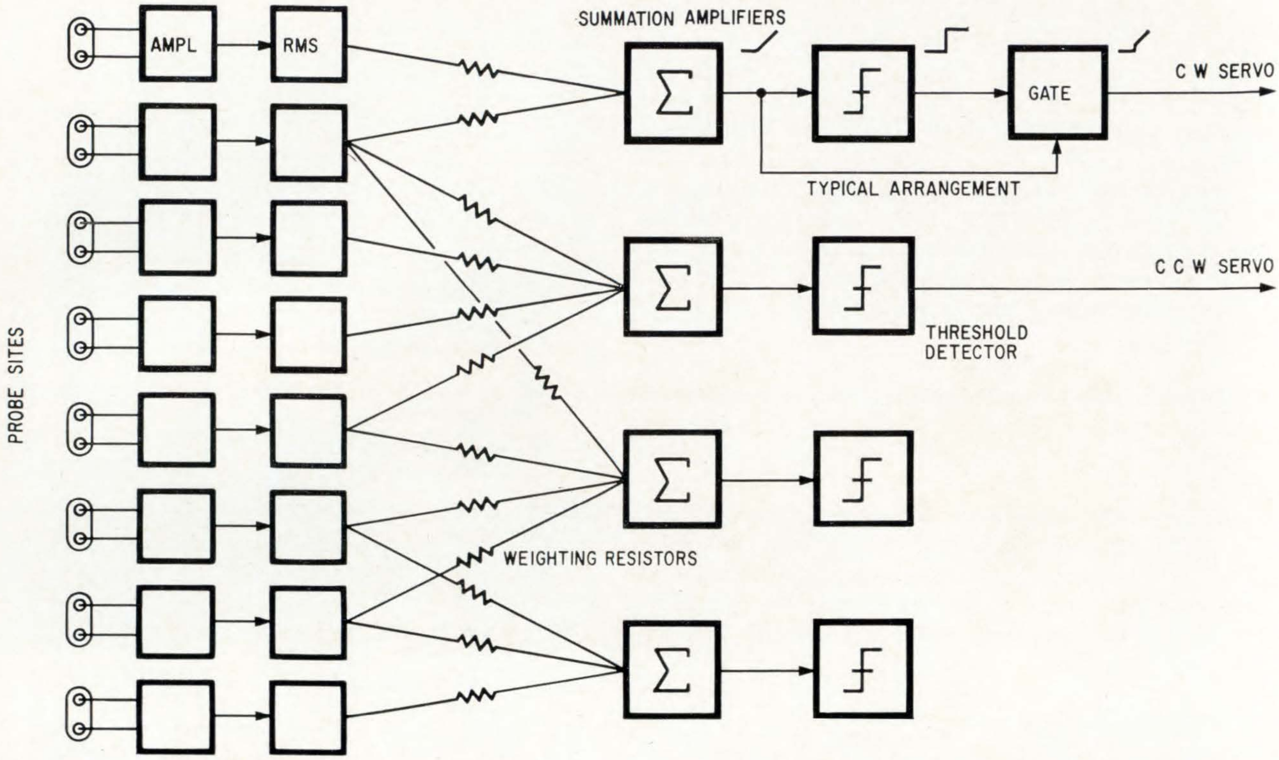


Diagram for the future. Microelectronic EMG signal processing equipment could well take this form. This is the logic for linearly discriminating EMG signals.

plot showed 100% separation of the two classes of motion. But separation was made on the basis of all data taken over the entire period of arm motion.

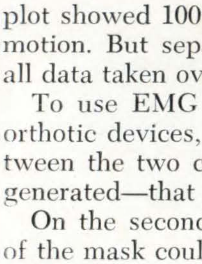
To use EMG signals to control prosthetic and orthotic devices, it is necessary to discriminate between the two classes while the signals are being generated—that is, for each separate line of data.

On the second computer run, the linear portion of the mask could not completely separate the patterns of individual data lines. On the third computer run, the quadratic term was also used as part of the mask, and complete separation was achieved.

This indicates that real-time processing networks could be built that would discriminate between the various motions and their particular EMG patterns.

These networks would be a package of first-quadrant multipliers and weighting resistors representing the "mask" function, shown above. But work, to define these rough EMG signals and the exact nature of the nerve-control process, is still needed.

The author



Lee Harrison decided to combine his interest in medicine with his training as an engineer after watching his brother perform a five-hour heart operation simply to measure the flow of blood from a diseased organ. He suspected that the result could have been done electronically. Now, as an engineer at Philco, he designs equipment to measure body signals.

Signal patterns determine body motion

In these experiments, Class A nerve activity was defined as activity required to move the arm straight forward and up. Class B was established as "everything else," such as raising the arm to the side, placing a hand behind the head, relaxing the arm, and so on. The B pattern that was closest to an A pattern and able to be defined was raising the arm 45° from a plane that would represent an arm raised straight forward and up. This shows that the patterns and the specific usable signal for each possible body movement must still be determined.

Further studies are seeking a relation between EMG signals and arm-movement speed, acceleration from one point to another, and arm positions.

The Philco study's basic finding is that biological signals of the EMG type can be found and quantized quickly and easily with the aid of a computer.

Efforts are also being made to determine some relation between fatigue and EMG, and between blood pressure and EMG. If a blood-pressure indicator can be found that is easy to monitor, microelectronic transmitters could be built without the need for placing transducers within the body. These could be used to reliably monitor the heart conditions of cardiac patients while they go about their normal activities. The system would be as simple to install as strapping on a watch.

This research was sponsored jointly by the Philco Corp.'s independent research - and - development fund and by the Office of Naval Research's psychological sciences division, engineering psychology branch.

ELECTRO INSTRUMENTS ANNOUNCES

NEW LINE

OF DIGITAL CAPACITANCE METERS

PROVIDING RAPID, PRECISE MEASUREMENTS WITHOUT TEDIOUS MANUAL ADJUSTMENTS

By Dr. Walter East
President, Electro Instruments, Inc

It is always a satisfying experience to introduce a product which is an improvement over anything in its field. But it is doubly satisfying when the improvements inherent in the product are such that they may open up whole new areas and fields of usage for it. That may well be the case with our new line of Digital Capacitance Meters.

Their primary users will continue to be those industries and firms which have a need to measure capacitance to highly precise degrees. As electrical engineers are well aware, this has heretofore required the services of a technically competent operator, and the measuring process itself could not be accomplished with any degree of accuracy in less than minutes of time.

Offer Production Savings

Our new capacitance meters, by completely eliminating the need for manual adjustment, make capacitance measuring a job which can now be handled by relatively unskilled personnel. Also, they cut the time element involved to less than a second. On both counts, therefore, these new capacitance meters offer such firms as manufacturers of electronic components, and manufacturers who utilize such components, valuable production savings.

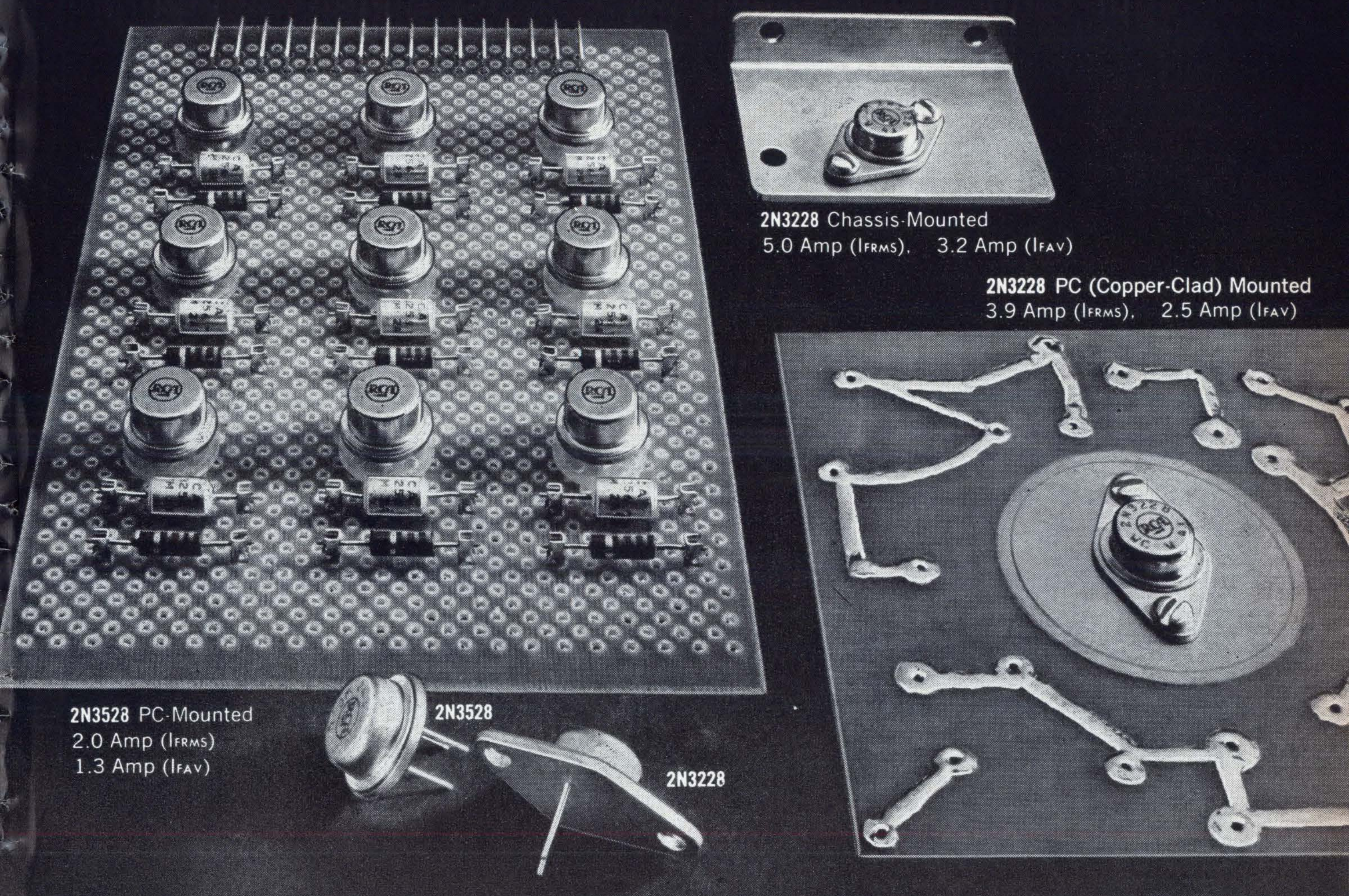
Other Possible Uses

But I can visualize a practical use for these new meters on research and manufacturing jobs where capacitance meters are not now normally employed. Automatically monitoring thicknesses, molecular structure, insulating properties of such solids as paper, plastics, fabrics—and many forms of liquid and gaseous matter.

Let one of our field sales engineers acquaint you with the advantages of our new digital capacitance meters today. Or call or write me directly.

Electro Instruments, Inc.
8611 Balboa Avenue San Diego, California 92112

ELECTRO INTERNATIONAL, INC., ANNAPOLIS, MD. • TRANSFORMER ENGINEERS, SAN GABRIEL, CALIF.



RCA 2N3528 Joins 2N3228

announcing another new low-cost RCA silicon-controlled rectifier

NOW RCA OFFERS A CHOICE OF ECONOMY-PRICED SCR'S IN SPACE-SAVER TO-8, OR DIAMOND PACKAGES, FOR 120- AND 240-VOLT LINE OPERATION

RCA introduces a new robust Silicon-Controlled Rectifier, 2N3528, companion to RCA's 2N3228 in the diamond package. The RCA 2N3528, in TO-8 case, joins RCA's family of low-cost SCR's designed for mass-produced appliances and for commercial and industrial power controls. Check the chart for types intended for 120- and 240-volt operation.

The new 2N3528, a lead-mounted unit, is rated at free air temperature and can be mounted directly on printed circuit boards. If you prefer, you can use a copper-clad printed circuit board as a heat sink with the RCA 2N3228. Mounting sockets are available for both SCR packages.

No matter what your product design may be—kitchen white ware, hand-held appliances, industrial relaying, card readout, solenoid drives, solid-state switches, light-dimming, or high-level logic systems—you have the ideal choice in the 2N3228 family.

Call your RCA Representative today for complete details, price, and delivery information on these and other RCA Silicon-Controlled Rectifiers. Application engineering assistance is available. For technical bulletins write: RCA Commercial Engineering, Section RN11-5, Harrison, New Jersey.

RCA ELECTRONIC COMPONENTS AND DEVICES, HARRISON, N. J.

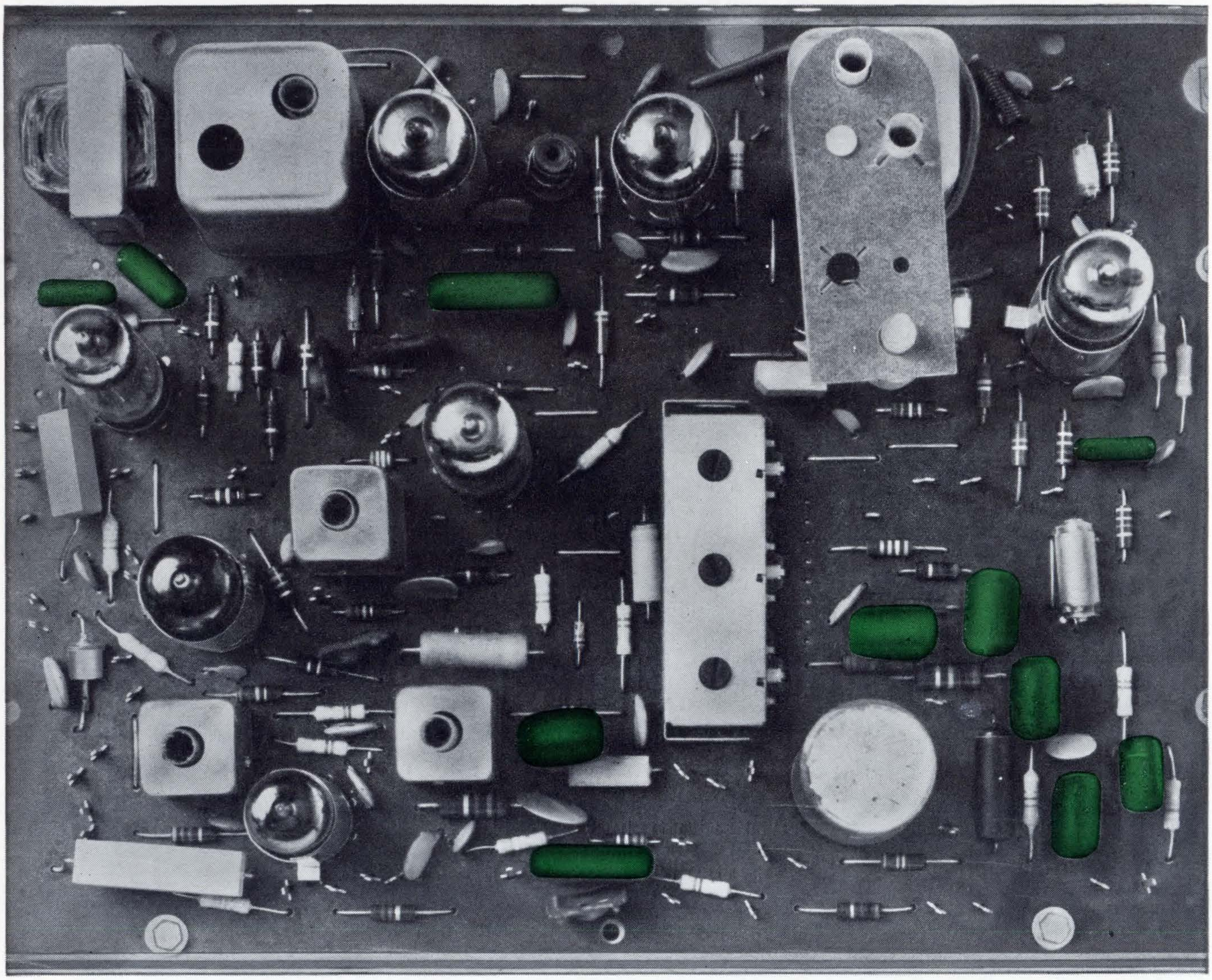
V_{RM} CASE RATINGS	DIAMOND PACKAGE		TO-8 PACKAGE		
	2N3228	2N3525	2N3528	2N3529	
Transient Peak Reverse Voltage (non-repetitive) V_{RM} (non-rep)	330	660	330	660	volts
Peak Reverse Voltage (repetitive), V_{RM} (rep)	200	400	200	400	volts
Peak Forward Blocking Voltage (Repetitive), V_{FROM} (rep)	600	600	600	600	volts
Forward Current @ $T_C=75°C$ and with heat sink AV DC Current I_{FAV}*	3.2	3.2	–	–	amps
RMS Value I_{FRMS}	5.0	5.0	–	–	amps
Forward current @ $T_{FA}=25°C$ and without heat sink AV DC Current I_{FAV}*	–	–	1.3	1.3	amps
RMS Value I_{FRMS}	–	–	2.0	2.0	amps

*at 180° conduction angle.

AVAILABLE THROUGH YOUR RCA DISTRIBUTOR

The Most Trusted Name in Electronics

Circle 81 on reader service card



In Westinghouse TV, capacitors of "Mylar"® replaced those of molded paper–

Bob Tesno, TV Engineering Supervisor, tells why:

1. Reliability

"We ran extensive tests comparing capacitors with a dielectric of 'Mylar'* with ones of paper, molded paper and dual dielectric. We found that the capacitors of 'Mylar' came out on top—with virtually no temperature, humidity or leakage problems. In the four years since their adoption, the reliability of capacitors of 'Mylar' in the field has been nearly perfect."

2. Size

"Actually, we first adopted capacitors of 'Mylar' for all Westinghouse TV receivers when printed circuit boards became important factors in production. Capacitors of 'Mylar' are considerably smaller than molded-paper ones of equivalent value. This avoids crowding of components on the board."

*Du Pont's registered trademark for its polyester film.

3. Price

"As a clincher," adds Tesno, "in most cases* capacitors with a dielectric of 'Mylar' cost no more, and, in fact, often cost less than molded-paper or dual dielectric capacitors." *(Note: This applies to capacitors that are up to .1mfd 400v in size.)

Can your designs benefit from the many advantages of capacitors of "Mylar"? For complete data, write Du Pont Film Dept., N10452 B-22, Wilmington, Delaware 19898.

DU PONT
REG. U.S. PAT. OFF.
Better Things for Better Living
...through Chemistry

only DU PONT makes
MYLAR®
POLYESTER FILM

Probing the News

Military electronics

Electronics at the bottom of the sea; Navy outlines $200-million program

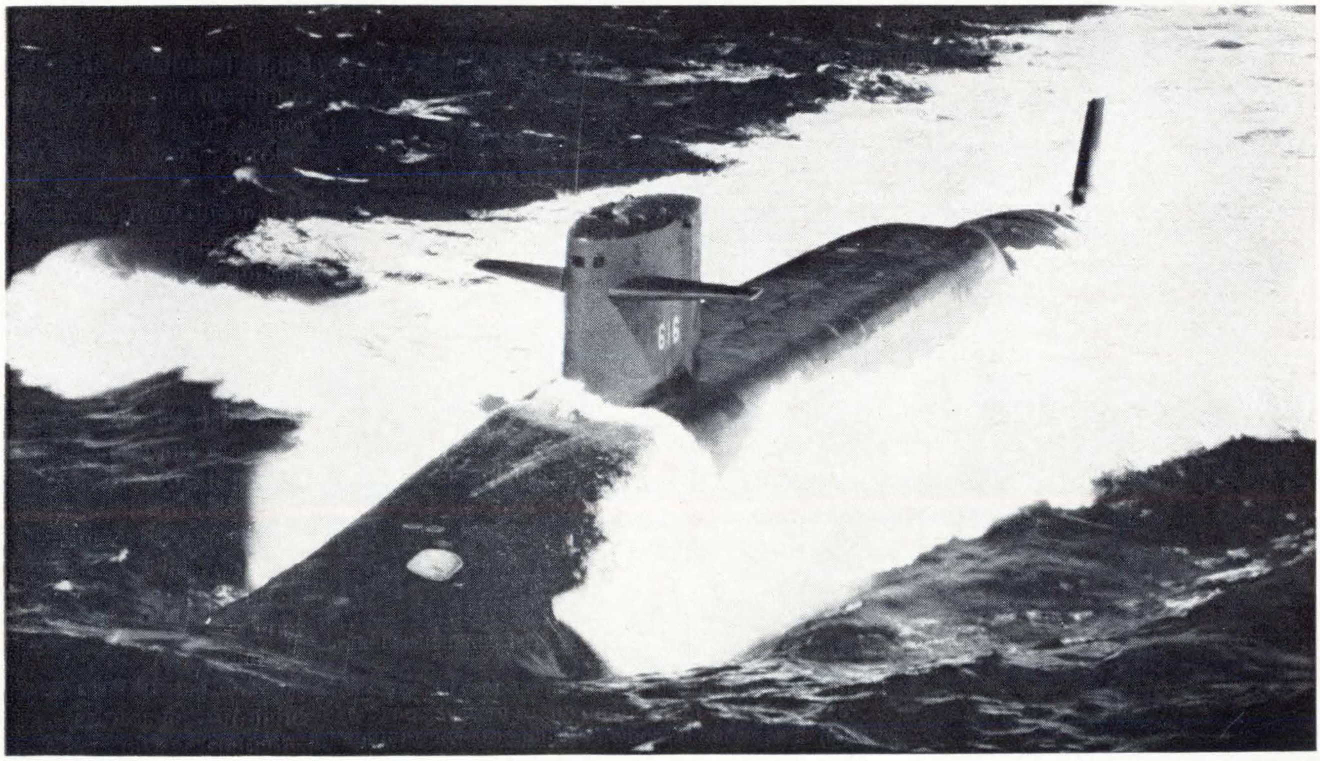
Deep-submergence project will improve man's ability to work deep in the ocean so seamen in disabled submarines can be rescued

The Navy, in one of the most ambitious deep-submergence programs ever, is planning to spend about $200 million over the next five years on techniques and equipment that will let man work at the bottom of the ocean.

At a briefing in Washington last week to which 450 industry representatives were invited, Navy spokesmen outlined the project. There will be heavy outlays for electronic equipment, and industry was alerted to expect stiff competition.

The main thrust of the program is to improve the Navy's ability to find and rescue disabled submarines. The loss of the submarine Thresher and its 129-man crew in April, 1963, spotlighted the need for a reappraisal of submarine search and rescue techniques. However, the deep-submergence systems program that was outlined by Joseph Cestone, chairman of the sensor committee set up by the Navy's special projects office, goes much further.

Techniques and equipment that will permit man to work on the ocean floor for extended periods will be valuable not only in rescue and recovery but in antisubmarine warfare, where detection sensors must be mounted and maintained at the bottom of the ocean. Equally important are wide commercial applications such as tapping minerals



Navy's deep-submergence program calls for modification of nuclear powered submarines. Small rescue vessels will ride piggyback to disaster area, then detach from mother submarine to perform rescue operations.

in seawater, drilling for oil, mining beneath the ocean floor and fish farming.

I. Search and rescue

The Navy plans call for a 12-man rescue craft of limited mobility that will be carried piggyback on a modified nuclear-powered submarine. The small craft will detach from its mother submarine to rescue personnel from a stricken submarine, either ferrying them to the mother submarine or to a surface ship. The rescue vessel will be light enough to be flown to the port nearest a disabled submarine.

Rescue vessels will be able to function at the maximum depth of today's submarines—about 6,000 to 8,000 feet. Rescue vessels' depth capabilities will be improved as deeper-diving submarines are introduced.

With the new rescue system, the Navy will have to modify its submarines so they will mate with the rescue vessels and be able to carry them piggyback to disaster scenes. It is still unclear whether this modification is intended to apply only to nuclear-powered submarines.

II. Electronics

Committee chairman Cestone believes that off-the-shelf equipment will account for 80% of the electronics in the deep-submergence program. He is urging companies with hardware that can be used in the program to communicate with him at the Navy's Special Projects Office in Washington.

Biggest problem. Perfecting sonars for search vehicles, says Cestone, will be the biggest problem: the goal is to find and identify objects as small as four inches at depths to 20,000 feet.

Cestone believes the problem will concern the switching frequencies needed for better imaging when a search is made for small objects like defective pieces of sunken submarines, or when ocean-bottom structures are being installed or maintained.

Electronic equipment will be expected to identify objects within 30 feet of the search vehicle. Submarine sonar now searches over long distances for objects that may be as large as a submarine.

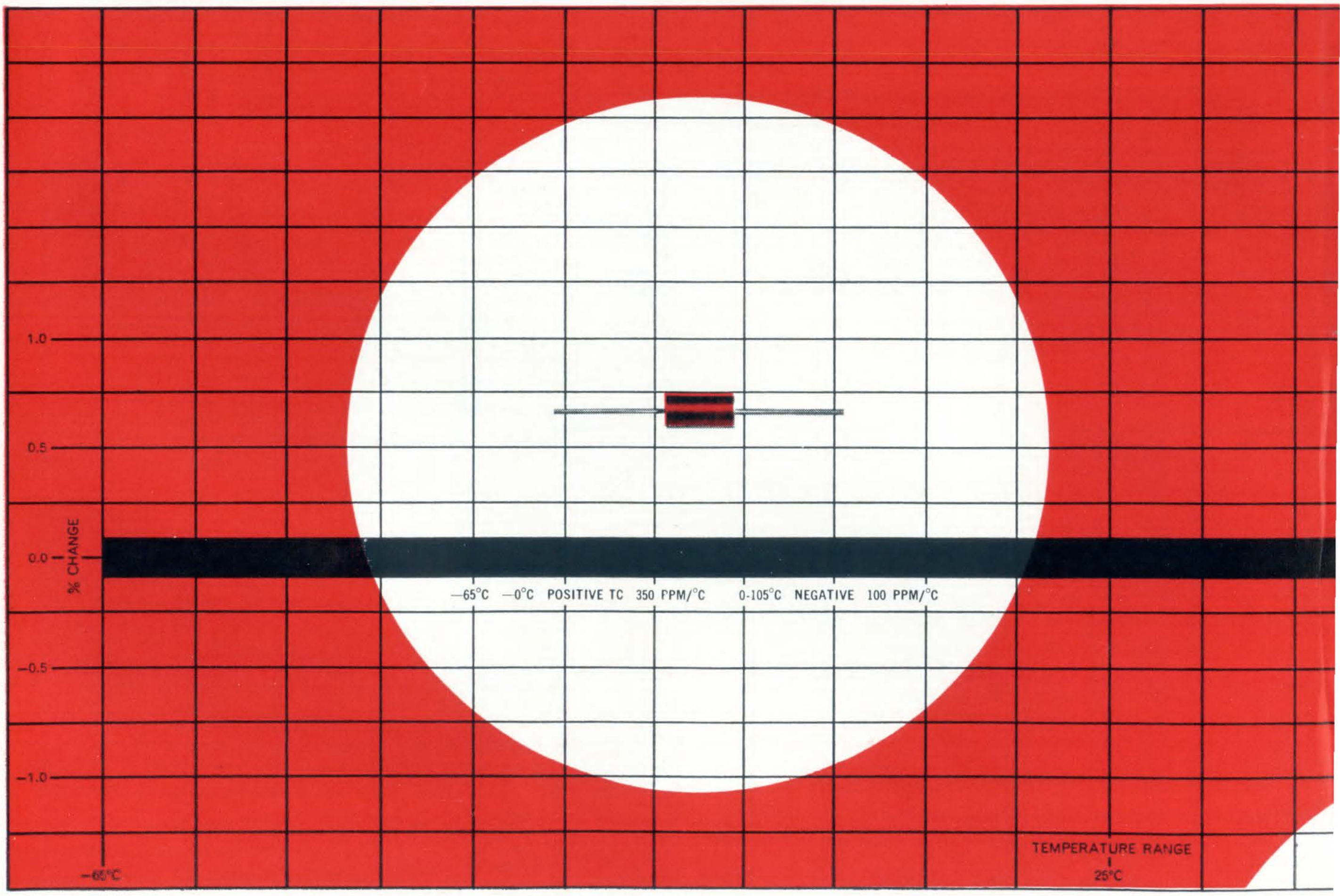
Off-the-shelf? Whether off-the-shelf hardware or equipment under development will fit into the deep-submergence program is debatable in the case of search sonars. The Westinghouse Corp. makes a side-looking sonar that the Navy uses to find mines. No evaluation for using this sonar in the new program has yet been made.

III. Launching the program

Right now the Navy thinks the project-definition phase could be eliminated and call for industry proposals could be issued in the spring. Hardware contracts would be awarded shortly thereafter.

The electronics industry will be asked to develop a suit of sensors for the search and rescue vehicle; a suit of sensors for the search and recovery vehicle; a suit of sensors for the support ships, and a variety of other electronic equipment.

In fiscal 1965 the Navy is expected to spend between $25 million and $30 million. Expenditures in subsequent years will account for the five-year total of $200 million.



Setting up radar behind enemy lines

Air Force is testing a device that five men can carry over rough terrain; set can be put together within a half-hour

A five-man combat team carrying a disassembled radar set slips behind enemy lines, and within a half-hour is ready to detect low-flying aircraft and transmit information about them. If necessary, the radar set itself can be used as a communication link or to fill a gap in a radar network.

These are the goals being set by the Air Force in developing a lightweight, highly reliable radar set to coordinate ground and air operations. Work on the system is being done at the service's development center at Rome, N.Y. An experimental model, weighing about 200 pounds, is already in operation, and the General Electric Co. and Emerson Electric, Inc., are preparing prototypes.

Easy to carry. The main sections of the device are being designed to weigh about 30 pounds each, so that a soldier can carry it over rough terrain. To make the set even more portable, the Bell Aerosystems division of the Bell Aerospace Corp. has designed a hip pack so that a section can be strapped to it easily.

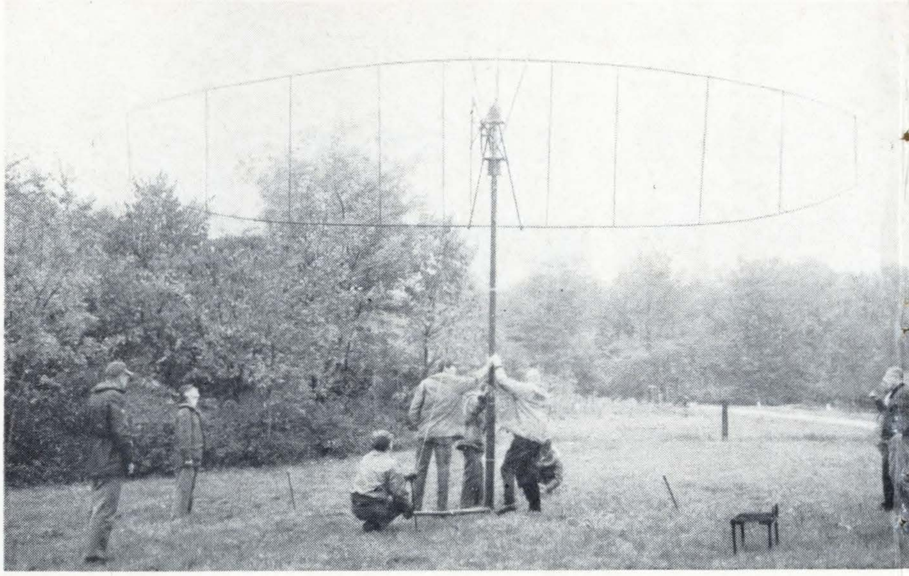
Much of the set uses solid-state components. The transmitter contains one of the first solid-state modulators designed specifically for radar use. The modulator has silicon controlled rectifiers, saturable reactors and a control transistor; it puts out a nine-kilovolt pulse, six microseconds wide, with a peak current of 10 amperes.

The pulse-repetition frequency varies from zero to 1,000 a second. The output circuit is a tuned plate-grid-cavity oscillator with an RCA 7651 tetrode as the driven element. The output power can be as high as 50 kilowatts.

The receiver and indicator units contain modular-construction discrete transistor circuits. The receiver has the ability of picking up signals 30 decibels below the clutter.

The indicator chassis contains many features used in much larger and more complex display units.

Circle 85 on reader service card



Lightweight radar set can be carried behind enemy lines by a five-man combat team and set up within a half-hour.

It has a five-inch daylight-type plan-position indicator, azimuth range strobes and digital readouts. The two units together weigh less than 27 pounds.

Good in the jungle. The radar unit operates in the ultrahigh-frequency range; transmission in this range suffers somewhat less from attenuation by jungle foliage than transmissions in the L-, C- or X-bands. This frequency range is also useful in communications.

The antenna, constructed of glass

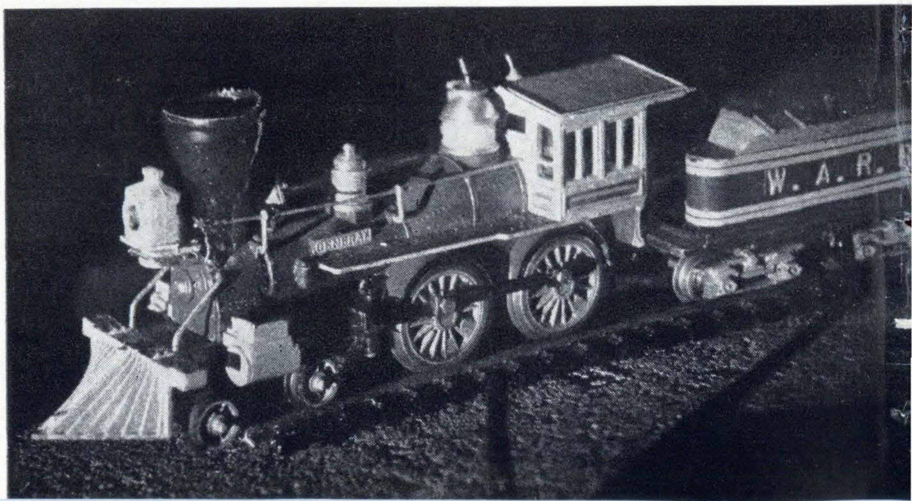
Advanced technology

The little train that wasn't

Laser and photographic plate 'restore' and magnify images in three dimensions

By George V. Novotny
Advanced Technology Editor

Reconstruction of train, photographed in two dimensions. Actual image is three-dimensional.



fiber, can be raised 60 feet by using five-foot-long telescopic sections. Its reflector and hogshead feed, both made of wire mesh, form a structure 27 feet wide and seven feet high. The antenna has a horizontal beam width of 5° and a vertical beam width of 23°.

Tests continue. The unit has been tested more than 160 hours. Tests and evaluation of the experimental unit will continue until the prototypes are ready in April. Meanwhile, the Air Force is conducting a parallel study using microelectronics in the set, especially in the indicator. The object is to attain better performance, capability and reliability, as well as further reductions in size and weight. Also, the developers plan to introduce identification friend-or-foe (IFF) capabilities into the unit.

The system was designed by Joseph Enrino, chief of the surveillance and equipment branch at the Rome development center. He was assisted by Sam Dispirito, section chief, and Charles Lewis, project engineer.

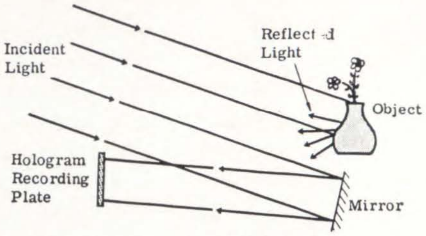
In a Boston hotel suite recently, a few dozen normally sedate scientists and engineers were playing with a toy locomotive, a toy train-conductor and other such items.

The train wasn't really there at all. But if you stood in exactly the right place and looked into a piece of equipment you would have seen it, real as life. The toys had been "reconstructed" by a technique that looks simple, yet is one of the most sophisticated developments in modern science.

The "reconstruction" was done with a gas laser made by the Perkin-Elmer Corp., and a "hologram," a special photographic plate made by researchers at the University of Michigan.

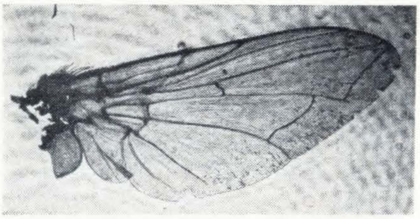
When you looked at the hologram, illuminated from behind by a gas laser, you saw the train and conductor toys right there on the table, in three dimensions. If you wanted to see what was behind the little man, or in front of the toy locomotive, you simply moved your head to see them. No need for viewing glasses, double images or squinting.

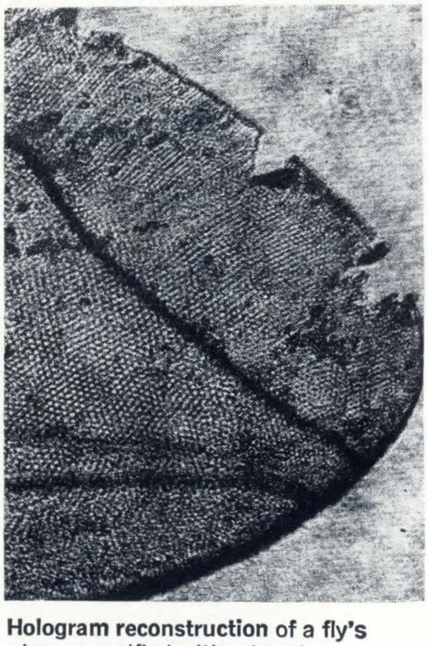
Holography. The new technique



Setup used to make hologram. Laser beam from upper left is used to illuminate object directly. Through a mirror, right, the beam is also channeled to the photographic plate to establish a reference point.

of recording objects—Prof. George W. Stroke and Emmett Leith of Michigan call it holography—uses laser light, ordinary black-and-white photographic plates, and no lenses or camera equipment. The laser beam is channeled to illuminate the subject and the photographic plate. Because its light is coherent, it establishes an interference pattern on the photographic plate. This pattern is what the plate records, and it bears no resemblance at all to the subject. In ordinary light it doesn't look like anything. But shine a coherent laser beam through it, and the subject springs into being.





Hologram reconstruction of a fly's wing, magnified without optics. At top, image has been magnified 20 times; at bottom 70 times.

Because there are no lenses, each point on the object is recorded all over the photographic plate. So you can take a hologram and cut it in half—or in a dozen pieces—and each piece will still show the entire object, from a slightly different point of view, with only a little loss in sharpness.

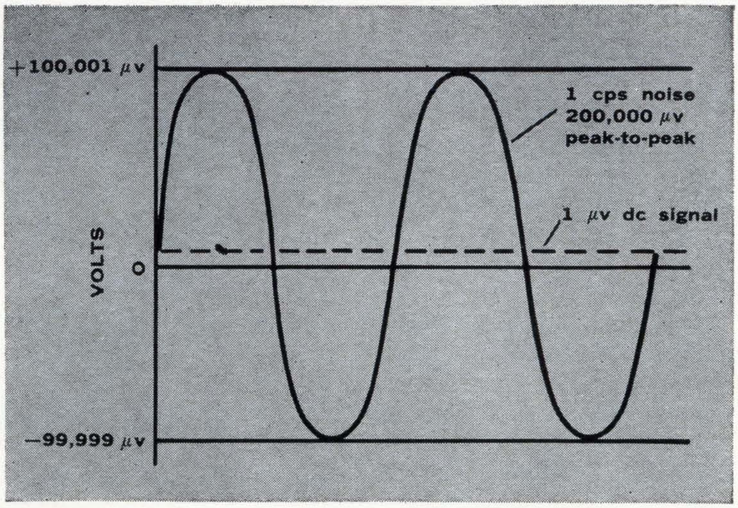
Besides making a fascinating display, holography has more serious uses. Since it can record three-dimensional information with more fidelity than any other known means, it can be used to study small objects such as complex molecules, through high-powered microscopes. It permits large magnification without lenses or other optics. It can magnify two ways: if the hologram is made by short-wave light—blue, for example—and reconstructed by long-wave light—red—the image seen is magnified by the ratio of the two wavelengths. Thus, holograms made with x-rays could be magnified millions of times when viewed with visible light.

No viewing optics. A second method of magnification uses diverging light. If the viewing laser beam is spread out by a concave lens to a greater divergence than the exposing beam, the image is also magnified. Since no viewing optics are used, the usual optical limits and distortions do not apply. In hologram microscopy, resolutions of one angstrom unit are not exceptional.

Besides scientific uses, military ones such as reconnaissance have been suggested. Multicolor holography may also come true some day, and there is no reason why it should not be used eventually in three-dimensional color television.

However, holography has some drawbacks. The main one is power: It is relatively inefficient, and bright light is needed for a good image. A solution might be a film far more sensitive than today's silver halide plates.

Another problem is subject stability. Today's holograms take 5 to 20 minutes of exposure, and during this time the subject and plate must stay still to within a fraction of the wavelength of light. This completely eliminates snapshots, at least for the present. But then, ordinary photography was even more inconvenient when it was invented in the early 1800's.



Even noise like this doesn't bother the new NLS 2917 integrating dvm.

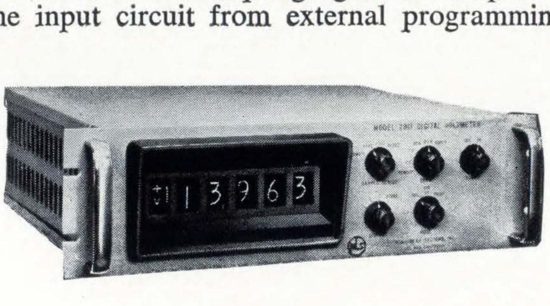
This advanced digital voltmeter with major innovations unlocks the full noise rejection capability inherent in an integrating dvm—and provides a host of other important features.

In some integrating dvms, superimposed noise greater than the dc being measured (as shown above) causes serious error. Not in the NLS 2917 . . . it measures a 1 μv dc signal with 100,000 μv of 60 cps superimposed ripple . . . it measures the input voltage average value or mathematically integrated value despite polarity changes. Furthermore, a 60 cps common-mode signal a million times greater than the dc being measured doesn't degrade accuracy.

Another example of imaginative engineering—beams of light are used as the coupling agent to completely isolate the input circuit from external programming commands and digital output signals.

Other features (many exclusive): range from 1μv to 1,200 v dc without preamps . . . floating differential input . . . automatic calibration (no frequent manual adjustment) . . . accuracy ±(0.01% of rdg. + 0.006% of f.s.) . . . overranging automatically gives 6 digits from 99999 to 120000 on each range . . . no "zero-crossing" error (some dvms accumulate 1-digit error for each noise cycle) . . . output for recorders . . . full remote control . . . 99.9% of components are on plug-in boards . . . only 25 w. dissipation—no fan . . . fully transistorized . . . only 5¼" high . . . accessories for ac and Ω . . . and more. Other 2900 models have auto ranging, measure voltage ratio or frequency.

Contact NLS for more information or a demonstration. 5-Digit 2917 with 6-Digit Overranging: $3,720 (other models less).



Originator of the Digital Voltmeter

non-linear systems, inc.

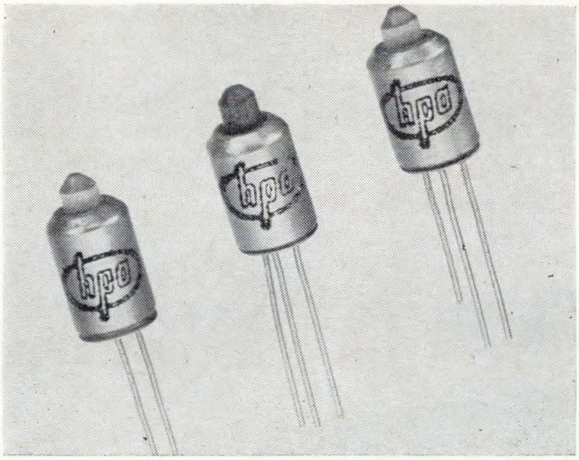
DEL MAR, CALIFORNIA (714) 755-1134

Design flexibility through optoelectronic devices

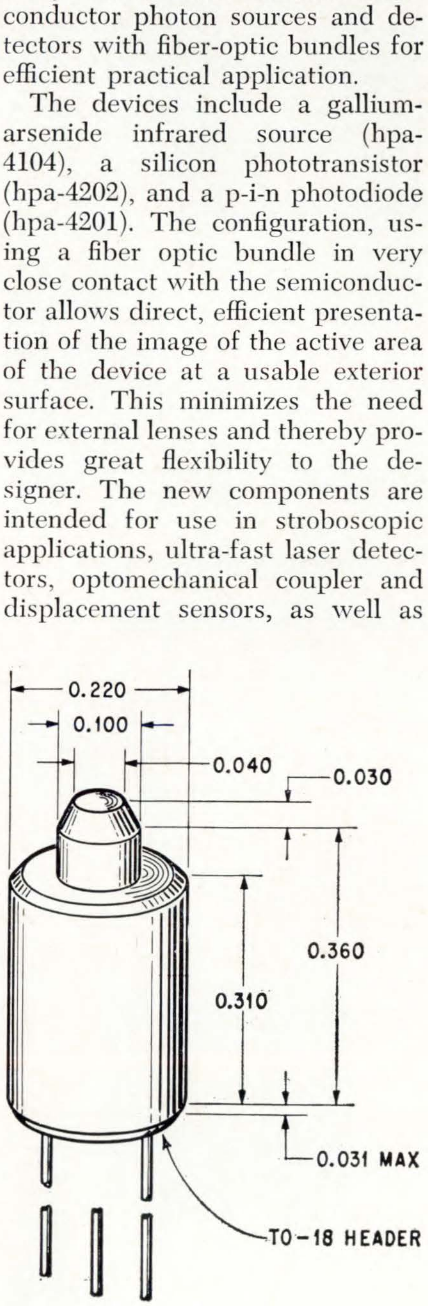
New components use fiber optic bundles in close contact with semiconductor photon sources and detectors

A new family of optoelectronic solid-state components, previously discussed while in the developmental stage [Electronics, July 27, p. 58], is now available commercially. These units combine semiconductor photon sources and detectors with fiber-optic bundles for efficient practical application.

The devices include a gallium-arsenide infrared source (hpa-4104), a silicon phototransistor (hpa-4202), and a p-i-n photodiode (hpa-4201). The configuration, using a fiber optic bundle in very close contact with the semiconductor allows direct, efficient presentation of the image of the active area of the device at a usable exterior surface. This minimizes the need for external lenses and thereby provides great flexibility to the designer. The new components are intended for use in stroboscopic applications, ultra-fast laser detectors, optomechanical coupler and displacement sensors, as well as card and tape readers.



All of these optoelectronic devices are available in TO-18 headers. The fiber optic bundle extends from the metal can to present a flat, easily and efficiently used surface.



Dimensional drawing applies to all three devices.

The hpa-4201 p-i-n photodiode is an ultra-fast light detector for use in the visible and near infrared, having a quantum efficiency of about 0.5 electron per photon. A fiber-optic light guide is employed in the package for greater flexibility; it simultaneously reduces the sensitivity to capacitively-coupled extraneous signals. The device features a response time of less than 0.2 nsec, a capacitance of 1 pf at −20 v, a breakdown voltage greater than 80 v and reverse leakage of less than 2 nanoamperes.

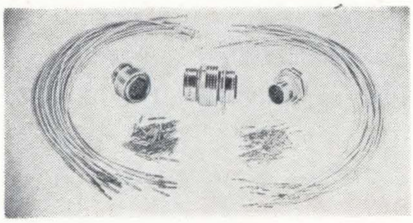
Type hpa-4202 phototransistor is a high-gain optical sensor for visible through near infrared radiation. A fiber-optic light pipe is used to guide photons impinging on the surface of the package to the active semiconductor area. This provides a versatile configuration that often can eliminate auxiliary optical components when the device is used as a small area sensor. The quantum gain is 200 and the response time is less than 2 μsec. Other characteristics include collector-base capacitance of 9 pf; collector to emitter breakdown voltage with base open, greater than 30 v. An external base lead is provided for normal electrical, as well as optical, inputs.

The light source, hpa-4104, utilizes a gallium-arsenide-injection luminescent diode in a package with a fiber-optic light pipe. The device provides a narrow spectral band of infrared radiation that can be electrically modulated at nanosecond rates. A fiber-optic-image conduit is used to channel the high intensity emission from the semiconductor to the package exterior. The external quantum efficiency of this device is greater than 0.001. It is intended for use at forward bias current of 2 to 30 ma. Electrical parameters include a low series resistance of less than 2 ohms, breakdown voltage greater than 5 v, reverse current less than 1 μa at −2 v, and a capacitance with zero bias of 120 pf.

The optoelectronic devices are available from stock at the following prices: hpa-4201, $55; hpa-4202, $125; hpa-4104, $75.

H P Associates, 620 Page Mill Road, Palo Alto, Calif. 94304.
Circle **301** reader service card

Tiny connector has high-density contacts

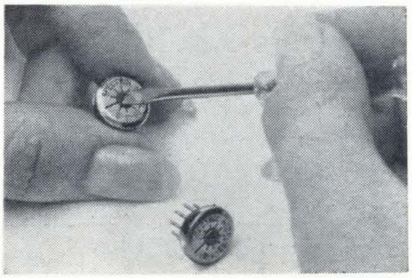


A new subminiature connector, the DSM series, puts three times the standard number of contacts in a given MS shell size. For example, shell size 19 can have as many as 61 No. 22 contacts. Other DSM sizes and insert arrangements include the 3-9 with 7 contacts, 7-15 with 19 contacts, 12-14 with 37 contacts, and the 27-30 with 91 contacts. This series is specifically designed for installation where weight, space, and multiple circuitry are primary factors. The push-pull coupling design provides instant disconnect, eliminates lock wiring, and insures a positive lock and seal. High performance silicone inserts provide a complete environmental and interfacial seals. The DSM meets or exceeds all the applicable requirements of MIL-C-26482.

The Deutsch Co., Municipal Airport, Banning, Calif. **[311]**

Rotary switch for direct mounting

A new miniature rotary switch mounts directly on printed-circuit cards. Model 88 single-pole switch is ½ in. in diameter and less than



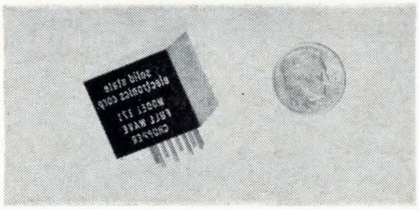
⅕ in. high in profile. It can have up to 10 positive non-shorting rotary indexing positions and is completely sealed by a silicone rubber case liner providing excellent performance under conditions of extreme humidity. Current rating is 100 ma at 28 v d-c. Unlike previous rotary switch designs with wiping contacts traveling only in one plane, the new unit has a wiper detent combination that actually lifts the wiper contact off and away from each fixed pad as the circuit is broken. This feature widens the "break" gap and thus reduces switch arcing. On the "make" portion of the cycle, the contact is dropped onto the next pad. The force of this impact and the resulting scrubbing action result in low contact resistances. Price in unit quantity is $3.75.

Spectrol Electronics Corp., 1704 South Del Mar Ave., San Gabriel, Calif. **[312]**

Toroidal transformer measures currents

This current transformer has an output voltage of 100 mv for an input current of 100 ma a-c. Model 8764 operates over a wide dynamic range, from 0.001 amp a-c input to 1.0 amp a-c input and over a wide frequency range. Basic accuracy is ±1%. Frequency of operation

should be specified for achieving highest accuracy. Frequency error is 2% from 400 to 800 cps. Output voltage appears across an internal 50-ohm resistor, and voltage drop on the current input winding is extremely low. The unit features small size (1 by 1 by ½ in.), printed-circuit type mounting, and is completely molded for meeting the most rugged environmental conditions. For general use in measuring currents, it also affords isolation and can be used for under and over current trip and indicating devices. Magnetico, Inc., 6 Richter Court, East Northport, L.I., N.Y. [313]

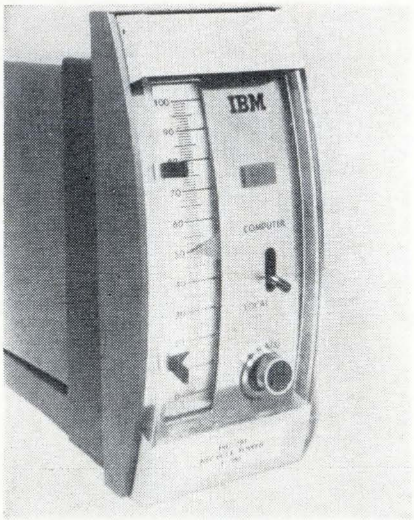


Transformer-coupled full-wave chopper

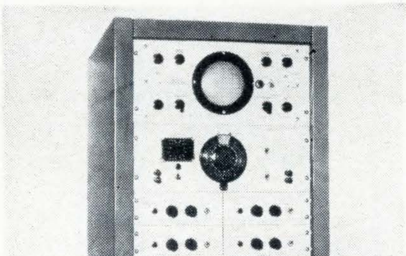
Model 171 silicon-transistor, full-wave chopper utilizes a transformer-coupled drive and a transformer-isolated output. The solidly encapsulated unit provides distinct advantages for the isolation of low-level signals where conflicting grounding interfaces exist between bridge networks and high input impedance amplifiers. An isolating drive transformer is also utilized to allow driving from a source common to the input or output signal. Model 171 is especially suitable for modulating low-level d-c signals from thermocouples, strain gages and bridge transducers having impedances up to 50 kilohms. Two transistor pairs are carefully selected and matched to assure low offset, low noise and close temperature tracking to provide stable, low-level operation from −55°C to +150°C. Model 171 is completely immune to the effects of shock, vibration or acceleration making it ideal for military, space, industrial and portable applications, or where miniaturization, power conservation and elimination of maintenance are a necessity. Solid State Electronics Corp., 15321 Rayen St., Sepulveda, Calif. 91343. [314]

New Instruments

Computer linked to process controller



A new instrument that links a computer to analog control equipment used in manufacturing processes has been announced. Model 891 set point station is designed to accept and convert the output of a digital computer to precise analog signals, and to transmit these signals to a controller. Two models are available—the 891P and 891E. The 891P is designed to operate with pneumatic process instrumentation; the 891E, with electronic process instrumentation. The station is designed for a wide range of process control applications in the oil, petrochemical, chemical, metals, paper, cement, textile, and utility industries. The station operates as follows: 1) a process variable transmitter sends a signal proportional to the measured variable to both a controller and the computer; 2) the computer receives the meas-



Phase standard accurate to ± 0.03°

This precision phase standard, accurate to ±0.03°, has a crystal-controlled oscillator for precision frequency generation. Typical uses by standards departments and development laboratories include the calibration of phase meters, phase shifters, resolvers, synchros, null detectors, delay lines and quadrature detectors. Because of its high frequency and high phase stability, model 7ONO is particularly suitable for accurate time delay measurements. Covering the entire 0° to 360° range, the standard utilizes expanded Lissajous patterns to easily identify extremely small phase differences, and provide a self-calibrating function at 1° increments. The normal frequency range of the precision phase standard is 30 cps to 50 kc, with other frequencies available. The instrument is capable of expansion to 12 different frequencies by using plug-in modules. The accuracy of the 7ONO is independent of output loading. The output level is 3 v rms from signal and reference points, and the output impedance is less than 10 ohms.

Acton Laboratories Inc., subsidiary of Bowmar Instrument Corp., 533 Main St., Acton, Mass. **[352]**

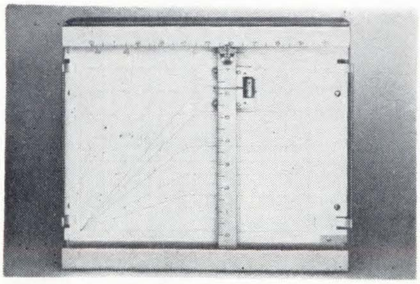
X-Y recorder offers 0.1% readout accuracy

An ultracompact, basic systems X-Y recorder, Model 7050A, features all solid-state circuitry with servo amplifiers that have single-ended inputs. Both electrical and mechanical damping are used for optimum performance. Any desired

ured variable and relates it to other variables and constants; 3) if a set point change is necessary, the computer determines its magnitude and transmits it to the set point station; 4) the station converts the computer output to an analog set point; 5) the analog controller adjusts its output to make the variable correspond to the set point. The station incorporates easily adjusted limits which enable full control of the process by the computer. A warning light goes on if the process drifts into unsafe or undesirable regions, and an audible alarm can be installed. Local operator control is provided for start-ups or emergency conditions. This feature is essential in the transition of a process from local control, with computed operating guides, into full computer control. Either slew or trim or multiple (pulse) contact closures can be accepted from the computer by the station.
International Business Machines Corp., 1000 Westchester Ave., White Plains, N. Y. 10604. [351]

---

single input span from 100 mv full scale to 100 v full scale, each axis, is available although 1 v full scale is standard. Accuracy is 0.1% full scale. Measuring only 10½ by 13 by 4½ in. and weighing about 10 lb, the model 7050A uses standard 8½ by 11-in. graph paper held in place on the flat-bed recording platen with mechanical grips. There is no control panel. Zero setting is accomplished by a screwdriver adjustment; calibration is ad-



justed internally. The reference voltage is supplied by a continuous zener reference supply. The linear balance potentiometer contact is located at the point of recording, thus eliminating gear backlash and increasing accuracy. Price is $975.
F.L. Moseley Co., 433 N. Fair Oaks Ave., Pasadena, Calif. [353]

Planning to change your address?

Use the form below to indicate a change of address. Because our issues are addressed in advance, please try to allow at least 5 weeks for change of address to become effective. Attach the address label from your most recent issue in the space provided below.

[Please print the following information for proper service]

Title or position ....

Name ....

Chief job responsibility ....

Company and Div ....

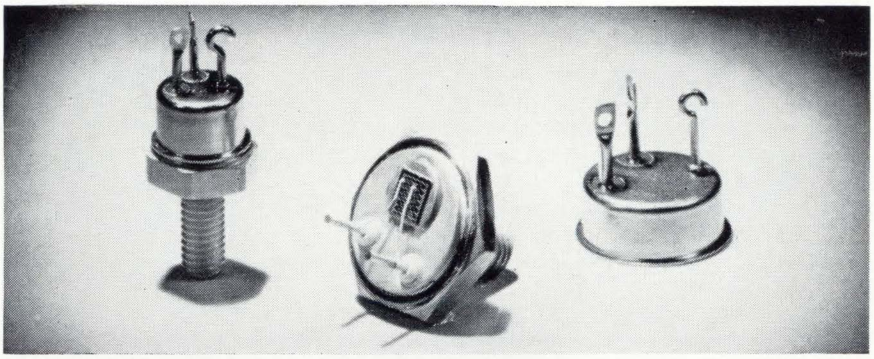
Product or Service .... Approx. No. of employees ......

Address ....

City .... Zone ...... State or Prov. ....

Mail to: Fulfillment Manager, **Electronics**
P.O. Box 430, Hightstown, N.J. 08520

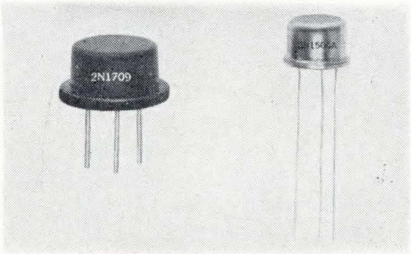
***Paste present mailing label or address from wrapper or envelope here.**



Interdigitated power transistors

A line of interdigitated-geometry, planar power transistors offer high reliability, low saturation voltage, high current gain, low collector capacitance and high breakdown voltage. Applications for the triple-diffused mesa units are in military, industrial and commercial use such as output stages of amplifiers, power supplies and inverters. A major advantage of the new line, according to the manufacturer, is the lower saturation voltage, which permits greater circuit efficiency. Hence for the same power, a lower junction temperature is achieved, increasing reliability. High-voltage breakdown, which increases performance, is rated typically at 125 v for the 2-amp model. The post-passivated, oxide-passivated, collector-base junction provides lower leakage current and improved current gain. A planar, oxide-passivated emitter-base junction increases reliability and gives more stable electrical characteristics. Internal leads which are welded to rigid posts provide increased ruggedness in high stress environments. The family of power transistors is divided into two categories: low current types rated up to 1 amp and higher current types rated up to 5 amps. Useful current gain up to 3 and 10 amps, respectively, are possible. Prices in small quantities range from $22.50 for the 2N2150 (higher current) to $55.50 for the 2N1724 (low current).

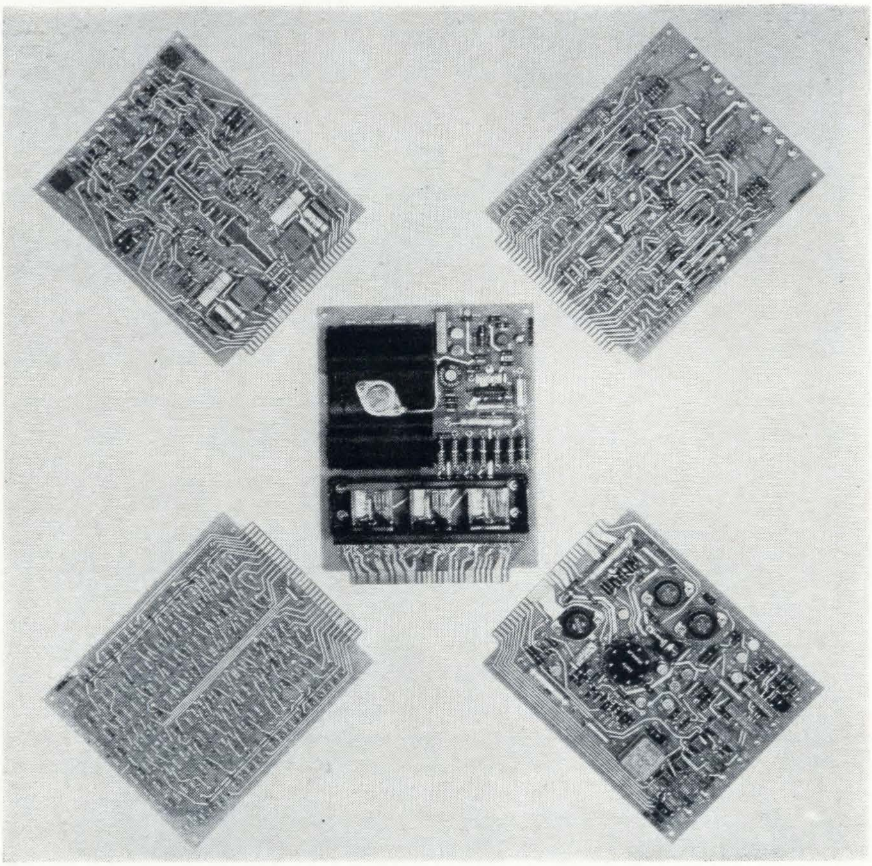
General Electric Co., Schenectady, N. Y. **[331]**



Communication-type silicon transistors

High-frequency, silicon mesa transistors are announced for military and commercial communications applications. The series consists of 2N1505, 1506, 1506A, 1709 and 1710. Principal characteristics of the npn devices are: r-f power outputs of 5 w at 30 Mc and 1 w at 70 Mc with transition frequencies up to 200 Mc. The 2N1505 and 1506 are available in TO-5 configuration and have typical power gains of 10 and 13 db respectively; power dissipation is 3 w at 25°C case temperature. The 2N1709 and 1710 are produced in TO-8 configuration; have typical power gains of 12 and 10 db; and power dissipation is 13 w at 25°C case temperature. In quantities of 1 to 99, prices are: 2N1505, $11; 1506, $19.80; 1506A, $12.20; 1709, $72; and 1710, $40.50.

Nucleonic Products Co., Inc., 3133 E. 12th St., Los Angeles, Calif. **[332]**



High reliability circuit modules

Five new electronic circuit modules—diode matrix 44 8040, single shot 8055, flip-flop 8070, power control 1 8081, and power control 2 8082—are now available. They are part of a complete family of series 8000 modules which make up a 1-Mc product line that is designed to operate over a temperature range of 0 to +55°C. Though primarily designed to be compatible with the electromagnetic characteristics of fixed- and flying-head magnetic drums and disk files, these modules are ideal for many other digital applications where high reliability is required. The 44 8040 module contains two decoder matrices with each matrix consisting of 16 identical circuits that are prewired to form a four bit decoder. It is priced at $191. The 8055 contains two single-shot circuits with each circuit capable of providing a means of establishing delays required in logic system operations; the circuits also serve as pulse shapers. Cost of this module is $247. Module 8070 contains four circuits, each of which can be used as the active element of a shift register, parallel and serial counter, data or address storage register, and the like used in logic systems. It costs $270. The 1 8081 in conjunction with the 2 8082 provides over under voltage protection for the electronic circuit modules used in the company's logic systems. Price of the 1 8081 is $500. Module 2 8082 controls the distribution of power to the buses serving the circuit modules in the company's logic systems. It is priced at $250.
Bryant Computer Products, 850 Ladd Road, Walled Lake, Mich. [371]

Crystal-controlled precision generators

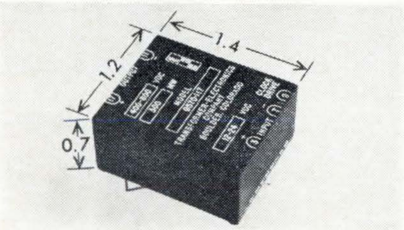
An oven-controlled crystal oscillator circuit has been designed to generate pulses at an accurate rate for precision timing applications.

It can be ordered to any frequency within the range of 1 kc to 250 kc at a factory set accuracy of 0.001%. For closer tolerance applications an external capacitor can be used for trimming to the exact frequency. Characteristics include an 8-v positive pulse output, a rise time of 1 μsec maximum, and a dynamic output impedance of 1,500 ohms maximum. Both crystal and circuit are housed within a rectangular plug-in oven assembly which inserts into a standard octal socket. The unit incorporates a solid-state assisted thermostat to permit dry switching of the mechanical contacts to prolong the life of the thermostat.

W. H. Ferwalt Co., P.O. Box 27, Lewiston, Idaho. **[372]**

Miniature converters aid designers

A new converter series is being introduced to solve a critical need facing many circuit and system designers. This series makes available, as an off-the-shelf item, 300 mw from 1 to 800 v d-c converters with high efficiency at low power levels, and small size (1.2 cu in.) and light weight (1 oz). In addition, these converters have proven oper-

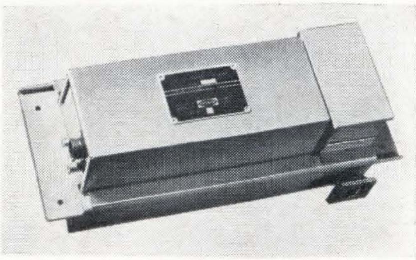


ation at extreme environments—three axes vibration (18 to 2,000 cps at 6.4 to 14.3 g), thermal vacuum (1×10^{-5} torr, $-30°C$ to $+70°C$), thermal shock, and acceleration. To further assure reliable operation, the manufacturer has evaluated all components through a burn-in and thermal aging program. Silicon semiconductors are used throughout. The entire unit is stress relieved prior to encapsulation. The unit is then encapsulated with NASA approved, low-outgassing compounds.

Transformer- Electronics Co., Boulder Industrial Park, Bouler, Colo. **[373]**

New Microwave

Power sources for X- and C-bands



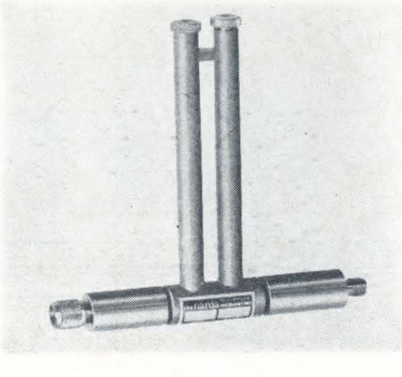
Two solid-state, microwave power sources feature extremely low spurious f-m and a-m modulation. The R-501 (C-band) and R-601 (X-band) can be used as local oscillators and parametric amplifier pumps in radar and communications receivers or other applications where very high signal-to-noise ratios are required. Model R-601, illustrated, provides f-m short term stability of better than 1.5 cycles rms max from 1 kc to 100 kc from the carrier. Short term a-m stability is 105 db minimum below the carrier from 1 kc to 10 kc from the carrier, and 110 db minimum below the carrier from 10 kc to 100 kc from the carrier. All measurements are with reference to a 100-cycle bandwidth. Characteristics of the model R-501 are comparable. The R-501 has a minimum output of 150 mw over a 3.5% frequency range in the band from 5.1 to 5.9 Gc. The 601 delivers at least 75 mw over a 2.5% frequency range between 10.225 and 10.525 Gc. Designed for field applications, the power sources are built to military specifications for vibration and shock. Crystals can be changed easily in the field without the need for re-tuning. Prices vary according to exact frequency desired and optional accessories selected. Typical R-501 units are priced at $2,730 each in quantities of 50. Price of typical R-601 units is $3,520 in the same quantities.

Raytheon Co., Microwave and Power Tube Division, Waltham, Mass. **[391]**

Double stub tuner covers broad range

A 1.0 to 12.4-Gc double stub tuner, model 4903, provides a variable susceptance over the broad frequency range to tune transmission lines for maximum power transfer, especially when such power is required from a klystron oscillator. The tuner can also be used to provide a conjugate impedance for matching purposes. When used with miniaturized crystal holders, such as model 4501, the stub tuner also provides a convenient d-c return circuit for crystal current. Another highlight design feature of the stub tuner are the subminiature NPM female and male connectors that can be mated with most standard connectors for the 0.141-in. coaxial line, such as BRM, OSM and STM. Over-all length of the stub, including connectors, is $4\frac{1}{16}$ in. Minimum height is 3⅝ in.; maximum $6\frac{31}{32}$ in. Net weight is 0.4 lb. Price of the model 4903 stub tuner is $175.

Narda Microwave Corp., Plainview, L.I., N.Y. **[392]**

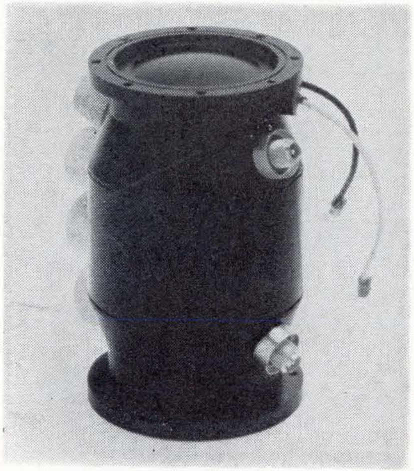


H-v switching diodes for microwave use

Microwave p-i-n switching diodes have been designed to provide maximum working voltages of 1,000 v and typical series resistance of 1.5 ohms at 500 Mc and 100 ma forward bias. They are designed with gold-plated ribbon leads for low inductance. The epoxy encapsulated body of the PS1400 measures 0.070 in. by 0.150 in. maximum. Price is $2.50 to $10 depending on type and quantity. Parametric Industries, Inc., 63 Swanton St., Winchester, Mass. 01890. [393]

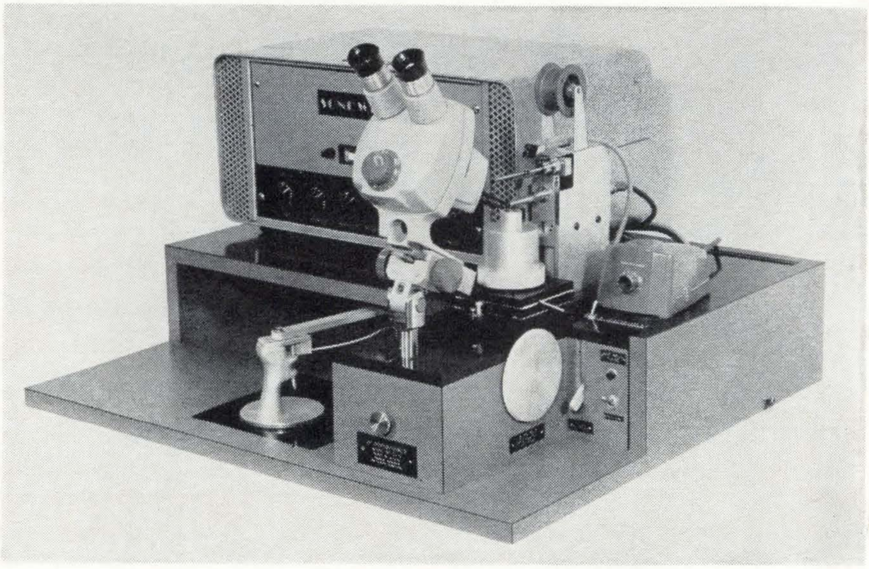
Metal-ceramic S-band klystron

A 32-oz klystron has been developed for space communications and tracking. The S-band, electrostatically-focused unit makes possible lighter weight, more compact and more efficient space communication systems, according to the manufacturer. The L-3910 all metal-ceramic tube combines the lightweight feature of the ppm-focused twt with the high power, ruggedness, reliability, efficiency and long life characteristics of the klystron. It delivers a nominal power output of 20 w c-w at 2287.5 Mc. This power level can be varied from 5 to 50 w at good efficiency



simply by varying the beam voltage. At the 20-w power level, the beam voltage is 1,650 v, the nominal efficiency is 30% (without a depressed collector), the gain is 20 db, the bandwidth is 5.5 Mc, and the noise figure is 28 db. These values do not vary substantially as the power is varied over its entire range. Since no magnetic focusing is used, there are no external magnetic fields, and, except for the cathode heater supply, only one power supply voltage is required. Litton Industries Electron Tube division, San Carlos, Calif. [394]

New Production Equipment



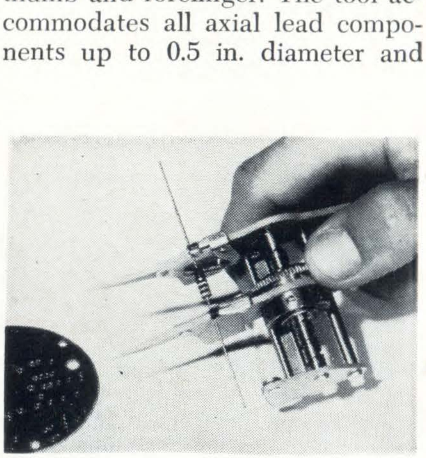
Ultrasonic welding micropositioner

Model MP-20-L micropositioner is a complete ultrasonic welding work station. It is designed for lead-wire bonding to semiconductor devices and for use in microcircuitry. The focus of the micropositioner design is the company's 20-watt ultrasonic welding system. The welding process eliminates a variety of problems associated with the heating cycle of thermocompression bonding and is very reproducible. The micropositioner provides for wire feed, work manipulation, welder head operation, and work positioning conveniently in one compact array. Single-hand operation includes X-Y positioning, welder-head lowering, clamping-force application, weld-cycle initiation, head lift, and wire feed without release of the hand grip. A single right-hand wheel control is used for the Z position (adjustable to 2 positions). Vacuum or mechanical chuck pedestals (rotational 360°) are available.

Sonobond Corp., West Chester, Pa. [421]

Tool bends leads for fast p-c insertion

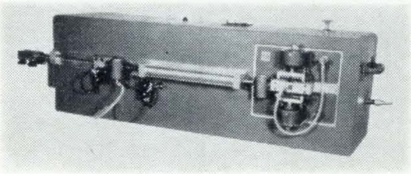
A portable handtool has been introduced for simple, fast, and exact spacing of electronic component lead bends for insertion in circuit boards. Model N-100 is especially adaptable to prototype development, short run production, and circuit repair. The lead bender is said to totally eliminate measurement and trial and error bending of component leads. Bent leads are free of all flat spots, nicks, and surface blemishes. Matching pointers with component lead holes in circuit board, by spinning a knurled wheel with the thumb, automatically spaces bends for insertion of the component into the board. Bends are formed by pressing leads against sides of pointers with thumb and forefinger. The tool accommodates all axial lead components up to 0.5 in. diameter and



1.5 in. long. Price of the model N-100 is $34.50.
Harwil Co., 1009 Montana Ave., Santa Monica, Calif. 90403. **[422]**

Machine produces p-c board jumpers

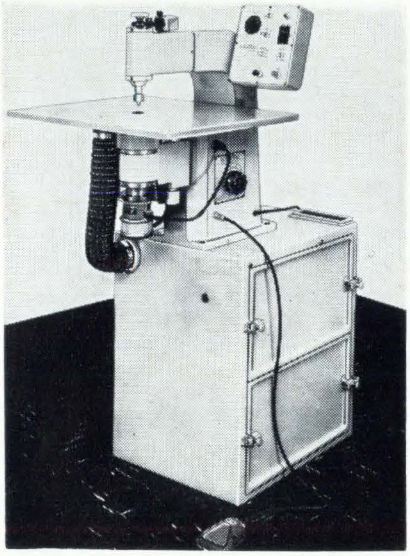
An automatic machine cuts, strips and forms insulated wire to make p-c board jumpers at a rate of 12,000 pieces per hour. The machine, which performs work previously done slowly and tediously by hand, can be set to produce jumpers with an insulated length of from $\frac{1}{8}$ in. to 8 in. and with the ends stripped from $\frac{1}{8}$ in. to $\frac{3}{8}$ in. The stripped ends are bent at right angles to the insulated portion of



the wire. Model 821 wire stripper/bender will accommodate solid-conductor wire in sizes from No. 28 to No. 16 Awg. It will strip all of the insulations commonly used in p-c board wiring, including Teflon, without damage to the conductor. It may also be used to measure, cut and form uninsulated wire. Air-powered and electrically-controlled, the machine has a clamp which grips the wire and carries it into a cutting and forming head. The distance the clamp travels determines the length of the finished wire. Clamp travel is governed by the stroke of an air cylinder, which may be changed in a minute or two by means of a micrometer adjustment. Die and blade changes, which are required for differences in wire sizes and strip length may be made within 3 or 4 minutes.
Eubanks Engineering Co., 225 West Duarte Road, Monrovia, Calif. **[423]**

Circuit board duplicating machine

The Acrodrill is a circuit board duplicating machine with capabilities of 100 and more closely spaced holes per minute, overhead stylus with continuously automatic and variable cycling feature and a built-in, cost-saving, dust removal mechanism. The operator can produce 48,000 holes and more per hour based on an average stack of 8 boards; 35,000 holes per hour is normal even for an operator with limited training. The overhead stylus lifts away from, and lowers to the template automatically at a rate predetermined by a timing circuit which provides an adjustable delay of from 0.2 sec to 16 sec, thereby permitting the machine to pace the operator at his own speed. Recycling continues as long as the operator's foot rests upon the control switch. The machine will accommodate from 4 to 10 circuit boards, each $\frac{1}{16}$ in. thick, with a template on top, all fastened stack-fashion with tight fitting pins in the register holes. The number of boards in a stack varies with drill size, board thickness and board material. The Acrodrill's built-in dust collector unit solves the costly clogged machinery problem for circuit board manufacturers by removing dust and chips directly from the drill table, preventing them from entering the drill mech-



anism. The dust collector unit also reduces space requirements; it functions as a base upon which the drilling machine is built. An optical center locating system is available for producing templates directly from artwork negatives or for short runs without templates.
Aetna Mfg. Co., Bensenville, Ill. **[424]**

Reprint order form

Send to: **Electronics Reprint Dept.**
330 West 42nd Street
New York, N. Y. 10036

For listing of reprints available see the reader service card.
To help expedite mailing of your reprints please send cash, check or money order with your order.
For reprints of the latest special report:
Field Effect Transistors, Part I

Send me ...... reprints of key no R-64 at 50¢ each.

For reprints of previous special reports fill in below:

Send me .... reprints of key

no. (s) .... at .... ¢ each.

For prices see the reader service card.

Name ....

Number & Street ....

City, State ....

Zip code ....

New Books

Transistor fundamentals

Semiconductor Circuit Analysis
Edited by Phillip Cutler
McGraw-Hill Book Co., Inc.,
1964, 642 pp., $10.

This outstanding volume fills a need in the existing literature on semiconductors for a solid practical foundation for the student or engineer who has no previous experience in their use.

While the book contributes little in the way of new or original work, it does present previously published material in a much clearer light. The author takes great pains to get his points across, at the risk of oversimplifying occasionally.

The nine well-written chapters lead the student through the field of semiconductors; a technique that is ideal for the engineer who has been out of school for a number of years. It would also be a good text for undergraduates. Even with a poor teacher, a student would receive a good practical grounding in semiconductors. With a good teacher he would receive an excellent course.

After two brief chapters training the student in the basics of physics and of the junction diode, the author spends a hundred pages on the transistor and its characteristics. The next six are well-organized chapters covering the following subjects: biasing and stabilization, equivalent circuits, frequency response, power amplifiers, feedback, and power-supply regulators.

In the problem sections the author uses an interesting innovation. Each time a new type of problem arises he gives one example and solves it in detail, showing the reader the method of attack. The next two problems in the same category give only the answers. Then, still more problems are listed without solutions so that an instructor may assign them as homework.

Few authors list all steps in a mathematical derivation. Most engineers remember undergraduate texts where only steps one and ten were listed and the derivation was left as an exercise for the student. Phillip Cutler has gone to great pains to detail every step in his derivation of equations.

Only two points were found distracting; one was the author's use of electron flow rather than conventional current flow. The second was the use of flow graphs with only a reference to the original papers on this technique.

James Collins
Kollsman Instrument Corp.

Magnetics for engineers

Physics of Magnetism
Soshin Chikazumi
John Wiley & Sons, Inc.
1964, 554 pp., $15.75.

The introduction of magnetic transducers, magnetic-effect devices and thin-film magnetism has greatly increased the knowledge of magnetism required of the electronics engineer. The author of this book, who is a professor of physics at the University of Tokyo, presents a comprehensive and up-to-date treatment of the subject, written on a graduate level.

An introduction to magnetic phenomena in general is followed by a description of the origins and mechanisms of paramagnetism, ferromagnetism, antiferromagnetism and ferrimagnetism.

Magnetic domain structures, and subjects such as magnetic anisotropy, magnetostriction and magnetostatic theory are dealt with next.

The later chapters discuss magnetization processes on the basis of domain structures, from static to dynamic or resonance phenomena. Special subjects, such as thin films, helical spins, neutron diffraction and the Mössbauer effect are treated, and the galvanomagnetic effect, magnetothermal effect and magnetomechanical effect are described in less detail.

The final section deals with engineering applications of magnetism. This includes magnetic materials, cores, twistors and gyrators.

The book is impressive in its thoroughness; it is profusely illustrated and well documented with up-to-date references. A few problems are also provided.

Although it could well be used as a postgraduate textbook, its main value will be as a reference for the engineer working on modern electronic components.

Technical Abstracts

Learning Circuits

Multilayer learning networks
Roger A. Stafford, Philco Research Laboratories, Philco Corp.
Newport Beach, Calif.

The problem of constructing learning networks is discussed, with emphasis on the automatic correction of errors made by the network during the learning process. If the network is considered as consisting of a very larger number of simple voting threshold elements—all of which participate in the final output—and if each element is considered to have a certain positive or negative weighting factor attached to it, the error correction will involve the changing of the element weights so as to optimize the learning behavior.

Selection of the network elements must satisfy five basic principles: There should be as few elements as possible; for each element, the sum of the products of the weight parameters and the inputs should be as small as possible; each element should be allowed to participate in determining the effectiveness of tentative weight changes to decide whether they should be made permanent; each element should autonomously decide whether its weights should be changed; and the network should have more logical capacity than is needed.

Two multilayer networks were designed and simulated by computer. One of these restricted all interconnecting weights to positive values, so that the effect on the output of any element weight change could be accurately ascertained. This method also tends to alter only a minimum of element weights, but leads to a loss of flexibility in the learning process.

In the second network built, interconnecting weights were allowed to be negative as well as positive. This had the advantage of increasing the network's logical capacity as well as its flexibility.

Both kinds of model networks were simulated and studied on an IBM 7090 computer.

Presented at the 1964 Western Electronic Show and Convention (Wescon), Aug. 25-28, Los Angeles.

Titanium-dioxide films

Application of insulating titanium dioxide films prepared by chemical vapor reaction. A.E. Feuersanger, General Telephone Electronics Laboratories, Inc., Bayside, N.Y.

A chemical vapor reaction technique has been developed for depositing insulating titanium-dioxide films on metal and semiconductor substrates at temperatures of 150°C.

These dielectric films have suitable properties for microelectronic capacitors. For example, a film on platinum has a dielectric constant of 82. With a thickness of 0.15 micron, the corresponding specific capacitance is 0.51 microfarad/cm^2 at 1 kilocycle/sec and the dissipation factor is 0.029. The d-c leakage resistivity is 3.6 teraohm-cm. Also successfully produced were films on substrates such as germanium, silicon, nickel, aluminum, tantalum and stainless steel of the 304 type.

In addition, another application of the films is in active devices such as surface varactors used in low-frequency tuning circuits for telemetry applications. Titanium-dioxide films on germanium and silicon have been used for surface varactors with cut-off frequencies of 100 gigacycles/sec. Space saving and the possibility of remote tuning in telemetry are the predominant advantages over conventional tuning capacitors in such an application.

The titanium dioxide, because of its higher dielectric constant, is favored over silicon dioxide in varactors where a large capacitance swing is desired. To obtain a capacitance ratio C_{max}/C_{min} of 10, about 50 volts are required for a junction varactor. This requires that a separate high-voltage supply be used in transistorized systems. With a surface varactor, however, the same capacitance ratio requires only a voltage swing of about 1.8 volts, and, therefore, the high capacitance of 0.5 nanofarad can be obtained in a single unit.

Presented at the National Electronics Conference and Exhibition, Oct. 19-21, Chicago.

LABORATORY TEST EQUIPMENT

HEWLETT-PACKARD

120AR Oscilloscope. DC to 200 kc.............$245
151 High-Gain Amplifier, DC to 10 mc..........$85
X281A Waveguide to Coax Adapter...............$15
350A Attenuator, 500 ohms impedance...........$45
S380A Calibrated Variable Attenuator..........$95
400A V.T.V.M. 10 cycles to 1 megacycle........$65
400C V.T.V.M. 20 cycles to 2 megacycles.......$80
400D V.T.V.M. 10 cycles to 4 megacycles......$145
410HR V.T.V.M. 10 cycles to 4 mc, (1% acc.)..$185
410B AC-DC. V.T.V.M. & Ohmmeter, to 700 mc.$145
415B SWR Indicator, 70 db range..............$135
430B Microwave Power Meter....................$95
430C Microwave Power Meter...................$145
506A Optical Tachometer Head..................$85
520A High Speed Decade Scaler................$265
623B S.H.F. Test Set. 5,925 to 7,725 mc......$645

GENERAL RADIO

544B Megohm Bridge...........................$245
631BL Stroboscopic Tachometer (Strobotac)......$95
648A Auxiliary Light Source (Strobolux)......$125
722N Precision Variable Capacitor..............$95
724B Precision Wavemeter, 16 kc to 50 mc.......$85
1001A Standard Signal Generator..............$395
1211A Unit Oscillator, 0.5 to 50 mc..........$145
1390B Random Noise Generator.................$175
1490B Decade Inductor, 11.11 h (0.001 h steps)..$145
1419A Capacitor Decade, Total 1.110 mfd. (1%)..$95
1409M Standard Capacitor, 0.02 mfd. (±0.05%)..$18
1432M Resistor Decade, Total 111.110 ohms......$75
1432N Resistor Decade, Total 11,111 ohms.......$75
1432Q Resistor Decade, Total 1.111.000 ohms.....$75

TEKTRONIX

107 Square-Wave Generator, 400 kc to 1 mc.....$115
112 Differential D-C Coupled Amplifier..........$95
161 Pulse Generator............................$65
162 Waveform Generator.........................$65
511A Oscilloscope, 5 cps to 10 mc.............$195
511AD Oscilloscope, 5 cps to 10 mc with delay..$225
516 Oscilloscope, dual trace, DC to 15 mc......$645
535 Oscilloscope, Plug-in type, DC to 11 mc.....$595
541 Oscilloscope, Plug-in type, DC to 30 mc.....$495
53/54C Dual Trace Plug-in Unit................$165
53/54K Fast Rise Hi-Gain Plug-in Unit..........$95
Type Z Differential Comparator Plug-in.........$295

KEPCO TRANSISTORIZED SUPPLIES

SC-18-4M: 0-18 V. 0-4 A. 0.1% regulation......$225
SC-32-5: 0-32 V. 0-5 A. 0.01% regulation......$185
SC-32-10: 0-32 V. 0-10 A. 0.01% regulation.....$225
SC-32-15: 0-32 V. 0-15 A. 0.01% regulation.....$275
SC-150-1: 0-150 V. 0.1 A. 0.01% regulation.....$185
SC-300-1: 0-300 V. 0-1 A. 0.01% regulation.....$275
2SC-32-1.5: Dual 0-32 V. 0-1.5 A. 0.01% reg....$175
2SC-100-0.2: Dual 0-100 V. 0-0.2 A. 0.01% reg..$185
SR-12-50: 5-13 V. 0.50 A. 1% regulation.......$395
SC-3672-0.5: 36-72 V. 0-0.5 A. 0.1% reg........$135
SC-3672-1M: 36-72 V. 0-1 A. 0.1% reg..........$195
PSC-10-2: 7.5-12.5 V at 2 A. 0.02% reg.........$195
PSC-20-2: 17.5-22.5 V at 2 A. 0.02% reg........$195

SOLA DC POWER SUPPLIES

28106: 15 volts at 2 amperes, 1% reg.............$65
28120: 48 volts at 4 amperes, 1% reg.............$75

LAMBDA DC POWER SUPPLIES

28M: 200-235 V. 0-100 MA. 6.3 @ 3A. 1%.......$45
50R: 0-500 V. 0-500 MA. 6.3(2) @ 5A 0.5%....$195
LA50-03A: 0-34 V. 0-5 A. Transistor'd. 0.05%..$185
LT-2095M. 0-32 V. 0-2 A. Transistor'd. 0.15%..$175
LT-2095AM. 0-32 V. 0-2 A. Transistor'd. 0.15%.$195

RECORDING INSTRUMENTS

BARNES DEV. CO: Type 4 Data Recorder......$750
SANBORN: Model 356-5480W, 6-channel.......$1,450
CONSOLIDATED ELEC: Mod. 5-114P3, 18-chn.$975
BRUSH ELEC: Model BL-262, 2-channel.......$245
B & K INST. CO: Type 2305A Level Recorder.$1,095
ESTERLINE-ANGUS: Model AW, 5-0-5 MA....$135

MILITARY TEST SETS

AN/UPM-10 Radar Test Set..................$775
AN/URM-43B RF Power Meter, 30 to 600 mc....$95
TS-118A/AP RF Wattmeter, 20 to 1,400 mc....$195
AN/URM-79 Frq. Met., 100 kc to 20 mc, .001%.$695
OS-8E/U Oscilloscope, portable, 2 mc bandwidth.$165
TS-47/APR Test Oscillator, 40 to 500 mc.......$65
AN/PRM-10 Grid Dip Oscillator, 2 to 400 mc...$110
FR-4/U Frequency Meter, 100 kc to 20 mc.....$595
TS-15C/AP Fluxmeter, 1200 to 9600 Gauss.......$45
TS-731/URM Summation Bridge, 1 kmc to 4 kmc.$65
TS-510A/U Signal Generator, 10 to 420 mc.....$650
AN/USM-24 Oscilloscope, 1.5 cps to 8.5 mc.....$450
AN/UPM-11A Radar Range Calibrator, 0-35.000 yds..$350

MISCELLANEOUS ITEMS

KROHN-HITE: Model 340A Servo Design Filter..$75
ELECTRO PULSE: Mod. 2120A Pulse Generator.$275
ELECTRO PULSE: Mod. 4120A Pulse Generator.$145
SERVO CORP: Model 1100A Servo Analyzer....$475
KINTEL: Model 301R DC Voltage Standard....$450
STATHAM INST: Model TC-5B/2-3 Temp. Test Chamber..$375
KINTEL: Mod. 453 Scan., programming device..$950
G.R. Co: Type 1570 Automatic Volt. Regulator..$295
BECKMAN: Mod. 4914, In-line, 4 digit Readout.$175
BRUSH: Model BL-262 Dual Channel DC Amplifier..$245
BECKMAN: Model 5630-37 Predetermined Counter..$125
SORENSEN: Model 500S Voltage Regulator......$85
SORENSEN: Model 1000S Voltage Regulator.....$125

POWER SUPPLY BARGAIN!

I.B.M. Corp. Computer Power Supply. Input: 208-230 volts, 60 cy, 1 ph. Output: 48 volts DC at 5 amps. Ripple .275 volts peak to peak. New, unused, in original wooden cases. Special, only $45.00 fob Binghamton, N. Y.

ELECTRONICRAFT, INC.
P.O. BOX 13, DEPT. E12, BINGHAMTON, N.Y. 13902
Phone: 607-724-5785

CIRCLE 951 ON READER SERVICE CARD

NORDEN
Digital Microgoniometer System, Model 512/219 (SE-12 Binary Shaft Angle Encoder). Complete Unit includes Model 512/219 Transducer. Output Freq. 5.12 KC, 524.288 Counts per turn system. Dual Preamplifier 506-100 and all associated plugs and parts manual. Unit appears to be Brand New. Write or Phone for Price.

HUGHES
Model 104 D Memo Scope. This is a storage type oscilloscope. It can be used as a conventional type scope, also having the feature of being able to retain displayed traces or wave forms on the screen for as long as desired. Complete with 3-plug-in preamplifiers 1-WB/410 (Dual Trace) 1-HS/6A, (High Sensitivity) 1-DI/11. These units recently calibrated and are in like New Condition, Complete 1895.00

ALFRED
Model 700 Microwave Leveler, used to sample RF Signal, compare it with a Reference Voltage and provide as output the amplified error, particularly applicable for automatic suppression of RF output variations from Klystron Oscillator. Amplifiers backward wave OSC. and Traveling Wave Amplifier Tubes. Exc. Cond......................1750.00

LABORATORIES FOR ELECTRONICS
Model 501 A, Time Rate Indicator, 7 Digit Readout Counter. Frequency measurement (MC), Period (SEC), Count (Units), Internal (SEC), Ratio (Units). Exc. Cond......................850.00

SOUTHWESTERN
Model R-1 Voltmeter, measures D.C. multivolts, (Scales 0-1; 2.5; 10; 25; 100; 250; 1000) DC Volts (Scales 0-1; 2.5; 10; 25; 100; 250; 1000) OHMS (Scales 0-1; 10; 10^2; 10^3; 10^4; 10^5; 10^6. Exc. Cond. 250.00

MILLIVAC INSTRUMENTS
Model MV27 D. DC Microvoltmeter 7 MV Ranges from .25 to 250. 7 Volt ranges from 1 to 1000. Ex. Cond. 150.00

DONNER SCIENTIFIC
Analog computer, complete unit includes Model 3000 Analog Computer, Model 3750 Function Generator; Model 3731, Function Multiplier Power Supply; 2 Problem Boards, Resistor Bank, all models mounted in 1-Rack. Exc. Cond.......575.00

KAY ELECTRIC Model SKV (935 A), Ligna Sweep. Exc. Cond. 450.00

JERROLD ELECTRONICS Model 900 Sweep Generator. Exc. Cond. 350.00

See previous issues for more equipment. Send for Flyers.
All material in excellent condition. All prices F.O.B., San Francisco, Cal., subject to prior sale. Send for Listing and Flyers.

Marty's Mart
1236 Market St., San Francisco 3, California
Phone: UNderhill 3-1215

CIRCLE 952 ON READER SERVICE CARD

STEPPING SWITCHES SIGMA HERMETICALLY SEALED KURMAN SENSITROLS WARD LEONARD STRUTHERS DUNN AUTOMATIC ELECTRIC ROTARY RACHET LEACH CLARE ALLIED LEDEX CLARE LEACH MINIA... SIGMA NORTH ELECTRIC DORMEYER TELEPHONE TYPE KURMAN STEVENS ARNOLD CONTACT MERCURY SOLENOIDS ADVANCE ALLEN BRADLEY POTTER BRUMFIELD ...EVENS ...NOLD ...ANCE ALLIED ...CRAFT LEDEX KEYING PHILLIPS CONTROLS AMPERITE WESTERN ELECTRIC CUTLER HAMMER GENERAL ELECTRIC GUARDIAN CONTACTORS PRICE ELECTRIC SQUARE D WESTON MINIATURE AIRCRAFT

LARGEST STOCK OF RELAYS IN THE WORLD

PRODUCTION QUANTITIES
MOST MAKES IN STOCK
Send for Latest Catalog
E

Universal RELAY CORP.
42 WHITE ST. NEW YORK 13, N. Y. WAlker 5-6900

CIRCLE 953 ON READER SERVICE CARD

V·I·S* SERVICE

2nd DAY between Chicago—Milwaukee and Eastern Terminals

4th DAY between Chicago—Milwaukee and West Coast.

LIFSCHULTZ FAST FREIGHT

NEW YORK — CHICAGO — PHILADELPHIA — BOSTON
HOLYOKE — BALTIMORE — BLOOMFIELD, N. J.
NEW HAVEN — PROVIDENCE — MILWAUKEE
LOS ANGELES — SAN FRANCISCO

CIRCLE 954 ON READER SERVICE CARD

RADAR AUTO-TRACK & TELEMETRY ANTENNA PEDESTALS 3 & 10 CM. SCR 584 AUTOTRACK RADARS. M-33 RADAR TPS-1D SEARCH. APS-45 TPS-10D HT. FINDERS. WX RADARS. FPN-32GCA. APS-10 APS-15B APS-27 (AMTI) SEARCH. ■ ■ APN-102 DOPPLER. DOZENS MORE. CARCINOTRONS. PFN'S. .25-.5-1-2-3-6 MEGAWATT PULSE MODULATORS. CAVITIES. PULSE TRANSFORMERS. IF STRIPS. WAVEGUIDE. BENDS 200 MC. 1 KMC. 3 KMC. 6 KMC. 9 KMC. 24 KMC. RF PKGS.

RADIO RESEARCH INSTRUMENT CO.
550 5TH AVE., NEW YORK 36, N. Y. JU 6-4691

CIRCLE 955 ON READER SERVICE CARD

TUBES & COMPONENT
FREE...CATALOG
BARRY ELECTRONICS
512 BROADWAY 212-WAlker 5-7000
NEW YORK 12, N.Y. TWX-571-0484

CIRCLE 956 ON READER SERVICE CARD

EMPLOYMENT OPPORTUNITIES

E. E.'s
for FEE-PAID Positions WRITE US FIRST!
Use our confidential application for professional, individualized service . . . a complete national technical employment agency.
ATOMIC PERSONNEL, INC.
Suite 1207L, 1518 Walnut St., Phila. 2, Pa.

ELECTRONICS ENGINEER
With experience in all aspects of instrument development from concept through breadboard, prototype, product engineering and small run production. B.S. or M.S. in Electronic Engineering with experience in medical, radiation, or analytical instrumentation
CONTROLS FOR RADIATION, INC.
130 Alewife Brook Parkway
CAMBRIDGE 40, MASS.
An Equal Opportunity Employer.

ADDRESS BOX NO. REPLIES TO: Box No. Classified Adv. Div. of this publication.
Send to office nearest you.
NEW YORK, N. Y. 10036: P. O. Box 12
CHICAGO, Ill. 60611: 645 N. Michigan Ave.
SAN FRANCISCO, Cal. 94111: 255 California St.

POSITION VACANT

Electronic Specialist for development of transistor circuitry for unusual pulse control and telemetering transmitters. At least 5 y. experience. Full or part time. P-5519, Electronics.

SELLING OPPORTUNITY WANTED

Mfrs' Export Reps with excel. world-wide connect., on their toes around the clock, are eager to export for you. Aacor International, 198 Broadway, New York 8, N. Y.

New Literature

System modules. Digital Equipment Corp., 146 Main St., Maynard, Mass. 01754. An informative brochure describes 16 of the latest additions to the complete, 200-module selection. Circle **451** reader service card

Ceramic fixed capacitors. JFD Electronics Corp., 1462 62nd St., Brooklyn, N.Y. 11219. Type UY01 microminiature ceramic fixed capacitors are described in bulletin UNM-64-1A. **[452]**

Pantograph engraver. Green Instrument Co., Inc., 295 Vassar St., Cambridge, Mass., offers a brochure on the model D-2 engraver for small and large objects including panels, scales, instruments and printed circuits. **[453]**

Component bridge. Wayne Kerr Corp., 14-22 Frink St., Montclair, N.J. A technical bulletin describes the model B-521, a versatile and accurate component bridge. **[454]**

Component-test fixture. Precision Metal Products Co., 41 Elm St., Stoneham, Mass., has published a bulletin on the model TJ60-1.5 Pigtail Grabber for fast, positive test of components. **[455]**

Synchronous motors. The Superior Electric Co., Bristol, Conn. 06012. Bulletin SS1163-1 gives technical data on Slo-Syn synchronous motors for a-c, 72 rpm, constant speed or phase-switched d-c stepping. **[456]**

Microelectronics. Amphenol Microelectronics, 2837 S. 25th Ave., Broadview, Ill., has published a brochure describing its capabilities, facilities and product lines in the field of microelectronics. A glossary of terms is included. **[457]**

Welding machine. Kahle Engineering Co., 3300 Hudson Ave., Union City, N.J., has available a catalog sheet on an automatic two-piece lead-wire welding machine. **[458]**

Backward-wave oscillators. Stewart Engineering Co., 467 Bean Creek Road, Santa Cruz, Calif. The SE-215 and SE-215A S-band backward-wave oscillators are discussed in a bulletin. **[459]**

Silicon power modules. Deltron, Inc., 4th and Cambria Sts., Philadelphia, Pa., 19133. Bulletin 103A introduces a highly regulated series of silicon power modules. **[460]**

Phase shifters. Weinschel Engineering, Gaithersburg, Md., has issued a bulletin on the 1504 and 1505 precision phase shifters for 1 to 12 Gc. **[461]**

Systems installation and start-up services. General Electric Co., Schenectady, N.Y. Bulletin GEA-7811 describes the technical advice and operational checks provided by the Installation & Service Engineering Department that are included in the contract price of each GE system. **[462]**

Oscilloscope accessories. Tektronix, Inc., P.O. Box 500, Beaverton, Ore., offers a catalog of accessories that extend oscilloscope utility, performance, and ease of operation. **[463]**

Fans & blowers. Rotron Mfg. Co., Inc., Woodstock, N.Y., has released a flyer listing fans and blowers available on a 24-hour delivery basis for development and prototype applications. **[464]**

Precision phase generator. North Atlantic Industries, Inc., 200 Terminal Drive, Plainview, N.Y. A preliminary data sheet on the new model 350 precision phase generator is available. **[465]**

High-intensity microphones. Gulton Industries, 212 Durham Ave., Metuchen, N.J. Bulletin AP50b describes three types of small, lightweight microphones for measurement of high intensity sound pressures in missiles and aircraft. **[466]**

Flat-cable connectors. Amphenol Connector Division, Amphenol-Borg Electronics Corp., 1830 S. 54th Ave., Chicago, 60650, offers a brochure describing its Flex-1 connectors for NAS 729 flat cable. **[467]**

Magnetic components. Leeds & Northrup Co., 4901 Stenton Ave., Philadelphia, Pa., 19144. Three data sheets contain detailed descriptions of a magnetic operational amplifier, a magnetic square-root extractor, and a magnetic multiplier/divider. **[468]**

Digital computer. Computer Control Co., Inc., Old Connecticut Path, Framingham, Mass., 01702. A 16-page catalog covers the new DDP-116 general-purpose digital computer. **[469]**

Display tubes. Baird-Atomic, Inc., 33 University Road, Cambridge, Mass., 02138. Bulletin DK-4 introduces Digitube neon tubes for display of numbers, letters, or symbols. **[470]**

Frequency control crystals. Monitor Products Co., Inc., 815 Fremont, South Pasadena, Calif. Frequency control crystals that feature low aging in the 10 to 125-Mc range are the subject of a new data sheet. **[471]**

Magnetic material. The Arnold Engineering Co., Box G, Marengo, Ill. A four-page brochure gives technical data on an improved Alnico 8 magnetic material. **[472]**

Wave soldering machines. Leesona Corp., Coil Winding Machinery Division, 26 Farwell St., Newtonville, Mass., 02160. A bulletin describing wave soldering machines for printed circuits includes features and specifications of two new models plus information on fixtures and accessories. **[473]**

Cast waveguide components. Microwave Associates, Inc., Northwest Industrial Park, Burlington, Mass. Brochure SF-2001 describes an expanded line of cast waveguide components available for use at frequencies from 1.25 to 75 Gc. **[474]**

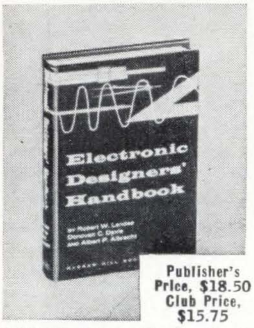
Zener voltage regulators. Sarkes Tarzian, Inc., Semiconductor Division, 415 North College, Bloomington, Ind. Catalog 64ZR9 contains a thorough technical discussion of a line of zener voltage regulators. **[475]**

Special Introductory Offer — To new members of the **ELECTRONICS and CONTROL ENGINEERS' Book Club**

ANY ONE FOR ONLY $1.00

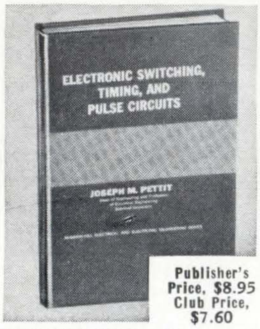
YOURS WITH A CHARTER MEMBERSHIP
AND SENT WITH YOUR FIRST SELECTION

VALUES FROM $7.00 TO $23.50



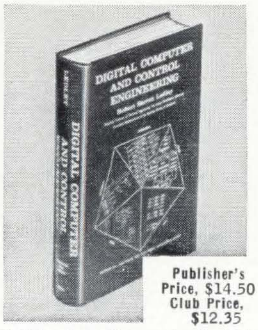
Publisher's Price, $18.50 Club Price, $15.75

Electronic Designers' Handbook, Edited by R. W. Landee, D. C. Davis, and A. P. Albrecht. Presents detailed, practical design data.



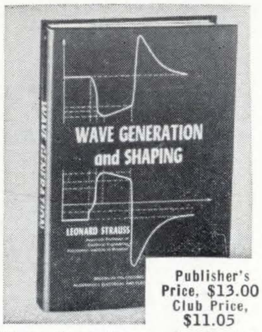
Publisher's Price, $8.95 Club Price, $7.60

Electronic Switching, Timing, and Pulse Circuits by J. M. Pettit. Provides a practical understanding of complex circuits.



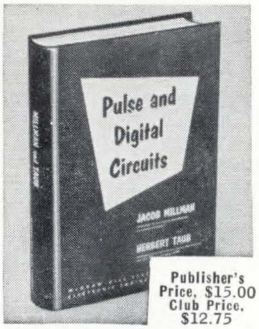
Publisher's Price, $14.50 Club Price, $12.35

Digital Computer and Control Engineering by R. S. Ledley. Full coverage from basic design to, advanced programming techniques.



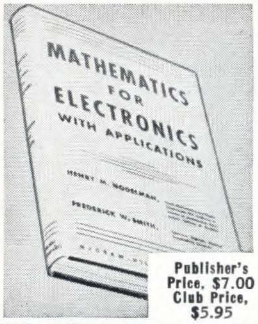
Publisher's Price, $13.00 Club Price, $11.05

Wave Generation and Shaping by L. Strauss. Essential features and techniques of practical wave-generating and -shaping circuits.



Publisher's Price, $15.00 Club Price, $12.75

Pulse and Digital Circuits, by J. Millman and H. Taub. Fully explains pulse and digital circuit operation for electronic systems design.

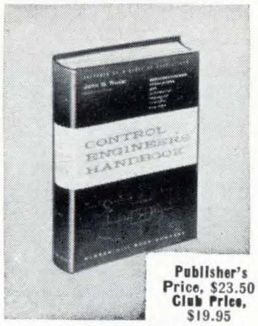


Publisher's Price, $7.00 Club Price, $5.95

Mathematics for Electronics with Applications by H. M. Nodelman and F. W. Smith, Jr. Methods for solving practical problems.

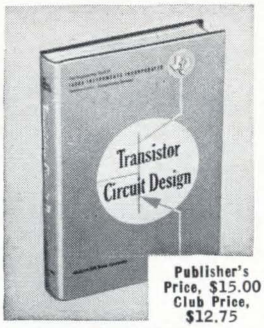
Publisher's Price, $10.00 Club Price, $8.50

Magnetic Recording Techniques by W. E. Stewart. Full description of magnetic recording methods and devices.



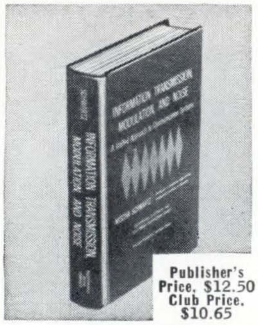
Publisher's Price, $23.50 Club Price, $19.95

Control Engineers' Handbook by J. C. Truxal. A wealth of practical help on automatic feedback control systems.



Publisher's Price, $15.00 Club Price, $12.75

Transistor Circuit Design, prepared by the Engineering Staff of Texas Instruments Inc. Reduces theory to actual practice.



Publisher's Price, $12.50 Club Price, $10.65

Information Transmission, Modulation, and Noise by M. Schwartz. A unified approach to communication systems.

How many of the books shown here do you wish you had immediately at hand?

Select one for **JUST A DOLLAR!** Choose from *Electronic Designers' Handbook, Magnetic Recording Techniques, Wave Generation and Shaping,* and seven other valuable books . . . your introduction to membership in *The Electronic and Control Engineers' Book Club.*

If you're missing out on important technical literature—if today's high cost of reading curbs the growth of your library—here's the solution to your problem. *The Electronic and Control Engineers' Book Club was organized for you,* to provide an economical **technical reading program that cannot fail** to be of value to you.

All books are chosen by qualified editors and consultants. Their thoroughgoing understanding of the standards and values of the literature in your field guarantees the authoritativeness of the selections.

How the club operates. Periodically, as issued, you receive free of charge *The Electronic and Control Engineers' Book Bulletin.* This gives complete advance notice of the next main selection, as well as a number of alternate selections. If you want the main selection you do nothing; the book will be mailed to you. If you want an alternate selection . . . or if you want no book at all for that particular period . . . notify the Club by returning the convenient card enclosed with each *Bulletin.*

We ask you to agree only to the purchase of three books in a year. Certainly out of the large number of books in your field offered in any twelve months there will be at least three you would buy anyway. By joining the Club you save yourself the bother of searching and shopping, and save in cost about 15 per cent from publishers' prices.

Send no money now. Just check **any two** books you want—one for only $1.00 and one as your first Club selection—in the coupon below. Take advantage of this offer *now,* and get two books for less than the regular price of one.

THIS COUPON IS WORTH UP TO $22.50

The Electronic and Control Engineers' Book Club Dept. FL-11-4
330 West 42nd Street, New York, N. Y. 10036

Please enroll me as a member of the Electronic and Control Engineers' Book Club. I am to receive the two books I have indicated at the right. You will bill me for my first selection at the special club price and $1 for my new membership book, plus local tax, and a few additional cents for delivery costs. (The Club assumes this charge on prepaid orders.) Forthcoming selections will be described to me in advance and I may decline any book. I need take only 3 selections or alternates in 12 months of membership. (This offer good in U.S. only.)

PLEASE PRINT

Name ....

Address ....

City.......................... State.............. Zip Code......

Company ....

NO RISK GUARANTEE If not completely satisfied, you may return your first shipment within 10 days and your membership will be canceled.

Check 2 Books: We will send the higher priced book for only $1.00, and the other as your Club Selection:

- ☐ Electronic Designers' Handbook, $15.75
- ☐ Electronic Switching, Timing, and Pulse Circuits, $7.60
- ☐ Digital Computer and Control Engineering, $12.35
- ☐ Wave Generation and Shaping, $11.05
- ☐ Pulse and Digital Circuits, $12.75
- ☐ Mathematics for Electronics with Applications, $5.95
- ☐ Magnetic Recording Techniques, $8.50
- ☐ Control Engineers' Handbook, $19.95
- ☐ Transistor Circuit Design, $12.75
- ☐ Information Transmission, Modulation, and Noise, $10.65

FL-11-4

Electronics Abroad

Volume 37
Number 30

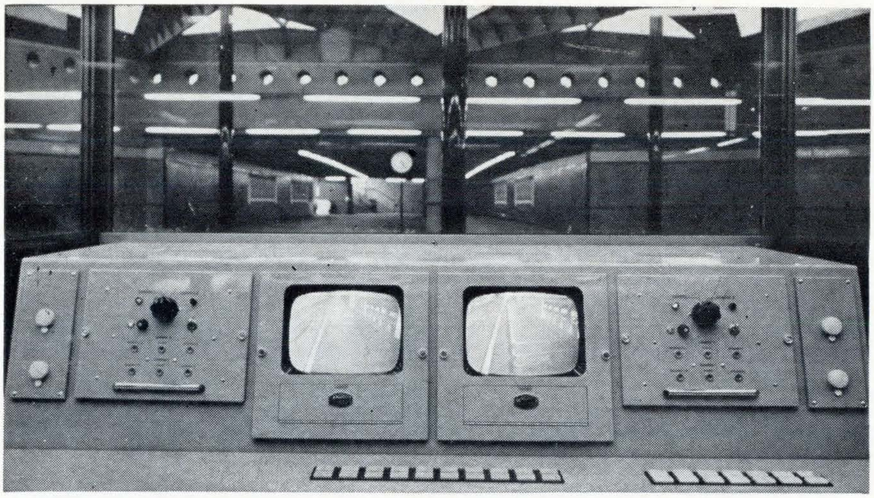
Italy

Subway alla Milanese

Italy's most avid television viewers work on Milan's new Metropolitana, the $70.4-million subway that opened Nov. 1.

They're central traffic directors, who keep track of the 48 station platforms along the seven-mile line by means of closed-circuit tv.

The Metropolitana is generally considered to be the most electronically controlled subway in the world. That distinction may be short-lived, however. Next March, San Francisco is scheduled to begin testing its new computer-controlled transit system.



Director's-eye view of platform, seen directly and as enlarged on tv screen

Big brother. The tv system operates with 30-megacycle, carrier-modulated signals. It permits the traffic director to see any station on his screen simply by pressing a button. Or he can use automatic programing to show all the stations in rotation at preset intervals.

He can choose either a wide-angle, over-all view of a station or a close-up.

When a platform is filled, he closes the gates until a train picks up some passengers.

As a back-up, each station also has gate guards and local dispatchers watching other tv monitors. The guards close the gates if the central director doesn't. The dispatcher signals the driver to close the train doors when everybody is aboard.

The cameras are equipped with vidicon tubes, built by the Radio Corp. of America, that give clear pictures with only the 10-lux emergency lighting.

Electron control. Although drivers remain on the job, the trains' speed is closely monitored by a scan-and-control system made by the Westinghouse Electric Co. If the driver fails to follow orders, the brakes are applied automatically.

The system is a third-rail type that has been in use several years in the United States and Europe. Magnetic pickups on the train identify control signals sent through the third rail. The driver receives instructions from back-lighted displays on a panel.

Each train also has an immediate-action monitor for blocked track. The monitor automatically cuts out the speed-control system and tells the driver to slow down.

To cut costs, one system monitors and controls both the control signals and the propulsion-power systems.

The system, called Fertrasco, operates on scanning, one a second, of the speed-signaling and power-transmission lines.

Communications. Controllers of traffic and of power have an elaborate communication system at their disposal. An automatic telephone exchange, using 60-volt power, combines both preselector and selector functions by means of a three-digit dialing system. It offers automatic dialing, automatic break-in for an emergency call if a line is busy, 10-party conference calls and a direct line between the traffic and power controllers.

An emergency system also allows a train driver to talk with either controller when necessary. He is connected with central control as soon as he starts talking; a magnetic-plug setup operates a phonic relay.

The central traffic controller also has access to loudspeakers at each station by means of a speaker-microphone. Ordinary messages about arrivals and departures are made automatically from tape recordings, but the controller can break in at any time with special messages.

West Germany

Brain drain

"If you want a top engineering job or a professorship in West Germany, first make your reputation abroad."

That advice from a German engineer typifies the attitude of many of his colleagues. They say Germans abroad are wooed by state and private concerns with a fervor unmatched in normal recruiting procedures within Germany.

Yet Germany's "brain drain" has not attained the scale prevalent in

Britain. And there are signs that it may never do so, thanks to some effective countermeasures by the Bonn government and private industry.

Lower pay. Most German research and development in electronics is conducted at publicly supported institutes by scientists who are paid less than half as much as they could get for comparable work in the U.S.

At the Max-Planck Institutes, for example, an experienced engineer with a master's or doctor's degree receives $300 to $420 a month. An institute director may be paid $440 to $635.

Yet the cost of living is not much lower than in the U. S. Food prices are slightly higher, clothing is considerably more expensive, and gasoline costs 55 cents a gallon.

Besides getting attractive offers from the U. S., German scientists are being lured away by international associations — Euratom, Cern, Esro and Eldo—whose salaries are often double those at comparable German organizations. Often an engineer in Germany works with a foreign colleague from an international association whose pay, for comparable work, is double the German's.

Countercurrent. In recent months, however, many German scientists have returned from abroad. The most celebrated is Nobel Prize winner Rudolf Mossbauer, the physicist for whom the Mossbauer effect is named. He has returned from the University of California to take a professorship in Munich.

Other factors prompt other engineers and physicists to return to Germany. One factor is a mixture of idealism and patriotism, spurred by Germany's resurgence in electronics and aviation.

New exodus. Another factor is Israeli pressure generated by German scientists' technical contributions to the war machine of the United Arab Republic. The Bonn government has tried to lure the 500 German rocket and aircraft specialists back from Egypt.

Bonn's efforts are beginning to produce results. In the past few weeks, about 120 West German

Rudolf L. Mossbauer, Nobel laureate

engineers—60% of one Egyptian plant's technical staff, including several top telemetry people—have given notice of their intention to leave Egypt by the end of the year. The exodus is said to include Germany's top three specialists involved in Egypt's rocket program.

Bonn is conducting a quiet campaign in German industry to find high-paying jobs for the nonpolitical engineers who still remain in Egypt. There aren't enough jobs in Germany, but suitable positions sometimes are found in France and the U. S.

Another group of returnees came from Werner von Braun's rocket specialists who went to the U. S. after World War II. Some of these men now work at private companies, and have been sent to Germany as representatives of their American employers.

Belgium

All-European satellite

In an unusual display of cooperation, six European countries are working together to launch a satellite. When it's built, Australia will participate in firing it near Darwin early in 1966.

Europa I represents the efforts of 1,000 engineers and the expenditure of $70 million this year alone.

The program is run by a group called the European Launcher Development Organization. Its goal is to develop a space program relatively independent of East-West competition.

British first stage. The British are building the heavy first stage. The four-engine second stage is French. West Germans are working on the third stage. Italy is building the payload. Belgian radio equipment will guide the satellite over the North and South Poles. And the Dutch are providing various telemetry and control systems.

There has been some concern that Britain's new Labor Government, in its present economy drive, might try to get out of this space effort. But Europa I seems too far advanced for any drastic curtailment.

Belgian role. The Belgian equipment has four tasks: to pick up and track the launch vehicle's third stage, to determine its position and velocity vectors, to guide it toward the optimum trajectory, and to calculate the points of injection into orbit and of separation of the satellite from the booster.

Belgium has mounted an industry-wide effort to develop and produce the guidance station, which will cost $10 million.

The only major equipment designed and produced outside of Europe is a CDC 3200 computer made by the Control Data Corp. The ideal trajectory is programed into the computer, and the actual trajectory is compared with it.

The computer puts the third stage on target with a minimum of fuel consumption.

Six antennas. On the ground, a six-antenna array comprises a pair of interferometers, in the form of a half-headed arrow, and a distance-measuring set.

Up-channel transmission is handled by the antenna farthest away —1,000 meters—from the reference antenna (the head of the arrow). Powered by a 10-kilowatt transmitter, the up-channel antenna emits a highly directional continuous-wave signal of 1,427 to 1,479 megacycles, frequency-modulated by ranging tones of 125 cycles, 2 kilocycles and 32 kilocycles. An f-m subcarrier carries the guidance signals.

The antenna next to that at the arrow tail is the other half of the ranging pair. It receives down-channel signals of 1,535 to 1,540 megacycles transmitted by a 200-milliwatt satellite-borne transponder. The phase difference between receipt of the ground signals and those returned by the satellite transponder is the basis for the distance measurement because doppler frequency-shift measures radial velocity.

Workhorse antenna. All other antennas are slaved to the range receiver dish. Along with its ranging function, the antenna autotracks the third stage through a simultaneous lobing system, using four primary feeds.

The first stage of the receiver for each antenna is a reflection-type parametric amplifier with passband of 9.5 megacycles and gain of 18 decibels.

Great Britain

Homemade quartz

Standard Telephones & Cables, Ltd., says it is manufacturing quartz suitable for some kinds of filters, although their Q is not high enough for use in oscillators.

The process for making quartz crystals was built into STC's \$2.8-million crystal factory, opened earlier this year at Harlow, Essex. The company says one-pound crystals are grown in 21 to 23 days in a specially designed pressure vessel. The same process takes three million years in nature.

Torture chamber. The crystals are made in a vessel 10 feet high and 12 inches in diameter. They are produced under pressure of 24,000 pounds per square inch, and heat of 400° C. Under this heat and pressure, small quartz chips are dissolved in caustic soda, and the quartz grows in seed crystals that are placed in the upper part of the chamber.

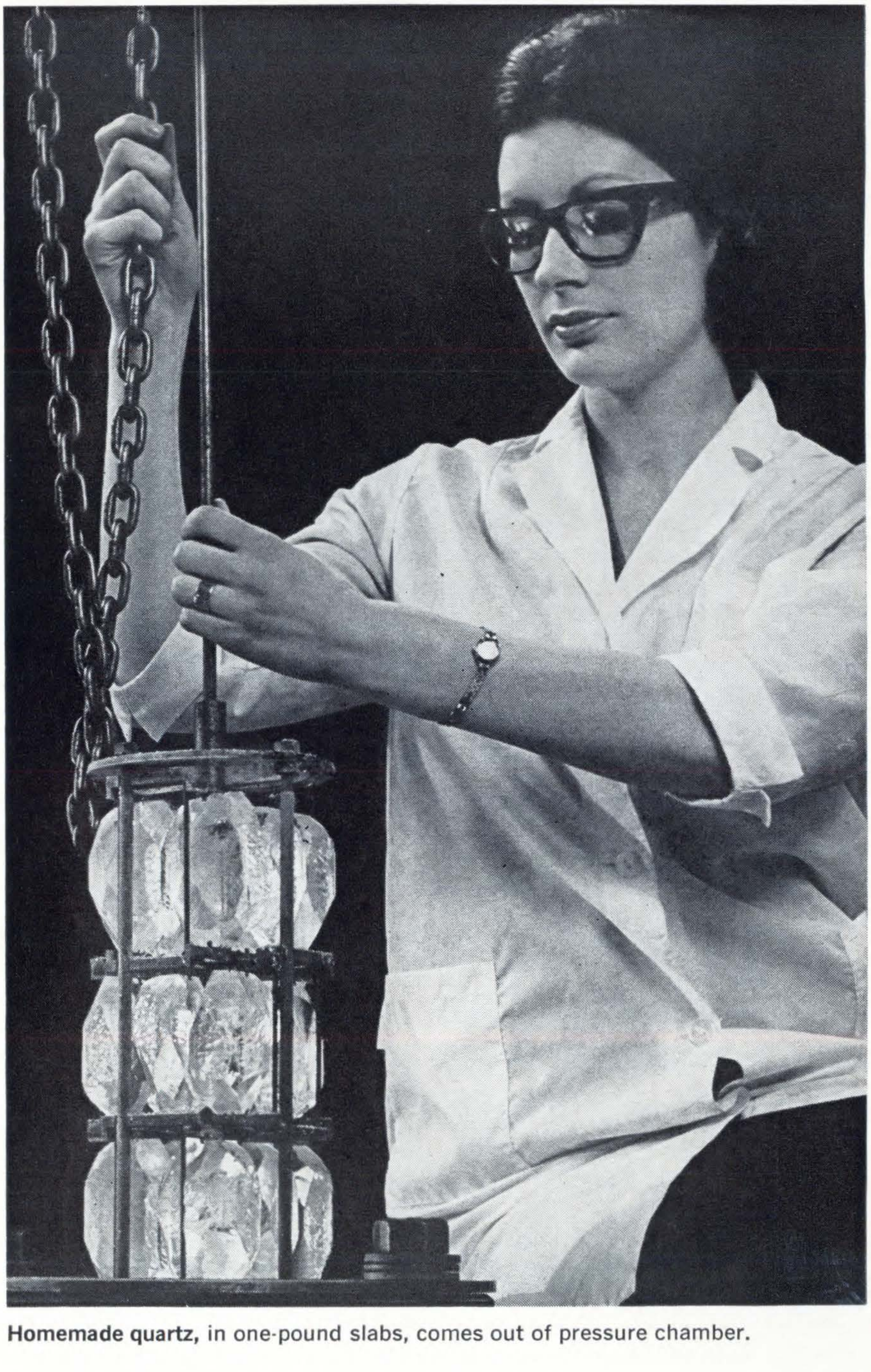
Ounce for ounce, man-made crystals are cheaper than natural ones, according to STC. But accurate cost comparisons are difficult to make.

One reason is that, with the STC process, quartz chips that formerly were wasted can now be used as seed, and it's difficult to place a value on this advantage.

Glass-coated microwire

Big advances are often based on tiny components. Now Applied Research, Ltd., says it has achieved a long-time goal of microcircuitry —glass-coated microwire.

The company says it's producing 100 reels of microwire a week, each reel containing 550 to 1,100 yards of glass-sheathed wire 20 to 54 microns in outside diameter. One-third of this output is sold in Brit-



Homemade quartz, in one-pound slabs, comes out of pressure chamber.

ain; the rest is exported.

Some companies in the United States are using the wire, often measured in fractions of a mil, for experimental models of tiny wire-wound resistors, transformers, inductor coils, relays, thermocouples and other devices.

Besides reducing the size, Applied Research says the glass wire often improves a device's performance.

Tiny but tough. A copper-core microwire 0.6 mil in diameter has withstood 320,000 pounds per square inch of pressure, according to the producer. Gold-core microwire is being used in miniaturized computer circuits, increasing reliability and eliminating any danger of oxidation or corrosion. The glass-coated wire also has been made with cores of silver and lead.

Its high insulation against radio frequencies makes glass-coated wire especially useful in amplifiers and intermediate-frequency transformers. With one exception, the wire seems to be unaffected by temperature extremes from —225° to +550°C. That exception is a temporary loss of insulation resistance during the excursion into high temperatures.

Another company, Glass Developments, Ltd., is working on sheathings for microwire nickel-alloy thermocouples for temperatures of 1,000° to 1,500°C. Glass Developments is also working on twin microwires, with two cores running down a glass sheath. It's also working on double-sheathed wires for greater strength.

Supersensitive. Herbert Wagner, a researcher at the Battelle Memorial Institute in Columbus, Ohio, says a 6-micron copper-core microwire can be substituted for the standard 0.8-mil wire in a galvanometer to increase the instrument's sensitivity without adding to its weight. The sensitivity can be increased tenfold with 0.1-mil microwire, Wagner adds, but this would require reducing the glass insulation.

Glass-coated wire goes back at least to 1924 when a botanist named G. F. Taylor was making it for thermocouples in his hothouse. He filled a glass tube with metal, heated the tube over a burner, and drew out the glass-coated filament as small as 0.01 mil in diameter.

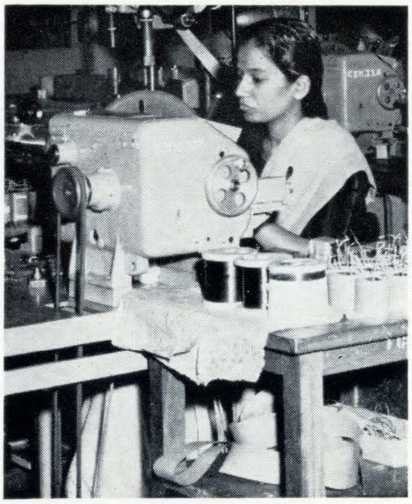
Taylor's methods were adopted in the Soviet Union. A Russian researcher recently reported attaining glass-coated microwire only 0.01 micron—0.0004 mil—in diameter. With it, relays and transformers 99% smaller than with conventional wire have been built.

India

Expansion

The Indian Defense Ministry is moving to expand its electronics plant in Bangalore.

By mid-1965, production at Bharat Electronics, Ltd., is expected to climb from the present $8.4 million to $14.7 million.



Winding coils at Bharat is one of 1,400 women employees.

The company will begin to make radar equipment in collaboration with Contraves AG of Switzerland, and telecommunication gear under technical agreements with companies in Britain, the Netherlands, West Germany and Japan. It is also considering computer manufacture.

The expansion will cost about $5 million.

Bharat, India's only electronics manufacturing company, has 3,500 employees, 40% of them women, and operates a technical school for 800 trainees for jobs in various branches of electronics.

The original Bharat plant was installed with technical help from CSF, the General Telegraph Co. of France.

Japan

Process control

In an attempt to sail on the rising tide of demand, Japanese makers of process-control instruments are hurrying to replace mechanical contacts with solid-state electronic components.

This was the most significant trend evident at the Osaka Instrument Show.

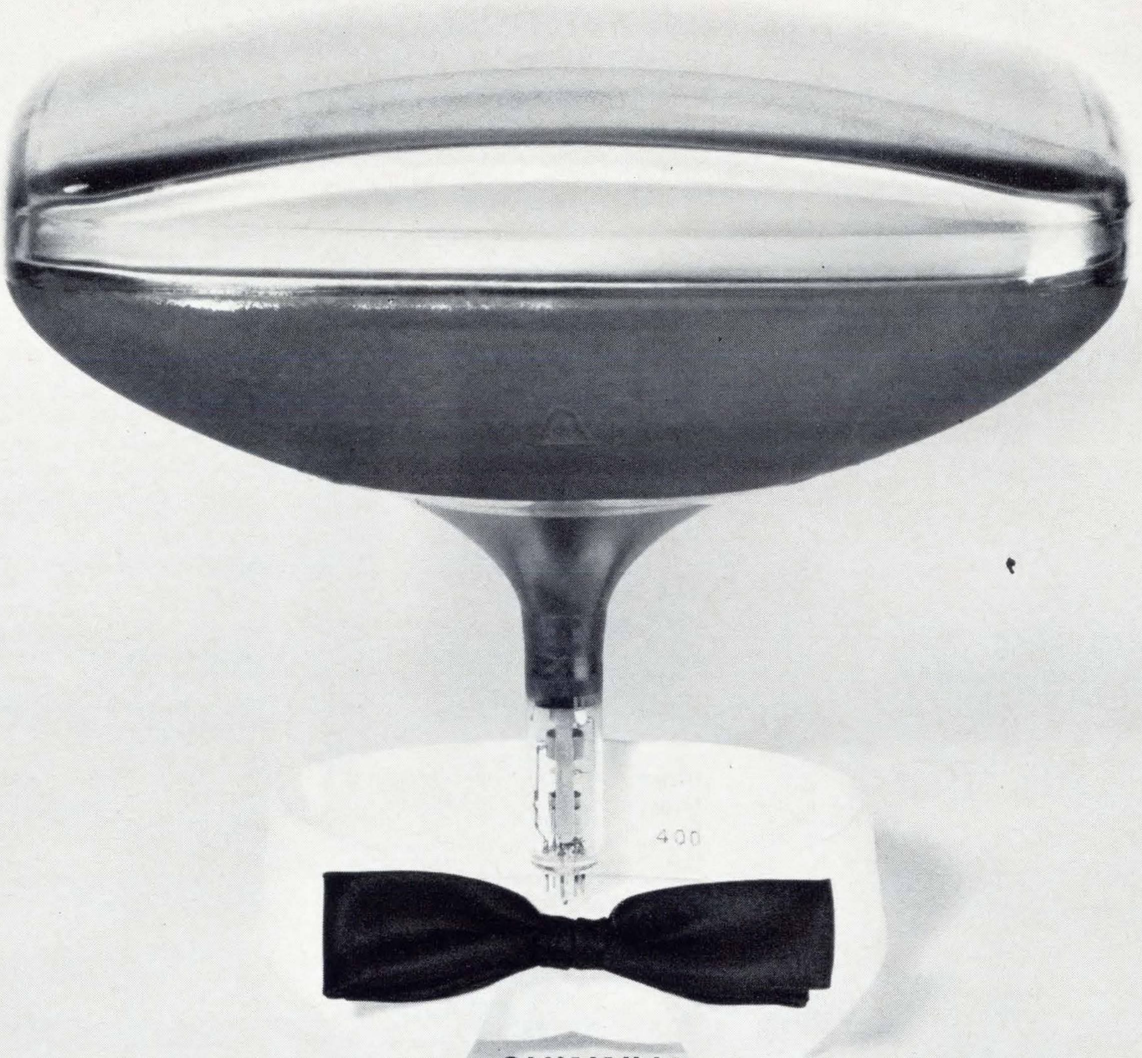
Even though manufacturers in the United States have been swinging to solid-state for several years —two to eight years, depending on the application—customer interest is just beginning to stir noticeably.

Out front. Japan's leader in the trend toward solid-state components seems to be Yokogawa Electric Works, Ltd., which showed a transistor amplifier for servo-type recording instruments. Yokogawa has replaced the mechanical choppers of its earlier instruments with photo choppers. The chopper uses two cadmium selenide photoconductor cells and two neon bulbs ignited by a transformer inside the chopper unit.

At $28, the photoconductor costs about 50% more than its mechanical rival. But it has longer life—two to three years of uninterrupted operation—and is unaffected by vibration, mounting position and magnetic fields. Yokogawa says the chopper requires no maintenance and does not give rise to voltage drifts caused by temperature variations.

Low drift. Hitachi, Ltd., showed instruments that featured silicon transistor choppers. Two transistors are enclosed in one can for close thermal coupling to eliminate any temperature differential.

A Hitachi engineer says several transistor choppers, tested for 18 months with a 10-millivolt input signal, had maximum drift of less than 0.2%.



SKINNY

Yes, very. That's the idea. When you have a skinny neck you don't eat so much. And this 12″ narrow neck picture tube has been specially designed to meet the requirements of low power consumption, portable transistorised TV.

Another advantage of being skinny is, of course, the space saved. An all important factor in the design of portables. Yet another advantage is the greater deflection possible by the reduction of overall length.

Hitachi manufactures B&W picture tubes ranging from 5.5 inches to 19 inches. Naturally, only tubes of 12 inches and less are specifically suitable for portables.

And don't forget, Hitachi manufactures the complete gamut of TV tubes. Not only the narrow neck, but standard B&W and colour tubes.

Type Number	Model	Angle	Neck Dia.	Overall Length	Ef (V)	IF (A)	Remarks
140DB4	5.5″	70°	0.788″	6.625″	12.6	0.05	TR'd TV
230EB4	9″	90°	0.788″	8.006″	12.6	0.05	TR'd TV
12AYP4	12″	110°	1.125″	9.313″	6.3	0.45	
12AZP4	12″	110°	1.125″	9.313″	6.3	0.6	
12BAP4	12″	110°	1.125″	9.313″	6.3	0.3	
310WB4	12″	110°	0.788″	9.331″	12.6	0.05	TR'd TV
310MB4	12″	90°	0.788″	10.551″	12.6	0.05	TR'd TV
310YB4	12″	110°	0.788″	9.331″	4.2	0.45	
16AUP4	16″	114°	1.125″	10.006″	6.3	0.6	
16BFP4	16″	114°	1.125″	10.006″	6.3	0.45	
400FB4	16″	114°	1.125″	10.006″	6.3	0.3	
16CBP22	16″	90°	1.438″	15.125″-	6.3	0.9	Color TV

Hitachi, Ltd.
Tokyo Japan

HITACHI SALES CORPORATION
333, N. Michigan Avenue, Chicago 1, Ill., U.S.A. Tel: 726-4572/4
666, 5th Avenue, New York, N.Y. 10019, U.S.A. Tel: 581-8844
12715, S. Daphne Avenue, Hawthorne, Calif., U.S.A. Tel: 757-8143
HITACHI, LTD., DUESSELDORF OFFICE:
Graf Adolf Strasse 37, Duesseldorf, West Germany Tel: 10846

Electronics advertisers

November 30, 1964

Classified advertising

F. J. Eberle, Business Mgr.

Classified advertisers index

Advertising sales staff

Gordon Jones [212] 971-2210
Advertising sales manager

Atlanta, Ga. 30309: Gus H. Krimsier, Michael H. Miller, 1375 Peachtree St. N.E., [404] TR 5-0523

Boston, Mass. 02116: William S. Hodgkinson, McGraw-Hill Building, Copley Square, [617] CO 2-1160

Chicago, Ill. 60611: Robert M. Denmead, Daniel E. Shea, Jr., 645 North Michigan Avenue, [312] MO 4-5800

Cleveland, Ohio 44113: Paul T. Fegley, 55 Public Square, [216] SU 1-7000

Dallas, Texas 75201: Richard P. Poole, The Vaughn Building, 1712 Commerce Street, [214] RI 7-9721

Denver, Colo. 80202: John W. Patten, David M. Watson, Tower Bldg., 1700 Broadway, [303] AL 5-2981

Houston, Texas 77025: Kenneth George, Prudential Bldg., Halcombe Blvd., [713] RI 8-1280

Los Angeles, Calif. 90017: Ashley P. Hartman, John G. Zisch, 1125 W. 6th St., [213] HU 2-5450

New York, N.Y. 10036:
Donald R. Furth [212] 971-3615
Frank LeBeau [212] 971-3615
George F. Werner [212] 971-3615
500 Fifth Avenue

Philadelphia, Pa. 19103: William J. Boyle, Warren H. Gardner, 6 Penn Center Plaza, [215] LO 8-6161

San Francisco, Calif. 94111: James T. Hauptli, 255 California Street, [415] DO 2-4600

London W1: Edward E. Schirmer, 34 Dover Street, Hyde Park 1451

Frankfurt/Main: Matthee Herfurth, 85 Westendstrasse Phone: 77 26 65 and 77 30 59

Geneva: Michael R. Zeynel, 2 Place du Port 244275

Paris VIII: Denis Jacob, 17 Avenue Matignon ALMA-0452

Tokyo: Nobuyuki Sato Shiba, Minato-ku (502) 0656

Osaka: Kazutaka Miura, 163, Umegae-cho, Kilta-ku [362] 8771

Nagoya: International Media Representatives, Yamagishi Bldg., 13,2-Chome, Oike-cho Naka-ku

Hugh J. Quinn: [212] 971-2335
Manager Electronics Buyers' Guide

David M. Tempest: [212] 971-3139
Promotion manager

Milton Drake: [212] 971-3485
Market research manager

Richard J. Tomlinson: [212] 971-3191
Business manager

Theodore R. Geipel: [212] 971-2044
Production manager

■ For more information on complete product line see advertisement in the latest Electronics Buyers' Guide

Executive, editorial, circulation and advertising offices: McGraw-Hill Building, 330 West 42nd Street, New York, N.Y., 10036. Telephone Area Code 212-971-3333. Teletype TWX N.Y. 212-640-4646. Cable: McGrawhill, N.Y. Officers of the Publications Division: Shelton Fisher, President; Vice Presidents: Joseph H. Allen, Operations; Robert F. Boger; Administration; John R. Callaham, Editorial; Ervin E. DeGraff, Circulation; Donald C. McGraw, Jr., Advertising Sales; Angelo R. Venezian, Marketing. Officers of the Corporation: Donald C. McGraw, President; Hugh J. Kelly, Harry L. Waddell, L. Keith Goodrich, Executive Vice Presidents; John L. McGraw, Treasurer; John J. Cooke, Vice President and Secretary.